Abstract Journal in Earthquake Engineering

Volume 6: 1976 Literature
December 1977
Earthquake Engineering Research Center
University of California, Berkeley

Editors: R. C. Denton and W. E. Wagy. *Editorial Assistance:* A. O. Burton and G. Fencsik. *Circulation Manager:* M. T. Stallings.

i - a

Abstract Journal in Earthquake Engineering, Volume 6, December 1977. 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

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. NSF/RA-770724	2.	3. Recipient's Accession No. PB290535

4. Title and Subtitle
Abstract Journal in Earthquake Engineering, Vol. 6, 1976 Literature

5. Report Date
December 1977

6.

7. Author(s)
R.C. Denton, W.E. Wagy, (Ed.)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
University of California
Earthquake Engineering Research Center
Berkeley, California 94720

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
Applied Science and Research Applications (ASRA)
National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550

13. Type of Report & Period Covered
Annual

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This volume contains over 1000 abstracts of technical papers, research reports, books, codes, and conference proceedings of the preceding year pertinent to the field of earthquake mitigation. The abstracts are obtained from technical journals and from publications of academic, professional, and governmental institutions in 23 countries. A list of contributing journals precedes the collection which is divided into sections of related topics on conference proceedings, general and selected topics in seismology, engineering seismology, strong motion seismometry, dynamics of soils, rocks, foundations, and structures, dynamic properties of materials and structural components, earthquake-resistant design and construction, hazard reduction, earthquake effects, and earthquakes as natural disasters. Included are a list of titles, author-subject indices, and suggestions for contributors.

17. Document Analysis a. Descriptors

Earthquakes	Seismometers	Seismic waves
Earthquake resistant construction	Dynamic structural analysis	Rock mechanics
Earthquake resistant structures	Soil dynamics	Foundations

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement
NTIS

19. Security Class (This Report)

20. Security Class (This Page)

22. Price
PCA13/MF-A01

See ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

Contents

Preface

The *Abstract Journal in Earthquake Engineering* is a comprehensive annual collection of abstracts and citations of current literature pertinent to the field of earthquake hazard mitigation. The present volume contains more than 1,000 abstracts of technical papers, research reports, books, codes, and conference proceedings. The abstracts are obtained from 84 technical journals, and from the publications of academic, professional, and governmental institutions in 23 countries. The staff of the abstract journal sincerely appreciates the efforts of those many individuals and organizations who have made valuable contributions to Volume 6.

Several changes in format have been made since Volume 5. Because of scheduling constraints, a number of citations have been included without accompanying abstracts. This permits faster dissemination of these citations than otherwise would be possible. Section 7 has been further divided into an additional two subsections: "Design and Construction of Foundations, Piles and Retaining Walls" and "Design and Construction of Soil and Rock Structures." It is hoped that the user will benefit by these changes.

National Information Service for Earthquake Engineering

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

Availability of Abstracted Publications from EERC Library

Many abstracts and citations have a dot (●) affixed to the 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, California 94804 (415) 231-9403.

Individuals and organizations in the United States may borrow these "dotted" publications from the library either by telephone or mail request, or by visiting the library. In addition, individuals and organizations regardless of location may obtain photocopies of many of these publications from the library for a nominal fee, provided that the intended use of such photocopies meets the fair-use criteria of the U.S. Copyright Law, effective January 1, 1978. Please note that the library will loan but will not photocopy EERC reports. Single copies of EERC reports may be purchased from the National Technical Information Service (address below). When requesting material from the EERC Library, please fully reference the desired material, including the abstract number, and indicate whether you wish to borrow or purchase a photocopy of the publication. Further details may be obtained from the library at the above address.

Availability of Abstracted Publications from NTIS

An NTIS accession number follows the bibliographic citation for some abstracts. 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 those users who have commented on Volume 5. To assist us in further improving the journal, we continue to welcome such constructive criticism and suggestions.

W. E. WAGY and R. C. DENTON, Editors

Intentionally Blank

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
Newbury RG13 1LA, Berkshire
England

Bollettino di Geofisica
Osservatorio Geofisico Sperimentale
34123 Trieste
Italy

*BUILD International**
Weena 700
Rotterdam, The Netherlands

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

*Journal of Testing and Evaluation**
American Society for Testing and Materials
1916 Race Street
Philadelphia, Pennsylvania 19103

Journal of Tsing Hua University 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** Allen, C. R. *et al.*, **Earthquake research in China,** *EOS, Transactions of the American Geophysical Union,* **56,** *11,* Nov. 1975, 838–881.

An American seismological delegation visited the People's Republic of China from Oct. 5 to Nov. 5, 1974. This report, prepared by eleven members of the delegation, is a summary of the visit. The topics covered are (1) Introduction and Overall Assessment; (2) National Program; (3) Chinese Universities and Institutes; (4) Geophysical Instrumentation and Observatories; (5) Seismotectonics in China; (6) Historic Records of Chinese Earthquakes; (7) Premonitory Effects of Earthquakes; (8) Statistics, Models, and Theory; (9) Rock Mechanics; (10) Earthquake Engineering in China; and (11) History and Politics of Chinese Earthquake Studies.

● **1.1-2** Rosenblueth, E., **Optimum resource allocation in earthquake engineering,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 153, 28. (For a full bibliographic citation see Abstract No. 1.2-6.)

The feasibility of optimal resource allocation is explored from the viewpoint of costs and benefits and a methodology is proposed. The paper is a natural outcome of decision trees, Bayesian statistics and preposterior analysis, together with a more embryonic attack on the problem, optimal design studies for renewal process disturbances and simplifications stemming from second-moment probability theory. The theory is developed in some detail; emphasis is placed on the treatment of statistically correlated variables.

● **1.1-3** Whiteman, J. R., comp., **A bibliography for finite elements,** Academic Press, London, 1975, 209.

This bibliography cites almost all of the significant papers on advances in the mathematical theory of finite elements. Reported are applications in aeronautical, civil, mechanical, nautical and nuclear engineering. Such topics as classical analysis, functional analysis, approximation theory, fluids and diffusion are covered. Over 2,200 references to publications up to the end of 1974 are included. Publications are listed alphabetically by author and also by key words. In addition, finite element packages are listed.

● **1.1-4** Lee, W. H. K. and Wang, S. C., comps., **Abstracts of articles on Chinese earthquakes and related studies,** *Open-File Report 76-460,* U.S. Geological Survey, Menlo Park, California, May 1976, 95.

In this report, the authors have compiled, as completely as possible, abstracts of articles on Chinese earthquakes and related studies. It is an updated version of a major section of an earlier report *Earthquake and China,* compiled by Lee in 1974. The report is divided into the following sections: General; Earthquake prediction; Seismicity, focal mechanism, and magnitude; Reports of large earthquakes; Earthquake catalogs; Earthquake tectonics; Structure of crust and mantle; Instrumentation and laboratory studies; Theoretical seismology; Engineering seismology. An author index is included.

● **1.1-5** Habercom, Jr., G. E., comp., **Offshore structures (A bibliography with abstracts),** National Technical Information Service, Springfield, Virginia, Aug. 1976, 150. (NTIS Accession No. NTIS/PS-76/0626)

Offshore structures are investigated relative to their feasibility, design, construction, marine environments, and environmental impact. Nuclear power plants, floating cities, and airports are among the facilities included in the feasibility studies. This updated bibliography contains 150 abstracts, 84 of which are new entries to the previous edition.

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

● 1.1-6 Hundemann, A. S., comp., **Seismology (A bibliography with abstracts)**, National Technical Information Service, Springfield, Virginia, Oct. 1975, 180. (NTIS Accession No. NTIS/PS-75/769)

One hundred eighty abstracts pertaining to seismic wave propagation, United States earthquakes and analyses of strong-motion earthquake accelerograms are presented. Excluded are abstracts on underground explosion detection.

1.1-7 Savinov, S. A. and Monakhenko, D. V., eds., **Development of analysis and design of hydraulic structures in seismic regions** (Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii, vozvodimykh v seismicheskikh raionakh, in Russian), ENERGIYA, Leningrad, 1976, 252.

The volume contains articles on analytic and experimental investigations of hydraulic structures in seismic regions. The problems under investigation include full-scale testing and the use of models, the effects of water, calculation of earthquake response and the study of dynamic properties of materials. All of the papers are abstracted in this volume of the *AJEE*. The titles and authors' names follow.

Numerical dynamic model of inhomogeneous elastic base for massive hydraulic structures, Ostroverkh, B. N.—*Investigations of the earthquake resistance of concrete gravity dams,* Lyakhter, V. M. and Semenov, I. V.—*On the interaction of structure and layered soil base during an earthquake,* Kaufman, B. D. and Shulman, S. G.—*Nonstationary vibrations of an oscillator interacting with an elastic half-space,* Kaufman, B. D. and Shulman, S. G.—*Design of concrete gravity dams in seismic regions,* Ivanishchev, V. F. and Natarius, Ya. I.—*Evaluation of the earthquake resistance of earth dams using methods of wave dynamics,* Lyakhter, V. M. and Ivanenko, I. N.—*Elastoplastic deformations in response of earth dams to seismic excitations,* Lombardo, V. N. and Olimpiev, D. N.—*On design of earth dams for seismic excitation,* Mozhevitinov, A. L. and Konstantinov, I. A.—*Operational methods for increased earthquake resistance of large dams,* Savinov, O. A.—*The balanced risk method and the reliability of hydraulic structures,* Sinitsyn, A. P.—*On the methodology of modeling earthquake response of dams,* Monakhenko, D. V.—*Investigations of the earthquake resistance of hydraulic structures on small scale models,* Malyshev, L. K.—*Investigation of the effects of design features and loading conditions on the earthquake resistance of arch dams using models,* Gutidze, P. A. and Bardanashvili, T. Z.—*Dynamic investigations of the Toktogul gravity dam,* Bakhtin, B. M. and Dumenko, V. I.—*Application of holographic interferometry for investigations of natural frequencies and mode shapes of hydraulic structures,* Panteleev, A. A.—*Investigation of the seismic response of underground hydraulic structures using optical methods,* Tsukerman, Ya. N.—*Experimental model investigations of the earthquake resistance of the piping of the inner perimeter of the Armenian nuclear power plant,* Airapetyan, B. M., Askov, V. L. and Slovesnyi, B. V.—*Prediction of dam response to seismic excitation,* Atrakhova, T. S., Golubyatnikov, V. L. and Nikiforova, M. M.—*Effect of water on seismic response of hydraulic structures,* Gordeeva, S. P. and Shulman, S. G.—*Simplified formulas for calculation of seismic water pressure in the pressure system of hydroelectric power plants,* Kilasoniya, Dzh. N.—*Calculation of the hydrodynamic effect of finite amplitude vibrations on reservoir structures,* Filippenok, V. Z.—*Calculation of the hydrodynamic effect of a fluid on the walls of a rectangular basin,* Averyanov, V. K. and Tyutyunnikov, A. I.—*Hydrodynamic effect of fluid on a rigid barrier with broken profile,* Pilipenko, V. A.—*Hydrodynamic effect on massive submerged hydraulic structures with rectangular profile,* Pilipenko, V. A.—*On the effect of ice cover on the reservoir surface on the earthquake response of hydroelectric power plant structures in water,* Sheinin, I. S., Mukhutdinova, R. Z. and Shames, M. P.—*Prediction of wave levels in a water reservoir in a region with complex seismic, tectonic and geological conditions,* Gvelesiani, T.—*Experimental investigations of the dynamic structural stability of loose soils subjected to shear,* Gorelyshev, P. I.—*Investigation of the dynamic stability of the body of sand-filled rock dams,* Gorelyshev, P. I. and Pyshkin, O. B.—*Investigation of the vibrations, stresses and stability of the soil base of foundations,* Eskin, Yu. M. and Eiler, L. A.—*A method for calculation of the alteration of embankment profiles during earthquakes,* Birbraer, A. N.—*Computer analysis of the seismic stability of earth slopes of hydraulic structures,* Krasnikov, N. D. *et al.*—*Dynamic analysis of the deformations of earth slopes of dams utilizing real accelerograms,* Dmitriev, Yu. V.—*Approximation method for calculation of the displacement of foundations on sand base subjected to short-duration dynamic loadings,* Berezantseva, E. V.—*Breaking strength of the base of gravitational structures in seismic conditions,* Kalaev, A. I.—*On improved seismic analysis of retaining walls,* Shikhiev, F. M. and Yakovlev, P. I.—*Seismic response of flexible and rigid retaining walls,* Gulyaev, E. A.—*On the problem of porous water pressure in earth dams under seismic conditions,* Mamradze, G. P. and Dzhindzhikhashvili, G. Ya.—*Investigation of the effect of surface topography on ground motion during earthquakes,* Ilyasov, B. I. and Saidova, Sh. S.

1.2 Proceedings of Conferences

● 1.2-1 Aynsley, R. M. and Cowan, H. J., eds., **Proceedings of the Australian and New Zealand Conference on the Planning and Design of Tall Buildings**, ASCE-IABSE Joint Committee on Tall Buildings, Lehigh Univ., Bethlehem, Pennsylvania, June 1974, 683.

The Twelfth Regional Conference was held in Sydney, Australia, Aug. 14-17, 1973. Forty-three papers were

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

presented at twelve sessions. Discussions were held following eleven of the sessions. The proceedings contain the names and affiliations of the conference participants and a combined keyword and author index.

The following five papers are relevant to earthquake engineering and are abstracted in this volume of the *AJEE*: *The six components of earthquakes*, Rosenblueth, E.—*New Zealand earthquake provisions*, Shepherd, R.—*The design and construction of the Bank of New Zealand, Wellington, New Zealand*, Smith, I. C.—*The behaviour of building structures under lateral loads*, Gero, J. S.—*Recent research on the strength, stiffness and ductility of steel building frames*, Lu, L.-W. and Beedle, L. S.

● 1.2-2 **Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings**, Japan Earthquake Engineering Promotion Society, International Inst. of Seismology and Earthquake Engineering, Tokyo, 1976, 396.

The objective of this research program, which is under the sponsorship of the U.S.-Japan Cooperative Science Program, is to propose a rational method for the earthquake-resistant design of reinforced concrete school buildings. The program was initiated following the 1968 Tokachi-oki earthquake in Hokkaido during which many reinforced concrete school buildings of modern design were severely damaged.

This meeting was held at the Univ. of Hawaii, Honolulu, on Aug. 18–20, 1975, to review the progress of the program and to formulate seismic design criteria and procedures. Joint seminars also were held in 1970 and in 1973.

All of the nineteen papers presented at the meeting are abstracted in this volume of the *AJEE*. The following is a list of the titles and authors' names: *Strong ground motion and seismic design criteria*, Jennings, P. C.—*Earthquake motion measurements and analysis of pile-supported building and its surrounding soil*, Kawamura, S., Osawa, Y. and Umemura, H.—*Characteristics of three-dimensional ground motions, San Fernando earthquake*, Kubo, T. and Penzien, J.—*Inelastic cyclic behavior of reinforced concrete flexural members*, Penzien, J., Bertero, V. and Atalay, B.—*Seismic design implications of hysteretic behavior of reinforced concrete elements under high shear*, Bertero, V. V., Popov, E. P. and Wang, T.-Y.—*Hysteretic behavior of reinforced concrete shear walls*, Shiga, T., Shibata, A. and Takahashi, J.—*Structural walls subjected to simulated earthquakes*, Sozen, M. A. and Otani, S.—*Experimental and analytical study on reinforced concrete chimneys*, Omote, Y. and Takeda, T.—*Aseismic measures for reinforced concrete structures-In view of damage from Oita earthquake of 1975*, Umemura, H.—*An evaluation method of earthquake resistant properties of existing reinforced concrete school buildings*, Hirosawa, M. *et al.*—*Assessment of earthquake safety and of hazard abatement*, Bresler, B., Okada, T. and Zisling, D.—*Seismic safety of existing low-rise reinforced concrete buildings—Screening method*, Okada, T. and Bresler, B.—*Nonlinear response spectra for probabilistic seismic design of reinforced concrete structures*, Murakami, M. and Penzien, J.—*Use of linear models in design to reflect the effect of nonlinear response*, Shibata, A. and Sozen, M. A.—*Simple nonlinear models for the seismic response of reinforced concrete buildings*, Aoyama, H.—*Nonlinear building response by the characteristics method*, Nishikawa, T., Batts, M. E. and Hanson, R. D.—*The strengthening method of existing reinforced concrete buildings*, Higashi, Y. and Kokusho, S.—*An experimental study on earthquake resistant strengthening work for existing reinforced concrete buildings*, Sasaki, T. *et al.*—*Repair and rehabilitation of reinforced concrete structures*, Lee, D. L. N., Wight, J. K. and Hanson, R. D.

● 1.2-3 Saul, W. E. and Peyrot, A. H., eds., **Methods of structural analysis**, Proceedings of the National Structural Engineering Conference, American Society of Civil Engineers, New York, 1976, 2 vols., 1091.

The Structural Division of ASCE held the National Structural Engineering Conference on Aug. 22–25, 1976, at the Univ. of Wisconsin, Madison. Contained in these proceedings are 64 selected papers out of about 160 presented. Also included are author and subject indexes. Sixteen papers relevant to earthquake engineering are abstracted in this volume of the *AJEE*. Following are the titles and authors' names.

Structural system failure analysis in a high load environment, Collins, J. D.—*Comparison of three-dimensional analysis of concrete shear wall buildings and their actual behavior*, Ramakrishnan, V.—*Forced vibrations of strip footings on layered soils*, Gazetas, G. C. and Roesset, J. M.—*Guide criteria to bridge and permit loads*, Chang, D. J.—*Historical review of earthquakes, damage, and building codes*, Berg, G. V.—*Measurements and evaluation of building response to ground motion at various stages of construction*, Honda, K. K.—*Interface shear transfer and dowel action in cracked reinforced concrete subject to cyclic shear*, Jimenez, R. *et al.*—*Recent Japanese developments in mixed structures*, Wakabayashi, M.—*A structural design decision methodology for nuclear power plants*, Zendehrouh, S. and Shinozuka, M.—*Review of selected topics in finite element analysis*, Cook, R. D.—*Analysis and design of laterally loaded piles and caissons in a layered soil system*, Naik, T. R. and Peyrot, A. H.—*Static and dynamic flexibility matrix for a semi-infinite solid*, Naik, T. R. and Wang, C.-K.—*Determination of the natural modes of a complex elastic structure in terms of the natural modes of the unconstrained components*, Abramowitz, J. S.—*Evaluation of an existing building complex for earthquake re-*

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

sponse, Freeman, S. A.—*Computer-aided structural analysis and design of the 37-story Bonaventure Hotel,* Nicoletti, J. P., Jhaveri, D. P. and Emkin, L. Z.—*Elastic and elastoplastic computerized dynamic analysis of frame structures subjected to blast overpressure,* Tseng, G. S. *et al.*

● **1.2-4 American Geophysical Union, Spring Annual Meeting, program and abstracts,** *EOS, Transactions of the American Geophysical Union,* **56,** *6,* June 1975, 342–480.

The 1975 Spring Annual Meeting of the American Geophysical Union was held in Washington, D.C., June 16–19, 1975. This issue of *EOS* contains the preliminary program, abstracts of papers presented at the meeting, and an author index (see Abstract No. 1.2-5 for post-deadline program changes). Following are the titles, authors' names and paper numbers (in parentheses) of the abstracts relevant to earthquake engineering. These abstracts are not contained in this volume of the *AJEE.*

First results from a new eastern Aleutian seismic network and geodetic level lines, Davies, J. N., House, L. S. and Jacob, K. H. (S5)—*The Pattan earthquake of December 28, 1974 in the western Himalayas, Pakistan; damage, tectonics, and possible premonitory effects,* Jacob, K. H., Pennington, W. and Armbruster, J. (S29)—*Fault plane solution and tectonic implications of the Pattan, Pakistan earthquake of December 28, 1974,* Chandra, U. (S30)—*Earthquakes, Chandler wobble, rotation and geomagnetic changes: A pattern recognition approach,* Press, F. and Briggs, P. (S50)—*Earthquake precursors,* Rikitake, T. (S51)—*On the cyclic behavior of the San Andreas Fault,* Turcotte, D. L. and Spence, D. A. (S52)—*Strain accumulation on the northern San Andreas fault zone since 1906,* Thatcher, W. (S53)—*A statistical study of earthquake occurrences along the San Andreas fault system,* Chon, Y. T. and Smith, D. E. (S54)—*Time-varying P-velocity anisotropy along the San Andreas Fault,* Steppe, J. A., Bakun, W. H. and Bufe, C. G. (S55)—*Earthquake prediction: Seismic velocity variations in southern California,* Whitcomb, J. H. (S56)—*Anomalous tilt before three recent earthquakes,* Stuart, W. D. and Johnston, M. J. S. (S57)—*Summary and implications of simultaneous observation of tilt and local magnetic field changes prior to a magnitude 5.2 earthquake near Hollister, California,* Johnston, M. J. S. *et al.* (S58)—*Correlation of strain and tilt episodes with ground-water encroachment and earthquakes near the Wasatch Fault, Utah,* Hamtak, F. J. and Cook, K. L. (S59)—*Secular strain, strain steps and earthquake prediction criteria from observations in the Matsushiro region, central Honshu, Japan,* Suyehiro, S. and Sacks, I. S. (S60)—*Time-dependent gravimetry in an active tectonic area,* Stewart, G. S., Hadley, D. M. and Whitcomb, J. H. (S61)—*Effect of dilatancy on the earth tides by ocean loading,* Tanaka, T. (S62)—*Search for temporal variation and anisotropy of resistivity using the magnetotelluric method,* Cole, D. M. *et al.* (S63)—*Strong ground motions in three dimensions for the San Francisco earthquake of 22 March 1957,* Porter, L. D. (S72)—*Anelastic attenuation of short-period Rayleigh waves in northeastern North America,* Street, R. L. and Turcotte, F. T. (S79)—*Spatial attenuation of intensities for central U. S. earthquakes,* Gupta, I. N. and Nuttli, O. W. (S80)—*Evidence from earthquake time sequences for a large-scale event involving the Pacific and Nazca plates during 1964–68,* Chinnery, M. A. and Landers, T. E. (T20)—*Quantitative interpretation of velocity variations caused by stress induced tension cracks,* Rothman, R. L., Greenfield, R. J. and Hardy, Jr., H. R. (T51)—*The location of the source of microshocks during water injection into rock under stress,* Lockner, D. and Byerlee, J. (T52)—*Relative importance of attenuation mechanisms of seismic waves in dry and saturated rocks,* Johnston, D. H. and Toksoz, M. N. (T54)—*Seismic velocities in rocks as a function of saturation condition and pressure,* Cheng, C. H. and Toksoz, M. N. (T55)—*P and S velocity anomalies at Blue Mt. Lake (BML), New York: Implications on the dilatancy mechanisms of earthquake precursors,* Aggarwal, Y. P. (T56)—*High pressure deformation and fluid flow in granular material,* Zoback, M. D. and Byerlee, J. D. (T57)—*Multiple failure model of earthquakes,* Robertson, E. C. (T58)—*Can a well tell?,* Kovach, R. L., Nur, A. and Wesson, R. L. (T59)—*Variations in the magnetism of a Gabbro in uniaxial failure tests,* Martin, III, R. J. and Wyss, M. (T60)—*Hydrofracturing stress measurements in the Sierra Nevada Mountains,* Haimson, B. C. (T61)—*A single borehole complete stress tensor gage requiring no cement,* Withjack, M. and Tullis, T. E. (T62)—*The effect of in situ stress state on seismic velocity and elastic modulus,* Pratt, H. R., Swolfs, H. S. and Black, A. D. (T63).

● **1.2-5 American Geophysical Union, Spring Annual Meeting, program and abstracts,** *EOS, Transactions of the American Geophysical Union,* **56,** *11,* Nov. 1975, 893–914.

This issue of *EOS* contains highlights and post-deadline program changes and abstracts of the 1975 Spring Annual Meeting, held June 16–19, 1975, in Washington, D.C. (see Abstract No. 1.2-4 for the preliminary program). Two abstracts pertinent to earthquake engineering were added. The following are the titles, authors' names and paper numbers (in parentheses). These abstracts are not included in this volume of the *AJEE.*

Direct measurement of premonitory changes in stress associated with a microearthquake, Swolfs, H. S., Brechtel, C. E. and Brace, W. F. (T50A)—*Resistivity of granite during stick-slip motion,* Wang, C. and Goodman, R. E. (T54A).

● **1.2-6 Proceedings, Fifth European Conference on Earthquake Engineering,** Earthquake Research Inst., Turkey, Ministry of Reconstruction and Resettlement, Ankara, 1975, 3 vols., 1543.

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

The Fifth European Conference on Earthquake Engineering was held in Istanbul, Sept. 22–25, 1975. There were 176 papers presented at the conference. Volumes 1 and 2 contain 167 of the conference papers and Volume 3 contains nine late-submitted papers, as well as a list of participants, the opening addresses and discussions. One hundred six papers were abstracted in Volume 5 of the Abstract Journal; the remainder are either abstracted or cited in this volume of the journal. For a complete listing of the papers contained in Volumes 1 and 2, see Abstract No. 1.2-8, Vol. 5, *AJEE.*

The titles and authors' names for the nine papers included in Volume 3 follow: *Trends in engineering seismology in Europe,* Ambraseys, N. N.—*Seismic zoning of the Balkan region,* Karnik, V.—*Balanced seismic coefficients for sites with different seismicity,* Grandori, G.—*A new approach for estimating earthquake risk,* Omote, S. and Matsumura, K.—*Response of rural dwellings to Lice earthquake Sept. 6, 1975, Turkey,* Arioglu, E. and Anadol, K.—*Structural response to translational and rotational ground motions,* Nathan, N. D., MacKenzie, J. R. and McKevitt, W. E.—*Recent research on earthquake prediction,* Hagiwara, T.—*Influence of soil layers in response spectra,* Duarte, R. T. and Ravara, A.—*Analysis of the 1973–74 Acores earthquakes,* Ravara, A. and Duarte, R. T.

● **1.2-7** Cheng, F. Y., ed., **Proceedings of the International Symposium on Earthquake Structural Engineering,** Dept. of Civil Engineering, Univ. of Missouri, Rolla, 1976, 2 vols., 1309.

The symposium was held Aug. 19–21, 1976, in St. Louis, Missouri. All 89 of the papers presented at the meeting are either abstracted or cited in this volume of the *AJEE;* the following are the paper titles and authors' names:

Volume I

Invited Lectures: *On the specification of a design earthquake,* Nuttli, O. W.—*Protection of communications facilities in earthquake areas,* deCapua, N. J. and Liu, S. C.—*Establishment of design earthquakes—Evaluation of present methods,* Bertero, V. V. with Herrera, R. A. and Mahin, S. A.

Session 1A—Buildings and Bridges: *A study of the effect of the frequency characteristics of ground motions on nonlinear structural response,* Derecho, A. T., Freskakis, G. N. and Fintel, M.—*Seismic retrofitting for highway bridges,* Longinow, A. *et al.*—*The non-linear deformations in the ground base of large-panel buildings under oscillations,* Shapiro, G. A. and Ashkinadze, G. N.—*Dynamic behavior of cable stayed bridges,* Egeseli, E. A. and Fleming, J. F.—*Modal analysis and seismic design of tall building frames,* Paramasivam, P., Nasim, S. and Lee, S. L.—*Development in structural solutions of multi-storey seismic-proof frameless buildings of in-situ reinforced concrete in U.S.S.R.,* Sokolov, M. E. and Glina, Yu. V.—*The inelastic seismic response of bridge structures,* Sharpe, R. D. and Carr, A. J.—*Effect of coupling earthquake motions on inelastic structural models,* Cheng, F. Y. and Oster, K. B.

Session 1B—Foundation and Structure Interaction: *The effect of foundation compliance on the fundamental periods of multi-storey buildings,* Mendelson, E. and Alpan, I.—*Inverted-pendulum effect on seismic response of tall buildings considering soil-structure interaction,* Lee, T. H.—*On the use of precast pile-foundations in construction of earthquake-proof large-panel buildings,* Martynova, L. D. *et al.*—*Some seismic response solutions for soil-foundation-building systems,* Minami, J. K. and Sakurai, J.—*Response of structures embedded in the ground to travelling seismic waves,* Prater, E. G. and Wieland, M.—*Some comparisons of dynamic soil-structure analyses,* Johnson, G. R., Epstein, H. I. and Christiano, P.—*Gypsum layer in soil-structure systems,* Hung, Y. C. and Snyder, M. D.—*The soil foundation-structure interaction under the action of earthquake loads,* Ciongradi, I. and Ungureanu, N.

Session 2A—Analysis and Design: *Critical excitation and response of free standing chimneys,* Wang, P. C. *et al.*—*Dynamic analysis of elastic-plastic space frames,* Morris, N. F.—*On the limit analysis of box-unit buildings under static and dynamic effects,* Nassonova, T. I. and Fraint, M. J.—*Dynamic response of cantilever beam-columns with attached masses supported on a flexible foundation,* Kounadis, A. N.—*Vibrations and interactions of layered beam foundations,* Shah, V. N. and Huang, T. C.—*Generating response spectra from displacement and velocity time history input,* Chuang, A. *et al.*—*A simplified nonlinear seismic response analysis of structures including vertical ground motion,* Bervig, D. R.—*Response of an elasto-plastic spherical structure in a fluid to earthquake motions,* Srimahachota, D., Hongladaromp, T. and Lee, S.-L.—*Dynamic response of retaining walls during earthquake,* Yeh, C.-S.—*Dynamic response of bridge grid under moving force,* Munirudrappa, N.—*A new method for numerical integration of equations of motion,* Goldberg, J. E.—*Sheraton Hotel in Santo Domingo, Dom. Rep.: Analysis, design, and construction techniques,* Ricart Nouel, A. A.

Session 2B—Dynamic Tests on Structures: *Reversing load tests of five isolated structural walls,* Fiorato, A. E., Oesterle, Jr., R. G. and Carpenter, J. E.—*Dynamic behavior of a reinforced concrete spray tower,* Fowler, T. J. and Williams, D. M.—*Experimental studies on hysteretic characteristics of steel reinforced concrete columns and frames,* Wakabayashi, M. and Minami, K.—*Static and dynamic tests of a large-size model of a frameless in-situ reinforced concrete residential building,* Barkov, Yu. V. and Glina, Yu. V.—*Experimental study on reinforced concrete truss frames as earthquake-resistance elements,* Shimazu, T. and Fuku-

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

hara, Y.—*Ductile behaviour of coupled shear walls subjected to reversed cyclic loading,* Santhakumar, A. R.—*Earthquake response of guyed towers,* du Bouchet, A. V.—*Experimental study on reinforced concrete columns with special web-reinforcements,* Umemura, H. *et al.*—*Torsional response at large eccentricities,* Meyer, K. J. and Oppenheim, I. J.

Session 3A—Analysis and Design: *A unified approach to designing structures for three components of earthquake,* Gupta, A. K. and Chu, S. L.—*Resizing of frames subjected to ground motion,* Venkayya, V. B. and Cheng, F. Y.—*Problems in establishing and predicting ductility in aseismic design,* Mahin, S. A. and Bertero, V. V.—*Shear coefficient and shear force distribution in nuclear power plant structures due to seismic loading,* Chokshi, N. C. and Lee, J. P.—*Evaluation of the reservoir effect on the dynamics of dams,* Akay, H. U. and Gulkan, P.

Volume II

Session 3A—Analysis and Design (continued): *Dynamic response characteristics of an elasto-plastic structure on a random soil ground,* Kobori, T., Inoue, Y. and Kawano, M.—*Some design considerations of earthquake resistant reinforced concrete shear walls,* Paulay, T.—*Earthquake resistance of structures with suspended masses,* Nikolaenko, N. A. and Burgman, I. N.—*Earthquake response of a tall multi-flue stack,* Karasudhi, P., Tsai, Y. C. and Chau, K. P.

Session 3B—Codes and Regulations: *On specifications for earthquake-resistant design of the Honshu-Shikoku Bridges (JSCE-1974),* Kawasaki, I. and Kuribayashi, E.—*Comparison of aseismatic steel building design practice in Japan and USA,* Cheng, P. H.—*Comparative study of the new Turkish earthquake resistant design code,* Celebi, M.—*Application of structural, mechanical and electrical codes and standards in the design of safety related structures, components and systems for nuclear power plants,* Mehta, D. S. and Meyers, B. L.—*On specifications for earthquake-resistant design of highway bridges (January 1971),* Kawakami, K. *et al.*—*The new Turkish aseismic code: A critical evaluation with emphasis on soil amplification considerations,* Gurpinar, A.—*Earthquake dynamic environment within buildings,* Merz, K. L.—*On earthquake resistant design of a submerged tunnel,* Tamura, C. and Okamoto, S.—*Seismic design of the Veteran's Administration Hospital at Loma Linda, California,* Holmes, W. T.

Session 4A—Safety, Reliability, and Power Plant Structures: *Structural damage and risk in earthquake engineering,* Hsu, D. S., Gaunt, J. T. and Yao, J. T. P.—*On nonstationary spectrum and mean square response of a simple structural system to earthquake excitation,* Kobori, T. and Takeuchi, Y.—*Dynamic earthquake analysis of a bottom supported industrial boiler,* Monroe, N. J. and Dasa, N.—*Effects of earthquake input in seismic responses of nuclear power plant sites,* Lu, B. T. D., Fischer, J. A. and Peir, J.—*Discrete modeling of containment structures,* Lin, Y. J. and Hadjian, A. H.—*Seismic risk analysis of nuclear power plant sites including power spectrum simulation of future earthquake motion,* Gurpinar, A.—*Safety of seismic protective systems with reserve elements,* Eisenberg, I. M.—*Seismic dynamic parametric study on finite element model of nuclear power plant facility,* Teraszkiewicz, J. S.—*Approximate random vibration analysis of elastoplastic multi-degree-of-freedom structures,* Gazetas, G. and Vanmarcke, E. H.—*Probabilistic approach to ultimate aseismic safety of structures,* Yamada, M. and Kawamura, H.—*Seismic analysis of hyperbolic cooling towers by the response spectrum method,* Gould, P. L., Sen, S. K. and Suryoutomo, H.

Session 4B—Ground Motions, Construction and Repair of Structures: *Methodology for incorporating parameter uncertainties into seismic hazard analysis for low risk design intensities,* McGuire, R. K.—*Epoxy repair of structures,* Plecnik, J. M. *et al.*—*A California structural engineer shares three years of on-site experiences in the design of reparations for buildings in Managua,* Creegan, P. J.—*Troika for earthquake-resistant building design, engineer-building code-contractor,* Tissell, J. R.—*Safety of cities during severe earthquakes,* Mann, O. C.—*Evaluation of Greek strong motion records,* Carydis, P. G. and Sbokos, J. G.—*Behavior of reinforced concrete structures during the Managua earthquake,* Estrada-Uribe, G.—*Site response analysis for earthquake loading,* Lou, Y. S., Dixon, S. J. and MacFadyen, C. R.

Invited Lecture: *Observational studies on the earthquake response of buildings in Japan,* Osawa, Y. *et al.*

Session 5—Structural Elements and Special Structures: *Discrete modeling of symmetric box-type structures,* Hadjian, A. H. and Atalik, T. S.—*Inelastic seismic response of isolated structural walls,* Freskakis, G. N., Derecho, A. T. and Fintel, M.—*Effects of sectional shape on the strength and ductility of slender structural walls in earthquake-resistant multistory buildings,* Ghosh, S. K. and Fintel, M.—*On the shear pinched hysteresis loops,* Celebi, M.—*Confined concrete in compression zones of structural walls designed to resist lateral loads due to earthquakes,* Kaar, P. H. *et al.*—*Response of an empty cylindrical ground supported liquid storage tank to base excitation,* Shaaban, S. H. and Nash, W. A.—*Seismic design of liquid storage tanks to earthquakes,* Chen, P. C. and Barber, R. B.—*Analysis of non-uniform coupled shear walls with two rows of openings,* Santhakumar, A. R.—*Aseismic design examples of prestressed concrete water tank,* Sakurai, A., Kurihara, C. and Iwatate, T.—*A new structural model for shear walls analysis,* Ungureanu, N.—*Response of reinforced concrete chimneys to earthquake forces,* Ramesh, C. K. and Fadnis, P. V.

● **1.2-8 Dynamic response of structures: Instrumentation, testing methods and system identification,** Proceedings of the ASCE/EMD Specialty Conference, Univ. of California, Los Angeles, 1976, 550.

The conference was held Mar. 30–31, 1976, at the Univ. of California, Los Angeles. The co-sponsors were the ASCE Engineering Mechanics Div.; the Earthquake Engineering Research Inst.; the Mechanics and Structures Dept., Univ. of California, Los Angeles; the Structural Engineers Assn. of Southern California; and the Wind Engineering Research Council. Thirty-two of the papers pertinent to the field of earthquake engineering are abstracted or cited in this volume of the *AJEE*. Following are the paper titles and authors' names:

Dynamic tests of full-scale structures, Hudson, D. E.—*California building strong motion earthquake instrumentation program,* Rojahn, C.—*System identification in structural dynamics,* Hart, G. C. and Yao, J. T. P.—*Laboratory model testing for earthquake loading,* Clough, R. W. and Bertero, V. V.—*Vibration instrumentation system measures an offshore platform's response to dynamic loads,* Durning, P. J. and Engle, D.—*Forced-vibration tests of a three-story reinforced concrete frame and shear-wall building in Tadzhik, S.S.R.,* Rojahn, C. and Negmatullaev, S. H.—*Recent advances in dynamic testing of full scale structures,* Foutch, D. A.—*Ambient vibration study of six similar high-rise apartment buildings: Comparison of the dynamic properties,* Kircher, C. A. and Shah, H. C.—*Ambient and forced vibration studies of a multistory triangular-shaped building,* Petrovski, J. and Stephen, R. M.—*Measurement and evaluation of high-rise building response to ground motion generated by underground nuclear explosions,* Honda, K. K.—*Structural response to nuclear detonation ground motions,* Medearis, K.—*Dynamic response characteristics of reinforced concrete structures,* Freeman, S. A., Chen, C. K. and Czarnecki, R. M.—*Ambient and forced vibration analysis of 230 KV air blast circuit breakers: Comparison of system properties before and after addition of Braun-Bowery dampers,* Kircher, C. A.—*Dynamic properties of Lions' Gate suspension bridge,* Ranier, J. H. and Van Selst, A.—*Digital filtering of ambient response data,* Taoka, G. T.—*Pseudo-dynamic testing of wall structural systems,* Bertero, V. V. *et al.*—*Earthquake tests of shear wall-frame structures to failure,* Otani, S.—*Highlights of an experimental investigation of the seismic performance of structural walls,* Fiorato, A. E. *et al.*—*Earthquake simulation tests of a steel frame allowed to uplift,* Huckelbridge, A. A. and Clough, R. W.—*Identification of the energy absorption characteristics of an earthquake resistant structure: Identification of parameters from shaking table experiments,* Matzen, V. C. and McNiven, H. D.—*Testing wall panels for earthquake response,* Freeman, S. A.—*Cyclic shear behavior of R/C plastic hinges,* Ma, S.-Y. M., Popov, E. P. and Bertero, V. V.—*Development of a simple apparatus for studying multi-storey frame connections,* Elkamshoshy, F. M. and Ward, M. A.—*Pseudo dynamic and earthquake simulation testing,* Ernst, G. C. and Smith, G. M.—*Recursive least squares time domain identification of dynamic structures,* Caravani, P., Watson, M. and Thomson, W. T.—*Identification of the energy absorption characteristics of an earthquake resistant structure: Description of the identification method,* McNiven, H. D. and Matzen, V. C.—*Experimental and theoretical analysis of buildings,* Ibanez, P., Vasudevan, R. and Smith, C. B.—*Modal identification for non-normal modes,* Beliveau, J.-G.—*Aseismic design implications of San Fernando earthquake records,* Bertero, V. V., Mahin, S. A. and Herrera, R. A.—*Evaluation of the seismic response in the Sylmar-San Fernando area, California, from the 1971 San Fernando earthquake,* Hays, W. W.—*A case study of site response,* Lou, Y. S., Dixon, S. J. and MacFadyen, C. R.—*Use of acoustic emission and holographic techniques to detect debonding in cyclically loaded concrete structures,* Hawkins, N. M., Kobayashi, A. S. and Fourney, M. E.

● **1.2-9 Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,** Architectural Inst. of Japan *et al.*, Tokyo, 1975, 1066.

The symposium was held Nov. 26–28, 1975, in Tokyo. The sponsors were the Architectural Inst. of Japan, the Japanese societies of Civil and Mechanical Engineers, the society of Soil Mechanics and Foundation Engineering, and the Seismological Society of Japan. All of the papers are either abstracted or cited in this volume of the *AJEE*. Those papers written in Japanese are indicated; all others are written in English.

Earthquake Ground Motion: *Periodical characteristics of large and middle earthquakes which occurred in a region of the Pacific Ocean in the vicinity of Japan and earthquake prediction* (in Japanese), Hirata, M.—*Source process of the Hiroo-oki earthquake of 1962 and long-period earthquake motions* (in Japanese), Sasatani, T. and Suzuki, S.—*Strong earthquake ground motions due to a propagating fault model considering the change of dislocation velocity-Parkfield earthquake of 1966 and Tokachi-oki earthquake of 1968* (in Japanese), Ishida, K. and Osawa, Y.— *On the regional distribution of the earthquake danger and the maximum amplitude in Japan,* Kitagawa, Y. and Hattori, S.—*A probabilistic approach to estimate damage potential design earthquakes for a site in terms of magnitude, epicentral distance and return period* (in Japanese), Yoshikawa, S., Iwasaki, Y. and Ishii, E.—*Seismic microzoning in areas of nuclear power plants,* Steinwachs, M.—*A questionnaire survey into human psychology and behavior during an earthquake* (in Japanese), Ohta, Y.—*On the degree of earthquake risk in Taiwan,* Hsu, M.-T.—*Hazards from earthquake faulting in Japan,* Kobayashi, Y.—*Effect of soft surface layer on the duration time and maximum acceleration of earthquake* (in Japanese), Hakuno, M. and Inoue, R.—*Dynamic behavior of the embankments on the soft*

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

ground deduced from the investigation of earthquake damages (in Japanese), Asada, A.—*The relation of mechanical properties of soils to P- and S-wave velocities in Japan* (in Japanese), Imai, T., Fumoto, H. and Yokota, K.—*A handy and high-precise shear wave measurement by means of standard penetration test* (in Japanese), Goto, N., Kagami, H. and Shiono, K.—*Simulation analysis for earthquake behavior in deep alluvial soil* (in Japanese), Tsugawa, T. *et al.*—*Earthquake observation on soft ground* (in Japanese), Yokoyama, M. *et al.*—*Underground earthquake motions in ports and harbours* (in Japanese), Arai, H., Kitajima, S. and Saito, S.—*Earthquake characteristics in plan* (in Japanese), Toriumi, I.—*Observation of earthquake response of ground with horizontal and vertical seismometer arrays*, Tsuchida, H. and Kurata, E.—*Seismic behavior of subsurface ground layers* (in Japanese), Iwasaki, T., Wakabayashi, S. and Tatsuoka, F.—*Reliability of ground motions by SMAC-B2 accelerographs* (in Japanese), Kuribayashi, E., Toki, K. and Wakabayashi, S.—*Vibrational characteristics of the ground as derived from strong motion earthquake records* (in Japanese), Tanaka, T. and Yoshizawa, S.—*Spectra of seismic waves in the period range from 1 to 10 seconds*, Buyukasikoglu, S. and Shima, E.—*1- to 5-sec. microtremors—Observations in Hachinohe and its importance in an interpretation of long period strong motion records* (in Japanese), Ohta, Y., Kagami, H. and Kudo, K.—*Spectral characteristics of microtremors and ground structures* (in Japanese), Irikura, K.—*On influence of underground structure on seismic wave spectra* (in Japanese), Sima, H.—*Experimental study of characteristic vibration near cliff due to SH waves, II* (in Japanese), Komaki, S., Ohbo, N. and Onda, I.—*Characteristics of earthquake motion on seismic bedrock* (in Japanese), Kobayashi, H. and Nagashashi, S.—*Two-dimensional horizontal earthquake motions of ground* (in Japanese), Kobayashi, H., Samano, T. and Yamauchi, M.—*Maximum ground accelerations at coasts in Tokyo Bay and Tokai district*, Uwabe, T. and Noda, S.—*Dynamic properties of fluid saturated elastic soil layers* (in Japanese), Taga, N. and Togashi, Y.—*Analysis and synthesis of the strong earthquake wave based on the digital filtering method* (in Japanese), Inaba, S. and Kinoshita, S.—*A method for obtaining reliable displacement curves from recorded earthquake motions* (in Japanese), Kubo, K. and Sato, N.—*Basic study on stochastic analysis of wave pattern of ground motions* (in Japanese), Shibata, H., Toshimitsu, S. and Mochio, T.—*Detection of phase velocity from strong-motion accelerograms* (in Japanese), Toki, K.—*Stress and strain in ground during strong earthquake,* Kamiyama, M.

Interaction Between the Ground and Structures: *Study on soil-reactor building interaction analysis of damping effects in energy dissipation through the bottom of foundation* (in Japanese), Tsushima, Y. *et al.*—*Forced vibration test and analysis as soil-structure system of nuclear reactor building* (in Japanese), Hirasawa, M. and Satoh, K.—*Earthquake response analysis of nuclear reactor building embedded in a ground by the thin layer element method* (in Japanese), Shimizu, N. *et al.*—*A resonance phenomenon in mutual action between a building and soil,* Mizoguchi, K.—*Analysis on dynamic behaviours of soil-structure systems* (in Japanese), Hanada, K. and Kudo, T.—*Elastic-plastic dynamic analysis of soil-foundation-structure interaction,* Ukaji, K., Hoeg, K. and Shah, H. C.—*Nonstationary restoring force characteristics and earthquake response of structural foundation-surface layer system* (in Japanese), Kitaura, M.—*Vibrations of structures embedded in a visco-elastic layered medium,* Kobori, T. and Suzuki, T.—*On wave propagation in one-dimensional elasto-plastic media,* Kobori, T. and Tosu, S.—*Spectra of spatially variant ground motions and associated transfer functions of soil-foundation system,* Matsushima, Y.—*Analysis and measurement tests on dynamic properties of coupled building-soil system,* Shibuya, J., Motosaka, M. and Shiga, T.—*Effects of varied damping values and vertical earthquake motions on the seismic response of soil-foundation-building systems* (in Japanese), Minami, J. K., Sakurai, J. and Ohno, T.—*Dynamic behaviors of a large-scale shaking table foundation,* Tajimi, H., Ogawa, N. and Minowa, C.

Dynamic Behavior of Soils: *Soil dynamic properties for dynamic response analysis—Dynamic characteristics of Kwanto-loam* (in Japanese), Hara, A. and Kiyota, Y.—*In-situ seismic survey and laboratory test on dynamic properties of soils* (in Japanese), Iwasaki, T. and Tatsuoka, F.—*Fundamental study of the application of seismic techniques to determination of soil properties,* Tanimoto, K., Noda, T. and Fudo, R.—*A new exploratory method for properties of ground through borehole wall* (in Japanese), Esashi, Y., Yoshida, Y. and Nishi, K.—*An experimental study of the characteristic of the subgrade reaction in the poor subsoil* (in Japanese), Aramaki, G. and Koga, K.—*Response analysis of a reclaimed deposit during earthquakes* (in Japanese), Ishihara, K. *et al.*—*Bearing capacity of saturated sand deposits during vibration,* Ishihara, K. and Matsumoto, K.—*Liquefaction of sand near structures during earthquakes* (in Japanese), Yoshimi, Y. and Tokimatsu, K.—*Active earth pressure during earthquake* (in Japanese), Ichihara, M., Matsuzawa, H. and Kawamura, M.—*Dynamic analysis of the earth retaining wall by the finite element method* (in Japanese), Shibata, T., Sato, T. and Tatumi, Y.

Seismic Stability of Piles and Caissons: *Earthquake observation and dynamic analysis of pile-supported building,* Sugimura, Y.—*Earthquake observation and analysis of plant tower built on the soft subsoil* (in Japanese), Hagio, K. *et al.*—*Earthquake measurement of pile supported building on the reclaimed ground—Comparison between building line and soil line* (in Japanese), Kawamura, S. and Umemura, H.—*Earthquake observation of cellular foundation with steel pipe piles* (in Japanese), Kidera, K. *et al.*—*Comparison of vibration characteristics during earthquakes of caisson piers before and after girder-construction* (in Japanese), Satake, M. *et al.*—*On the conversion of a hysteretic structure into the model with equivalent viscous*

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

damping—Fundamental studies on the approximate function of restoring force characteristics of pile (in Japanese), Kitagawa, H. and Mochizuki, T.—*Earthquake response analysis of structures supported on piles by a test apparatus-computer on line real time system* (in Japanese), Mochizuki, T., Nagashima, F. and Koizumi, T.—*Vibrational characteristics of building with pile foundation—A study of introducing the plasticity of soil in the estimation of spring constant* (in Japanese), Takeuchi, M., Kotoda, K. and Kazama, S.—*Dynamic response of pile-supported bridge pier in mud deposit* (in Japanese), Masaki, Y. *et al.*—*Sheet pile foundation and its dynamic properties,* Komada, K. and Okahara, M.—*Forced vibrational characteristics of rigid body in the ground* (in Japanese), Masao, T. and Suzuki, T.—*On dynamic characteristics of an embedded structure with rounded corners rectangular section* (in Japanese), Miura, K., Terada, S. and Tajime, T.

Seismic Stability of Buildings, Tanks, etc.: *Dynamic study on aseismic design method of wooden house* (in Japanese), Sakamoto, I.—*Aseismic capacity of buildings based upon resonance-fatigue-characteristics* (in Japanese), Yamada, M. and Kawamura, H.—*Relation between seismic coefficient and ground acceleration for gravity quaywall,* Noda, S. and Uwabe, T.—*Behavior of underground tanks during earthquakes,* Hamada, M., Izumi, H. and Sato, S.—*Earthquake observations of a spherical L.P.G. tank and the surrounding ground* (in Japanese), Minami, T., Osada, K. and Osawa, Y.—*Dynamic behaviour of cylindrical tanks with the comparative rigidity* (in Japanese), Miyawaki, K.—*On the response of sloshing of liquid in cylindrical and spherical storages,* Sogabe, K. and Shibata, H.—*Effect of big earthquake motion on structures—Sloshing of fluid in a cylindrical tank* (in Japanese), Nasu, N. *et al.*—*A study on earthquake response of large-sized liquid-filled tanks* (in Japanese), Sakai, F. and Sakoda, H.

Seismic Stability of Pipe Lines and Dams: *An analysis of transient stresses produced around a tunnel by the integral equation method* (in Japanese), Kobayashi, S., Fukui, T. and Azuma, N.—*Observation of dynamic behavior of Kinuura submerged tunnel during earthquakes* (in Japanese), Nakayama, S. and Kiyomiya, O.—*Dynamic stresses of submerged tunnels during earthquakes,* Hamada, M., Akimoto, T. and Izumi, H.—*Quantitative analysis of seismic damage to buried pipelines* (in Japanese), Kubo, K., Katayama, T. and Sato, N.—*Stress on the underground pipeline during earthquakes* (in Japanese), Miyajima, N., Miyauchi, J. and Ueno, K.—*Dynamic behaviour of underground pipelines* (in Japanese), Takada, S.—*Efficiency of joint parts for aseismic strength of buried pipelines* (in Japanese), Takada, S. and Nagao, S.—*Study on dynamic behaviors of rockfill dams,* Takahashi, T. *et al.*—*Study on the material properties and the earthquake,* Sawada, Y. and Takahashi, T.—*Study on mechanism of failure of rockfill dams during earthquakes on results of vibration failure tests of large scale models of the dam* (in Japanese), Tamura, C. *et al.*—*Three-dimensional dynamic analysis of a rockfill dam for inclined incident traveling seismic waves*(in Japanese), Komada, H. *et al.*—*The verification of reliability of a numerical method of seismic analyses for rock and earth fill dams through both model tests and observation of earthquake on an actual dam,* Watanabe, H.

Earthquake Response of Structures: *Rocking vibration considering up-lift and yield of supporting soil,* Izumi, M. *et al.*—*Vertical load effects on structural dynamics,* Tani, S. and Soda, S.—*Vertical response observation of ten-storied building during right under earthquakes* (in Japanese), Sakurai, A., Masuko, Y. and Kurihara, C.—*Earthquake responses of nuclear reactor building* (in Japanese), Yamamoto, S. *et al.*—*One dimensional vibration test and simulation analysis for HTGR core* (in Japanese), Muto, K. *et al.*—*Dynamic behavior of the cooling tower* (in Japanese), Muto, K. *et al.*—*Dynamic response of hyperbolic cooling towers subjected to propagating seismic waves* (in Japanese), Kondo, H.—*A basic study on the behaviour of long dimensional size buildings during earthquakes* (in Japanese), Iguchi, M.—*Earthquake response analysis considering building size* (in Japanese), Nakamura, M. and Matsuoka, O.—*A proposal for the wave propagation in gridworks* (in Japanese), Matsuoka, O. and Yahata, K.—*Study on damping appreciation of forced vibration tests—Evaluation of damping effects for the dissipation energy at the Hamaoka Nuclear Power Plant No. 1* (in Japanese), Mizuno, N. *et al.*—*A method of determining viscoelasticity as damping estimation by forced vibration* (in Japanese), Akagi, T.—*Dynamic response analysis of systems with non-proportional damping,* Yamada, Y. and Kawano, K.—*Equivalent linear models to determine maximum inelastic response of nonlinear structures for earthquake motions,* Shibata, A.—*Evaluation of the effects of earthquake on structures on elasto-plastic response envelope spectrum with time-domain* (in Japanese), Hisada, T. and Igarashi, K.—*Ductility factor control method,* Ishimaru, S.—*Probabilistic considerations on plastic fatigue failure of structural steel members excited by earthquakes* (in Japanese), Goto, H. *et al.*—*The static-reliability of multi-story frames subjected to large lateral forces,* Sato, T. and Hannuki, T.—*Study on earthquake response of structures by considering non-deterministic variables,* Yamazaki, Y.—*Inelastic response of multistory K-braced frames subjected to strong earthquakes,* Goel, S. C.—*Coupling effects between structural systems with different properties* (in Japanese), Mizuno, H.—*Earthquake response of a cable-stayed bridge* (in Japanese), Iida, Y.—*Earthquake response characteristics of three spans continuous truss bridge with high piers* (in Japanese), Kotsubo, S. *et al.*

Restoring Force Characteristics of Structures and Structural Elements: *An analytical study on restoring force characteristics of reinforced concrete framed structures,* Nagasaka, T.—*Bi-axial effect of flexural members on the strong-motion response of R/C structures,* Takizawa, H. and

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

Yoshimura, M.—*Experimental study on the restoring force characteristics of the reinforced concrete frames with a shear wall* (in Japanese), Abeki, N.—*Restoring force characteristics of reinforced concrete shear walls*, Takahashi, J. and Shiga, T.—*Study on low cycle fatigue and restoring force characteristics of steel frames and steel-concrete frames*, Mizuhata, K. *et al.*—*Earthquake responses by the restoring force characteristics to ultimate collapse* (in Japanese), Tani, S. and Hiramatsu, A.—*Inelastic cyclic behavior of axially loaded steel members*, Kahn, L. F. and Hanson, R. D.—*Earthquake response characteristics of deteriorating hysteretic structures* (in Japanese), Goto, H. and Iemura, H.

Shaking Tables; Earthquake Damages; Miscellaneous: *On the natural period in actual buildings* (in Japanese), Yamabe, K., Jin, M. and Kanai, K.—*Dynamic stress analysis with model made of gelatin gel* (in Japanese), Tamura, C. and Morichi, S.—*Development of earthquake simulator (Part 1. Effects of test structure and their compensation method)* (in Japanese), Matsuzaki, A., Hirai, H. and Yoneda, T.—*Development of earthquake simulator (Part 2. Acceleration control type earthquake simulator)* (in Japanese), Matsuzaki, A., Hirai, H. and Kumagai, H.—*The bi-axial shaking table and its dynamic characteristics* (in Japanese), Hisada, T. *et al.*—*Damage of structures caused by the Izuhanto-oki earthquake 1974* (in Japanese), Ohtani, K. *et al.*—*Damage due to Izuhanto-oki earthquake* (in Japanese), Okamoto, S. and Sawada, K.—*Relation of earthquake intensity to ground motions for seismic design*, Krinitzsky, E. L. and Chang, F. K.—*Non-linear space problems in structural earthquake resistance theory*, Nikolaenko, N. A., Nazarov, Yu. P. and Ulyanov, S. V.—*Physical spectrum of earthquake acceleration*, Hoshiya, M. and Chiba, T.—*Quantitative classification of earthquake wave by principal component analysis*, Hoshiya, M. and Katada, T.

● **1.2-10** Solnes, J., ed., **Engineering seismology and earthquake engineering**, *Series E: Applied Sciences, No.3*, Proceedings of NATO Advanced Study Institute, Noordhoff International Publishing, Leyden, The Netherlands, 1974, 315.

An Advanced Study Inst. on Engineering Seismology and Earthquake Engineering was held in Izmir, Turkey, July 2-13, 1973, under the auspices of the Scientific Affairs Div. of NATO. Ninety-three scientists and engineers from 18 countries attended the Institute, which comprised lectures, discussions and panel meetings. Several main lectures are published in this volume. These lectures place more emphasis on material for advanced instruction, rather than on descriptions of research projects. The authors and titles of the lectures follow. None of these is abstracted in this volume of the *AJEE.*

Seismotectonics of the Eastern Mediterranean area, Papazachos, B. C.—*Notes on engineering seismology*, Ambraseys, N. N.—*Analysis of seismic risk*, Caputo, M.—*Earthquake ground motions: Measurement and characteristics*, Cherry, S.—*Estimating underground motions from surface accelerograms*, Cherry, S.—*Design input for seismic analysis*, Cherry, S.—*Problems in seismic zoning*, Housner, G. W. and Jennings, P. C.—*Fundamentals of dynamic earthquake response analysis*, Solnes, J.—*Earthquake resistant design of tall buildings in Japan*, Muto,K.—*Stochastic response of structures to earthquake excitations*, Penzien, J.—*Codes and regulations: Problem of implementation*, Gurpinar, A.—*An epidemiologist's view of earthquakes*, Lechat, M. F.

● **1.2-11** Jaeger, T. A., comp., **Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology**, Commission of the European Communities, Brussels, Vol. 4, Part K, 1975.

The conference, held Sept. 1-5, 1975, in London, was organized by the International Assn. for Structural Mechanics in Reactor Technology, the Commission of the European Communities and the British Nuclear Energy Society. The transactions are arranged in a set of volumes according to the technical divisions of the conference. Volume 4, Part K, "Seismic Response Analysis of Nuclear Power Plant Systems," contains papers pertinent to earthquake engineering.

The following is a list of the titles and authors' names. For those titles with an asterisk following, only the abstract of the paper was published in the transactions; these abstracts are not included in this volume of the *AJEE.* All papers without asterisks are abstracted in this volume of the Abstract Journal.

K1. Seismic Motion and Design Criteria: *Problems of seismic microzoning in areas of nuclear power plants,** Steinwachs, M. (K1/1)—*Probabilistic determination of seismic design criteria*, Shah, H. C. and Benjamin, J. R. (K1/2)—*Safe shutdown earthquake loading: Deterministic and probabilistic evaluations*, Shukla, D. K., Kissenpfennig, J. F. and Rizzo, P. C. (K1/3)—*Proposed guidelines for synthetic accelerogram generation methods*, Shaw, D. E., Rizzo, P. C. and Shukla, D. K. (K1/4)—*Seismic review of existing nuclear power plants*, Yanev, P. I., Mayes, R. L. and Jones, L. R. (K1/5)—*Statistical analyses of earthquake response spectra*, Hall, W. J., Newmark, N. M. and Mohraz, B. (K1/6)—*Generation of artificial time-histories, rich in all frequencies, from given response spectra*, Levy, S. and Wilkinson, J. P. D. (K1/7)—*Correlations of artificially generated three component time histories*, Chen, C. and Lee, J. P. (K1/8)—*Vertical design response spectra for rock sites*, Rizzo, P. C., Shaw, D. E. and Snyder, M. D. (K1/9)—*Seismic response analysis considering wave passage,** Shaw, D. E. and Rizzo, P. C. (K1/10)—*Rational determination of the operational basis earthquake and its impact on overall safety and cost of nuclear facilities,** Stevenson, J. D. (K1/11).

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

K2. Soil-Structure Interaction I: *Seismic wave effects on soil-structure interaction,* Scanlan, R. H. (K2/1)—*Comparison of models for soil-structure interaction,*• Waas, G. (K2/2)—*Mesh size criteria for soil amplification studies,* Costantino, C. J., Miller, C. A. and Lufrano, L. A. (K2/3)—*Continuum and finite element analyses for soil-structure interaction analysis of deeply embedded foundations,*• Hall, Jr., J. R., Kissenpfenning, J. F. and Rizzo, P. C. (K2/4)—*A comparison of experimental and theoretical investigations of embedment effects on seismic response,* Hadjian, A. H., Howard, G. E. and Smith, C. B. (K2/5)—*A contribution to the spring method for embedded foundations,*• Kausel, E., Morray, J. and Elsabee, F. (K2/6)—*Structure-soil-structure interaction of nuclear structures,* Snyder, M. D., Shaw, D. E. and Hall, Jr., J. R. (K2/9)—*Seismic response analysis of nuclear power plant structure under special consideration of non-linear soil-structure interaction,*• Khanna, J. K. and Setlur, A. V. (K2/10).

K3. Soil-Structure Interaction II: *Case study of soil-structure interaction for nuclear power plants,* Lee, A. J. H. (K3/1)—*Experimental and analytical studies for a BWR nuclear reactor building: Evaluation of soil-structure interaction behaviour,* Mizuno, N. and Tsushima, Y. (K3/2)—*Seismic analysis of a nuclear power plant accounting for soil-structure interaction effects,*• Ali, S. A. and Arango, I. (K3/3)—*Earthquake analysis of nuclear reactor buildings including foundation interaction,* Gutierrez, J. A. and Chopra, A. K. (K3/4)—*Nonlinear soil-structure interaction due to base slab uplift on the seismic response of an HTGR plant,* Kennedy, R. P. *et al.* (K3/5)—*Approximate soil-structure interaction with separation of base mat from soil (lifting-off),* Wolf, J. P. (K3/6)—*Stability and toe pressure calculation of a reactor building subject to seismic disturbance,* Bervig, D. R. and Chen, C. (K3/7)—*Impact of soil-structure interaction on the probabilistic frequency variation of concrete structures,* Hadjian, A. H. and Hamilton, C. W. (K3/8).

K4. Seismic Analysis of Nuclear Power Plant Structures I: *The state-of-the-art for seismic design of nuclear power plants—An assessment,* Smith, C. B. (K4/1)—*Experimental study of structural response of earthquakes,* Clough, R. W. *et al.* (K4/2)—*On response analysis for structural design and its reliability,* Shibata, H. (K4/3)—*Matrix of transmission in structural dynamics,* Mukherjee, S. (K4/4)—*A numerical method for vibration analysis of composite structures with different damping capacities,* Brusa, L. *et al.* (K4/5)—*A computational method for direct integration of motion equations of structural systems,* Brusa, L. *et al.* (K4/6)—*On the reliability of a simple model under nonstationary earthquake excitation,* Grossmayer, II, R. (K4/7)—*Response of self-strained structures to multiple time-phased seismic excitation,* Paz, M. and Wong, J. (K4/8).

K5. Seismic Analysis of Nuclear Power Plant Structures II: *A response spectrum approach for inelastic seismic design of nuclear reactor facilities,* Newmark, N. M. (K5/1)—*A discussion of coupling and resonance effects for integrated systems,*• Lin, C.-W. (K5/2)—*Vertical responses of nuclear power plant structures subject to seismic ground motions,* Lee, J. P. and Chen, C. (K5/3)—*Development and use of seismic instructure response spectra in nuclear plants,* Stoykovich, M. (K5/4)—*Floor response spectra for multi-degree-of-freedom systems by Fourier transform,* Scanlan, R. H. and Sachs, K. (K5/5)—*Torsional earthquake effects in symmetrical structures,*• Shah, H. and Valathur, M. (K5/6)—*Response of equipment in nuclear power plants to airplane crash,*• Schalk, M. and Wolfel, H. (K5/7).

K6. Seismic Analysis of Nuclear Power Plant Structures III: *Bell-ring vibration response of nuclear containment vessel with attached-mass under earthquake motion,* Shiraki, K. *et al.* (K6/1)—*Axisymmetric finite element analyses of the KKP-II containment and reactor pressure vessel structures,* Kost, G., Tsui, E. Y. W. and Krutzik, N. (K6/2)—*Approximate and detailed analyses for structures of reactor containment buildings, using three-dimensional computer program,* Kadar, I. (K6/3)—*Computational approach in the assessment of seismic structural safety for spherical shells with openings analysis of the KWU-PWR containment vessel,*• Weber, F. G. and Elfmann, W. (K6/4)—*Non-linear dynamic response of reactor containment,* Takemori, T., Sotomura, K. and Yamada, M. (K6/5)—*Aseismic design of turbine houses of nuclear power plants* (in German), Danisch, R. and Labes, M. (K6/6)—*Seismic analysis of a nuclear containment polar crane,* Snyder, M. D., Shaw, D. E. and Kissenpfenning, J. F. (K6/7)—*Theoretical and experimental analyses of natural frequencies for the crane bridge structure of the PEC reactor,*• Cesari, F. and Milella, P. P. (K6/8)—*Seismic resistant design of a nuclear category I earth dam,*• Vaidya, N. R., Ries, E. R. and Kissenpfenning, J. F. (K6/9).

K7. Seismic Analysis of Nuclear Power Plant Piping and Equipment: *A study on the multi-dimensional spectral analysis for response of a piping model with two-seismic inputs,* Suzuki, K. and Sato, H. (K7/1)—*An improved modal synthesis method for the transient response of piping systems,* Leonard, J. W. (K7/2)—*Seismic structural response analysis for multiple support excitation,* Shaw, D. E. (K7/3)—*Effect of torsional excitation on equipment seismic loads,* Scavuzzo, R. J. and Lam, P. C. (K7/4)—*On the behaviour of pressurized pipings under excessive-stresses caused by earthquake loadings,* Udoguchi, Y., Akino, K. and Shibata, H. (K7/5)—*Seismic stresses of piping systems and equipment on heat exchanger supporting structures,* Leung, K. E. (K7/6)—*Seismic response analysis of a reactor coolant pump,* Villasor, Jr., A. P. (K7/7)—*Facility design constraints for combined seismic and thermal loading,* Miller, C. A. and Costantino, C. J. (K7/8)—*Seismic qualification tests of electric equipment for Caorso Nuclear Plant: Comments on adopted test procedure and results,* Baccarini, L. *et al.* (K7/9)—*Techniques for the design of*

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

highly damped structures, Nelson, F. C. (K7/10)—*Sensitivity analyses of a seismic response event tree model of a nuclear plant safety system,* Charlwood, R. G., Anderson, D. L. and Chapman, C. B. (K7/11).

K8. Seismic Analysis of Reactor Core Structures: *Aseismic design of structures with nuclear reactors: Method of earthquake response analysis for reactor internals,* Tsushima, Y., Jido, J. and Abe, Y. (K8/1)—*Scram and nonlinear reactor system seismic analysis for a liquid metal fast reactor,* Morrone, A. (K8/4)—*Nonlinear seismic response of a series of interacting fuel columns consisting of stacked elements,* Lee, T. H. and Wesley, D. A. (K8/5)—*Seismic test on 1/5 scale HTGR core model,** Gorholt, W., Neylan, A. J. and Olsen, B. E. (K8/6)—*Seismic response analysis for block-type fuel HTGR core,* Ikushima, T. and Kawakami, M. (K8/7)—*One-dimensional vibration test and simulation analysis for HTGR core,* Muto, K. *et al.* (K8/8)—*Seismic study of HTGR core* (in French), Buland, P. *et al.* (K8/9)—*Seismic model of the gas cooled fast breeder reactor core support structure,* Penzes, L. E., Chang, K. H. and Lee, G. E. (K8/10).

● **1.2-12 Seminar on Earthquake Response of Gravity Dams and Probabilistic Prediction of Seismic Response of Structures,** Inst. of Earthquake Engineering and Engineering Seismology, Univ. "Kiril and Metodij," Skopje, Yugoslavia, 1975, var. pag.

The seminar was held Sept. 15–17, 1975. It was sponsored by the National Science Foundation and the Assn. for Scientific Works of S.R. Macedonia. Of the eight papers presented, seven were reprints. The titles and authors are listed below. None of these papers is abstracted in this volume of the *AJEE.*

Earthquake analysis of gravity dams including hydrodynamic interaction, Chopra, A. K.—*Mathematical models for the dynamic analysis of concrete gravity dams,* Chopra, A. K.—*Hydrodynamic pressures and response of gravity dams to vertical earthquake component,* Chopra, A. K.—*Predicting the performance of structures in regions of high seismicity,* Penzien, J.—*The earthquake experience at Koyna Dam and stresses in concrete gravity dams,* Chopra, A. K.—*Seismic analysis of long multiple-span highway bridges,* Penzien, J.—*Dynamics of towers surrounded by water,* Chopra, A. K.—*Earthquake analysis of axisymmetric towers partially submerged in water,* Chopra, A. K.

● **1.2-13 Proceedings, Fourth National Meeting of the Universities Council for Earthquake Engineering Research,** *UCEER-4,* Universities Council for Earthquake Engineering Research, California Inst. of Technology, Pasadena, 1976, 273.

The meeting was held on the campus of the University of British Columbia, June 28–29, 1976. The purpose of the meeting was to provide a vehicle for the exchange of information related to current and projected university research in earthquake engineering and to evaluate progress in specific areas of research and establish goals and priorities for future work. One hundred and ten individuals attended the meeting, representing 39 universities, various government agencies and industries. The sponsor was the National Science Foundation.

There were six sessions consisting of brief five-minute research reports. Sixty-four individuals gave reports. The written summaries of these reports are contained in this volume. The summaries are arranged according to university.

In addition to the research presentations, there were two panel discussions. The subject of the first panel was "Earthquake Prediction and Earthquake Engineering Research" and that of the second was "Current Capabilities and Future Needs in Experimental Earthquake Engineering Research." Copies of position papers by each panel member along with summaries by the panel recorders are included in this volume.

1.2-14 Sheinin, I. S. and Kalitseva, I. S., **The Sixth U.S.S.R. Conference on the Improved Reliability of Hydraulic Structures Subjected to Dynamic Excitations** (VI vsesoyuznoe soveshchanie "Povyshenie nadezhnosti gidrotekhnicheskikh sooruzhenii pri dinamicheskikh vozdeistviyakh," in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 6,* 1976, 71–73.

The conference took place in Moscow in Apr. 1976 and was attended by representatives of over 40 organizations, including research institutes, universities, power plants and ongoing construction projects. The number of speakers was 65. Three major research areas were discussed: (a) dynamic loads arising from power plant operations and spillways; (b) structural vibrations; (c) fatigue and dynamic behavior of construction materials and members.

A survey of papers presented at the conference is given.

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

2. Selected Topics in Seismology

2.1 Seismic Geology

● 2.1-1 Gencoglu, S., **Experimental methods for generating waves** (Dalgalarinin meydana getirilisi ve uygulamasi uzerinde deneysel calismalar, in Turkish), *Deprem Arastirma Enstitusu Bulteni*, 2, 6, July 1974, 67-90.

Various types of wave generators are first described. Determination of underground structure by using wave analysis is then discussed.

● 2.1-2 Sullivan, R., **Geological hazards along the coast south of San Francisco**, *California Geology*, **28**, 2, Feb. 1975, 27-33.

The coastal zone south of San Francisco has had a long history of landslide problems that continue to exist. The landslides are the result of a combination of factors centered around urban development, the nature of Late Cenozoic sediments, coastal erosion and seismic activity along the San Andreas fault. To illustrate the earthquake hazards in that area, the effects of the 1906 and the 1957 San Francisco earthquakes are summarized.

2.1-3 Arabasz, W. J. and Robinson, R., **Microseismicity and geologic structure in the northern South Island, New Zealand**, *New Zealand Journal of Geology and Geophysics*, **19**, 5, 1976, 569-601.

Locations, rates of occurrence, and composite focal mechanisms of microearthquakes in the Marlborough region are used to examine the tectonics of the region. Earthquakes in the upper crust reflect regional compression along an axis trending NW to WNW; their strike-slip and thrust mechanisms can be related to the regional geology. Seismicity deeper than about 20 km trends obliquely to the structural grain and appears to be intimately related to an underlying Benioff zone. Earthquakes in the 20-35 km depth range indicate a stress distribution markedly different from that in the upper crust and a predominance of normal faulting, suggesting either depth-varying stresses within continental crust or intraplate deformation within subducted oceanic lithosphere, depending on where the plate interface lies.

Shallow microseismicity in the vicinity of the Clarence and Awatere faults indicates that these currently are the most seismically active breaks in the Marlborough region. Activity along the Wairau fault, the direct continuation of the Alpine fault, is very low. Northwest of the Alpine fault, microearthquakes in two recognizable aftershock zones—that of the 1968 Inangahua earthquake (M_L = 7.1) and that of a magnitude 5.9 event that occurred 5 months before the survey—dominate the observed microseismicity.

The northern South Island straddles the Indian-Pacific plate boundary. Strike-slip mechanisms with ENE-trending slip vectors support the interpretation that the present plate boundary can be traced as a broad complex zone of transform faulting that connects the central Alpine fault with the southern Hikurangi trench.

2.1-4 Bibby, H. M., **Crustal strain across the Marlborough faults, New Zealand**, *New Zealand Journal of Geology and Geophysics*, **19**, 4, 1976, 407-425.

The shear strain across the Marlborough district was determined by comparison of the angles observed in the low-accuracy triangulation survey of 1878 to 1884 with those of the second and third order survey made between 1951 and 1960. The shear strain is significantly nonzero across a zone about 100 km wide, with a mean rate over the 70-year interval of 0.5± 0.1μrad/year. Shear strain is not concentrated near the Wairau, Awatere or Clarence faults, which indicates that little or no slip has occurred on these faults between the surveys. On the Hog Swamp fault, however, the concentration of shear strain is consistent

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

with a right lateral displacement of about 300 mm. The azimuth of the principal axis of shortening varies between 100° and 128°, and is consistent with the post-glacial right lateral strike-slip movement known to have taken place on each of the faults. The axis of shortening also agrees with the principal axis of compressive stress determined from microearthquake studies in the area. The total annual movement across the Marlborough shear zone is estimated to be between 25 mm and 45 mm.

● 2.1-5 Walper, J. L., **State of the art for assessing earthquake hazards in the United States - Report 5: Plate tectonics and earthquake assessment,** *Misc. Paper S-73-1,* Soils and Pavements Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Mar. 1976, 106.

In this report, plate boundary regimes are examined and the variable factors influencing plate interaction and earthquake generation are evaluated. These findings are applied to various boundary regimes found along the west coast of the United States. The geologic history of the United States, interpreted in terms of plate tectonics, is outlined to emphasize that crustal structures currently active in producing earthquakes had their origin long ago in episodes of continental rifting and collision. The processes of orogeny and epeirogeny are examined in terms of earthquake generation. The seismicity of the United States is reviewed and related to plate tectonic phenomena currently active and to contemporary stress fields.

● 2.1-6 Savage, J. C. and Prescott, W. H., **Strain accumulation on the San Jacinto fault near Riverside, California,** *Bulletin of the Seismological Society of America,* **66,** *5,* Oct. 1976, 1749–1754.

Geodimeter measurements from 1969 to 1975 of a geodetic network (aperture 12km) across the San Jacinto fault near Riverside, California, indicate simple right-lateral shear accumulation at the rate 0.4±0.1 μstrain/yr (engineering shear) parallel to the fault. A 12-km level line extending across the fault shows no consistent pattern of elevation change. The measured shear accumulation is interpreted in terms of a conventional dislocation model for strike slip, i.e., continuous slip on the vertical fault beneath a surficial locked zone. The observation of strain accumulation constrains the model to cases in which the ratio of the slip rate to the depth of the locked zone is about $1.2x10^{-6}$/yr (e.g., 25mm/yr slip below 20 km).

2.1-7 Nikolayev, N. I., **Tectonic and tectonophysical conditions for the occurrence of earthquakes connected with the engineering activity of man,** *Physics of the Solid Earth,* **12,** *10,* 1976, 643–651.

In the earth's interior, vast reserves of potential (latent) energy are concentrated. These are related to the stresses accumulated in the crust. Due to the engineering activity of man, elastic energy is released in the unstable, tectonically "prepared" zones. Construction of water reservoirs causes release of elastic stresses, which manifests itself in the form of induced earthquakes. These earthquakes belong to a class which is higher than the one determined on the basis of seismic zoning. In this connection, alterations in the following factors take place: (1) the frequency of the tremors, (2) the regime of the seismic energy release and (3) the localization of the epicenters predeterminable from the tectonics.

● 2.1-8 Barrows, A. G., **A review of the geology and earthquake history of the Newport-Inglewood structural zone, Southern California,** *Special Report 114,* California Div. of Mines and Geology, Los Angeles, 1974, 115.

Included in the report are the following: Description of the zone; History of investigation and recognition; History of hypotheses on origin and development of structural features; Inferred history of deformation; Earthquake history; Conclusions; Appendix A: Bibliography of reports dealing with effects of Long Beach earthquake; Appendix B: Annotated bibliography of seismological and geological references to the Long Beach earthquake.

● 2.1-9 Zaruba, Q. and Mencl, V., **Engineering geology,** *Developments in Geotechnical Engineering 10,* Elsevier Scientific Publishing Co., Amsterdam, 1976, 504.

The book contains the following chapters: Geological investigations; Geological maps and sections; Mechanical properties of rocks; Subsurface exploration; Geophysical methods; Weathering of rocks; Slope movements, landslides; Excavation and workability of rocks; Geological investigation of building material deposits; Foundation of buildings and industrial structures; Roads and railways; Tunnels and underground power plants; Engineering-geological investigations for hydraulic structures; Tasks of geological investigation in regional planning and environmental policy. Also included are a bibliography and a subject index.

● 2.1-10 Molnar, P. *et al.,* **The spectral composition of earthquakes in the Pamir-Hindu Kush region: Evidence for the existence of a high-gain zone in the upper mantle** (Spektralnyi sostav Pamiro-Hindukushskikh zemletryasenii: svidetelstvo sushchestvovaniya vysokodobrotnoi zony v verkhnei mantii, in Russian), *Sbornik sovietsko-amerikanskikh rabot po prognozu zemletryasenii,* 140–158. (For a full bibliographic citation see Abstract No. 2.8–12.)

The recording stations in Garm and elsewhere in Tadzhikistan have been registering very high frequencies (5–10 Hz) during earthquakes in the Pamir-Hindu Kush zone with focal depths exceeding 70 km. To explain the presence of such high frequencies, the existence of a high

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

energy factor in the upper mantle must be assumed. In recordings of Hindu Kush earthquakes obtained in India or Pakistan, high frequencies and large amplitudes are found for S_n waves. The spectral composition of these earthquakes indicates that stress varies with depth at the earthquake foci.

2.2 Wave Propagation

2.2-1 Morozov, Yu. G. and Chigarev, A. V., **On the statistics of reflected waves in composite media** (K statistike otrazhennykh voln v sloistykh sredakh, in Russian), *Mekhanika deformiruemogo tverdogo tela, 1,* 1975, 117–121.

A probabilistic description of wave propagation in composite media is given. At the initial moment, one wave is traveling in the first layer. At a random point in time, it is transformed into a refracted and a reflected wave, both of which are again transformed into a pair of waves at a random moment, etc. In order to calculate mean wave amplitudes, it is necessary to know the distribution of waves of various types inside and on the boundary of each layer. A technique is worked out whereby the corresponding probabilities can be derived using properties of the binary process just described.

● 2.2-2 Epstein, H. I., **The effect of curvature on Stoneley waves,** *Journal of Sound and Vibration,* **46,** *1,* May 8, 1976, 59–66.

The effect of curvature is investigated for plane waves propagating in the circumferential direction along concave and convex cylindrical surfaces, and at the interface of a circular cylindrical inclusion in smooth or bonded contact with an unlike infinite medium. The waves propagate with an arbitrary, but generally large number of circumferential modes. These problems reduce to Rayleigh and Stoneley waves in the limit as the curvature vanishes. Dispersion relationships are presented for each case.

● 2.2-3 Blake, T. R. and Dienes, J. K., **On viscosity and the inelastic nature of waves in geological media,** *Bulletin of the Seismological Society of America,* **66,** *2,* Apr. 1976, 453–465.

An asymptotic solution for spherical wave propagation in linear viscoelastic solids is compared with particle velocity measurements from underground explosive tests in tuff; the magnitudes of these experimental data are of the order of $5x10^2$ cm/sec. The qualitative nature of the theoretical solution is similar to that of the measured velocity time histories. When material and kinematic parameters in the model are specified, good quantitative agreement is obtained with respect to radial attenuation of the magnitudes and radial growth of the wavelengths. Both the phenomenological character of the viscoelastic model and limitations on its applicability are discussed.

● 2.2-4 Molnar, P. *et al.*, **Lg wave propagation in central Asia** (Volny Lg i ikh rasprostranenie v tsentralnoi Azii, in Russian), *Sbornik sovietsko-amerikanskikh rabot po prognozu zemletryasenii,* 185–206. (For a full bibliographic citation see Abstract No. 2.8-12.)

Experimental data found in the literature regarding the kinematic and dynamic characteristics of Lg waves, the local variations of these characteristics and their relationship to the structure of the earth's crust are summarized. Existing theoretical models of Lg waves are surveyed briefly. The relative intensity of Lg waves is investigated in detail in various zones of central Asia and neighboring areas.

2.3 Source Mechanisms

● 2.3-1 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,** *Earthquake Engineering and Structural Dynamics, 4, 4,* Apr.-June 1976, 315–332.

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.

● 2.3-2 Archuleta, R. J. and Brune, J. N., **Surface strong motion associated with a stick-slip event in a foam rubber model of earthquakes,** Inst. of Geophysics and Planetary Physics, Scripps Institution of Oceanography, Univ. of California, San Diego, La Jolla, Apr. 1975, 24.

In this paper, dynamic displacement data are presented and interpreted for a stick-slip event in a foam rubber model of earthquake faulting. Static displacement data are used to infer the stress drop. The rupture velocity also is inferred from the data. The observed particle displacement and particle velocity data are compared with analytical and numerical predictions. Energy focusing by rupture propagation is clearly observed. No large transverse displacement pulse such as that observed at Station No. 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 neighbor-

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

hood of a fault and thus helps in the problem of microzonation for earthquakes.

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

● 2.4-1 Tabban, A., **Interpretation of new earthquake map of Turkey** (Yeni Turkiye deprem bolgelerl haritasinin getirdikleri, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **1**, *2,* July 1973, 146–162.

● 2.4-2 Sherburne, R. W., **Seismicity of the eastern Santa Barbara Channel,** *California Geology,* 28, *6,* June 1975, 133–134.

Over 411 earthquakes for the eastern Santa Barbara Channel were examined for the period 1900–1972. The events considered were confined to the Channel and about 1 km inland.

Although the average annual seismicity of the Channel does not appear large when compared to other areas of California and no great earthquakes ($M > 8$) are known to have occurred, the Santa Barbara Channel has been a region of great tectonic activity throughout the last 65 million years. The historical seismic record does show that nearby areas have experienced severe shocks, such as the Nov. 4, 1927, Point Argüello earthquake ($M = 7.5$). Also, the Santa Barbara Channel is considered a segment of the Transverse Ranges Province of California where several well-documented large earthquakes have occurred.

2.4-3 Trimble, A. B. and Smith, R. B., **Seismicity and contemporary tectonics of the Hebgen Lake-Yellowstone Park Region,** *Journal of Geophysical Research,* **80**, *5,* Feb. 10, 1975, 733–741.

Detailed seismic monitoring of the Hebgen Lake-western Yellowstone Park region of Wyoming and Montana has delineated a zone of earthquakes extending 80 km in a direction N80°W from the northwest edge of the Yellowstone calderas to the Madison Valley. The active zone includes the epicentral area of the 1959 Hebgen Lake earthquake (magnitude 7.1). Focal depths ranged from near surface to 15 km in the Hebgen Lake region, whereas near the caldera boundaries the maximum focal depths decreased to 5 km.

The abrupt change to shallow focal depths over and near the calderas may be related to increased temperature and pore pressure sufficient to inhibit brittle fracture. Six composite and four single event fault plane solutions indicate north-south regional extension. Three composite fault plane solutions for earthquakes along the northwest boundary of the Yellowstone calderas indicate northwest-southeast crustal shortening, possibly from uplift on concentric fractures around the calderas.

2.4-4 Robinson, R. and Arabasz, W. J., **Microearthquakes in the north-west Nelson region, New Zealand,** *New Zealand Journal of Geology and Geophysics,* 18, *1,* 1975, 83–91.

Focal depths of microearthquakes indicate that seismicity in the northwest Nelson region is confined to depths less than about 15 km. This result provides a contrast with the Marlborough and Wellington regions where earthquake activity extends through the lower crust and well into the mantle. A composite focal mechanism implies current NW-SE compression in accord with results for shallow earthquakes in other parts of central New Zealand.

● 2.4-5 Napetvaridze, Sh. G., Jabauri, G. G. and Gogelia, T. I., **Effect of groundwater and relief on seismicity of soils,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 14, 8. (For a full bibliographic citation see Abstract No. 1.2-6.)

Saturated soils are usually considered such an important factor that for cases of high standing groundwater, seismic design standards in the U.S.S.R. require an increase in the seismicity of the building area by intensity I, which is equal to the doubling of the seismic acceleration of ground particles. Such a result was obtained on the basis of empirical data of inspection of the consequences of strong earthquakes. The object of this paper is to give a quantitative estimation of this phenomenon.

A specific feature of this paper concerning the effect of topography on seismicity is that the method of calculation applied makes it possible to obtain spectral characteristics of seismic oscillations on different areas of the surface taking into account differentiation of seismic oscillations at various points of a soil deposit, caused by an inclination of the seismic wave front.

● 2.4-6 Grases G., J., **Migration of destructive earthquakes in Middle America and associated risk of occurrence,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 159, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

The occurrence of destructive earthquakes since 1700 in the Middle American region associated with the Pacific active seismic belt shows an apparent migration pattern advancing from northwest to southeast at a rate of about 3° of geographical longitude per century. The foregoing implies that at the present time there should be seismic zones of dissimilar earthquake activity; this has been confirmed through seismicity studies on the basis of instru-

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

mental data of the last two and a half decades. Seismic risk estimations have been weighted, since given a mean regional rate of occurrence of events the probability is not equally likely in the area under consideration (about 300 km^2).

● **2.4-7** Ahorner, L. and Rosenhauer, W., **Probability distribution of earthquake accelerations for sites in Western Germany,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 157, 7. (For a full bibliographic citation see Abstract No. 1.2-6.)

Based on the observed earthquake activity of the period 1750–1969 and the distribution of neotectonic structural activity, a regional seismicity model has been established to calculate the earthquake risk for sites in Western Germany using a computer program. The calculation procedure makes use of Gumbel's extreme value theory and gives the recurrence intervals of various earthquake magnitudes for finite volume elements of seismically active regions and the probability distribution of earthquake accelerations at the earth's surface as a function of distance from the entirety of finite focal volumes. Numerical calculations were made for 220 sites within an area of 160,000 sq km. From the results, earthquake risk maps have been drawn giving isolines of probabilities for earthquake accelerations higher than 100 and 300 cm/s^2. The highest earthquake risk has been found in the western part of the Lower Rhine graben between Aachen and Koln, where two seismically active zones (the Rhenish and the Belgian) intersect.

● **2.4-8** Shah, H. C. and Movassate, M., **Seismic risk analysis–California State Water Project,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 156, 14. (For a full bibliographic citation see Abstract No. 1.2-6.)

At Stanford Univ. iso-acceleration maps are being developed for California in general and for the California water system in particular. These maps have the following variables associated with them: peak ground acceleration, economic or exposure time of the structure and the probability of exceeding the peak ground acceleration at a point during the economic life of the structure.

These maps could be considered as expected hazard maps; however, these maps by themselves do not help engineers or planners in deciding the risk level they are taking or, for that matter, which map to use out of the many maps available for different times and different probabilities. To help in determining the acceptable risk level and hence the design level, the relationship between mean return period and peak ground acceleration is developed, based on the iso-acceleration maps. This relationship is shown in the form of acceleration zone graphs.

● **2.4-9** McGuire, R. K., **Methodology for incorporating parameter uncertainties into seismic hazard analysis for low risk design intensities,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1007-1021. (For a full bibliographic citation see Abstract No. 1.2-7.)

A methodology is described for incorporating into seismic risk analysis statistical uncertainties in the rate of earthquake occurrences, the maximum epicentral intensity, and the division of the study region into seismotectonic provinces. Using this methodology, a seismic risk analysis is performed for a chain of sites on the east coast of the United States between Florida and Maine. The modified Mercalli intensity associated with an annual risk of 10^{-4} is found to be between VIII and IX for the sites considered. This result holds for a wide variety of hypothesized seismotectonic provinces. Also, at any given site the calculated intensity is not sensitive to the seismotectonic provinces adopted for the analysis. Further conclusions are that the available earthquake history is adequate to estimate accurately the recurrence rate of events but not the maximum possible epicentral intensity in typical seismotectonic provinces. Thus statistical uncertainty in the recurrence rate has a minor effect on design intensities, but uncertainty in the upper bound intensity of provinces must be accounted for explicitly. At modified Mercalli intensity levels of interest, annual risks at a site change by approximately a factor of 6 for a change of one unit in intensity level. Thus the modified Mercalli intensities associated with annual risks of 10^{-6} are between X and XII for the sites considered.

2.4-10 Kozmin, B. M. and Larionov, A. G., **Earthquake distribution patterns in the Yakut A.S.S.R.** (Osobennosti prostranstvennogo raspredeleniya zemletryasenii v Yakutii, in Russian), *Seismicheskoe raionirovanie Yakutii i sopredelnykh territorii,* Akademiya Nauk SSSR, Yakutsk, 1975, 20–28.

Using seismicity maps of the Yakut A.S.S.R. for 1735–1975, the most active zones are found as follows: the middle section of the Olekma River, the Stanovoi mountain range in the south and the Cherskogo range in the northeast. A series of massive earthquakes have occurred there. The obvious relationship between the location of epicenters and the tectonic structure of the region is noted. On the basis of focal depth calculations (from 4 to 31 km), the surface origins of the earthquakes are derived.

● **2.4-11** Algermissen, S. T. and Perkins, D. M., **A probabilistic estimate of maximum acceleration in rock in the contiguous United States,** *Open File Report 76-416,* U.S. Geological Survey, n.p., 1976, 45.

This paper presents a probabilistic estimate of the maximum ground acceleration to be expected from earthquakes occurring in the contiguous United States. It is

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

based primarily upon the historic seismic record which ranges from very incomplete before 1930 to moderately complete after 1960. Geologic data, primarily distribution of faults, have been employed only to a minor extent, because most such data have not been interpreted yet with earthquake hazard evaluation in mind.

The map provides a preliminary estimate of the relative hazard in various parts of the country. The report provides a method for evaluating the relative importance of the many parameters and assumptions in hazard analysis. The map and methods of evaluation described reflect the current state of understanding and are intended to be useful for engineering purposes in reducing the effects of earthquakes on buildings and other structures.

● **2.4-12** Bolt, B. A. and Miller, R. D., **Catalogue of earthquakes in northern California and adjoining areas—1 January 1910-31 December 1972**, Seismographic Stations, Univ. of California, Berkeley, 1975, 567.

● **2.4-13** Bath, M., **Seismicity of the Tanzania region**, *1-75*, Seismological Inst., Uppsala, Sweden, Jan. 1975, 38.

The seismicity within the region bounded by the latitudes 2°N and 12°S and the 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.

● **2.4-14** Omote, S. and Matsumura, K., **A new approach for estimating earthquake risk**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 3, 1975, 81-93. (For a full bibliographic citation see Abstract No. 1.2-6.)

● **2.4-15** Meyers, H. *et al.*, **An analysis of earthquake intensities and recurrence rates in and near Alaska**, *NOAA Technical Memorandum EDS NGSDC-3*, National Geophysical and Solar-Terrestrial Data Center, Boulder, Colorado, Oct. 1976, 101.

The National Geophysical and Solar-Terrestrial Data Center has compiled an Alaska Earthquake Data File that contains instrumental and intensity data for earthquakes of historical record in that state through 1974. This publication analyzes and summarizes the intensity data and recurrence rates of earthquakes in Alaska. It also describes the intensity file, the formats in which intensity data are available, and the sources and limitations of the data. Included with this publication are two sets of microfiche that contain listings of the complete intensity file. The first is chronological (sorted by intensity and city within date); the second is alphabetical (sorted by intensity and date within city). In a previous NGSDC publication, instrumental data for Alaska was summarized and described.

Because of the large distances between cities in Alaska, and because most large earthquakes occur offshore many miles from populated centers, intensities reported often are not indicative of the severity of the earthquakes in this, the most seismic of the 50 states. As the instrumental history in Alaska is available from 1899, two sections have been included in this publication titled "Maximum Earthquake Intensities in Alaska Using a Magnitude-Maximum Intensity Conversion" and "Magnitude-Frequency Relationships." Using over 1500 Alaska intensity reports from earthquakes of known magnitude, the historical intensity regime that would have existed if Alaska had contained population centers comparable to those in the western United States has been developed from the larger file of magnitude observations.

● **2.4-16** Kitagawa, Y. and Hattori, S., **On the regional distribution of the earthquake danger and the maximum amplitude in Japan**, *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 104, 23-30. (For a full bibliographic citation see Abstract No. 1.2-9.)

The values of m and log k in Ishimoto-Iida's statistical formula are derived for each component of the maximum displacement amplitude observed at many stations of the network of the Japan Meteorological Agency. The relation between magnitude and the maximum displacement amplitude also is obtained from the same data. A distribution map of expected maximum displacement amplitude for the earthquake recurrence periods of 25, 50 and 100 years is made based on the derived values of m and log k. The map indicates quantitatively the regional distribution of earthquake risk in and around Japan. It is seen from this map that the general level of earthquake risk varies throughout Japan. This variation reflects well the pattern of seismic activity throughout the area. The earthquake risk increases along the Pacific side of Hokkaido, Tohoku and Kanto districts and decreases in the southwestern and inland areas of Japan. Small variations are also recognized, which might suggest that earthquake risk and the maximum amplitude are affected by local geological and subsoil effects.

● **2.4-17** Hirata, M., **Periodical characteristics of large and middle earthquakes which occurred in a region of the Pacific Ocean in the vicinity of Japan and earthquake prediction** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 101, 1-8. (For a full bibliographic citation see Abstract No. 1.2-9.)

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

2.4-18 Topfer, K. D., **Provisional seismicity map of the Republic of Zambia and its preliminary interpretation,** *Journal of Geophysics,* 42, *3,* 1976, 225-236.

The provisional seismicity map of the Republic of Zambia has been compiled from data made available by Goetz Observatory, Rhodesia, for the period from 1966 to 1972. Seismicity anomalies have been compared with the provisional gravity map and the geological map of Zambia. Seismicity highs are closely associated with negative Bouguer anomalies and the distribution of zones of zero to moderate seismic activity seems to be related to the regional geology of Zambia. It appears that seismicity is not directly related to the geochronological history of Zambia.

● 2.4-19 Ambraseys, N. N. and Moinfar, A. A., **Iran earthquakes 1969,** *63,* Technical Research & Standard Bureau, Iran, Plan and Budget Organization, Tehran, Aug. 1976, 22.

This is the second in a series of reports that will document all of the seismic events which have occurred in Iran during the twentieth century. The emphasis is on the engineering effects of earthquakes rather than on the purely seismological effects.

● 2.4-20 Ambraseys, N. N., Moinfar, A. A. and Amin, M., **Iran earthquakes 1970** (in English with Persian summary), *53,* Technical Research & Standard Bureau, Iran, Plan and Budget Organization, Tehran, June 1975, 42.

This is the first issue of a series of reports that will document all seismic events which have occurred during the present century in Iran. The emphasis is on the engineering effects of earthquakes rather than on the purely seismological effects.

● 2.4-21 Singh, V. N., Srivastava, L. S. and Arya, A. S., **Seismic risk analysis–A review,** *Bulletin of the Indian Society of Earthquake Technology,* 13, *2,* Paper No. 166, June 1976, 35-44.

The earthquake risk to a structure at a given site cannot be expressed in deterministic terms because of uncertainties in the number, sizes and location of future earthquakes. A probabilistic approach should, therefore, be followed for evaluating the earthquake risk. This paper describes various methods for determining the earthquake risk. The importance of these methods in the choice of design earthquake parameters has been discussed.

● 2.4-22 Srivastava, V. K., Chouhan, R. K. S. and Nigam, R., **Largest value theory applied to probability of earthquake occurrence,** *Bulletin of the Indian Society of Earthquake Technology,* 13, *1,* Paper No. 164, Mar. 1976, 19-23.

Gumbel's theory of largest values is applied to estimate the probability of occurrence and return period of the largest possible earthquake in the northwest Kashmir region. For this study, data on earthquake occurrences for the period 1902 to 1974 have been used. Magnitudes which will be exceeded with the probability 1% are compared with the largest magnitude actually observed during the period 1902-1974. The time-inequalities and their time development are studied.

● 2.4-23 Menke, W. H. and Jacob, K. H., **Seismicity patterns in Pakistan and northwestern India associated with continental collision,** *Bulletin of the Seismological Society of America,* 66, *5,* Oct. 1976, 1695-1711.

Data from a local array of 12 short-period seismic stations located near the Tarbela reservoir in the lesser Himalayas of northern Pakistan are analyzed to estimate the anomalous thickness of the crust at the boundary between the colliding Indian and Eurasian subcontinents in the western Himalayas and the Baluchistan arc. P_n and S_n travel times indicate high upper-mantle velocities (8.50 ± 0.35 km/sec for P_n at distances up to 1,500 km) combined with a thick crust near the continental plate boundary. Beneath the Himalayas the crust may be 97 ± 15 km thick, which suggests it has been doubled in thickness. Local evidence indicates that this thickening occurs by imbricate underthrusting of the Indian shield.

In the Indo-Gangetic basin a heretofore unrecognized continuous zone of seismicity was found to strike parallel to the Himalayas about 200 km south of the Himalayan main boundary thrust. This zone rarely contains events with large magnitudes ($m > 5$); but since it traverses centers of dense population (e.g., Delhi and Lahore) and straddles potential sites of planned nuclear power plants, it may constitute a serious seismic hazard. In the Himalayas and the Baluchistan arc a comparison is made of the pattern of locally determined seismicity with that of events located as teleseisms. Local network data cover a period of about one year and magnitudes $m > 2$, whereas teleseismic data cover a period of 14 years and magnitudes $m > 4$, based on recordings of the World Wide Standard Seismograph Network as reported by the U.S. Geological Survey. Both data sources show similar patterns. The main difference is that teleseismic events with large magnitudes fall mostly on major faults, whereas locally recorded events with small magnitudes occur more scattered and often fall off major faults. Several seismic gaps in the present seismicity along the Himalayas and the Baluchistan arc are identified. At some gaps the corresponding fault segment appears to be at a low stress level because it has recently undergone a major stress relief, while in other gaps stresses may be high and, hence, the fault may be in preparation for a major stress relief in the not too distant future.

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

● 2.4-24 Verma, R. K., Mukhopadhyay, M. and Ahluwalia, M. S., **Seismicity, gravity, and tectonics of northeast India and northern Burma,** *Bulletin of the Seismological Society of America,* **66,** *5,* Oct. 1976, 1683–1694.

Practically the whole of northeastern India and northern Burma is characterized as an anomalous gravity field as well as an area of high seismicity. The Bouguer anomaly in the region varies from +44mgals over Shillong Plateau to -255mgals near North Lakhimpur in Assam Valley. Isostatic anomaly (Hayford) varies from +100 to -130mgals in these areas. Over Arakan-Yoma and the Burmese plains, the isostatic anomalies vary from -20mgals to -100mgals.

Regions of high seismicity in the area include the eastern Himalaya (including Assam syntaxis), Arakan-Yoma including the folded belt of Tripura, Irrawaddy basin, Shillong Plateau, Dauki fault and the northern part of Bengal basin. The abnormal gravity and seismicity are related to large-scale tectonic movements that have taken place in the area mostly during the Cretaceous and Cenozoic times, due to interaction of the Indian, Tibetan, and Burmese plates. The high seismicity indicates that the movements are continuing. The seismic zone underlying Burma is approximately V shaped and dips toward the east underneath Arakan-Yoma. Most of the intermediate-focus earthquakes in Burma underlie the area characterized by negative isostatic anomalies, indicating the probable existence of a subduction zone underneath the Arakan-Yoma and the Burmese plains.

The Shillong Plateau has a history of vertical uplift since Cretaceous times. Provided this statement is true, the uplift of the plateau preceded Himalayan tectonics starting 20 to 30m.y. before continental India made solid contact with the Eurasian plate. The plateau is characterized by large positive isostatic anomalies as well as high seismicity. The positive isostatic anomalies may be due to intrusion or incorporation of basic material from the mantle into the crust underlying the plateau. These intrusions may have taken place through deep seated faults such as the Dauki and could be responsible for its uplift as well.

2.4-25 Kuchay, V. K. and Panomaryev, V. S., **On estimating the probability of occurrence of strong earthquakes from an aggregate of geophysical and geological characteristics,** *Physics of the Solid Earth,* **12,** *9,* 1976, 570–574.

The investigations of the Combined Seismological Expedition of the Earth Physics Inst. of the U.S.S.R. Academy of Sciences in the Garm geophysical polygon have shown that the epicentral zones of strong earthquakes are selective in relation to the characteristics ("indicators") of the geological and seismological fields. This inference has been made as a result of the application of simple ideas from the theory of probability and mathematical statistics. The present article is devoted to the technique of estimation of the probability of occurrence of strong earthquakes and it presents the results of application of this technique to the Garm polygon.

2.4-26 Artem'yev, M. E., Dosymov, A. and Nersesov, I. L., **An attempt to identify seismic-risk zones in Central Asia from gravimetric data,** *Physics of the Solid Earth,* **12,** *8,* 1976, 505–512.

In the present paper the authors have formed a relationship between the gravity anomalies in the topographic-isostatic and in the Glennie reduction and also between the horizontal gradients of these anomalies with the systematic distribution of the epicenters of earthquakes of different energy classes. It is established that the earthquakes with K $\geq$ 12 occur more often in regions where the absolute values of the isostatic anomalies are high and especially in regions where the values of the horizontal gradients of the anomalies are large ($>$ 0.7 mgl/km). It is determined that the regions characterized by increased values of A, A' and K_{max} (calculated on the basis of Yu. V. Riznichenko's method) gravitate towards zones with high isostatic anomaly values and regions with increased horizontal gradients of these anomalies. On the basis of the above relationships, the zones of the possible occurrence of earthquakes with K $\geq$ 14 are identified.

2.4-27 Zverev, S. M. *et al.,* **Microearthquakes of northern Iceland,** *Physics of the Solid Earth,* **12,** *10,* 1976, 636–642.

The results of research on the seismicity of northern Iceland, carried out by an expedition of the Academy of Sciences of the U.S.S.R. in the summers of 1972 and 1973, are presented. The total duration of the earthquake recordings was 2.5 months. A total of about 900 earthquakes with a magnitude m_{SH} ranging from -1.5 to 2.0 were recorded; for 208 earthquakes the coordinates were determined and the focal mechanisms were studied. It is shown that the epicenters may be divided into three groups. The first group consists of a compact cluster of foci on the shore of the Axarfjord (H = 3–13 km), the second stretches along the Husavik fault (H = 2–8 km), and the third consists of scattered foci in the sea (H $<$ 20 km). Over most of the rift zone no earthquakes were recorded. The upper 2 km of the cross section, which contain numerous extension structures, are not seismically active. The focal mechanisms show a stable character of the acting stresses, with a predominance of shearing strains in a nearly vertical plane. On the whole, the distribution of the foci and energy characteristics of the earthquakes is fairly stable. It is related to the general features of the geomorphology and tectonics of the region and does not agree with existing concepts regarding northern Iceland developed from the standpoint of plate tectonics.

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

● 2.4-28 Borcherdt, R. D. and Gibbs, J. F., **Prediction of maximum earthquake intensities for the San Francisco Bay region**, *Open-File Report 75-180*, National Center for Earthquake Research, U.S. Geological Survey, Menlo Park, California, 1975, 31.

The intensity data for the California earthquake of Apr. 18, 1906, are strongly dependent on distance from the zone of surface faulting and the geological character of the ground. Considering only those sites (approximately one square city block in size) for which there is good evidence for the degree of ascribed intensity, the empirical relation derived between 1906 intensities and distance perpendicular to the fault for 917 sites underlain by rocks of the Franciscan formation is: Intensity = 2.69 - 1.90 log (Distance) (km). For sites on other geologic units, intensity increments, derived with respect to this empirical relation, correlate strongly with the average horizontal spectral amplifications (AHSA) determined from 99 three-component recordings of ground motion generated by nuclear explosions in Nevada. The resulting empirical relation is: Intensity Increment = 0.27 + 2.70 log (AHSA), and average intensity increments for the various geologic units are -0.29 for granite, 0.19 for Franciscan formation, 0.64 for the Great Valley sequence, 0.82 for Santa Clara formation, 1.34 for alluvium, and 2.43 for bay mud. The maximum intensity map predicted from these empirical relations delineates areas in the San Francisco Bay region of potentially high intensity from future earthquakes on either the San Andreas fault or the Hayward fault.

2.4-29 Gorbunova, I. V. *et al.*, eds., **Earthquakes in the U.S.S.R. in 1972** (Zemletryaseniya v S.S.S.R. v 1972g., in Russian), NAUKA, Moscow, 1976, 192.

The papers of this volume contain discussion and analysis of instrumental and macroseismic data on earthquakes in the U.S.S.R. and adjacent areas. Separate articles describe the seismicity during 1972 of various earthquake zones including the Carpathian mountains, the Crimea, Caucasus, Kopetdagh, Central Asia, northern Tien Shan, Altay, Sayan mountains, the Baikal, Yakut A.S.S.R., the northwestern U.S.S.R., Sakhalin, the Kuril Islands and the Kamchatka Peninsula. Articles on earthquakes with $M \geq 4.5$ in the U.S.S.R. and on the world-wide distribution of earthquakes with $M \geq 6$ are also included. All articles contain earthquake catalogs and maps showing the location of epicenters.

● 2.4-30 **Estimation of earthquake risk 1 June 1972 - 30 June 1974**, Dept. of Earth and Planetary Sciences, Massachusetts Inst. of Technology, Cambridge, July 1974, 54.

Statistical modeling of earthquake occurrences is studied. First, a statistical method of detecting dependent events and aftershocks using spatial and temporal information is developed and applied to Japanese and California earthquake catalogs. On the basis of a statistic s ($s = \pi r^2 kt$), where r is the distance between two events, k is the normal earthquake rate and t is the time interval between the events, a decision was made whether a pair of events were dependent. The theoretical distribution of s for a catalog consisting of only independent events was compared to the actual catalogs. On the basis of the differences between the distributions, the number of inferred dependent events was determined.

This discrimination technique was applied to the earthquake catalogs of northern Japan (1926–1960) and southern California (1934–1960). Thirty percent of all events in the Japanese catalog and 42 percent of events in the southern California catalog were identified as dependent events. The statistical properties of the catalogs without dependent events were examined, in particular with respect to the Poisson process. Some small discrepancies with the Poisson process still existed using a decision threshold of s = 0.02. Clusters of events were found that could not be related to any large magnitude main event.

For modeling of earthquake and aftershock occurrences, a compound Poisson-Markov process was examined. The state variable for the Markov model was assumed to be the accumulated strain energy. Suitable functions for the rate and transition probabilities were chosen to duplicate the known decay relation for aftershock sequences and the frequency magnitude relation. It was found that in order for large strain energy to accumulate it was necessary for energy to be put into the model in sudden bursts. The model was simulated on a computer using a random number generator. Catalogs generated in this way departed from the real catalog in only one manner; namely that large aftershocks inhibit rather than trigger subsequent aftershocks.

● 2.4-31 Shah, H. C. and Benjamin, J. R., **Probabilistic determination of seismic design criteria**, *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology*, Vol. 4, Paper K 1/2, 10. (For a full bibliographic citation see Abstract No. 1.2-11.)

A probabilistic technique of forecasting bedrock isoacceleration contours in terms of time, magnitude, and exceedance probability is presented along with examples from field applications. The relationships among recurrence intervals, return periods, mean rates of occurrence, time, exceedance probabilities, and nominal design levels are discussed and illustrated. It is shown that nominal deterministic design levels can be readily related to probabilistic measures including the influence of the design life and importance of the facility.

It is shown that a consistent risk level for a given class of structure located in different seismic zones can be maintained. Seismic zoning, based on the concept of acceptable risk for a given class and use of structure, is developed. Illustrative examples from practice are included.

● 2.4-32 Alsan, E., Tezucan, L. and Bath, M., **An earthquake catalogue for Turkey for the interval 1913-1970,** *7-75,* Kandilli Observatory, Cengelkoy-Istanbul, and Seismological Inst., Uppsala, Sweden, July 1975, 166.

An earthquake catalogue is presented for the whole area of Turkey for the interval 1913-1970. Source parameters (origin time, epicentral coordinates, focal depth) have been calculated on computer, as far as available data permit. For magnitude determinations, a consistent scheme has been adhered to for the whole period under investigation. Our aim has been to achieve the highest possible homogeneity in tabulated material over the whole interval, coupled with maximum possible completeness and reliability. All results, including error computations, are compiled in a catalogue. The catalogued data may serve as a basis for continued investigations of Turkish seismicity, as well as a source of information for all other purposes concerned, such as for engineering.

● 2.4-33 Shukla, D. K., Kissenpfennig, J. F. and Rizzo, P. C., **Safe shutdown earthquake loading: Deterministic and probabilistic evaluations,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 1/3, 11. (For a full bibliographic citation see Abstract No. 1.2-11.)

Mainly, two obstacles arise in the use of probabilistic procedures for safe shutdown earthquake (SSE) determination. Often, statistically insufficient data are available on past earthquakes and assumptions for the following critical input data required for probabilistic SSE estimation have not yet been studied thoroughly: (1) earthquake recurrence rate versus intensity relationships, (2) maximum intensity earthquakes to be considered in the analysis, (3) choice of recurrence period for the basis of SSE, (4) interpretation of seismic activity distribution in the near vicinity of the site. In addition, probabilistic as well as deterministic results depend upon the following factors: (1) earthquake ground motion attenuation characteristics, (2) definition of seismotectonic provinces (areas of equipotential seismicity) and major mapped faults.

This paper comprehensively studies the implications of various assumptions regarding the above inputs to the SSE determination and documents rational procedures to account for these assumptions. Specifically, the logarithm of recurrence rate has generally been considered to vary linearly with the intensity for intensities less than the highest defined MM intensity of XII. Such relationships usually predict unrealistically high recurrence rates for high-intensity earthquakes which were never observed in the regional recorded history of earthquakes. This paper describes procedures, first, to estimate the probability of validity of various recurrence rate relations and the associated maximum intensity and, secondly, to rationally account for these probabilities in the SSE determination. It discusses the appropriate design recurrence periods that should be used as the basis for SSE determination.

Refining the probabilistic procedures so that they can be rationally and realistically used in SSE determination, this presentation provides an understanding of similarities and differences in results obtained from deterministic and probabilistic procedures. Possible pitfalls in both methods are discussed and an outline for future research is suggested.

2.5 Studies of Specific Earthquakes

● 2.5-1 Beeby, D. J. and Hill, R. L., **Galway Lake Fault,** *California Geology,* **28,** *10,* Oct. 1975, 219-221.

On May 31, 1975, a 5.2 magnitude earthquake occurred on the Mojave Desert in the Galway Lake area of San Bernardino County. Briefly summarized are the surface effects (ground rupture and ground shaking) caused by the earthquake in this previously unmapped fault area.

● 2.5-2 Roussopoulos, A. A., **Leukas earthquake of November 4, 1973, Greece,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 138, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

The Greek islands in the Ionian Sea have often been shaken by strong earthquakes. On Nov. 4, 1973, the island of Leukas was shaken by a strong earthquake of magnitude 6.0. Shortly thereafter, an aftershock of magnitude 5.0 occurred.

The peak acceleration of the main shock recorded by an SMA-1 strong-motion seismograph was about 0.53 g and is the highest ever recorded in Greece by a strong-motion accelerograph. The epicenter was located in the sea at a distance of 18 km northwest of the island. Both the main shock and the aftershock accelerograms were analyzed and the main characteristics of the earthquakes were obtained (acceleration, velocity and displacement). These quantities provided the basis for spectral calculations.

In addition to the above calculations, microtremor measurements were carried out in order to obtain some information about the soil conditions of the region.

● 2.5-3 Moinfar, A. A. and Banisadr, M., **Bandar-e-Abbas, Iran earthquake of November 8, 1971,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2,

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

Paper No. 136, 12. (For a full bibliographic citation see Abstract No. 1.2–6.)

At 6:36 a.m. on Nov. 8, 1971, a moderately destructive earthquake and a severe wind storm occurred in the Bandar Abbas region. The magnitude of the shock was 5.9 and the focal depth was about 36 km. The intensity of the earthquake in the most severely damaged area (approximately 2 km from Bandar Abbas Airport) was observed to be less than VII on the Modified Mercalli Scale. No faulting was observed in the area.

2.5–4 Pustovitenko, B. G., **On special features of the focal zones of the strong Crimean earthquakes of June 26 and September 11, 1927** (Ob osobennostyakh ochagovykh zon silnykh krymskikh zemletryasenii 26 iyunya i 11 sentyabrya 1927 goda, in Russian), *Voprosy inzhenernoi seismologii, 18,* 1976, 103–114.

On the basis of a unified study of the behavior and migration of aftershocks, macroseismic fields and data concerning the direction of the fault plane, it is concluded that both Crimean earthquakes of 1927 consisted of a foreshock and a main shock. The focal depth of the foreshock exceeded that of the main shock and, apparently, the direction of the fault planes was perpendicular.

● **2.5–5** Sasatani, T. and Suzuki, S., **Source process of the Hiroo-oki earthquake of 1962 and long-period earthquake motions** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 102, 9–14. (For a full bibliographic citation see Abstract No. 1.2–9.)

A major earthquake (M=7.0, h=70 km) occurred on Apr. 23, 1962, off the coast of the Tokachi district, Hokkaido. Special interest has been shown toward this event, because acceleration as great as 0.4 g was observed at the Kushiro seismological station, while no damage was caused to buildings in the city of Kushiro.

The source process of this event is studied on the basis of P-wave first motion data, aftershock area and close-in seismograms recorded by the JMA strong-motion seismograph at Hiroo, Kushiro and Urakawa stations. Synthetic seismograms are computed by the Haskell method and compared with the observed seismograms to estimate the fault parameters. The S-wave portion is mainly used for comparison. Good agreement between the synthesized and observed seismograms was obtained at Hiroo and Urakawa, while the amplitude of the observed seismograms at Kushiro was several times as large as that of the synthesized one. The disagreement of amplitudes between the observed and synthesized seismograms can be explained by the effect of the underground structure down to a depth of about 4 km. The fault parameters are estimated as follows: fault dimension, 30 km x 10 km; rupture velocity, 3.5 km/sec; rise time, 1 sec; average dislocation, 2 m. The analyses show that the procedure presented is practical for clarifying the characteristics of the long-period earthquake motions.

2.5–6 Robinson, R., Calhaem, I. M. and Thomson, A. A., **The Opunake, New Zealand, earthquake of 5 November 1974,** *New Zealand Journal of Geology and Geophysics,* **19,** *3,* 1976, 335–345.

The Opunake earthquake (M_L = 6.1) was centered at 39°.54S, 173°.45E, very near the Maui gas field, at a shallow depth. This is about 35 km off the SW Taranaki coast in a region where the Cape Egmont fault zone forms the western margin of the Taranaki graben. Damage due to the event was minor. The focal mechanism solution implies an equal amount of thrust and strike-slip motion, and a nearly horizontal compression-axis that trends NE–SW. The aftershock sequence (128 events with $M_L \geq 3.5$ up to the end of November was of long duration and had a high *b*-value of 1.35. The aftershock epicenters occupied an area of about 15 x 10 km. The main event was somewhat unusual in that it was, for its magnitude, a very compact event (radius of equivalent circular dislocation 6 km) with a large displacement (0.17 m) and high stress drop (1.2 x 10^6 N/m^2).

2.5–7 Rogers, G. C., **The Terrace earthquake of 5 November 1973,** *Canadian Journal of Earth Sciences,* 13, *4,* Apr. 1976, 495–499.

On Nov. 5, 1973, at 12 h 36 m 17 s UT, a shallow focus earthquake (M_L = 4.7, m_b = 4.2) occurred about 20 km southwest of Terrace, British Columbia near 54.4° N and 128.8° W. The area has been aseismic in historic time. The earthquake appears to have no relation to nearby hot springs or to the geologically recent volcanism in the area. It was felt to distances of 120 km and the maximum intensity observed was V on the Modified Mercalli Scale. Only minor damage was reported. The inclusion of this earthquake in seismic risk calculations slightly elevates the risk computed for Terrace.

2.5–8 Rogers, G. C., **The Vancouver Island earthquake of 5 July 1972,** *Canadian Journal of Earth Sciences,* 13, *1,* Jan. 1976, 92–101.

An earthquake occurred at 10 h 16 m 39 s GMT on July 5, 1972, in close proximity to the west coast of Vancouver Island, near 49.5° N and 127.2° W. Its magnitude (m_b) was 5.7 and the hypocenter was near the middle of the crust. A well defined P nodal solution has a pressure axis with a north–south orientation and a tension axis with an east–west orientation. The preferred nodal plane suggests right lateral strike-slip faulting on a near vertical fault, striking in a north–northwest direction. The other nodal plane suggests that left lateral strike-slip faulting on

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

a near vertical fault striking in an east–northeast direction is also a plausible solution. A field study with portable seismographs revealed that very few aftershocks were associated with this earthquake. The largest aftershock had a magnitude (m_L) of 3.4. The distribution of intensity of the mainshock observed on Vancouver Island differs from that predicted by the intensity versus distance relation presently used for western Canada.

● 2.5-9 Bollinger, G. A., Langer, C. J. and Harding, S. T., **The eastern Tennessee earthquake sequence of October through December, 1973,** *Bulletin of the Seismological Society of America,* 66, 2, Apr. 1976, 525–547.

An earthquake sequence consisting of one foreshock, a magnitude 4.6 main shock, and more than 30 aftershocks occurred south of Knoxville, Tennessee, during the latter part of 1973. The foreshock had a magnitude of 3.4, preceded the main shock by one month, and had a felt area of 2,100 km^2. The area had been inactive for the preceding 2 years.

A focal mechanism solution for the main shock indicated primarily dip-slip faulting, but the data were too sparse to accurately define the direction of the motion. However, based on other data (trend of epicenters, vertical distribution of hypocenters, regional in-situ stress measurements), a northwest-striking reverse fault is interpreted as the most likely causal fault. A detailed intensity survey revealed a felt area of 65,000 km^2 that exhibited a rapid decrease of intensity to the north and unusually low decrease of macroseismic effects to the south. Topographic focusing of seismic energy is suggested by the intensity data for the town of Maryville, Tennessee.

A network of eight portable seismographs was operated in the epicentral area for a period of some 10 days following the main shock. Data from these stations allowed the determination of 18 aftershock hypocenters, whose depth ranged from approximately 1 to 10 km. A composite focal mechanism solution (CFMS) study was made of 14 of the better-recorded aftershocks. The CFMS for the four shallow events ($\geq$ 1 km) gave a northwest-trending reverse fault solution similar to that for the main shock. However, the majority of events were at greater depths ($\geq$ 5 km), and their CFMS showed a near-vertical nodal plane (dip-slip motion) and a near-horizontal nodal plane (strike-slip motion). The number and quality of these data are such that the implied reorientation of stresses between the main shock and the deeper aftershocks is tentative.

2.6 Seismic Water Waves

● 2.6-1 Hwang, L. and Divoky, D., **Numerical investigations of tsunami behavior,** Tetra Tech, Inc., Pasadena, California, Mar. 1975, 37. (NTIS Accession No. PB 252 487)

The present paper describes progress in the numerical modeling of tsunamis. In particular, work described by Hwang and Divoky has been extended and improved, and new applications are shown. These include a computation of the midocean character of the 1960 Chilean tsunami, the 1964 Alaskan tsunami, and a special calculation of local wave behavior at Hilo, Hawaii, which provides an approximate description of the observed coastal effects of the Alaskan tsunami. For both source calculations, the best available data regarding actual bottom displacements were used as input to the model. Some discussion of tsunami-energy radiation patterns is presented.

2.7 Artificially Generated Ground Motions or Seismic Events

2.7-1 Negmatullaev, S. Kh., ed., **Induced seismicity near the Nurek water reservoir** (Vozbuzhdennaya seismichnost vblizi Nurekskogo vodokhranilishcha, in Russian), DONISH Publishing, Dushanbe, 1975, 91.

The tectonics and seismicity of the region of the Nurek reservoir are described. The maximum possible earthquake magnitude is found to be 6.5. Spatio-temporal properties of the seismic process are discussed. The greatest number of earthquakes was observed at the end of 1972 and the beginning of 1975 which coincides with the period when the filling of the reservoir was most intense. The number of earthquakes during this period was three times greater than normal, hence the assumption that the earthquakes are a consequence of the construction of the reservoir. The approximate extent of the area of increased seismicity is determined. A transformation of earthquake source mechanism and a tilting of the ground surface are found in the region surrounding the water reservoir.

● 2.7-2 Schenk, V., **Maximum values of the particle velocities produced by explosive sources and their properties,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 9, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

In order to determine to what degree a building is endangered by the effects of seismic waves generated by explosive sources, the relation between the values of the maximum amplitudes of the particle velocity V_{max}, the distance R from the source and the weight W of the source is used frequently. If this relation is known for a given set of conditions, not only can explosions be applied more widely in practice, but they can also be exploited economically. A large number of dependencies, which may differ by as much as 1 to 2 orders of particle velocity for small distances from the source, have been established in the past. Even though these differences are understandable with a view to the scatter of the observed values of V_{max}, it has

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

always been necessary so far to carry out seismic measurements to determine this dependence with regard to the actual evaluation of the degree to which a building is affected. The pattern of this dependence is influenced by many factors which the author not only distinguishes from one another, but also determines, as far as possible, the degree to which they affect V_{max}, as a function of R and W.

2.7-3 Lyuke, E. I., Daragan, S. K. and Peregontseva, V. E., **On prediction of seismic wave spectra of powerful underground explosions from spectra of small preliminary explosions** (O prognoze spektrov seismicheskikh voln moshchnykh vzryvov po spektram nebolshikh predvaritelnykh vzryvov, in Russian), *Izvestiya Akademii Nauk SSSR, 2,* 1976, 39–49.

The construction of an experimental method for the prediction of seismic effects of powerful underground explosions (on the order of several kilotons) is considered. Ground motion records of explosions of the order of hundreds of kilograms obtained in the same region are used. The calculation of longitudinal spectra produced by a large explosion makes use of the seismic source model developed by Seggern and Blandford.

● 2.7-4 Gupta, H. K. and Rastogi, B. K., **Dams and earthquakes,** *Developments in Geotechnical Engineering, Vol. 11,* Elsevier Scientific Publishing Co., Amsterdam, 1976, 229.

Initiation and/or enhancement of seismic activity following the impounding of reservoirs behind large dams has been well evidenced at about 30 sites all over the world. Earthquakes at some of these dam sites have been very destructive and exceeded magnitude 6 on the Richter scale.

This is the first book on this subject. It reviews the present-day knowledge of reservoir-associated earthquakes. A general introduction to the topic is followed by an assessment of the focal parameters and the macroseismic effects of the earthquake at Koyna, India, on Dec. 10, 1967, which caused severe damage and claimed over 200 lives. The geology, hydrology and seismicity of all the known seismic reservoir and fluid injection sites are summarized in the third chapter. Subsequently, the characteristic seismic features of the reservoir-associated earthquakes and how they reflect upon the changes in the mechanical properties of rock masses are described. Procedural details for the calculation of added stresses by a reservoir are outlined. Theoretical and laboratory investigations on the effect of pore pressure in causing shear failure, and the part played by increased pore-fluid pressure in triggering earthquakes at Denver, Rangely, Kariba, Kremasta and Koyna are included. Recent developments in fluid flow stress analysis and in situ measurement of stress are also described. Recommendations on dam site investigations and seismic surveillance form the last chapter. Also discussed is why certain large reservoirs are aseismic.

The volume contains a lengthy bibliography and an author and a subject index.

2.7-5 Lyuke, E. I., Daragan, S. K. and Peregontseva, V. E., **Forecasting the seismic wave spectra of large underground detonations from the spectra of small preliminary detonations,** *Physics of the Solid Earth,* 12, 2, 1976, 103–109.

The possibility of developing an experimental method for forecasting the seismic effect of powerful underground detonations (of some kilotons magnitude) from the results of registering the seismic waves generated by a charge of some hundreds kilogram magnitude exploded in the same region has been investigated. The Seggern–Blandford model of seismic source has been used for the calculation of the longitudinal wave spectrum of powerful detonation from the experimentally obtained spectrum of a calibrating explosion.

● 2.7-6 Stuart-Alexander, D. E. and Mark, R. K., **Impoundment-induced seismicity associated with large reservoirs,** *Open-File Report 76-770,* U.S. Geological Survey, Menlo Park, California, 1976, 1.

Included is a diagram showing the relationship between water depth and the reservoir capacity of all large reservoirs listed in the *World Registry of Dams* which were associated with impoundment-induced seismicity. For 33 reservoirs, symbols indicate the maximum Richter magnitude of induced earthquakes. Also included is a histogram showing the relationship between observed frequency of induced seismicity in percent and reservoir water depth in meters. References are given.

● 2.7-7 Singh, S., Agrawal, P. N. and Arya, A. S., **Filling of Ramganga Reservoir, Kalagarh, U.P., India and its possible influence on seismic activity,** *Bulletin of the Seismological Society of America,* 66, 5, Oct. 1976, 1727–1731.

The construction of a 125-m-high earth-and-rock-fill dam across the river Ramganga near Kalagarh was completed in early 1974. Its reservoir with a capacity of 2.49 x $10^9 m^3$ was partially filled during the 1974 summer monsoon. A detailed seismicity study has been made using the data from 2 months' microearthquake recording to determine the possible effect of reservoir filling. No interrelationship of seismic activity and reservoir filling has been found.

● 2.7-8 Rogers, A. M. and Lee, W. H. K., **Seismic study of earthquakes in the Lake Mead, Nevada-Arizona region,**

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

Bulletin of the Seismological Society of America, **66**, *5*, Oct. 1976, 1657–1681.

A nine-station telemetered array was installed around the Boulder Basin portion of Lake Mead, Nevada-Arizona. During 1 1/2 years of monitoring, approximately 1,360 events were detected in the magnitude range $-1.0 \leq M_L \leq 2.9$, and half this number were locatable. Many of the events, which ranged in depth from 0 to 13 km, can be associated with mapped faults. In particular, epicenter lineations clearly indicate activity on portions of steeply dipping faults on the east side of Boulder Basin, which generally confirms earlier work by Carder. The strike of these faults is approximately north. Focal mechnisms are in agreement with this strike and show right-lateral motion on near-vertical faults. The tension axis for this solution is oriented northwest-southeast in agreement with the stress pattern for other parts of the Basin and Range Province.

Although lake load increased 20 percent during the monitoring period, neither number of events nor energy release shows a correlation with this change. Carder found similar results for periods after 1949. A higher *b* value (1.45) was obtained than in the past, and lower monthly energy release was observed than in the late 1930s and 1940s when seismic activity at Lake Mead was first recorded. A 2-yr seismicity map of southern Nevada, including the monitoring period, shows that Lake Mead activity is now no greater than that of the surrounding area.

The pre-Lake Mead seismic history is not well known because the founding of Boulder City occurred just a few years before Lake Mead was impounded. The existence of earthquakes in the region before the reservoir was filled has been questioned in the literature. However, a search of the *Las Vegas Review Journal* for felt reports pre- and postimpoundment and compilation of a catalog of the largest events from the literature confirm that there was a significant increase in the number of felt events at Las Vegas after the reservoir was filled.

The results indicate that the filling of Lake Mead has triggered release of tectonic stresses having the same orientation as the regional stress field. These stresses are probably being released in a way that is more dependent on tectonic stress buildup than on small changes in pore pressure (~ 1 bar) due to fluctuating lake level. Given that the shear strength of rock decreases with increasing pore pressure, one might explain the decreasing energy release since the 1940s and the high *b* value as due to a decrease in elastic-energy density of the rock. A test of this hypothesis based on the order of magnitude of energy released seems to support it.

● 2.7–9 Simpson, D. V. and Soboleva, O. V., **Induced seismicity mechanisms in the region of the Nurek water reservoir** (Mekhanizm vozbuzhdennoi seismichnosti v raione Nurekskogo vodokhranilishcha, in Russian), *Sbornik sovietsko-amerikanskikh rabot po prognozu zemletryasenii,* 70–79. (For a full bibliographic citation see Abstract No. 2.8–12.)

A mechanism by which earthquakes are induced is described based on investigations of the induced seismicity in the region of the Nurek water reservoir. The mechanism is based on the interaction of stresses arising from additional loadings from the weight of the water and variations in pore pressure.

2.8 Earthquake Prediction

● 2.8–1 Bacon, C. F. *et al.,* **Crustal movement studies near Parkfield, California,** *California Geology,* **28**, *9*, Sept. 1975, 202–210.

Described are crustal movement studies being conducted in the Parkfield, California, area. These studies are being carried out for several reasons.

First, tilt precursors to earthquakes have tentatively been identified on the San Andreas Fault in the creeping section near Hollister. The California Div. of Mines and Geology (CDMG) tiltmeters will determine whether such precursors precede earthquakes on a part of the San Andreas Fault which is quite different from the section near Hollister. Second, microacoustic, telluric current, and gravity methods are being tested to determine whether they might also serve in earthquake warning systems. Third, the tellurometer, geodimeter, and creepmeter studies will enable CDMG to examine the creep behavior of the fault in great detail. This in turn will give a better understanding of the physical processes by which strain accumulates and is released in this area. A clear understanding of this process is essential for explaining why earthquakes occur where and when they do.

2.8–2 Zoback, M. D. and Byerlee, J. D., **The effect of microcrack dilatancy on the permeability of Westerly granite,** *Journal of Geophysical Research,* **80**, *5*, Feb. 10, 1975, 752–755.

Permeability and volumetric strain were measured under constant confining pressure and pore pressure as a function of increasing and decreasing differential stress. Permeability was found to increase appreciably during dilatancy. Our results have also shown that permeability and dilatant volume changes are not unique functions of differential stress and that permeability changes with differential stress are not uniquely dependent upon dilatant volume changes. Most significant, however, is that if dilatancy fluid diffusion occurs in situ, our results indicate that microcrack dilatancy is not a reasonable physical mechanism to account for such a phenomenon.

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

2.8-3 Aggarwal, Y. P. *et al.*, **Spatial and temporal variations in t_s/t_p and in *P* wave residuals at Blue Mountain Lake, New York: Application to earthquake prediction,** *Journal of Geophysical Research,* 80, 5, Feb. 10, 1975, 718-732.

Renewed earthquake activity at Blue Mountain Lake (BML), New York, in July 1973 provided an excellent opportunity to monitor the travel time ratio of *S* to *P* waves (t_s/t_p) in real time and to test the t_s/t_p technique as a predictive tool. From a mean value of 1.73 on July 30, 1973, t_s/t_p decreased to about 1.5 over the next 2-3 days. On Aug. 1 a prediction was made that an earthquake of magnitude 2.5-3 would occur in a few days. Upper limits of the magnitude and the time of occurrence of the expected earthquake were inferred from the spatial extent of the seismic anomaly. As a result of the prediction an additional strong-motion accelerograph (SMA) was installed in the source region. At 2310 UT on Aug. 3, 1973, a magnitude 2.6 earthquake occurred at BML and triggered two SMAs. In addition to the seismic activity a number of explosions were recorded from a variety of azimuths. The *P* wave arrivals from distant quarry blasts, refracted from a high-velocity layer at 4 km beneath BML, showed late arrivals at five stations during the premonitory low in t_s/t_p. The *P* wave delays were maximum (0.13 s) in the hypocentral region of the earthquake and decreased away from it along two profiles. These results indicate that changes in t_s/t_p are caused by changes in the material properties of the earthquake source region. The anomalous zone (region of low *P* velocity) for the Aug. 3 earthquake (aftershock length 1 km, depth 1 ± 0.1 km) was about 3-5 km in radius and was wholly or largely limited to the layer above the interface at 4 km depth. In contrast to the *P* delays observed from distant quarry blast, *P* and *S* arrivals from local construction blasts ($\Delta < 10$ km) show no large premonitory changes in either *P* or *S* travel times. This observation suggests that either no significant velocity anomalies occurred in the upper 0.5 km of the BML region or that the dilatant cracks were predominantly horizontal, the result being strong velocity anisotropy. This conclusion is supported by data from seismic sources; events located at shallow depths show normal (1.75) to high (1.85) t_s/t_p values even when values as low as 1.5 are observed from deeper sources. This finding places constraints on the use of artificial sources to monitor changes in velocity, since the effects of anisotropy may have to be taken into account in addition to ensuring that ray paths to the recording stations penetrate the zone of anomalous velocity. A maximum likelihood method was used to invert data from individual small earthquakes to determine *P* and *S* velocities in the anomalous zone. The results, which are consistent with the explosion data, indicate that the premonitory decreases in *P* and *S* velocities were much more pronounced from sources at depths of 1-2 km than for those near the surface. The inferred low values of *P* and *S* velocities were, respectively, about 22 and 12% below normal. This study also shows that t_s/t_p inferred from a Wadati plot is a function of the distribution of stations relative to the anomalous zone. To optimize the use of t_s/t_p as a predictive tool, this study suggests that not only temporal but spatial variations of velocity anomalies should be monitored. This emphasizes the need for multistation coverage for reliable earthquake prediction.

● 2.8-4 Wakita, H., **Kawasaki earthquake: Will it occur or not? Geochemical studies of unidentified ancient water,** *Technocrat,* 8, 7, July 1975, 6-17.

The Geographical Survey Inst. of Japan carried out levelling studies of the ground between Tokyo and Fujisawa. These studies showed that the region within a radius of several kilometers of Kawasaki City has been moving continuously upward since 1971 by a maximum of 1 cm per year: a total upheaval of 1 to 4.7 cm has been observed since then. As a result of these findings, the Coordinating Committee for Earthquake Prediction publicly appealed for local organizations and private enterprises to investigate the phenomenon.

In this paper, the results of some of the geochemical studies of the area are presented. These studies showed that the abrupt ground upheaval may be related to the reduction of water being pumped up. However, more accurate surveys may be required for upheaval phenomena over the entire region.

● 2.8-5 Adams, R. D., **The Haicheng, China, earthquake of 4 February 1975; The first successfully predicted major earthquake,** *Earthquake Engineering and Structural Dynamics,* 4, 5, July-Sept. 1976, 423-437. (Also in *Bulletin of the New Zealand National Society for Earthquake Engineering,* Mar. 1976.)

The earthquake of magnitude 7.3 that occurred near the town of Haicheng in northeast China on Feb. 4, 1975, was the first major earthquake anywhere in the world known to have been predicted with enough certainty for people to have been warned and measures taken for civil protection. These steps were successful in keeping the number of casualties small. This paper describes a visit to the affected area seven and a half months after the earthquake and discussions with Chinese scientists about their successful prediction methods. The prediction resulted from the synthesis of many types of investigation, but the main methods used for long-, mid- and short-term prediction appear to have been based on studies of seismicity, deformation and foreshocks respectively.

● 2.8-6 Hagiwara, T., **Recent research on earthquake prediction,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 3, 1975, 119-124. (For a full bibliographic citation see Abstract No. 1.2-6.)

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

2.8-7 Hodych, J. P., **Single-domain theory for the reversible effect of small uniaxial stress upon the initial magnetic susceptibility of rock,** *Canadian Journal of Earth Sciences,* **13**, *9*, Sept. 1976, 1186–1200.

The phenomenon of small uniaxial stress changing the magnetic susceptibility of rock is of current interest as a possible aid in earthquake forecasting. In this paper, theoretical expressions are derived (using rigorous energy-minimization, but ignoring thermal activation) for reversible susceptibility change parallel to the stress axis for samples containing single-domain grains of a ferromagnet with cubic magnetocrystalline anisotropy (K_1 positive or negative) and anisotropic magnetostriction. The grains are assumed to be noninteracting and randomly oriented spheres or ellipsoids of revolution elongated along (100), (111) or (110). Also approximate expressions are given for samples containing multidomain grains with very strongly pinned walls.

For susceptibility change perpendicular to the stress axis, one expects -1/2 the above expressions, which is proven for spherical single-domain grains with isotropic magnetostriction using a magnetometer analogy. The expressions predict that for magnetite-bearing rock the decrease in susceptibility along a 100 bar compression axis should be 4.7% for spherical single-domain grains (coercive force ~100 Oe), 1.6% for 1.4 to 1 elongation along (111) (coercive force ~500 Oe), and 0.6% for great elongation along (111). The decrease for equidimensional multidomain grains with strongly pinned walls(coercive force ~100 Oe) should be ~1.2%—less at smaller coercive force according to some theoreticians, possibly more according to the author's experiments.

● **2.8-8** **Predicting earthquakes: A scientific and technical evaluation—With implications for society,** Panel on Earthquake Prediction, Committee on Seismology, National Research Council, Washington, D.C., July 1976, 62.

This report presents a brief summary of the scientific bases for earthquake prediction, a summary of current status, and a statement of outlook. Appendixes A and B review in some detail the background and progress of prediction studies in the United States, the Soviet Union, Japan, and the People's Republic of China.

● **2.8-9** Rikitake, T., **Earthquake prediction,** *Developments in Solid Earth Geophysics, No. 9,* Elsevier Scientific Publishing Co., Amsterdam, 1976, 357.

Current research in earthquake prediction in Japan, the United States, the Soviet Union and the People's Republic of China, as well as the development of prediction-oriented earthquake studies, are summarized in this volume. Much of the material on the various effects pertinent to earthquake prediction is based on Japanese and Chinese research results which are often inaccessible to people in other countries. The effects are classified into the following disciplines: land deformation as detected by geodetic means, land deformation relative to sea level, continuous observation of crustal movement, seismic activity, change in seismic wave velocities, geomagnetic and geoelectric effects, active faulting and folding, gravity, underground water, oil flow, radon content, etc. On the basis of analyses of these effects, theories of earthquake prediction are put forward which are useful for evaluating the present status of earthquake prediction study. A brief account of earthquake modification and control is given although it will be some time before earthquake control can be applied to major earthquakes. In conclusion, the author emphasizes the importance of the sociological study of response to earthquake prediction.

● **2.8-10** Smith, A. R. *et al.*, **Investigation of radon-222 in subsurface waters as an earthquake predictor,** *LBL-4445,* Lawrence Berkeley Lab., Univ. of California, Berkeley, Nov. 1975, 12. (Presented at IEEE Nuclear Science Symposium, San Francisco, Nov. 19-21, 1975.)

Changes of radon-222 content of well water in seismically active regions may provide earthquake precursor signals, according to reports of recent Chinese and Russian work. A high-precision γ-ray system for continuous monitoring of radon in wells and springs has been developed at the Lawrence Berkeley Lab., where monitoring began in Apr. 1975, and has been extended to other sites, including the San Andreas fault zone.

2.8-11 Whitham, K. *et al.*, **Earthquake prediction in China,** *Geoscience Canada,* 3, *4*, Nov. 1976, 263–268.

This report, based on a visit to China in the fall of 1975, describes the Chinese program for earthquake prediction. An account is given of the prediction of the Haicheng earthquake, M7.3, Feb. 4, 1975.

● **2.8-12** Sadovskii, M. A. *et al.*, eds., **Collection of Soviet-American studies in earthquake prediction** (Sbornik sovietsko-amerikanskikh rabot po prognozu zemletryasenii, in Russian), *Vol. 1, No. 1,* DONISH, Dushanbe and Moscow, 1976, 235.

This volume describes the first results of joint Soviet-American studies of methods to predict earthquakes. The studies were performed in the U.S.S.R. and the U.S.A. during 1974 and 1975. Data from seismological observations and from laboratory investigations of earthquake models are presented. Techniques to evaluate seismic risk and to determine the location of strong earthquakes are considered. Engineering seismology results are discussed. An appendix and 11 papers are included. The appendix provides details of the joint projects established in 1973 by the Soviet-American Working Group on Earthquake Pre-

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

diction. The appendix also presents the 1974-75 program of projects. All of the papers are abstracted in this volume of the *AJEE*.

A radiotelemetric seismic instrumentation system, Besson, R. L. *et al.*—*A portable digital seismometric station*, Prothero, W.—*Results of joint seismological field investigations in the Khait region during 1974*, Besson, R. L. *et al.*—*Results of joint seismological field investigations in the Khrebt Petra Pervogo region during 1975*, Besson, R. L. *et al.*—*Induced seismicity mechanisms in the region of the Nurek water reservoir*, Simpson, D. V. and Soboleva, O. V.—*Analysis of the polarized structure of local earthquakes in the Garm region*, Kopnichev, Yu. F. *et al.*—*Preliminary results of investigations of the earthquake spectra of the Garm region in light of the earthquake prediction problem*, Martynov, V. G. *et al.*—*The spectral composition of earthquakes in the Pamir-Hindukush region: Evidence for the existence of a high-gain zone in the upper mantle*, Molnar, P. *et al.*—*Effects of wave propagation direction and the location of recording station on spectra of local earthquakes in the Garm region*, Molnar, P. *et al.*—*Time-dependent changes in amplitudes and travel times of seismic P waves measured by the networks at Garm, California, LASA and NORSAR*, Aki, K.—*et al.*—*Lg wave propagation in central Asia*, Molnar, P. *et al.*

● 2.8-13 Aki, K. *et al.*, **Time-dependent changes in amplitudes and travel times of seismic P waves measured by the networks at Garm, California, LASA and NORSAR** (Vremennye izmeneniya fluktuatsii amplitud i vremen probega teleseismicheskoi volny P na gruppakh Garm, Kaliforniya, LASA i NORSAR, in Russian), *Sbornik sovietsko-amerikanskikh rabot po prognozu zemletryasenii*, 171-184. (For a full bibliographic citation see Abstract No. 2.8-12.)

The correlation between the deviation from the mean of amplitude logarithms and travel times is investigated using the records of earthquakes which occurred in Kamchatka and Japan. The records were obtained by the Garm, the NORSAR (Norway), the LASA (Montana, U.S.A.) and the California networks. The technique may be used to investigate the quantitative characteristics of the geodynamic process and to predict earthquakes.

● 2.8-14 Kopnichev, Yu. F. *et al.*, **Analysis of the polarized structure of local earthquakes in the Garm region** (Analiz polyarizatsionnoi struktury mestnykh zemletryasenii garmskogo raiona, in Russian), *Sbornik sovietsko-amerikanskikh rabot po prognozu zemletryasenii*, 80-95. (For a full bibliographic citation see Abstract No. 2.8-12.)

The characteristics of earthquakes in the Garm region are investigated by a computerized analysis of seismograms. A polarized filtration algorithm is used in the analysis. In some cases an anisotropy between SV and SH waves is detected. The tail portion of the seismograms has a regular polarized structure. Polarized waves consistently appear in the seismograms after an interval of .5 to 1.0 sec. Suggested procedures for polarization studies for earthquake prediction are described.

2.9 Special Topics

● 2.9-1 Bacon, C. F., **Acoustic emission along the San Andreas Fault in southern central California**, *California Geology*, **28**, *7*, July 1975, 147-154.

The California Div. of Mines and Geology (CDMG) has completed the first phase of a pilot study, begun in 1972, to monitor audio frequency microseismic activity along a major fault zone.

Preliminary results of the pilot study determined the feasibility of monitoring acoustic emissions for possible use in the prediction of earthquakes along the San Andreas Fault. Field measurements to date were not intended to monitor earthquake precursors as such. The project successfully determined: (1) that audio frequency microseismic activity can be detected; (2) that certain types of areas will make the best sites for further study; and (3) that certain types of instrumentation and techniques will be most successful for this purpose.

The six stations established for the pilot project, between Parkfield and Palmdale, on both active and locked segments of the San Andreas Fault, will continue to be monitored to provide further information. The critical question, whether detectable variations in the level and type of acoustic microseismic emissions actually occur just prior to earthquake-causing movements along a given fault, remains to be answered. The technique, instruments, and theory are available, but their success in predicting damaging earthquakes can be proven only by adequate measurement of acoustic emissions preceding earthquake events.

● 2.9-2 Gencoglu, S., **Research on microtremor characteristics of the earth by means of experimental studies of seismic waves** (Sismik dalgalarin deneysel etudleri yoluyla mikrotremorlarin karateristikleri uzerine arastirmalar, in Turkish), *Deprem Arastirma Enstitusu Bulteni*, **2**, *8*, Jan. 1975, 1-86.

This work reviews various aspects of microtremor characteristics of the earth, which have been extensively studied by many researchers. In particular, experimental and statistical investigations are discussed, and the applicability of the findings in these studies to earthquake engineering is emphasized.

2.9-3 **Interpretation of seismological and neotectonic data** (Interpretatsiya dannykh seismologii i neotektoniki, in Russian), *Vychislitelnaya seismologiya*, *8*, 1975, 192.

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

This volume is dedicated to the application of modern mathematical and computer techniques to an analysis of geological and geophysical data. A combined analysis of seismological and neotectonic data is considered with a view towards evaluation of seismic risk and prediction of earthquake location.

● 2.9-4 Hedayati, A., Brander, J. L. and Berberian, M., **Microearthquake survey of Tehran region, Iran,** *Bulletin of the Seismological Society of America,* **66,** *5,* Oct. 1976, 1713–1725.

A short microearthquake survey of part of north central Iran around the city of Tehran made late in 1974 showed that earthquakes occurred at the rate of 21.37 events per day.

Epicentral locations for 37 events, using a geometric ray path technique, show the observed activity to be concentrated in three principal groups: two associated with the known major fault on the south flank of the Alborz mountain, while the third constitutes a previously unrecognized lineation passing very close to the city of Tehran.

The cumulative number versus magnitude relation was obtained from the study of 198 well-recorded events. The slope of the linear portion of the relation (b value), -0.79, agrees well with the value of -0.86 determined from the USCGS records of larger earthquakes between 1961 and 1973.

Composite fault-plane solutions were made for each of the three principal groups, showing predominantly strike-slip movement with a thrust component on the south of the Alborz and thrusting on the new lineation.

The seismic intensity risk curve calculated for the area shows that the city of Tehran can expect ground movement of MM intensity VII every 12 years, and intensity IX every 350 years.

● 2.9-5 Rogers, G. C., **A microearthquake survey in northwest British Columbia and southeast Alaska,** *Bulletin of the Seismological Society of America,* **66,** *5,* Oct. 1976, 1643–1655.

In an 81-day period during the summer of 1969 four portable seismographs were operated in northwest British Columbia and southeast Alaska. One hundred and forty microearthquakes were detected. Epicenters were located near the Queen Charlotte-Fairweather fault and the Denali fault. The Chatham Strait fault showed no activity and only a few events were located in the Quaternary volcanic zone of British Columbia. A scattering of microearthquakes through the archipelago and the Coast Range and a concentration in the Glacier Bay region suggest that the seismicity may be more complex than the pattern indicated by the distribution of larger earthquakes. The most numerous seismic events recorded, numbering in the thousands, were low-frequency events emanating from a number of specific areas where large glaciers are located.

● 2.9-6 Ravara, A. and Duarte, R. T., **Analysis of the 1973-74 Azores earthquakes,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 3, 135–140. (For a full bibliographic citation see Abstract No. 1.2-6.)

From Oct. 1973–Feb. 1974 the Pico and Faial Islands (Azores) were hit by a seismic swarm related to volcanic activity. The damage to rural dwellings is reported with brief comments on problems relating to fatigue when designing against a seismic swarm. The recorded accelerograms are analyzed in order to identify the main characteristics of the ground motion. Response spectra and power spectral density of acceleration are presented and the near epicentral character of the records is highlighted.

3. Engineering Seismology

3.1 General

3.1-1 Rashidov, T., **Calculation of earthquake intensity from indications of damage or failure of underground pipelines** (Opredelenie ballnosti zemletryasenii po priznakam povrezhdenii i razrushenii podzemnykh truboprovodov, in Russian), *Seismicheskaya shkala i metody izmereniya seismicheskoi intenzivnosti,* NAUKA, Moscow, 1975, 117–120.

A classification of underground pipelines and the types of damage sustained by them is given. This classification is applied to determine earthquake intensity from the extent and severity of damage to such pipelines.

3.1-2 Polyakov, S. V. and Zharov, A. M., **Remarks on the planned new seismic scale** (Nekotorye zamechaniya k proektu novoi seismicheskoi shkaly, in Russian), *Seismicheskaya shkala i metody izmereniya seismicheskoi intenzivnosti,* NAUKA, Moscow, 1975, 139–145.

Problems concerning the structure of the new seismic intensity scale are discussed. The set of ground motion parameters to be included and their numerical values are considered. The importance of the duration of seismic excitation in calculations of the reliability of structures is emphasized.

3.1-3 **Seismic scale and methods of seismic intensity measurement** (Seismicheskaya shkala i metody izmereniya seismicheskoi intenzivnosti, in Russian), NAUKA, Moscow, 1975, 279.

In this volume an account is given of the work of leading institutions of the U.S.S.R. on improvements of the seismic scale and methods of seismic intensity measurements. Results of investigations of a whole range of problems related to the seismic scale are published here for the first time, including the classification of natural phenomena, the statistics of surface effects, the analysis of strong-motion recordings and the foundations of the stochastic theory of seismic excitations.

Five papers of interest to earthquake engineers are abstracted in this volume of the *AJEE: On evaluation of seismic intensity,* Shebalin, N. V.—*Damage to structures with aseismic design features,* Karapetyan, B. K.—*Calculation of earthquake intensity from indications of damage or failure of underground pipelines,* Rashidov, T.—*Remarks on the planned new seismic scale,* Polyakov, S. V. and Zharov, A. M.—*On calculation of the duration of seismic ground motion,* Kats, A. Z.

3.1-4 Shebalin, N. V., **On evaluation of seismic intensity** (Ob otsenke seismicheskoi intensivnosti, in Russian), *Seismicheskaya shkala i metody izmereniya seismicheskoi intenzivnosti,* NAUKA, Moscow, 1975, 87–109.

A seismic scale based on a statistical investigation of the behavior of people, objects and buildings during earthquakes is presented. The scale is correlated with focal parameters and amplitudes, periods and duration of ground motion. The nonlinear relationship between the intensity and the logarithm of ground motion amplitude is established.

● 3.1-5 Arias S., A., **Intensity of earthquakes and corrected earthquake spectra** (Deprem siddeti ve duzeltilmis deprem spektrumlari, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* **2**, *6,* July 1974, 115–129.

In this study, a definition of earthquake intensity based on ground acceleration and velocity is proposed and discussed. A new definition for an intensity spectrum is given. Accelerometers are classified in view of characteristic frequencies of ground motion.

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

3.1-6 Zharov, A. M. and Nikiporets, G. L., **On classifications of seismic ground motion using instrumental data** (O klassifikatsiyakh seismicheskogo dvizheniya grunta, ispolzuyushchikh instrumentalnye dannye, in Russian), *Seismicheskaya shkala i metody izmereniya seismicheskoi intensivnosti,* NAUKA, Moscow, 1975, 179–193.

Objective quantitative criteria for evaluation of seismic disturbance are presented with the demands of the state-of-the-art methods of earthquake-resistant building design in mind. Various methods of earthquake classification are considered with emphasis on statistical classifications. A quantitative relationship is established between the classifications discussed here and present-day scales.

3.1-7 Rasskazovskii, V. T., Gamburg, Yu. A. and Shirova, Z. Kh., **Quantitative earthquake intensity scale** (Kolichestvennaya shkala intenzivnosti zemletryasenii, in Russian), *Seismicheskaya shkala i metody izmereniya seismicheskoi intensivnosti,* NAUKA, Moscow, 1975, 194–202.

A method for calculating earthquake intensity from correlational parameters of accelerograms is presented. A quantitative seismic intensity scale is considered and earthquake intensities at various points of the scale are correlated with the response of structures calculated from accelerograms.

3.1-8 Shabalin, N. V., **On the uniformity of intensity scale** (O ravnomernosti shkaly ballnosti, in Russian), *Seismicheskaya shkala i metody izmereniya seismicheskoi intensivnosti,* NAUKA, Moscow, 1975, 222–233.

Two kinds of nonuniformity in seismic scales are considered. Nonsystematic nonuniformity arises from the nonhomogeneous distribution of macroseismic effects. Systematic nonuniformity is connected with the generally accepted log-linear relationship between vibration amplitudes and the intensity scale. The aggregate of instrumental correspondence between acceleration and intensity may be ordered only on the basis of a slower than linear increase of the logarithm of amplitude with intensity.

3.1-9 Aptikaev, F. F., **Effects of the duration of ground motion in instrumental evaluation of seismic intensity** (Uchet dlitelnosti kolebanii pri instrumentalnoi otsenke seismicheskoi intensivnosti, in Russian), *Seismicheskaya shkala i metody izmereniya seismicheskoi intensivnosti,* NAUKA, Moscow, 1975, 234–239.

Various definitions of the duration of seismic ground motion are formulated. The motion of impulse width is found most suitable for purposes of engineering seismology. On the basis of a detailed analysis of data the most probable acceleration values are calculated for various earthquake intensities.

● 3.1-10 Poceski, A., **On the intensity of strong motion earthquakes,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 11, 9. (For a full bibliographic citation see Abstract No. 1.2-6.)

The intensity of strong-motion earthquakes is defined by the spectral energy absorption per unit mass of one-degree-of-freedom elasto-plastic systems, integrated from 0 to 3 sec of the spectrum. The basic assumption is that the maximum response displacements of elastic and elasto-plastic systems are equal. The proposed intensity is connected by the commonly used engineering parameters: ductility and seismic coefficients. Thus, it should be an engineering measure of the intensity. The proposed intensity is similar to Housner's spectral intensity, but the meaning of it is different.

● 3.1-11 Medvedev, S. V., Nersesov, I. L. and Bune, V. I., **Relation between macroseismic effect and ground vibration velocity,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 5, 4. (For a full bibliographic citation see Abstract No. 1.2-6.)

Ground vibration velocity determines the main earthquake parameters: magnitude, focus energy, focus moment. It is, therefore, proposed that the velocity of ground vibrations determines intensity as well.

The velocity of ground vibrations recorded at seismic stations during strong earthquakes is a quantity of energy characteristic of earthquake intensity as the density of seismic energy flow is proportional to velocity square. Measurements of the velocity of vibrations of the earth's surface during strong earthquakes allow the direct connection between the velocity and the intensity of an earthquake to be obtained. Material deformations linearly depend on vibration velocities. This fact is of importance for the estimation of earthquake motion on the ground and on structures.

● 3.1-12 Mortgat, C. P. and Shah, H. C., **An intensity scale for earthquakes,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 2, 9. (For a full bibliographic citation see Abstract No. 1.2-6.)

There is a need for an engineering intensity scale that would reflect the impact of earthquake ground motion upon structures of all types, of all ages and of all locations. Intensity scales currently in use are largely based on subjective reactions and judgments of persons and on the effect upon given structures. They also overlook parameters that have a definite importance in structural behavior.

The proposed scale, patterned somewhat after Blume's Engineering Intensity Scale, takes the following parameters into consideration: the frequency content, the duration, and the total energy of the ground motion together with the

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

dynamic characteristics of the structure. It describes the intensity of a given earthquake through total response histories of single-degree-of-freedom systems of given damping; it can be expanded in probabilistic terms so as to describe the seismicity of a given area.

● 3.1-13 Brazee, R. J., **An analysis of earthquake intensities with respect to attenuation, magnitude, and rate of recurrence,** *Final Report, NOAA Technical Memorandum EDS NGSDC-2,* National Geophysical and Solar-Terrestrial Data Center, Boulder, Colorado, Aug. 1976, 99.

Earthquake intensity reports collected by various agencies of the U.S. Government from many thousand localities for the years 1928 through 1973 have been encoded and filed on magnetic tape. A method for determining systematically the isoseismal areas and distances is developed and used for the analysis of intensity attenuation. Suites of curves, with corresponding formulas, are developed depicting the attenuation regimes for the eastern and western United States and for each of several subregions. A method of calculating recurrence curves is presented, which permits the determination of such a curve by electronic computer/plotter for any point in the conterminous United States. Magnitude versus area of perceptibility relationships are developed and magnitude versus maximum intensity is defined for the various regions.

● 3.1-14 Ambraseys, N. N., **Trends in engineering seismology in Europe,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 3, 1975, 39-52. (For a full bibliographic citation see Abstract No. 1.2-6.)

● 3.1-15 Krinitzsky, E. L. and Chang, F. K., **Relation of earthquake intensity to ground motions for seismic design,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 261, 1031-1037. (For a full bibliographic citation see Abstract No. 1.2-9.)

Correlations between earthquake intensity and peak ground motions have been expressed by curves that do not adequately represent the great dispersion in the data. It is proposed that the data be separated into near field and far field, then to enter the plots at levels that are consistent with the safety requirements of a project. Appropriate parameters can then be generated for velocity, acceleration, and displacement. These parameters may then form the basis for developing time histories that are suitable for dynamic analyses.

● 3.1-16 Alonso G., J. L. *et al.*, **Basic plan for seismic investigations in Venezuela** (Plan basico para las investigaciones sismicas en Venezuela, in Spanish), Fundacion Venezolana de Investigaciones Sismologicas, Caracas, Oct. 1974, 178.

3.2 Strong Motion Records, Interpretation, Spectra

3.2-1 Kats, A. Z., **On calculation of the duration of seismic ground motion** (Ob otsenke dlitelnosti seismicheskikh kolebanii grunta, in Russian), *Seismicheskaya shkala i metody izmereniya seismicheskoi intenzivnosti,* NAUKA, Moscow, 1975, 251-252.

The duration of seismic ground motion is regarded as a consequence of resonance phenomena. Data on the duration of ground motion and its relationship to the type of seismic wave and to soil properties are discussed.

● 3.2-2 Gencoglu, S., **Some applications for empirical determination of earthquake parameters** (Deprem parametrelerinin amprik olarak hesaplanmasi uzerinde bazi uygulamalar, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* 2, 6, July 1974, 47-66.

In this paper, graphical representations of some empirical formulas based on the studies of expected values of surface or base rock velocity and acceleration of earthquake motions have been provided as a practical aid to the designer.

3.2-3 Suvilova, A. V. *et al.*, **On evaluation of ground motion parameters for seismic risk calculations** (Ob otsenke parametrov dvizheniya grunta pri raschetakh seismicheskogo riska, in Russian), *Seismicheskaya shkala i metody izmereniya seismicheskoi intensivnosti,* NAUKA, Moscow, 1975, 203-221.

Destructive earthquakes in the United States are analyzed. The effects of magnitude and focal distance on parameters such as length of recording, maximal amplitudes, frequencies, the number of maxima, etc., are investigated. The dispersion of the parameters is found to be so great as to necessitate a judicious choice of "average" or "most dangerous" accelerograms.

● 3.2-4 Petrovski, D., **Proposed methods for data processing of strong motion acceleration measurements in Yugoslavia,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 8, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

Data-processing methods are proposed to aid in obtaining maximum information from strong-motion measurements in Yugoslavia and to aid in making comparisons with the measurements obtained in other parts of the world.

The methods of analysis of ground acceleration records that are used at the Inst. of Earthquake Engineering and Engineering Seismology, Skopje, are actually modified methods developed and applied at the California Inst. of

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

Technology, Pasadena. The modification was made because different means of data digitalization and processing were used. For digitalization of records, the semi-automatic A-D converter, type SM-2, is used, while for data-processing the IBM-1130 electronic computer is used.

● 3.2-5 Sandi, H., **Estimates of non-synchronous seismic disturbances,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 52, 6. (For a full bibliographic citation see Abstract No. 1.2-6.)

The propagation velocity of seismic waves in ground is finite. Due to this fact, the seismic motion of different ground points is not identical and the disturbances applied to different points of contact between a structure and the ground are nonsynchronous.

This paper is based on a previously developed approach in order to deal with linear oscillations due to nonsynchronous seismic disturbances. That approach explicitly deals with the role of space correlations of seismic motion at different ground points or in different directions. The paper is intended to contribute to a reasonable estimation of the seismic input, considering the developments referred to.

● 3.2-6 Hoshiya, M., Shibata, S. and Nishiwaki, T., **Upper bound of response spectrum,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 65, 13. (For a full bibliographic citation see Abstract No. 1.2-6.)

Despite the fact that the average response spectrum is of great use in seismic-resistant design, there remain some questions concerning its reliability. Important structures, such as nuclear power plants, must be designed with great reliability against every earthquake expected during their lifetimes. In these cases, use of a deterministic upper bound against response spectra, if found, can be one of the most desired seismic-resistant design methods. This paper presents a theoretical analysis of the upper bound, or equivalently the worst pseudo-acceleration, against a normalized response spectrum by the input maximum acceleration.

● 3.2-7 Derecho, A. T., Freskakis, G. N. and Fintel, M., **A study of the effect of the frequency characteristics of ground motions on nonlinear structural response,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 21-36. (For a full bibliographic citation see Abstract No. 1.2-7.)

In conducting deterministic nonlinear dynamic response studies of a specific structure, it is essential to know what general type of accelerogram to use as input in order to obtain a good estimate of the expected maximum response with a limited number of analyses. Insofar as dynamic structural response is concerned, the major parameters characterizing the ground motion are intensity, duration and frequency content. The effects of intensity and duration on dynamic response have been studied by a number of investigators. However, little has been done to study the effect of the frequency characteristics of the input motion. This report presents the results of nonlinear dynamic analyses of isolated structural walls with hysteresis loops characterized by a stiffness that decreases with increasing amplitudes of inelastic deformation. A rough basis for classifying accelerograms in terms of their damped velocity spectra as "broad band" and "peaking" is proposed. The results of the study indicate that when extensive yielding occurs in a structure, so that a significant change in the effective period of vibration results, a broad band accelerogram is likely to produce a more severe response compared to a peaking accelerogram of the same intensity and duration. On the other hand, when only minor yielding occurs so that no significant increase in the effective period results, a peaking record will more likely produce the more severe response.

● 3.2-8 Chuang, A. *et al.*, **Generating response spectra from displacement and velocity time history input,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 331-344. (For a full bibliographic citation see Abstract No. 1.2-7.)

An investigation has been made to explore a method for generating response spectra from displacement and velocity time history input instead of acceleration time history. The ability to generate response spectra from digitized displacement and velocity time history input is required in order to show that the displacement input used for some component tests or analyses is, in fact, equivalent to the input when specified in terms of acceleration.

The analytical approach used in this investigation was successively to integrate by parts the expression of the absolute acceleration response of a single degree-of-freedom oscillator; the final results are in terms of Duhamel's integrals involving only displacement and velocity excitations. The numerical computations of these integrals were facilitated by making use of recurrence relations. The response spectra obtained were compared with those generated by conventional methods using acceleration input.

● 3.2-9 Crouse, C. B., **Horizontal ground motion in Los Angeles during the San Fernando earthquake,** *Earthquake Engineering and Structural Dynamics,* 4, 4, Apr.-June 1976, 333-347.

Accelerograms, Fourier amplitude spectra and response spectra from ground motion recorded in the San Fernando earthquake at selected sites in Los Angeles were examined and compared. Although differences exist in the data from the bases of a group of six tall buildings close together near the intersection of Wilshire Boulevard and

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

Normandie Avenue, the differences are not significant from the standpoint of design. A single design spectrum is most appropriate for this area, even though there exists a variety of foundation conditions, building properties and basement configurations for the six sites.

The degree to which soil-structure interaction and local geology affected the response could not be precisely determined from the basement accelerograms, although the data from the six Wilshire-Normandie sites offered some evidence that soil-structure interaction and local site conditions did not contribute significantly to the character of the recorded motions. There was some correlation between the degree of similarity in the response at two sites and their distance apart; thus, it is possible that some differences in the response of the closely spaced buildings could result from different superposition of the seismic waves.

The shapes of response spectra from all of the sites studied, including the spectra from seven buildings 2-3 miles distant from the buildings near the intersection of Wilshire Boulevard and Normandie Avenue, indicate that the character of the ground motion was probably more dependent on the source mechanism and the travel paths of the earthquake waves, rather than on more local effects.

● **3.2-10** Carydis, P. G. and Sbokos, J. G., **Evaluation of Greek strong motion records,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1079-1093. (For a full bibliographic citation see Abstract No. 1.2-7.)

In this paper, the two horizontal components for four strong earthquakes which occurred in Greece are presented. Absolute acceleration, relative velocity and relative displacement response spectra are evaluated. The ground acceleration, velocity and displacement, as well as the energy flux, are plotted as a function of time. The following information concerning these earthquakes is presented: the name, location and date of occurrence, epicentral distance, magnitude, intensity, kind of soil, maximal values of the ground motions and their duration.

● **3.2-11** Hanks, T. C., **Observations and estimation of long-period strong ground motion in the Los Angeles basin,** *Earthquake Engineering and Structural Dynamics,* **4,** 5, July-Sept. 1976, 473-488.

While the accurate estimation of ground-motion amplitudes across the entire frequency band of engineering interest is not possible at the present time, the excitation and propagation of long-period strong ground motion can be understood with existing seismological methodology. In the Los Angeles basin, the long-period strong ground motion excited by the San Fernando earthquake is dominated by the presence of surface waves, whose gross amplitude and frequency content are easily attributable to physical properties of the earthquake source and source-station propagation paths. Observed measures of the long-period strong ground motion of the Kern County earthquake relative to the San Fernando earthquake at two sites in the Los Angeles basin, which recorded both shocks, can be predicted with considerable accuracy by a simple earthquake source model. This source model is extrapolated to represent the maximum credible earthquake likely to affect the Los Angeles area, taken to be a repeat of the Fort Tejon (1857) earthquake along the San Andreas fault. The measures of long-period strong ground motion in the Los Angeles basin estimated for it agree well with the comparable measures of Earthquake A-2, intended to represent the same situation. For the purpose of aseismic design of long-period structures, Earthquake A-2 is a reasonable, if not all inclusive, estimate of the long-period strong ground motion in the Los Angeles basin generated by a magnitude 8+ earthquake along the San Andreas fault north and east of Los Angeles.

● **3.2-12** Trifunac, M. D. and Brady, A. G., **Correlations of peak acceleration, velocity and displacement with earthquake magnitude, distance and site conditions,** *Earthquake Engineering and Structural Dynamics,* **4,** 5, July-Sept. 1976, 455-471.

A brief review of proposed correlations between peak accelerations and earthquake magnitude and distance has been presented. It has been found that most investigators agree favorably on what should be the amplitude of peak accelerations for the distance range between about 20 and 200 km. For distances less than 20 km, there is significant disagreement in the predicted peak amplitudes, reflecting the lack of data there and the uncertainties associated with the extrapolation.

Correlations of peak accelerations, peak velocities and peak displacements with earthquake magnitude, epicentral distance and the geologic conditions of the recording sites have been presented for 187 accelerograms recorded during 57 earthquakes. This data set describes strong earthquake ground motion in the western United States during the period from 1933 to 1971.

For large earthquakes, dependence of peak acceleration, velocity and displacement amplitudes on earthquake magnitude seems to be lost. This suggests that the amplitudes of strong ground motion close to a fault are scaled primarily by the maximum dislocation amplitudes and the stress drop, rather than the overall "size" of an earthquake as measured by magnitude. The influence of geologic conditions at the recording station seems to be of minor importance for scaling peak accelerations, but it becomes noticeable for the peaks of velocity and even more apparent for the peaks of displacement.

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

● **3.2-13** Osawa, Y. *et al.*, **Observational studies on the earthquake response of buildings in Japan,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1123–1149. (For a full bibliographic citation see Abstract No. 1.2-7.)

The present state of earthquake observation projects in Japan is introduced with special emphasis on soil-structure interaction effects. The analyses are made using records obtained of moderate earthquake motions at three building sites and one spherical tank site as illustrative examples. The results indicate that the interaction effects can be observed in the form of a spectral ratio between the Fourier spectra at the base of structures and the surface of the ground and that the shear wave velocity in a soil layer plays an important role in determining the suitable model of a soil-structure interaction system.

● **3.2-14** Taoka, G. T., **Digital filtering of ambient response data,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 253–262. (For a full bibliographic citation see Abstract No. 1.2-8.)

This paper is concerned with problems that may arise when ambient data are filtered nonrecursively by the use of a fast Fourier transform algorithm. Some preliminary results of applying this method to a 40-story building are also presented.

● **3.2-15** Bertero, V. V., Mahin, S. A. and Herrera, R. A., **Aseismic design implications of San Fernando earthquake records,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 492–501. (For a full bibliographic citation see Abstract No. 1.2-8.)

Although the magnitude of the 1971 San Fernando earthquake was only moderate, damage to seismic-resistant structures located near the fault rupture was very severe. The main features of this damage appear to be the result of a few large displacement excursions rather than of numerous intense oscillations, as was the case at sites farther from the fault zone. Unfortunately, no accelerograms were obtained in or near buildings in the area of heaviest shaking. The only record near the faulting was obtained at the Pacoima Dam.

The objectives of the study reported herein were (1) to determine whether the Pacoima Dam record was representative of other ground motions near the rupture; (2) to analytically study whether this record could account for the unusual type of building damage observed at near-fault locations; and (3) to assess the implications of this type of record and of the observed damage to the aseismic design of buildings located near possible earthquake faulting.

3.2-16 Skorik, L. A., **The effects of local fluctuations in fields of high-frequency microtremors** (Uchet lokalnykh fluktuatsii v polyakh vysokochastotnykh mikroseism, in Russian), *Voprosy inzhenernoi seismologii, 18,* 1976, 69–74.

A technique is presented to separate spectra of high-frequency microtremors from noise background found in microtremor recordings in populated areas. The recording was made using a frequency-selective seismic station. A method is described for obtaining optimally reliable average spectra by means of an analysis specially developed for this purpose and multiple microtremor recordings at the same observation point.

● **3.2-17** Tsuchida, H. and Kurata, E., **Observation of earthquake response of ground with horizontal and vertical seismometer arrays,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 118, 137–144. (For a full bibliographic citation see Abstract No. 1.2-9.)

A horizontal seismometer array having six observation points along a straight line of 2500 m length has been established at the Tokyo International Airport. Each observation point is equipped with two horizontal seismometers. Downhole seismometer arrays have also been established at two points, one at an end of the observation line and the other at a point 500 m inside the other end of the line. The observations started in Apr. 1974 and 28 earthquakes had been recorded as of June 1975. Correlations among the ground motions at the points on the ground surface and the two points in the ground where the downhole seismometers have been installed are studied. The relative displacements between the points are also studied.

● **3.2-18** Tanaka, T. and Yoshizawa, S., **Vibrational characteristics of the ground as derived from strong motion earthquake records** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 121, 161–168. (For a full bibliographic citation see Abstract No. 1.2-9.)

Spectra of earthquake ground motion generally vary considerably with different earthquakes. However, the average of the spectra for many earthquakes at a site is considered to show the vibrational characteristics of the ground. The spectrum of the incident waves to the bedrock can be computed by taking the ratio and the average of each spectrum. The Fourier acceleration spectra of 113 components of the strong-motion records from 35 earthquakes were investigated from this point of view.

● **3.2-19** Inaba, S. and Kinoshita, S., **Analysis and synthesis of the strong earthquake wave based on the digital filtering method** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper

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

No. 131, 241–248. (For a full bibliographic citation see Abstract No. 1.2-9.)

In this paper, we discuss a method for synthesizing the two-dimensional strong earthquake wave. For this purpose, a filter for prediction error and an autoregressive spectrum estimation are applied to the synthesis, assumming that such a wave is a sample function from a locally stationary stochastic process. The design of a lattice-type digital filter is first described. The method is applied to data from the 1968 Tokachi-oki earthquake.

3.2-20 Kramynin, P. I. and Shteinberg, V. V., **Ground motion parameters in dense soils during strong earthquakes** (Parametry kolebaniya plotnikh gruntov pri silnykh zemletryaseniyakh, in Russian), *Voprosy inzhenernoi seismologii, 18,* 1976, 23–35.

The effect of magnitude and epicentral distance on maximal acceleration and vibration frequencies of dense soils is investigated. The effect varies in character as the epicentral distance increases due to the real dimensions of the earthquake source. The results of this work are applied to quantitative seismic zoning.

3.2-21 Rautian, T. G., **The role of the source function and medium response in the formation of seismic vibrations** (Rol funktsii ochaga i otklika sredy v skheme formirovaniya seismicheskikh kolebanii, in Russian), *Voprosy inzhenernoi seismologii, 18,* 1976, 3–14.

The formation of seismograms as output signals is considered, where the surrounding medium is regarded as the processor and the role of input signal is played by vibrations emitted from the source with periods shorter than the duration of source activity. On the basis of this scheme a method is given for the calculation of time-varying spectra of strong earthquakes from those of weak earthquakes known from observations. The analysis covers both point-like and extended sources of strong earthquakes.

● 3.2-22 Kobayashi, H., Samano, T. and Yamauchi, M., **Two-dimensional horizontal earthquake motions of ground** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 128, 217–224. (For a full bibliographic citation see Abstract No. 1.2-9.)

In this paper, the authors analyze two-dimensional horizontal earthquake ground motions using the following methods: maximum and minimum values of response spectra as a result of changing the coordinates; filtered particle orbit and two-dimensional response diagram; response ratio of principal axes of response diagram; overall response diagram.

● 3.2-23 Buyukasikoglu, S. and Shima, E., **Spectra of seismic waves in the period range from 1 to 10 seconds,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 122, 169–176. (For a full bibliographic citation see Abstract No. 1.2-9.)

The observation of seismic waves in the longer period range was carried out at Kawasaki near Tokyo. For the recordings, a velocity-type seismometer having a natural period of 5 sec was used. A Fourier analysis of the earthquake records in the period range from 1 to 10 sec was made. The magnitudes of the analyzed earthquakes were between 4.3 and 6.4. The average velocity spectrum of the earthquakes with $M \geqslant 5.5$ 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.

● 3.2-24 Toki, K., **Detection of phase velocity from strong-motion accelerograms** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 134, 265–272. (For a full bibliographic citation see Abstract No. 1.2-9.)

The present paper deals with the detection of phase velocity of seismic waves with short periods from strong-motion accelerograms. The transverse and longitudinal components of acceleration at four stations were determined from accelerograms which were recorded at each station during the San Fernando earthquake, Feb. 9, 1971.

3.2-25 Riznichenko, Yu. V. and Seyduzova, S. S., **Spectra and systems of spectra of earthquakes,** *Physics of the Solid Earth,* **12**, *3,* 1976, 170–178.

The authors consider the general principles and the actual construction of a new basic system of seismological reference data: systems of average spectra and seismograms in dependence of the magnitude of earthquakes and the distance from the focus. The main applications are physics of both the focus and a set of foci with a connection to geodynamics; investigations of structural details and properties of the earth, particularly its nonideally elastic and dissipative properties; problems of seismic risk when the intensity of tremors is expressed in parameters of engineering and physics, including the probabilistic aspect of the problem. A real example, viz., the construction the Tashkent system of average energy spectra of earthquakes, is considered.

● 3.2-26 Kubo, K. and Sato, N., **A method for obtaining reliable displacement curves from recorded earthquake motions** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 132, 249–256. (For a full bibliographic citation see Abstract No. 1.2-9.)

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

This paper presents a new method for the transformation of recorded earthquake motions to displacement curves and examines its validity by using several simultaneous records of acceleration, velocity and displacement.

● 3.2-27 Shibata, H., Toshimitsu, S. and Mochio, T., **Basic study on stochastic analysis of wave pattern of ground motions** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 133, 257–264. (For a full bibliographic citation see Abstract No. 1.2-9.)

● 3.2-28 Kamiyama, M., **Stress and strain in ground during strong earthquake**, *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 135, 273–280. (For a full bibliographic citation see Abstract No. 1.2-9.)

The author has derived an equation to calculate stress and strain produced in the ground for three conditions of wave propagation: the multiple reflection of shear waves (S-wave), Love wave and Rayleigh wave. Using this equation, the author analyzes stress and strain produced in the ground where strong earthquake motion was recorded.

● 3.2-29 Bath, M. *et al.*, **Engineering analysis of ground motion in Sweden**, *5-76*, Seismological Inst., Uppsala Univ., Uppsala, Sweden, 1976, 58.

In order to meet recent strict requirements for reliable information on seismic risk, especially in connection with the design of nuclear power plants, an effort is made to analyze ground motion (acceleration, velocity, displacement) by means of the permanent seismograph network in Sweden. Results for a number of regional events are given both in terms of Fourier spectra and response spectra. The potentialities and limitations of this approach are discussed, including a quantitative comparison of macroseismic and instrumental accelerations. The Fourier spectra have been evaluated to yield attenuation for acceleration, velocity and displacement for a series of frequency intervals. This serves as a basis for developing a regional magnitude scale and energy-magnitude relations. Finally, prediction of seismic risk based on the seismic history for Fennoscandia is investigated briefly.

● 3.2-30 **Strong motion earthquake accelerograms, digitized and plotted data: Uncorrected accelerograms - Part 1: Accelerograms 028 through 064 from the Friuli, Italy, earthquake of May 6, 1976 and aftershocks**, Commissione CNEN-ENEL per lo studio dei problemi sismici connessi con la realizzazione di impianti nucleari, Rome, July 1976, 218.

This is the first volume of a series designed to collect the data resulting from the processing of accelerograph records in the possession of the Italian Commission for Nuclear Energy (CNEN)-the Italian State Power Board (ENEL) Joint Study Commission. It is entirely devoted to the seismic events that struck an Italian region, the Friuli, in May 1976, causing several hundred casualties and the near total destruction of the inhabited areas located inside the epicentral zone.

At the time of this earthquake, the ENEL accelerographic network was in perfect working condition. Also the CNEN and ENEL mobile stations were available for immediate intervention. Of the hundreds of tremors that occurred, many were recorded by these accelerographs and a good deal of the resulting accelerograms were able to be processed.

This volume presents the uncorrected data relating to the first set of accelerograms, referring to the tremors that occurred within the first five days of the prolonged period of seismicity that affected the region. The remaining accelerograms will be dealt with in later publications.

● 3.2-31 Levy, N. A. and Mal, A. K., **Calculation of ground motion in a three-dimensional model of the 1966 Parkfield earthquake**, *Bulletin of the Seismological Society of America*, **66**, *2*, Apr. 1976, 405–423.

Near-field ground displacements are calculated from an earthquake source in a homogeneous, elastic halfspace. An analytical formulation of the problem is presented that requires no physical approximations except at the source. A model of the source is constructed by retaining the essential kinematic character of the faulting process. A computer program is developed to calculate ground motion from an assumed model of the 1966 Parkfield, California earthquake. Favorable agreement is obtained between the theoretically computed ground displacements and those derived from the recorded accelerations. The relative contributions of the body waves and surface waves to the displacement field are examined. The results indicate that a significant portion of near-field motion may consist of surface waves, especially in the vertical component of the ground motion.

● 3.2-32 Uwabe, T. and Noda, S., **Maximum ground accelerations at coasts in Tokyo Bay and Tokai district**, *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 129, 225–232. (For a full bibliographic citation see Abstract No. 1.2-9.)

In order to obtain fundamental data which will be helpful in planning countermeasures against earthquake disasters, accelerations due to expected catastrophic earthquakes were estimated at the ground surface of 223 sites around the coasts along Tokyo Bay and the Tokai district. Four strong earthquakes such as the 1923 Kanto earthquake were chosen as the models of the seismicity of these areas. Ground motions were calculated by means of the

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

multireflection theory in which strain dependent modulus and damping of the soil were considered.

According to the results, the major ports and the littorals in both districts were indicated to be in danger because of the relatively large ground acceleration and the low natural frequencies of the subsoil layer that were expected. Therefore, it is suggested that the seismic-resistant capacity of the facilities in the ports and along the coasts be reexamined so that they will remain operationable during a strong earthquake.

● 3.2-33 Ohta, Y., Kagami, H. and Kudo, K., **1- to 5-sec microtremors—Observations in Hachinohe and its importance in an interpretation of long period strong motion records (in Japanese)**, *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 123, 177–184. (For a full bibliographic citation see Abstract No. 1.2-9.)

In 1973 and in 1974 observations of long-period microtremors were carried out at Hachinohe City in Japan. The reason for surveying there was because a very large acceleration with a period of 2.5 sec was recorded in the Tokachi-oki earthquake of 1968. Points were surveyed along the coastal line from bedrock to deep soil deposits. Observed time and wind conditions are shown. Examples of the wave forms are illustrated. The spectra of each record were calculated by means of an analog-type spectrum analyzer; the results are summarized.

3.2-34 Riznichenko, Yu. V., Kondrat'yeva, T. G. and Seyduzova, S. S., **Fourier spectra and response spectra of seismic oscillations,** *Physics of the Solid Earth,* **12**, *6,* 1976, 355–361.

The Fourier spectra and the response spectra were compared for 60 accelerograms of strong motions originating from California earthquakes with magnitudes of M = 5.3–7.7 and maximum intensities rated at 7–11 units. The possibility of converting the spectra was studied. Average intensity ratios of the spectra were calculated; the deviation of the individual ratios from the average relations was estimated for various oscillation periods. As an example, the energy spectra and other Fourier spectra were derived for the main tremor of the 1966 Tashkent earthquake. Approximate response spectra were determined for various oscillations of an oscillatory system which models a building.

● 3.2-35 Hall, W. J., Mohraz, B. and Newmark, N. M., **Statistical analyses of earthquake response spectra,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 1/6, 11. (For a full bibliographic citation see Abstract No. 1.2-11.)

This work was undertaken to develop statistically valid seismic response spectra for both horizontal and vertical ground motion. The first study included 25 earthquake recording stations, of which 14 had records for all three components of motion, and was published as a joint work by the two groups making the study. This was adopted as a Regulatory Guide by the U.S. Atomic Energy Commission. Following that publication, additional studies of over 100 earthquake motion records from 56 stations were made by the authors. The results of the more recent studies indicate that some simplification, as well as a reduction in conservatism, could be made in the earlier recommendations.

The data presented give statistical parameters for median response spectra and log-normal standard deviations, from which response spectra for any probability of exceedance can be determined. The data also include studies of the effect of intensity of motion on spectral amplification factors and other statistical parameters defining ground motion, such as the median and the standard deviation of (1) the ratio of maximum ground acceleration multiplied by maximum ground displacement divided by the square of the maximum ground velocity; (2) the ratios of maximum to minimum values of motion in the horizontal directions; and (3) the relative values of maximum ground displacement, velocity, and acceleration.

Considerable attention is focused on the relative values of vertical to horizontal motion and the implications on design of the simultaneous motions in various directions.

● 3.2-36 Levy, S. and Wilkinson, J. P. D., **Generation of artificial time-histories, rich in all frequencies, from given response spectra,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 1/7, 12. (For a full bibliographic citation see Abstract No. 1.2-11.)

In order to apply the time-history method of seismic analysis, it is often desirable to generate a suitable artificial time history from a given response spectrum. The method described in this paper allows the generation of such a time-history that is also rich in all frequencies in the spectrum. The richness is achieved by choosing a large number of closely spaced frequency points such that the adjacent frequencies have their half-power points overlap. In developing an artificial time-history, it is desirable to specify the envelope and duration of the record, very often in such a manner as to reproduce the envelope property of a specific earthquake record, and such an option is available in the method described. Examples are given of the development of typical artificial time-histories from earthquake design response spectra and from floor response spectra.

● 3.2-37 Hays, W. W. *et al.*, **Guidelines for developing design earthquake response spectra,** *M-114,* U.S. Geologi-

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

cal Survey, Golden, Colorado, June 1975, 349. (NTIS Accession No. AD A012 728)

State-of-the-art information required for developing design earthquake response spectra is compiled and synthesized in a manual-like format to provide the user with general guidelines for estimating the ground motion load expected for sites of interest located throughout the United States. The information contained in this document constitutes a subset of the comprehensive body of knowledge available in the field. This subset is considered pertinent for a technical understanding of the theoretical and empirical bases currently used to develop design earthquake response spectra for use in construction.

These guidelines relate to the following analyses: (1) determination of seismicity parameters, (2) estimation of seismic attenuation functions, (3) estimation of maximum intensity of shaking, (4) estimation of ground motion response spectra, and (5) estimation of local soil amplification effects. Basic information needed to perform each analysis and to make judgments is provided. Examples are extracted from published reports dealing with the Lawrence Livermore Lab., Livermore, California; the Bellefonte Nuclear Plant, Alabama; and Veterans Administration hospitals in Charleston, South Carolina, and Bedford, Massachusetts, to demonstrate representative U.S. seismic design problems and the use of the guidelines. Extensive references are provided to enable the user to obtain additional information on specific topics of interest.

● 3.2-38 Kubo, T. and Penzien, J., **Time and frequency domain analysis of three dimensional ground motions San Fernando earthquake,** *EERC 76-6,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Mar. 1976, 234. (NTIS Accession No. PB 260 556)

Principal directions and components are generated for the strong ground motions recorded during the San Fernando earthquake of Feb. 9, 1971. Characteristics of the principal components are investigated using the moving-window technique applied in both the time and frequency domains. A nonstationary random process is defined reflecting these same characteristics in a statistical sense. A computer program for generating principal directions and components of motion, wave-form characteristics, and sample accelerograms from the nonstationary random process is listed.

● 3.2-39 Murakami, M. and Penzien, J., **Nonlinear response spectra for probabilistic seismic design and damage assessment of reinforced concrete structures,** *EERC 75-38,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Nov. 1975, 99. (NTIS Accession No. PB 259 530)

In the investigation reported herein, twenty each of five different types of artificial earthquake accelerograms were generated for computing nonlinear response spectra of five structural models representing reinforced concrete buildings. To serve as a basis for probabilistic design and damage assessment, mean values and standard deviations of ductility factors were determined for each model having a range of prescribed strength values and having a range of natural periods. Adopting the standard philosophy; i.e., only minor damage is acceptable under moderate earthquake conditions and total damage or complete failure should be avoided under severe earthquake conditions, required strength levels were investigated for each model. Selected results obtained in the overall investigation are presented and interpreted in terms of prototype behavior.

● 3.2-40 Rizzo, P. C., Shaw, D. E. and Snyder, M. D., **Vertical design response spectra for rock sites,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 1/9, 13. (For a full bibliographic citation see Abstract No. 1.2-11.)

The state of the art of nuclear plant seismic design involves the use of design response spectra together with modal analysis of a mathematical simulation of the actual structure. In an effort to describe and make available to the public methods and techniques acceptable to the USAEC Regulatory Staff for implementing specific parts of the USAEC regulations pertaining to design for natural phenomena, such as earthquakes, the USAEC published Regulatory Guide 1.60 entitled, "Design Response Spectra for Seismic Design of Nuclear Power Plants," in Oct. 1973. It emphasized that Regulatory Guides are not substitutes for regulations and compliance with them is not required. Methods and solutions different from those set out in the guides are acceptable if they provide a basis for the findings requisite to issuance of a permit by the USAEC.

The USAEC prepared Regulatory Guide 1.60 on the basis of work performed by Newmark and Blume. Whereas the work by Blume is concerned primarily with horizontal motions, the work by Newmark treats both horizontal and vertical motions. Both researchers address the question of foundation compliances in a limited fashion, i.e., accelerograms recorded on rock versus accelerograms recorded on soil, but the corresponding effect is not reflected in the Regulatory Guide. This is understandable in that it is the objective of the Regulatory Guide to be useful for sites underlain by either rock or soil deposits.

The purpose of this paper is to present the results of additional research with respect to vertical response spectra for rock sites. Whereas Newmark treats vertical motion, only three of the fourteen vertical earthquake records considered were made on rock. However, both Blume and Newmark recognized that response spectra for records made on rock are less severe than response spectra for records made on soil deposits. Further, Newmark recommends that further studies be conducted to define more clearly the effect of site characteristics.

The research reported herein is based on analyses of thirty vertical recordings made on rock or rock-like sites. All analyses and statistical interpretations are very similar to the methods used by Newmark. Each of the thirty strong-motion accelerograms was first baseline corrected following the methods of M. D. Trifunac by filtering the uncorrected accelerogram below 0.07 Hz. The baseline corrected accelerograms were then corrected for instrument response using the appropriate instrument natural periods and damping values. The corrected records were then used to compute damped response spectra at a total of 125 frequency points between 0.05 Hz and 50 Hz. Each of the individual response spectra was then normalized to peak ground motions of 1.0 g acceleration, 1.0 in./sec velocity and 1.0 in. displacement, respectively, thereby forming three normalized spectra for each record for each damping value considered. The resulting normalized spectra were then processed statistically to yield smooth design response spectra for each damping value following the methods of Newmark.

The results of this research effort indicate that vertical response spectra for rock sites should be different from those sites on soil and somewhat less severe.

● 3.2-41 Martynov, V. G. *et al.*, **Preliminary results of investigations of the earthquake spectra of the Garm region in light of the earthquake prediction problem** (Predvaritelnye rezultaty issledovaniya spektrov zemletryasenii garmskogo raiona v svete problemy prognoza silnykh zemletryasenii, in Russian), *Sbornik sovietsko-amerikanskikh rabot po prognozu zemletryasenii*, 96–139. (For a full bibliographic citation see Abstract No. 2.8–12.)

Changes with time in the spectra of weak shocks are investigated for magnitude 4 to 5 earthquakes. These changes appear in addition to a ground noise which varies a great deal. Lacking a study of the effects of the physical factors determining the spectrum of each earthquake, the correlation of these time-dependent changes with the formation of strong earthquakes is not sufficiently established. The effects on earthquake spectra of conditions at the source are analyzed.

● 3.2-42 Molnar, P. *et al.*, **Effects of wave propagation direction and the location of recording station on spectra of local earthquakes in the Garm region** (Vliyanie puti rasprostraneniya voln i mesta registratsii na chiss-spektry mestnykh zemletryasenii garmskogo raiona, in Russian), *Sbornik sovietsko-amerikanskikh rabot po prognozu zemletryasenii*, 159–170. (For a full bibliographic citation see Abstract No. 2.8–12.)

Distortion of spectra due to conditions at the recording site was investigated as follows: first, by comparison with spectra of direct waves from deep earthquakes in the Hindukush and, second, using the instantaneous coda spectra of local earthquakes. The results of both methods converge. Based on these data, a practical technique for correction of spectra is developed.

● 3.2-43 Hoshiya, M. and Katada, T., **Quantitative classification of earthquake wave by principal component analysis**, *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 265, 1059–1066. (For a full bibliographic citation see Abstract No. 1.2–9.)

● 3.2-44 Chen, C. and Lee, J. P., **Correlations of artificially generated three component time histories**, *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology*, Vol. 4, Paper K 1/8, 7. (For a full bibliographic citation see Abstract No. 1.2–11.)

In this paper the authors calculate variances and covariances of strong-motion accelerograms recorded at 104 sites using the assumption of an ergodic process. Examination of the results reveals that the majority of the covariances between the vertical and the horizontal directions are higher than those of the two randomly oriented horizontal directions. This is an indication that the vertical axis is not always one of the principal axes. The contradiction is probably caused by the assumption that all three components have the same intensity function. In reality they are not the same, hence, the direction of principal axes of ground motion in general is a function of time. Therefore, the statistically uncorrelated time histories cannot be used as a criterion. Since the nuclear power industry needs a criterion to define the correlations among the three components, this paper calculates the statistical values of the correlation coefficients from the recorded accelerograms at 104 sites of random orientation and recommends those values as the criterion of correlation among the three components.

● 3.2-45 **Strong motion earthquake accelerograms: Index volume**, *EERL 76-02*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Aug. 1976, 72.

In 1968, the California Inst. of Technology undertook a program of digitization and data processing of strong-motion accelerograms which would ensure wide dissemination of the basic data in a form convenient for use by all investigators. At the conclusion of this project, the total number of three-component accelerograms in the uniformly processed data bank was 381. The records came from 57 different earthquakes, ranging from magnitudes as small as M = 3 to the maximum M = 7.7 of the Kern County earthquake.

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

This report supplies cross-referenced index lists which facilitate the location of these earthquake records from particular earthquakes and sites. These lists and the accompanying maps also describe the location of all stations. A secondary purpose of the report is to collect in one place various corrections, addenda, and supplementary information to assist research workers in making use of the data.

For abstracts and citations of individual reports in this series, see the following volumes of the *AJEE:* Subsection 2.3, Vol. 1; Subsection 3.2, Vols. 2-5.

3.3 Artificial and Simulated Earthquake Records

● 3.3-1 Kubo, T. and Penzien, J., **Characteristics of three-dimensional ground motions, San Fernando earthquake,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings,* 35–51. (For a full bibliographic citation see Abstract No. 1.2–2.)

Using the concept of an orthogonal set of principal axes for earthquake ground motions, characteristics of the three-dimensional motions produced by the San Fernando, California, earthquake of Feb. 9, 1971, are determined. These principal axes are defined such that the corresponding variances of motions have maximum, minimum, and intermediate values and their covariances equal zero. Results of the analyses indicate a significant correlation of directions of principal axes with directions to the fault zone. It is concluded that three-dimensional ground motions which are generated artificially can be uncorrelated statistically provided the components are directed along principal axes.

3.3-2 Pergament, V. Kh., Medvedev, S. V. and Bogatskii, V. F., **Prediction of seismic ground motion velocities in explosions** (Prognoz skorostei seismicheskikh kolebanii pri vzryvakh, in Russian), *Sbornik nauchnykh trudov Magnitogorskogo gorno-metallurgicheskogo instituta, 151,* 1975, 3–22.

A technique designed for prediction of maximal ground motion velocities is presented. This technique is based on elastic soil characteristics near the explosion and at the recording site, and on the investigation of velocity damping characteristics as a function of corrected epicentral distance. The concept of equivalent corrected epicentral distance is employed as a generalized variable. It incorporates all charges and distances as well as the linear dimensions of the instantly exploded mass and its orientation relative to the direction of observations.

● 3.3-3 Gasparini, D. and Vanmarcke, E. H., **Simulated earthquake motions compatible with prescribed response spectra,** *R76-4,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Jan. 1976, 99.

Alternate methodologies for generation of simulated earthquakes are briefly reviewed. The method of superposition of sine waves is discussed in detail. Theoretical relationships existing between the ground acceleration spectral density function and the response spectrum are derived. The program SIMQKE, which can generate response spectrum-compatible artificial motions, is listed and explained. Properties of resultant simulated motions are presented, and their use in seismic design is discussed.

3.3-4 Rautian, T. G., Golubyatnikov, V. L. and Nikiforova, M. N., **Investigation of seismic vibration parameters and construction of synthetic seismograms for strong earthquakes** (Izuchenie kharakteristik seismicheskikh kolebanii i metodika postroeniya sinteticheskikh seismogramm silnykh zemletryasenii, in Russian), *Voprosy inzhenernoi seismologii, 18,* 1976, 15–22.

A method is presented for developing seismograms of strong earthquakes from time-dependent spectral amplitudes calculated beforehand. Statistical properties of seismic vibrations are considered and the techniques for studying time-varying spectral amplitudes of weak earthquakes in a given area are discussed. These data form the basis for developing seismograms of strong earthquakes in accordance with local conditions of seismic wave excitation and propagation.

● 3.3-5 Duarte, R. T. and Ravara, A., **Influence of soil layers in response spectra,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 3, 1975, 127–131. (For a full bibliographic citation see Abstract No. 1.2–6.)

Earthquake ground accelerations are modelled as a Gaussian stationary stochastic process, their power spectral density of acceleration being in a one-to-one correspondence with the response spectra. The transfer function of the soil layers, assumed to behave as a linear multidegree-of-freedom system, is used to find the power spectral density of acceleration in the surface from the power spectral density in the bedrock; the ratio of the corresponding response spectra defines an amplification spectrum. A brief discussion of the influence of thickness, stiffness and damping properties of the soil layers, in the light of their ability to change the gross features of response spectra, is also presented.

● 3.3-6 Ishida, K. and Osawa, Y., **Strong earthquake ground motions due to a propagating fault model considering the change of dislocation velocity-Parkfield earthquake of 1966 and Tokachi-oki earthquake of 1968** (in Japanese), *Proceedings of the Fourth Japan Earthquake*

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

Engineering Symposium-1975, Paper No. 103, 15–22. (For a full bibliographic citation see Abstract No. 1.2-9.)

The source function of a dynamic fault model, considering the change of dislocation velocity, is proposed. Theoretical earthquake ground motions calculated using Haskell's method were compared with observed ones. The recordings from two strong-motion accelerograph stations, Cholame station No. 2 during the Parkfield earthquake of June 1966, and the Hachinohe station during the Tokachi-oki earthquake of May 16, 1968, were used for this comparison.

● 3.3-7 Johnson, G. R. and Epstein, H. I., **Short duration analytic earthquake,** *Journal of the Structural Division, ASCE,* **102,** *ST5,* Proc. Paper 12109, May 1976, 993–1001.

A time-history analysis of an elastic structure subjected to an earthquake can be computationally expensive due to the complexity and time duration of the earthquake. A response spectrum analysis of the structure can also be complex because the natural frequencies and mode shapes must be obtained and then the modal responses must be added together in some probabilistic manner. Previously generated artificial earthquakes typically consist of random oscillatory motion of significant time duration. In this work, an analytic earthquake consisting of variable frequency sinusoidal motion is used. The short time duration and the smooth response spectrum of the sine sweep lead to computational efficiency. It is demonstrated that the sine sweep earthquake, applied to an elastic structure, gives results that agree with those obtained using an actual earthquake. Furthermore, by varying the parameters of the sine sweep earthquake, various design spectra can be approximated. The sine sweep earthquake is shown to give consistent modal participation and therefore a time-history analysis using this short duration analytic earthquake can be confidently employed.

3.3-8 Seyduzova, S. S., **Mathematical modeling of the energy field of seismic oscillations,** *Physics of the Solid Earth,* **12,** 9, 1976, 563–569.

It is shown how mathematical modeling of the process of change in the flux density of seismic energy generated at a focus as a function of the distance, earthquake energy class, and a number of other factors has been developed in seismological studies. Multidimensional models of energy spectra as one of the necessary steps in this development are presented. An analysis is made of these models as a function of the use of observed data. Theoretical spectra calculated according to the models are presented.

● 3.3-9 Hoshiya, M. and Chiba, T., **Physical spectrum of earthquake acceleration,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 264, 1051–1058. (For a full bibliographic citation see Abstract No. 1.2-9.)

Since earthquake ground motions are nonstationary in the amplitude and frequency domains, this study discusses a method for measuring nonstationary characteristics using a physically meaningful nonstationary spectrum and generating an artificial earthquake acceleration record with the same nonstationary characteristics as an original earthquake record.

● **3.3-10** Shaw, D. E., Rizzo, P. C. and Shukla, D. K., **Proposed guidelines for synthetic accelerogram generation methods,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 1/4, 11. (For a full bibliographic citation see Abstract No. 1.2-11.)

This paper studies currently available artificial time history generation techniques from the standpoint of various properties: (1) response spectra, (2) peak ground acceleration, (3) total duration, (4) time-dependent enveloping functions defining the rise time to strong motion, duration of significant shaking and decay of the significant shaking portion of the seismic record, (5) Fourier amplitude and phase spectra, (6) ground motion parameters and (7) apparent frequency. The aim is to provide guidelines of the time history parameters based on historic strong-motion seismic records.

Properties 1 through 4 are based predominantly on the seismotectonic features governing the site seismicity so that they will become part of the seismic design criteria for a nuclear power plant. Consequently, properties 1 through 4 present clear constraints on any technique utilized to generate artificial accelerograms in order to preserve a similarity of artificial accelerograms and physical seismic records.

Properties 5 through 7 represent characteristics of seismic time histories not readily amenable to predications resulting from seismotectonic site investigations but, nonetheless, have considerable effect on artificially generated time histories and the structural implications of any artificial time history used in seismic qualifications of nuclear power plant structures and equipment.

Due to the similarity of the zero damping pseudo-velocity response spectra to the Fourier spectra of historic strong-motion records, the similarity of the artificial time history Fourier amplitude spectra to Fourier amplitude spectra of existing strong-motion records is more or less assured by all techniques currently available for generating artificial time histories which are founded on manipulation of the frequency content of time history functions to achieve the desired response spectra. Phase spectra, however, are highly dependent upon the generation process. In discussing improvements in the authors' time history generating method, a comparison is presented of manipulating strong-motion amplitude spectra, thereby preserving the phase relationships, to the use of random number generators for assigning phase.

Ground motion parameters, property 6, have been studied by several investigators for historic recorded accelerograms and can serve as a basis for judging the acceptability of artificial time histories compared to actual physical records.

The apparent frequency of aseismic time history is an indication of the number of zero crossings which affect the cyclic seismic response of equipment and structures and can have a drastic effect on the general shape of artificial time histories. Discussions are presented of the implications of the number of zero crossings present in seismic accelerograms on phenomena such as fatigue evaluations and the evaluation of liquefaction potential.

3.4 Seismic Zoning

3.4-1 Bune, V. M., **Fundamental problems of instrumental investigations in seismic microzoning** (Osnovnye zadachi instrumentalnykh issledovanii pri seismicheskom mikroraionirovanii, in Russian), *Seismicheskoe mikroraionirovanie v usloviyakh vechnoi merzloty,* NAUKA, Novosibirsk, 1975, 27–34.

The tasks of instrumental investigations are formulated as follows: a temporary network of recording stations is to be constructed with soil conditions at the sites varying sufficiently in order to obtain initial data for synthetic accelerograms and spectral characteristics. A comparison of recordings on the soil surface with those at a depth of 10–15 m can be especially useful. Detailed surveys must be carried out to determine P and S wave velocities in the upper layers and the thickness of layers with various wave velocity and damping characteristics.

3.4-2 **The acoustic stiffness method** (Metod akusticheskikh zhestkostei, in Russian), *Seismicheskoe mikroraionirovanie v usloviyakh vechnoi merzloty,* NAUKA, Novosibirsk, 1975, 34–43.

The acoustic stiffness method in seismic microzoning is based on the experimentally established correlation between seismic intensities and the acoustic stiffness of soils, the depth of ground water and the thickness of the porous soil layer. A technique for calculating seismic intensity increments for thawed and frozen soils by the acoustic stiffness method is described. Velocity distribution in permafrost soils is discussed. According to acoustic stiffness, soils fall into four groups: excellent—monolithic rock, favorable—gravel and fragmented bedrock, unfavorable—silt and loam with high ice content, unsuitable—thawed Quaternary deposits.

The seismic properties of permafrost Quaternary deposits are similar to those of bedrock. Seismic intensity increments calculated from acoustic stiffness are in good agreement with those obtained from earthquake records. Resonance periods given by the acoustic stiffness method are always smaller than those obtained from earthquake records.

3.4-3 **The amplitude-frequency method of seismic microzoning from recordings of weak and remote earthquakes** (Amplitudno-chastotnyi metod seismicheskogo mikroraionirovaniya s ispolzovaniem zapisei slabykh i udalennykh zemletryasenii, in Russian), *Seismicheskoe mikroraionirovanie v usloviyakh vechnoi merzloty,* NAUKA, Novosibirsk, 1975, 43–59.

The following topics are discussed: the error in calculating parameters of the seismic recording apparatus in field conditions, observation techniques, processing of records, spectral characteristics of earthquakes and the effects of soil conditions on vibration spectra. A sharp increase in seismic effects is found when the volume of thawed ground is comparatively small. Thin layers of frozen soil with thickness up to 9 m lying over thawed ground have no substantial effect on vibration amplitudes. The seismic response of thick layers of well-frozen porous soils is similar to that of rock. Vibration amplitudes and the shape of spectral curves depend, in general, on the thickness of the frozen stratum and on the angle of incidence of the seismic wave at the boundary between the soil and the rock base. The soil temperature affects both acoustic stiffness and vibration amplitudes. The shapes of spectral curves for thawed and frozen soils differ substantially.

3.4-4 Pavlenov, V. A. and Pavlov, O. V., **The amplitude-frequency method using recordings from explosions** (Amplitudno-chastotnyi metod s ispolzovaniem zapisei vzryrov, in Russian), *Seismicheskoe mikroraionirovanie v usloviyakh vechnoi merzloty,* NAUKA, Novosibirsk, 1975, 59–69.

Seismic response of permafrost soils is investigated using explosions. The following types of soils are considered: (1) frozen rock, (2) coarsely fragmented, with temperatures below -4°C, (3) frozen gravel, with temperatures below -4°C, (4) frozen gravel with loam layers, (5) one of the above types with temperatures between 0° and -1°, (6) zones of thawed ground surrounded by permafrost strata.

Results from explosions are compared to data obtained by other methods. Seismic microzoning by means of explosions requires far smaller amounts of time and expenditure compared to earthquake observations. Recording spectra at

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

a given location depend on three factors: the medium in which the explosion takes place; the depth of change; the size of the change. If these parameters are kept fixed, then the stability of recordings is fairly good.

● **3.4-5** Stojkovic, M., **Seismic microzoning of Banja Luka urban area,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 6, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

The urban area of Banja Luka having about 80,000 inhabitants was affected by a strong earthquake on Oct. 27, 1969. The epicenter of the earthquake was 9 km to the north of the city center, the hypocenter was at 25 km depth and the magnitude was 6.6. Twelve people were killed by the earthquake. Most buildings were severely damaged, a small number partially failed and some collapsed completely. The macroseismic intensity in town was from 6 to 9 degrees (MSK-64). Such a wide range can be explained only by the influence of the soil conditions. Therefore, it was required that the new urban plan of repair and construction take into account the seismic soil conditions.

Seismic microzoning was carried out in order to obtain the seismic parameters necessary for planning and design of earthquake-resistant structures. Many seismological investigations were conducted. The most important results of these investigations, examinations of the earthquake effects on the urban area, and the seismic microzoning procedure are presented in this paper.

3.4-6 **Seismic zoning of the Yakut A.S.S.R. and neighboring territories** (Seismicheskoe raionirovanie Yakutii i sopredelnykh territorii, in Russian), Akademiya Nauk SSSR, Yakutsk, 1975, 91.

In this volume seismological, geophysical, geological and neotectonic seismicity criteria are presented on the basis of the most recent data. The seismic zoning of the Yakut A.S.S.R. and neighboring territories is carried out. The articles are accompanied by maps showing earthquake epicenters, location of seismic activity, maximal expected earthquakes, geological and geophysical criteria for seismicity, neotectonics and seismic zoning.

● **3.4-7** Shah, H. C. *et al.,* **A study of seismic risk for Nicaragua, Part II, Commentary,** *12A,* The John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, Mar. 1976, 268.

This document is the second and final report on the study of seismic risk for Nicaragua. It provides detailed discussions on the development of seismic hazard maps, damage prediction and insurance risk, a design methodology and a summary of the design methodology development. See Abstract No. 7.1-13 for a summary of the methodology and the results of the proposed design procedure.

● **3.4-8** Hsu, M.-T., **On the degree of earthquake risk in Taiwan,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 108, 59-64. (For a full bibliographic citation see Abstract No. 1.2-9.)

A seismic zoning map for Taiwan is presented. The map is based on the seismic record of the Central Weather Bureau during the past one hundred years. The expected maximum earthquake acceleration for 50, 75 and 100 years and the expected maximum intensity are shown.

3.4-9 Ershov, I. A., **Comparison of macroseismic and seismic microzoning data for the town of Makhachkala** (Sopostavlenie makroseismicheskikh dannykh i dannykh seismicheskogo mikroraionirovaniya po g. Makhachkale, in Russian), *Voprosy inzhenernoi seismologii, 18,* 1976, 75-83.

Macroseismic estimates of intensity modifications and estimates obtained from instrumental seismic microzoning are compared for the towns of Petropavlovsk-Kamchatskii and Makhachkala. Unified estimates are compared with estimates obtained from separate procedures.

● **3.4-10** Karnik, V., **Seismic zoning of the Balkan region,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 3, 1975, 55-66. (For a full bibliographic citation see Abstract No. 1.2-6.)

Seismic zoning of the Balkan region was one of the aims of the UNESCO/UNDP project. The resulting maps which can be used for zoning are epicenter map, maximum-expected intensity for return periods T = 50, 100, 200, 500 and infinity years, maps of expected acceleration and particle velocity with 70% probability of not being exceeded in 25 or 200 years. The methods and results are briefly discussed.

● **3.4-11** Steinwachs, M., **Seismic microzoning in areas of nuclear power plants,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 106, 39-49. (For a full bibliographic citation see Abstract No. 1.2-9.)

Seismic data in the form of time histories and response spectra are used in designing nuclear power plants which are secure from effects of earthquakes. In Europe and USA standardized data are used because for most nuclear power plant locations there are no strong-motion records available. Not considered in the standardized data are generally the filter effects of near-surface geologic layers on earthquake waves. The filter effects can result in selective amplification or attenuation of the earthquake waves.

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

Using the method of microzoning, the soil amplification at a particular location can be estimated by means of recordings of explosions, microearthquakes, or microseismic noise. The author considers the "noise method" particularly suitable because of the great range of frequencies and the natural occurrence of microseismic noise.

The application of the noise method requires exact study of the noise at the location relative to the position of the noise sources and its dominant frequencies. Procedures and examples are given for studying the isotropic and stationary properties of the noise.

The limits of applicability of the method are determined by the location of the area in which the microzoning is to be carried out. The noise method is unsuitable in municipal areas where there are difficult-to-identify microseismic sources such as automobile traffic. However, since nuclear power plants are generally located outside of municipal areas, the method is readily usable. Nevertheless, the necessary registration of microseismic noise at the site must be made before construction work begins.

● 3.4-12 **Active fault mapping and evaluation program, ten year program to implement Alquist-Priolo Special Studies Zones Act,** *Special Publication 47,* Dept. of Conservation, California Div. of Mines and Geology, Sacramento, 1976, 42.

This report is in response to the California legislative analyst and the legislature's requests for the Div. of Mines and Geology's plan defining the scope and priorities of its program of active fault mapping, as established by the Alquist-Priolo Special Studies Zones Act of 1972. This report, which was presented to the California legislature on Dec. 1, 1975, is the requested plan, including objectives, policies, funding levels, fault traces to be mapped, priorities and completion dates. This report also presents important background data on what geologists know—and don't know— about faults, about the Alquist-Priolo Act, and some of the problems and experiences met in the three years of administering it.

● 3.4-13 Shah, H. C., Movassate, M. and Zsutty, T. C., **Seismic risk analysis for California State Water Project, Reach C,** 22, The John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, Mar. 1976, 111.

A seismic hazard map for the region described as "Reach C" for the California Water Project is developed in this report. Reach C is defined as that portion of the California Water Project from Tehachapi afterbay up to and including the Perris Dam and Lake. The key facilities within this reach include Tehachapi afterbay, Cottonwood power plant site, Pearblossom pumping plant, Mojave siphon, Silverwood Dam and Lake, San Bernardino Tunnel, Devil Canyon power plant, Santa Ana Valley pipeline, Perris Dam and Lake and Perris O & M Subcenter.

The report discusses the data base, the seismic sources considered and the resulting iso-acceleration maps. Relative risks of various sites and their implications are presented.

3.5 Influence of Geology and Soils on Ground Motion

● 3.5-1 Kogan, L. A. and Giller, V. G., **Effects of soil conditions during earthquakes,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 21, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

In this paper, it is shown that ground motions of a layer of soil 10 m thick or less generated by weak earthquakes are the same as those of underlying layers; that increases in ground motion amplitudes are determined by resonant properties of soils; that 6 m thick layers of dry loess-like loam do not change the amplitude and frequency composition of underlying saturated loam strata; and that saturated soil motion amplitudes are approximately twice as high as those of dry soil.

● 3.5-2 Arnold, P., Vanmarcke, E. H. and Gazetas, G., **Frequency content of ground motions during the 1971 San Fernando earthquake,** *R76-3,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Jan. 1976, 74.

Description of the site ground motion is an important step in the process of designing a structure subject to strong earthquake ground shaking. Both the intensity and frequency content of ground motions are important in the evaluation of structural response. As a part of an overall effort to demonstrate the application of random vibration analysis to evaluate structural response to earthquake excitation, measurements made during the San Fernando, California, earthquake of 1971 have been used to study extensively ground motion characteristics. The estimated power spectral density function is used as the primary tool for studying ground motion characteristics, but comparisons based on peak acceleration, peak velocity, the ratio of peak values of velocity and acceleration, and selected response spectral values are also briefly reviewed. Observations are made on the variations in ground motion characteristics, followed by a tentative examination of the possible causes of these variations. In particular, the distance and direction from the source (azimuth) and the characteristics of local soil conditions are identified as factors which exert a potentially major influence on the characteristics of ground motions. The effects of both local soil conditions and profile direction are found to have an important influence on the ground motion characteristics.

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

● 3.5-3 Mohraz, B., **A study of earthquake response spectra for different geological conditions**, Civil and Mechanical Engineering Dept., Inst. of Technology, Southern Methodist Univ., Dallas, Aug. 1975, 43.

The objective of this study is to examine the effects of geological conditions on ground motion, response spectra, and response amplifications. Results from statistical studies are presented and design spectra are given and compared for four site conditions; namely, alluvium deposits, rock deposits, deposits of less than approximately 30 ft of alluvium, and deposits of approximately 30–200 ft of alluvium both underlain by firm soil deposits. The latter two categories were selected primarily because those deposits provide intermediate cases between alluvium and rock and because substantial earthquake records from stations located on such deposits are available. The results are presented for both horizontal and vertical components of earthquake records and for five damping coefficients.

● 3.5-4 Toriumi, I., **Earthquake characteristics in plain** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 117, 129–136. (For a full bibliographic citation see Abstract No. 1.2–9.)

● 3.5-5 Imai, T., Fumoto, H. and Yokota, K., **The relation of mechanical properties of soils to P- and S-wave velocities in Japan** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 112, 89–96. (For a full bibliographic citation see Abstract No. 1.2–9.)

Discussed in this paper is the extent of distribution of the P- and S-wave velocities of the surface ground, alluvial, diluvial and Tertiary deposits in urban areas. The relation of the velocities to some soil mechanics index values is examined. Fairly good correlations are discernible between the S-wave velocity and the engineering properties of soils, such as the N-value of the standard penetration test or the unconfined compressive strength. A formula is obtained. As a result of examination of these data, a new interpretation is made regarding the valuation of the elasticity of soils by strain level.

● 3.5-6 Irikura, K., **Spectral characteristics of microtremors and ground structures** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 124, 185–192. (For a full bibliographic citation see Abstract No. 1.2–9.)

Earthquake motions were observed at adjacent rock and ground sites (the distance between the two sites is about 2 km), on the eastern side of Kyoto basin. Microtremors were observed in the area surrounding the observational point on the ground. Soil deposits in this area dip from the east to the west. Amplification factors of the earthquake motions on the ground were studied by comparing the spectral characteristics between motions on the ground and those at the rock site. The responses of the P and S motions on the ground are estimated to be different depending upon the direction of seismic arrivals. The frequency and amplitude characteristics of microtremors tend to vary in space with the thickness of the deposit layers.

● 3.5-7 Yokoyama, M. *et al.*, **Earthquake observation on soft ground** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 115, 113–120. (For a full bibliographic citation see Abstract No. 1.2–9.)

The authors have been conducting continuing earthquake observations on typical soft ground where thick alluvial strata have accumulated. The location of the observation site is at Urayasu in Chiba Prefecture. This is a landfill area at the river-mouth delta of the Edo River where the thickness of the alluvium is approximately 60 m. Underground seismometers are set at three points—GL -1.0 m, -7.5 m, and -66 m.

Eleven earthquakes are analyzed in this paper. As a result, distinct amplification characteristics of the surface subsoil are obtained by means of averaging power spectra and amplification ratios. These amplification characteristics have sharp peaks even at higher modes indicating that internal damping of the surface subsoil is unexpectedly small. Also, the acceleration amplitudes of observation results increase suddenly near the surface of the ground, and this is thought to be due to the filled soil at the upper part being so soft that earthquake waves independently show multiple reflections within the layer. This, along with the small damping in higher modes, is a serious condition for lower buildings and wooden houses.

Based on the travel times obtained from the observation results, a structural model of the surface subsoil is prepared and a trial comparison is made between the theoretical analysis results according to the S-wave multiple reflection theory and the amplification spectra of the observed results. As a result, the theoretical and observation values are seen to agree fairly well.

● 3.5-8 Kobayashi, H. and Nagahashi, S., **Characteristics of earthquake motion on seismic bedrock** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 127, 209–216. (For a full bibliographic citation see Abstract No. 1.2–9.)

The spectra of earthquake motions observed on the surface of layered ground can be regarded as the product of the two major factors: the spectrum of the earthquake motion on the seismic bedrock and the amplification spectrum of the ground. Using the velocity response spectra of the earthquake ground motions observed at SMAC

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

sites, the authors show by means of diagrams that spectra at the same site are similar to each other regardless of the difference of the seismic mechanism. These stationaries in the spectra at the same site can be considered as the amplification characteristics of the ground. The amplification factors of the ground, educed as the geometric mean values of the amplification spectra, are shown also.

3.5-9 Ivanova, T. G., **Time-varying spectral analysis of vibrations of a land fill** (Spektralno-vremennoi analiz kolebanii zemlyanogo zavala, in Russian), *Voprosy inzhenernoi seismologii, 18,* 1976, 62–65.

In the present article an attempt is made to study the wave pattern of vibrations in a setting characterized by complex surface topography. To this end, methods of time-varying spectral analysis are employed which can trace the development of vibration spectra.

● **3.5-10** Hakuno, M. and Inoue, R., **Effect of soft surface layer on the duration time and maximum acceleration of earthquake** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 110, 73–80. (For a full bibliographic citation see Abstract No. 1.2-9.)

● **3.5-11** Sima, H., **On influence of underground structure on seismic wave spectra** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 125, 193–200. (For a full bibliographic citation see Abstract No. 1.2-9.)

Seismic wave spectra are examined to determine the influence of the underground structure from observations on the surface and at a depth of 17 m below the surface. Soil conditions at the recording site consist of clay 9 m thick, underlain by a layer of sandy gravel in which thin clay is included at depths of 16–18 m and 40 m. Other boring observations show a boundary at a depth of about 70 m. From analysis of microtremors, predominant periods at this site are found to be 0.16 sec, 0.29 sec, 0.77 sec, and 1.0–1.3 sec, which correspond to the above-mentioned soil characteristics.

● **3.5-12** Duke, C. M. *et al.,* **Effects of site on ground motion in the San Fernando earthquake,** *UCLA-ENG-7688,* School of Engineering and Applied Science, Univ. of California, Los Angeles, Aug. 1976, 44.

Records obtained at basement and free-field accelerograph stations which recorded the San Fernando, California, earthquake of Feb. 9, 1971, were compared with geological and geophysical site data, particularly shear wave velocity profiles. Geophysical surveys were made at 47 accelerograph sites to determine the velocity profiles to about 70 ft in depth. Both peak particle velocity and Arias instrumental intensity were found to have statistically significant dependence upon the mean shear wave velocity and the rate at which it increased with depth.

● **3.5-13** Borcherdt, R. D. and Gibbs, J. F., **Effects of local geological conditions in the San Francisco Bay region on ground motions and the intensities of the 1906 earthquake,** *Bulletin of the Seismological Society of America,* **66,** 2, Apr. 1976, 467–500.

Measurements of ground motion generated by nuclear explosions in Nevada have been completed for 99 locations in the San Francisco Bay region, California. The recordings show marked amplitude variations in the frequency band 0.25 to 3.0 Hz that are consistently related to the local geological conditions of the recording site. The average spectral amplifications observed for vertical and horizontal ground motions are, respectively: (1, 1) for granite, (1.5, 1.6) for the Franciscan formation, (3.0, 2.7) for the Santa Clara formation, (3.3, 4.4) for alluvium, and (3.7, 11.3) for bay mud. Spectral amplification curves define predominant ground frequencies in the band 0.25 to 3.0 Hz for bay mud sites and for some alluvial sites. Amplitude spectra computed from recordings of seismic background noise at 50 sites do not generally define predominant ground frequencies.

The intensities ascribed to various sites in the San Francisco Bay region for the California earthquake of Apr. 18, 1906, are strongly dependent on distance from the zone of surface faulting and the geological character of the ground. Considering only those sites (approximately one square city block in size) for which there is good evidence for the degree of ascribed intensity, the intensities for 917 sites on Franciscan rocks generally decrease with the logarithm of distance as: Intensity = 2.69–1.90 log (distance in kilometers). For sites on other geological units, intensity increments, derived from this empirical relation, correlate strongly with the Average Horizontal Spectral Amplifications (AHSA) according to the empirical relation: Intensity Increment = 0.27 + 2.70 log (AHSA).

Average intensity increments predicted for the various geological units are -0.3 for granite, 0.2 for the Franciscan formation, 0.6 for the Great Valley sequence, 0.8 for the Santa Clara formation, 1.3 for alluvium, and 2.4 for bay mud. The maximum intensity map predicted on the basis of these data delineates areas in the San Francisco Bay region of potentially high intensity for large earthquakes on either the San Andreas fault or the Hayward fault. The map provides a crude form of seismic zonation for the region and may be useful for certain general types of land-use zonation.

● **3.5-14** Arai, H., Kitajima, S. and Saito, S., **Underground earthquake motions in ports and harbours** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering*

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

Symposium-1975, Paper No. 116, 121–128. (For a full bibliographic citation see Abstract No. 1.2–9.)

Earthquake motions in soil layers were observed as a result of bore-hole seismometer installations at the ports of Tokyo, Funabashi, Nagoya, Osaka and Kurihama. The records of the seismometers are proportional to the accelerations of the earthquake motions. The records of the motions at the top of the layers (accelerations from 7.4 to 60.9 gals) were analyzed. The records indicate that the main motions travel vertically in the soil layers and are amplified in particular in the upper part of the layers. The effects of the characteristics of the earthquakes and the vibrational property of the soil layer on the Fourier amplitude spectra were investigated. The shapes of the motions in the soil layers were computed from the shapes of the motions recorded at the tops of the layers by the theory of the multiple reflections of vertically traveling S-waves.

● 3.5–15 Chang, F. K., **An empirical interpretation of the effects of topography on ground motion of the San Fernando, California, earthquake, 9 February 1971,** *Miscellaneous Paper S-76-1,* Soils and Pavements Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Mar. 1976, 35.

The objectives of this study were to determine site effects on earthquake ground motion and the correlation between acceleration and/or velocity generated during the San Fernando earthquake of Feb. 9, 1971, and topography of the San Gabriel Mountain range. A literature review of the effects of topography on ground motion directly related to this earthquake is included. It was found that the contours of peak acceleration and peak velocity generally follow the topography of the San Gabriel Mountain range. The topographical effects on the ground motion could be interpreted in a simple manner as a function of elevation and direction of wave transmission path. The elevation and direction become the dominant factors in the distribution of the ground motion in the near field. A simple, practical method for calculating the bedrock motion using the ground motion-elevation gradient has been applied in the area south of Kagel Mountain and north of Santa Monica Mountain, in the San Fernando Valley. This method is validated using aftershock data. This ground motion-elevation gradient method was applied to an area where the topography has its highest elevation at the epicentral region and decreases in elevation to the surrounding locations in the near field (within 30 km). In any case, when the epicenter occurs at an elevation lower than the elevation of the surrounding area, this gradient method may not be applicable and must be tested for this alternate condition. Accelerations recorded in the rock were higher than those recorded in the alluvium as might be expected, but the integrated displacements from the acceleration were indicated in an opposite direction for alluvium. The integrated velocities did not follow a definite trend.

3.5–16 Ilyasov, B. I. and Saidova, Sh. Sh., **Investigation of the effect of surface topography on ground motion during earthquakes** (Issledovanie vliyaniya relefa mestnosti na kolebaniya gruntov pri zemletryaseniyakh, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 227–228. (For a full bibliographic citation see Abstract No. 1.1–7.)

Results of investigations of the effect of surface topography on ground motion intensity during earthquakes are reported.

● 3.5–17 Tsugawa, T. *et al.*, **Simulation analysis for earthquake behavior in deep alluvial soil** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 114, 105–112. (For a full bibliographic citation see Abstract No. 1.2–9.)

Urayasu is a landfill area located in the northeastern part of Tokyo Bay. The surface layer of the ground is reclaimed soil or fine sand of 15 m thickness. The second layer is silt or clay of 25 m or more. Residential or commercial buildings are expected to be built on the site in the future. Since the fall of 1973, the authors have been conducting earthquake observations in this area. By using three accelerometers installed at 0.5, 15 and 41.4 m below the surface, several earthquake records were obtained. After examination of the records, it was noted that the surface and intermediate layers tended to be excited with predominant periods of 1.0 and 0.3 sec, respectively, while motions of the diluvium were likely to be white noises. Amplification ratios of acceleration by the alluvial layers were estimated at less than 3.8.

If subsoil earthquake accelerations could be accurately reproduced by computerized methods, it would be possible to develop an earthquake response analysis of buildings considering soil-foundation interaction. This paper describes simulation studies conducted on models of alluvial layers. Based on the data of standard penetration tests, dynamic triaxial tests and a wave propagation survey, a lumped-mass model fixed at 41.4 m under the surface was established. Its predominant periods and mode shapes corresponded to recorded ones.

Damping characteristics were discussed as parameters for simulation. A good combination of damping factors for each mode resulted from many trials. The factors are 7%, 3% and 1% for respective fundamental modes. These damping factors were large and different from those determined using conventional damping theory. Slight modification of the model was necessary without changing the damping effects in each mode. It is concluded that a modified model must have a dashpot at the level of the input earthquake. The dashpot would provide a large amount of dissipating damping of the soil layers during earthquake motion.

3.6 Seismic Site Surveys

● **3.6-1** Lu, B. T. D., Fischer, J. A. and Peir, J., **Effects of earthquake input in seismic responses of nuclear power plant sites,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 883–897. (For a full bibliographic citation see Abstract No. 1.2–7.)

In order to demonstrate the site-dependency effect in a seismic response evaluation and to develop an understanding of the degree of conservatism inherent in utilizing seismic input based only upon NRC's Regulatory Guide 1.60, a series of one-dimensional seismic response evaluations were performed for the soil conditions at a nuclear power plant site, using a one-dimensional strain compatible shear wave propagation theory. Thirty-three earthquake records, as well as the artificial time history generated in accordance with Regulatory Guide 1.60, were used as input in the response analyses.

The results of this study indicate that the use of seismic input obtained from Regulatory Guide 1.60 can be overly conservative in defining the seismic design parameter evaluation for a nuclear power plant site. In the seismic evaluation of a specific site, it is more appropriate to utilize various earthquake time histories recorded at similar site conditions as input.

● **3.6-2** Gurpinar, A., **Seismic risk analysis of nuclear power plant sites including power spectrum simulation of future earthquake motion,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 913–926. (For a full bibliographic citation see Abstract No. 1.2–7.)

Seismic risk analysis of possible nuclear power plant sites may in some cases be the deciding factor in the site selection process. This article includes the results of a case study for two such sites in northwestern Turkey, as well as a proposition for a more efficient risk analysis format.

In the case study, site A was found to have higher bedrock peak acceleration risks than site B; but on the other hand, site B had local soil conditions which amplified oncoming wave acceleration by about 2.5 on the average. For site A, there was no amplification. An amplification study was carried out using a power spectrum simulation which assumes a band limited white noise spectral density function for the bedrock acceleration. This average amplification of 2.5 was incorporated in seismic risk curves.

Noting the deficiencies of some current methods of seismic risk analysis, the author proposes a new format for this purpose. The proposal suggests the use of the root mean square value of velocity instead of peak acceleration and includes the effects of angle of incidence O, P-wave velocity power spectrum and vertical motion. It is also pointed out that the method enables the risk analyst and the structural design engineer to work together with more cooperation and greater efficiency.

● **3.6-3** Lou, Y. S., Dixon, S. J. and MacFadyen, C. R., **Site response analysis for earthquake loading,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1109–1122. (For a full bibliographic citation see Abstract No. 1.2–7.)

Several methods for evaluating the site response during earthquakes are presently available. Most of these methods are based on the assumption that the site response is induced by the upward propagation of shear waves from the underlying bedrock. However, the question of how accurate these methods can predict the site response has not yet been substantiated by using actual recorded bedrock and surface motions for comparison.

A site response study was performed using actual records of bedrock and surface motions from the San Fernando earthquake, 1971. The shear wave propagation technique developed by Schnabel, Lysmer and Seed was used in the site response calculation. The result of this study indicates that this technique does predict a different site response from those motions actually recorded. However, the technique is still a valuable tool in site response analysis. It is also concluded that engineering experience and judgment are still important factors in evaluating site response under earthquake loadings.

● **3.6-4** Ballard, Jr., R. F. and McLean, F. G., **Seismic field methods for in situ moduli,** *Misc. Paper S-75-10,* Soils and Pavements Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Apr. 1975, 39.

The design and evaluation of the response of engineered structures to earthquake excitation have increased the current use of seismic field studies to determine soil properties at low strain levels for in situ materials. These studies use the finite element technique and modal or time-step analysis. Their validity and the interpretation of their results depend on a reliable assessment of input values for in situ foundation properties. This report presents procedures for planning seismic field investigations for the determination of soil properties. Emphasis is placed on the selection of appropriate seismic techniques to obtain sufficient redundant data with which to establish internal consistency for reliable assessments of determined properties. A summary of various available methods, as well as recent innovations in equipment and procedures, is presented. Comparisons of data derived from different types of tests are shown, and case histories are presented. Interpretive techniques are reviewed, with special attention to those factors which influence the reliable determination of soil moduli.

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

● **3.6-5** Hannon, W. J. and McKague, H. L., **An examination of the geology and seismology associated with Area 410 at the Nevada Test Site,** *UCRL-51830,* Lawrence Livermore Lab., Univ. of California, Livermore, May 23, 1975, 30.

This report summarizes regional and local geology at the Nevada Test Site and identifies major tectonic features and active faults. Sufficient information is given to perform seismic safety analyses of present and future critical construction at the Super Kukla Site and Sites A and B in Area 410. However, examination of local minor faults and joints and soil thickness studies should be undertaken at construction time. The Cane Spring fault is identified as the most significant geologic feature from the viewpoint of the potential seismic risk. Predictions of the peak ground acceleration (0.9g), the response spectra for the "safe shutdown earthquake" and the maximum displacement across the Cane Spring fault are made.

● **3.6-6** Hays, W. W., **Evaluation of the seismic response in the Sylmar-San Fernando area, California, from the 1971 San Fernando earthquake,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 502–511. (For a full bibliographic citation see Abstract No. 1.2–8.)

The purpose of this paper is to describe the estimated response spectra of ground motion for sites in the Sylmar-San Fernando area which sustained damage but did not record the magnitude 6.4, Feb. 9, 1971, San Fernando earthquake.

● **3.6-7** Lou, Y. S., Dixon, S. J. and MacFadyen, C. R., **A case study of site response,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 512–522. (For a full bibliographic citation see Abstract No. 1.2–8.)

Using recorded bedrock and ground surface motions, the author compares the accuracy of one method for evaluating the site response during earthquakes. The strongest aftershock (magnitude: 4.9, 3/31/71) which occurred at the Joseph Jensen Filtration Plant near Sylmar, California, following the 1971 San Fernando earthquake was used for this study.

3.6-8 Ratnikova, L. I. *et al.*, **Seismic risk analysis for the region of a power plant construction site** (Otsenka seismicheskoi opasnosti raiona stroitelstva elektrostantsii, in Russian), *Voprosy inzhenernoi seismologii, 18,* 1976, 41–61.

Focal zones of strong earthquakes in central and southern Armenia are outlined and the probable depth and frequency of earthquakes is determined on the basis of a combined analysis of seismic and tectonic data. Ground motion accelerograms of a power plant construction site are analyzed for potential strong earthquakes in the region considered.

● **3.6-9** Grandori, G., **Balanced seismic coefficients for sites with different seismicity,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 3, 1975, 69–77. (For a full bibliographic citation see Abstract No. 1.2–6.)

A method is presented for the comparison of sites with different levels of seismicity. The method attempts to bring a degree of uniformity to the way in which the level of protection in different sites is chosen. The basic concept of the method is the "marginal cost of a saved life." In order to obtain uniform protection at various sites, the principle should be adopted that the seismic design coefficients at all sites have the same marginal cost of a saved life. An application of the method to a seismic area in Italy is shown. The final result is a map with the contour lines of the seismic design coefficients (C) shown. For the most seismic site of the area the value C = 0.1 is chosen.

● **3.6-10** Yoshikawa, S., Iwasaki, Y. and Ishii, E., **A probabilistic approach to estimate damage potential design earthquakes for a site in terms of magnitude, epicentral distance and return period** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 105, 31–38. (For a full bibliographic citation see Abstract No. 1.2–9.)

The authors describe a method for obtaining a design earthquake in terms of magnitude, epicentral distance and return period based on historical and recently observed earthquake data. Gumbel's model is used to simulate the occurrence of the maximum magnitude earthquake within a given time and a given epicentral distance.

As an example, a design earthquake for the Osaka area was studied. The result using historical earthquake data shows approximately the same tendency of occurrence but a much longer return period than that found using recently observed data. The design earthquake was obtained using a combination of both results, with weight added because of the limitation of extrapolation of the method and the present tendency of seismicity represented by the recently observed earthquake data.

The method is useful when the design earthquake for a site considers not only maximum acceleration but also various ground motion characteristics such as frequency and duration.

● **3.6-11** Taleb-Agha, G. and Whitman, R. V., **Seismic risk analysis of discrete systems,** *MIT-CE R75-48,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Dec. 1975, 77.

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

Two efficient schemes have been developed for the analysis of systems of discrete sites. Both schemes have the same objective of finding the probability of simultaneous failure of any number of sites belonging to a given system of sites subject to threats from a given set of earthquake sources with known seismic history. In the first scheme, systems with deterministic site resistances can effectively be analyzed using a nonlinear transformation of variables. In the second scheme, systems with random site resistances can be analyzed. To overcome the computational difficulties involved in the analysis, a new set of simple recursive formulas has been developed and used effectively. Based on these two schemes, two efficient computer programs were prepared and used to perform a parametric study on a system of nine actual or contemplated nuclear power plants in New England. The results have shown that the problem is very sensitive to the coefficient of variation of the resistances and not so sensitive to the mean resistances.

● 3.6-12 Slemmons, D. B., **Fault activity and seismicity near the Los Alamos Scientific Laboratory geothermal test site, Jemez Mountains, New Mexico,** *LA-5911-MS,* Los Alamos Scientific Lab., Univ. of California, Los Alamos, New Mexico, Apr. 1975, 26.

The purpose of this study is to develop guidelines for evaluating geothermal sites for earthquake hazards and for the possibility of siting on an active fault. These guidelines were used to minimize these risks for a specific geothermal test site of the Los Alamos Scientific Lab. on the Jemez Plateau, a few miles west of the Valles Caldera, at the center of the Jemez Mountains in north-central New Mexico.

The approach to the problem involves new methods of low-sun-angle aerial photography and photogeology, in combination with conventional geological and seismicity studies. The possibility of future surface faulting or occurrence of strong local earthquakes is analyzed by comparing the structural and seismic setting of the area of investigation with that of the Rio Grande depression and other active zones in the western United States. The evaluation includes identification, delineation and characterization of faults in the region with conventional high-sun-angle aerial photographs, special low-sun-angle aerial photographs taken specifically for this project, Earth Resources Technology Satellite imagery, manned space satellite photography, search of the geological literature, and aerial and ground reconnaissance using both low and high sun angles of illumination at midday, early morning, and late afternoon.

The site area is near the western edge of the Rio Grande depression, the most active seismic zone of New Mexico. The Rio Grande depression is marked in places by geologically youthful fault scarps and in places is known to have significant normal faults. The very low seismic risk is indicated not only by the low level of fault activity, but also by the low level of earthquake activity for New Mexico, the low level of activity in the Rio Grande structural depression (the most important fault zone in New Mexico), the general lack of any earthquakes of Richter magnitudes above 6, and the very sparse distribution of microearthquakes in the Jemez Mountains.

● 3.6-13 **Seismicity, geology and design earthquake report for South Haiwee Dam, Inyo County, California,** Lindvall, Richter & Assoc., Los Angeles, June 1976, 58.

● 3.6-14 Thorpe, R. K. and Wight, L. H., **A geological and seismological investigation for the 834, 836, and 854 building complexes at LLL's site 300,** *UCRL-52006,* Lawrence Livermore Lab., Univ. of California, Livermore, Jan. 29, 1976, 41.

This report reviews the regional and local geology for Site 300, the high-explosive test site of the Lawrence Livermore Lab. The site is located approximately 18 km east of Livermore, near several major active faults. The seismic hazard associated with these faults is evaluated for several areas within Site 300. An acceleration response spectrum with a free-field peak surface acceleration of 0.8 g characterizes this hazard. Differential surface faulting and seismically induced liquefaction present no hazard at any of these areas, although slope stability requires future investigation at one area.

● 3.6-15 Ishihara, K. *et al.,* **Response analysis of a reclaimed deposit during earthquakes** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 154, 423-430. (For a full bibliographic citation see Abstract No. 1.2-9.)

In order to investigate the site characteristics of a steel manufacturing yard, four sets of accelerometers were buried in drilled holes at depths of 8, 25 and 50m, as well as on the ground surface. Four records were obtained of small earthquakes that occurred south and east of Tokyo.

In addition, a seismic survey was conducted near the site of the observation to determine the soil profile and insitu soil properties to be used in the response analysis. Undisturbed samples of cohesive soils were also secured by means of thin-wall samplers and tested in a triaxial test apparatus to determine strain-dependent shear moduli and damping ratios.

Using the soil properties thus estimated, a response analysis was made based on the wave propagation method. The accelerations at depth 50m recorded during the two recent earthquakes were used as input base motions and the accelerations at depths 8m, 25m and on the ground surface were computed. The computed motions were compared with the recorded motions in terms of acceleration response spectrum, with the result that both compare favor-

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

ably. It was shown in particular that the predominant period of motion increases from 0.7 sec at the base up to about 1.0 sec on the surface, reflecting the response characteristics of soft soils existing in the top layer.

● **3.6-16** Costantino, C. J., Miller, C. A. and Lufrano, L. A., **Mesh size criteria for soil amplification studies,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 2/3, 12. (For a full bibliographic citation see Abstract No. 1.2-11.)

In the seismic response analyses of structures, the finite element method is often used to determine the response of the structure. Criteria for horizontal accelerograms are usually specified at the surface of the soil overburden. Two-dimensional finite element meshes are then developed which extend from the surface to bedrock, with the structure embedded within the surface of the mesh. Input to the mesh is usually the associated horizontal accelerogram developed at the basement of the mesh, from which the structural response is calculated. The basement accelerogram, of course, is determined by convolution analysis, and then input to the mesh without the embedded structure yields as output to the original criteria surface accelerogram.

No general criteria are currently available to the analyst for selecting the finite element mesh size so as to yield sufficient accuracy in the computed responses. It is well known that the finite element solution has inadequate wave transmission capability above a certain mesh cut-off frequency, and it is this feature which leads to errors in the computed solution.

In this paper, finite element solutions were obtained for the vertical one-dimensional convolution phase of the study. The amplification functions generated for each finite element mesh considered in the analysis were then compared with the exact convolution solution and errors determined as a function of frequency. Six different soil sites were considered in this study, three being actual sites considered for nuclear plant sitings, and three sites being generalized uniform sand sites. The sites considered ranged from shallow (100 ft depth) to deep soil sites (600 ft) and loose to dense sand conditions. For each site considered, five different finite element meshes were used, with frequency transmission capability varying from 5 Hz to 25 Hz.

From this matrix of problems, the results have been organized to allow the choice of the required size of the finite element mesh in any soil layer so as to limit the numerical errors in transmission to within a specified magnitude.

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

4. Strong Motion Seismometry

4.1 Instrumentation

● 4.1-1 Kuribayashi, E., Toki, K. and Wakabayashi, S., **Reliability of ground motions by SMAC-B2 accelerographs** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 120, 153–160. (For a full bibliographic citation see Abstract No. 1.2–9.)

In this paper the characteristics of an SMAC-B2 accelerometer are examined in order to evaluate the reliability of ground motions obtained by use of this type of accelerometer. Since displacements are very important in the range of longer periods, the reproducibility of displacements integrated from digitized values of triggered accelerograms is examined.

● 4.1-2 Gates, J. H. and Davis, R. E., **Dynamic response of bridges to seismically induced ground vibrations. Phase l; Pilot field tests - strong-motion instrument installation,** *CA-DOT-DS-4164-75-5,* Div. of Structures, California Dept. of Transportation, Sacramento, July 1975, 34.

Strong-motion accelerometers were installed on bridges located in three seismically active areas in California as a pilot project to assess installation problems and to compare usefulness of data furnished by different types of instruments, including the Teledyne-Geotech Model RRA-100 and the Nimbus Model TMA-100 accelerographs, and the Engdahl Model PSR1200-SL peak-shock recorder. Instruments were installed during construction and on existing bridges. General guidelines and recommendations for future installations are presented. Data obtained from these installations during future seismic events will be used to assess the validity of assumptions and analytical tools employed in the design process.

● 4.1-3 Prothero, W., **A portable digital seismometric station** (Portativnaya tsifrovaya seismicheskaya stantsiya, in Russian), *Sbornik sovietsko-amerikanskikh rabot po prognozu zemletryasenii,* 21–27. (For a full bibliographic citation see Abstract No. 2.8–12.)

A portable digital seismometric station operating in an earthquake-triggered mode is described. Four stations of this type were tested under field conditions. The system was based on a fixed-location station which had been in operation for two years. The seismic signal is recorded on magnetic tape only if the output signal of the analog-to-digital converter exceeds a preestablished threshold value. The magnetic tape is capable of recording 1.4 million digits, corresponding to three hours on a single channel recording 128 readings per sec.

4.2 Regional Data Collection Systems

4.2-1 Rogers, G. C., **A survey of the Canadian strong motion seismograph network,** *Canadian Geotechnical Journal,* 13, *1,* Feb. 1976, 78–85.

At the end of 1974 there were 45 accelerographs and 75 seismoscopes deployed in Canada. The Department of Energy, Mines, and Resources and the National Research Council of Canada have installed most of the instruments but one quarter of them are privately owned. Three quarters of the instruments are located near the west coast with the next largest concentration in the St. Lawrence Valley region. There is one instrument in the Arctic. The majority have been deployed to measure ground motion in populated areas, but a few have been deployed in areas of higher seismicity remote from population centers. In western Canada particular emphasis has been placed on measuring the response of different soil types and soil depths. The only

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

major structures in the country that have been instrumented are two large dams.

● 4.2-2 Polyakov, S. V. *et al.*, **Engineering-seismometric information in earthquake resistant structural design,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 125, 13. (For a full bibliographic citation see Abstract No. 1.2-6.)

In the U.S.S.R., the effects of earthquakes are recorded by the Single Service for Seismic Observation of the U.S.S.R. (SSSO) and by the Engineering-Seismometric Service (ESS). ESS records vibrations of buildings and structures and of adjacent areas of the ground during earthquakes. The material obtained is the initial data for verifying and clarifying methods for calculation and design of earthquake-resistant structures. With an appropriate analysis, these data help to evaluate actual bearing capacity under seismic effects. ESS stations are located in all seismically active regions and cover a range of buildings and structures.

● 4.2-3 Rojahn, C., **California building strong motion earthquake instrumentation program,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 40-60. (For a full bibliographic citation see Abstract No. 1.2-8.)

Described in this paper are the guidelines developed for selecting and instrumenting buildings under the California Strong Motion Instrumentation Program.

● 4.2-4 **Strong-motion accelerograph station list - 1975,** *Open-File Report No. 76-79,* Seismic Engineering Branch, U.S. Geological Survey, Menlo Park, California, Mar. 1976, 81.

This list contains information on the strong-motion accelerographs maintained by the U.S. Geological Survey in a national network of strong-motion instrumentation that it maintains for the National Science Foundation in cooperation with other federal, state and local agencies and organizations. In addition, similar information on strong-motion stations installed and maintained by others is included if sufficient information about the stations is known. Since this list is continuously changing, it is impossible to have complete information about all of the stations at any one time. Rather, it is intended to provide the community of persons interested in the strong-motion program with a reasonably complete indication of the extent of the strong-motion network at this time, and to update the information periodically.

● 4.2-5 Mihailov, V., Petrovski, D. and Kirijas, T., **The strong-motion earthquake observation network in Yugoslavia,** *Publication No. 47,* Strong Motion Lab., Inst. of Earthquake Engineering and Engineering Seismology, Univ. Kiril and Metodij, Skopje, Yugoslavia, Mar. 1975, 83.

This report summarizes a project, entitled "Establishment of Strong Motion Network in Yugoslavia," which was begun in 1972 and completed in 1975. The project, based on scientific collaboration between the United States and Yugoslavia, was carried out by the Inst. of Earthquake Engineering and Engineering Seismology at the Univ. of Skopje and the California Inst. of Technology in Pasadena.

● 4.2-6 Besson, R. L. *et al.*, **Results of joint seismological field investigations in the Khait region during 1974** (Rezultaty sovmestnykh polevykh seismologicheskikh issledovanii 1974 g. v Khaite, in Russian), *Sbornik sovietsko-amerikanskikh rabot po prognozu zemletryasenii,* 28-42. (For a full bibliographic citation see Abstract No. 2.8-12.)

The first results obtained from joint Soviet-American field investigations in the Khait region (Tadzhik S.S.R.) during 1974 are described. The primary purpose of this work was the comparison of instrumentation, field techniques and methods of analysis employed in the U.S.S.R. and the U.S.A. Earthquake energy classifications based on data from the U.S. Geological Survey and its Soviet counterpart are compared. The distribution of the ratio of compressional to shear-wave velocity is investigated.

● 4.2-7 Besson, R. L. *et al.*, **A radiotelemetric seismic instrumentation system** (Kompleks seismologicheskoi radiotelemetricheskoi apparatury, in Russian), *Sbornik sovietsko-amerikanskikh rabot po prognozu zemletryasenii,* 9-20. (For a full bibliographic citation see Abstract No. 2.8-12.)

A detailed description is given of the radiotelemetric seismic instrumentation system used during the joint Soviet-American seismological field experimentation in the Garmsk region during 1974-75.

● 4.2-8 Besson, R. L. *et al.*, **Results of joint seismological field investigations in the Khrebt Petra Pervogo region during 1975** (Rezultaty sovmestnykh polevykh seismologicheskikh issledovanii 1975 g. v. raione Khrebta Petra Pervogo, in Russian), *Sbornik sovietsko-amerikanskikh rabot po prognozu zemletryasenii,* 43-69. (For a full bibliographic citation see Abstract No. 2.8-12.)

This work is a continuation of the program of joint Soviet-American field investigations. Further comparison is made between the recording capabilities of the networks of the U.S. Geological Survey and its Soviet counterpart. The propagation velocity structure of the region is investigated and areas of various velocity characteristics are distinguished. Source mechanisms are examined.

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

5. Dynamics of Soils, Rocks and Foundations

5.1 General

● 5.1-1 Sandler, I. S., DiMaggio, F. L. and Baladi, G. Y., **Generalized cap model for geological materials,** *Journal of the Geotechnical Engineering Division, ASCE,* 102, *GT7,* Proc. Paper 12243, July 1976, 683-699.

A description has been given of the general features of the cap model as used to represent geological materials. In addition, the theoretical basis for the model has been indicated and a particular example of the model has been presented. The model is intended to represent the behavior of a wide range of geological materials in problems for which the nonlinear hysteretic nature of such materials is significant. Although the primary area of application of the model in the past has been in the numerical computation of ground shock effects in layered sites due to explosive sources, the model should be applicable to other fields of interest such as earthquakes and various types of penetration into soils and rocks.

● 5.1-2 Goto, N., Kagami, H. and Shiono, K., **A handy and high-precise shear wave measurement by means of standard penetration test** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 113, 97-104. (For a full bibliographic citation see Abstract No. 1.2-9.)

Several in-situ measurements of shear waves have been developed and used for earthquake engineering applications. In Japan in-situ measurements of shear waves have been used at the construction sites of high-rise buildings to determine underground characteristics. In order to more easily measure shear wave velocity, an experiment was carried out to develop a new technique for measuring shear wave velocity simultaneous with the application of the standard penetration test.

5.2 Dynamic Properties of Soils, Rocks and Foundations

● 5.2-1 Wasti, Y., **Determination of soil parameters used in soil dynamics problems** (Zemin dinamigi problemlerinde kullanilan zemin parametrelerinin tayini, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* 2, *6,* July 1974, 13-45.

In analyses of the response of soil layers to earthquake motions and in problems associated with the design of foundations to resist dynamic loadings, reliable values of the shear modulus and damping ratio have to be determined.

Although computerized methods for soil response analyses are being introduced into Turkish engineering literature, soil laboratories are not equipped with dynamic testing facilities, and wave velocity determination in the field is not frequently done. Therefore, the dynamic soil properties are assumed for the analyses. However, it should be remembered that the choice of soil parameters which describes the extremely complex dynamic behavior of soils is as important as the choice of the method of dynamic analyses.

In this paper factors affecting shear modulus and damping ratio and the determination of them by laboratory and field procedures are outlined. Empirical expressions for shear modulus and their limitations are given. In cases where soil dynamic parameters cannot be determined directly with low enough cost or in the case of preliminary design, the use of empirical expressions and design curves for choosing the proper values of the parameters for foundation design and soil response analysis is explained.

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

5.2-2 Smolin, E. S., **On the effects of inertial properties of elastic base in free vibrations of elastic beams** (Ob vehete inertsionnykh svoistv uprugogo osnovaniya pri svobodnykh kolebaniyakh uprugikh balok, in Russian), *Trudy TsNII stroitelnykh konstruktsii, 45,* 1975, 53–57.

A model of elastic base consisting of Winkler springs and semi-infinite springs is described. This model is found to be useful in considerations of the dissipative properties of building foundations subjected to seismic excitations.

● 5.2-3 Langer, M., **The calculation of soil-dynamic parameters based on a general rheological model of the subsoil,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 33, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

A rheological method proposed for determining the dynamic moduli of soil is described in detail. This method takes into account the nonlinear character of the stress-strain behavior by comparing the load and rebound curves of an in-situ compression test. In addition, the author establishes and substantiates the dependence on time of the modules of deformation and of shearing by having recourse to a simple rheological equation of matter. The author likewise makes use of this time-dependence for the purpose of determining the damping ratio. The rheological equation used corresponds to a nonlinear generalized Schofield-Scottblair-body. This method might replace the approximate calculus formula used up to this time.

● 5.2-4 Gurpinar, A., **The new Turkish aseismic code: A critical evaluation with emphasis on soil amplification considerations,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 783–793. (For a full bibliographic citation see Abstract No. 1.2-7.)

The new Turkish aseismic code is evaluated with respect to its soil amplification regulations. The major critique is directed to the computation of the predominant soil period.

A brief outline of the code in general and a more detailed outline of soil considerations in the code are first presented. Then, the results from an earlier two-dimensional modal study are given. These results include several relationships between modal periods, thicknesses and P and S wave velocities of soil layers. A comparison between these and code formulas, as well as several recommendations, are included.

● 5.2-5 Nasu, M., **Dynamic properties of alluvial clay for aseismic design of Tokyo central underground station,** *Quarterly Reports, Railway Technical Research Institute,* **17,** *1,* Mar. 1976, 1–5.

The seismic-resistant design for the Tokyo underground station structure, recently constructed in weak ground, has been carried out. Dynamic moduli and damping ratios of soil have been measured by a vibrational triaxial compression test apparatus.

● 5.2-6 Anderson, D. G. and Woods, R. D., **Time-dependent increase in shear modulus of clay,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT5,* Proc. Paper 12147, May 1976, 525–537.

Two time domains for modulus increase have been identified, primary and secondary. Primary is the same as for primary consolidation and secondary is the open interval after primary in which modulus increases continuously with time. It was found that all cohesive soils exhibit secondary modulus increase, i.e., (1) The modulus increase for clays ranges from 3% to 20% per logarithmic cycle of time; (2) confining pressure dependence can be removed by normalizing modulus based on the 1,000-min modulus; and (3) secondary increases in modulus occur at all shear strain amplitudes. The rate of secondary increase is related to the undrained shearing strength and the initial void ratio of the soil. An empirical equation is presented to show this relationship. Thixotropy best explains secondary modulus increase.

● 5.2-7 Sherif, M. A. and Ishibashi, I., **Dynamic shear moduli for dry sands,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT11,* Proc. Paper 12572, Nov. 1976, 1171–1184.

Using the torsional simple shear device, the authors investigated the relationship between the equivalent dynamic shear moduli and shear strain for Ottawa, Del Monte, Golden Gardens, and Seward Park sands. Based on their experimental findings, the authors propose two equations relating shear moduli to shear strain (below and above 0.03%) as a function of the soil angle of internal friction and the effective confining pressure. Also, a relationship is proposed that considers the effects of the number of stress cycles on equivalent shear moduli. A nomograph is proposed to assist in the easy determination of equivalent shear moduli for sands. A comparison is made between the authors' findings and the results of previous researchers.

● 5.2-8 Meehan, R. L., **Dynamic strength of hydraulic fill** (Technical Note), *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT6,* Proc. Paper 12169, June 1976, 641–646.

This note presents results of 120 dynamic triaxial tests performed on samples of medium dense hydraulic fill obtained from several old dams located in California's Sierra Nevadas. Although the overall sample represents a range of soil classifications, the generally similar origin and method of placement provide a basis for considering them

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

as a special soil type and for inspecting the test results for general dynamic strength characteristics.

● 5.2-9 Lee, K. L., **Discussion of: One-dimensional volume change characteristics of sands under very low confining stresses,*** *Soils and Foundations,* 16, 2, June 1976, 58-60. (*By Yoshimi, Y., Kuwabara, F. and Tokimatsu, K., Sept. 1975, 51-60.)

● **5.2-10** Drnevich, V. P. and Jent, J. P., **Response of saturated sands to cyclic shear at earthquake amplitudes,** *Research Report No. 87,* Water Resources Research Inst., Univ. of Kentucky, Lexington, Oct. 1975, 35. (NTIS Accession No. PB 247 551)

Both quasi-static and resonant cyclic shear tests were performed on hollow cylindrical specimens of saturated sands at various densities and confining stresses. Shear moduli measured at nondestructive amplitudes were shown to be independent of frequency for the range of 0.1Hz to 50Hz. Application of cyclic shear at larger amplitudes caused effective stresses to decrease and failure. The number of cycles to failure was related to the ratio of cyclic shear stress to maximum drained shear stress. Effective confining stress reduces approximately linearly with number of cycles. Shear modulus and shear damping can be described by the Hardin-Drnevich equations if change in effective stress is properly adjusted. Procedures were developed to use research results in analyzing soils in dams or other profiles to predict factor of safety against liquefaction failure and to estimate shear modulus and damping of soils for subliquefaction conditions when these soils are subjected to earthquakes.

● **5.2-11 Evaluation of soil liquefaction potential for level ground during earthquakes - A summary report,** Shannon & Wilson, Inc. and Agbabian Assoc., Seattle, Washington and El Segundo, California, Sept. 1976, 113.

The report evaluates the results of a three-year research program conducted to investigate the settlement and liquefaction of sands under multidirectional shaking. The investigation indicated that the behavior of a saturated sand under cyclic loading conditions is a function of its geologic and seismic history and grain structure as well as its placement density. It is concluded that the resistance to liquefaction of a sand deposit can best be estimated by laboratory testing on undisturbed samples.

It is shown that cyclic triaxial tests used in conjunction with appropriate correction factors to account for multidirectional shaking, simple shear loading conditions, and overconsolidation effects can provide valid data on cyclic loading characteristics. The concepts of limited strain potential and acceptable value of the factor of safety against initial liquefaction are introduced in the report. Finally, the two basic methods for evaluating liquefaction potential and the effects of liquefaction are reviewed and updated with the information obtained through this research effort.

● 5.2-12 Chaichanavong, T., **Dynamic properties of ice and frozen clay under cyclic triaxial loading conditions** (Ph.D. Thesis), Dept. of Civil and Sanitary Engineering, Michigan State Univ., East Lansing, 1976, 460.

The cylindrical polycrystalline ice samples were prepared using natural snow and distilled water for high density samples (about 0.904 g/cc) or natural snow and carbonated water for low density samples (about 0.77 g/cc). The samples were tested at various strain amplitudes, temperatures, frequencies, and confining pressures. The values of the dynamic Young's modulus and the damping ratios were varied also.

Two types of frozen clay samples were used in the research program: (1) Ontonagon clay, termed "O-clay," and (2) a mixture of Ontonagon and sodium montmorillonite clay (fifty percent each by weight), termed "M+O-clay." The O-clay was prepared at different water contents to assess the influence of water (ice) content on dynamic properties. The M+O-clay was used to investigate the influence of specific surface area (related to unfrozen water content). The samples were tested at various strain amplitudes, temperatures, frequencies and confining pressures. Also varied were the values of the dynamic Young's modulus and the damping ratios.

The dynamic properties of ice and frozen clay obtained in the present study at the lowest strain amplitude were compared to those obtained in previous studies, and the results are discussed.

5.2-13 Giller, V. G. and Kogan, L. A., **Application of sequential analysis to comparison of seismic properties of soils** (Primenenie posledovatelnogo analiza pri sravnenii seismicheskikh svoistv gruntov, in Russian), *Voprosy inzhenernoi seismologii, 18,* 1976, 66-68.

An application of the method of sequential analysis to the determination of seismic properties of soils is considered. When this method is applied, the question of the number of earthquakes necessary for the exact determination of these properties is removed.

● 5.2-14 Taga, N. and Togashi, Y., **Dynamic properties of fluid saturated elastic soil layers** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 130, 233-240. (For a full bibliographic citation see Abstract No. 1.2-9.)

● **5.2-15** Iwasaki, T. and Tatsuoka, F., **In-situ seismic survey and laboratory tests on dynamic properties of soils** (in Japanese), *Proceedings of the Fourth Japan Earthquake*

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

Engineering Symposium-1975, Paper No. 150, 391–398. (For a full bibliographic citation see Abstract No. 1.2–9.)

To evaluate ground motion during earthquakes, it is necessary to obtain the dynamic deformational properties, especially the strain amplitude-dependent shear modulus and the damping coefficient, of soil deposits. At two sites, Iruma, Minami-Izu-cho and Ohgi-shima, Kawasaki-shi, in-situ seismic surveys were carried out. At the former, a sand embankment was damaged during the Off-Izu-peninsula earthquake of 1974 and the latter is reclaimed land where borehole accelerometers are installed. In addition, sands sampled from these sites were tested with a resonant-column apparatus of Drnevich type to obtain shear modulus and damping capacity at small strain. Laboratory test results showed that two natural sands which were well graded and included fine particles had smaller shear modulus than uniform clean sands such as Toyoura or Ottawa sands.

The comparison of shear modulus from shear wave velocity with that from resonant-column tests was performed and excellent agreement between the two values was obtained for both of the sites. At the same time, it was disclosed that the precise estimate of shear modulus for earthquake response analysis could not be performed from N-values using experimental formulas. The earthquake response analysis for Iruma was performed by shear wave propagation theory taking into account the nonlinear deformational properties of the soil deposits.

● 5.2-16 Tanimoto, K., Noda, T. and Fudo, R., **Fundamental study of the application of seismic techniques to determination of soil properties,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 151, 399–406. (For a full bibliographic citation see Abstract No. 1.2–9.)

The mechanical properties of sandy soils are often measured with remolded samples in the laboratory. However, based on geological and loading histories, such samples seem to have different structures than those of in-situ samples, even if they have equal densities and water content. For this reason, field measurement is considered to be more reasonable for determining the mechanical properties of soils. Also, anisotropy of the ground, which often exists in the field condition, should be taken into account in the measurement.

This paper describes: (1) a laboratory study of the seismic method and the shear test to examine the shear parameter as an index of the mechanical properties of soils and (2) the application of the techniques to field case studies. From the study, some correlations among soil density, soil moisture, seismic velocity and shear parameter were obtained, and some characteristics of such correlations with respect to anisotropic soils were clarified.

● 5.2-17 Komada, K. and Okahara, M., **Sheet pile foundation & its dynamic properties,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 168, 535–542. (For a full bibliographic citation see Abstract No. 1.2–9.)

The sheet pile foundation was first used in 1965 as the foundation for blast furnaces and began to be used for bridge foundations in 1969. The sheet pile foundation construction method has been adopted for 40 bridges in all, and it will probably be used more and more in the future.

In this paper, the structure of the sheet pile foundation and its characteristics are described. The sheet pile bridge foundations currently in existence are classified by type, size, penetration length, diameter, etc. Discussed are the results of field vibration tests, including the dynamic properties and the seismic design of the foundations tested. The dynamic properties, such as resonant frequencies and damping characteristics, are compared with those of caisson foundations and multi-pile foundations. In addition, the earthquake resistance of sheet pile foundations is compared with the earthquake resistance of caisson foundations and the multi-pile foundations.

● 5.2-18 Esashi, Y., Yoshida, Y. and Nishi, K., **A new exploratory method for properties of ground through borehole wall** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 152, 407–414. (For a full bibliographic citation see Abstract No. 1.2–9.)

● 5.2-19 Booker, J. R., Rahman, M. S. and Seed, H. B., **GADFLEA: A computer program for the analysis of pore pressure generation and dissipation during cyclic or earthquake loading,** *EERC 76-24,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Oct. 1976, 63. (NTIS Accession No. PB 263 947)

During earthquakes, pore water pressures are induced in soils by the cyclic stress applications induced by the ground motions. At the same time, pore water pressures may dissipate from the soil due to drainage. Until very recently it had not been possible to couple the two effects. However, it has recently been shown that under one-dimensional conditions the pore-pressure generating effects of cyclic loading could be incorporated into a dissipation analysis by the introduction of a source term. This approach has also been extended to situations involving radial flow in studies of the feasibility of using gravel drains to stabilize potentially liquefiable soil deposits. An interesting aspect of this approach is that although it was initially developed to analyze cyclic loads induced by earthquakes it is equally applicable to many other forms of cyclic loading and may thus, for example, be used to analyze pore pressure generation and dissipation induced by wave action on offshore structures. In this report a method of analysis of the equations governing pore pressure generation and dissipation based on the finite element method is developed and illustrated by application to a variety of problems.

5.3 Dynamic Behavior of Soils and Rocks

5.3-1 Finn, W. D. L. and Byrne, P. M., **Estimating settlements in dry sands during earthquakes,** *Canadian Geotechnical Journal,* 13, *4,* Nov. 1976, 355-363.

An analytical method for predicting the settlement of a horizontal stratum of dry sand subjected to earthquake excitation is presented. An equivalent linear viscoelastic dynamic analysis is used to determine the time-history of shear strains at various levels within the stratum. The vertical strains caused by these shear strains are calculated by an empirical relationship shown to be in close agreement with laboratory test data over a wide range of relative densities. This allows the settlement distribution with depth to be calculated as a function of time.

The method was applied to a 50 ft (15 m) stratum of sand. A base acceleration corresponding to 0-10 s of the N-S component of El Centro earthquake was used. Settlement distribution versus depth, as well as surface settlements for various relative densities and earthquake scaling factors, are shown. The effect of surcharge loading on settlements is investigated in an approximate manner.

The results may be used to estimate differential settlement of a structure due to an earthquake. The results show that while the compaction of the upper layers may be sufficient to reduce the settlements due to static loads to tolerable amounts, deep-seated settlements will still occur during an earthquake.

5.3-2 Ostapenko, V. A., **Waves in elasto-plastic halfspace subjected to concentrated dynamic force** (Volny v uprugo-plasticheskom poluprostranstve, nagruzhaemom sosredotochennoi dinamicheskoi siloi, in Russian), *Nelineinaya mekhanika, 1,* 1975, 110-120.

Interaction of plastic waves in the plastic zone of an elasto-plastic halfspace subjected to concentrated dynamic force is considered. The size of the area of limit stress is found to depend substantially on the form of the dynamic excitation. An analysis is made of the forms of dynamic excitation leading to the largest possible region of failure.

5.3-3 Kalyuzhnyuk, M. M., **Vibration propagation in elastic halfspace from a pile-type linear axisymmetric impulse source** (Rasprostranenie kolebanii v uprugom poluprostranstve ot lineinogo osesimmetrichnogo impulsnogo istochnika tipa svai, in Russian), *Volny v gruntakh i voprosy vibrometrii,* FAN, Tashkent, 1975, 48-54.

Displacement field components due to a pile-type linear impulse source are calculated under some simplifying assumptions. The medium is regarded as an elastic halfspace; forces are assumed uniformly distributed along the line of impact and actuated simultaneously. A Dirac-type impulse is considered.

● 5.3-4 Faccioli, E. and Ramirez, J., **Earthquake response of non-linear hysteretic soil systems,** *Earthquake Engineering and Structural Dynamics,* 4, *3,* Jan.-Mar. 1976, 261-276.

The seismic amplification response of horizontally stratified soil deposits with Ramberg-Osgood stress-strain behavior is analyzed by a random-vibration method. The deposit is modelled by a discrete shear beam system with radiation damping at the base. Parameters of an equivalent system are obtained by a harmonic linearization technique in which the actual relative displacement response at the surface is represented by a suitable sinusoidal motion. Despite the simplifications introduced, results for a number of different soil profiles and material description parameters are in good agreement with those given by numerical simulation techniques. Due to the much greater computational effort required by the latter, the proposed method seems preferable for predicting spectral amplification characteristics over a broad range of excitation intensities.

● 5.3-5 Silver, M. L. and Park, T. K., **Liquefaction potential evaluated from cyclic strain-controlled property tests on sands,** *Soils and Foundations,* **16**, *3,* Sept. 1976, 51-65.

A method for evaluating the liquefaction potential of loose to medium dense sands from strain-controlled triaxial property tests was developed. It was found that liquefaction potentials determined from stress-controlled liquefaction tests and strain-controlled property tests were in good agreement for medium dense sands. For the same material at the same density, values of modulus and liquefaction potential were significantly higher for specimens prepared using wet rodding methods than for specimens prepared using dry vibration methods. On the other hand, there was no significant difference between damping values for samples prepared by either method.

● 5.3-6 Ishihara, K. and Watanabe, T., **Sand liquefaction through volume decrease potential,** *Soils and Foundations,* **16**, *4,* Dec. 1976, 61-70.

Cyclic triaxial shear tests were performed on granular materials with a variety of grain sizes and uniformity coefficients to determine the effect of grain composition on the liquefaction potential of cohesionless soils. In place of the conventional measure of relative density as a density index, the difference between the current and minimum void ratios—defined as the volume decrease potential—was used as a new density parameter to define liquefaction

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

potential in a more meaningful way. It was found that the stress ratio required to cause liquefaction in a given number of cycles is intimately related to the volume decrease potential. To aid in using this concept, design curves are presented that may be used to estimate values of this potential from field standard penetration test results.

● 5.3-7 Ishihara, K. *et al.*, **Prediction of liquefaction in sand deposits during earthquakes**, *Soils and Foundations*, **16**, *1*, Mar. 1976, 1–16.

A previously developed method for computing the progressive rise of pore pressures in saturated sands subjected to cyclic loading has been adjusted to fit data obtained from triaxial torsion tests. Also, the method has been incorporated into a computer code for the computation of pore pressures based on shear stresses obtained from an independent earthquake response analysis of the ground. The method has been applied in three case studies involving sand deposits where actual acceleration records were obtained during recent major earthquakes. The predicted behavior of the sand deposits has been compared with the observed damage related to the deposits.

5.3-8 Rasvlov, Kh. Z., **Theoretical aspects of the earthquake resistance of saturated cohesive soils** (Nekotorye teoreticheskie polozheniya seismicheskoi ustoichivosti vodonasyshchennykh svyaznykh gruntov, in Russian), *Stroitelstvo i arkhitektura Uzbekistana*, *3*, 1976, 40–43.

Deformations due to seismic forces in structures built on weak saturated cohesive soils are calculated. A large body of experimental data is analyzed. Saturated silt subjected to dynamic loads may become dynamically excited with a resulting loss in general stability.

● 5.3-9 Seed, H. B., Martin, P. P. and Lysmer, J., **Pore-water pressure changes during soil liquefaction**, *Journal of the Geotechnical Engineering Division, ASCE*, **102**, *GT4*, Proc. Paper 12074, Apr. 1976, 323–346.

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 10–30 min after the earthquake. However, for coarse sands and gravels with an 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 build-up of pore pressure or a condition approaching liquefaction can develop. Improving the drainage capability of a sand deposit 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.

● 5.3-10 Bazant, Z. P. and Krizek, R. J., **Endochronic constitutive law for liquefaction of sand**, *Journal of the Engineering Mechanics Division, ASCE*, **102**, *EM2*, Proc. Paper 12036, Apr. 1976, 225–238.

A nonlinear constitutive law is developed, together with the previously established model for an inelastic two-phase medium, to give a realistic prediction of the pore pressure buildup and associated liquefaction of sand due to cyclic shear. The law is of the endochronic type and consists of quasilinear first-order differential equations expressed in terms of intrinsic time, which is an independent variable whose increments depend on the strain increments. This accounts for the accumulation of particle rearrangements, which are characterized by a parameter termed the rearrangement measure. The basic extensions of this work with regard to the application of endochronic theory to metals are due to the fact that sands densify upon shearing and are sensitive to confining stress; these two features are shared with the formulation of endochronic theory for concrete. Several typical examples are given to illustrate densification, hysteresis, and liquefaction tendency of sands subjected to cyclic shear in laboratory tests.

● 5.3-11 Meehan, R. L., **Discussion of: 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*, **102**, *GT4*, Proc. Paper 12013, Apr. 1976, 384–386. (*By Seed, H. B. *et al.*, Proc. Paper 11541, Sept. 1975.)

● 5.3-12 Tanaka, M., **Considerations on liquefaction tests of sandy soils** (in Japanese), *Reports of the Technical Research Institute, Taisei Corporation*, *8*, Nov. 1975, 135–142.

To investigate the liquefaction of sandy soils, dynamic triaxial tests were performed by simultaneous application of cyclic pressures of the same magnitude with a phase lag of 180° in the vertical and horizontal directions. The samples used in the experiments were from Niigata City. Specimens were prepared in two ways: from frozen undisturbed and from unfrozen disturbed samples.

● 5.3-13 Banister, J. R. *et al.*, **In-situ pore pressure measurements at Rio Blanco**, *Journal of the Geotechnical Engineering Division, ASCE*, **102**, *GT10*, Proc. Paper 12471, Oct. 1976, 1073–1091.

The nuclear test RIO BLANCO offered a unique opportunity to observe in-situ pore pressure increases

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

caused by seismic motion. In-situ pressure and ground motion measurements were made at five stations which ranged in distance from 2 km to 22 km from the test. Observed peak component accelerations ranged from 0.3 to 18 times the earth's gravitational acceleration. The observed sustained pore pressure increases were well under the values associated with soil liquefaction and no surface evidence of liquefaction was found. The excess pore pressures decayed in a minute or less. Soil samples were taken at the levels at which piezometers were installed. These samples were subjected to cyclic triaxial tests. The pore pressure increases observed on these tests were correlated with field observations considering the observed ground motion history. Field pressure increases were generally 10% or less of the values predicted from laboratory tests. Possible reasons for this discrepancy and the implications of rapid pressure decay are examined.

● **5.3-14** Easterling, R. G. and Heller, L. W., **Discussion of: Statistics of liquefaction and SPT results,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102**, *GT10,* Proc. Paper 12439, Oct. 1976, 1126–1128. (*By Christian, J. T. and Swiger, W. F., Proc. Paper 11701, Nov. 1975.)

● **5.3-15** Finn, W. D. L., Byrne, P. M. and Martin, G. R., **Seismic response and liquefaction of sands,** *Journal of the Geotechnical Engineering Division, ASCE,* **102**, *GT8,* Proc. Paper 12323, Aug. 1976, 841–856.

An effective stress analysis has been developed for determining the dynamic response of horizontal saturated sand deposits to earthquake motions consisting of vertically propagating shear waves. A hyperbolic stress-strain law is used for sands in shear and during the earthquake motions the modulus and damping properties of the sands are modified continuously for the effects of dynamic shear strains and pore-water pressures. The pore-water pressures are continuously updated using equations which relate pore-water pressures to dynamic shear strain history. Comparisons between data from the effective stress analysis and current total stress methods show that only the effective stress method can predict and reproduce the phenomena that occur in saturated sands during earthquakes. It gives the time to liquefaction, the time history of the development of pore-water pressures and surface accelerations comparable in form to those recorded on saturated sands during earthquakes.

● **5.3-16** Zolkov, E., **Discussion of: Statistics of liquefaction and SPT results,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102**, *GT10,* Proc. Paper 12439, Oct. 1976, 1128–1129. (*By Christian, J. T. and Swiger, W. F., Proc. Paper 11701, Nov. 1975.)

● **5.3-17** Christian, J. T. and Swiger, W. F., **Closure of: Statistics of liquefaction and SPT results,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102**, *GT12,* Proc. Paper 12585, Dec. 1976, 1279–1281. (*By Christian, J. T. and Swiger, W. F., Proc. Paper 11701, Nov. 1975.)

● **5.3-18** Martin, G. R., Finn, W. D. L. and Seed, H. B., **Closure of: Fundamentals of liquefaction under cyclic loading,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102**, *GT9,* Proc. Paper 12363, Sept. 1976, 1025–1027. (*By Martin, G. R., Finn, W. D. L. and Seed, H. B., Proc. Paper 11284, May 1975.)

● **5.3-19** Lee, K. L., **Discussion of: Influence of degree of shear stress reversal on the liquefaction potential of saturated sand,*** *Soils and Foundations,* **16**, *2,* June 1976, 53–58. (*By Yoshimi, Y. and Oh-oka, H., Sept. 1975, 27–40.)

5.3-20 Dashevskii, M. A., **Analysis of cavities in elastic medium subjected to non-stationary plane compression waves** (Raschet polostei v uprugoi srede na deistvie nestatsionarnoi ploskoi volny szhatiya, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 3,* 1976, 42–46.

The flow of a single plane shock wave around a circular cavity in an elastic medium is investigated. Laplace transformation is used for the solution. The reverse Laplace transform is calculated using series expansion in Jacobian polynomials. Examples and diagrams showing displacements and stresses at the contour of the cavity are given.

● **5.3-21** Iwasaki, T., Wakabayashi, S. and Tatsuoka, F., **Seismic behavior of subsurface ground layers** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 119, 145–152. (For a full bibliographic citation see Abstract No. 1.2-9.)

This paper discusses the dynamic behavior of subsurface soil and rock layers on the basis of acceleration records triggered during moderate earthquakes. Borehole accelerometers are installed at four sites around the Bay of Tokyo. These were installed from 1970 through 1974 in connection with the Tokyo Bay Loop Highway Project proposed by the Ministry of Construction.

5.3-22 Babich, V. M., Chikhachev, B. A. and Yanovskaya, T. B., **Surface waves in a vertically inhomogeneous elastic halfspace with a weak horizontal inhomogeneity,** *Physics of the Solid Earth,* **12**, *4,* 1976, 242–245.

A method is presented for constructing surface-wave fields for the halfspace whose parameters vary slowly in the horizontal directions, while the free surface and the layer interfaces have a small curvature.

5.3-23 Biswas, A., **Propagation of Love-type waves in heterogeneous elastic layers,** *Journal of Geophysics,* **42**, *2,* 1976, 137–145.

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

The propagation of Love-type waves in an isotropic nonhomogeneous stratum of finite depth has been studied for two different cases: (1) the layer is embedded between two isotropic homogeneous elastic halfspaces; (2) the layer is in welded contact with another heterogeneous layer of different properties. The existence of such waves has been proved by obtaining numerical solutions of frequency equations.

● 5.3-24 Hara, A. and Kiyota, Y., **Soil dynamic properties for dynamic response analysis—Dynamic characteristics of Kwanto loam** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 149, 383–390. (For a full bibliographic citation see Abstract No. 1.2–9.)

This paper describes the design of a new dynamic shear apparatus and its application to the measurement of stress-strain relationships of Kwanto loam. The apparatus both reproduces the field stress conditions and is of practical use. Six specimens made from the same block sample were tested under static, dynamic and random programs. The experimental results are shown and compared with each hysteresis loop.

● 5.3-25 Kobori, T. and Tosu, S., **On wave propagation in one-dimensional elasto-plastic media**, *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 144, 343–350. (For a full bibliographic citation see Abstract No. 1.2–9.)

● 5.3-26 Yegian, M. K., **Seismic design decision analysis - Report No. 26: Risk analysis for earthquake-induced ground failure by liquefaction**, *R76-22*, Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, May 1976, 331.

A methodology is proposed to study the likelihood of ground failure as a result of liquefaction. Two alternate probabilistic models are developed which consider the uncertainties present both in the methods of analysis employed and the parameters used. The first model is based on a new empirical method of analysis for liquefaction which employs earthquake magnitude and hypocentral distance. The second probabilistic model is based on a modified version of a current method of analysis for liquefaction. These two probabilistic models are later incorporated into risk analyses for liquefaction. Following the proposed procedure for liquefaction risk analysis, the actual site of a nuclear power plant is studied and the results are presented in this report.

● 5.3-27 Liou, C. P., **A numerical model for liquefaction in sand deposits**, *UMEE-76R3*, Dept. of Civil Engineering, Univ. of Michigan, Ann Arbor, Apr. 1976, 201.

A numerical model is developed for liquefaction in a horizontal, or nearly horizontal, deposit subjected to ground shaking. The deposit is considered to be one dimensional, composed of layers of soils with different properties, with the water table lying at or below the ground surface. The model is composed of two interactive parts, i.e., the shear wave submodel and the pressure wave submodel. The modeling of plane shear wave propagation in a soil deposit is reviewed. The development of the pressure wave submodel and a coupling between the two submodels are presented in detail.

● 5.3-28 Bazant, Z. P. and Krizek, R. J., **Endochronic constitutive law for liquefaction of sand**, *Contract Report S-76-9*, Technological Inst., Dept. of Civil Engineering, Northwestern Univ., Evanston, Illinois, Aug. 1976, 24.

A nonlinear constitutive law is developed to describe the densification and hysteresis of sand under cyclic loading. This law, together with the previously established model for an inelastic two-phase medium, gives a realistic prediction of the pore pressure buildup and associated liquefaction of sand due to cyclic shear. The law is of the endochronic type and consists of quasilinear first-order differential equations expressed in terms of intrinsic time, which is an independent variable whose increments depend on the strain increments. This accounts for the accumulation of particle rearrangements, which are characterized by a parameter termed the rearrangement measure. The basic extensions of this work with regard to the application of endochronic theory to metals are due to the fact that sands densify upon shearing and are sensitive to confining stress; these two features are shared with the formulation of endochronic theory for concrete. Several typical examples are given to illustrate the ability of the developed theory to adequately characterize the densification, hysteresis, and liquefaction tendency of sands subjected to cyclic shear in laboratory tests.

● 5.3-29 Mitchell, J. K., Chatoian, J. M. and Carpenter, C. C., **The influences of sand fabric on liquefaction behavior**, *Contract Report S-76-5*, College of Engineering, Univ. of California, Berkeley, June 1976, 73.

Relationships between sand fabric, sample preparation method, and liquefaction and drained compression behavior under triaxial loading were determined for Monterey No. 0 sand. Reproducible samples were fabricated at 50 percent relative density using pluvial, moist tamping, and moist vibration methods of compaction. Pluviation and moist tamping were used to prepare samples at 80 percent relative density. Fabric was characterized by particle long axis and interparticle contact orientations.

Samples at both 50 percent and 80 percent relative density prepared by dry pluviation exhibited much lower strength under cyclic loading than did samples prepared by the other methods. At 50 percent relative density, samples prepared by pluviation were less stiff, compressed more prior to dilation and dilated less than samples prepared by the other methods. Differences were less pronounced at 80 percent relative density.

Preferred orientation of long axes of particles developed in the horizontal direction for each of the methods studied, with the intensity increasing in the order: moist vibration (nearly random), moist tamping, dry pluviation. At a relative density of 50 percent, preferred orientation of interparticle contact planes existed in the range of ±0° to 30° of the horizontal, with the proportion increasing in the order: dry pluviation, moist tamping, moist vibration. At 80 percent relative density more interparticle contact plane orientations were in the range of ±0° to 30° of the horizontal for samples prepared by dry pluviation than by moist tamping. For a given average relative density, substantial variations in density in a longitudinal direction could be seen in radiographs. These variations differed for sample preparation by different methods.

● **5.3-30** Seed, H. B. and Lysmer, J., **Soil response to earthquakes (RANN Utilization Experience. Case Study No. 1)**, Univ. of California, Berkeley, 1975, 25. (NTIS Accession No. PB 247 245)

This report deals with the utilization of three computer programs, entitled SHAKE, QUAD-4, and LUSH, which represent the state-of-the-art in the prediction of soil response to earthquakes. The programs are used by virtually every engineering consulting firm in the United States engaged in earthquake analysis related to construction. The study concluded that, even if no other results had been produced from this broad project, the comprehensiveness with which these computer programs meet certain specific national needs fully justifies the expenditure of funds from the National Science Foundation–Research Applied to National Needs program. The funds invested in the research seem modest when compared to the widespread utilization of the results and the activities to which they are applied.

● **5.3-31** Ishihara, K. and Matsumoto, K., **Bearing capacity of saturated sand deposits during vibration**, *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 155, 431–438. (For a full bibliographic citation see Abstract No. 1.2–9.)

Liquefaction of saturated sand deposits during earthquakes has been identified as a major cause of damage to buildings and earth structures, and comprehensive studies have been made to evolve rational procedures for assessing the liquefaction potential of sand deposits. These studies, however, deal exclusively with the liquefaction that develops in level ground with a free surface. However, when concern is with design of foundations in potentially liquefiable ground, it is necessary to see what effect the presence of structures may exert on the development of liquefaction in the underlying deposit and to determine how the ground loses its bearing capacity, leading to the settlement of the structures. This paper describes some of the preliminary model tests which were carried out for clarifying these problems.

● **5.3-32** Ichihara, M., Matsuzawa, H. and Kawamura, M., **Active earth pressure during earthquake** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 157, 447–454. (For a full bibliographic citation see Abstract No. 1.2–9.)

Laboratory measurements of dynamic active earth pressures using a large vibrating soil bin have been carried out for ten years. As the result of these measurements, the following characteristics of earth pressures have been determined. As acceleration is increased: (1) the resultant force of earth pressure against a movable wall becomes larger, (2) the relative height of its applied point becomes higher and (3) wall friction decreases.

A formula has been derived of active earth pressure during earthquakes which satisfies the conditions of these three characteristics mentioned above by the concept of redistribution of the earth pressure. The calculated results agree well with those observed from the experiments with dry and submerged sands.

● **5.3-33** Yoshimi, Y. and Tokimatsu, K., **Liquefaction of sand near structures during earthquakes** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 156, 439–446. (For a full bibliographic citation see Abstract No. 1.2–9.)

Most of the previous research on the liquefaction of saturated sands has been concerned with level ground without structures. However, heavy structures might have significant influence on the liquefaction potential of sand in their vicinity. The object of this paper is to study such influence and to make recommendations for a method of foundation design for structures to be constructed on liquefaction-prone soils.

Shaking table tests were conducted on models of structures placed on saturated sand which was "wet-rained" in a box 140 cm long and 20 cm wide to a depth of 30 cm. The void ratio of the sand was about 0.75 which corresponded to a medium relative density. Five types of models were tested: (1) sand without structures, (2) a structure placed on the sand, (3) a heavier structure placed on the sand, (4) a pair of rigid walls embedded in the sand, and (5) a structure placed on the sand between the embedded walls. The average contact pressure of the structures was linearly scaled to simulate stresses on the sand.

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

All tests were run at a horizontal acceleration of 100 gal and a frequency of 3 Hz on a shaking table of the free-vibration type. The tests on the sand without structures showed that nearly free-field conditions prevailed in the portion of the sand where the pore pressure gages were installed.

The tests on the sand with structures showed that (1) the sand directly below the structure was less likely to liquefy than the sand away from the structure, and much less so for the heavier structure; and (2) the sand enclosed within the embedded walls was less likely to liquefy than the sand in the free field; and when a structure was placed on the sand between the walls, the liquefaction potential was further reduced and the excess pore pressure in the sand dissipated more quickly.

On the basis of the above findings, slurry trench walls around a structure are recommended as a means to minimize settlement of the structure due to liquefaction, and items to be checked during the design and construction are enumerated.

● 5.3-34 Faccioli, E. and Resendiz, D., **Soil dynamics behavior including liquefaction,** *E15,* Inst. de Ingenieria, Univ. Nacional Autonoma de Mexico, Mexico City, May 1975, 109.

● 5.3-35 Seed, H. B. and Booker, J. R., **Stabilization of potentially liquefiable sand deposits using gravel drain systems,** *EERC 76-10,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Apr. 1976, 62. (NTIS Accession No. PB 258 820)

In many cases, the installation of a system of vertical columnar drains offers an attractive and economical procedure for stabilizing an otherwise potentially liquefiable sand deposit. In fact, the method has already been used in one case involving the construction of stone columns in a relatively loose sand deposit, and it is currently being proposed for stabilization of a medium dense sand layer which is known to have developed some degree of liquefaction in a recent earthquake, but which appears to be too dense for stabilization by further densification using currently available procedures.

The report presents a simplified theory which provides a convenient basis for evaluating the possible effectiveness of a gravel drain system in such cases. Where appropriate, additional analyses may readily be made using the computer program LARF described in the report; but, for most practical cases, it is believed that the results presented in chart form will provide an adequate basis for design and selection of a suitable drain system for effective stabilization of potentially liquefiable sand deposits.

5.4 Dynamic Behavior of Soil and Rock Structures

● 5.4-1 Korcinski, N. and Ieremia, M., **A method to diminish the settling of buildings in seismic regions,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 31, 7. (For a full bibliographic citation see Abstract No. 1.2-6.)

The distribution of pressure beneath a foundation-slab depends on the rigidity of the slab. This distribution has a saddle aspect. Sometimes the concentration of the stresses near the borders of the foundation-slab may exceed the plastic limit of the soil resistance. The consequence is a slow but permanent settling of a building, which may be accentuated during an earthquake when the building oscillates. A method is presented for eliminating this problem.

5.4-2 Brilliantov, A. A., Konstantinov, I. A. and Mozhevitinov, A. L., **On response of earth dams to seismic excitation** (K raschetu zemlyanykh plotin na seismicheskoe vozdeistvie, in Russian), *Trudy Leningradskogo politekhnicheskogo instituta, 349,* 1976, 83–89.

The effects of dam base yield, earth fill deformation modulus, the Poisson coefficient and the direction of seismic excitation on stresses are investigated. One- and two-dimensional dam models are used and both rigid and elastic bases are considered. In the two-dimensional analysis the finite element method is employed. A decrease of the Poisson coefficient from .495 to 0 results in a 20% reduction of the total horizontal load on the dam. The maximal loads occur as a result of horizontal vibrations. The stability of the downstream slope is found to increase with the stiffness of the dam base.

● 5.4-3 Asada, A., **Dynamic behavior of the embankments on the soft ground deduced from the investigation of earthquake damages** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 111, 81–88. (For a full bibliographic citation see Abstract No. 1.2-9.)

Since 1962, the author has investigated the earthquake damage to embankments on soft ground using not only a static method but also a dynamic method, such as measurement of microtremors. By analyzing the results, the dynamic behavior of such embankments was studied.

● 5.4-4 Marcuson, III, W. F. and Krinitzsky, E. L., **Dynamic analysis of Fort Peck Dam,** *Technical Report S-76-1,* Soils and Pavements Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Mar. 1976, 298.

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

Because of the slide in the Lower San Fernando Dam during the San Fernando earthquake of Feb. 9, 1971, the U.S. Army Corps of Engineers initiated earthquake studies of its hydraulic-fill structures located in seismically active areas. Fort Peck Dam is a large hydraulic-fill dam in northeast central Montana, on the Missouri River, built during the period from 1933–1940.

Extensive geological and seismological investigations were performed to determine the so-called "design" earthquake. These studies included: (a.) a review of the seismic history of the area, including an extensive literature review; (b.) field and aerial reconnaissance, including air-photo interpretation; (c.) a review of oil company data related to faults in the Fort Peck area; (d.) a review of microseismic tremors obtained by instrumentation, records of which were specifically processed by Teledyne, Inc.

The results of these investigations showed no active faults in the immediate vicinity of Fort Peck Dam. A geologic anomaly, Tiger Butte, exists approximately 10 mi from the dam. This anomaly was assumed to be seismically active and is the postulated source of the so-called design earthquake. This earthquake is a magnitude 5.5 and is assumed to produce a peak acceleration of 0.2 g on bedrock under Fort Peck Dam. To simulate this earthquake, the Helena, Montana, record of 1935 was scaled to 0.2 g.

An extensive field investigation was conducted to obtain undisturbed samples of materials representative of the dam and its foundation and to evaluate the in situ properties of the soil. To evaluate the liquefaction potential of the dam, isotropically and anisotropically consolidated undrained cyclic triaxial compression tests were performed on reconstituted specimens of the shale and foundation material. Isotropically consolidated undrained cyclic triaxial compression tests were conducted on undisturbed specimens of the core material. Cyclic triaxial test results obtained from undisturbed and reconstituted specimens were compared. This comparison shows that the undisturbed material is about 1.75 times stronger than the reconstituted materials.

A nonlinear 2-D gravity-turn-on finite element static analysis was conducted for the dam cross section at sta 42+00 to determine the effective stresses in the dam prior to the earthquake. A 2-D equivalent linear dynamic finite element analysis was made for the dam cross section at sta 42+00. Embankment response to the traveling seismic wave in the shale was calculated by the program. This analysis was made at the Univ. of California, Berkeley, using a program developed by them for WES and soil parameters determined in WES laboratory studies. The scaled Helena record was used as input.

An analysis of the stability comparing the calculated dynamic stresses imposed by the earthquake and the dynamic strengths of the material was made using standard procedures. This analysis shows that the factor of safety against 5 percent strain, normalized to five equivalent cycles of loading, is greater than one in all cases. For a large portion of the dam cross section, the factor of safety is greater than two. It is concluded that this can be interpreted to mean that the dam is safe under all earthquake loadings considered possible.

● 5.4-5 Sawada, Y. and Takahashi, T., **Study on the material properties and the earthquake behaviors of rockfill dams**, *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 219, 695–702. (For a full bibliographic citation see Abstract No. 1.2–9.)

Longitudinal and transverse wave velocities in recently constructed rockfill dams were investigated in detail. From the investigations, it was found that the velocities in the dams greatly increase with burden pressure and that the relationship between the velocity and burden pressure could be generally formulated by a simple expression. A dynamic structural model was formulated as a result of the study; it was proved that the model was appropriate for predicting the behavior of rockfill dams during earthquakes.

● 5.4-6 Komaki, S., Ohbo, N. and Onda, I., **Experimental study of characteristic vibration near cliff due to SH waves, II** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 126, 201–208. (For a full bibliographic citation see Abstract No. 1.2–9.)

An experimental study of the characteristic vibration near a cliff due to SH waves was carried out at a test site on a cliff at Koma River in Hidaka Saitama prefecture, where weathered loam overlies a thin gravel layer lying on a thick layer of loam with gravels.

● 5.4-7 Takahashi, T. *et al.*, **Study on dynamic behaviors of rockfill dams**, *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 218, 687–694. (For a full bibliographic citation see Abstract No. 1.2–9.)

The earthquake behavior of some recently constructed tall rockfill dams has been studied by means of observations and field tests. It was found that the elastic wave velocities, Vp and Vs, are especially small in the upper part, from the surface to 25 m below, but that in the lower part, below 25 m, the relationship between the velocity and the depth of each dam is almost the same. Considering the distribution of elastic velocities in dams, a multiple reflection method is a simple and useful one for earthquake responses. The observations showed that the dynamic behavior of the dams was linear up to a remarkably greater value of strain than that which resulted from three axial tests.

● **5.4-8** Watanabe, H., **A numerical methods of seismic analyses for rock and earth fill dams and verification of its reliability through both model test and observation of earthquake on an actual dam,** *C: 74003,* Technical Lab. No. 2, Central Research Inst., Electric Power Industry, Abiko City, Japan, May 1975, 32.

5.4-9 Mamradze, G. P. and Dzhindzhikhashvili, G. Ya., **On the problem of pore water pressure in earth dams under seismic conditions** (K voprosu o porovom davlenii vody v tele plotiny iz gruntovykh materialov v seismicheskikh usloviyakh, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 219–221. (For a full bibliographic citation see Abstract No. 1.1–7.)

The boundary-value problem of transient filtration through a rectangular area in two dimensions is investigated. The area containing saturated sand with a five-grain structure is assumed to undergo horizontal harmonic vibrations. Porosity is regarded as a harmonic function of time and an exponential function of the vertical coordinate. A formula is derived giving the pressure at any point as the sum of a series.

5.4-10 Birbraer, A. N., **A method for calculation of the alteration of embankment profiles during earthquakes** (Metod rascheta izmenenii profilei nasypei pri zemletryaseniyakh, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 185–189. (For a full bibliographic citation see Abstract No. 1.1–7.)

A new approximate method to calculate the irreversible changes in noncohesive soil embankment profiles during earthquakes is outlined. Typical profiles are considered and investigated using the method described. As a result of numerical calculations, general principles are formulated regarding the effects of profile geometry and dimensions on the velocity of change of the profile. The numerical results are compared to experimental data.

5.4-11 Mozhevitinov, A. L. and Konstantinov, I. A., **On design of earth dams for seismic excitation** (K raschetu zemlyanykh plotin na seismicheskoe vozdeistvie, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 64–68. (For a full bibliographic citation see Abstract No. 1.1–7.)

The effects of the pulsation of pore pressure inside a dam on the stability of its downstream face during earthquakes are investigated. Two types of loadings were considered: the two-dimensional elastic problem using the finite element method and a cantilever beam with variable cross section. For the first case, the effects of soil stiffness module, the Poisson coefficient, the direction of the seismic excitation and foundation yield on the seismic load are investigated.

5.4-12 Lombardo, V. N. and Olimpiev, D. N., **Elastoplastic deformations in response of earth dams to seismic excitations** (Raschet plotin iz gruntovykh materialov na seismicheskie vozdeistviya s uchetom uprugoplasticheskogo deformirovaniya, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 56–64. (For a full bibliographic citation see Abstract No. 1.1–7.)

A method is presented to analyze the response of earth dams to static and dynamic loads. The material forming the body of the dam is assumed to behave as an elasto-plastic body.

5.4-13 Lyakhter, V. M. and Ivanenko, I. N., **Evaluation of the earthquake resistance of earth dams using methods of wave dynamics** (Otsenka seismostoikosti zemlyanykh plotin metodami volnovoi dinamiki, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 50–56. (For a full bibliographic citation see Abstract No. 1.1–7.)

A method is presented to analyze the dynamic response of earth dams. Equations describing the behavior of the dam before and after the critical state are analyzed. The calculation is based on the solution of the two-dimensional problem of wave dynamics. An explicit solution is obtained using the finite difference method. As a result, the stress and residual displacement fields of the soil fabric and the variation of pore pressure are calculated. One of the variants of the method utilized is considered using the example of the seismic response of the dam of the Nurek hydroelectric power plant.

5.4-14 Krasnikov, N. D. *et al.*, **Computer analysis of the seismic stability of earth slopes of hydraulic structures** (Raschet na ETsVM seismicheskoi ustoichivosti otkosov gidrosooruzhenii iz gruntovykh materialov, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 190–195. (For a full bibliographic citation see Abstract No. 1.1–7.)

A program written for the M-220 computer is presented for analyzing the seismic response of hydraulic earth structures utilizing the methods of Krei and Mozhevitinov (in the two-dimensional case). The basic ideas behind the algorithm are discussed. An example involving the seismic

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

response of the slope of a gravel dam with a clay central core is given.

5.4-15 Dmitriev, Yu. V., **Dynamic analysis of the deformations of earth slopes of dams utilizing real accelerograms** (Dinamicheskii raschet deformatsii otkosov plotin iz gruntovykh materialov s ispolzovaniem realnoi akselerogrammy, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh*, 195–197. (For a full bibliographic citation see Abstract No. 1.1–7.)

A method is presented for calculating the seismic response of the earth slopes of dams when caving with a cylindrical slip surface is present. Numerical results are calculated.

● 5.4-16 Tamura, C. *et al.*, **Study on mechanism of failure of rockfill dams during earthquakes on results of vibration failure tests of large scale models of the dam** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 220, 703–710. (For a full bibliographic citation see Abstract No. 1.2–9.)

For the purpose of clarifying the mechanisms of failure of rockfill dams during earthquakes, vibration failure tests on the models of a rockfill dam were conducted. The models, which were constructed on a shaking table, were 1.4 m in height and consisted of gravel or crushed stone. Results of experiments on models of uniform material and numerical stress analysis of the stability of the dams are presented.

● 5.4-17 Komada, H. *et al.*, **Three-dimensional dynamic analysis of a rockfill dam for inclined incident traveling seismic waves** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 221, 711–718. (For a full bibliographic citation see Abstract No. 1.2–9.)

A rockfill dam does not necessarily vibrate at a certain phase during an earthquake. It is preferable that the dynamic response analysis be conducted taking into account the phase lag seismic wave, when the wavelength of the seismic wave is longer than the main length of the structure. First the traveling seismic wave is assumed to be the S-wave with several angles incident to the ground surface. Then the phase lag of input seismic wave at the points of the base is considered. A three-dimensional dynamic response analysis method for a structure with traveling seismic waves is developed in this paper.

The method was applied to the seismic response analysis of a rockfill dam with a long crest. The input earthquake was assumed to be applied in the plane involving the dam axis and a vertical line. Four cases of input earthquakes were analyzed and compared: (1) traveling seismic wave propagating in a direction of 24 degrees to the right bank from the vertical line, (2) traveling seismic wave propagating in a direction of 24 degrees to the left bank from the vertical line, (3) traveling seismic wave propagating in a direction of the vertical line, (4) usual uniform input seismic wave is simultaneously applied to the dam base.

5.5 Dynamic Behavior of Foundations, Piles and Retaining Walls

5.5-1 Barkan, D. D. and Rashidov, T. R., **The state and development of the dynamics of foundations and underground structures during the last five years** (Sostoyanie i razvitie dinamiki osnovanii, fundamentov i podzemnykh sooruzhenii v techenie poslednykh pyati let, in Russian), *Svoistva gruntov pri vibratsiyakh*, FAN Publishing, Tashkent, 1975, 3–23.

In the past five years developments in the dynamics of foundations have occurred in three directions: design of pile foundations, modification of the mechanical properties of soils subjected to dynamic excitation and the effects of soil properties on seismic intensity. A new research topic has emerged: the study of the earthquake resistance of underground structures (e.g., pipelines and tunnels).

Insufficient work has been done on problems of dynamic plasticity and vibration creep. Problems of seismic microzoning are discussed. The inadequacy of instrumentation and equipment for experimental investigations of the dynamics of soils is pointed out.

● 5.5-2 Gazetas, G. C. and Roesset, J. M., **Forced vibrations of strip footings on layered soils**, *Methods of Structural Analysis*, Vol. I, 115–131. (For a full bibliographic citation see Abstract No. 1.2–3.)

This paper presents a semi-analytical solution of the problem for a rigid strip footing on an elastic, linearly hysteretic, layered halfspace. Parametric studies were conducted, investigating the effect of the rigidity of the rock on which the layer of soil rests for different stratum depths and the effect of the "smoothness" of the footing.

● 5.5-3 Naik, T. R. and Wang, C.-K., **Static and dynamic flexibility matrix for a semi-infinite solid**, *Methods of Structural Analysis*, Vol. II, 644–660. (For a full bibliographic citation see Abstract No. 1.2–3.)

Using Boussinesq's equation, the authors obtain a static flexibility matrix for a semi-infinite solid. A dynamic flexibility matrix for a semi-infinite solid is obtained using Lamb's theory. Then, using matrix formulation, the reaction and the displacement of a foundation under either

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

static or dynamic loads can be determined. Mat foundations of irregular shapes and discontinuities can be analyzed.

The dynamic Boussinesq displacement functions give results which compare quite well (within approximately 5%) with Rayleigh's elasticity solution. The displacement functions also are in good agreement with Sung's solution.

● 5.5-4 Saran, S. and Prakash, S., **Dynamic passive earth pressure distribution in retaining walls,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 28, 10. (For a full bibliographic citation see Abstract No. 1.2-6.)

A relatively little known procedure that appears to have considerable merit for determining pressure distribution is introduced. The method, called the method of redistribution of pressure, was proposed by Dubrova in 1963. Dubrova's work is improved and extended to the more general case of an inclined wall with inclined backfill. Earthquake forces have also been taken into consideration.

● 5.5-5 Yeh, C.-S., **Dynamic response of retaining walls during earthquake,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 387–392. (For a full bibliographic citation see Abstract No. 1.2–7.)

A model of a shear beam-Winkler spring retaining wall system is employed to describe the interaction between backfill and a wall. The wall is assumed to be a rigid body which undergoes horizontal translational and rocking motions. A set of coupled integro-partial differential equations describing the vibration of the whole system is reduced into a set of coupled ordinary differential equations by employing Galerkin's method. Modal analysis is used to solve the equations. For certain cases, the frequencies and the corresponding mode shapes are calculated. The effects of force and moment on the wall during a design earthquake also are presented. The significance of the effect of wall motion on the responses also is shown.

● 5.5-6 Nogami, T. and Novak, M., **Soil-pile interaction in vertical vibration,** *Earthquake Engineering and Structural Dynamics,* **4,** *3,* Jan.-Mar. 1976, 277–293.

The interaction between a soil layer and an end bearing pile is theoretically investigated. The pile is assumed to be vertical and elastic; the soil is considered as a linear viscoelastic layer with hysteretic type damping. The layer alone is solved first, and the wave modes of the layer are used in the analysis of the pile response. The pile response to a harmonic load is obtained in a closed form and used to define stiffness and damping at the level of the pile head. The dimensionless parameters of the problem are identified. A parametric study is conducted to determine the main features of the response and of the equivalent stiffness and damping. The validity of equivalent viscous damping is examined. A comparison is made with the simpler plane strain theory used previously and its accuracy is assessed.

● 5.5-7 Awojobi, A. O. and Tabiowo, P. H., **Vertical vibration of rigid bodies with rectangular bases on elastic media,** *Earthquake Engineering and Structural Dynamics,* **4,** *5,* July–Sept. 1976, 439–454.

Dual double integral equations completely representing the mixed boundary-value problem of the vertical vibration of rigid bodies with rectangular bases on semi-infinite elastic media are exactly formulated for the first time. An exact solution of these equations—even for the static case—is at present formidable, but an approximate solution is given by reducing the pair of dual double integral equations to another pair which shows an approximate relation between the three-dimensional and axisymmetric systems. This new method is used to generate response curves for Poisson's ratio 0.25 and side ratios 1, 2, 3, 4 and 5, from known results for circular bases, for the dynamic problem. Results obtained by using this technique are in good agreement with experiments where expanded rubber is used as the elastic medium. The present theory, which is applicable for any Poisson's ratio, also shows some measure of agreement with the theory of Elorduy et al. which is limited, by its numerical nature, to a Poisson's ratio of 0.25.

● 5.5-8 Wong, H. L. and Luco, J. E., **Dynamic response of rigid foundations of arbitrary shape,** *Earthquake Engineering and Structural Dynamics,* **4,** *6,* Oct.-Dec. 1976, 579–587.

An approximate numerical procedure for calculation of the harmonic force-displacement relationships for a rigid foundation of arbitrary shape placed on an elastic halfspace is presented. This procedure is used to evaluate the vertical, rocking and horizontal compliance functions for rigid rectangular foundations and the vertical compliance for a rigid square foundation with an internal hole. Several comparisons between the results obtained by the proposed approach and other methods are also presented.

● 5.5-9 Apsel, R. J. and Luco, J. E., **Torsional response of rigid embedded foundation,** *Journal of the Engineering Mechanics Division, ASCE,* **102,** *EM6,* Proc. Paper 12627, Dec. 1976, 957–970.

A series representation is obtained for the harmonic torsional response of a rigid massless semi-ellipsoidal foundation embedded in an elastic halfspace and subjected to the action of both an external torque and a plane nonvertically incident SH wave. Numerical results are presented for the torsional impedance function for different embedment ratios over a range of frequencies. Numerical results are

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

also shown for the torsional response of embedded foundations to plane wave excitation with different angles of incidence. It is shown that obliquely incident SH waves may induce a large torsional response of the foundation.

5.5-10 Barkan, D. D. *et al.*, **Investigation of the behavior of pile foundations with intermediate cushions for seismic regions** (Issledovanie raboty svainykh fundamentov s promezhutochnoi podushkoi dlya seismicheskikh raionov, in Russian), *Fundamenty i podzemnye sooruzheniya pri dinamicheskikh vozdeistviyakh,* FAN, Tashkent, 1975, 16–22.

One of the methods for reducing the seismic forces acting on piles is the installation of granular cushions between the piles and the foundation slab. Results of experimental field investigations of full-scale structures with such cushions are reported. Based on the data obtained from testing of foundations and separate piles using cyclic vertical loads, the elastic stiffness coefficients of the system are calculated.

5.5-11 Medvedev, S. V. and Sinitsyn, A. P., **Stability of retaining wall on saturated two-layer base** (Ustoichivost podpornoi steny raspolozhennoi na vodonasyshchennom dvukhsloinom osnovanii, in Russian), *Voprosy inzhenernoi seismologii, 18,* 1976, 131–136.

A technique for dynamic stability analysis of rigid retaining walls on a two-layer base is described. The effect of liquefaction on buckling is studied. Formulas are obtained for calculating critical loads for traveling seismic waves. Due to the presence of nonlinear vibrations dependent on the ratio of wall height to foundation width, stability is reduced by a factor of up to 2.5.

● 5.5-12 Nogami, T. and Novak, M., **Soil-pile interaction in vertical vibration,** Faculty of Engineering Science, Univ. of Western Ontario, London, Canada, 1974, 45.

The interaction between a soil layer and an end bearing pile is theoretically investigated. The pile is assumed to be vertical and elastic; the soil is considered as a linear viscoelastic layer with hysteretic type damping. The layer alone is solved first and the wave modes of the layer are used in the analysis of the pile response. The pile response to a harmonic load is obtained in a closed form and used to define stiffness and damping at the level of the pile head. The dimensionless parameters of the problem are identified. A parametric study is conducted to determine the main features of the response and of the equivalent stiffness and damping. The validity of equivalent viscous damping is examined. A comparison is made with the simpler plane strain theory used previously and its accuracy is assessed.

● 5.5-13 Kitaura, M., **Nonstationary restoring force characteristics and earthquake response of structural foundation-surface layer system** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 142, 327–334. (For a full bibliographic citation see Abstract No. 1.2-9.)

This paper discusses the restoring force characteristics of a structural foundation-surface layer system. The results of model experiments are represented by an empirical formula, and a hysteresis law for describing the response of yielding structures to earthquake acceleration is presented.

● 5.5-14 Miyahara, F. and Ergatoudis, J. G., **Matrix analysis of structure-foundation interaction,** *Journal of the Structural Division, ASCE,* **102**, *ST1,* Proc. Paper 11836, Jan. 1976, 251–265.

For the unified analysis of skeletal structures and foundations, a one-dimensional finite element for the foundation is formulated. This is achieved by assuming the same displacement field for the foundation as that used for the beam. The foundation is assumed to be of the Winkler type but it offers resistance not only to normal forces but to shear and torsional ones. The new foundation stiffness matrix is easily incorporated into existing structural analysis computer programs. Numerical examples are given. They include single members on or in an elastic medium and general skeletal structures partially or fully buried underground. Accurate and efficient solutions are obtained.

● 5.5-15 Shibata, T., Sato, T. and Tatumi, Y., **Dynamic analysis of the earth retaining wall by the finite element method** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 158, 455–462. (For a full bibliographic citation see Abstract No. 1.2-9.)

In analyzing the dynamic characteristics of complex structure-foundation systems, the finite element method has been generally used. However, there are many difficulties in a finite element idealization of such systems. With this method, only a finite number of nodal points can be considered and the response of a system changes considerably with the position of the boundary which divides the finite area from the infinite media. Furthermore, radiation-damping is difficult to take into account, because the energy of the incident waves cannot be radiated through the boundary as the closed-form solutions in an infinite solid. The purpose of this paper is to investigate the influence of radiation-damping on the dynamic properties of a retaining wall.

● 5.5-16 Ghazzaly, O. I., Hwong, S. T. and O'Neill, M. W., **Approximate analysis of a pile under dynamic, lateral loading,** *Computers & Structures,* **6**, *4/5,* Aug.–Oct. 1976, 363–368.

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

An analytical study of the behavior of a vertical pile subjected to low-amplitude, periodic, surface, lateral loading was performed. A rational approach is proposed in which the pile response is represented by the vibrations of a beam on an elastic foundation. The foundation medium is considered as a linearly elastic halfspace whose properties are expressed by the shear modulus and Poisson's ratio. The appropriate dynamic properties of soils are introduced to describe the behavior of the foundation medium.

The governing equation of a laterally vibrating pile embedded in an elastic halfspace is shown to be a fourth order, partial differential equation with nonconstant coefficients. This equation can be solved by the finite difference method, which allows the soil and pile properties to be varied along the pile length. Solutions were considered for various boundary conditions at the pile head and for different stress distributions at the soil-pile interface. The analytical solution was incorporated in a computer program which calculates deflection and moment at designated pile increments for selected time intervals.

The reliability of the proposed method of analysis is illustrated by comparing bending moments and deflections, measured in tests on instrumented, small-scale piles embedded in cohesive and cohesionless soils and subjected to low-amplitude lateral vibrations, with computed values. The agreement between the computed and measured results was generally acceptable.

● **5.5-17** Takeuchi, M., Kotoda, K. and Kazama, S., **Vibrational characteristics of building with pile foundation—A study of introducing the plasticity of soil in the estimation of spring constant** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 166, 519–526. (For a full bibliographic citation see Abstract No. 1.2–9.)

● **5.5-18** Umek, A., **On the influence of the geometry of the foundation on its impulse response**, *Journal of Applied Mechanics*, 43, Series E, 2, June 1976, 300–303.

The influence of the foundation geometry on the antiplane impulse response of an embedded foundation is the topic. The foundations of a semicircular and a rectangular cross section are selected as characteristic examples. First, the impulse response for the semicylindrical foundation is obtained from its admittance derived by Luco and Trifunac. Then it is compared with the impulse response of the rectangular foundation as obtained by Thau and Umek. On the basis of this comparison, it can be concluded that the foundation geometry does not decisively influence its antiplane impulse response.

5.5-19 Saito, H. and Chonan, S., **Forced longitudinal vibration of an elastic circular rod on an elastic halfspace**, *The Journal of the Acoustical Society of America*, 59, *4*, Apr. 1976, 861–865.

A solution is given for the problem of the forced longitudinal vibration of an elastic circular rod, one end of which is attached to the surface of an elastic halfspace and to another end of which a periodic disturbing force is applied. Resonance curves for the motions of rods are derived using specific boundary conditions. Attention is directed to the effective damping of the motion of the rod due to dissipation of waves to infinity.

5.5-20 Berezantseva, E. V., **Approximation method for calculation of the displacement of foundations on sand base subjected to short-duration dynamic loadings** (Priblizhennyi sposob opredeleniya smeshenii fundamentov na peschanykh osnovaniyakh pri deistvii kratkovremennykh dinamicheskikh nagruzok, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh*, 197–201. (For a full bibliographic citation see Abstract No. 1.1–7.)

An approximation method is presented to calculate the irreversible displacements of foundations in the two-dimensional case with loadings applied at the center. The direction of the loading is either vertical or is along an inclined axis. The soil is regarded as an incompressible granular medium with internal friction. The boundaries of the shear domain are assumed to be close to the boundaries given by the theory of limit equilibrium. Further experiments are required to determine the scope of application of the formulas obtained.

5.5-21 Shikhiev, F. M. and Yakovlev, P. I., **On improved seismic analysis of retaining walls** (Ob utochnenii rascheta podpornykh stenok na seismicheskie vozdeistviya, in Russian), *Sovershenstvovanie metodov rascheta i proëktirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh*, 208–214. (For a full bibliographic citation see Abstract No. 1.1–7.)

A technique is presented to calculate active and passive soil pressures on the basis of the theory of limiting stress. The variation of soil pressure due to seismic excitations is investigated using this technique. The results are compared to those obtained using the methods prescribed by the Soviet building code.

● **5.5-22** Lee, A. J. H., **Case study of soil-structure interaction for nuclear power plants**, *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology*, Vol. 4, Paper K 3/1, 12. (For a full bibliographic citation see Abstract No. 1.2–11.)

The dynamic response of a turbine pedestal foundation was analyzed for earthquake and emergency unbalanced

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

loadings. A method is described for studying the effect of soil-structure interaction on such response. The objective is to determine a realistic design for the pedestal and the foundation mat. The method utilizes the concept of the foundation spring approach.

5.6 Experimental Investigations

● **5.6-1** Gungor, B. and Wasti, Y., **The effect of the amplitude of vertical vibration on the compression of noncohesive soils** (Dusey titresim genliginin kohezyonsuz zeminlerin sikistirilmasina etkisi, in Turkish), *Deprem Arastirma Enstitusu Bulteni*, 3, *10*, July 1975, 45–57.

Densification of dry noncohesive (granular) soils by vertical sinusoidal vibrations in cylindrical molds was studied experimentally. Ottawa sand and crushed basalt stone and three molds of different diameters and the same height/diameter ratio were used in the experiments. The effect of the displacement amplitude on the peak density obtained by vibrations and the acceleration required to achieve that density and the effect of the mold diameter on the peak density obtained by vibrations were investigated.

5.6-2 Novak, M. and Grigg, R. F., **Dynamic experiments with small pile foundations**, *Canadian Geotechnical Journal*, 13, *4*, Nov. 1976, 372–385.

Dynamic experiments with small pile foundations were conducted in the field. Individual piles and a group of piles were tested. The experimental data were compared with theoretical predictions made on the basis of a theory described previously by Novak. It was found that the theory predicts the general characteristics of the response very well. Resonant amplitudes and natural frequencies can be predicted reasonably well when a shear modulus of the soil derived from a static test of a pile is used and when a correction for the effect of pile group (interaction) is made.

5.6-3 Prevost, J.-H. and Hoeg, K., **Reanalysis of simple shear soil testing**, *Canadian Geotechnical Journal*, **13**, *4*, Nov. 1976, 418–429.

Simple shear devices are used fairly extensively in soil mechanics research, lately especially in connection with cyclic testing. This presentation starts out by extending existing isotropic, elastic analyses of stresses and strains in the simple shear test. The effects of partial differential boundary slippage at the interface between the soil specimen and the top and bottom caps of the apparatus are analyzed. A comparison is made between constant volume and truly undrained simple shear tests.

Because there is a coupling of shear and normal strains in soils, both may result from either shear or normal stresses, and vice versa. Therefore, an applied simple shear state of strain will not in general produce a simple shear state of stress in a soil sample, and it is shown analytically and experimentally that significant changes in lateral stresses do occur in simple shear tests. Such patterns of behavior are thereafter incorporated in the interpretation of cyclic loading simple shear tests on sand.

5.6-4 Perov, V. P., **Analysis of the response of pile models in multi-layered base to horizontal loads** (Issledovanie modelei svai v mnogosloinom osnovanii pri deistvii gorizontalnoi nagruzki, in Russian), *Sbornik trudov Leningradskogo inzhenerno-stroitelnogo instituta, 112*, 1976, 20–26.

The experimental technique for investigating piles in a three-layered medium is described. The experimental results are given. The effects of the thickness of the outer layer, the density of packing and the presence of a weak intermediate layer as well as other factors on the behavior or horizontally loaded piles are investigated.

● **5.6-5** Stavnitser, L. R. and Karpenko, V. P., **An experimental investigation of seismic effects on the bearing capacity of soils**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 30, 3. (For a full bibliographic citation see Abstract No. 1.2–6.)

Tests were conducted on soils at a field site by means of rectangular rigid test plates. Horizontal harmonic vibrations were induced in the soil mass by a vibrator embedded into the soil at some distance from the test plates. Each series of tests was carried out both under central and eccentric loading. The results show that for the same vertical loads affecting the test plate larger settlements were observed when vibrations in the soil were excited than under similar static conditions. The dependence of the ultimate strength of the foundation base of vibrations in the soil is a linearly decreasing function for various shapes of test plates and eccentricities of loads.

5.6-6 Root, R. M. and Cunniff, P. F., **Shock spectrum of a two-degree-of-freedom nonlinear vibratory system**, *The Journal of the Acoustical Society of America*, **60**, *6*, Dec. 1976, 1314–1318.

The shock spectrum of the foundation or isolator mass of a two-degree-of-freedom vibratory system was studied. The system had a cubic hardening elastic nonlinearity in the foundation or isolator restoring force. The system was impulsively shocked, and analytical, experimental, and numerical methods used to determine the resulting shock spectrum. The system was studied theoretically in two ways. An analytic solution was developed using a perturbation expansion of the nonlinear equations of motion, combined with an analytic solution for the shock spectrum due to the motion. A numerical solution to the nonlinear equations of motion was developed and used to verify the range of validity of the solution developed from the pertur-

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

bation expansion. The nondimensional parameter of the perturbation expansion was found to be directly dependent on the coefficient of the cubic hardening spring and the square of the initial velocity of the foundation or isolator mass, and inversely dependent on the generalized mass and the fourth power of the natural frequency of each linear mode. The numerical solutions of the equations of motion verified that variations in this parameter defined the degree to which the behavior of the nonlinear system departed from the behavior of the linear system. The theoretical studies predicted that the cubic hardening spring would cause the peaks in the shock spectrum corresponding to the linear natural frequencies to be shifted to higher frequencies, and that significant additional peaks would be introduced at combinations of the shifted frequencies. An experimental study of a two-degree-of-freedom system with a cubic hardening spring was undertaken. The experimental results verified shifting of the frequencies of the peaks and introduction of additional peaks in the shock spectrum.

● **5.6-7** Tokue, T., **Characteristics and mechanism of vibratory densification of sand and role of acceleration,** *Soils and Foundations,* **16,** *3,* Sept. 1976, 1–18.

Vertical vibration tests with a rigid mold as well as dynamic and cyclic simple shear tests were conducted on sand to investigate the characteristics and mechanism of densification. Vertical acceleration was applied to the sample in the vertical vibration tests, but the dynamic stress was very small relative to the confining stress. Dynamic and cyclic simple shear tests were conducted by using the same simple shear apparatus. Both dynamic shear stress and horizontal acceleration were applied to the sample in the dynamic simple shear tests. Cyclic simple shear tests were conducted under the following two kinds of conditions to investigate the role of acceleration in the densification of sand by vibration: (1) Only the cyclic shear stress, whose amplitude was equal to that of the dynamic shear stress, was applied to the sample by stress controlling. (2) The shear strain amplitudes, which were equal to that of the dynamic simple shear tests, were applied to the sample by strain controlling.

From these results, it was recognized that vibratory acceleration participated in the densification of sand in two ways. One was as an average dynamic stress and the other was as body force applied directly to each grain of sand. When dynamic shear stress became the dominant factor, the body force and the damping resistance in a sample influenced the densification of sand to a degree that was not negligible. Moreover, the relationship between the volume change and the shear strain was not significantly affected by the values of overburden pressures and accelerations or the randomness of shear strain amplitudes.

● **5.6-8** Oh-oka, H., **Drained and undrained stress-strain behavior of sands subjected to cyclic shear stress under nearly plane strain condition,** *Soils and Foundations,* **16,** *3,* Sept. 1976, 19–31.

A series of static drained and dynamic undrained cyclic shear tests of complete reversal were conducted to obtain fundamental information about the stress-strain behavior of sands using a ring torsion apparatus to apply cyclic shear stresses under a nearly plane strain condition.

In the static drained tests, the relative density of specimens ranged from 20% to 85%, and amplitudes of the cyclic shear stress were 0.21 and 0.33 kg/cm^2 under effective overburden pressure of 1.0 kg/cm^2. Test results indicated that there were hyperbolic relationships between the number of stress cycles N and volumetric strain accumulated up to the Nth cycle, between N and the shear modulus in the Nth cycle, and between N and total energy absorbed in a unit volume up to the Nth cycle, irrespective of initial relative density and of shear stress amplitudes.

Dynamic undrained test results indicated that the ratio of the increment of pore water pressure per stress cycle to dynamic shear stress amplitude was proportional to the fourth power of dynamic shear stress amplitude to initial effective overburden pressure for specimens of relative density of about 40%. And this relationship was explained by using the above-mentioned stress-strain behavior of the static drained tests.

● **5.6-9** Silver, M. L. *et al.,* **Cyclic triaxial strength of standard test sand,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT5,* Proc. Paper 12145, May 1976, 511–523.

A cooperative cyclic triaxial strength test program was performed by eight university, government, and consulting laboratories to define the cyclic strength characteristics, often called the liquefaction potential or cyclic mobility of a standard test sand. Other laboratories may check the adequacy of their cyclic triaxial test equipment and testing procedures by duplicating the results of these tests. It was found that a good degree of agreement for cyclic soil strength values could only be achieved among different laboratories when proper attention was given to the following testing details: (1) Great care must be taken in measuring specimen dimensions and weight to accurately calculate specimen dry weight; (2) tested specimen dry weights must be within 0.5 pcf (8 kg/m^2) of the specified value; (3) specimen preparation techniques must not deviate from the specified method; and (4) a smooth periodic loading wave form, such as a sine wave, should be used for testing.

● **5.6-10** Kim, J. B. and Brungraber, R. J., **Full-scale lateral load tests of pile groups,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT1,* Proc. Paper 11849, Jan. 1976, 87–105.

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

Twenty 10BP42 steel piles were driven in cohesive soil, six piles in each of three groups and two isolated single piles (one vertical and one batter). Two of the pile groups consisted of piles spaced 3 ft (0.9m) apart and one group consisted of piles at 4 ft (1.2m) spacing. The third group also featured a 3 ft (0.9m) spacing but four of the piles were battered, 3.5 vertical to 1 horizontal. The results indicate that each pile in a group with 4 ft (1.2m) spacing had a lateral load resistance approximately 3 to 6 times that of a single isolated vertical pile; for a group having 3 ft (0.9m) spacing, the lateral capacity per pile was only about twice that of a single pile. For a given lateral load, the pile group with batter piles deflected laterally only 1/3 to 1/2 as much as the pile group with vertical piles only. The maximum positive moments in the piles in the group with 3 ft (0.9m) spacing (Group II) were 1.6 times those in the piles with 4 ft (1.2m) spacing.

● **5.6-11** Yang, Z. and Hatheway, A. W., **Dynamic response of tropical marine limestone,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT2,* Proc. Paper 11893, Feb. 1976, 123-138.

Widespread bodies of marine limestone border many tropical coastlines. Consequently, siting and design of nuclear power plants will depend in part on the dynamic properties of the limestone. Results of comprehensive laboratory studies performed on tropical marine limestone are presented. Resonant column and cyclic triaxial test methods were utilized to determine dynamic soil properties. Laboratory work was supplemented by in situ geophysical measurements for dynamic property determinations. Appreciable differences were observed between field and laboratory determined values of shear wave velocities; causal effects were attributed to hard zones causing first arrival from refracted wave, secondary time effect occurring in the laboratory test, etc. Laboratory results for the established geologic unit also indicated nonlinear stress-strain behavior similar to that noted in the literature for soils.

● **5.6-12** Khosla, V. K. and Wu, T. H., **Stress-strain behavior of sand,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT4,* Proc. Paper 12079, Apr. 1976, 303-321.

The paper presents results of laboratory static and cyclic loading tests on Ottawa sand. A variety of stress paths were used. The results are analyzed by elastic-plastic-work hardening theory. It is shown that the Mohr-Coulomb failure criterion, combined with an expanding elliptical cap, can satisfactorily represent material behavior. The proposed model makes it possible to predict soil response to diverse stress paths from the results of hydrostatic compression and drained triaxial compression tests. The model is applicable to material behavior under both static and cyclic loading.

● **5.6-13** Yegian, M. K. and Oweis, I. S., **Discussion of: Liquefaction and cyclic mobility of saturated sands,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT3,* Proc. Paper 11949, Mar. 1976, 265-268. (*By Castro, G., Proc. Paper 11388, June 1975.)

● **5.6-14** Saito, J. and Hirama, K., **Behavior of lime- or cement-stabilized soil under dynamic loading [Part 2]** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 11,* 1975, 43-47.

Static and dynamic triaxial compression tests were carried out on nonstabilized and stabilized soils to clarify the properties under dynamic loading. Outlines of testing methods, test results and a number of interesting tendencies are presented.

● **5.6-15** Tsunoda, T. *et al.,* **Vibration test of pile foundation** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 11,* 1975, 32-36.

The authors have carried out a number of tests with various combinations of the conditions of a foundation-pile-soil system, pile top and vibrating force magnitude. The details of these tests are reported.

● **5.6-16** Saito, J., Goto, Y. and Kimura, K., **Dynamic shear modulus of elasticity of cohesive soils in small strain regions** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 10,* 1975, 63-66.

A new type test apparatus was constructed to measure the dynamic shear modulus of the elasticity of soil, which is necessary in earthquake response analysis of ground motion. This apparatus has some weak points in the control of the test conditions, but has special features such as high sensitivity of strain measurement (i.e., up to 10^{-5}) and a wide range in frequency (i.e., 0.2~30 Hz).

Two kinds of cohesive soils were tested. The test results were analyzed to show the relations between the strain amplitude and the shear modulus or the equivalent damping coefficient and also the fatigue effect from repeated shearing on the shear modulus. Conclusions similar to those of Seed and Shibata were reached. A method of setting the dynamic elastic limit and applying elasto-plastic theory to the earthquake response analysis of ground is discussed.

● **5.6-17** Saito, J. and Hirama, K., **Behavior of lime- or cement-stabilized soil under dynamic loading [Part 1]** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 10,* 1975, 86-90.

Dynamic triaxial compression tests were carried out on nonstabilized and stabilized soils to clarify the properties under dynamic loading. Outlines of testing methods, test

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

results and a number of interesting tendencies are given in this report.

● **5.6-18** Howells, D. A., **Discussion of: Liquefaction and cyclic mobility of saturated sands,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT3,* Proc. Paper 11949, Mar. 1976, p. 265. (*By Castro, G., Proc. Paper 11388, June 1975.)

● **5.6-19** Ishibashi, I. and Sherif, M. A., **Closure of: Soil liquefaction by torsional simple shear device,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT1,* Proc. Paper 11816, Jan. 1976, 110-111. (*By Ishibashi, I. and Sherif, M. A., Proc. Paper 10752, Aug. 1974.)

● **5.6-20** Matlock, H. and Foo, S. H. C., **Discussion of: Full-scale lateral load tests of pile groups,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT12,* Proc. Paper 12585, Dec. 1976, 1291-1292. (*By Kim, J. B. and Brungraber, R. J., Proc. Paper 11849, Jan. 1976.)

● **5.6-21** Gleser, S. M., **Discussion of: Full-scale lateral load tests of pile groups,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT12,* Proc. Paper 12585, Dec. 1976, 1288-1291. (*By Kim, J. B. and Brungraber, R. J., Proc. Paper 11849, Jan. 1976.)

● **5.6-22** Castro, G., **Closure of: Liquefaction and cyclic mobility of saturated sands,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT12,* Proc. Paper 12585, Dec. 1976, 1277-1278. (*By Castro, G., Proc. Paper 11388, June 1975.)

● **5.6-23** Skoglund, G. R., Marcuson, III, W. F. and Cunny, R. W., **Evaluation of resonant column test devices,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT11,* Proc. Paper 12567, Nov. 1976, 1147-1158.

Resonant column tests were performed by six participants in a program designed to evaluate results from various devices. The participants were Drnevich, Hardin and Woods; Shannon & Wilson, Inc.; the U.S. Army Engineer Cold Regions Research and Engineering Lab.; and the U.S. Army Engineer Waterways Experiment Station. Tests were performed on fine sand and clayey silt. Each participant was given more or less identical samples of material and specific instructions intended to keep the test conditions as nearly identical as possible. Differences in shear and compression moduli ranged from minus 19% to plus 32% of the average. These differences could be explained largely by differences in unit weight and specimen preparation techniques. No systematic differences were noted because of differences in apparatus used.

● **5.6-24** Anderson, D. G. and Richart, Jr., F. E., **Effects of straining on shear modulus of clays,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT9,* Proc. Paper 12428, Sept. 1976, 975-987.

High strain amplitude resonant column tests were conducted on hollow cylindrical samples of five natural cohesive soils and one artificially prepared bentonite silica flour mixture to assess effects of shearing strain amplitude and repetitions of shearing strain on dynamic shear modulus. Results of these tests show that: (1) a threshold level for strain exists below which the modulus is virtually independent of strain or number of cycles of strain; (2) cycles of strain cause a progressive decrease in modulus when strain amplitude exceeds a threshold level; (3) cycling above a threshold level causes a decrease in low-amplitude modulus measured immediately after the end of the high-amplitude cycling; and (4) a time-dependent increase in low-amplitude modulus occurs if additional cycles of high-amplitude strain are not applied. Cycle and post-straining effects are then empirically related to strain amplitude, number of repetitions of strain, and time.

● **5.6-25** De Alba, P., Seed, H. B. and Chan, C. K., **Sand liquefaction in large-scale simple shear tests,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT9,* Proc. Paper 12403, Sept. 1976, 909-927.

Samples used in the study were approximately 90-in. long by 42-in. wide and 4-in. thick and they were subjected to uniform stress cycles at a frequency of 4 Hz. Measurements of changes in pore-water pressure and shear strain development are presented for samples prepared at relative densities of 54%, 68%, 82% and 90%, and the results are interpreted to determine the values of stress ratio causing initial liquefaction and different degrees of shear strain, giving appropriate consideration to the effects of system compliance. It is shown that a condition of initial liquefaction could be induced in all samples; but for samples with relative densities greater than about 45%, initial liquefaction was accompanied by limited shear strains, the limiting strain potential decreasing with the relative density. The test results are compared with data from other investigations and conclusions are drawn concerning the accuracy of tests on small-scale samples and shaking table investigations.

● **5.6-26** Castro, G. and Christian, J. T., **Shear strength of soils and cyclic loading,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT9,* Proc. Paper 12387, Sept. 1976, 887-894.

This paper describes the results of undrained triaxial tests on undisturbed samples of three soils: (1) a slightly clayey silt, (2) a silty clay and (3) a sand. The static undrained loading tests to failure were performed after various numbers of cycles of undrained cyclic loading as well as with no previous cyclic loading. No drainage was allowed between undrained cyclic loading and the und-

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

rained monotonic shearing. The ultimate undrained shear strength was essentially independent of the previous cyclic loading, but it did correlate well with the void ratio. The modulus of deformation was greatly reduced by the cyclic loading. Therefore, the major effect of undrained cyclic loading on the subsequent undrained behavior is to increase the strains while the available ultimate strength is largely unchanged.

● **5.6-27** Oweis, I. S., **Discussion of: Liquefaction and cyclic mobility of saturated sands,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT6,* Proc. Paper 12163, June 1976, 654–656. (*By Castro, G., Proc. Paper 11388, June 1975.)

● **5.6-28** Mulilis, J. P., Horz, Jr., R. C. and Townsend, F. C., **The effects of cyclic triaxial testing techniques on the liquefaction behavior of Monterey No. 0 sand,** *Misc. Paper S-76-6,* Soils and Pavements Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Apr. 1976, 40.

The objectives of this investigation were to (a) participate in a cooperative cyclic triaxial testing program with seven other laboratories and (b) determine the effect of various testing techniques and equipment, e.g. specimen preparation and compaction, B value, density, loading wave form, and compaction equipment on the cyclic triaxial strength of a sand.

A total of 28 saturated isotropically consolidated-undrained cyclic triaxial tests were conducted on 2.8 in. diameter by 7 in. high specimens of Monterey No. O sand. Specimens were compacted to 60 percent relative density (98.5 pcf) using three different compaction techniques (i.e., dry rodding, moist rodding, and moist tamping) with some instances of undercompacting the lower layers. Some specimens were compacted to a relative density of about 66 percent while others were tested when the B value reached approximately 0.91. The effect of loading wave shape was evaluated by subjecting specimens to either a rectangular, near triangular, or sinusoidal loading wave form.

It was found that if careful attention was given to testing details good agreement could be obtained by different testing laboratories. The test results also demonstrated that the cyclic triaxial strength is greatly influenced by the method of specimen compaction, density, and shape of loading wave. Specimens prepared moist, either rodded or tamped, were 38–58 percent stronger than comparable specimens compacted dry to the same relative density. A 12 percent increase in the relative density was sufficient to cause an increase in strength of approximately 22–30 percent. Furthermore, the severity of loading wave form on the cyclic triaxial strength was found to decrease in the following order: square, nearly triangular, and sine, with strength differences of 13 to 30 percent being due to the loading wave shape. The test results also showed that for this sand, changing the diameter of the compaction foot, decreasing the molding water content from 12.8 to 8.0 percent, or testing specimens with a B value of 0.98 or 0.91 had no significant effect on the cyclic triaxial strength of specimens.

● **5.6-29** Aramaki, G. and Koga, K., **An experimental study of the characteristic of the subgrade reaction in the poor subsoil** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 153, 415–422. (For a full bibliographic citation see Abstract No. 1.2–9.)

● **5.6-30** **Determination of soil liquefaction characteristics by large-scale laboratory tests,** *NUREG-0027, NRC-6,* Shannon & Wilson, Inc., and Agbabian Assoc., Seattle, Washington, and El Segundo, California, Sept. 1976, 153.

The testing program described in this report was carried out to study the liquefaction behavior of a clean, uniform, medium sand. Horizontal beds of this sand 42 in. by 90 in. by 4 in. were prepared by pluviation with a special sand spreader, saturated, and tested in a shaking table system designed for this program, which applied a horizontal cyclic shear stress to the specimens. Specimen size was selected to reduce boundary effects as much as possible.

Values of pore pressures and shear strains developed during the tests 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 the stress ratio causing liquefaction at the various relative densities.

The study showed that liquefaction of the sand at relative densities greater than approximately 50 per cent is a matter of definition of the maximum acceptable shear strain. The results were compared with those of small-scale laboratory simple shear tests, and it was found that liquefaction test results obtained from Roscoe-type simple shear equipment closely approximated the shaking table results. Finally, correction factors were established for cyclic triaxial liquefaction tests on specimens of the same sand, prepared by the same method.

Values of the stress ratio representative of cyclic simple shear conditions are obtained applying correction factors on the order of 0.61 to 0.66 to the triaxial test data, depending on the number of cycles involved. To obtain values representative of field conditions, correction factors of 0.55 to 0.59 should be applied.

5.6-31 Gorelyshev, P. I., **Experimental investigations of the dynamic structural stability of noncohesive soils subjected to shear** (Eksperimentalnye issledovaniya dinamicheskoi ustoichivosti struktury nesvyaznykh gruntov pri

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

sdvige, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 172–178. (For a full bibliographic citation see Abstract No. 1.1–7.)

The experimental apparatus and methodology are described and the fundamental results presented. The investigations were carried out using simple shear with controlled static and dynamic stresses and deformations. General formulas are obtained to calculate the dynamic stability parameters of noncohesive soils from given data characterizing their density, static stress and the frequency of dynamic shear excitation.

5.6-32 Gorelyshev, P. I. and Pyshkin, O. B., **Investigation of the dynamic stability of the body of sand-filled rock dams** (Issledovanie dinamicheskoi ustoichivosti gruntov tela kamenno-peschanoi plotiny, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 178–182. (For a full bibliographic citation see Abstract No. 1.1–7.)

Results of experimental investigations of the dynamic stability of saturated sand filling between rocks are presented. The effects of various construction technologies (underwater, above-water and mixed) are studied. The investigations were carried out using a large-scale shaking table. It is found that the dynamic stability of the sand fillings is the same irrespective of the technology employed, provided their density is identical.

● 5.6-33 Seed, H. B., Pyke, R. and Martin, G. R., **Effect of multi-directional shaking on liquefaction of sands,** *EERC 75-41,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Dec. 1975, 47. (NTIS Accession No. PB 258 781)

Both qualitative results of shaking table tests on dry sand and the results of a quantitative evaluation using data from cyclic simple shear tests are used to show that the shear stresses causing liquefaction under multidirectional shaking with two equal components are 10 to 20 percent less than the shear stresses causing liquefaction under one-directional shaking. Since in practice it is unlikely that a second component of motion would be equal to the single component used for design purposes, it is suggested that a reduction of 10 percent in the shear stresses causing liquefaction is a suitable general procedure for accounting for the effects of multidirectional shaking. Combining this factor with the correction factor which should be applied to cyclic triaxial test results in order to obtain the shear stresses causing liquefaction under simple shear conditions with unidirectional shaking, an overall correction factor of about 0.57 is suggested on the basis of studies conducted on normally consolidated samples of Monterey No. 0 sand.

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

6. Dynamics of Structures

6.1 General

6.1-1 21-IL RILEM Committee, **The effect of impact loading on building: State-of-the-art report,** *Matériaux et Constructions,* 8, *44,* Mar.-Apr. 1975, 77-130.

Committee 21 of RILEM (International Union of Testing and Research Labs. for Materials and Structures) was formed at a meeting held in Copenhagen from Feb. 25-26, 1971. The committee obtained information about the occurrence and the nature of impact loadings on buildings and the implications of such loadings for structural safety and economy. In addition, the committee investigated the possibility of devising standard tests for impact resistance.

Throughout its work, the committee concentrated on the limited topic of impact loading and did not consider all types of dynamic loadings. The committee ignored earthquake loadings because it felt they were covered by other organizations. However, impulsive loadings closely aligned with impact loadings were considered.

The report is arranged into the following parts: 1: Introduction; 2: Examples of impact and and impulsive loading in the field of civil engineering; 3: Theoretical analysis of stress and strain propagation during impact; 4: Properties of materials at high rates of straining or loading; 5: Impact resistance of reinforced and prestressed concrete members; 6: Practical application to testing, design and research.

6.1-2 Ward, H. S., **Dynamic disturbances,** *Civil Engineering,* Aug. 1975, 40-49.

In this first part of a two-part article, the relationships between the principal factors influencing structural vibration are identified. The problem is divided into three main components: the source, the building system and the response. An important property of the source is its energy content as a function of frequency. As far as the structural system is concerned, its dynamic characteristics play a vital role. Information on the dynamic characteristics of structures and dynamic loads is included.

● **6.1-3** Vanmarcke, E. H. *et al.,* **Evaluation of seismic safety of buildings - Report No. 3: Comparison of seismic analysis procedures for elastic multi-degree systems,** *R76-5,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Jan. 1976, 94.

This report compares different approaches to the dynamic analysis of multidegree-of-freedom systems and especially evaluates the distribution of computed responses for the different approaches. Three methods of analysis are considered—exact time integration of real and artificial motions, a response spectrum approach, and a random vibrations approach—for several shear-type buildings covering a range of fundamental periods. It is concluded that the random vibration analysis gives a (theoretical) distribution of responses which is in good agreement with the distribution obtained by repeated time integration of artificial motions. The mean responses of the real motions agree with those predicted by random vibration but, as expected, the scatter about the mean responses is much larger.

● **6.1-4** Leyendecker, E. V. *et al.,* **Abnormal loading on buildings and progressive collapse: An annotated bibliography,** *NBS Building Science Series 67,* National Bureau of Standards, U.S. Dept. of Commerce, Washington, D.C., Jan. 1976, 60.

This bibliography on the subjects of abnormal loading and progressive collapse is an annotated listing of articles that have appeared in the technical literature from 1948 through 1973. Both subject and author indexes are included. The references listed have been selected as most

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

representative of the historical background and best representing the origin and present state-of-the-art of current practice without undue repetition of data.

References pertaining to characteristics, frequencies, incidents, tests, design procedures, and regulations for many types of abnormal loadings are included. Among these are various types of accidental impacts, construction loads, explosions, faulty practices, and extreme atmospheric loads. Heavy emphasis was placed on referencing applicable building codes and regulations pertaining to the subjects of progressive collapse and abnormal loadings. This bibliography also contains numerous references to contemporary professional opinion as expressed in editorials and discussions of the subject and, particularly, on the various regulations proposed. A large number of proposed analysis and design procedures, as well as applicable test results, are referenced.

6.2 Dynamic Properties of Materials and Structural Components

● 6.2-1 Celebi, M. and Citipitioglu, E., **Natural periods of structural systems** (Yapi sistemlerinin ozel periyodlari, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* 2, *7,* Oct. 1974, 1–8.

The design of structural systems against wind and earthquake loads is dependent upon the natural period which can be evaluated by different procedures. In this paper, some of these procedures are both reviewed and discussed.

● 6.2-2 van der Burgh, A. H. P., **On the higher order asymptotic approximations for the solutions of the equations of motion of an elastic pendulum,** *Journal of Sound and Vibration,* 42, *4,* Oct. 22, 1975, 463–475.

The elastic pendulum is an example of a phenomenon exhibiting nonlinear internal resonance when the uncoupled normal frequency ratio equals two. In this paper the case where the uncoupled normal frequency ratio equals one is studied. When the analysis is limited to approximations up to $O(\epsilon)$, it is found that the amplitudes are constant, which means that no energy transfer between the two modes for all relevant initial conditions will take place. This is in contrast with the case where the uncoupled normal frequency ratio equals two.

● 6.2-3 Swamy, R. N. and Bandyopadhyay, A. K., **The elastic properties of structural lightweight concrete,** *Proceedings, The Institution of Civil Engineers,* 59, Paper 7749, Sept. 1975, 381–394.

A knowledge of the elastic properties of concrete is essential for the design of reinforced and prestressed concrete structures. Such information is generally lacking in CP 110 for structural lightweight concrete. Data are presented on static and dynamic moduli, Poisson's ratio and the damping properties of structural lightweight concrete, and the effects of strength, age and curing conditions are discussed. Equations are presented for predicting static modulus, dynamic modulus and Poisson's ratio. An equation also is developed for estimating the static modulus from the dynamic modulus, which is easier to determine.

● 6.2-4 Mukherjee, P. R. and Coull, A., **Vibrations of coupled shear walls on framed supports,** *Proceedings, The Institution of Civil Engineers,* 59, Paper 7824, Sept. 1975, 469–485.

A method is presented for the analysis of the free vibrations of coupled shear walls supported on columns or a portal frame. The analysis is based on the continuous medium approach, and Hamilton's principle is used to derive the governing differential equations and boundary conditions. Transverse, longitudinal and rotatory inertia effects are included. The solution of the dynamic equations is achieved by a numerical method based on the Ritz-Galerkin technique, yielding both vibration frequencies and mode shapes. The influence of the flexibility of the supporting structure and of the different inertia forces on the vibration characteristics are investigated for a typical coupled shear wall system.

● 6.2-5 Zhunusov, T., **Earthquake resistance of prestressed reinforced concrete,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 118, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

The paper reports on estimation of the seismic resistance of buildings having prestressed reinforced concrete supporting construction on the basis of analysis of strength and dissipative properties of prestressed reinforced concrete elements subjected to dynamic loading.

As a general characteristic of the system's response to dynamic effects, a dynamic coefficient is considered which for elastoplastic systems is a ratio of an equivalent static force to the maximum value of an external dynamic force. As dissipative characteristics, energy capacity and a vibration damping coefficient are considered, the latter being a ratio of the decrement to the vibration period over the whole operation range of an element from the moment of loading to the failure phase.

● 6.2-6 Ghosh, S. K. and Fintel, M., **Effects of sectional shape on the strength and ductility of slender structural walls in earthquake-resistant multistory buildings,** *Proceedings of the International Symposium on Earthquake*

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

Structural Engineering, Vol. II, 1181–1193. (For a full bibliographic citation see Abstract No. 1.2–7.)

An in-depth study of the effects of sectional shape on the behavior of structural walls (shear walls) is reported in this paper. The approach used is a computer simulation of the response of a large number of structural wall sections with varying shapes. Sectional shape is varied by changing three variables: flange width, flange thickness, and web thickness, while keeping a fourth variable, total depth, unchanged. The result for each section analyzed is obtained in the form of its moment-curvature diagram. Each of these diagrams is idealized into a bilinear curve which can be completely defined in terms of four parameters: initial elastic stiffness, yield level, post-yield stiffness, and ductility ratio. Conclusions are drawn concerning the effects on these four parameters of the above three variables.

6.2–7 Caputo, M., **Vibrations of an infinite plate with a frequency independent Q,** *The Journal of the Acoustical Society of America,* **60,** *3,* Sept. 1976, 634–639.

The dissipation in an elastic medium is represented by a dissipation mechanism which is similar to one used in an earlier paper, but is simpler and has a frequency-independent Q^{-1}. The vibrations of a plate are studied by obtaining the eigenfrequencies, the amplitude of the displacement, the dispersion relation, the Q^{-1}, the hysteresis cycle, and the yield stress.

6.2–8 Sakata, T., **Natural frequencies of orthotropic rectangular plates with varying thickness,** *The Journal of the Acoustical Society of America,* **60,** *4,* Oct. 1976, 844–847.

An approximate formula is derived for the estimation of the fundamental natural frequency of the simply supported orthotropic rectangular plate with thickness varying linearly in one direction. The accuracy of the formula and the influence of the flexural rigidity $D°_1$ on the natural frequency are discussed.

6.2–9 Shtol, A. T., **Investigation of stability of columns subjected to seismic excitation** (Issledovanie ustoichivosti kolonny pri seismicheskom vozdeistvii, in Russian), *Trudy TsNII stroitelnykh konstruktsii, 44,* 1975, 59–65.

Stability of frame columns subjected to seismic loads is investigated. Normal and tangential forces and bending moments are taken into account. The seismic excitation is regarded as a stationary random process with a horizontal and a vertical component.

6.2–10 Mirza, S. and Setiawan, B., **Free vibration of two span rectangular plates with some non-classical boundary conditions,** *International Journal of Mechanical Sciences,* **18,** *4,* Apr. 1976, 165–170.

This paper deals with the vibration of two span rectangular plates resting on linear and torsional springs. The two opposite continuous edges of the plate are considered as simple supports. The resulting equations are general. Numerical results have been obtained by varying spring stiffness and the aspect ratio. Some limiting cases of interest have also been developed.

● 6.2–11 Nau, R. W., **Computation of upper and lower bounds to the frequencies of clamped cylindrical shells,** *Earthquake Engineering and Structural Dynamics,* **4,** *6,* Oct.–Dec. 1976, 553–559.

Methods for obtaining bounds on natural frequencies are demonstrated for the free vibration of thin, clamped cylindrical shells. The upper bounds are obtained by a Rayleigh-Ritz procedure. The lower bound method used is an extension of one previously applied to simpler structures; the extension is needed to adjust to limit points in a spectrum. For both bounds the problems reduce to matrix eigenvalue problems. Numerical techniques are employed to keep the order of these reduced problems small.

6.2–12 Goroshko, O. A. and Emelyanenko, V. V., **Dynamic stability of anisotropic composite shells** (Dinamicheskaya vstoichivost sloistykh anizotropnykh obolochek, in Russian), *Prikladnaya mekhanika,* **11,** *7,* 1975, 42–49.

Dynamic stability of orthotropic composite shells subjected to periodic external loading is investigated with various types of boundary conditions. The linear theory of dynamic stability is used.

6.2–13 Zhinzher, N. I., **Dynamic boundary effects in orthotropic elastic shells** (Dinamicheskie kraevye effekty v ortotropnykh uprugikh obolochkakh, in Russian), *Prikladnaya matematika i mekhanika,* 39, *4,* 1975, 752–755.

The theory of dynamic boundary effects is applied to free vibrations of thin elastic shells. Principally flexural vibrations are considered. The conditions of Vlasov's equations are assumed to hold. A differential equation with constant coefficients is obtained. A solution is found in the form of a sum of a generating solution and a summand representing dynamic boundary effects. The properties of the characteristic roots of the equation and their relationship to the type and velocity of boundary damping effects are investigated.

● 6.2–14 Saito, J., Koide, T. and Kimura, K., **Ground vibrations and countermeasures (Part 3): Interception methods based on vibration damping wall in the ground-Outdoor experiments on ordinary street** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 11,* 1975, 37–42.

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

Using data from experiments of vibration damping walls, taking into consideration construction on ordinary streets and given the conditions of Kanto loam ground, vibration generating methods and depth of wall embedment, the authors describe comparison studies of the effects of differences in wall layer form using concrete and rigid foam polyurethane as the wall damping materials.

6.2-15 Sorokin, E. S., **Frequency-independent internal friction in materials and Focht's hypothesis** (Chastotnonezavisimoe vnutrennee trenie v materialakh i gipoteza Fokhta, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 2,* 1976, 68–72.

Focht's hypothesis assumes that internal friction in solids is proportional to the velocity of deformation. An analysis of applications of this hypothesis is given and the narrow range of problems where its application does not lead to substantial error is defined exactly. The use of Focht's hypothesis is found to be inadmissible in problems involving systems with frequency-independent internal friction having more than one degree-of-freedom. In the case of systems having one degree-of-freedom, the hypothesis is applicable only for calculation of forced vibration amplitudes arising from a single harmonic excitation.

6.2-16 Vasile, Z., **Dynamic strength of concrete subjected to repeated loadings** (Dinamicheskaya prochnost betona pri nemnogochislennykh povtornykh nagruzheniyakh, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 4,* 1976, 54–57.

Elastic characteristics of concrete are investigated, including the modulus of elasticity, shear modulus and Poisson's coefficient. Studied are the effects of the grade and age of concrete, the presence of stress, the frequency and velocity of loading and the skewness coefficient on the elastic characteristics.

6.2-17 Bubnovich, E. V., **Investigation of resonances in forced coupled vibrations of a flexible cable** (Issledovanie rezonansov pri vynuzhdennykh vzaimosvyazannykh kolebaniyakh gibkoi niti, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 4,* 1976, 44–47.

Forced vibrations of a flexible cable with fixed supports all on the same level are considered. The investigation of vibrations with simultaneous external and internal resonance of the first and second order is emphasized. Amplitude versus frequency response characteristics are derived for stationary vibration modes.

6.2-18 Stratonova, M. M. and Tolmach, G. U., **Free vibrations of a quadratic plate supported by bars at the four corners** (Sobstvennye kolebaniya kvadratnoi plastiny, opirayushcheisya na sterzhni v uglovykh tochkakh, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 2,* 1976, 55–57.

The finite element method is employed to determine the natural frequencies and mode shapes of a quadratic plate supported at the corners by bars. The effects of the stiffness of the bars on the behavior of the system are investigated. The results obtained here may be applied in the evaluation of the strength of beamless floor slabs.

● 6.2-19 Sharma, S. K. and Bhattacharyya, R. K., **An analytical model for uniaxial cyclic inelastic behavior of reinforced concrete**, *CERL-TR-M-180,* U.S. Army Construction Engineering Research Lab., Champaign, Illinois, May 1976, 24. (NTIS Accession No. AD A024 910)

This report presents an analytical model for uniaxial cyclic inelastic behavior of reinforced concrete. The model was synthesized from the analytical models for plain concrete and reinforcing steel. The parameters of the models were derived from extensive experimental data taken from the literature. Cyclic experimental tests on plain concrete and steel involving large inelastic strains were simulated by the plain concrete and reinforcing steel models; the experimental and analytical results showed close agreement.

● 6.2-20 Eringen, A. C. and Suhubi, E. S., **Elastodynamics; Vol. II: Linear theory**, Academic Press, Inc., New York, 1975, 1003.

This volume is devoted to an exposition of the dynamic theory of linear isotropic elasticity. The scope of this treatise includes a thorough discussion of the fundamental theorems concerning elastodynamics and various mathematical methods of solutions and their applications to a class of problems in one, two, and three dimensions. The uniqueness and reciprocal theorems are presented and applied. The solutions by means of potentials, singular solutions, complex function technique, methods of integral equations, and integral transforms are explored. Free and forced vibrations of bodies, of finite and infinite extent, having boundaries that are plane, cylindrical (circular, elliptic), ellipsoidal, and spherical shapes are discussed in some detail. Both initial- and boundary-value problems, including displacement traction and mixed boundary conditions, are solved. The book closes with a chapter on diffraction theory.

● 6.2-21 Eringen, A. C. and Suhubi, E. S., **Elastodynamics; Vol. I: Finite motions**, Academic Press, Inc., New York, 1974, 341.

Chapter I deals with the development of the fundamental equations of the dynamic theory of thermoelasticity. The concepts relevant to finite deformations, strains, rotations, their invariants, length, area, volume changes, compatibility conditions of strain, kinematics of continua,

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

global and local balance laws, thermodynamics of continua, and constitutive theory are discussed concisely. The field equations are obtained for the exact nonlinear theory and the linear and quadratic theories. Chapter II deals with the propagation of singular surfaces. Geometric, kinematic, and dynamic conditions are obtained and used for the study of shock waves and acceleration waves. In Chapter III the solution is presented of various problems for the finite motions of elastic bodies: radial oscillations of cylinders and spheres and a discussion of the simple wave theory. Chapter IV is devoted to a study of small motions superimposed on large static deformations, a topic which is fundamental to stability theory. Appendixes A and B on tensor analysis and the theory of characteristics provide the necessary background for study of Volume I.

● **6.2-22** Pulmano, V. A. and Gupta, R. K., **Frequency analysis of tapered rectangular plates by the finite strip method,** *UNICIV Report No. R159,* School of Civil Engineering, Univ. of New South Wales, Kensington, N.S.W., Australia, 1976, 21.

In this paper, the frequency analysis of rectangular plates of variable thickness using higher order finite strips is presented. The stiffness and mass matrices of a higher order strip whose thickness variation may be defined by one coordinate polynomial of any degree in its transverse direction has been derived in a simple manner, and with the same ease as that of the conventional finite strip. Results from numerical examples are in excellent agreement with other solutions.

● **6.2-23** Brunelle, E. J. and Robertson, S. R., **Vibrations of an initially stressed thick plate,** *Journal of Sound and Vibration,* 45, *3,* Apr. 8, 1976, 405–416.

By using previously derived equations for a thick plate in an arbitrary state of nonuniform initial stress, the vibrational behavior of a thick, simply supported rectangular plate subjected to initial stress is investigated. The initial stress is taken to be a combination of pure bending plus extensional stress in the plane of the plate. The vibrational behavior is correlated to the buckling behavior in order to explain how, in certain cases, higher modes can vibrate at frequencies lower than those of the lower order modes.

● **6.2-24** Jones, R. and Milne, B. J., **Application of the extended Kantorovich method to the vibration of clamped rectangular plates,** *Journal of Sound and Vibration,* **45**, *3,* Apr. 8, 1976, 309–316.

The transverse vibrations of rectangular plates are analyzed by using the extended Kantorovich method of variational calculus. Several combinations of simply supported and clamped boundary conditions are discussed, and closed-form solutions are obtained.

● **6.2-25** Lees, A. W., Thomas, D. L. and Wilson, R. R., **Analysis of the vibration of box beams,** *Journal of Sound and Vibration,* 45, *4,* Apr. 22, 1976, 559–568.

The natural frequencies and mode shapes of a number of box beams are calculated by using the finite element displacement method. The structures are considered as assemblages of plates, and in general it is necessary to consider both the in-plane and transverse motion of the plates. A method of representing these two types of motion in the analysis of the vibrations of box beams is presented. A number of box beams of varying sectional parameters are analyzed as systems of plates and the results compared with the predictions of Euler and Timoshenko beam theories. The comparisons show that for short beams constructed of thin plates the new method can successfully represent the localized plate deformations, which cannot be described by beam theory.

● **6.2-26** Yamaki, N. and Nagai, K., **Dynamic stability of circular cylindrical shells under periodic shearing forces,** *Journal of Sound and Vibration,* **45**, *4,* Apr. 22, 1976, 513–527.

On the basis of the Donnell-type equations modified with the transverse inertia force, the dynamic stability of circular cylindrical shells under periodic shearing forces is theoretically analyzed under four different boundary conditions. The Galerkin procedure is used to reduce the problem to that for a finite-degree-of-freedom system, the stability boundaries of which are determined by utilizing Hsu's general result for the coupled Hill equations. Calculations are carried out for typical shells under each boundary condition and the instability regions of practical importance, associated with both principal and combination parametric resonances, are clarified for relatively low frequency ranges, with the effect of static shearing forces taken into consideration.

● **6.2-27** Srinivasan, R. S. and Bobby, W., **Free vibration of non-circular cylindrical shell panels,** *Journal of Sound and Vibration,* **46**, *1,* May 8, 1976, 43–49.

In the free vibration analysis of clamped non-circular cylindrical shell panels, a matrix method has been used to solve the governing differential equations, which have variable coefficients. The effect of the curvature, thickness ratio and aspect ratio on the natural frequencies has been studied. The results obtained for circular cylindrical panels are compared with other available results. The convergence of the solution is found to be good.

● **6.2-28** Godwin Joseph, M. and Radhakrishnan, R., **Natural patterns of vibration of building frames,** *Journal of Sound and Vibration,* **46**, *1,* May 8, 1976, 15–32.

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

World codes for aseismic design of structures prescribe empirical rules for determining the fundamental period of buildings approximately and no rules have been laid down for the higher mode frequencies. For preliminary designs, the structural engineer looks for handy methods for determining the fundamental and a few higher mode frequencies. Stodola's method of iteration with the dynamic and the inverse dynamic matrix, respectively, provide the fundamental and highest frequencies. Buildings in vibration can be categorized as "bending", "shear" or of "linear" type. The frequency ratio patterns of buildings can be idealized as the classical ones for pure bending and pure shear cantilever beams. For the linear pattern, a rule for frequency ratio has been derived. Based on the frequency patterns, a frequency characteristics chart has been developed and is presented in the paper; it provides good trial frequency values for use in the Holzer technique for the determination of the intermediate frequencies.

A nondimensional parameter termed the "nature parameter" connecting the fundamental and highest frequencies and the total number of floors has some interesting properties relevant to the pattern of vibration and indicates the inherent behavior of a building in vibration. The nature parameters for four well-known buildings in the world and for a number of frames including those of U.S. researchers have been compared with the ideal patterns.

Results of a computerized case study of 156 shear frames of 5 to 40 stories and various column stiffness patterns indicate that the frequencies follow a defined pattern depending upon the story stiffness and that a nondimensional "period parameter", connecting the total story stiffness and and mass, predicts exactly the fundamental frequency on the basis of some derived expressions. Frequency ratios for determining higher frequencies, mode shapes and mode participation factors also follow regular patterns and the values can be predicted from tables. The salient features are presented in the paper.

● **6.2-29** Goel, R. P., **Free vibrations of a beam-mass system with elastically restrained ends,** *Journal of Sound and Vibration,* 47, *1,* July 8, 1976, 9-14.

The vibration problem of a beam with an arbitrarily placed concentrated mass and elastically restrained against rotation at either end is solved by using Laplace transforms. The effects on eigenfrequencies of the system produced by varying the ratios of the concentrated mass to the mass of the beam, stiffness of the end spring to the stiffness of the beam and position of the mass to the total length of the beam are presented. The effect of neglecting the mass of the beam is considered.

● **6.2-30** Goel, R. P., **Transverse vibrations of tapered beams,** *Journal of Sound and Vibration,* 47, *1,* July 8, 1976, 1-7.

Transverse vibrations of linearly tapered beams, elastically restrained against rotation at either end, have been investigated. Results for the first three eigenfrequencies, with different values of stiffness ratios (ratio of spring stiffness and beam stiffness at either end) and taper ratio are presented. Cases of a tapered cantilever beam with a concentrated mass at the free end and spring hinged at the other end have also been presented.

● **6.2-31** Kanaka Raju, K. and Venkateswara Rao, G., **Axisymmetric vibrations of circular plates including the effects of geometric non-linearity, shear deformation and rotary inertia,** *Journal of Sound and Vibration,* **47,** *2,* July 22, 1976, 179-184.

In this paper, axisymmetric vibrations of circular plates are studied, with inclusion of the effects of geometric nonlinearity, shear deformation and rotatory inertia. The finite element method is employed to formulate the problem. Both simply supported and clamped plates are considered. The results indicate that the influence of geometric nonlinearity is greater when the effects of shear deformation and rotatory inertia are included than when they are neglected.

● **6.2-32** Rao, D. K., **Transverse vibrations of pre-twisted sandwich beams,** *Journal of Sound and Vibration,* **44,** *2,* Jan. 22, 1976, 159-168.

A set of equations of motion governing the bending and extensional displacements of a pretwisted sandwich beam of rectangular cross section are derived by using Hamilton's principle. The middle viscoelastic core is assumed to deform mainly through the classical shearing mechanism. The eigenvalues and loss factors of simply supported pretwisted sandwich beams are computed by using the variational method. Analysis of the results revealed that pretwisting the beam increases the real part of the eigenvalue by as much as 20% while reducing the loss factor by as much as 30%. The loss factor of very soft, thick-cored beams is especially sensitive to even small angles of pretwist; e.g., a 22.5° pretwist may reduce the loss factor by as much as 80%. The effect of pretwist is, however, shown not to be appreciable for soft, thin-cored beams. In any case, pretwisting of the beam has a detrimental effect on the maximum loss factor that one can obtain for a specific size of the beam when only the shear parameter of the beam is changed.

● **6.2-33** Chandrasekaran, K. and Kunukkasseril, V. X., **Forced axisymmetric response of circular plates,** *Journal of Sound and Vibration,* **44,** *3,* Feb. 8, 1976, 407-417.

Forced axisymmetric response of circular plates is considered on the basis of an improved theory which takes into account the effect of rotatory inertia and shear deformation. Explicit solutions are obtained for distributed, ring

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

and concentrated impulsive loadings with half-sine, triangular, blast and rectangular pulse shapes. Natural frequencies are presented for the first 20 modes of four plate models with clamped and supported edges. Numerical results are presented to illustrate the differences between the improved and classical theories, and the effects of edge conditions, loading conditions, pulse shapes and pulse durations.

● 6.2-34 Banerjee, M. M., **On the non-linear vibrations of elastic circular plates of variable thickness,** *Journal of Sound and Vibration,* 47, *3,* Aug. 8, 1976, 341-346.

An analysis of the large amplitude vibrations of circular plates of variable thickness is presented. The method is based on Berger's assumption of neglecting the second invariant of the middle surface strain in the expression corresponding to the total potential energy of the system, in conjunction with a Galerkin procedure.

● 6.2-35 Ramamurti, V. and Pattabiraman, J., **Free vibrations of circular cylindrical shells,** *Journal of Sound and Vibration,* 48, *1,* Sept. 8, 1976, 137-155.

The finite element method is used to predict the free vibration dynamic behavior of circular cylindrical shells. A suitable shape function for the circumferential displacement distribution has been proposed. This reduces the three-dimensional character of the problem to a two-dimensional one. The simultaneous iteration method to determine the eigenfrequencies and eigenvectors is utilized for solving the eigenvalue problem. The accuracy of the method has been checked by verifying the results of known cases. Finally an experimental shell structure containing elastic rings welded at the ends has also been analyzed and the experimental results compared with the theoretical ones.

● 6.2-36 Aksu, G. and Ali, R., **Free vibration analysis of stiffened plates using finite difference method,** *Journal of Sound and Vibration,* 48, *1,* Sept. 8, 1976, 15-25.

Free vibration characteristics of rectangular stiffened plates having a single stiffener have been examined by using the finite difference method. A variational technique has been used to minimize the total energy of the stiffened plate and the derivatives appearing in the energy functional are replaced by finite difference equations. The energy functional is minimized with respect to discretized displacement components and natural frequencies and mode shapes of the stiffened plate have been determined as the solutions of a linear algebraic eigenvalue problem. The analysis takes into consideration inplane deformation of the plate and the stiffener and the effect of inplane inertia on the natural frequencies and mode shapes. The effect of the ratio of stiffener depth to plate thickness on the natural frequencies of the stiffened plate has also been examined.

● 6.2-37 Sato, K., **Free vibration analysis of a composite rectangular membrane consisting of strips,** *Journal of Sound and Vibration,* 49, *4,* Dec. 22, 1976, 535-540.

The work is concerned with the free vibration problem of a composite rectangular membrane consisting of strips of different materials under certain initial conditions. Discussion of the special case of a homogeneous membrane is also included.

● 6.2-38 Raju, I. S., Venkateswara Rao, G. and Kanaka Raju, K., **Effect of longitudinal or inplane deformation and inertia on the large amplitude flexural vibrations of slender beams and thin plates,** *Journal of Sound and Vibration,* 49, *3,* Dec. 8, 1976, 415-422.

Large amplitude flexural vibrations of slender beams and thin circular and rectangular plates have been studied when a compatible longitudinal or inplane mode is coupled with the fundamental flexural mode. It is shown that the effect of longitudinal or inplane deformation and inertia is to reduce the nonlinearity in the flexural frequency-amplitude relationship. Further, for slender beams and thin plates, the effect of longitudinal or inplane inertia is negligible.

● 6.2-39 Chonan, S., **The free vibrations of elastically connected circular plate systems with elastically restrained edges and radial tensions,** *Journal of Sound and Vibration,* 49, *1,* Nov. 8, 1976, 129-136.

The free vibrations of elastically connected circular plate systems with elastically restrained edges and initial radial tensions are investigated analytically. By using the equations developed for the general *n*-plate system, the plate systems consisting of three and two identical plates with identical boundary conditions and a uniform radial tension are treated in detail. Both axisymmetric and nonaxisymmetric vibrations are considered. Attention is directed to the influence of the radial tension and the elastic edge constraints on the first nine eigenvalues and the corresponding natural frequencies of the systems.

● 6.2-40 Markus, S., **Damping properties of layered cylindrical shells, vibrating in axially symmetric modes,** *Journal of Sound and Vibration,* 48, *4,* Oct. 22, 1976, 511-524.

The damping of cylindrical shells coated with unconstrained layers of viscoelastic material either on one side of the shell (inside or outside) or on both sides is estimated. The basic equations of motion are derived which describe harmonic forced flexural damped vibrations in axisymmetric modes. For pure sinusoidal modes expressions for the overall loss factors are given. The damping properties of cylindrical shells of finite length, coated on the inside or outside, or on both sides (symmetrically or unsymmetrically), are compared. Classical thin shell theory is used for the analysis. It is shown how two-layered damped shells differ from two-layered damped beams. The extent of damping reduction in shells resulting from the fact that the shell cross section is closed is discussed.

● **6.2-41** Chandra, R., **Large deflection vibration of cross-ply laminated plates with certain edge conditions,** *Journal of Sound and Vibration,* 47, *4,* Aug. 22, 1976, 509–514.

This paper deals with the large deflection flexural vibration of unsymmetric cross-ply laminated plates which are simply supported at two opposite edges and clamped at the other two edges. Stress-free and movable in-plane boundary conditions are considered. Nonlinear frequency is obtained as a function of lamination parameters, material constants, aspect ratio, linear frequency and amplitude of vibration. Nonlinear frequency to linear frequency ratio versus amplitude curves are presented for isotropic, glass-epoxy, graphite-epoxy and boron-epoxy plates.

● **6.2-42** Jacquot, R. G., **The forced vibration of singly modified damped elastic surface systems,** *Journal of Sound and Vibration,* **48,** *2,* Sept. 22, 1976, 195–201.

A technique is developed to predict the forced vibration of membranes, beams, plates or shells when they have attached to them at a single point a linear lumped parameter element or assembly of elements. The distributed parameter element is treated as viscously damped and the lumped parameter assembly may also contain viscous dampers. Solution is obtained in terms of generalized Fourier series in the unmodified eigenfunctions for the distributed portion of the system and the principle of superposition is used to handle the imposed forces and those generated at the attachment. The method is illustrated by investigating a uniformly forced simply supported rectangular plate with a lumped mass at its center and that of a point forced simple beam with a rigid pin support imposed at some arbitrary point.

● **6.2-43** Hyer, M. W., Anderson, W. J. and Scott, R. A., **Non-linear vibrations of three-layer beams with viscoelastic cores I. Theory,** *Journal of Sound and Vibration,* **46,** *1,* May 8, 1976, 121–136.

Approximate equations of motion are developed for large amplitude motions of three-layered axially restrained unsymmetrical beams with viscoelastic cores. The external force consists of a constant plus an oscillatory term. The combination of this form of forcing and the large amplitude motions cause the beam to respond at multiples of the forcing frequency. This can lead to difficulties in the complex modulus approach to viscoelasticity. These are overcome here through use of hereditary integrals and their relationships with complex moduli. Theoretical results on the frequency response of clamped, symmetrical beams are compared with earlier experimental work. On the whole, reasonable agreement is found.

● **6.2-44** Sun, C. T. and Shafey, N. A., **Influence of physical non-linearity on the dynamic behaviour of composite plates,** *Journal of Sound and Vibration,* **46,** *2,* May 22, 1976, 225–232.

Influence of the physically nonlinear property is investigated for three types of motion in laminated plates, namely harmonic waves, free vibrations and shock waves. Only the nonlinearity in the transverse shear deformation is included.

● **6.2-45** Harari, A., **Generalized non-linear free vibrations of prestressed plates and shells,** *International Journal of Non-Linear Mechanics,* **11,** *3,* 1976, 169–181.

This paper investigates the nonlinear free vibration of prestressed plates and shells in a general form. The analysis includes the effects of in-plane inertia. The analysis is based on the nonlinear equations of motion and uses a perturbation procedure. No assumption is made a priori for the form of the time or space mode. The boundary conditions are treated in a general manner including boundary conditions where nonlinear stress resultants are specified. The method is illustrated by three examples.

● **6.2-46** Yamada, Y. and Kawano, K., **Dynamic response analysis of systems with non-proportional damping,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 235, 823–830. (For a full bibliographic citation see Abstract No. 1.2-9.)

In this paper, the dynamic analysis of a tower and pier system of a long-span suspension bridge with nonproportional damping is performed by means of the finite element method; the diagonalization of the nonproportional damping matrix is explained.

● **6.2-47** Leung, K. E., **Seismic stresses of piping systems and equipment on heat exchanger supporting structures,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 7/6, 14. (For a full bibliographic citation see Abstract No. 1.2-11.)

A three-dimensional structural analysis program was used to analyze an unsymmetrical heat exchanger steel frame structure with an externally attached piping system and a laminated steel stack. The analysis indicated that the seismic stresses in the piping system considerably exceeded those from the conventional piping analysis in which the coupling effect between the piping system and the structure was neglected. It appears that to calculate the stresses due to the differential seismic displacements of the pipe anchors according to ASME Section IV may not be sufficient in this

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

case. Local stresses such as those at the stack bracing connections were computed by modeling the local system as finite elements and using the response spectra generated there. These local stresses were then combined with those obtained from the overall 3D structural response analysis. Some equipment and piping may have gaps. This was treated by using gap elements.

In conclusion, for nuclear piping systems with anticipated high temperature loads, it is necessary to consider the coupling effect between the piping and the building in the seismic stress computation.

● 6.2-48 Kotsubo, S. *et al.*, **Earthquake response characteristics of three spans continuous truss bridge with high piers** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 245, 903–910. (For a full bibliographic citation see Abstract No. 1.2–9.)

Takachiho bridge is a three-span continuous truss girder railway bridge built on tall piers. Previously, the authors calculated the earthquake response of this bridge using the dynamic characteristics gained from a horizontal vibration test. In this paper, the authors treat the bridge as a space truss. Using an analytical model of the bridge and the substructure method, the authors calculate the natural frequencies and modes of vibration. The theoretical results agree well with the field vibration test results. The maximum displacement response obtained using the response spectrum method agrees well with that obtained by the method of modal analysis. Those factors which are most important for aseismic design are discussed.

● 6.2-49 Nagasaka, T., **An analytical study on restoring force characteristics of reinforced concrete framed structures**, *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 246, 911–918. (For a full bibliographic citation see Abstract No. 1.2–9.)

In this paper an analytical approach is developed which takes into account the restoring force characteristics of reinforced concrete framed structures based on structural and cross-sectional geometry and material properties. Interactive bond actions between concrete and steel, correlative effects of axial force and bending moment on member stiffness and rigid body rotation including the P-Δ effect are considered. The method is applied to several structural models with differing element arrangements. The results are discussed.

● 6.2-50 Matsuoka, O. and Yahata, K., **A proposal for the wave propagation in gridworks** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 232, 799–806. (For a full bibliographic citation see Abstract No. 1.2–9.)

Recently, the influence of the wave difference and the phase difference in earthquake response analysis for structures having long spans has been investigated. For this purpose, it is better to investigate dispersion curves, which represent the important characteristics regarding the dynamic properties of a medium.

In this paper, continuum theory is used to derive dispersion curves for wave propagation in gridworks. The curves are verified using a matrix method. The curves are studied qualitatively and quantitatively for the purpose of obtaining information on wave propagation. The value obtained is compared with the eigenvalue found from the matrix analysis. The impulsive wave propagation problem is solved. The results agree with those found using the dispersion curves.

6.3 Dynamic Properties of Linear Structures

6.3-1 Karmishin, A. V. *et al.*, **Statics and dynamics of thin shell structures** (Statika i dinamika tonkostennykh obolochechnykh konstruktsii, in Russian), Mashinostroenie Publishing, Moscow, 1975, 376.

Strength, stability and vibrations of symmetrically loaded structures consisting of shells of revolution joined either directly or via elastic frames are investigated.

Special attention is given to numerical algorithms for nonlinear problems and to algorithms for finding critical loads, natural frequencies and mode shapes. Buckling of symmetrically loaded shell structures is considered. The methodological basis of the algorithms is explained. Results of investigations of the stability and vibrations of shells of revolution and related structures are reported.

6.3-2 Shtol, A. T., **Instability analysis of columns subjected to seismic excitation** (Issledovanie ustoichivosti kolonny pri seismicheskom vozdeistvii, in Russian), *Trudy TsNII stroitelnykh konstruktsii, 44,* 1975, 59–65.

Stability of columns of frame buildings subjected to seismic loading is investigated. Normal and tangential forces and bending moments are incorporated into the analysis. The seismic excitation is regarded as a stationary random process. Both horizontal and vertical excitations are considered.

● 6.3-3 Abramowitz, J. S., **Determination of the natural modes of a complex elastic structure in terms of the natural modes of the unconstrained components**, *Methods of Structural Analysis*, Vol. II, 689–706. (For a full bibliographic citation see Abstract No. 1.2–3.)

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

The purpose of this paper is to describe a different procedure for calculating the natural modes of a complex elastic structure. The procedure is similar to the conventional Rayleigh-Ritz procedure but makes use of the unconstrained natural mode shapes of the components as shape functions. The unconstrained natural mode shapes are those for the component without constraints at the interfaces it makes with neighboring components. With this choice for the shape functions, it will be convenient to satisfy internal force continuity at the component interfaces. Continuity of displacements will not be required and as a result, the displacements will in general be discontinuous at the interfaces. With the continuous internal force distribution across the interfaces, the new procedure yields improved results for the internal force distribution compared with the results given by the conventional Rayleigh-Ritz procedure.

● 6.3-4 Sandi, H., **Seismic effects on rheologically nonhomogeneous structures,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 87, 6. (For a full bibliographic citation see Abstract No. 1.2-6.)

The analysis of seismic effects on structures is performed currently under the assumption that the mechanical systems dealt with are rheologically homogeneous. The linear dynamic analysis of such systems under the assumption referred to is reduced on this basis to a classical eigenvalue problem. However, the assumption of rheologic homogeneity does not correspond to real structural properties. This is due essentially to two causes: (a) The systems as a rule have parts consisting of materials with different properties. (b) The stiffness moduli of materials corresponding to pure dilatation and to pure shear deformation are different from the viewpoint of rheologic properties.

Case (a) is found most frequently when ground-structure systems are dealt with or when light appendix-like structures are supported by massive structures. Case (b) is found when a rigorous treatment is adopted for systems where at least two different moduli occur (e.g., bending and shear deformation of beams and dilatation and shear deformation of continua.

This paper presents briefly both aspects referred to. Particular consideration is given to the computations involved.

● 6.3-5 Nemtchinov, Y. I. *et al.,* **Analysis of earthquakeproofness of thin-walled spatial systems,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 84, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

● 6.3-6 Shaaban, S. H. and Nash, W. A., **Response of an empty cylindrical ground supported liquid storage tank to base excitation,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1219-1230. (For a full bibliographic citation see Abstract No. 1.2-7.)

The structure under consideration is an elastic cylindrical liquid storage tank attached to a rigid base slab. A finite element analysis is presented for the free vibrations of the empty tank permitting determination of natural frequencies and associated mode shapes. The response of the empty tank to simple deterministic base excitation as well as to artificial earthquake excitation also is determined by finite elements.

● 6.3-7 Jeary, A. P. and Irwin, A. W., **Vibrations of a nuclear power station charge hall,** *Earthquake Engineering and Structural Dynamics,* 4, 3, Jan.-Mar. 1976, 221-229.

In an effort to determine the nature and size of the response of unusually shaped power station buildings, an investigation of one power station building has been made, both theoretically and experimentally. The dynamic response of the structure to wind excitation has been monitored, analyzed and compared with theoretical values obtained from an analysis of a simplified structure. The shapes of pure modes of vibration are consistent with the predicted shapes, and correlation between measured and predicted frequency is better than 10 per cent. Damping measurements from the experimental study are included where the signal/noise ratio permitted, and these were found to be in a range that is consistent with values found in other types of steel construction.

6.3-8 Uzdin, A. M., **On the problem of the role of nonelastic resistance in the analysis of foundation-structure interaction during earthquakes** (K voprosu ob uchete neuprugikh soprotivlenii pri analize vzaimodeistviya sooruzheniya i ego osnovaniya pri zemletryasenii, in Russian), *Izvestiya BNII gidrotekhniki, 108,* 1975, 193-197.

The effects of internal friction inside a structure-foundation system on the fundamental vibration frequency and the intensity of damping and also on the stable vibration amplitude in the case of harmonic excitation are analyzed. Two hypotheses are used for internal friction: Voigt's and Sorokin's. The only case when the two hypotheses lead to substantially different results is in a narrow band of critical values when the system is in transition from periodic to nonperiodic motion.

6.3-9 Reznikov, L. M., **On some features of the behavior of systems in transition stage subjected to random excitations** (O nekotorykh osobennostyakh povedeniya sistem v perekhodnom rezhime pri sluchainykh vozdeistviyakh, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 4,* 1976, 57-58.

It is well known that the methods of Voigt and of Sorokin lead to differing results when applied to the

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

behavior of systems with friction in the transition stage. The divergence of results is shown to arise from application of the methods of the complex theory of internal friction in a nonstationary problem.

● **6.3-10** Haviland, R., **Evaluation of seismic safety of buildings - Report No. 5: A study of the uncertainties in the fundamental translational periods and damping values for real buildings,** *R76-12,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Feb. 1976, 115.

The first step in the seismic safety analysis of buildings is to determine the distribution of responses caused by uncertainty in design ground motion parameters. Further uncertainties due to expected period and damping values will alter the distribution of responses obtained for a model which is described by deterministic dynamic properties.

Data is collected herein on the fundamental translational periods and damping values for real buildings by means of a literature survey. Sources of uncertainty are identified and methods to statistically quantify this information are investigated. Finally, methodologies are suggested for incorporating the results into the safety analysis.

● **6.3-11** Caughey, T. K. and Vijayaraghavan, A., **Stability analysis of the periodic solution of a piecewise-linear nonlinear dynamic system,** *International Journal of Non-Linear Mechanics,* 11, 2, 1976, 127-134.

The stability of the periodic solution under harmonic excitation of a nonlinear dynamic system with "linear hysteretic damping" is examined proceeding from first principles. The method can be extended to the case of multidegree-of-freedom systems unlike regular perturbation procedure.

● **6.3-12** Yamada, M. and Kawamura, H., **Aseismic capacity of buildings—Based upon resonance-fatigue-characteristics** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 202, 567-574. (For a full bibliographic citation see Abstract No. 1.2-9.)

● **6.3-13** Beliveau, J.-G., **Identification of viscous damping in structures from modal information,** *Journal of Applied Mechanics,* 43, Series E, 2, June 1976, 335-339.

The identification of damping, stiffness, and mass parameters from modal information is formulated within a general Bayesian framework. A modified Newton-Raphson scheme is used to modify parameter estimates, given natural frequencies, associated damping constants, mode shapes, and phase angles. Actual data from a nine-story steel structure are used in an application of the method.

● **6.3-14** Yamabe, K., Jin, M. and Kanai, K., **On the natural period in actual buildings** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 254, 975-982. (For a full bibliographic citation see Abstract No. 1.2-9.)

The present investigation was carried out in order to obtain a more appropriate empirical formula concerning the natural period of actual high rise buildings. The period estimation procedure used is a statistical method utilizing a correlation factor. The relation between the fundamental periods obtained by vibration tests as well as by microtremor observations and the number of stories of actual buildings is investigated.

● **6.3-15** Ozaki, M. and Ishiyama, Y., **An evaluation method for the earthquake resistant capacity of reinforced concrete and steel reinforced concrete columns,** *BRI Research Paper No. 64,* Building Research Inst., Japan, Ministry of Construction, Tokyo, Feb. 1976, 19.

This paper deals with an evaluation method for the earthquake-resistant capacity of reinforced concrete and steel-reinforced concrete columns, based on the philosophy that the safety of a structure against strong earthquakes should be considered in terms of the collapse of the entire structure. The force deflection curves of column specimens subjected to axial force and repeated and reversed lateral loading of considerable intensity are utilized. The method also contains a proposal for determining a new allowable stress system of reinforced concrete and steel-reinforced concrete columns subjected to strong earthquakes by taking the collapse of structures into consideration. This method is applicable to the evaluation of the earthquake-resistant capacity of girders, girder and column joints, shear walls and any structures constructed of reinforced concrete and steel reinforced concrete.

6.4 Deterministic Dynamic Behavior of Linear Structures

● **6.4-1** Gero, J. S., **The behaviour of building structures under lateral loads,** *Proceedings of the Australian and New Zealand Conference on the Planning and Design of Tall Buildings,* 544-555. (For a full bibliographic citation see Abstract No. 1.2-1.)

The behavior of tall buildings under static lateral loads is discussed. Four structural systems (frames, interacting frames and shear walls, tube structures and "top-hat" structures) are examined. The parameters studied are beam inertia, column area, column inertia, wall inertia, wall shear area, beam depth and column width.

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

● **6.4-2** Moroianu, A. and Mihalcea, A., **Consideration on resistant dams in seismic areas,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 54, 6. (For a full bibliographic citation see Abstract No. 1.2-6.)

A buttress dam and a rockfill dam, having the same height and on the same site, were analyzed. The ground had a great compliance with respect to the concrete. A horizontal motion in the plane of the buttress caused a strong response. However, the response was weaker for a horizontal motion orthogonal to the plane of the buttress. An even weaker response resulted for the rockfill dam.

● **6.4-3** Rajanna, B. C. and Munirudrappa, N., **Response of highway bridges under dynamic load,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 151, 8. (For a full bibliographic citation see Abstract No. 1.2-6.)

In this paper the dynamic response of a highway bridge grid is reported. Experimental and theoretical studies of the free and forced vibrations carried out for an orthogonal bridge grid consisting of five cross beams and three longitudinal beams are presented. The effect of the slab is considered by the additional masses lumped at the joints. Modal analysis was used to evaluate the dynamic response of a bridge grid model by assuming a linearly varying, time-dependent force moving at constant velocity. The deflections were calculated at different mass points and were studied for different moving load speeds. The methods established for free and forced vibrations are quite general and, as such, they can be applied to bridge grids of other configurations and boundary conditions with suitable modification.

● **6.4-4** Malyshev, L. K. and Shulman, S. G., **Seismic stability of massive structures,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 51, 4. (For a full bibliographic citation see Abstract No. 1.2-6.)

The paper presents investigations of the stress-strain state of massive structures under seismic action. The principal task of the work lies in comparing the results obtained in terms of theories of static and linear-spectral seismic stability. Considering a prescribed foundation movement and the propagation of nonstationary elastic waves in the foundation-structure system, the authors present the structure as a two-dimensional and three-dimensional problem. Structural material is considered as a homogeneous linear-elastic continuum. A massive structure of a rectangular shape and a dam of a triangular shape are subjected to vertical and horizontal seismic action. Appropriate one-dimensional static and dynamic problems are solved by well-known elementary methods, while two-dimensional problems are solved by the finite difference method and the finite element method. Optic [*sic*] methods are used to solve elastic models. Numerical results are presented.

● **6.4-5** Monroe, N. J. and Dasa, N., **Dynamic earthquake analysis of a bottom supported industrial boiler,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 869-882. (For a full bibliographic citation see Abstract No. 1.2-7.)

In this paper, a dynamic earthquake analysis of a large bottom-supported boiler is presented. The assumptions and modeling techniques necessary for developing the mathematical model are stated, and the dynamic response of the structure and the resultant stresses are tabulated. The results of the dynamic analysis are compared to the results of the static earthquake analysis which is presently required by the various nationally accepted building codes. In addition, results are presented of a dynamic analysis of the same boiler using a more detailed mathematical model. The advantages of both models are discussed and recommendations are made based on a comparison of the results presented.

● **6.4-6** Munirudrappa, N., **Dynamic response of bridge grid under moving force,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 393-412. (For a full bibliographic citation see Abstract No. 1.2-7.)

This paper deals with the analytical and experimental verification of an orthogonal bridge grid (consisting of longitudinal beams and cross beams) subjected to a moving force under constant velocities. The natural frequency, mode shapes and the dynamic response of the bridge grid are presented for two cases, lumping the masses at the joints, in one case, for the self weight of the grid and, in the second case, for the self weight of the grid plus the weight of the slab. Modal analysis is used for the evaluation of the dynamic response of the bridge. The moving force is treated as a transient pulse which is triangular in nature and assumed to be acting at the modal points. The resulting differential equation is solved by using Laplace's transformation, taking into account the two-dimensional behavior of the structure. Theoretical and experimental comparisons are carried out for forced vibration effects. The results are compared with Timoshenko's beam theory. The variation in impact factors is studied for the load moving on different beams.

● **6.4-7** Irvine, H. M. and Griffin, J. H., **On the dynamic response of a suspended cable,** *Earthquake Engineering and Structural Dynamics,* **4**, *4,* Apr.-June 1976, 389-402.

Linearized equations are derived to account for the additional tensions and deflections induced by dynamically exciting a suspended cable. Wave-type and modal solutions

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

are presented to explore the influence of a fundamental geometric and elastic parameter.

● 6.4-8 Karasudhi, P., Tsai, Y. C. and Chau, K. P., **Earthquake response of a tall multi-flue stack,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 699–709. (For a full bibliographic citation see Abstract No. 1.2-7.)

The seismic response of a tall multiflue stack is investigated. Each flue consists of a number of equal lengths supported on platforms. The platforms are connected to rubber bearings which, in turn, are supported by the outer shell. The outer shell mass was idealized into the same number of elements as the flue lengths. The system was represented by a number of masses with associated springs and damping elements. The equation of motion was derived by means of a Lagrangian equation, incorporating the rotational effects of all masses. The stiffness of the outer shell and the flues were computed on the assumption that they behaved like slender beams. The damping matrix in the system was assumed to be proportional to the stiffness matrix of the system. The equations of motion were solved by the classical normal mode method.

The reinforced concrete stack chosen for illustrating the analysis is 242 m high. The outer shell with a 26 m diameter encloses three elliptical flues. Comparing the responses for cases with rubber bearings with those having rigid bearings, the authors found that rubber bearings reduce the fundamental frequency, maximum shear force and bending moment in the outer shell by approximately 50%.

● 6.4-9 Shaaban, S. H. and Nash, W. A., **Finite element analysis of a seismically excited cylindrical storage tank, ground supported, and partially filled with liquid,** *UMASS GI39644-3,* Dept. of Civil Engineering, Univ. of Massachusetts, Amherst, July 1976, 112.

The structure under consideration is an elastic cylindrical liquid storage tank attached to a rigid base slab. The tank is filled to an arbitrary depth with an inviscid, incompressible liquid. A finite element analysis is presented for the free vibrations of the coupled system permitting determination of natural frequencies and associated mode shapes. The response of the partially filled tank to artificial earthquake excitation is also determined through use of finite elements. Examples, together with program listing, are offered.

● 6.4-10 Zeck, U. I., **Seismic resistance of precast concrete panel buildings - Report No. 1: Joints in large panel precast concrete structures,** *R76-16,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Jan. 1976, 174.

Large panel structures can be desirable from an economic viewpoint; however, the presence of joints may be a reason for concern in seismic regions or progressive collapse situations. Since the floor and wall assemblies in large panel buildings are expected to act as diaphragms and shear walls in lateral load resistance, there is a need to understand joint behavior and the influence of joints on overall structural response.

In this report, the forces which various loading conditions require joints to transfer and the means by which they may do so (transfer mechanisms) are investigated. Some typical joint types (including plain and reinforced concrete, post-tensioned, welded and bolted) have been identified. These may be categorized on the basis of location (horizontal or vertical) or construction (wet, semi-wet or dry). Available information on the behavior of various joint types has been studied, and based on this, the potential behavior of joints under ultimate loads, including reversals, and their possible influences on structural performance are discussed.

● 6.4-11 Prendergast, J. D. and Choi, C. K., **Three-dimensional seismic structural analysis of Letterman Hospital,** *CERL-TR-M-175,* Construction Engineering Research Lab., U.S. Dept. of Army, Champaign, Illinois, Jan. 1976, 49.

This report summarizes the results of a three-dimensional seismic analysis of the primary structural elements of Letterman Hospital, Presidio of San Francisco, performed using response spectrum modal analysis procedures. The results of the three-dimensional analysis are compared with the results of a two-dimensional analysis of the hospital, which used time history modal analysis procedures.

Overall agreement between the two analyses was good considering (1) the difference in analysis methods, (2) the numerous instances where engineering judgment was required to idealize the complex structure and compute the required structural properties, and (3) the assumptions inherent in the computer programs. Both analyses, as compared to the original seismic design forces, provide (1) more realistic estimates of the dynamic forces the structure may be expected to resist, (2) the influence of the higher modes on the response of the structure, and (3) the actual distribution of the dynamic forces among the structural members. Furthermore, computing the dynamic response of Letterman Hospital using the response spectrum modal analysis method was not significantly more complex than computing the structure's static response when subjected to equivalent lateral loadings.

● 6.4-12 Laura, P. A. A., Pombo, J. L. and Luisoni, L. E., **Forced vibrations of a circular plate elastically restrained against rotation,** *Journal of Sound and Vibration,* **45,** 2, Mar. 22, 1976, 225–235.

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

Simple polynomial expressions and a variational approach are used to study the behavior of a thin, elastic, circular plate elastically restrained along the boundary and subjected to sinusoidal excitation. The results are in excellent agreement with those obtained by using Nowacki's solution, valid only for a simply supported edge and a highly idealized material.

● 6.4-13 Goodno, B. J. and Gere, J. M., **Earthquake behavior of suspended-floor buildings,** *Journal of the Structural Division, ASCE,* **102,** *ST5,* Proc. Paper 12105, May 1976, 973–992.

The earthquake integrity of a new type of multistory building, referred to as suspended-floor high rise, is investigated. In these structures floors are supported by steel tension elements called hanger straps which are draped over the end walls of two reinforced concrete core towers. Limited-capacity connecting elements called bumper bars couple the motions of the suspended floors and the supporting core towers. A three-dimensional analytical model and pertinent dynamic analysis techniques are presented. Finite element representations of the core towers are incorporated into substructure models which feature all basic components of the system. The model is assembled using series elimination, and the linear dynamic response to several earthquake loadings is provided to illustrate structure behavior. Dynamic testing performed at the site of two existing suspended-floor buildings produced natural frequencies and damping values.

● 6.4-14 Shaaban, S. H. and Nash, W. A., **Response of an empty cylindrical ground supported liquid storage tank to base excitation,** Engineering Research Inst., Univ. of Massachusetts, Amherst, Aug. 1975, 98.

The structure under consideration is an elastic cylindrical liquid storage tank attached to a rigid base slab. A finite element analysis is presented for the free vibrations of the empty tank permitting determination of natural frequencies and associated mode shapes. The response of the empty tank to several simple deterministic base excitations as well as to artificial earthquake excitation is also determined by finite elements. Examples together with complete program listings are offered.

6.4-15 Korenev, B. G., Volotskii, M. Ya. and Fuks, O. M., **Vibration damping of tall smokestacks using dampers with bounded vibration amplitudes** (Vibrogashenie vysokikh dymovykh trub pri ogranichennykh amplitudakh kolebanii mass gasitelei, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 5,* 1976, 59–62.

Problems of vibration damping of tall smokestacks subjected to wind resonance are considered. The effects of various factors on damping efficiency are analyzed. Damping properties necessary for reducing internal stresses in the case of two types of structures assuming that the dampers have bounded relative vibration amplitudes are discussed.

● 6.4-16 Villasor, Jr., A. P., **Seismic response analysis of a reactor coolant pump,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 7/7, 12. (For a full bibliographic citation see Abstract No. 1.2-11.)

The Westinghouse Type 93A reactor coolant pump (RCP) is analyzed for seismic response. Simply described, the RCP is a vertical, single-stage, centrifugal pump designed to move 90,000 gpm (568 m^3/sec) of water and driven by a 6000 hp motor for use in the PWR primary system.

The RCP assembly is generally axisymmetric and is modeled using 3-dimensional finite elements to represent its parts. These finite elements are of the types normally found in general purpose computer programs such as ANSYS or NASTRAN. The structural frame and the rotating shaft are the principal branches of the model. Each consists of a series of pipe elements complemented by mass elements. Orthogonal sets of linear spring elements connect the branches at the bearings and possibly at each labyrinth. Fluid elements are added to include the interaction between the shaft and the pump case through the intervening water mass. To complete the model, stiffness matrix elements representing the support structure and the neighboring loop piping are attached. It is impractical to idealize faithfully each geometric irregularity. Several adjacent sections are combined into one suitable element with total stiffness and mass equivalence. The number of elements in the model is thus minimized. Shear deflection of the pipe elements is considered; mass and mass inertia are lumped at nodal points, as needed, to compensate for the actual material distribution. The RCP model contains 82 nodes, 155 elements and 160 master dynamic degrees-of-freedom.

The seismic analysis is performed by the spectrum method in ANSYS, with seismic velocity as the input excitation parameter. In each computer run, the model is excited with a set of three orthogonal spectra: SSE-X, SSE-Y and SSE-Z. The first and third spectra are exactly the same in magnitude and are horizontal with a given orientation. SSE-Y is vertical at 2/3 the magnitude of the horizontal spectrum. Additional sets of horizontal excitation on another orientation can be included in the same run. For each load excitation, the modal displacement, forces and stresses are computed at each node. Then a post-run subroutine calculates the square root of the sum of the squares (RSS) for each quantity. The vector sum of one horizontal RSS and the vertical RSS are recorded as the final values: SSE X-Y and SSE Y-Z. To determine which orientation of the horizontal spectra was the worst stress case, six 15-degree positions were run for the softest and stiffest support matrices. The 0-degree and 30-degree orien-

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

tations appeared to give high stresses with the model on the stiffest support. Absolute displacements were reviewed for selected nodes along the model branches. For clearance evaluation, the relative displacements at bearing and labyrinths were computed for comparison with actual gaps. Finally, the accelerations of nodes previously chosen were listed in the printout.

The in-depth analysis in this work, believed to have no precedent, has found the RCP adequate to withstand the imposed seismic loading. All component stresses were within the applicable faulted criteria and the relative movements between closely mated parts fell inside their nominal clearance limits.

6.4-17 Kulterbaev, Kh. P., **Vibrations of cylindrical shells due to wind loads** (Kolebaniya tsilindricheskikh obolochek pod deistviem vetrovoi nagruzki, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 5,* 1976, 52–54.

A single degree-of-freedom system is considered. In calculating the stationary forced vibration parameters the wind velocity is considered as a stationary normal process. The stability of the solutions found was tested using the linear approximation of the perturbation equation. The effect of variations in the mean wind velocity on the behavior of shells is discussed.

6.4-18 Gutidze, P. A. and Bardanashvili, T. Z., **Investigation of the effects of design features and loading conditions on the earthquake resistance of arch dams using models** (Issledovanie na modelyakh seismostoikosti arochnoi plotiny s uchetom konstruktivnykh osobennostei i uslovii zagruzheniya, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 93–95. (For a full bibliographic citation see Abstract No. 1.1-7.)

The earthquake response of the arch dam of the Inguri hydroelectric power plant is investigated by means of physical models. The method is based on linear elastic analysis and the spectral theory of earthquake response. Considerations of similitude are employed to convert the numerical results to the full-scale structure.

6.4-19 Lyakhter, V. M. and Semenov, I. V., **Investigations of the earthquake resistance of concrete gravity dams** (Issledovaniya seismostoikosti betonnykh gravitatsionnykh plotin, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 18–23. (For a full bibliographic citation see Abstract No. 1.1-7.)

Results of numerical investigations of the response of gravity dams of various cross sections using methods of wave dynamics are presented. The dam is regarded alternatively as a rigid slab on an elastic base or as a beam system. Modification of earthquake motions due to soil-structure interaction is analyzed. The extent to which the analytical techniques utilized are applicable to dams of arbitrary cross section is discussed.

● **6.4-20** Iida, Y., **Earthquake response of a cable-stayed bridge** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 244, 895–902. (For a full bibliographic citation see Abstract No. 1.2-9.)

Cable-stayed bridges have only been constructed recently in Japan. The bridges have been constructed using the Japan Road Assn.'s "Specifications for Earthquake-Resistant Design of Highway Bridges" (January 1971) which apply to highway bridges with spans no longer than 200 m. This paper considers the earthquake response of a large-scale cable-stayed bridge model with long spans and deep foundations. The model is studied using modal analysis. Response acceleration curves of the Japan Society of Civil Engineers' "Specifications for Earthquake-Resistant Design of the Honshu-Shikoku Bridges" (1974) are employed. Considering the combination of loads and the increase in allowable stresses, it is concluded that the design is safe for a maximum ground acceleration of 180 gals where the foundations are supported; however, the main tower design needs to be improved to make it more earthquake resistant.

● **6.4-21** Kondo, H., **Dynamic response of hyperbolic cooling towers subjected to propagating seismic waves** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 229, 775–782. (For a full bibliographic citation see Abstract No. 1.2-9.)

The hyperboloid of revolution supported on columns has proved to be efficient for use in reinforced concrete natural draft cooling towers. The purpose of this paper is to analyze the dynamic response of hyperbolic cooling towers subjected to propagating seismic waves.

One may usually neglect the effect of the propagating speed of seismic waves, and then one can see that hyperbolic cooling towers will vibrate with their parallel circle remaining a circle, that is, in beam vibration modes. The author takes into account the propagating speed of seismic waves, and then shows that hyperbolic cooling towers vibrate not only in beam vibration modes but in higher vibration modes. Total displacements of hyperbolic cooling towers, which are supposed to be connected to the foundation with spring action, are divided into displacements due to propagating seismic waves and displacements due to elastic deformation. The latter displacements are obtained by a modal analysis method.

Numerical examples show that under a propagating horizontal seismic wave a hyperbolic cooling tower vi-

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

brates mainly in "ovaling" modes and that under a propagating vertical seismic wave it vibrates mainly in "rocking" modes, if the value $\alpha R/V$ is considerably large, where α, R and V are the circular frequency of the earthquake, the radius of a hyperbolic cooling tower at the foundation and the propagating speed of the seismic wave, respectively.

● 6.4-22 Hamada, M., Akimoto, T. and Izumi, H., **Dynamic stresses of submerged tunnels during earthquakes,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 213, 647–654. (For a full bibliographic citation see Abstract No. 1.2-9.)

In order to clarify the dynamic behavior of submerged tunnels during earthquakes, earthquake observations and model tests have been conducted in the past. From the results of this work, a practical method for dynamic response analysis of submerged tunnels was proposed. In this method the ground along the axis is divided into a number of segments, and each segment of the ground is replaced with a one-mass, one-spring model which has the same period as the fundamental natural period of the ground segment. By means of this method, the stresses of a tunnel during earthquakes can be obtained more easily than the other methods such as the finite element method. It was used for the earthquake-resistant design of seven actual submerged tunnels.

The authors conducted earthquake observations at the Tokyo Port undersea tunnel. The adequacy of the response analysis method was reviewed by using the result of the earthquake observations.

● 6.4-23 Muto, K. *et al.*, **Dynamic behavior of the cooling tower** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 228, 767–774. (For a full bibliographic citation see Abstract No. 1.2-9.)

● 6.4-24 Sakurai, A., Masuko, Y. and Kurihara, C., **Vertical response observation of ten-storied building during right under earthquakes** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 225, 743–750. (For a full bibliographic citation see Abstract No. 1.2-9.)

● 6.4-25 Shiraki, K. *et al.*, **Bell-ring vibration response of nuclear containment vessel with attached-mass under earthquake motion,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 6/1, 13. (For a full bibliographic citation see Abstract No. 1.2-11.)

Two types of vibrations, beam type and bell-ring type, occur in such axisymmetric thin shell structures as nuclear containment vessels. To date, seismic analysis for such shells has examined only beam-type vibration. This may be because the response participation factor for bell-ring type vibration under seismic motion is zero when a shell structure is perfectly axisymmetric. When a shell has attached to it several heavy masses such as an equipment hatch, however, the bell-ring type vibrations are unexpectedly large and more important than beam-type vibration.

In this paper, the bell-ring vibration response of a nuclear containment vessel with attached masses is determined. The theoretical results agree well with the experimental results.

6.5 Nondeterministic Dynamic Behavior of Linear Structures

● 6.5-1 Fischer, E. G. and Daube, W. M., **Combined analysis and test of earthquake-resistant circuit breakers,** *Earthquake Engineering and Structural Dynamics,* 4, 3, Jan.-Mar. 1976, 231–244.

Following the severe earthquake damage at San Fernando in 1971, it became of technical and perhaps psychological importance to demonstrate that properly re-designed electrical equipment is able to withstand even worse transient vibration phenomena which can be produced in an earthquake simulator laboratory. This has been accomplished for one column of a 500 kV gas circuit breaker and the test results are used to qualify the much larger original 3-column assembly by means of a computer-aided structural analysis. Since the equipment exhibited some closely spaced, cross-coupled modes of vibration, a valuable comparison could be obtained between the effects produced by El Centro 1940 ground acceleration and those for a more purposeful sine beat vibration input. The latter can be adjusted to produce definite stresses and fatigue effects in specific parts of the equipment due to quasi-resonance response.

6.6 Deterministic Dynamic Behavior of Nonlinear Structures

● 6.6-1 Bertero, V. V., Popov, E. P. and Wang, T.-Y., **Seismic design implications of hysteretic behavior of reinforced concrete elements under high shear,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings,* 75–106. (For a full bibliographic citation see Abstract No. 1.2-2.)

This paper reviews the research carried out at Berkeley on hysteretic behavior of structural components of ductile moment-resisting frames and frame-wall systems

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

under high shear. The first part of the paper summarizes and evaluates the main results of experiments conducted on relatively short girders and girder-column subassemblages, and discusses their implications regarding the aseismic design of ductile moment-resisting frames. The second part considers results obtained in the tests on wall models of the first three stories of a 10-story dual frame-wall structural system to evaluate present code provisions for the aseismic design of such systems.

● **6.6-2** Shiga, T., Shibata, A. and Takahashi, J., **Hysteretic behavior of reinforced concrete shear walls,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings,* 107-117. (For a full bibliographic citation see Abstract No. 1.2-2.)

The results of a laboratory investigation on the force-displacement relationship of single-story reinforced concrete shear walls are presented. Seventeen medium-size shear walls were subjected to static loads representing gravity loads and earthquake forces. The variables were the wall reinforcement ratio, the level of gravity load and the loading history. The characteristics of cyclic hysteresis loops under various types of load reversal and their envelope curves are investigated.

● **6.6-3** Aoyama, H., **Simple nonlinear models for the seismic response of reinforced concrete buildings,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings,* 291-309. (For a full bibliographic citation see Abstract No. 1.2-2.)

The shear model, frequently used to simplify inelastic response analysis, is shown to be improper for weak girder type frames because it ignores the story interaction by the columns. A new model, called the SB model, is proposed which improves the shear model by adding bending springs to represent the story interaction. A procedure is proposed to determine parameters for the SB model by which the degree of story interaction is automatically evaluated. The SB model includes the shear model as a special case. It is shown that the response analysis using the SB model is satisfactorily accurate for frames with a wide variety of structural characteristics.

● **6.6-4** Lu, L.-W. and Beedle, L. S., **Recent research on the strength, stiffness and ductility of steel building frames,** *Proceedings of the Australian and New Zealand Conference on the Planning and Design of Tall Buildings,* 633-649. (For a full bibliographic citation see Abstract No. 1.2-1.)

For buildings designed to resist earthquake or other dynamic loads, the ductility and the energy absorption capacity of the members and connections are important design problems. A rational approach often requires a careful consideration of the interrelationship among strength, stiffness and ductility. This paper is a condensed review of the recent research conducted at the Fritz Engineering Lab. in these three areas with special emphasis on frame response in the inelastic range. The topics included are (1) ultimate strength of frames, (2) frame, floor and wall interaction and (3) ductility and hysteresis characteristics.

● **6.6-5** Yuzugullu, O., **Inelastic behavior of shear wall-frame systems estimated by the f.e.m.,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 128, 14. (For a full bibliographic citation see Abstract No. 1.2-6.)

In this report the behavior of a reinforced concrete shear wall-frame system and a high-rise shear wall is investigated analytically. Cracking of concrete is taken into account by a modification of the stiffness properties of the affected elements. Classical plasticity theory is used for the nonlinear behavior of the concrete. The behavior of both systems is predicted under monotonically increasing loading conditions.

● **6.6-6** Suzuki, T. *et al.,* **The experimental study of hysteretic characteristic of braced frames,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 104, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

In general the design of braced structures (often used for low-rise buildings) neglects the interaction between the two principal axes of the frames. The present paper illustrates how the above design method cannot explain the real behavior of such structures and explains the necessity for investigating elasto-plastic response to horizontal two-dimensional ground motion.

● **6.6-7** Carydis, P. G. and Vagelatou-Nikolaidou, O., **Simplifying considerations on the aseismic design of shear structures,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 129, 6. (For a full bibliographic citation see Abstract No. 1.2-6.)

The theory for shear-type distributed mass systems is applied with use of a computer program to a 26-story model shear structure. The maximum dynamic displacements and story shears are computed. Using another computer program, the maximum dynamic response of the 26-story shear structure is computed as a lumped-mass system. Several lumped-mass systems are used by concentrating the story masses either in every central story line, in every second, in every third and so forth. A comparison of the results of the above-described models shows good agreement. An envelope of response spectra for the Athenian bedrock was used in the comparison.

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

● **6.6-8** Santhakumar, A. R., **Ductile behaviour of coupled shear walls subjected to reversed cyclic loading,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 501-512. (For a full bibliographic citation see Abstract No. 1.2-7.)

The behavior of two quarter-sized seven-story reinforced concrete coupled shear walls, with conventionally and diagonally reinforced coupling beams, subjected to static reversed cyclic loading to simulate seismic effects, is compared in terms of stiffness degradation, ductility and energy absorption capacity. For the walls coupled by conventionally reinforced coupling beams, the sliding shear failure of the beams limits the energy absorption capacity of the structure. In every respect the superior performance of the structure containing diagonally reinforced beams is established. The use of ductile diagonally reinforced coupling beams enabled a considerable portion of the total energy to be dissipated by the coupling system thereby relieving plastic hinges in the walls. The results show that with careful detailing coupled shear wall structures are effective earthquake-resistant structures.

● **6.6-9** Cheng, F. Y. and Oster, K. B., **Effect of coupling earthquake motions on inelastic structural models,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 107-125. (For a full bibliographic citation see Abstract No. 1.2-7.)

Response parameters have been studied for two structural models subjected to the coupling earthquake motions of the vertical and horizontal components of the 1940 El Centro earthquake. Bilinear material behavior, the P-delta effect, damping and the reduction of plastic moment capacity have been considered in the investigation. The structural models are lumped mass in nature. One model has masses lumped at structural joints, and the other has additional nodes at the centers of individual girders. Structures analyzed consist of a four-story, three-bay and a ten-story, single-bay rigid frame. The results show that the model containing nodes at girder centers can realistically reveal the effect of coupling earthquake motions on structural systems and that the significance of a vertical earthquake component depends on the structural parameters. The observation is based on a comparison of displacement response, energy absorption and the ductility and excursion ratios of the systems analyzed.

● **6.6-10** Sharpe, R. D. and Carr, A. J., **The inelastic seismic response of bridge structures,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 91-105. (For a full bibliographic citation see Abstract No. 1.2-7.)

This paper describes the application of an inelastic dynamic analysis of two very different bridge structures subjected to an earthquake excitation. The paper discusses the effects on the response of the structures of variations in the moment-curvature relationships of the piers and also the effects of the interaction of the axial forces in the members with the yield moments.

● **6.6-11** Egeseli, E. A. and Fleming, J. F., **Dynamic behavior of cable stayed bridges,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 59-72. (For a full bibliographic citation see Abstract No. 1.2-7.)

A procedure is described for analyzing a cable-stayed bridge subjected to dynamic loads. The procedure considers the nonlinear behavior of both the cables, due to changing sag, and the towers and girders, due to the interaction of axial and bending deformations. It is concluded that the nonlinearity of the structure must be considered in determining the stiffness of the structure in the dead load state; however, a linear dynamic analysis from the dead load state will give results well within normally required design accuracy. Damping in the structure should be considered.

● **6.6-12** Freskakis, G. N., Derecho, A. T. and Fintel, M., **Inelastic seismic response of isolated structural walls,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1165-1180. (For a full bibliographic citation see Abstract No. 1.2-7.)

This paper presents the results of an analytical investigation to determine the effect of important structural characteristics on the seismic response of isolated structural walls. The properties considered include the fundamental period of vibration as affected by the stiffness, the strength or yield level, the stiffness in the post yield range, strength taper, and viscous damping.

The basic structure considered in the study is a 20-story building. The corresponding analytical model consists of a cantilever with masses concentrated at floor levels. Inelasticity is allowed by point "plastic hinges" which form at the ends of elements when the yield moment is exceeded. The moment-rotation characteristics for these hinges account for the decrease in stiffness resulting from cyclic loading. The input motion used is the first 10 sec of the E-W component of the 1940 El Centro record, with the acceleration amplitude adjusted to obtain a 5% damped spectrum intensity equal to 1.5 times that of the N-S component of the El Centro record.

The effect of the various structural parameters on the seismic response is evaluated essentially qualitatively with particular attention given to the ductility requirements of the hinging region and the interstory displacements along the height of the building. It is found that increasing the stiffness of a structure, and thus decreasing its fundamental period, results in a reduction in the interstory displacements but an increase in the ductility requirements. An

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

increase in the yield level generally tends to decrease both the ductility requirements and the magnitude of the interstory displacements.

6.6-13 Napetvaridze, Sh. G. and Chlaidze, N. Sh., **Utilization of the finite element method for the three-dimensional problem of the earthquake resistance of arch dams** (Primenenie metoda konechnykh elementov dlya resheniya trekhmernykh zadach rascheta arochnykh plotin na seismostoikost, in Russian), *IX obedinennaya sessiya nauchnoissledovatelskikh institutov zakavkazskikh respublik po stroitelstvu,* Aiastan, Erevan, Vol. 1, 1975, 95–97.

Behavior of the arch dam of the Inguri hydroelectric station is investigated. The rock base of the dam is assumed elastic with inhomogeneous yielding. The maximal effect of base yield on stresses in the body of the dam does not exceed 15–20%. At the same time, the effect of seismic excitations on the tensile stresses in the concrete may reach 10%. In the bottom section, the dam tensile stresses reach inadmissible levels, thus necessitating the installation of special horizontal seams.

● 6.6-14 Shapiro, G. A. and Ashkinadze, G. N., **The nonlinear deformations in the ground base of large-panel buildings under oscillations,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 51–58. (For a full bibliographic citation see Abstract No. 1.2–7.)

It is assumed that compressive deformations of ground are elastic-plastic and that ground cannot move under tension. Based on these assumptions, a nonlinear analytical model of a large-panel building base under rocking vibrations was developed. Good corroboration of the analytical model was obtained in the vibration tests of a one-quarter sized model of the 10-story building erected on the ground base. The dynamic properties and the seismic response of buildings on the nonlinear ground base are dealt with in this paper.

● 6.6-15 Takizawa, H. and Aoyama, H., **Biaxial effects in modelling earthquake response of R/C structures,** *Earthquake Engineering and Structural Dynamics,* **4**, *6,* Oct.–Dec. 1976, 523–552.

Recent studies reveal that R/C structural members subjected to biaxial flexure due to two-dimensional earthquake excitation can deform much more than would be predicted by conventional one-dimensional response analysis. The biaxial flexure may, therefore, have a significant effect on the dynamic collapse process of structures subjected to intense ground motions. The present paper is intended to develop a new formulation of the two-dimensional restoring force model of R/C columns acted upon by biaxial bending moments, and to discuss the dynamic response properties of R/C structures. The model considered is a two-dimensional extension of various nonlinear models for one-dimensional response analysis, including the degrading trilinear stiffness model which is one of the simpler idealizations of the restoring force characteristics of flexural-failure-type R/C structures. The modelling validity is then examined by comparison with experimental data on the biaxial bending behavior of R/C columns. Calculations are made to study the role of different system properties on the influence of inelastic biaxial bending on the dynamic structural response. It is shown that the inelastic biaxial effect is generally significant and, in some cases, critical in the case of R/C structures with stiffness-degrading properties, while the effect is not so important for the nondegrading inelastic cases.

6.6-16 Iskhakov, Ya. Sh., **Response of thin reinforced concrete shells to seismic loadings using the limit equilibrium method** (Uchet seismicheskikh nagruzok v raschete tonkostennykh zhelezobetonnykh obolochek po metodu predelnogo ravnovesiya, in Russian), *Prostranstvennye konstruktsii zdanii i sooruzhenii, 2,* 1975, 148–153.

Using the limit equilibrium method, the author presents methods and results of investigations of the behavior of thin shallow reinforced concrete shells of positive curvature. The shells are assumed to be statically loaded to the elastic limit before the application of the inertial loading due to vertical seismic excitation.

● 6.6-17 Bervig, D. R., **A simplified nonlinear seismic response analysis of structures including vertical ground motion,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 345–374. (For a full bibliographic citation see Abstract No. 1.2–7.)

The seismic response of structures was studied by using small and large displacement analyses for one- and two-story models. Both the small and large displacement analyses used in this study include the effect of a bilinear or elasto-plastic force-displacement relationship. In addition, the large displacement analysis includes the large displacement coupling term relating the horizontal and vertical displacement, the P-delta effect and vertical ground motion.

● 6.6-18 Anderson, J. C. and Singh, A. K., **Seismic response of pipelines on friction supports,** *Journal of the Engineering Mechanics Division, ASCE,* **102**, *EM2,* Proc. Paper 12043, Apr. 1976, 275–291.

The nonlinear responses of two pipeline configurations, which are representative of an above-ground crude oil pipeline, are studied. Resistance to horizontal movement is provided by a combination of widely spaced anchor supports and intermediate friction supports. Following the application of operating pressure and thermal loads, the systems are subjected to strong earthquake ground motions.

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

Results show that the inertia forces that develop during an earthquake tend to negate the restraining effect of the friction forces in the operating condition. This causes the pipe to move toward the position it would assume if there were no friction. The earthquake motion may result in either an increase or decrease in the critical bending moment depending on the geometrical configuration and the earthquake acceleration level.

● **6.6-19** Kaar, P. H. *et al.*, **Confined concrete in compression zones of structural walls designed to resist lateral loads due to earthquakes,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1207–1218. (For a full bibliographic citation see Abstract No. 1.2-7.)

The Portland Cement Assn. is carrying out a combined analytical and experimental program to develop design criteria for reinforced concrete structural walls used as lateral bracing in earthquake-resistant buildings. As part of this program, tests have been performed on specimens representing full-sized compression zones of structural walls. The results are being used to evaluate the effects of rectangular hoops as confinement reinforcement and to determine the effective stress versus strain relationship of confined concrete.

The test specimen has been adapted from one developed earlier for the determination of the stress versus strain relationship for plain concrete. Controlled variables included hoop size, hoop spacing, amount of longitudinal reinforcement, concrete strength, and size of specimen.

Analysis of the test results showed that all arrangements of rectangular hoops were effective in significantly increasing the limiting concrete strain. For those specimens with hoop reinforcement meeting the requirements of Appendix A of the ACI Building Code, limiting concrete strains exceeded 0.015. The spacing and amount of transverse reinforcement were the primary variables affecting the stress versus strain relationship of the concrete. The amount of longitudinal reinforcement had little effect.

● **6.6-20** Ma, S.-Y. M., Popov, E. P. and Bertero, V. V., **Cyclic shear behavior of R/C plastic hinges,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 352–362. (For a full bibliographic citation see Abstract No. 1.2-8.)

With the data available from studies conducted by the authors and others, it is possible to attempt to define the actual mechanisms of degradation in stiffness, strength and energy capacities that have been observed in the critical regions under earthquake-like excitations. The main objective of this paper is to present the results of such an attempt.

The main data analyzed were obtained from tests on nine cantilever beams. After a brief description of the test specimens and test procedures, the general behavior of the beams is discussed, with emphasis on the failure mechanism and how it is modified under different amounts of shear. Conclusions regarding the observed behavior are drawn, and their implications in aseismic design of ductile-resisting frames are discussed.

● **6.6-21** **Study on prestressed concrete reactor vessel (PCRV) structures** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 10,* 1975, 12–17.

This report describes test results of the star-type 1/70-scale PCRV support model subjected to earthquake motions and static lateral loads and the methods of analysis. Load-deflection relationships of this model are characterized as being almost spindle shaped in the static tests, even after initiation of cracks and yielding of reinforcement; residual deflection is small. The changes of rigidity and energy absorption in each loop of the test are compared with the calculated amounts. Dynamic behavior is calculated based on two simplified assumptions reflecting static analysis: (1) trilinear stiffness degrading envelope, and (2) variable viscous damping value governed by previously attained maximum response deflection. The calculated results agree well with the measured ones.

● **6.6-22** Cheng, F. Y. and Oster, K. B., **Dynamic instability and ultimate capacity of inelastic systems parametrically excited by earthquakes - Part II,** *Civil Engineering Study 76-1, Structural Series,* Dept. of Civil Engineering, Univ. of Missouri, Rolla, Aug. 1976, 313.

An analytical study is presented for the behavior of multistory framed structures subjected to the interaction of horizontal and vertical components of an earthquake. Typical structures having three to ten stories and one to three bays are studied on the basis of a lumped mass model with elastic, elastoplastic and bilinear material behavior. The studies include the characteristics of energy absorption in the form of input energy, kinetic energy, elastic strain energy, and dissipated strain and damping energy; the reduction of plastic moment capacity of columns; ductility and excursion ratios; and the P-delta effect, as well as the effect of two different lumped mass models on the response parameters.

The response parameters selected to describe the investigative results are maximum horizontal floor displacements, maximum relative floor displacements, maximum vertical displacements and accelerations at the centers of girders, ductility and excursion ratios of girders and columns, and the variation of input, stored and dissipated energy. The energy evaluation is used not only to indicate the response behavior of various structural systems but also

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

to check the accuracy of step-by-step numerical solutions by determining the maximum percent error at every time increment.

Numerical results show that the inclusion of the vertical ground motion can significantly influence the response parameters. For example, the ductility requirements of girders are remarkably increased. A new concept of ductility ratio based on energy is proposed in this work and has been compared with other ductility concepts of symmetric bending and curvature. The proposed ductility evaluation has been proved to be advantageous over the other two in both qualitative and quantitative measurements.

Other results may be simply summarized as: (a) Structures having a certain range of natural frequencies are sensitive to vertical earthquake motions. (b) The reduction in plastic moment capacity of columns can increase the influence of vertical earthquake motion on weak column-strong girder systems. (c) Although the consideration of damping in an elastic or inelastic analysis results in a reduction in response as expected, the general behavior of the significant influence of vertical earthquake component on response parameters remains the same as that of undamped systems.

The computer program has been comprehensively developed and can be conveniently used by research workers and practitioners for seismic analysis of large structures.

● **6.6-23** Takayanagi, T. and Schnobrich, W. C., **Computed behavior of reinforced concrete coupled shear walls,** *UILU-ENG-76-2024, Structural Research Series No. 434,* Univ. of Illinois, Urbana, Dec. 1976, 192.

The nonlinear response history and failure mechanism of coupled shear wall systems under dynamic loads and static loads are investigated through an analytical model. The walls and coupling beams are replaced by flexural elements. The stiffness characteristics of each member are determined by inelastic properties. The suitable hysteresis loops for each constituent member are established to include the specific characteristics of coupled shear wall systems. The computed results are compared with the available test results.

● **6.6-24** Borges, J. F. *et al.,* **Methodology for the seismic study of prefabricated panel buildings** (Metodologia para o estudo sismico de edificios prefabricados por paineis, in Portuguese), *Memoria No. 468,* Lab. Nacional de Engenharia Civil, Lisbon, 1975, 6.

The use of prefabricated panel buildings in seismic areas requires different kinds of studies in order to determine the major aspects of the seismic behavior of the buildings. Such studies should concern: (i) idealization of structural behavior under horizontal loads; (ii) linear and nonlinear seismic response; and (iii) resistance and ductility of individual members and the whole structure. A suitable combination of analytical and experimental techniques should be used for studying these problems.

In the last ten years the Lab. Nacional de Engenharia Civil (LNEC) has studied several prefabricated panel structures to be built both in Portugal and abroad. This paper briefly reports the experience of the LNEC in this field and describes the methodology that is being used.

● **6.6-25** Mukhopadhyay, A. K. and Kingsbury, H. B., **On the dynamic response of a rectangular sandwich plate with viscoelastic core and generally orthotropic facings,** *Journal of Sound and Vibration,* **47,** *3,* Aug. 8, 1976, 347-358.

This paper explores the effect of facing anisotropy on the damped response to harmonic transverse dynamic loads of a rectangular sandwich plate with a viscoelastic core. The membrane facings are generally orthotropic and the measure of anisotropy is the angle between the geometric plate axes and the elastic axes of the facing material. A Fourier series solution is obtained to the governing plate equations for the case of simply supported edges. The response of the plate at fundamental resonance for several loss factors between 0 and 1 is computed for varying facing anisotropy. It is found that the rotation of facing elastic axes increases maximum lateral deflection, the rate of dissipation of energy and the total strain energy of the core, and decreases the fundamental natural frequency.

Increasing loss tangent decreases lateral deflection, but also decreases the rate of energy loss. It is found that the contribution of the core in-plane shear strain energy to the total strain energy is independent of facing anisotropy and loss tangent. For all configurations of facing anisotropy, the lateral response of the plate is insensitive to the change in loss modulus for values beyond 0.7. Typical response curves are shown.

● **6.6-26** Saito, H., Sato, K. and Yutani, T., **Non-linear forced vibrations of a beam carrying concentrated mass under gravity,** *Journal of Sound and Vibration,* **46,** *4,* June 22, 1976, 515-525.

The nonlinear dynamic behavior of a simply supported beam, with ends restrained to remain a fixed distance apart, carrying a concentrated mass and subjected to a harmonic exciting force at an arbitrary point under the influence of gravity is analyzed. By using the one mode approximation and applying Galerkin's method, the governing equation of motion is reduced to the well-known Duffing type equation. The harmonic balance method is applied to solve the equation and the dynamic response of a concentrated mass is derived. The effects of the weight, the location, and the vibratory amplitude of the concentrated mass on the natural frequency are also discussed.

● **6.6-27** Kahn, L. F. and Hanson, R. D., **Inelastic cycles of axially loaded steel members**, *Journal of the Structural Division, ASCE,* **102**, *ST5,* Proc. Paper 12111, May 1976, 947-959.

Sixteen fixed-ended steel bars of rectangular cross section 1/2 in. x 1 (12.7 x 25.4-mm) and of various lengths were tested under static and dynamic loads to determine the cyclic hysteretic response of steel columns. The specimens were subjected to tensile yielding and post-buckling deflection. Column slenderness ratios ranged from 85 to 210. This research complemented a corresponding elasto-plastic theoretical development; the experimental results generally agreed with theoretical predictions, yet significant deviations were noted. Principal findings were that the buckling load decreased with number of cycles, the columns exhibited net tensile or compressive plastic deformation in a cycle depending on deflection level, and the static and dynamic responses were similar.

● **6.6-28** Benveniste, Y., **The finite amplitude motion of an incompressible composite hollow sphere**, *Journal of Sound and Vibration,* **46**, *4,* June 22, 1976, 527-535.

The finite dynamic deformations of a composite hollow sphere made of an arbitrary number of layers is treated. The layers are assumed to be made of a nonlinearly elastic incompressible material. The cavity wall is subjected to a spatially uniform radial pressure and the spherically symmetric motions of the layered hollow sphere are considered. A nonlinear ordinary differential equation governing the motion of the cavity wall is obtained and solved by a numerical method.

● **6.6-29** Paulay, T. and Santhakumar, A. R., **Ductile behavior of coupled shear walls**, *Journal of the Structural Division, ASCE,* **102**, *ST1,* Proc. Paper 11852, Jan. 1976, 93-108.

The behavior of two quarter full-size seven-story reinforced concrete coupled shear walls, with conventionally and diagonally reinforced coupling beams, subjected to static reversed cyclic loading to simulate seismic effects, is compared in terms of stiffness degradation, ductilities attained, and energy-absorption capacity. In the walls coupled by conventionally reinforced coupling beams, the sliding shear failure of the beams limits the energy absorption capacity of the structure. In every respect the superior performance of the structure containing diagonally reinforced beams is established. The use of ductile diagonally reinforced coupling beams enabled a considerable portion of the total energy to be dissipated by the coupling system thereby relieving plastic hinges in the walls. The results show that with careful detailing coupled shear wall structures can be made to possess all the desirable features of an effective earthquake-resistant structure.

● **6.6-30** Mazalov, V. N. and Nemirovsky, Ju. V., **Dynamical bending of rigid-plastic annular plates**, *International Journal of Non-Linear Mechanics,* **11**, *1,* 1976, 25-40.

Dynamic bending of circular rigid-plastic annular plates, fixed along the exterior boundary and free on the interior boundary, when subjected to instantaneously applied transverse uniformly distributed blast-type load is investigated in this paper. It is shown that annular plates are preferable to plates without holes, since their load capacity increases while residual deflections decrease. A so-called boundary parameter is introduced to estimate the effect of boundary conditions on the radial bending moment. A procedure for determining the residual deflections at every point of a plate is developed for use on an electronic computer. Numerical examples are given. In the end of the paper, the particularities of solution of our problem for annular plates, corresponding to the setting of Wang, Wang and Hopkins for plates without holes, are discussed.

● **6.6-31** Cheng, F. Y. and Oster, K. B., **Ultimate instability of earthquake structures**, *Journal of the Structural Division, ASCE,* **102**, *ST5,* Proc. Paper 12117, May 1976, 961-972.

The parametric motions considered are very general and may be due to mechanical vibrations or horizontal and vertical components of earthquakes. A computer program has been developed for the nonlinear dynamic response of structural systems which are formulated in incremental form based on the displacement method and numerical integrations. Numerical examples are provided from which one may observe that the structure becomes dynamically unstable when a certain frequency of vertical motion is present and that the growth of the vibrating amplitude may possibly cause lateral collapse of the system. Although no definite relationship between vertical earthquake frequencies and the lateral natural frequencies exists for an earthquake structure, the vertical earthquake motions can excite some structures having certain natural frequencies becoming dynamically unstable due to large deflections. The vertical force may not always be critical to dynamic response and can actually cause certain structures to have smaller deflections than that of the associated systems without the influence of the axial force.

● **6.6-32** Nagaya, K., **Transient response of a continuous plate on elastic supports**, *Journal of Sound and Vibration,* **47**, *3,* Aug. 8, 1976, 359-370.

This paper discusses the vibration and the transient response problem of a nonperiodical elastically supported continuous plate. In the analysis, the restoring forces of the

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

elastic supports are formally represented, initially as unknown external forces applied to the plate. Expressions for displacements and bending moments of the plate when it is subjected to impact loads are obtained from the equation of motion in terms of the "unknown" forces by using Laplace transform methods. The natural frequencies and dynamic responses of two- and three-span plates are shown in a numerical example, and the dynamic behavior of the plate is discussed in detail.

● 6.6-33 Srirangarajan, H. R. and Srinivasan, P., **The pulse response of non-linear systems,** *Journal of Sound and Vibration,* **44**, *3*, Feb. 8, 1976, 369–377.

The response of a nonlinear, nonconservative, single-degree-of-freedom system subjected to a pulse excitation is analyzed. A transformation of the displacement variable is effected. The transformation function chosen is the solution of the linear problem subjected to the same pulse. With this transformation the equation of motion is brought into a form where Anderson's ultraspherical polynomial approximation is applicable for the solution of the problem. The method is applied to a cubic Duffing oscillator subjected to various pulses. The pulses considered are cosine, exponentially decaying and the step function. The analytical results are compared with the digital solution obtained on an IBM 360/44 system by using a Runge-Kutta fourth order method. The analytical results compare well with the digital solution.

● 6.6-34 Tani, J., **Influence of deformations before instability on the parametric instability of conical shells under periodic pressure,** *Journal of Sound and Vibration,* **45**, *2*, Mar. 22, 1976, 253–258.

On the basis of the dynamic version of linear Donnell-type equations and with deformations before instability taken into account, the dynamic instability of clamped, truncated conical shells under periodic pressure is analyzed. The principal instability regions are determined by combining Bolotin's method and a finite difference procedure. Calculations are carried out for two kinds of conical shells. The effect of bending deformations before instability is found to change the width of the principal instability regions in the vicinities of twice the natural frequencies of asymmetric vibration. Other principal instability regions are detected in the neighborhoods of the resonances of symmetrically forced vibrations.

● 6.6-35 Kerr, A. D., **On the dynamic response of a prestressed beam,** *Journal of Sound and Vibration,* **49**, *4*, Dec. 22, 1976, 569–573.

The dynamic bending response of a prestressed beam, in which the prestressing rod is continuously supported, is studied analytically and experimentally. It is found that a resultant axial prestressing force which passes through the centroids of the beam cross section has no effect upon the bending response of the beam. For example, the natural frequencies are not affected by the magnitude of the prestressing force. Also, the prestressed beam is always stable, even for very large values of the prestressing force.

● 6.6-36 Sakamoto, I., **Dynamic study on aseismic design method of wooden house** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 201, 559–566. (For a full bibliographic citation see Abstract No. 1.2-9.)

The aseismic design method of wooden houses in Japan which was established more than twenty years ago should be re-examined. The re-examinations are necessary because of the introduction of many new housing systems in recent years.

This paper deals with the study of the earthquake resistance of wooden houses from the viewpoint of dynamic response analysis. Equivalent linear systems and standard response spectra are employed to evaluate the maximum response of ordinary wooden houses which are designed according to the Japanese aseismic design method.

The relationships between the equivalent natural period and the story displacement are obtained based on the assumptions of trilinear P - δ curves. The equivalent damping factor including viscous and hysteresis damping is estimated as 20% based on reports of vibration tests and static loading tests. The standard displacement response spectra are assumed to be the earthquake input force based on those of well-known strong-motion accelerograms, with the maximum acceleration of 300 gals and with the prescribed damping.

● 6.6-37 Mochizuki, T., Nagashima, F. and Koizumi, T., **Earthquake response analysis of structures supported on piles by a test apparatus-computer on line real time system** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 165, 511–518. (For a full bibliographic citation see Abstract No. 1.2-9.)

● 6.6-38 Takada, S., **Dynamic behaviour of under-ground pipelines** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 216, 671–678. (For a full bibliographic citation see Abstract No. 1.2-9.)

The dynamic behavior of underground pipelines which are allowed to slide during strong-motion earthquakes is studied. This slide is resisted by friction between the pipe and the surrounding ground. Model experiments are performed to determine the characteristics of nonlinear frictional force. An analytical solution is also deduced to obtain the relative displacement between the pipe and the ground, making use of the results of the experiments.

● **6.6-39** Takizawa, H. and Yoshimura, M., **Bi-axial effect of flexural members on the strong-motion response of R/C structures,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 247, 919–926. (For a full bibliographic citation see Abstract No. 1.2–9.)

Recent studies reveal that R/C structural members subjected to biaxial flexure due to two-dimensional earthquake excitation can deform much more than would be predicted by conventional one-dimensional response analysis. The biaxial flexure may therefore have a significant effect on the dynamic collapse process of structures subjected to intense ground motions.

The present paper is intended to summarize briefly the authors' formulation of two-dimensional restoring force characteristics of R/C columns acted upon by biaxial bending moments and their discussion of the dynamic response for the case where the columns play the most important role in the overall restoring force characteristics of the structure.

● **6.6-40** Ramu, S. A. and Iyengar, K. J., **Plastic response of orthotropic circular plates under blast loading,** *International Journal of Solids and Structures,* 12, 2, 1976, 125–133.

The dynamic behavior of a simply supported, orthotropic, circular plate subjected to strong blast is considered. The blast is assumed to impart an axisymmetric transverse velocity which has a general Gaussian distribution spatially. It is concluded that the rate of growth of plastic regimes and the final plastic deformation strongly depend upon the initial Gaussian distribution parameter.

● **6.6-41** Goel, S. C., **Inelastic response of multistory K-braced frames subjected to strong earthquakes,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 242, 879–886. (For a full bibliographic citation see Abstract No. 1.2–9.)

This paper presents an analytical study of the inelastic behavior of K-braced structures of steel when subjected to a strong earthquake motion. A 10-story structure designed by current code procedure is subjected to a horizontal ground motion 1.5 times the intensity of the 1940 El Centro earthquake. Elasto plastic type hysteresis behavior in bending is assumed for girders and columns with axial force effects included for the columns. The hysteresis model for the axially loaded bracing members considers tension yielding and elastic buckling with no energy dissipation in the postbuckling range. The effect of three different patterns of bracing (K, V and X) on the structural response is studied.

The results for K-braced frames differ significantly from earlier results obtained by Nilforoushan, in which he used a more realistic postbuckling behavior of the bracing members in his hysteresis model. Thus it appears that postbuckling behavior is an important factor in predicting the behavior of a K-braced frame structure. A combination of the K- and V- pattern of bracing (the X-pattern) results in the least ductility demand on girders and on bracing members.

● **6.6-42** Murthy, N. K. A. and Alwar, R. S., **Nonlinear dynamic buckling of sandwich panels,** *Journal of Applied Mechanics,* 43, Series E, 3, Sept. 1976, 459–463.

Nonlinear dynamic buckling of simply supported rectangular sandwich panels with isotropic cores and with initial curvature under transverse loads is analyzed. The large deflection sandwich panel equations proposed by Reissner are solved using a trigonometric series spacewise and by the Houbolt scheme for timewise integration. The resulting nonlinear algebraic equations are solved by Newton's iterative method to yield the deflection coefficients at all time intervals. The present investigation essentially deals with the influence of dynamic loads on the snap-through behavior of sandwich panels. The effect of the initial curvature and core modulus is studied in detail. Static snap-through collapse loads are also calculated and compared with dynamic loads. As a check for the present analysis, the results obtained for the static case for a homogeneous plate are compared with the available results. It has been shown that, for a given sandwich panel with a given initial curvature, the dynamic snap-through loads can be estimated directly from the static snap-through loads without actually resorting to dynamic analysis.

● **6.6-43** Takahashi, J. and Shiga, T., **Restoring force characteristics of reinforced concrete shear walls,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 249, 935–942. (For a full bibliographic citation see Abstract No. 1.2–9.)

The results of a laboratory investigation of the restoring force characteristics of reinforced concrete shear walls surrounded by a frame for low-rise buildings are presented. Seventeen medium-sized shear walls were subjected to static loads representing gravity and earthquake loads. The variables were wall reinforcement ratio, gravity load and loading history, that is, cyclic deflection amplitude and a number of cyclic loadings.

The results suggest that the restoring force characteristics of reinforced concrete shear walls can be modelled by a

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

combination of the envelope curve and the hysteresis loops corresponding to the deflection levels.

● **6.6-44** Luyties, III, W. H., Anagnostopoulos, S. A. and Biggs, J. M., **Studies on the inelastic dynamic analysis and design of multi-story frames,** *Evaluation of Seismic Safety of Buildings, No. 6, R76-29,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, July 1976, 195.

This report studies the inelastic response of plane frames subjected to earthquake loadings. A computer program, which accounts for the state of yield of the entire structure at every time step to calculate response, is used for the analyses. Two different models of member inelastic behavior can be used—a single component model which places inelastic springs at the ends of members or a dual component model which considers members to consist of an elastoplastic and an elastic component acting in parallel.

The two models are compared in terms of overall story response and local ductilities for a 4-story frame. Results show that both models predict fairly close interstory and total displacements as well as story shears. Local values of ductility factors are in most cases in good agreement, although some differences have also been observed.

Two real buildings designed according to a procedure based on an inelastic response spectrum and a two-level earthquake are analyzed and the results are compared with predicted values. There are both similarities and differences in the results, which are discussed and explained.

Further studies on the use of inelastic response spectra in design are made, in which the response spectrum portion of the design load is isolated. A 4-story and a 10-story frame are designed considering several different effects and analyzed for several different earthquake motions. Results show a strong dependence on initial gravity loads and on the distribution of member resistances throughout the frame. In all cases, an inelastic spectrum design fails to limit either maximum ductilities or the average of the maximum story ductilities over height to the design value.

● **6.6-45** Kahn, L. F. and Hanson, R. D., **Inelastic cyclic behavior of axially loaded steel members,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 252, 959-966. (For a full bibliographic citation see Abstract No. 1.2-9.)

This paper summarizes studies conducted at the Univ. of Michigan of the theoretical and experimental behavior of steel members subjected to cyclic axial loading into tension yielding and compression buckling. Experiments included static and dynamic tests of rectangular steel bars of various lengths.

Column slenderness ratios ranged from 85 to 210. The experimental results generally agreed with theoretical predictions; yet significant deviations were noted. Principal experimental findings were that the buckling load decreased with number of cycles, the columns exhibited net tensile or compressive plastic deformation in a cycle depending on deflection level, and the static and dynamic responses were similar.

● **6.6-46** Baratta, A., **Plastic frames under strong earthquakes: A simplified treatment,** *Journal of Structural Mechanics,* 3, *2,* 1974-1975, 197-220.

The response to strong ground shaking of a single-degree-of-freedom shear frame supporting vertical loads is studied for the purpose of deriving simple first approximation formulas.

As a first approach, the rigid-plastic assumption is introduced, and it is shown that significant results can be obtained by neglecting phases of plastic motion with negative velocity. These results, which can be expressed in closed form, are then compared with the response of an undamped elastic-plastic frame, and the range of validity of the approximate formulas presented is discussed.

● **6.6-47** Mizuhata, K. *et al.,* **Study on low cycle fatigue and restoring force characteristics of steel frames and steel-concrete frames,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 250, 943-950. (For a full bibliographic citation see Abstract No. 1.2-9.)

For the purpose of investigating the seismic safety of steel frame and steel-concrete frames to be used in highrise residential buildings, constant displacement amplitude tests were conducted to clarify the low-cycle fatigue and restoring force characteristics. By formulating the restoring force characteristics, an earthquake response analysis becomes more realistic and, at the same time, by applying the random fatigue theory to the low-cycle fatigue test results, the response analysis results can be evaluated more reasonably.

● **6.6-48** Krajcinovic, D., **Dynamic response of rigid-plastic beams—General case of loading,** *Journal of Structural Mechanics,* 3, *4,* 1974-1975, 439-457.

This paper presents a derivation of a closed-form solution for the dynamic response of a simply supported beam subjected to a uniformly distributed dynamic load of arbitrary pressure-time history.

● **6.6-49** Morrone, A., **Scram and nonlinear reactor system seismic analysis for a liquid metal fast reactor,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K

8/4, 12. (For a full bibliographic citation see Abstract No. 1.2-11.)

Earthquake vibrations cause large forces and stresses and can significantly increase the scram time required for safe shutdown of a nuclear reactor. The horizontal deflections of the reactor system components cause impact between the control rods and their guide tubes and ducts. The resulting friction forces delay the travel time of the control rods. To obtain seismic responses of the various reactor system components (for which a linear response spectrum analysis is considered inadequate) and to predict the control rod drop time, a nonlinear seismic time history analysis is required. The nonlinearities consist of the clearances or gaps which exist between the various components. When the relative motion of adjacent components is large enough to close the gaps, impact takes place with large impact accelerations and forces. These impact forces are then utilized to calculate scram times.

This paper presents the analysis and results for a liquid metal fast reactor system which was analyzed for both scram times and seismic responses such as bending moments and impact forces. The reactor system was represented with a one-dimensional nonlinear mathematical model with two-degrees-of-freedom per node (translation and rotation). The model was developed to incorporate as many reactor components as possible without exceeding computer limitations. The results give time history plots of various seismic responses, and plots of scram times as a function of control rod travel distance for the most critical scram initiation times. The total scram time considering the effects of the earthquake was still acceptable but about four times longer than that calculated without the earthquake.

6.6-50 Rakovshchik, Yu. A., **On plastic buckling of structures subjected to cyclic loading** (O vypuchivanii konstruktsii pri tsiklicheskom nagruzhenii za predelom uprugosti, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii*, *5*, 1976, 49-51.

Elasto-plastic buckling under cyclic loads of beams, plates and shells with initial imperfections is considered. It is demonstrated that buckling may occur at loads less than the critical static load. In the case considered, there exists for any value of external load (within a certain interval) a critical frequency, i.e. a frequency resulting in buckling of the system. Experimental values for the critical frequencies of beams are presented.

● **6.6-51** Snyder, M. D., Shaw, D. E. and Kissenpfennig, J. F., **Seismic analysis of a nuclear containment polar crane**, *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology*, Vol. 4, Paper K 6/7, 9. (For a full bibliographic citation see Abstract No. 1.2-11.)

The seismic analysis of a nuclear containment polar crane is discussed including analytical methods and specific problems relating to the nature of the seismic loading of a structure having support conditions typical of crane structures. Without positive restraints, a nuclear containment polar crane is in contact with the containment vessel only through the wheels in contact with crane runway rails. In the direction normal to the crane bridge girders, the crane has rolling supports, while in a direction parallel to the bridge girders, support is provided only by the frictional forces acting at the wheel-rail interface. Since this latter force transfer mechanism is frictional in nature, it is dependent upon a vertical force which depends upon the combination of dead load, vertical seismic load and other vertical live loads considered for the design criteria.

Owing to the frictional and rolling support of the crane wheels, the seismic response of a polar crane becomes nonlinear allowing both rigid body and elastic modal response to seismic excitation. Since the seismic loading of a polar crane arises from support motion, we must consider the question of whether the structural integrity of a polar crane is enhanced or degraded by the use of positive load transfer mechanisms which affix the crane to the rails.

Since the crane is operational only during a plant refueling period, a unique parking position for the crane may be assigned, thereby simplifying the design of restraints to retain the crane on the rails during a seismic event. Discussions are presented on the probability of a seismic event occurring during crane operation when the crane would not be positively affixed to the rails. It is shown that the probability of an SSE occurring during crane operation is exceedingly small. Similar considerations are made for the OBE which led to secondary support devices designed to prohibit the crane from falling from the rails as a rigid body.

The seismic analysis of the polar crane was performed using a finite element model comprised of three-dimensional beam and flat plate elements using the response spectra technique to determine the SRSS internal forces, moments and stresses. A total of nine response spectra, arising from the coupled response of the containment structure, were incorporated into design response spectra for the analysis. Details of both the finite element modeling and the analysis are discussed.

As a Class I nuclear structure, the primary design objective was to prohibit either total structural collapse or falling from the rails without structural collapse. The latter problem was resolved through the use of positive restraint mechanisms based on the above considerations. In the evaluation of the stresses, no single design code was found to be directly applicable. Therefore, a discussion is presented that resulted in the combined use of the American

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

Inst. of Steel Construction Code, Crane Manufacturers Assn. of America Specification No. 70, and DIN4114.

● 6.6-52 Arzola A., R. E., Garcia V., H. H. and Saragoni H., G. R., **Analysis of the maximum response of simple structures to some North American and Latin American earthquakes** (Analisis de las respuestas maximas de estructuras simples para algunos sismos Norteamericanos y Latinoamericanos, in Spanish), *SES I-3/74*, Seccion Estructuras, Dept. de Obras Civiles, Univ. de Chile, Santiago, Sept. 1974, 145.

6.6-53 Kuznetsov, B. N., **Displacements of continuous two-span beam subjected to repeated alternate loads** (Opredelenie peremeshenii nerazreznoi dvukhproletnoi balki pri povtorno-peremennom nagruzhenni, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 5*, 1976, 38-41.

Accumulation of plastic deformations in a continuous two-span beam subjected to an alternating sequence of loading patterns is investigated. The effects of beam cross-section and the load parameters on the nature of the process are examined.

● 6.6-54 Popov, E. P. and Stephen, R. M., **Tensile capacity of partial penetration welds,** *EERC 76-28*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Oct. 1976, 39. (NTIS Accession No. PB 262 899)

The flanges of six W 14 x 320 sections with milled ends were joined together at mid-height with different size partial penetration welds to form short columns; one additional specimen had full penetration welds through both flanges. Four of the specimens were failed directly in tension; three were subjected to a few compression-tension cycles until failure. The experiments were designed to simulate conditions which can develop in some columns of steel frames during severe earthquakes. The spliced joints developed their specified strengths with the smallest weld attaining highest stress. Failure for all specimens with partial penetration welds occurred through the splice exhibiting very limited ductility. The data generated by these experiments should be useful for earthquake design as well as provide basic information on the behavior of partial penetration welds of unprecedented size.

● 6.6-55 Klingner, R. E. and Bertero, V. V., **Infilled frames in earthquake-resistant construction,** *EERC 76-32*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Dec. 1976, 291. (NTIS Accession No. PB 265 892)

The effects of masonry infill panels on the seismic hysteretic behavior of reinforced concrete frames are investigated experimentally and analytically. The experimental phase consists of quasi-static cyclic load tests on a series of one-third-scale model subassemblages of the lower three stories of an eleven-story, three-bay frame with infills in the two outer bays. Emphasis is placed on simulating the proper force and displacement boundary conditions. The infilled frames are designed and constructed in accordance with the following guidelines: (1) frame members (particularly the columns) are designed for high rotational ductility and resistance to degradation under reversed cyclic shear loads; (2) gradual panel degradation is achieved by using closely spaced infill reinforcement; and (3) panel thickness is limited so that the infill cracking load is less than the available column shear resistance.

The infilled frames are found to offer many advantages over comparable bare frames, particularly with respect to their performance under strong ground motions. The analytical phase consists of developing relatively simple, macroscopic mathematical models for predicting the experimentally observed bare and infilled frame behavior. In particular, the infilled frame model is found to give excellent predictions of the observed response. It is concluded that the procedure used can be applied to the analysis of large infilled frame structures. The aseismic design implications of these results are discussed, and areas for further investigation are recommended.

● 6.6-56 Kawashima, K. and Penzien, J., **Correlative investigations on theoretical and experimental dynamic behavior of a model bridge structure,** *EERC 76-26*, Earthquake Engineering Research Center, Univ. of California, Berkeley, July 1976, 246. (NTIS Accession No. PB 263 388)

This report is one in a series to result from the project, "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 correlations between analytical and experimental seismic responses of a model bridge structure which was constructed to have the same features as the typical full-scale high-curved highway bridge structure.

Modifications of the previously reported mathematical procedures for simulating the nonlinear behavior of expansion joints are presented. These include subdividing the time interval of integration and applying an equilibrium correlation at the end of each interval and each subinterval.

Correlations of displacement response of the bridge model carried out for the three different excitations are described. Parameter studies conducted to assist in the interpretation of correlation results are presented and the characteristics of the dynamic behavior of the bridge model are discussed.

Finally, based on the correlation results presented, general conclusions are deduced and summarized.

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

● **6.6-57** Popov, E. P., Takanashi, K. and Roeder, C. W., **Structural steel bracing systems: Behavior under cyclic loading,** *EERC 76-17,* Earthquake Engineering Research Center, Univ. of California, Berkeley, June 1976, 81. (NTIS Accession No. PB 260 715)

A survey is made of existing literature on the performance of steel braced frame structures under cyclic excitations. Particular emphasis is placed on inelastic behavior under extreme credible excitations which may occur during a severe earthquake. The experimental and analytical studies of the behavior of an individual brace are described. The effect of the individual braces on the behavior of the entire structural system is then brought out. The behavior of a concentrically braced frame is discussed with respect to dynamic response to given excitations as well as its quasistatic hysteretic behavior under cyclic load. The advantages and limitations of the two possible approaches to design and correlations are indicated.

The overall problem is very complex and has not been completely resolved, but a number of plausible design concepts have been advanced. These are reviewed in the report. Most of these are based on static methods of analysis and are intended to assure good dynamic performance of the structure. These approaches are not a substitute for dynamic analysis, but they help simplify the design procedure. Several design concepts, such as the eccentrically connected braced frame, show that braced frames can perform well under extreme excitations. Finally, the limitations of current knowledge are summarized and recommendations for further research are made.

● **6.6-58** Clough, R. W. and Gidwani, J., **Reinforced concrete frame 2: Seismic testing and analytical correlation,** *EERC 76-15,* Earthquake Engineering Research Center, Univ. of California, Berkeley, June 1976, 172. (NTIS Accession No. PB 261 323)

The earthquake simulator testing and analytical correlation of the second reinforced concrete frame studied as part of the NSF project "Energy Absorption Characteristics of Structural Systems Subjected to Earthquake Excitation" are described. This frame differed from the first only in avoiding a significant construction error, and in the sequence of earthquake tests to which it was subjected. Except for local damage attributed to the construction error of the first frame, the behavior of this frame was similar to that of the first. Damage apparently is a cumulative result of the total cyclic strain history to which the structure is subjected, and is not sensitive to the testing sequence. Adequate analytical correlation with the observed results was obtained using the same mathematical modeling concepts as were employed with Frame 1, based on a bilinear frame analysis program with a superposed first mode stiffness degradation and determination mechanism.

● **6.6-59** Kan, C. L. and Chopra, A. K., **Coupled lateral torsional response of buildings to ground motions,** *EERC 76-13,* Earthquake Engineering Research Center, Univ. of California, Berkeley, May 1976, 175. (NTIS Accession No. PB 257 907)

This study of earthquake response of buildings for which the lateral motions are coupled with the torsional motion is presented in three parts: The elastic response of torsionally coupled one-story buildings to earthquake ground motion, characterized by idealized shapes for the response spectrum, is studied. Influence of the basic system parameters on the response is investigated. The relationship between the forces—base shears and torque—in a torsionally coupled system and the base shear in a corresponding torsionally coupled system and the base shear in a corresponding torsionally uncoupled system is established, and the effects of torsional coupling on earthquake forces are identified. Useful upper and lower bounds are presented for the base shears and torque due to simultaneous action to two horizontal components of ground motion of equal intensity. A simple, semiempirical analysis procedure, accompanied by the necessary numerical data, is presented to provide a convenient means to obtain conservative estimates of earthquake forces in torsionally coupled buildings.

A simple procedure is developed for the analysis of the elastic response of a particular class of torsionally coupled multistory buildings to earthquake ground motion, characterized by smooth response spectra. In this procedure the response of an N-story torsionally coupled building—a system with 3N degrees-of-freedom (DOF)—is determined by analyzing two systems: (1) An N-story torsionally uncoupled counterpart of the actual building—a system with N DOF. (2) An associated one-story torsionally coupled system—a system with 3 DOF. The simpler procedure leads to "exact" results if the structure belongs to the particular class of buildings and the variation of earthquake spectral acceleration with vibration period is idealized as flat or hyperbolic. For arbitrary but smooth shapes of the response spectrum, it is shown through numerical examples that the results of the simpler procedure are essentially exact for the particular class of buildings, and accurate enough for design purposes for buildings that satisfy some but not all of the restrictions of the particular class.

With the aid of perturbation analysis of vibration frequencies and mode shapes, it is shown that any lower vibration mode of a torsionally coupled building may be approximated as a linear combination of three vibration modes of the corresponding torsionally uncoupled system (a system with coincident centers of mass and resistance but all other properties are identical to the actual system): one translational mode along each of the two principal axes of resistance and one mode in torsional vibration. This result provides the motivation for a procedure simpler than the standard for analyzing the response of torsionally coupled

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

multistory buildings to earthquake ground motion. To illustrate the application of this procedure, a numerical example is presented.

● **6.6-60** Powell, G. H. and Row, D. G., **Influence of analysis and design assumptions on computed inelastic response of moderately tall frames,** *EERC 76-11,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Apr. 1976, 113.

The investigation described is essentially a pilot study which develops general conclusions on the inelastic behavior of buildings designed by elastic methods. The investigation is limited to single-bay frames of only ten stories subjected to ground motions of short durations.

The analysis includes the effects of column overdesign, stiffness degradation and the P-delta effect. Maximum values of story displacements, interstory drifts, beam and column hinge rotations and column axial forces are determined and compared.

● **6.6-61** Ma, S.-Y. M., Bertero, V. V. and Popov, E. P., **Experimental and analytical studies on the hysteretic behavior of reinforced concrete rectangular and T-beams,** *EERC 76-2,* Earthquake Engineering Research Center, Univ. of California, Berkeley, May 1976, 260. (NTIS Accession No. PB 260 843)

This report describes an experimental and analytical program carried out for investigating the inelastic behavior of critical regions that may develop in a beam near its connection with the column of a reinforced concrete ductile moment-resisting space frame when subjected to severe earthquake excitations.

In the experimental program, a series of nine cantilever beams, representing halfscale models of the lower story girder of a 20-story ductile moment-resisting reinforced concrete office building, were designed according to present seismic codes. These beams were designed in order to study the effects of (1) the slab by testing T-beams with a top slab width equal to the effective width specified by the ACI 318-71 Code; (2) relative amounts of top and bottom reinforcement by varying the amounts of bottom reinforcement; (3) supplementary ties by providing hairpin ties around the main bars not restrained by the corners of stirrup ties; (4) the high shear force by varying the shear-span ratio; and (5) loading histories by testing some beams under loading reversals inducing a gradually increased deformation, and others under monotonic loadings to large deformations in one direction. Detailed descriptions of the specimens, testing procedures, experimental data, and results obtained are presented. The significance of the experimental results in relation to the seismic design of the reinforced concrete critical region is also discussed.

The results showed that the main effect of the slab in T-beams was an increase in the moment capacity of the beam in one direction due to the slab reinforcement at the top. By increasing the bottom steel area up to the same amount as that of the top steel area, the energy dissipation capacity of the beam increased between 27 and 54 percent; by providing supplementary ties for supporting main compression bars not restrained by the corner of ties, the energy dissipation capacity increased about 74 percent. The development of a maximum nominal shear stress, v_{max}, of $5.3\sqrt{f'_c}$ in the shortest beam reduces the energy dissipation by one half when compared with a similar, but longer, beam with a v_{max} of $3.5\sqrt{f'_c}$. Greater amounts of energy can be dissipated by subjecting the beam to loading reversals of gradually increasing amplitude than by subjecting it directly to loading reversals of large amplitude. The inelastic rotations obtained from the test beams reached peak values in each sense ranging from 0.026 rad. to 0.058 rad. These values are considered to be adequate for the efficient design of a ductile moment-resisting frame member.

Photogrammetric measurements proved useful for studying the deformation patterns of the beam critical region subjected to reversed loadings. These measurements were especially useful for detecting shear deformation occurring along large cracks that were forming across the entire beam section.

Analytical studies were carried out to gain a better understanding of the flexure, shear, and bond-resisting mechanisms in the reinforced concrete critical regions subjected to inelastic load reversals. The analytical studies include: (1) a moment-curvature analysis, based on a hysteretic stress-strain model of reinforcing steel developed from tests on machined main reinforcing bars; (2) a finite element analysis of stress transfer (bond) between concrete and anchored main bars; and (3) an analysis of the shear force-shear deformation hysteretic relationship of reinforced concrete beams considering aggregate interlocking, stirrup-tie resistance, dowel action of main bars, and shear resistance offered by uncracked concrete. The significance of these studies is discussed and summarized.

6.6-62 Bakhtin, B. M. and Dumenko, V. I., **Dynamic investigations of the Toktogul gravity dam** (Dinamicheskie issledovaniya Toktogulskoi gravitatsionnoi plotiny, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 100–104. (For a full bibliographic citation see Abstract No. 1.1-7.)

The methods and results of experimental investigations of the seismic response of the Toktogul gravity dam are described. The nonlinear effects of vertical deformable seams are studied. The roughness of contact surfaces at the seams was incorporated into the model at the scale of 1:400. Impulse loading was applied with a prescribed

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

design accelerogram. It was found that the coupled response of adjoining sections has a substantial effect on the overall behavior and vibration parameters of the structure. A single-mass dynamic model is constructed to approximate the nonlinear vibrations of the dam sections.

6.6-63 Kalaev, A. I., **Breaking strength of the base of gravitational structures in seismic conditions** (Predelnaya prochnost osnovanii gravitatsionnykh sooruzhenii v usloviyakh seismiki, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 202–208. (For a full bibliographic citation see Abstract No. 1.1-7.)

A theoretical solution is given for the three-dimensional problem of the seismic response of the base of gravitational structures subjected to maximum stress. The relevant differential equations are obtained and solved. The computed value of the breaking strength does not differ significantly from experimental data. The discrepancy is under 10–20%.

● 6.6-64 Hisada, T. and Igarashi, K., **Evaluation of the effects of earthquake on structures on elasto-plastic response envelope spectrum with time-domain** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 237, 839–846. (For a full bibliographic citation see Abstract No. 1.2-9.)

The elastoplastic response envelope spectrum approach is an effective method for determining the effect of the repeated oscillation of earthquake motions on structures and for investigating the time duration and natural period of earthquake motions which cannot be determined from the usual response spectrum method.

An analytical model used in this calculation is the simple one-mass bilinear model whose yielding acceleration is 300 gal. This model is subjected to five earthquake motions: El Centro, Taft, Parkfield, Hachinohe, and Hiroo, the maximum accelerations of which are adjusted to 200 gal. The results show that (1) each earthquake motion has its own characteristics, (2) the number of repetitions in the plastic range caused by each earthquake motion are different, (3) many peaks can be seen in the short natural period, 0.12-0.4 sec, (4) two earthquake motions, Taft E-W and Hiroo E-W, caused the most severe effects to structures whose natural period is between 0.15 and 0.4 sec and (5) the result of the Hiroo E-W component explains the fact that the low-rise reinforced concrete structures on the solid ground were damaged by shear forces by being subjected to repeated loads in the plastic range many times the Tokachi-oki earthquake. This analytical method also is of use for determining the range of deformation and the number of repeated loads in static experiments.

● 6.6-65 Iguchi, M., **A basic study on the behaviour of long dimensional size buildings during earthquakes** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 230, 783–790. (For a full bibliographic citation see Abstract No. 1.2-9.)

This paper deals with a theoretical analysis of the vertical behavior of long structures on ground, when subjected to harmonic earthquake motion whose waves are incident at an angle with respect to the vertical axis. For simplicity an elastic base plate is considered as the structure. The distinctive features of this analysis are as follows: (1) the plane shape of the plate is rectangular, (2) the elastic deformation of the plate is taken into account, (3) the ground is treated three dimensionally. This type of problem can be formulated with integral equations, which are solved using Galerkin's method.

● 6.6-66 Goto, H. and Iemura, H., **Earthquake response characteristics of deteriorating hysteretic structures** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 253, 967–974. (For a full bibliographic citation see Abstract No. 1.2-9.)

The deteriorating characteristics of the stiffness and energy-absorbing capacity of structures are discussed by examining recorded seismograms. A time-dependent bilinear model whose equivalent linear parameters degrade with decreasing residual strength is proposed to investigate the earthquake response characteristics of deteriorating structures.

● 6.6-67 Abeki, N., **Experimental study on the restoring force characteristics of the reinforced concrete frames with a shear wall** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 248, 927–934. (For a full bibliographic citation see Abstract No. 1.2-9.)

This paper investigates the restoring force characteristics of reinforced concrete structures with shear walls. From experiments, it has been shown that axial loads effectively increase the lateral strength of shear walls. The increment of the shear stress is proportionate to the axial loading stresses. In this paper, hysteresis loops have been determined from testing twelve one-tenth scale reinforced concrete models: seven frames with, and five frames without, walls. The frames were subjected to constant axial and to lateral loads. The lateral displacements at ultimate strength are affected by the axial loads. The axial loads tend to increase the lateral displacements at ultimate strength.

● 6.6-68 Takemori, T., Sotomura, K. and Yamada, M., **Non-linear dynamic response of reactor containment,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K

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

6/5, 10. (For a full bibliographic citation see Abstract No. 1.2–11.)

A computer program for determining the elasto-plastic behavior of structures is described. As an example, the nonlinear response of a reactor containment building of a PWR plant was obtained. The building consisted of three components: a concrete internal structure, a steel containment vessel and a concrete outer shield. The components, considered to be resting on a rigid foundation mat, were modelled as lumped masses which were coupled to the foundation. The direct integration method was used in the analysis. Comparison is made of the difference between elastic and elasto-plastic response analysis.

● **6.6–69** Udoguchi, Y., Akino, K. and Shibata, H., **On the behavior of pressurized pipings under excessive-stresses caused by earthquake loadings,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 7/5, 10. (For a full bibliographic citation see Abstract No. 1.2–11.)

In Japan the application of the emergency condition of the ASME code to the aseismic design of nuclear piping systems is being considered. For this purpose, the elasto-plastic behavior of pressurized piping under seismic loading conditions is analyzed. Five types of experiments on the breaking and rupturing of pipe elements and piping structures have been carried out from 1971 to 1973 by the Japan Electric Assn. Some of the experiments were conducted on a shaking table. The proposal of allowable stresses under earthquake loading presented in this paper is obtained by modifying those of the emergency condition of the ASME code. The authors conclude that their proposed criteria and the ASME's seismic design criteria of Class I pipe elements provide enough margin of safety under the specified earthquake loadings in Japan.

● **6.6–70** Ikushima, T. and Kawakami, M., **Seismic response analysis for block-type fuel HTGR core,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 8/7, 10. (For a full bibliographic citation see Abstract No. 1.2–11.)

This report describes analytical and experimental studies of the seismic response of a block-type fuel reactor core. Three analytical models were considered. The results calculated using all three models were similar.

The following observations were made: (1) At low input-wave frequencies, the response value increases with the clearance between the blocks. Beyond a certain point, however, the effect of clearance is negligible. (2) When the blocks are restrained horizontally, the response value decreases with increase of the restraint mechanism stiffness. The mechanism is thus effective in earthquake resistance. (3) The response value increases with block stiffness so that short massive blocks are better for earthquake resistance. (4) The response value decreases with increase of the block damping factor; but beyond a certain point, this effect is only small. (5) Stiffness and damping in the restraint mechanism for the reactor core do not have much effect on earthquake resistance. A computer simulation method also is described.

● **6.6–71** Buland, P. *et al.*, **Seismic study of HTGR core** (in French), *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 8/9, 9. (For a full bibliographic citation see Abstract No. 1.2–11.)

This paper presents the results of an experimental study of an HTGR core model. Comparisons are made with analytical results. Two series of tests were performed on the shaking table VESUVE: sinusoidal test and time history response. The El Centro time history displacement was reproduced on the shaking table. Acceleration of graphite blocks, forces on the boundaries, relative displacement of the core and PCRV model and impact velocity of the blocks on the boundaries were recorded. Sinusoidal tests consisted of frequency sweeps at constant displacement level and sine dwells at constant g-levels.

These tests have shown the strongly nonlinear dynamic behavior of the core. The resonant frequency of the core is dependent on the level of the excitation. These phenomena have been explained by a computer code, which is a lumped mass nonlinear model. Good correlation between experimental and analytical results was obtained for impact velocities and forces on the boundaries. This comparison has shown that the damping of the core is a critical parameter for the estimation of forces and velocities.

● **6.6–72** Munro, I. R. M., **Seismic behaviour of reinforced concrete bridge piers,** *Research Report 76/9,* Dept. of Civil Engineering, Univ. of Canterbury, Christchurch, New Zealand, Feb. 1976, 106.

The characteristics of the seismic behavior of circularly reinforced concrete bridge piers were studied. A one-third scale model of a prototype pier was tested using static displacement-controlled loading cycles to simulate seismic motions. The results indicate that adequate energy dissipation by post-elastic deformations of the pier is possible, without significant reduction in load capacity.

A series of dynamic inelastic computer analyses of the prototype pier were conducted to provide a basis for the theoretical prediction of the dynamic response of the pier. Measurement of this response was made during the dynamic test of a second model pier, of one-sixth scale, on an electro-hydraulic shaking table. Comparison between the theoretical and experimental behavior is made and the ductility requirements for bridge piers, specified by the

New Zealand Ministry of Works and Development, are discussed on the basis of the results of this research.

The significance of foundation conditions on the ductility requirements of bridge piers is discussed as an introduction to future programs of study of this problem.

● 6.6-73 Anraku, H., Takemoto, Y. and Takeda, T., **Elasto-plastic analysis of stud shear connector** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 10,* 1975, 23-29.

Composite beams are widely used in the design of steel buildings; these beams are analyzed taking into account the slippage between steel beams and concrete slabs which are connected to each other with shear connectors. Theoretical studies on the failure mechanisms and load-slip curves of such shear connectors, however, are difficult to find. A theoretical analysis of the elasto-plastic behavior of stud shear connectors is presented with the intention of examining the failure mechanisms and to obtain load-slip curves useful for numerical analysis of composite beams.

● 6.6-74 Furuya, N. and Takemoto, Y., **Development of concrete slabs using upward-ribbed precast concrete panels [Part 2]** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 10,* 1975, 18-22.

This report presents bending test results of composite concrete T-beams. The slabs on the beams consist of precast concrete panels upon which concrete is cast in place. The ratio of extended stirrups used to transfer horizontal shear and intentionally provided roughness of contact surfaces are employed as test parameters. The test results show that horizontal shear forces are fully transferred, provided the extended stirrups are sufficient for the vertical shear requirement, and that intentional roughness is effective when the stirrup ratio is comparatively low.

6.7 Nondeterministic Dynamic Behavior of Nonlinear Structures

● 6.7-1 Helvaci, I. and Gurpinar, A., **Random vibrations of elasto-plastic systems** (Elasto-plastik sistemlerin gelisiguzel titresimi, in Turkish), *Deprem Arastirma Enstitusu Bulteni,* 2, 7, Oct. 1974, 17-30.

In this paper, the random vibration of elasto-plastic systems with one degree-of-freedom excited by earthquake-like excitations is studied. Results are given in graphical form.

6.7-2 Makarov, B. P. *et al.*, **On random vibrations of elasto-plastic systems subjected to seismic excitations** (O sluchainykh kolebaniyakh uprugo-plasticheskikh sistem pri seismicheskikh vozdeistviyakh, in Russian), *Trudy TsNII stroitelnykh konstruktsii, 44,* 1975, 83-87.

An analytical expression is presented of the nonlinear relationship between restoring force and displacement. Using static methods the reliability of the system subjected to seismic excitation is evaluated. The possibility of an analytical solution for the problem of markedly nonlinear systems is demonstrated.

● 6.7-3 Ibrahim, R. A. and Roberts, J. W., **Broad band random excitation of a two-degree-of-freedom system with autoparametric coupling,** *Journal of Sound and Vibration,* 44, 3, Feb. 8, 1976, 335-348.

The response of a two-degree-of-freedom system with autoparametric coupling under the action of broad band random excitation is investigated. The system corresponds to the autoparametric vibration absorber and is also typical of many common structural configurations. A method based upon the Markov vector approach, together with an approximate treatment of third and higher statistical moments, is used to derive a set of fourteen coupled nonlinear equations for the first and second moments of the system responses. A numerical integration procedure is used to obtain quantitative results for the system mean and mean square responses over a range of system parameters.

The results show that large random motions of the coupled system may occur when the internal detuning parameter is close to the principal internal resonance, and that these motions may give rise to a suppression effect on the random motions of the main system. A feature of the results is that under conditions of internal resonance the random motions are found to be quasi-stationary, with steady oscillatory terms in the response moments. This suggests the possibility of entrainment of regular harmonic responses by the system random motions.

● 6.7-4 Tani, S. and Soda, S., **Vertical load effects on structural dynamics,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 224, 735-742. (For a full bibliographic citation see Abstract No. 1.2-9.)

In this paper, the effects of vertical and gravity loads on the horizontal displacement of a tall building are examined by a statistical method using a shear model with a single degree-of-freedom.

The system is nonlinear and excitations are assumed to be stationary. Bilinear hysteresis is assumed to represent the system nonlinearity and it is transformed into the elliptic hysteresis of a linear system with structural damping, considering that the area and the amplitude of each hysteresis loop are the same.

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

The P-Δ effect due to the increase of horizontal displacement is examined. Though the effect of the vertical component of the earthquake excitation proved to be negligible, there are cases where the gravity effect must be taken into consideration, and some characteristics of the gravity effects on tall buildings are obtained.

● 6.7-5 Goto, H. *et al.*, **Probabilistic considerations on plastic fatigue failure of structural steel members excited by earthquakes** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 239, 855–862. (For a full bibliographic citation see Abstract No. 1.2–9.)

This paper presents the results of some plastic fatigue tests of H-section SS41 steel members in order to investigate the effectiveness of the theory of cumulative fatigue damage as the criterion for plastic fatigue failure.

A simple beam 100x100x6x8 mm with a span length of 1400 mm was used throughout this series of experiments. A concentrated reversible load was applied to the midspan of the beam. Different loading patterns were chosen: constant, random, and on-line dynamic controlled by an analog computer.

The test results were estimated using a probabilistic method. A first-order approximation of reliability theory was introduced in the analysis of the randomly excited plastic fatigue failure. Uncertainties in the prediction procedure were analyzed. The theoretical and experimental results are compared.

6.8 Soil-Structure Interaction

6.8-1 Rashidov, T., Khozhmetov, G. and Mardonov, B., **Vibrations of structures interacting with the soil** (Kolebaniya sooruzhenii vzaimodeistvuyushchikh s gruntom, in Russian), FAN Publishers, Tashkent, 1975, 176.

This volume consists of three chapters. In the first chapter the response of underground structures to seismic excitations is investigated using experiments on full-scale structures and models. In the second chapter vibrations of underground structures embedded in various kinds of soils (elastic, viscoelastic, elasto-plastic) are discussed. The response of underground structures of finite length is investigated. The effects of stationary seismic waves on an underground pipeline embedded in viscoelastic soil are considered. Numerical results are obtained for the problems considered. In the third chapter vibrations of building foundations are investigated using dynamic earthquake response analysis. The effects of soil conditions on building response are considered.

6.8-2 Rashidov, T. R. *et al.*, **Earthquake resistance of subway tunnels** (Seismostoikost tonnelnykh konstruktsii metropolitenov, in Russian), TRANSPORT, Moscow, 1975, 120.

Earthquake response of underground structures is studied. The dynamic interaction of subway tunnels with the surrounding soil is analyzed and earthquake damage is investigated. Recommendations concerning the design and construction of tunnel casings are given. The tunnel casings of the Tashkent subway are considered.

6.8-3 Bobakov, L. N., **Vibration damping in structures due to wave refraction at the boundary of the adjacent medium** (Zatukhanie kolebanii stroitelnykh konstruktsii vsledstvie perelomleniya voln v zone kontakta s granichashchei sredoi, in Russian), *Trudy TsNII stroitelnykh konstruktsii, 44*, 1975, 30–38.

Wave propagation theory is applied to an analysis of dynamic processes in buildings. Criteria for regarding the building as a system with uniformly distributed parameters are discussed. The flow of vibration energy from the building to the soil base determines, to a large extent, the dissipative properties of the object considered.

Free vibration of various systems is analyzed and the range of application of each formula given for the logarithmic decrement is determined. The effects of the excitation level and frequency on vibration damping are discussed in the special case when vibration damping in the approximate model is solely the result of wave dispersion at the base.

6.8-4 Dmokhovskii, A. V. and Alpaidze, Z. G., **Concentration of dynamic stresses in models of circular tunnels with casing subjected to longitudinal waves** (Kontsentratsiya dinamicheskikh napryazhenii v modelyakh krugovykh tunnelei s obdelkoi pri vozdeistvii prodolnykh voln, in Russian), *Sbornik trudov Moskovskogo inzhenerno-stroitelnogo instituta, 125–126*, 1975, 178–181.

The effects of the thickness of tunnel casing on concentration of dynamic stresses are investigated using methods of dynamic photoelasticity on two-dimensional models. Diffraction of plane longitudinal P-waves is studied near circular openings reinforced by casings with varying acoustic stiffness. Tunnel casing prevents the development of dangerous tensile stresses in the surrounding area. Maximal contact stresses increase with the thickness of the casing.

● 6.8-5 Bobakov, L. N., **Application of the theory of wave propagation to the analysis of buildings under earthquakes**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 50, 5. (For a full bibliographic citation see Abstract No. 1.2–6.)

The paper deals with propagation of a one-dimensional elastic shear wave (or dilatational wave) in a struc-

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

ture. Transient characteristics were obtained for systems with distributed parameters and with and without lumped masses. Propagation of harmonic waves was studied. For an approximate model a formula of the logarithmic decrement of vibrations due to radiation of elastic waves into the semispace of the foundation base was found. Formulas for calculating parameters of an approximate model of the interaction between the structure and the foundation base were obtained. These formulas were obtained in terms of the hypothesis substantiated by the estimates, concerning the predominant effect of the energy flow directed into the outside medium on the attenuation of vibrations. Additional generalized characteristics of the behavior of different buildings and structures under various soil conditions as a function of impedance ratio were introduced.

● 6.8-6 Lee, T. H., **Inverted-pendulum effect on seismic response of tall buildings considering soil-structure interaction,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 147-160. (For a full bibliographic citation see Abstract No. 1.2-7.)

Analyses of the seismic response of tall buildings have been customarily performed without taking into account the dynamic effects resulting from the dead weight of the structures. In the event of an earthquake disturbance, the rotation of the building due to soil-structure interaction will shift the center of gravity of the building laterally. This means that, while responding to the excitations due to ground motion, the system will behave as an inverted pendulum influenced by its own weight. Furthermore, the phenomena can be shown to be coupled with the structural deformation which causes the centers of gravity of the structural members to move laterally. Although it is known to seismic analysts that this gravitational effect depends primarily upon the aspect ratio of the system and the foundation stiffness, its significance has not been accurately quantified for tall buildings on soft ground where the soil-structure interaction effect plays an important role.

This paper demonstrates how the phenomena can be studied by using a soil-structure interaction model. Modified governing equations were derived and incorporated in an interaction analysis utilizing fixed-base modes of the superstructures. In this manner, the problem was investigated by modelling the soil medium as an elastic halfspace. The inverted pendulum effects, with and without the consideration of structural deformation, are discussed on the basis of the numerical results obtained.

● 6.8-7 Shah, V. N. and Huang, T. C., **Vibrations and interactions of layered beam foundations,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 315-330. (For a full bibliographic citation see Abstract No. 1.2-7.)

A beam and its supporting soil foundation are represented by a layered beam system. Each beam in this system is either a classical beam or a shear beam, and each is separated from its adjacent beams by spring layers. Natural frequencies and normal modes are obtained by two different methods: the state space method and the power series method. Numerical examples are given. In a succeeding paper, orthogonality conditions will be derived for these modes and applied to the investigation of forced vibrations.

● 6.8-8 Prater, E. G. and Wieland, M., **Response of structures embedded in the ground to travelling seismic waves,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 183-198. (For a full bibliographic citation see Abstract No. 1.2-7.)

The interaction of a long structure with the ground is investigated using the theory of wave propagation. The special feature of the investigation is the consideration of the spatial variations of the input motions applied at points on the boundary of the system. In the illustrative problem, the underground is assumed to consist of horizontal layers terminated by vertical transmitting boundaries and a horizontal soil-rock interface. Nonlinear soil behavior is taken into account using a Ramberg-Osgood model for the deviatoric stress-strain behavior. The equations of motion are discretized using central finite differences in space and time. The use of a dual grid gives more efficient discretization and greatly simplifies the relations at interfaces and boundaries. The analysis of travelling wave motions does not give rise to much extra computational effort as compared with the case in which the spatial variations of input motions are ignored. This is not the case with the finite element method, which becomes much less efficient for travelling wave analysis.

● 6.8-9 Mendelson, E. and Alpan, I., **The effect of foundation compliance on the fundamental periods of multistorey buildings,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 127-145. (For a full bibliographic citation see Abstract No. 1.2-7.)

The study deals with the effect of soil-structure interaction on the fundamental periods of framed reinforced concrete multistory structures. Typical structures of various heights and several foundation systems are examined, as the relevant soil parameters are varied for each foundation system.

An approximate formula for the fundamental period, with consideration of the elastic compliance of the foundation, is presented. This formula shows the effect of soil-structure interaction to increase the fundamental period of the structure. The influence of the elastic compliance is shown to be particularly pronounced in the cases of isolated footings on sand and of raft foundations on soft clay.

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

This influence increases with the height of the structure. The influence of the compliance is small in the case of pile foundations and it decreases with increases in the height of the structure.

● **6.8-10** Johnson, G. R., Epstein, H. I. and Christiano, P., **Some comparisons of dynamic soil-structure analyses,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 199–214. (For a full bibliographic citation see Abstract No. 1.2–7.)

For the lumped parameter and finite element methods applied to dynamic soil-structure interaction problems, the effects of various parameters and possible sources of error are investigated using a limited parametric study. Single- and multidegree-of-freedom systems with various mass ratios, with and without internal and radiation damping, are subjected to severe loadings. The single-degree-of-freedom system consists of a rigid disk resting on the surface of an elastic stratum. Five-mass models are used for the multidegree-of-freedom systems. For the lumped parameter model, a rational procedure is presented to find appropriate springs, dashpots, effective masses and equivalent modal damping. This study considers the vertical motion of surface-mounted axisymmetric structures on a homogeneous elastic stratum underlain by bedrock. For these problems, it is demonstrated that the lumped parameter method can produce results that give good general agreement with finite element results which include the soil. The results indicate that it is possible to apply the lumped parameter method to problems beyond those of a harmonic forcing function and an elastic halfspace.

● **6.8-11** Hung, Y. C. and Snyder, M. D., **Gypsum layer in soil-structure systems,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 215–232. (For a full bibliographic citation see Abstract No. 1.2–7.)

The motion of an embedded foundation will differ during an earthquake from the free field as a result of the soil-structure interaction. For most sites, the soil profile is horizontally layered. This paper investigates the extent of the interaction of structure, foundation and soil when the soil layer is interrupted by the presence of a relatively stiff gypsum layer of irregular profile. The site studied for a reactor building consists mainly of layers of sand, clay, sandstone and gypsum.

Two finite element models were constructed to investigate the effect of the gypsum geometry in the proximity of the reactor building. One finite element model assumes the horizontal layering of the soil profile with an interbedded layer of gypsum of uniform thickness, while the other considers the actual profile of an interbedded layer of gypsum of varying thickness. Plane strain elements were used for the soil layers, reactor foundation and reactor building structural systems.

Static and dynamic aspects of the layering effect were studied. The static analysis was undertaken by applying vertical, horizontal and moment loadings to the foundation mat to assess the influence of the gypsum layer on the static soil spring constants. The dynamic analyses were performed to study the influence of the gypsum layer on the soil-structure interaction. Complex transfer functions were determined between bedrock and the structure-foundation to evaluate the dynamic characteristics of each soil profile from the two finite element models.

● **6.8-12** Kobori, T., Inoue, Y. and Kawano, M., **Dynamic response characteristics of an elasto-plastic structure on a random soil ground,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 655–668. (For a full bibliographic citation see Abstract No. 1.2–7.)

The dynamic, random ground compliance of a soil represented by a two-dimensional finite element model is presented and evaluated using the Monte Carlo simulation method. Using this random ground compliance, the authors discuss the response of a soil-structure system to a white random excitation.

● **6.8-13** Luco, J. E., **Torsional response of structures to obliquely incident seismic SH waves,** *Earthquake Engineering and Structural Dynamics,* **4**, *3,* Jan.-Mar. 1976, 207–219.

A study is made of the torsional response of an elastic structure placed on a rigid circular foundation, supported on an elastic halfspace and subjected to the action of obliquely incident plane SH-waves. The problem is solved by considering first the steady-state response of a massless rigid foundation excited externally by a harmonic torque and through the soil by an obliquely incident plane SH-wave. In a second stage the coupling between the structure and the soil is considered to obtain the torsional response at the base and top of the superstructure. The results obtained indicate a range of conditions under which the torsional effects will be most pronounced.

6.8-14 Stallybrass, M. P. and Scherer, S. E., **Forced vertical vibration of a rigid elliptical disc on an elastic half-space,** *International Journal of Engineering Science,* **14**, *6,* 1976, 511–522.

The forced vertical vibration of a rigid frictionless elliptical disc on the surface of an elastic halfspace is considered. This mixed boundary value problem is reduced to a (two-dimensional) integral equation. An approximation is obtained for the displacement of the disc by using a variational procedure.

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

● 6.8-15 Scanlan, R. H., **Seismic wave effects on soil-structure interaction**, *Earthquake Engineering and Structural Dynamics, 4, 4,* Apr.-June 1976, 379–388.

One of the most common hypotheses implicit in the seismic analyses of structures is that the earthquake input motion is identical at all points beneath the structure. Very little experimental evidence presently is available to supplant this viewpoint. However, one may infer a spatially distributed surface motion of the soil if the earthquake is simply assumed to consist of a complex of surface waves traversing the plan of the structural site.

Under these conditions, as shown in the paper, the effects of passing waves must be integrated over the structural area to obtain their net effects as exciting functions to the structure. When this is done for individual Fourier components of the earthquake, one important result is the diminution or "self-cancelling" effect of some inputs, particularly for those waves the wavelengths of which are comparable to the dimensions of the structure, or shorter. Another important effect is the torsional excitation of the structure.

The present paper is not necessarily aimed at replacing present analysis methods but at discussing some of the effects which will inevitably be entrained by the introduction of any information or hypotheses regarding the spatial distribution of earthquake motions. This analysis tends to suggest why higher frequencies are of lesser importance for a structure having a large rigid foundation.

6.8-16 Kaufman, B. D. and Shulman, S. G., **On interaction of a structure with viscoelastic base during earthquakes** (O vzaimodeistvii sooruzheniya s uprugo-vyazkim osnovaniem pri zemletryasenii, in Russian), *Izvestiya VNII gidrotekhniki, 109,* 1975, 92–96.

The structure is regarded as a viscoelastic oscillator and the base considered as a semi-infinite bar. Various theories are employed to account for the viscous properties of the structure and its base, e.g. Maxwell's and Voigt's models and the standard viscoelastic body. Equations describing the earthquake response of the structure and the effects of the bases are derived and analyzed.

● 6.8-17 Minami, J. K. and Sakurai, J., **Some seismic response solutions for soil-foundation-building systems**, *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 169–182. (For a full bibliographic citation see Abstract No. 1.2–7.)

Behavior of buildings in earthquakes, taking into consideration the interaction effects of the supporting ground and the foundation consisting of basement, piles and piers, the energy dissipative capacities (damping) of soils, and the influence of the vertical component of earthquake motion, has been investigated by means of a cyclic truss-type model that represents a soil-foundation-building (SFB) vibratory system. The 1940 El Centro and 1952 Taft earthquake waveforms have been used, normalized to 100 gal horizontal and 60 gal vertical components which are fed into the SFB system at the base of the surface soil layers. The buildings considered range from low to medium height, 1 to 15 stories above the ground level. The damping of the buildings is assumed to be 3% of critical and 10% and 20% damping ratios have been assigned to the hard, soft and filled soil types. The case of uniform damping ratio of 5% for the soil and the building has also been studied for the purpose of comparison.

Seismic response in terms of base shear coefficient, base axial force coefficient and base overturning moment coefficient has been determined by performing hundreds of simulation experiments. Some of the findings do not conform to long-established concepts, but they provide satisfactory explanations for building damage observed in the past.

6.8-18 Temirbekov, A., **Calculation of dynamic pressure on the soil from a rigid structure subjected to seismic excitation** (Otsenka dinamicheskogo davleniya na grunt v usloviyakh seismicheskogo vozdeistviya na zhestkoe sooruzhenie, in Russian), *Izvestiya Akademii Nauk Uzbekskoi SSR Seriya tekhnicheskikh nauk, 4,* 1975, 45–48.

Various elements of soil-structure interaction during earthquakes and their usefulness for providing more exact information on soil conditions in seismic microzoning are discussed.

6.8-19 Matkarimov, A. Kh. and Vakhabov, G., **Investigation of the earthquake resistance of viscoelastic underground pipelines** (Issledovanie seismostoikosti vyazkouprugikh podzemnykh truboprovodov, in Russian), *Fundamenty i podzemnye sooruzheniya pri dinamicheskikh vozdeistviyakh,* FAN, Tashkent, 1975, 87–104.

The dynamic response of underground pipelines with viscoelastic properties is investigated. Equations describing longitudinal vibrations are given. Displacements, stresses and deflections due to seismic excitations are calculated for each pipeline section. The solution for the elastic case is obtained. Stationary problems of the earthquake resistance of underground pipelines embedded in viscoelastic soil are investigated.

● 6.8-20 Ciongradi, I. and Ungureanu, N., **The soil-foundation-structure interaction under the action of earthquake loads**, *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 233–251. (For a full bibliographic citation see Abstract No. 1.2–7.)

The equations of motions of the structural system take into account the interaction with the soil; corrections used when the interaction is ignored also are emphasized. The method for determining the elements of the soil flexibility matrix, referring to the contact surface with the structural system, is shown for different soil models. The results obtained are used for the determination of conventional seismic loads. The proposed solution is particularized for framed structures with isolated foundations or with foundation beams. Using a computer program, the authors carry out a seismic analysis for a framed structure with consideration of the two types of foundations and the two types of soils differentiated from each other by their deformability modulus. Some of the results obtained are discussed.

● 6.8-21 Nakagawa, K. *et al.*, **Dynamic properties of testing laboratory structure having large opposing twin reaction walls** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 11,* 1975, 27-31.

In order to obtain information about the interaction between a relatively rigid structure with a basement and the surrounding soil, the authors conducted tests using the structural testing facility of the company. These tests consisted of vibration tests and observation of seismic responses of the structure and the ground. Experimental results include earth pressure distributions at the base and side walls of the basement, fundamental dynamic properties and interesting vibration phenomena regarding the large opposing twin reaction walls.

In this report, the authors have summarized the results of the tests and developed a dynamic model simulating the large opposing twin reaction walls and basement-surface soil layer-subsoil layer system. Calculated results based on the model show good correlation with observed test results.

● 6.8-22 Hadjian, A. H., **Discussion of: Soil-structure interaction analyses for seismic response,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT4,* Proc. Paper 12013, Apr. 1976, 380-384. (*By Seed, H. B., Lysmer, J. and Hwang, R., Proc. Paper 11318, May 1975.)

● 6.8-23 Beliveau, J.-G., **Modal identification for nonnormal modes,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 431-442. (For a full bibliographic citation see Abstract No. 1.2-8.)

The damping in soil-structure interaction problems is known not to be proportional; thus the mode shapes are not normal. Parameters, including those associated with damping, may be estimated, however, if use is made of phase angle information.

Two examples of this interaction are considered. In the first, a one-story relatively flexible building, the interaction coefficients are estimated. Soil parameters are identified in the second example of a stiff structure representing a nuclear reactor containment vessel. Modal information is used in both instances.

● 6.8-24 Idriss, I. M. and Sadigh, K., **Seismic SSI of nuclear power plant structures,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT7,* Proc. Paper 12246, July 1976, 663-682.

Nuclear power plant structures are massive structures typically embedded at a considerable depth in a soil deposit. An important aspect in the seismic design of these structures is the evaluation of the dynamic interaction between the structure and the soil. This paper presents the results of a study conducted to evaluate seismic soil-structure interaction (SSI) effects for a partially embedded massive nuclear plant structure using the finite element method of analysis. The analyses were carried out using the finite element program LUSH, which incorporates the use of variable modulus and variable damping in the soil. The high frequency ranges, which must be considered in the study of SSI for nuclear power plants, are also adequately accounted for in the computer program used. Several significant parameters that could affect seismic SSI are examined. Consideration was given to parameters affecting: (1) accuracy, (2) core storage requirements, and (3) execution time.

● 6.8-25 Pender, M. J., **Discussion of: Some effects of dynamic soil properties on soil-structure interaction,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT12,* Proc. Paper 12585, Dec. 1976, 1281-1283. (*By Richart, Jr., F. E., Proc. Paper 11764, Dec. 1975.)

● 6.8-26 Kausel, E., Roesset, J. M. and Christian, J. T., **Nonlinear behavior in soil-structure interaction,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT11,* Proc. Paper 12579, Nov. 1976, 1159-1170.

The relative importance of secondary nonlinear effects in soil-structure interaction is investigated by means of the iterative linear method. It is found that the refinement in the analyses, while increasing the cost of computation several times, does not change the dynamic response in the structure to a significant degree. At the same time, an improved algorithm is presented for the computation of the characteristic strain used in the iterative approach.

● 6.8-27 Kobori, T. and Shinozaki, Y., **Discussion of: Torsional response of structures to obliquely incident seismic SH waves,*** *Earthquake Engineering and Structural Dynamics,* **4,** *6,* Oct.-Dec. 1976, 616-619. (*By Luco, J. E., Jan.-Mar., 1976, 207-219.)

● 6.8-28 Hall, Jr., J. R., Kissenpfennig, J. F. and Rizzo, P. C., **Discussion of: Soil-structure interaction analyses for**

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

seismic response,* *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT6,* Proc. Paper 12163, June 1976, 650–652. (*By Seed, H. B., Lysmer, J. and Hwang, R., Proc. Paper 11318, May 1975.)

● **6.8-29** Hanada, K. and Kudo, T., **Analysis on dynamic behaviours of soil-structure systems** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 140, 311–318. (For a full bibliographic citation see Abstract No. 1.2-9.)

This paper presents three types of soil-structure models, at the boundary of which energy-absorbing dampers are introduced for the analysis of dynamic problems involving an infinite continuous medium.

● **6.8-30** Hirasawa, M. and Satoh, K., **Forced vibration test and analysis as soil-structure system of nuclear reactor building** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 137, 289–296. (For a full bibliographic citation see Abstract No. 1.2-9.)

● **6.8-31** Tsushima, Y. *et al.,* **Study on soil-reactor building interaction analysis of damping effects in energy dissipation through the bottom of foundation** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 136, 281–288. (For a full bibliographic citation see Abstract No. 1.2-9.)

A mathematical model was used for the vibration tests. The model stiffness was first estimated by the complex stiffness method. Using Tajimi's vibrational admittance theory, the authors also estimated the ground stiffness of the model for horizontal and rocking motions. Relations between the fundamental period and the damping ratio, the shear wave velocity of the ground and the damping ratio, and the dimensionless frequency and the damping ratio were obtained. Also obtained were the frequency transfer functions of acceleration.

● **6.8-32** Mizoguchi, K., **A resonance phenomenon in mutual action between a building and soil,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 139, 305–310. (For a full bibliographic citation see Abstract No. 1.2-9.)

Described are the results of a study of a compressor with a foundation embedded in an elastic semi-infinite body of soil.

● **6.8-33** Shimizu, N. *et al.,* **Earthquake response analysis of nuclear reactor building embedded in a ground by the thin layer element method** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 138, 297–304. (For a full bibliographic citation see Abstract No. 1.2-9.)

In this analysis, the following assumptions are made to obtain the theoretical solution of a dynamic interaction problem of a nuclear reactor building and the surrounding soil: (1) Bedrock is assumed to exist under the place where a nuclear reactor building is built, (2) soils, except ones which surround the building, are modeled by homogeneous elastic thin layer elements, (3) building and surrounding soil are modeled by an assemblage of rectangular finite elements, (4) soil and building are modeled as two-dimensional elastic plane-strain, (5) damping due to the impedance ratio of the soil and bedrock, and internal damping of soil itself are all converted to material damping of soil. On the basis of these assumptions, the equations of motion of the building-soil interaction system are derived. By using these equations, numerical studies of models were conducted to fix vertical boundaries between the thin layer element and finite element, and to study the method for introducing the damping into soil materials, etc.

As a result of the above-mentioned examinations, data for determining an analytical model for the parametric study of nuclear reactor buildings are obtained for evaluating the interaction between the nuclear reactor building and soil. Consequently, the proposed method is found to be useful to a wide range of dynamic interaction problems.

● **6.8-34** Kobori, T. and Suzuki, T., **Vibrations of structures embedded in a visco-elastic layered medium,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 143, 335–342. (For a full bibliographic citation see Abstract No. 1.2-9.)

Described in this paper is a more realistic model of a soil-structure interaction system than has been proposed in the past. The system is composed of a flexible structure embedded in a viscoelastic, multilayered medium over a rigid halfspace. The structure is subjected to horizontal, harmonic, base rock motions or exciting forces acting at the top of the structure. The method of the dynamic response analysis for such an interaction system is described on the basis of the expansion technique of eigenfunctions and the variational method. Assuming that the system is two dimensional, an analysis is performed for the two cases in which SH-waves and P- and SV-waves are caused respectively for the two mutually perpendicular directions. To prove the validity of the method of analysis, some numerical examples for the system of a Voigt solid are shown in graphical form. Discussed are how the shape of a structure and the stiffness ratio between the structure and the ground affect the dynamic responses of the displacement and the earth pressure caused in the interaction system.

● **6.8-35** Minami, J. K., Sakurai, J. and Ohno, T., **Effects of varied damping values and vertical earthquake motions on the seismic response of soil-foundation-building systems** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 147, 367–

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

374. (For a full bibliographic citation see Abstract No. 1.2–9.)

The paper presents some results of an investigation relating to the effects of assigning different damping ratios to the soil and the building in a soil-foundation-building (SFB) interacting system and also the effects of vertical earthquake motion on the base axial forces in the columns.

A continuous cyclic truss type model has been designed to represent the soil, basement and foundation construction with and without piles or piers. The model is continuous in the horizontal direction with the buildings located 50 m center to center. The buildings are 10 m wide, consisting of two 5 m spans and the number of stories above the ground ranges from 1 to 15 stories, the story height being 3.5 m. They are provided with either none or 1 basement of 5 m story height and some are supported by piles or piers. The surface soil types are assigned predominant periods of vibration of 0.25 sec, 0.50 sec, and 1.0 sec to represent hard, soft, and fill type soils, respectively. Damping values of 10% and 20% of critical have been assigned to each soil type in the first mode and 3% of critical to the building, also in the fundamental mode. To solve the complex eigenvalue problem caused by the varied damping values, the double QR method has been utilized to determine the vibrational characteristics. Solutions for uniform 5% damping for the soil and building have also been obtained for the purpose of comparison.

Maximum accelerations of 100 gal horizontal and 60 gal vertical of the 1940 El Centro and 1952 Taft earthquakes have been chosen as input earthquake forms at the bottom of the surface soil layer at -15 m from the ground level. Seismic response solutions have been obtained approximately by the modal superposition procedure but neglecting the phase difference angles of the masses and the damping on the lower mode shapes.

The building vibration periods in the SFB interacting system are definitely influenced by the difference in the soil types, basement and foundation construction including piles and piers. Base shear coefficient values are influenced both by the soil type and damping values. Low rigid buildings of 1, 2, 3 or 5 stories, depending on the type of soil supporting them, move with the predominant periods of the ground as rigid bodies. Base shear coefficients are largest for the hard soil, least for the fill soils and intermediate for the soft soil. For taller buildings, the base shear coefficients decrease in the familiar manner relating to earthquake spectrum curves and they are further reduced as the soil damping values are increased. The vertical component of earthquake motion produces axial forces of plus-minus 0.2 of the building weight for the 60 gal vertical input which in certain cases should not be ignored as it usually is in current earthquake-resistant design practice.

● 6.8-36 Tajimi, H., Ogawa, N. and Minowa, C., **Dynamic behaviors of a large-scale shaking table foundation,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 148, 375–382. (For a full bibliographic citation see Abstract No. 1.2–9.)

This paper describes the dynamic behavior of a large-scale shaking table foundation and its surrounding soils. The table is part of the research facilities of the National Research Center for Disaster Prevention. The measurements were conducted by forced vibrations as well as by using actual earthquake records. The measurements were verified by analyses.

● 6.8-37 Ukaji, K., Hoeg, K. and Shah, H. C., **Elastic-plastic dynamic analysis of soil-foundation-structure interaction,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 141, 319–326. (For a full bibliographic citation see Abstract No. 1.2–9.)

The primary objectives of this study are to develop procedures for determining the response of soil-foundation-structure systems during earthquakes as well as to investigate the nature of interaction phenomenon. A two-dimensional soil-foundation-structure model is formulated to simulate the dynamic behavior of a system which consists of a plane framed building, rigid embedded foundation and horizontally layered soil deposit. The method of finite elements, representing the soil deposit, is incorporated in the interaction model utilizing an equivalent linear and elastic-plastic stress-strain relationship. A special side boundary treatment is used to eliminate the influence of artificial side boundaries. The parameter studies are carried out changing soil properties and depth, structures, foundation embedment and bedrock motions. The results of the parameter studies are discussed by means of an amplification factor and interaction coefficient.

● 6.8-38 Shibuya, J., Motosaka, M. and Shiga, T., **Analysis and measurement tests on dynamic properties of coupled building-soil system,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 146, 359–366. (For a full bibliographic citation see Abstract No. 1.2–9.)

Dynamic properties of coupled building-soil systems are investigated. The building is replaced by a single-degree-of-freedom oscillator. The soil is modelled by a discrete system with varying stiffness and damping dependent on exciting frequency simulating an elastic halfspace. Simple approximate formulas for the calculation of dynamic properties of the coupled system are developed. Results from the simplified approach agree well with those from the analytical method.

Interaction effects in actual buildings measured in microtremor tests are analyzed using the method developed. The results found using the method agree well with the experimental results.

● 6.8-39 Ramachandran, J. and Murthy, P. A. K., **Nonlinear vibrations of a shallow cylindrical panel on an elastic foundation,** *Journal of Sound and Vibration,* **47,** *4,* Aug. 22, 1976, 495–500.

The dynamic von Karman field equations are used to analyze the influence of large amplitude on the free vibrations of shallow cylindrical shells made of orthotropic material and resting on an elastic Winkler foundation. The "snap-through" phenomenon for such shells subjected to a dynamically applied uniform pressure that increases linearly with time is also investigated.

● 6.8-40 Miyajima, N., Miyauchi, J. and Ueno, K., **Stress on the underground pipeline during earthquakes** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 215, 663–670. (For a full bibliographic citation see Abstract No. 1.2–9.)

An experiment was carried out to examine soil bond stress which induces axial dynamic loads on underground pipelines during earthquakes. The procedure of the experiment was as follows: A pipeline was set underground and sinusoidal axial forces acting upon the pipe end and its displacements were measured simultaneously. Results indicated that the relationship between the axial forces and the displacements formed a closed curve. On the other hand, calculated displacements at the steady state, taking into account an inertia force, a damping force and a restored force, showed that the relationship between the displacements and the axial forces formed an ellipse. Equating the areas of the loops mentioned above, and using the amplitude of the axial force and that of the displacement, a spring costant (K) and a viscous coefficient (C) were obtained. As a result, K and C were constant when the amplitude of the displacement was small, but they were inversely proportional to the amplitude when the amplitude was large. In addition, C was proportional to the period.

These results were applied to the calculation of the stress upon an infinitely long straight pipe. The stress calculated by this method was 1/7 - 1/5 as large as the one included in the "Petroleum Pipeline Engineering Criteria."

● 6.8-41 Miura, K., Terada, S. and Tajime, T., **On dynamic characteristics of an embedded structure with rounded corners rectangular section** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 170, 551-558. (For a full bibliographic citation see Abstract No. 1.2–9.)

This paper deals with the interaction problem between soil and structures embedded in a surface stratum on bedrock. Many theoretical studies on this problem have been conducted in the past, but these were performed under the assumption that structures have circular cross sections. The interaction with regard to structures with rectangular cross sections has not been studied yet. The dynamic characteristics of an embedded structure with rectangular corners replaced by quadrants are studied in this paper by making use of three-dimensional wave propagation theory.

● 6.8-42 Luco, J. E., **Torsion of a rigid cylinder embedded in an elastic half space,** *Journal of Applied Mechanics,* **43, Series E,** *3,* Sept. 1976, 419–423.

A study is made of the axially symmetric torsion of a rigid cylinder partially embedded in a layered elastic halfspace. The problem is formulated on the basis of perfect bonding between the cylinder and the surrounding material. Integral representations are used to reduce the problem to the solution of two integral equations. Stress singularities of fractional order are obtained along the perimeter of the base of the cylinder. A numerical solution of the integral equations is used to obtain the torque-twist relationship for different embedment depths and for different values of the elastic constants.

● 6.8-43 Dravinski, M. and Thau, S. A., **Multiple diffractions of elastic waves by a rigid rectangular foundation: Plane-strain model,** *Journal of Applied Mechanics,* **43, Series E,** *2,* June 1976, 291–294.

A rigid rectangular foundation embedded in a elastic halfspace moves in a direction perpendicular to the surface of the halfspace. The model under consideration is of the plane-strain type. By application of the Laplace, Fourier, and Kantorovich-Lebedev transforms, the equation of motion for the foundation is derived. The transient response of the foundation is exact during the period of time required for a longitudinal wave to traverse the base of the foundation twice; thus the process of multiple diffractions at the corners of the foundation is taken into account.

● 6.8-44 Dravinski, M. and Thau, S. A., **Multiple diffractions of elastic shear waves by a rigid rectangular foundation embedded in an elastic half space,** *Journal of Applied Mechanics,* **43, Series E,** *2,* June 1976, 295–299.

A rigid rectangular foundation, embedded in an elastic halfspace, is subjected to a plane, transient, horizontally polarized shear (SH) wave. Embedment depth of the foundation and the angle of the incidence of the plane wave are assumed to be arbitrary. The problem considered is of the antiplane-strain type. The Laplace and Kantorovich-Lebedev transforms are employed to derive the equation of motion for the foundation during the period of time required for an SH-wave to traverse the base width of the

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

obstacle twice. Therefore, this solution includes the process of multiple diffractions at the corners of the foundation.

● **6.8-45** Scanlan, R. H., **Seismic wave effects on soil-structure interaction,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 2/1, 6. (For a full bibliographic citation see Abstract No. 1.2-11.)

One of the most commonly used hypotheses in the seismic analysis of structures is that the earthquake input motion is identical at all spatial points on a given level beneath the structure. This is clearly not generally true, and any actual spatial variation of this motion away from complete uniformity will give rise to effects not usually considered—in particular, self-cancelling effects by those displacement components which happen to oppose each other in direction, and torsional effects by those motions which have different lever arms with respect to the structural center of mass.

The present paper examines this situation analytically under the following circumstances: a rectangular structural mass or foundation block is assumed to rest upon distributed soil springs, and a travelling seismic wave is assumed to pass under the springs. The dynamics of this system are analyzed. When soil motion is assumed to be in the direction of wave propagation (as with P-waves), it is found that the net forces on the structure which are initiated by soil motion are modified from those values that would be attributable to a spatially uniform earthquake. The case of seismic motion transverse to the direction of wave propagation (as with shear waves) is shown to give analogous results, applicable to transverse rather than longitudinal, effects. Furthermore, the origin of the torsional moment which is applied by this process to even symmetric structures is clearly delineated. Torsional effects have already been discussed by Newmark from a different vantage point.

The evolution of the above-mentioned effects with increasing wave number parameter R_n is explored in the paper in two basic graphs. These show that the effects under consideration can become important for design, particularly since many practical cases can occur where seismic wavelengths are of the order of foundation dimensions. Because of the self-cancelling wave effects which enter into the calculation of the generalized forces of the problem, the study suggests that the commonly used hypothesis of a spatially uniform earthquake may be inherently highly conservative in some cases.

Though the present study is exploratory and based on an elementary soil-spring model, the issues it raises are of inevitable importance with other models—such as finite element models—as well. The paper closes with remarks anticipating the analogous problem when spatial distribution of seismic input motion is alternatively postulated as random rather than simple wave passage.

● **6.8-46** Hadjian, A. H., Howard, G. E. and Smith, C. B., **A comparison of experimental and theoretical investigations of embedment effects on seismic response,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 2/5, 12. (For a full bibliographic citation see Abstract No. 1.2-11.)

A research program has been conducted both to gain insight into the effects of embedment on the seismic response of nuclear power plant containment structures and to verify current analytical methods for the prediction of their seismic response. Tests were first performed on small wooden cylinders, rectangles, and cubes using a shaking table to conduct parametric studies of the effects of geometry, height-to-diameter ratio, and amount of embedment. The effects of the shaking table were isolated by repeating the tests on specimens buried in actual soils. Next, a larger-scale concrete model (height–2 m, weight–1700 kg) was fabricated and tested at varying embedments using an eccentric mass structural vibrator. These tests were conducted at a field site where the dynamic properties of the soil for low strains were well known. Additionally, an attempt was made to correlate the experimental results with simplified and finite element models that included both embedment and nonlinear effects. The embedment effects in the simplified model were taken as an increase of the impedance coefficients used for structures on the ground. Nonlinear effects were incorporated by calculating strain levels and using published data to adjust the site soil parameters.

The results reported in the paper are applicable to cases where the foundation materials under and around the structure are similar. It was found that when very low strains were applied the embedment effect was progressively more important as the depth-to-diameter ratio increased. However, with larger strain, where the response of the cylinder was in the range of 0.75 to 1.25 g, the effect of embedment was negligible up to a depth-to-diameter ratio of 0.5. This phenomenon can be explained by the plastic deformation of the surrounding soil and loss of effective contact with the cylinder.

In conclusion, both the analytical and experimental work indicate that the effect of embedment can be incorporated into the seismic analysis of structures by simple models. In particular, embedment effects can be neglected during seismic excitations if the depth-to-diameter ratio is less than 0.5. For deeper embedments good agreement with experimental results can be achieved with simplified models and by selection of soil parameters evaluated at the appropriate strain levels.

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

● 6.8-47 Snyder, M. D., Shaw, D. E. and Hall, Jr., J. R., **Structure-soil-structure interaction of nuclear structures,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 2/9, 8. (For a full bibliographic citation see Abstract No. 1.2-11.)

Structure-to-structure interaction resulting from coupling of the foundations through the soil has traditionally been neglected in the seismic analysis of nuclear power plants. The basis of this assumption has received limited treatment.

This paper examines the phenomenon and available methods of analytical treatment, including finite element and lumped parameter methods. Finite element techniques have led to the treatment of through-soil coupling of structural foundations using two-dimensional plane strain models owing to the difficulty of considering three-dimensional finite element models. The use of two-dimensional finite element models leads to overly conservative through-soil coupling effects since the mode of energy transfer between the foundations involves two-dimensional cylindrical waves instead of three-dimensional spherical waves. Also, with use of the two-dimensional finite element approach it is not possible to consider the simultaneous application of three orthogonal directions of excitation currently required for the seismic analysis of nuclear structures.

This paper treats the coupling problem by means of a lumped parameter model derived from elastic half-space considerations. Consequently, the method is applicable to the interaction of any number of foundations and allows the simultaneous application of tridirectional excitation. The method entails the idealization of interacting structures as lumped mass/shear beams with lumped soil springs and dampers beneath each foundation plus a coupling matrix between the interacting foundations. Utilizing classical elastic halfspace methods, the individual foundation soil springs and dampers may be derived, accounting for the effects of embedment and soil layering, analogous to the methods used for single soil-structure interaction problems. The coupling matrix is derived by generating influence coefficients based on the geometric relationship of the structures using classical halfspace solutions. The influence coefficients form the coupling flexibility matrix which is inverted to yield the coupling matrix for the lumped parameter model.

● 6.8-48 Kennedy, R. P. *et al.*, **Nonlinear soil-structure interaction due to base slab uplift on the seismic response of an HTGR plant,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 3/5, 16. (For a full bibliographic citation see Abstract No. 1.2-11.)

Two major reasons have been expressed as to why dynamic base slab uplift should be minimized: (1) As nuclear power plants are normally designed for seismic loadings based upon linear analysis, and since soil-structure interaction becomes nonlinear when only a portion of the base slab is in contact with the soil, linear elastic analysis may be unacceptable if base slab uplift occurs (as the resultant design loads may be incorrect), and (2) substantial uplift could cause excessive toe pressures in the supporting soil and significant impact forces when the slab recontacts the soil. The primary purpose of this paper was to evaluate the importance of the nonlinear soil-structure interaction effects resulting from substantial base slab uplift occurring during a seismic excitation; that is, will there be either significant shifts in magnitude or frequency of structural response or excessive toe pressures and large heel uplift distances when there is significant base slab uplift.

The structure considered for this investigation consisted of the containment building and prestressed concrete reactor vessel for a typical HTGR plant. A simplified dynamic mathematical model was utilized consisting of a conventional lumped mass structure with soil-structure interaction accounted for by translational and rotational springs whose properties are determined by elastic half-space theory. Three different site soil conditions (a rock site, a moderately stiff soil and a soft soil site) and two levels of horizontal ground motion (0.3 g and 0.5 g earthquakes) were considered.

Based upon the parametric cases analyzed in this investigation, it may be concluded that linear analysis, which ignores the nonlinear soil-structure interaction effects of base slab uplift, can be used to conservatively estimate the important behavior of the base slab, even under conditions of substantial base slab uplift. For all cases investigated here, linear analysis resulted in higher base overturning moments, greater toe pressures, and greater heel uplift distances than nonlinear analyses. It may also be concluded that the nonlinear effect of uplift does not result in any significant lengthening of the fundamental period of the structure. Also, except in the short-period region (period less than half of the fundamental period), only negligible differences exist between in-structure response spectra based on linear analysis and those based on nonlinear analysis. Finally, it can be concluded that for sites in which soil-structure interaction is not significant, as for the rock site, the peak structural response (shears and moments) at all locations above the base mat are not significantly influenced by the nonlinear effects of base slab uplift. However, for the two soil sites, the peak shears and moments are, in a few instances, significantly different in the linear and nonlinear analyses. As a result, linear analysis may be used to determine all structural responses for rock sites even when there is substantial base slab uplift. However, for soil sites, nonlinear analyses are necessary if substantial base slab uplift occurs.

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

● **6.8-49** Wolf, J. P., **Approximate soil-structure interaction with separation of base mat from soil (lifting-off),** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 3/6, 12. (For a full bibliographic citation see Abstract No. 1.2-11.)

In reactor buildings having a shield-building (outer concrete shell) with a large mass, which is particularly the case if the plant is designed for an airplane crash, large overturning moments are developed for earthquake loading. If for a circular base mat, the overturning moment exceeds the product of the normal force (which is equal to the dead weight minus the effect of a vertical earthquake) and one-third of the radius, then tension occurs in the area of contact, assuming the static distribution of stress, if the standard linear elastic halfspace is used to model the foundation in the soil-structure interaction. As this is incompatible with the constitutive law of soils, the base mat will become partially separated from the foundation. Assuming that only normal stresses in compression and corresponding shear stresses (friction) can occur in the area of contact, an approximate method of analyzing soil-structure interaction including lifting-off is derived, which otherwise is based on elastic behavior of the soil. A rigorous iterative procedure is outlined, based on dynamic influence matrices of displacements on the surface of an elastic halfspace at a certain distance from a rigid strip or disc. A simpler method consists of determining the area of contact of the rigid circular disc on the elastic halfspace for a given overturning moment and normal force, using the static influence coefficients of Boussinesq. The complex-valued compliance or impedance functions can be estimated by substituting an equivalent circular plate for the actual area of contact. The impedance function can be represented by an equivalent spring and viscous dashpot.

Internal material damping can be added. Transforming the equivalent lumped system to the center of the plate, the nonlinear stiffness and damping matrices of the soil are derived, which depend on the ratio of the overturning moment to the normal force and thus on the deformations of the plate. The location of the center of gravity of the contact area is also unknown. Slipping can also be taken into consideration. The nonlinear equations of motion are solved by direct integration using a generalization of the linear-acceleration method. For each time step, several iterations are necessary to reduce the residual load vector to a negligible quantity.

The reactor building of a 1000-megawatt plant is analyzed. As the effective radius diminishes, the more the structure lifts off and the more flexible the soil-structure system becomes. In the case studied, the relative displacements are increased while the total accelerations and the stress resultants in the structure are somewhat diminished. As part of the base mat acts as a cantilever when separated from the soil, the moments in the plate are distributed differently. The maximum values are increased by more than 50%. For a strong earthquake (0.4g), the response is highly nonlinear. Parametric studies for a softer and stiffer site are also carried out. The influence of the frequency of the oscillator on the distribution of stress in the area of contact which causes the beginning of lift-off is also investigated.

● **6.8-50** Gutierrez, J. A. and Chopra, A. K., **A substructure method for earthquake analysis of structure-soil interaction,** *EERC 76-9,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Apr. 1976, 150. (NTIS Accession No. PB 257 783)

A general substructure method for analysis of response of structures to earthquake ground motion including the effects of structure-soil interaction is presented. Flexibility of the structural base, spatial variations in the free field ground motion, structural embedment and interaction between two or more structures, all these factors are included in the analysis. The soil region may be idealized either as a homogeneous halfspace or as an assemblage of finite elements. In the latter case, results are shown to be equivalent with a direct finite element analysis. However, it is shown that the substructure method is more efficient.

The structure-soil system is considered to be composed of two substructures, the structure and the soil region, and the analysis via the frequency domain is carried out in two stages. The earthquake input is defined as the free field ground motion at the structure-soil interface. The dynamic stiffness (or impedance) matrix for the soil region, determined separately, enters into the governing equations for the structure. A drastic reduction in the computational effort is achieved by separating the structural displacements into two parts: the quasistatic displacements associated with the interaction displacements at the structure-soil interface and the remaining dynamic displacements and expressing the latter as superposition of the first few modes of the structure on fixed base. It is demonstrated that only those modes with natural frequencies within, or slightly beyond, the frequency range of interest need to be included. Further reduction in computational effort is achieved by expressing the displacements of the structure-soil interface as superposition of a few generalized displacements. For example, generalized displacement representing rigid body motion of the structure-soil interface may suffice in analysis of a nuclear reactor containment building because the base slab is very stiff and massive.

Several methods to determine the dynamic stiffness matrix for soil regions idealized as an assemblage of finite elements are described. For situations where the soil can be better represented as a laterally unbounded, horizontally layered region, an efficient method which utilizes symmetry and antisymmetry considerations is presented. This approach provides an alternative to the use of wave transmitting boundaries in reducing the computational effort.

Application of the substructure method to analysis of dynamic response of two or more nearby structures, in which case the response of one structure may influence the response of others through interaction with the soil, is also presented. The general substructure method is evaluated for efficiency and effectiveness. It is shown that, even for the analysis of structure-soil systems idealized as an assemblage of finite elements, the substructure method is more efficient and preferable because it eliminates the deconvolution calculations usually necessary in the direct method.

● 6.8-51 Lysmer, J. *et al.*, **FLUSH - A computer program for approximate 3-D analysis of soil-structure interaction problems,** *EERC 75-30,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Nov. 1975, 139. (NTIS Accession No. PB 259 332)

This report discusses the general principles of seismic soil-structure interaction by finite element methods and provides the theory and manual for a specific computer code, called FLUSH. This code is a further development of the complex response finite element computer program LUSH. The new program is considerably faster than LUSH, thus the name FLUSH = Fast LUSH and it includes a large number of new features such as transmitting boundaries, beam elements, an approximate 3-D ability, deconvolution within the program, out-of-core equation solver, new input/output features, etc., all of which make the program more efficient and versatile.

6.8-52 Eskin, Yu. M. and Eiler, L. A., **Investigation of the vibrations, stresses and stability of the soil base of foundations** (Issledovanie vibratsii napryazhennogo sostoyaniya i ustoichivosti gruntov v osnovanii fundamentov, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 182-185. (For a full bibliographic citation see Abstract No. 1.1-7.)

In this paper the dynamic response to vibration loading of a multilayered soil base under the footings of turbines and other machinery is investigated. The calculations are carried out in a two-dimensional elastic framework using the finite element method. The results are used to establish a testing procedure for measuring the dynamic response of the soil base under footings of the type considered.

6.8-53 Tsukerman, Ya. N., **Investigation of the seismic response of underground hydraulic structures using optical methods** (Issledovanie seismonapryazhennogo sostoyaniya podzemnykh gidrosooruzhenii opticheskimi metodami, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 108-111. (For a full bibliographic citation see Abstract No. 1.1-7.)

Polarized optical and interferometric methods are employed to investigate the two-dimensional elastic problem of the dynamic response of the rigid casing of pressure tunnels and the rock surrounding four sites of the underground pressure unit of a hydroelectric power plant under construction. Seismic excitation is assumed to be in the form of a compression impulse. The locations of maximum stress in the casing and the rock surrounding the tunnels are determined.

6.8-54 Kaufman, B. D. and Shulman, S. G., **Non-stationary vibrations of an oscillator interacting with an elastic half-space** (Nestatsionarnye kolebaniya ostsillatora, vzaimodeistvuyushchego s uprugoi poluploskostyu, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 41-44. (For a full bibliographic citation see Abstract No. 1.1-7.)

The interaction of a single-mass system and the soil base during seismic excitation is analyzed.

6.8-55 Kaufman, B. D. and Shulman, S. G., **On the interaction of structure and layered soil base during an earthquake** (O vzaimodeistvii sooruzheniya so sloistym osnovaniem pri zemletryasenii, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 31-35. (For a full bibliographic citation see Abstract No. 1.1-7.)

Soil-structure interaction during an earthquake is considered. Seismic excitation is modeled as an arbitrary deformation wave and the structure is regarded as a linear oscillator with damping satisfying the conditions of Voigt or Sorokin. The soil base is modeled as a semi-infinite multilayered bar. The solution obtained allows one to take into account the effects of the layered soil base by considering the structure as one resting on a rigid plate with a corresponding change in its parameters.

● 6.8-56 Izumi, M. *et al.*, **Rocking vibration considering up-lift and yield of supporting soil,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 223, 727-734. (For a full bibliographic citation see Abstract No. 1.2-9.)

Earthquake excitation causes rotational movements in alternate directions at the base of structures, especially of such slender structures as apartment houses. This type of rocking vibration has been studied extensively in the past; however, in very few cases have uplift and the elasto-plastic characteristics of the soil been considered. In this paper, the authors theoretically investigate the problem.

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

Using a Winkler model, relationships were obtained between the rotation angles of the bases and overturning moments at the bases.

The results obtained are as follows: (1) Uplift usually occurs before the soil reaches its yield point. (2) In the analyzed example of an eight-storied apartment house, uplift occurred under much smaller horizontal loading than expected. (3) Under cyclic alternate loading, stiffness degrades in each cycle of the large amplitude of rotation and energy dissipation is small even when the soil reaches its yield point. (4) The results of response analysis using a single-degree-of-freedom system and a two-degree-of-freedom system show larger responses than those of generally used nonlinear systems.

● **6.8-57** Yamamoto, S. *et al.*, **Earthquake responses of nuclear reactor building** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 226, 751–758. (For a full bibliographic citation see Abstract No. 1.2-9.)

● **6.8-58** Gutierrez, J. A. and Chopra, A. K., **Earthquake analysis of nuclear reactor buildings including foundation interaction**, *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology*, Vol. 4, Paper K 3/4, 9. (For a full bibliographic citation see Abstract No. 1.2-11.)

Presented is a general method of analysis which provides a unified treatment for idealizing all types of foundations. The method overcomes the deficiencies in the commonly used procedures for including foundation interaction effects in the earthquake analysis of nuclear reactor buildings.

The method is based on the substructure concept. The dynamic equilibrium equations for the structure, idealized as a finite element system with foundation interaction effects included, are expressed in the frequency domain. Foundation interaction introduces a frequency-dependent foundation stiffness matrix in the structural equations. This matrix for the foundation is associated only with the degrees-of-freedom at the structure-foundation interface; it is obtained by analysis of the foundation separately for unit harmonic load or displacement applied in each interface degree-of-freedom. In carrying out this analysis, it would be appropriate to use a finite element idealization if the foundation consists of a relatively flexible medium underlain by much stiffer media which can be assumed as rigid. At many sites the material near the ground surface may extend to large depths; idealization of the foundation as a viscoelastic halfspace would be more appropriate for such situations. Results for the frequency-dependent stiffness coefficients for both types of idealizations of the foundation are summarized.

This substructure approach directly treats the free-field motion at all the degrees-of-freedom on the structure-foundation interface. Fourier decomposition of the free-field ground motion, solution of the structural equations including the foundation interaction terms to determine the steady-state harmonic response over a range of excitation frequencies and Fourier synthesis of the harmonic responses lead to response of the structure including foundation interaction effects to arbitrary earthquake excitation.

Before proceeding with solution of the equations, the structural displacements are represented as the sum of the quasistatic displacements and the dynamic displacements, with the latter expressed as a linear combination of the first few mode shapes of the structure on a rigid foundation.

This method permits better modelling of the structure-foundation system, and is very efficient because the use of modal coordinates leads to a drastic reduction in computational effort.

● **6.8-59** Mizuno, N. and Tsushima, Y., **Experimental and analytical studies for a BWR nuclear reactor building: Evaluation of soil-structure interaction behaviour**, *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology*, Vol. 4, Paper K 3/2, 13. (For a full bibliographic citation see Abstract No. 1.2-11.)

The purpose of this paper is to evaluate the spatial characteristics of the dynamic properties, especially the soil-structure interaction behavior, of a BWR nuclear reactor building. Experimental and analytical studies were conducted. The modal superposition method for a multidegree-of-freedom system was used to estimate the damping effects. The structural damping was approximated with a constant complex stiffness and the dynamic soil foundation stiffness was approximated by linear or quadratic eigenvalues.

The experimental results of the No. 1 reactor building of the Hamaoka nuclear power station of the Chubu Electric Power Co., Ltd., are presented. The regression analyses of the experimental resonance curves of a one-degree system show that the critical damping ratio is larger than the 0.10 used in the design for the fundamental natural period. A simulation of the experimental results was attempted using the method just described. The simulated model was a 48-degree-of-freedom spring-mass system: 8 masses for the 8 floors, including the base foundation, and 6-degrees-of-freedom for the mass.

It is concluded that the above-mentioned method is reasonable for estimating damping effects in soil-structure interaction because of good agreement with experimental results.

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

● **6.8-60** Mizuno, H., **Coupling effects between structural systems with different properties** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 243, 887–894. (For a full bibliographic citation see Abstract No. 1.2-9.)

This paper deals with the coupled responses of two structural systems with different properties. The structure is assumed to be a single-degree-of-freedom elastic system with damping; the foundation, a rigid semicylinder; and the ground, a two-dimensional elastic halfspace. The ground is subjected to vertically incident SH waves.

● **6.8-61** Minami, T., Osada, K. and Osawa, Y., **Earthquake observations on a spherical L.P.G. tank and the surrounding ground** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 206, 591–598. (For a full bibliographic citation see Abstract No. 1.2-9.)

Observations of the data from 16 earthquakes recorded at the site of a soil-tank system have been analyzed. Transfer characteristics obtained from earlier occurring ground motion at different depths, strongly reflecting the relatively shallow surface layer formation at the observation site, coincide in the predominant periods with the transfer functions computed using one-dimensional wave propagation theory. The observed amplitude ratios, however, are much less than the theoretical values because of the possible greater material damping inherent in soils and the complex formation of the surface soil layer.

Running-window Fourier spectra for near and distant earthquakes with similar maximum accelerations show that the earthquakes possess different features, i.e., the near earthquakes have a few short spectral peaks in the large frequency range while distant earthquakes with relatively large magnitudes have extremely long energy concentrations in the low frequencies. The different patterns of energy distribution over the time-frequency domain that considerably influence the earthquake response of the superstructure should be studied in more detail.

Variation of power spectra and spectral ratios at different depths caused by changing the direction of the seismometers was also studied. Since the spectral ratios fluctuate much more than the power spectra themselves, it is suggested that the average power spectra of two perpendicular components of the horizontal motion be used when determining the transfer characteristics of the ground.

The effective mass of the contained liquid varied between 15–50%. For this reason, the natural period of the tank did not fluctuate very much, although the full weight of the contained liquid was much larger than the dead load of the spherical shell.

Soil-tank interaction effects are analyzed using the proposed modified shear beam model to show the necessity for including the surface soil layer characteristics in the analytical model, especially when the predominant period of the ground is close to the natural period of the superstructure.

6.9 Fluid-Structure Interaction

● **6.9-1** Alarcon, P. N., **Dynamic behaviour of concrete gravity dams during earthquakes**, *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering*, **11**, 1975, 192–206.

The behavior of the concrete gravity Tagokura Dam during the 1964 Niigata earthquake is described. Some of the author's conclusions are (1) The presence of the reservoir water increases the response of the dam at high water level and that an analysis neglecting the interaction effect between the dam and the reservoir leads to some computational errors. (2) In an earthquake comprising low-frequency vibrations, a dam will vibrate the same as the foundation rock while the natural period of a dam will predominate in an earthquake comprising high-frequency vibrations. Moreover, in an earthquake in the range of the predominant period of the ground with its epicenter very close to the dam site, resonance is likely to occur. (3) The damping ratio varied greatly with respect to the shape of the dam, topography of the valley and geology of the base rock. However, it is believed that during a strong earthquake, it is possible for a dam to develop a large damping ratio which can help it in withstanding damage.

● **6.9-2** Gordeeva, S. P. and Shulman, S. G., **Interaction between a hydraulic structure and water during earthquakes**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 1, Paper No. 88, 4. (For a full bibliographic citation see Abstract No. 1.2-6.)

The problem of the dynamic interaction between a hydraulic structure and water during earthquakes is studied. Elastic and elastic-viscous structures are analyzed as one-dimensional problems (with bending and shear strains as well as sectional rotation inertia taken into account). The problem of the vibration of water as an ideally compressible fluid is solved as a two-dimensional problem. The hydrodynamic problem is solved by both the Fourier and the gridwork methods. A set of equations of hydroelasticity is reduced to an integral equation, which is solved numerically.

Based on the calculations, the problems of natural and induced vibrations of vertical fencing walls, gravity and facilitation dams, circular cylinder piles and other structures are studied. Values of modes and frequencies of natural vibrations and amplitude-frequency characteristics as well as the distribution of water pressure under seismic

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

influence are obtained. Proposed are simplified expressions for assessing seismic loads acting upon a structure when evaluation is performed by spectral curves.

● 6.9-3 Akay, H. U. and Gulkan, P., **Evaluation of the reservoir effect on the dynamics of dams,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 643-654. (For a full bibliographic citation see Abstract No. 1.2-7.)

A finite element procedure is presented for obtaining the approximate mass coefficients of two-dimensional dam-reservoir systems. The procedure is applied to obtain the dynamic response of a specific dam. The results are compared with the case in which the presence of the reservoir is not considered. It is concluded that for the large rockfill dam studies in the example the added mass terms do not alter the dynamic response significantly when water is assumed to be incompressible.

● 6.9-4 Srimahachota, D., Hongladaromp, T. and Lee, S.-L., **Response of an elasto-plastic spherical structure in a fluid to earthquake motions,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 375-386. (For a full bibliographic citation see Abstract No. 1.2-7.)

The dynamic response of a single-degree-of-freedom spherical structure restrained elastically-plastically and submerged in a fluid of infinite extent is investigated by taking into account the fluid resistance given by Basset in terms of added mass, viscous drag and Basset history integral. The elastic-plastic behavior of the structure is characterized by a bilinear resisting force displacement relationship. The governing equation of motion is solved numerically for the response of the submerged system subjected to the 1940 El Centro earthquake.

The study covers the effects of the ductility factor, Stokes number, diameter and density of the sphere and natural frequency. To facilitate the design of such a structural system, response spectra for the N-S component of the 1940 El Centro earthquake are generated for different values of the parameter in practical ranges. Response spectra in terms of the optimum yield displacement which may be used as a guide in selecting the member when the displacement is an important constraint in design are also generated.

6.9-5 Shulman, S. G., **On calculation of seismic loads on hydraulic structures in a statistical setting** (K opredeleniyu seismicheskikh nagruzok na gidrosooruzheniya pri reshenii zadachi v statisticheskoi postanovke, in Russian), *Izvestiya VNII gidrotekhniki, 108,* 1975, 165-167.

Loadings on hydraulic structures interacting with water and subjected to random seismic excitations are calculated. The structure is regarded as a one-mass vibrating system. Dynamic loads are calculated for stationary random excitations from hydrodynamic pressures due to the motion of the structure and the ground. The results are extended to systems with discrete and continuous parameters. Stresses, strains and seismic loads for the latter are calculated.

● 6.9-6 Clough, D. P. and Clough, R. W., **Earthquake simulator studies of liquid-filled cylindrical shells,** Society for Experimental Stress Analysis, Westport, Connecticut, 1976, 55. (Presented at 1976 SESA Spring Meeting, Silver Spring, Maryland, May 9-14, 1976.)

The earthquake simulator testing of a model thin-shell liquid storage tank is described. The test structure is 12 ft in diameter and 6 ft high; it was subjected to the base motions of the El Centro 1940 earthquake with a peak acceleration of 0.5g. The principal test parameter considered in the results which are discussed was the base support condition: either free or clamped against uplift displacements. Response measurements included stresses and displacements of the tank walls as well as water pressures and wave heights. The observed displacement response shows significant contributions in the third and fourth circumferential harmonics.

● 6.9-7 Wu, C. I. *et al.*, **Natural frequencies of cylindrical liquid storage containers,** Dept. of Civil Engineering, Univ. of Massachusetts, Amherst, June 1975, 61.

The problem of coupled natural frequencies of a slab-supported elastic circular cylindrical shell filled to an arbitrary depth with an incompressible, inviscid liquid is treated analytically. The analysis permits consideration of a variety of shell boundary conditions. A computer program into which may be entered the elastic and geometric parameters of the system is presented. The natural frequencies and associated mode shapes are displayed in the computer printout.

● 6.9-8 Laura, P. A. A. and Gutierrez, R., **Fundamental frequency of vibration of clamped plates of arbitrary shape subjected to a hydrostatic state of in-plane stress,** *Journal of Sound and Vibration,* 48, 3, Oct. 8, 1976, 327-332.

The present paper makes use of conformal mapping and Galerkin's method to determine the fundamental frequency of vibration of clamped plates of arbitrary shape subjected to uniform in-plane stress. Numerical results are presented for several plates of regular polygonal shape. Frequency curves obtained by means of Lurie's expression are also given for simply supported plates.

● 6.9-9 Engblom, J. J. and Nelson, R. B., **In-fluid response of complex structures with application to orthotropic**

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

spheres, *Journal of Sound and Vibration*, 49, *1*, Nov. 8, 1976, 1–8.

A method is presented for determining the response of a closed structure, immersed in an infinite acoustic medium, undergoing harmonic vibratory motion. The mathematical representation of the structure is based on a finite element approach so that arbitrarily shaped surfaces with or without internal structures may be studied. Applied and fluid-structure interaction forces are related to response quantities through a velocity mobility matrix form, obtained via an *in vacuo* eigensolution. A supplemental acoustic relationship in velocity impedance matrix form is used to quantify the effects of the fluid medium. This relation, based on a discretization of the Helmholtz integral equations, assures continuity of the acoustic variables at the fluid-structure boundary. Both structure and fluid-structure relationships are combined to yield a structural-acoustic velocity mobility matrix form suitable for digital computer solution. The formulation is utilized to investigate the response of solid isotropic, hollow isotropic and laminated orthotropic spheres.

● **6.9-10** Miyawaki, K., **Dynamic behaviour of cylindrical tanks with the comparative rigidity** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 207, 599–606. (For a full bibliographic citation see Abstract No. 1.2-9.)

A basic dynamic analysis of cylindrical tanks of circular cross section and high rigidity was conducted. Only the liquid and the circular cylindrical shell were analyzed. The liquid was analyzed using a potential theory, and then the dynamic liquid pressures, the base shear and the overturning moment were calculated. In this case, an internal viscosity of the liquid was considered and deformations of the shell plate were negligible because of the higher rigidity.

● **6.9-11** Sakai, F. and Sakoda, H., **A study on earthquake response of large-sized liquid-filled tanks** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 210, 623–630. (For a full bibliographic citation see Abstract No. 1.2-9.)

In the seismic design of large storage tanks with thin walls, it is desirable that the interaction between the liquid and the tank wall be explicitly taken into account. In this paper the finite element method is used to analyze such interaction. The entire tank is treated as a shell-liquid vibration system. Many numerical examples of large-sized tanks are analyzed to investigate the oscillation characteristics. In addition, a simple approximation method is examined.

6.9-12 Sheinin, I. S., Mukhutdinova, R. Z. and Shames, M. P., **On the effect of ice cover on the reservoir surface on the earthquake response of hydroelectric power plant structures in water** (O vliyanii ledyanogo pokrova na poverkhnosti vodoema na kolebaniya konstruktsii GES v vodnoi srede pri zemletryaseniyakh, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh*, 162–165. (For a full bibliographic citation see Abstract No. 1.1-7.)

A viscoelastic problem involving two bodies is considered. A structure with a vertical wall is vibrating inside a reservoir covered with ice. Water is regarded as an ideal incompressible fluid. The curvature of the ice is regarded as smooth and, as a consequence, the integral-differential equations for the forced vibrations are reduced to a system of linear algebraic equations. The latter are solved using an M-222 computer. The program utilized allows the computation of the first m natural frequencies of the wall and the ice for any given set of physical parameters of the system.

6.9-13 Kilasoniya, Dzh. N., **Simplified formulas for calculation of seismic water pressure in the pressure system of hydroelectric power plants** (Uproshchennye zavisimosti dlya opredeleniya seismicheskogo davleniya vody v napornoi sisteme GES, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh*, 138–140. (For a full bibliographic citation see Abstract No. 1.1-7.)

Simplified formulas are given to calculate hydrodynamic pressure in water conduits and tunnels of hydroelectric power plants. The formulas are obtained by considering seismic excitations as random processes. The following cases are considered: water reservoir–pressure conduit (or tunnel)– floodgate, compensation reservoir–turbine conduit–floodgate and water reservoir–pressure tunnel–compensation reservoir. For each of these structures, maximum seismic pressures are calculated.

6.9-14 Gvelesiani, T., **Prediction of wave levels in a water reservoir in a region with complex seismic, tectonic and geological conditions** (Prognozirovanie vysoty volny v vodokhranilishche v raione so slozhnymi seismotektonicheskimi i geologicheskimi usloviyami, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh*, 165–168. (For a full bibliographic citation see Abstract No. 1.1-7.)

A technique to calculate the maximum possible elevation of water levels caused by substantial ground motion at the reservoir walls or bottom is necessary for designing dams in seismic regions. The problem of wave formation in a simplified reservoir model due to cave-in of one of the reservoir walls is considered and solved in three dimensions. A given quantity of water is displaced as a result of

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

the movement of a section of the reservoir wall, followed by the given-duration vertical load generated by the sliding and cave-in. The results of numerical calculations performed on a computer using the formulas obtained are compared to data from laboratory experiments for a preliminary stage of analysis. The agreement is good.

6.9-15 Pilipenko, V. A., **Hydrodynamic effect on massive submerged hydraulic structures with rectangular profile** (Gidrodinamicheskoe vozdeistvie na zatoplennye massivnye gidrosooruzheniya pryamougolnogo profilya, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 156–161. (For a full bibliographic citation see Abstract No. 1.1–7.)

The two-dimensional problem of hydrodynamic effects on a massive submerged structure with a rectangular profile is examined. Only small displacements are considered and wave phenomena on the free surface are not taken into account. Hydrodynamic response parameters are calculated.

6.9-16 Pilipenko, V. A., **Hydrodynamic effect of fluid on a rigid barrier with broken profile** (Gidrodinamicheskoe vozdeistvie zhidkosti na zhestkuyu pregradu lomanogo profilya, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 149–156. (For a full bibliographic citation see Abstract No. 1.1–7.)

The problem of the hydrodynamic effect of fluid on a rigid obstacle with broken profile (a boundary consisting of three rectilinear segments) is investigated. Hydrodynamic pressures are calculated using various parameters.

6.9-17 Averyanov, V. K. and Tyutyunnikov, A. I., **Calculation of the hydrodynamic effect of a fluid on the walls of a rectangular basin** (Opredelenie gidrodinamicheskogo vozdeistviya zhidkosti na stenki basseina a pryamougolnym telom, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 146–149. (For a full bibliographic citation see Abstract No. 1.1–7.)

Hydrodynamic effects in a rectangular basin during forced vibration of basin walls and fluid are considered in two dimensions. The fluid is considered ideally noncompressible and wave formation on the free surface is not taken into consideration. The region investigated is broken up into many small elements and the velocity potential is computed using separation of variables. The results are plotted and formulas are given.

6.9-18 Filippenok, V. Z., **Calculation of the hydrodynamic effect of finite amplitude vibrations on reservoir structures** (Opredelenie gidrodinamicheskikh vozdeistvii na konstruktsii reservuara pri ego kolebaniyakh s konechnoi amplitudoi, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 140–146. (For a full bibliographic citation see Abstract No. 1.1–7.)

Horizontal harmonic vibrations of reservoir walls with rectangular cross section are considered. The boundary conditions at the wall face are in exact form and take into account the finite vibration amplitudes of the walls. The fluid is incompressible and subject to potential motion. Wave formation on the free surface is considered in a two-dimensional linear framework. The hydrodynamic effect of the fluid is calculated.

6.9-19 Gordeeva, S. P. and Shulman, S. G., **Effect of water on seismic response of hydraulic structures** (Vliyanie vodnoi sredy na seismicheskie kolebaniya gidrosooruzhenii, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 134–137. (For a full bibliographic citation see Abstract No. 1.1–7.)

A technique is presented to solve the viscoelastic equations of motion of a bar undergoing flexural and shear deformations. Both internal friction and rotational inertia are taken into account. A computer program is written for a hydraulic structure surrounded by water. Free and forced stationary vibrations of hydraulic structures are investigated under various additional conditions (e.g., reservoir shape, character of deformations, etc.). An algorithm and computer program are given to calculate seismic loads on hydraulic structures using the technique described based on the linear spectral theory of earthquake response. Approximate formulas are derived to calculate seismic loads on massive hydraulic structures.

● **6.9-20** Sogabe, K. and Shibata, H., **On the response of sloshing of liquid in cylindrical and spherical storages,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 208, 607–614. (For a full bibliographic citation see Abstract No. 1.2–9.)

For the seismic-resistant design of liquid storage tanks, it is important to obtain the displacement records of strong earthquakes which contain a long-period component in order to determine the vibrational characteristics of sloshing liquid in the tanks. The authors carried out a series of experiments to determine the fundamental characteristics of the sloshing effects of liquid in cylindrical and spherical storage tanks. Observations were conducted to determine the response of a cylindrical storage tank during actual earthquakes. It was found that both acceleration and displacement responses were exhibited and that the analyses for both types of responses should be taken into account in the aseismic design of liquid storage tanks.

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

● **6.9-21** Nasu, N. *et al.*, **Effect of big earthquake motion on structures: Sloshing of fluid in a cylindrical tank** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 209, 615–622. (For a full bibliographic citation see Abstract No. 1.2-9.)

The authors studied the seismograms of the ground motions of the Kwanto earthquake and others which have occurred in the Tokyo district. As a result, they determined that two types of ground motions occur in Tokyo: one is the Sagami-Bay type—the earthquakes belonging to this type have multiple sources and their ground motion contains long-period waves; the other is the Tokyo-Bay type—this type of earthquake has a single source and consequently the properties of the ground motion differ from those of the Sagami-Bay-type earthquakes.

In this study, the dynamic behavior of the fluid in two tanks is used to investigate the effect of strong earthquake motions of these two types. The two tanks studied were 80 m in diameter, 20 m in height, and 45 m in diameter, 13 m in height, respectively. The results show that quite a bit of sloshing occurs in the larger tank in response to the earthquake motions of the Sagami-Bay type and that the sloshing increases gradually with time after a lapse of 70 sec from the beginning of the shock, whereas less sloshing occurs in the Tokyo-Bay type earthquake.

6.10 Vibration Measurements on Full Scale Structures

6.10-1 Goldenblat, I. I. and Polyakov, S. V., eds., **Earthquake-resistant reinforced concrete and masonry structures** (Seismostoikie konstruksii iz zhelezobetona i kamennoi kladki, in Russian), Stroiizdat, Moscow, 1975, 103.

Earthquake resistance of reinforced concrete and masonry structures is investigated. Seismic response of standard and special structures is investigated. Full-scale measurements of the dynamic parameters of frame buildings are described and analyzed.

6.10-2 Katen-Yartsev, A. S. *et al.*, **Full-scale investigations of building vibrations in the Crimea** (Naturnye issledovaniya kolebanii zdanii v Krymu, in Russian), *Trudy TsNII stroitelnykh konstruktsii, 44*, 1975, 112–126.

Full-scale investigations of building vibrations in the Crimea which are currently being conducted are discussed. The organizational principles of instrumental observations under the conditions of low-level seismicity prevailing in the Crimea are set forth. Experimental investigations of building vibrations in Yalta and Sebastopol during microtremors and artificial dynamic excitations are described. Results of vibration measurements on 16 story buildings in Yalta are presented. The installation of seismometric stations in these buildings is envisaged.

6.10-3 Polyakov, S. V. and Tursumuratov, M. T., **Full-scale investigations of the dynamic behavior of tall frame buildings** (Naturnye issledovaniya dinamicheskikh kharakteristik karkasnykh zdanii povyshennoi etazhnosti, in Russian), *Trudy TsNII stroitelnykh konstruktsii, 45*, 1975, 58–89.

The dynamic response of the tall frame buildings on Lenin Avenue in Alma-Ata was investigated both theoretically and experimentally. Dynamic behavior was studied using both free and forced vibrations. Correlational analysis and Fourier amplitude-frequency spectra were used. The discrepancy between estimated and actual vibration periods is explained by the stiffness of elements left out of the analysis but nevertheless having an effect on building response.

● **6.10-4** Kawamura, S., Osawa, Y. and Umemura, H., **Earthquake motion measurements and analysis of pile-supported building and its surrounding soil,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings*, 12–34. (For a full bibliographic citation see Abstract No. 1.2-2.)

This report describes the outline and analytical results of earthquake-motion measurements of a pile-supported 7-story apartment building and the surrounding soil. The earthquakes measured were not of high intensity, but as a result of the analysis, many characteristics were recognized regarding the soil-structure vibration. A theoretical analysis was made in the elastic range, and the results were compared with observed values. The volume of the surrounding soil which moved with the piles and the modal damping factors of the soil and the structure were obtained.

● **6.10-5** Honda, K. K., **Measurements and evaluation of building response to ground motion at various stages of construction,** *Methods of Structural Analysis*, Vol. I, 403–418. (For a full bibliographic citation see Abstract No. 1.2-3.)

A seismic analysis of three moment-resisting reinforced concrete space-frame buildings revealed that their architectural elements considerably influenced their dynamic characteristics. High-rise building response behavior due to underground nuclear explosions at the Nevada Test Site (NTS) has been measured for the past 12 years as part of a structural response research program being conducted for the U.S. Energy Research and Development Admin. The research described here offered the rare opportunity of measuring building response at several stages of construction.

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

Three buildings, located in Las Vegas about 170 km southeast of the NTS, were studied. One of the buildings was first measured for its response to ground motion when the structural framing was completed and before any architectural elements were installed. The response of the other two was first measured after the architectural partitions had been partly installed.

Using data from building drawings and field surveys, a mathematical model was constructed so that the response characteristics of structural and architectural elements could be determined. Measured and computed values were correlated to determine the characteristics of each value and its contribution to the total response.

● **6.10-6** Ashkinadze, G. and Simon, J., **Improvement of vibration (resonance) test methods for buildings,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 117, 2. (For a full bibliographic citation see Abstract No. 1.2-6.)

● **6.10-7** Jurukovski, D., **Interaction between partially jointed structural units,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 112, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

● **6.10-8** Izenberg, Ya. M. *et al.*, **Research into gravity seismic isolating system by means of modeling and full scale test,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 103, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

Methods and results of a gravity vibration-isolation system are reported. Damping factors and optimum parameters of a vibration-isolated system under tests were estimated. A simulation of real seismic actions on a structure with a seismic damping system and disengaging braces was carried out.

Two vibration-isolated buildings in Sevastopol were tested under dynamic loads. The results of the full-scale test proved the effectiveness of the proposed system.

● **6.10-9** Ashkinadze, G., Zacharow, W. and Simon, J., **Investigation non-linear behavior of carcassless buildings with powerful vibration generators,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 109, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

Large-panelled buildings from four to nine stories, the shells of structures and large models of other types were tested in their resonant zones. During testing numerous occurrences of nonlinear oscillations took place. Changes in stiffness and other dynamic characteristics of the buildings varied, depending on the testing conditions. In several cases visible damage occurred. The effects of soil-structure interaction were of special importance.

● **6.10-10** Fowler, T. J. and Williams, D. M., **Dynamic behavior of a reinforced concrete spray tower,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 455-466. (For a full bibliographic citation see Abstract No. 1.2-7.)

The paper reports results of dynamic tests and complementary dynamic analyses of a reinforced concrete spray tower. The tower has an overall height of 80 ft. The 25 ft diameter x 54 ft high cylindrical section is supported on four 42 in. diameter columns. The structure is founded on 42 in. diameter caissons carried to lava bedrock 20 ft below grade.

The structure was excited by cylic air pressure waves in an associated redwood demister. The structural response was determined at the top of the support columns and at the top of the tower. The primary natural frequency, mode shape, and an estimate of the damping were determined. A series of theoretical dynamic analyses of the structure were carried out using a finite element computer program. The analyses gave good agreement with the measured primary natural frequency and mode shape. The effect of varying some of the analytical assumptions also is reported.

A second dynamic test of the structure was carried out approximately four years after the first test. The primary natural frequency of the structure was found to be unchanged. The results of a response spectrum earthquake analysis of the spray tower also are reported.

6.10-11 Mislavskii, B. G. and Lebedich, I. N., **Investigation of the dynamic response of a 20-story steel frame building** (Issledovanie dinamicheskikh kharakteristik 20-etazhnogo zdaniya s nesushchim stalnym karkasom, in Russian), *Materialy koordinatsionnogo soveshchaniya po dinamike stroitelnykh konstruktsii i metodam borby s vibratsiyami,* STROIIZDAT, Moscow, 1975, 107-112.

Results of full-scale investigations of the dynamic behavior of a tall steel frame building are presented. Natural vibration parameters are obtained for the first two modes. Vibration decrements are calculated. Microtremors and the braking effect of a building crane were used as vibration sources. Experimental techniques are described. Analytical results are compared with experimental data.

● **6.10-12** Barkov, Yu. V. and Glina, Yu. V., **Static and dynamic tests of a large-size model of a frameless in-situ reinforced concrete residential building,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 481-488. (For a full bibliographic citation see Abstract No. 1.2-7.)

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

The report presents the objectives, methods and results of static and dynamic tests of a large-sized ten-story model of a seismic-resistant building without frames, built from in situ reinforced concrete on a natural soil foundation.

A brief description of the model and its construction methods is given. The results of the model design, considering the actual physical and mechanical characteristics of the structural materials and the yielding of the soil foundation, are shown. Analyzed is the joint behavior of piers and lintels, as well as the interaction between the model and its soil foundation at different intensities of horizontal inertia loads applied by means of vibrators.

● **6.10-13** Kiyomiya, O., Nakayama, S. and Tsuchida, H., **Observations of dynamic response of Kinuura submerged tunnel during earthquakes and dynamic response analysis** (in Japanese), *Technical Note 221,* Port and Harbour Research Inst., Yokosuka, June 1975, 77.

Observations for the purpose of investigating the dynamic response of the submerged Kinuura tunnel during earthquakes have been conducted since Aug. 1973. Twenty seismometers, six dynamic strainmeters, eight bar stress transducers and a displacement meter are installed in the structures and on the ground surface. Four earthquake records have been obtained up to Jan. 1975.

The following conclusions can be made: (a) The ground and the structures showed roughly identical movement; however, the nature of interaction between the ground and the structures differs depending on the seismic waveform. (b) Maximum acceleration observed at the middle of the channel section is the same as or a little less than the value observed at the slant tube and the ventilation houses. (c) Maximum acceleration of the vertical component at the ventilation houses is a half or a quarter of that of the horizontal component. (d) The nature of vibration at each submerged tunnel section in the longitudinal direction depends on the ground condition at that place. (e) The period of the longitudinal direction differs from that of the orthogonal direction. Axial strains and bending strains which resulted from a dynamic response analysis using the observed earthquakes as input are roughly the same as the observed value.

The determination of the soil condition, period of the ground, Young's modulus, damping constant, etc., and the questions of the dynamic response analysis method itself will be studied in the future.

● **6.10-14** Honda, K. K., **Measurement and evaluation of high-rise building response to ground motion generated by underground nuclear explosions,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 190–199. (For a full bibliographic citation see Abstract No. 1.2-8.)

As part of the U.S. Energy Research and Development Admin.'s structural response research program, the response behavior of high-rise buildings in Las Vegas, Nevada, due to ground motion caused by underground nuclear explosions (UNEs) at the Nevada Test Site has been measured for the past 12 years. Results obtained include variation in dynamic response properties as a function of amplitude of motion, influence of nonstructural partitions in the building response, and comparison of calculated and measured response. Some of these results have been presented in the past. This report presents these data for three reinforced concrete high-rise buildings, all designed as moment-resisting space frames.

Instrumentation of these three buildings varied from a simple two-horizontal component seismometer placed at the top level of the buildings to 12 horizontal seismometers placed at various locations in the buildings. The simple top-level response measurements yielded information on periods and period changes, while the multiple response measurements furnished data on mode shapes, damping characteristics, and torsional response behavior. Some measurements were taken during construction as well as after its completion, which provided data for examining the influence of nonstructural elements.

Data from building drawings and field surveys were used to construct mathematical models of the buildings so that structural response characteristics could be calculated. Correlations between measured and computed values were used to aid in established techniques for predicting the response of buildings to ground motion. Although this work was done in relation to the effects of UNEs, the results are significant for earthquake engineering.

● **6.10-15** Hudson, D. E., **Dynamic tests of full-scale structures,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 1–39. (For a full bibliographic citation see Abstract No. 1.2-8.)

This summary is devoted almost entirely to the force generation problem of dynamic testing and, in particular, to the forced vibration testing of full-scale structures. Steady-state resonance, variable frequency excitation and transient excitation testing are considered.

● **6.10-16** Ibanez, P., Vasudevan, R. and Smith, C. B., **Experimental and theoretical analysis of buildings,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 412–430. (For a full bibliographic citation see Abstract No. 1.2-8.)

This paper discusses certain new concepts in instrumentation, test procedures, and data processing with the goal of identifying the dynamic properties of structures from vibration testing. On-line spectral analysis, the mathematical planning and execution of tests, and hypothetical

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

examples, as well as the analysis of two actual structures, are included. Both forced vibration tests using sinusoidal vibrators and ambient vibration tests are discussed. Evaluation of several theoretical models of one of the tested buildings is also discussed.

● **6.10-17** Medearis, K., **Structural response to nuclear detonation ground motions,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 200–209. (For a full bibliographic citation see Abstract No. 1.2-8.)

● **6.10-18** Freeman, S. A., Chen, C. K. and Czarnecki, R. M., **Dynamic response characteristics of reinforced concrete structures,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 210–219. (For a full bibliographic citation see Abstract No. 1.2-8.)

This paper summarizes a program of vibration investigations of two identical four-story reinforced concrete test structures, which were constructed in 1965 at the Nevada Test Site. These investigations were conducted as part of a structural response program associated with the detonation of underground nuclear explosions. The structures were built to obtain experimental data on the dynamic response characteristics of high-rise concrete buildings, ultimately leading to the development of improved techniques for predicting damage and response to ground motion. The design of these structures was consistent with the 1963 edition of the American Concrete Inst. building code; design for lateral loads was based on horizontal static forces recommended by the 1961 version of the Uniform Building Code (UBC) for Seismic Zone 3. Provisions for ductility and reserve energy absorption capacity were also incorporated into the design of these structures. In anticipation of the possible additional weight of testing equipment and nonstructural partitions, the actual dead load plus 100 psf live load was used in computing the weight of each story for the design lateral force calculations. Thus, when loaded with dead load plus live load, the structures satisfied UBC Seismic Zone 3 requirements; but, when only dead load was present (the most common configuration), these structures had nearly twice the capacity of the 1961 UBC Seismic Zone 3, or approximately the capacity required by the 1976 UBC Seismic Zone 4. The design and construction of the structures is discussed.

● **6.10-19** Rainer, J. H. and Van Selst, A., **Dynamic properties of Lions' Gate suspension bridge,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 243–252. (For a full bibliographic citation see Abstract No. 1.2-8.)

The Lions' Gate Suspension Bridge crosses the First Narrows of Burrard Inlet at Vancouver, British Columbia. Because of the need for extensive repairs to the bridge deck and requirements for wider traffic lanes, a complete rebuilding of the deck structure is planned. Since changes in geometric and structural properties could influence the behavior of the modified bridge under wind loading, an aerodynamic investigation is being undertaken which includes wind tunnel section tests and a full aeroelastic model. To obtain some guidance in establishing the dynamic parameters for the model tests and the design calculations, measurements on the existing structure were carried out to determine its dynamic properties. This paper describes the measurement program and the results obtained, as well as comparisons between the observed values of natural frequencies and those from two different methods of calculation.

● **6.10-20** Omote, Y. *et al.,* **Vibration test of existing chimney** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 11,* 1975, 13–15.

The chimney tested was constructed by a sliding form system and is a flue-type reinforced concrete structure 180m in height. This report discusses the results of vibration tests of the chimney and of analyses carried out thereon. Three kinds of tests were conducted: observation of microtremors, free vibration tests for the first mode and the usual vibration generator tests for high modes. Damping constants obtained by these tests were almost equal at around 1% for the first to third modes. Natural periods were shorter than the design value.

The mathematical model of the chimney was a bending type multilumped-mass system. When assuming rocking and swaying effects on the foundation obtained from test results and also assuming the elastic modulus of concrete to be 1.3 times the design value by considering concrete compressive strength and reinforcement effect, the simulation analysis was in good agreement with the test results.

● **6.10-21** Rojahn, C. and Negmatullaev, S. H., **Forced-vibration tests of a three-story reinforced concrete frame and shear-wall building in Tadzhik, S.S.R.** (abstract only), *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* p.159. (For a full bibliographic citation see Abstract No. 1.2-8.)

● **6.10-22** Petrovski, J. and Stephen, R. M., **Ambient and forced vibration studies of a multistory triangular-shaped building,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 180–189. (For a full bibliographic citation see Abstract No. 1.2-8.)

Forced and ambient vibration studies were performed on the Century City South-Theme Tower in Los Angeles. Because of the favorable advantages of the ambient vibration method in dynamic testing of full-scale structures, it was desirable to compare both methods in order to assess

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

the accuracy of each method in evaluating the dynamic properties of the structural systems.

● **6.10-23** Kircher, C. A., **Ambient and forced vibration analysis of 230 KV air blast circuit breakers: Comparison of system properties before and after addition of Braun-Bowery dampers,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 220–227. (For a full bibliographic citation see Abstract No. 1.2-8.)

In an attempt to better understand the mechanism of energy dissipation or damping, as well as to determine the mode shapes and natural frequencies, a structural system, composed of 230 KV air blast circuit breakers and support structure, was analyzed. The breaker system was part of an electrical switchyard located at the A. D. Edmonston pumping plant on the California Aqueduct. This structure was chosen because its size was sufficiently small, permitting forced vibration excitation from an electromagnetic shaker system, and because the dynamic characteristics required by an earthquake analysis procedure could not be accurately determined from a mathematical model alone. An additional reason for the selection of this structure to be analyzed was that the structure existed in two forms, with and without the addition of mechanical "earthquake" dampers at the base of each of the four columns of the support structure. The results presented in this paper focus their attention on the comparison of the mode shapes, natural frequencies, and energy dissipation characteristics for the unmodified and modified 230 KV breaker systems.

● **6.10-24** Kircher, C. A. and Shah, H. C., **Ambient vibration study of six similar high-rise apartment buildings: Comparison of the dynamic properties,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 168–179. (For a full bibliographic citation see Abstract No. 1.2-8.)

Two 12-story high-rise apartment buildings and four 8-story high-rise 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 dynamic similarity of the buildings, excited by ambient level forces, as well as the method of vibration analysis. All results contained in this work are based strictly on analyses of ambient level vibrations.

The purpose of this paper is to present the calculated natural frequencies and modal damping values for the six buildings analyzed, and to compare the dynamic properties of similar buildings by comparing their power spectral density functions obtained for similar accelerometer positions. For this purpose a method has been developed for the statistical comparison of two power spectral density functions. The essence of this method is to perform a point by point correlation of the two power spectral density functions. The results of the correlation indicate where and to what degree the power spectral density functions are similar. A detailed description of this method of statistical comparison of power spectra will be presented at some later time with results of comparisons of power spectral density functions obtained for a variety of accelerometer locations and orientations within the same building, as well as similar buildings.

● **6.10-25** Foutch, D. A., **Recent advances in dynamic testing of full scale structures,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 160–167. (For a full bibliographic citation see Abstract No. 1.2-8.)

An extensive series of forced vibration tests has been undertaken at Caltech in an attempt to broaden the understanding of the dynamic behavior of multistory buildings and to help identify modeling assumptions which may be appropriate to use in describing the observed behavior. The purpose of this paper is to discuss the selection and use of the instrumentation used in these studies. In doing this, the nature and significance of the modeling problem will also be discussed.

● **6.10-26** Durning, P. J. and Engle, D., **Vibration instrumentation system measures an offshore platform's response to dynamic loads,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 143–158. (For a full bibliographic citation see Abstract No. 1.2-8.)

A self-contained drilling and production platform in the upper Cook Inlet of Alaska has been instrumented to provide data to aid in the earthquake-resistant design of a steel offshore platform structure. The instrumentation provides the following data: (1) strain measurements on the center column during ice and earthquake conditions and (2) acceleration measurements of the structure's response to ice or earthquake loading.

This paper will first describe the strain gauge and accelerometer installation, recording equipment and functioning procedure. The description of the data reduction sequence will be followed by an explanation of the spectral treatment of the platform time-history behavior. Damping estimates were made based on several different calculation methods and their results will be compared.

6.10-27 Verner, D., **On the problem of vibrations due to people** (K voprosu o kolebaniyakh, vozbuzhdaemykh lyudmi, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 1,* 1976, 58–59.

Vibration of buildings caused by human movement was investigated experimentally. Vibration parameters are

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

determined. Loads and admissible accelerations are calculated for auditoriums and dance halls.

● **6.10-28** Cameron, G. R. and LeBrun, J., **Static and dynamic testing tower number four unstrung**, *ME-76-1*, Bonneville Power Admin., U.S. Dept of the Interior, Portland, Oregon, 1976, 123.

Static and dynamic field testing of an unstrung transmission line tower, Suspension Tower Number 4 at the Moro (Oregon) Mechanical Test Facility, Bonneville Power Admin., was carried out in conjunction with analysis by several structural finite element computer programs. Static and dynamic properties of that tower were obtained for comparison with these properties after the conductor bundles were strung. Experience in field testing of large structures, equipment usage, and program development analysis was obtained.

The static field testing of the tower and comparison of the results with those from the static computer analysis provided some significant information. The tower does respond in a linear, elastic manner with computer predictions of tower displacements being very close to those measured. Very little movement of the footings was observed during the static testing. Attempts to record strain gage information were not successful.

The dynamic field testing of the tower also provided some significant information. Comparison of the dynamic computer analysis with values obtained by testing were within nine percent. Foundation motion may account for the anomaly. The fundamental frequency of vibration was found to be 2.2 Hz, and the damping was quite low at 0.3 percent of critical.

● **6.10-29** Foutch, D. A., **A study of the vibrational characteristics of two multistory buildings**, *EERL 76-03*, Earthquake Engineering Research Lab., California Inst. of Technology, Pasadena, Sept. 1976, 202.

Forced vibration tests and associated analysis of two multistory buildings are described. In one case, the dynamic properties of the building measured during the tests are compared to those predicted by simple analytical models. A three-dimensional finite element model of the second building was constructed for the purpose of evaluating the accuracy of this type of analysis for predicting the observed dynamic properties of the structure.

Forced vibration tests were performed on Millikan Library, a nine-story reinforced concrete shear wall building. Measurements of three-dimensional motions of approximately 50 points on each of six floors (including the basement) were taken for excitation in the N-S and E-W directions. The results revealed a complex interaction between lateral and vertical load-carrying systems in both directions. The results also suggest that a significant change in the foundation response of the structure occurred in the stiffer N-S direction during the San Fernando earthquake. This phenomenon was investigated through the use of two analytical models of the building which included the effects of soil-structure interaction.

The Ralph M. Parsons World Headquarters building, a twelve-story steel frame structure, was also tested. The natural frequencies, three-dimensional mode shapes, and damping coefficients of nine modes of vibration were determined. Other features of this investigation included the study of nonlinearities associated with increasing levels of response and the measurement of strain in one of the columns of the structure during forced excitation. The dynamic characteristics of the building determined by these tests are compared to those predicted by a finite element model of the structure. The properties of primarily translational modes are predicted reasonably well; but adequate predictions of torsional motions were not obtained. The comparison between measured and predicted strains suggests that estimates of stress obtained from finite element analyses of buildings should be within 25 percent of those experienced by the structure for a known excitation.

● **6.10-30** Carden, H. D. and Mayes, W. H., **Experimental forced vibration responses of two test houses used during the Edwards Air Force Base phase of the National Sonic Boom Test Program**, *NASA TM X-72705*, NASA Langley Research Center, Hampton, Virginia, June 1975, 17.

Experimental vibration studies were conducted on two houses to determine some of the dynamic response characteristics resulting from sonic boom. The primary objectives of the vibration tests were to identify the mode shapes associated with the various frequencies determined from the sonic boom response data, and to obtain some basic information about the vibration behavior of buildings in general.

This paper presents the results of forced sinusoidal vibration studies of some components of the test structures. Included are acceleration response data on selected walls, wall surface modal patterns, and vibration-induced noise measurements at various locations in the test structures.

● **6.10-31** Masaki, Y. *et al.*, **Dynamic response of pile-supported bridge pier in mud deposit** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 167, 527-534. (For a full bibliographic citation see Abstract No. 1.2-9.)

The main pier of the ARA River Coast Side Bridge consists of a submerged footing resting on sixty steel pipe piles, each of which is 1.5m in diameter, 38m in length and extend through soft deposit layers. The vibration characteristics of this pier have been studied, using experimental and theoretical approaches; i.e., forced vibration tests, microtremor measurements, artificial earthquake observation, and analytical simulations using lumped mass and finite element idealizations.

● **6.10-32** Nakayama, S. and Kiyomiya, O., **Observation of dynamic behavior of Kinuura submerged tunnel during earthquakes** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 212, 639–646. (For a full bibliographic citation see Abstract No. 1.2–9.)

Observations of the dynamic behavior of a submerged tunnel during earthquakes have been carried out since Aug. 1973 at the Kinuura submerged tunnel situated in Aichi Prefecture. This tunnel is composed of 6 steel-shell elements 7.13 m high, 15.6 m wide and 80.0 m long. Twenty accelerometers, one displacement meter, six dynamic strain-meters and eight bar stress transducers are used for these observations.

Seven earthquakes have been recorded up to Jan. 1975 and four earthquake records were analyzed. Earthquake response calculations were made and the results were compared with the observed results. In the calculations, the ground was idealized as a lumped mass system and the tunnel as a beam which was connected to the masses with springs and dampers. The input earthquake motions to the system are based on the observed ground accelerations.

The following results were found. The dynamic behavior of the submerged tunnel depends largely on the characteristics of earthquakes, such as the frequency component. Most of the observed maximum accelerations of the submerged tunnel were not larger than the maximum accelerations at the ground surface. The observed maximum accelerations, bending moment and axial force agreed with those calculated by the previously described procedure, with acceptable differences.

● **6.10-33** Hamada, M., Izumi, H. and Sato, S., **Behavior of underground tanks during earthquakes,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 205, 583–590. (For a full bibliographic citation see Abstract No. 1.2–9.)

Recently, many underground tanks have been constructed in Japan for crude oil and liquefied natural gas, etc., and most of them are on soft reclaimed lands. In order to obtain the dynamic characteristics of underground tanks, earthquake observations and numerical analyses were carried out; and a practical seismic-resistant design method is proposed for underground tanks on the basis of these results.

● **6.10-34** Masao, T. and Suzuki, T., **Forced vibrational characteristics of rigid body in the ground** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 169, 543–550. (For a full bibliographic citation see Abstract No. 1.2–9.)

● **6.10-35** Satake, M. *et al.*, **Comparison of vibration characteristics during earthquakes of caisson piers before and after girder-construction** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 163, 495–502. (For a full bibliographic citation see Abstract No. 1.2–9.)

For the seismic-resistant design of bridges, it is important to know the vibration characteristics of bridge substructures during earthquakes. Seismographs were set at the tops and at the bases of two caisson piers of the Iinogawa Bridge; earthquake observations have been conducted since the beginning of the construction of the girder. In this report, the vibration characteristics of the caisson piers before and after girder construction are compared. Analyses are made by Fourier spectrum and correlation function analysis.

● **6.10-36** Kidera, K. *et al.*, **Earthquake observation of cellular foundation with steel pipe piles** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 162, 487–494. (For a full bibliographic citation see Abstract No. 1.2–9.)

Recently, cellular foundations with steel pipe piles have been used for bridge foundations. However, many problems remain to be solved in the seismic-resistant design of such foundations. In order to investigate the soil-foundation dynamic interaction, a forced vibration test was conducted in Mar. 1974. Since June 1974, earthquake observations have been conducted. Several earthquakes were recorded, three of which were of intensity 4. The results of the earthquake observations and the forced vibration test are compared. The dynamic behavior of the foundations is discussed.

● **6.10-37** Kawamura, S. and Umemura, H., **Earthquake measurement of pile supported building on the reclaimed ground—Comparison between building line and soil line** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 161, 479–486. (For a full bibliographic citation see Abstract No. 1.2–9.)

Continuous earthquake motion measurements in and around a pile-supported, seven-story reinforced concrete apartment building have been conducted. The thickness of the reclaimed layer at the site is as shallow as 4 - 5 m and it consists mainly of sand. The measurement system is composed of a building line and a soil line. The building line consists of 5 points: two points in the building, one at 4 m (ancient sea bed), one at 12 m (pile bottom) and one at 24 m just below the building. The soil line is parallel to the building line and consists of 4 points at the same level with

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

the building line. The distance between the two lines is about 20 m. Since Dec. 1971 the accelerations of more than 80 earthquakes have been recorded. All of them belong to the small or middle class of intensity, IV or less on the Japanese Meteorological Agency Scale.

● **6.10-38** Hagio, K. *et al.*, **Earthquake observation and analysis of plant tower built on the soft subsoil** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 160, 471–478. (For a full bibliographic citation see Abstract No. 1.2–9.)

Dynamic interaction between a structure and its subsoil becomes important when the structure is built on reclaimed soft subsoil and supported by piles or piers. To monitor actual soil-structure interaction behavior, continuous earthquake observations in and around a precast concrete apartment house have been conducted. In addition, a new earthquake observation system has been placed around the petrochemical plant towers on the soft reclaimed ground in Chiba prefecture. In this report, the observation system and analytical results based on the observed records are described.

● **6.10-39** Sugimura, Y., **Earthquake observation and dynamic analysis of pile-supported building,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 159, 463–470. (For a full bibliographic citation see Abstract No. 1.2–9.)

This paper introduces some results of earthquake observations from twenty-one seismographs stationed underground in piles and in a superstructure. Also presented are results of theoretical analyses carried out to investigate the dynamic behavior of a fourteen-story residential building supported on long piles.

Seven observed earthquakes were chosen for this study and spectral analyses, such as power spectral densities and spectral ratios, were computed for the acceleration data of each location. Response and frequency analyses were conducted for analytical models of the ground and the building.

● **6.10-40** Wiss, J. F. and Nicholls, H. R., **A study of damage to a residential structure from blast vibrations,** American Society of Civil Engineers, New York, 1974, 73.

A primary objective of this test project was to study, under carefully controlled conditions, the effects of earthborn blast vibrations upon a residential structure. Another objective was to compare the propagation characteristics of earthborn blast vibrations when the explosive was detonated in soil with the extensive information already available on blasts in bedrock.

The residence under study was subjected to progressively more intense blast vibrations until damage was observed. Existing cracks in the residence were documented and changes in crack width were measured. Dynamic recordings were made of the blast vibrations in the earth, basement, interior and exterior walls, and of strains in the interior gypsum wallboard.

The wave shapes and propagation characteristics of the earthborn blast vibration were similar to those observed from blasts in bedrock. No damage occurred to the residence at an earth particle velocity of 7.0 ips; three new cracks in the gypsum wallboard were observed at approximately 20 ips. Variations in the width of existing cracks were greater during intervals when blasting was not done than during periods when blasting occurred. The dynamic strain recordings in the interior walls confirmed that ground peak particle velocity is the best criterion of potential damage to residential structures.

● **6.10-41** Mizuno, N. *et al.*, **Study on damping appreciation of forced vibration tests: Evaluation of damping effects for the dissipation energy at the Hamaoka nuclear power plant No. 1** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 233, 807–814. (For a full bibliographic citation see Abstract No. 1.2–9.)

6.11 Experimental Facilities and Investigations

● **6.11-1** Penzien, J., Bertero, V. and Atalay, B., **Inelastic cyclic behavior of reinforced concrete flexural members,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings,* 52–74. (For a full bibliographic citation see Abstract No. 1.2–2.)

Presented is a brief summary of the findings obtained in four series of tests on doubly reinforced concrete members. These tests were designed to obtain basic information on the force-deformation and failure characteristics of the members under large-deformation reversed cyclic loading conditions. Specifically, the four series of tests were carried out to study (1) the flexural hysteretic behavior of critical regions under pseudo-static conditions, (2) the effect of rate of loading on the flexural hysteretic behavior, (3) the effect of shear on the flexural hysteretic behavior, and (4) the effect of axial force on the flexural hysteretic behavior.

● **6.11-2** Sozen, M. A. and Otani, S., **Structural walls subjected to simulated earthquakes,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings,* 118–134. (For a full bibliographic citation see Abstract No. 1.2–2.)

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

This is a progress report on recent tests at the Univ. of Illinois, Urbana, investigating the earthquake response of multistory structural walls.

● **6.11-3** Omote, Y. and Takeda, T., **Experimental and analytical study on reinforced concrete chimneys,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings,* 135–163. (For a full bibliographic citation see Abstract No. 1.2–2.)

This paper is concerned with the tests and analyses of reinforced concrete chimneys subjected to strong earthquake ground motions. One objective of the investigation is to develop a realistic mathematical model for the calculation of nonlinear response of reinforced concrete chimneys. In order to find a suitable model, one must first establish the moment-curvature relationship for a reinforced concrete cylinder subjected to full reversals of bending. For this purpose, four physical models of chimneys were tested on an earthquake simulator and nonlinear response analyses were conducted using the subelement method proposed in this paper. Static and dynamic test results show good agreement when compared with analytical predictions.

● **6.11-4** Sasaki, T. *et al.*, **An experimental study on earthquake resistant strengthening work for existing reinforced concrete buildings,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings,* 352–370. (For a full bibliographic citation see Abstract No. 1.2–2.)

The object of this investigation is to present a practical method for strengthening existing reinforced concrete buildings which have inadequate earthquake resistance. The method investigated herein is to cover an existing concrete column by a thin steel plate and to grout the clearance between the column and the steel plate with nonshrink mortar.

The test was performed by applying repeated alternate distortions to the column specimen, simulating the effects of earthquakes. This paper deals with existing columns, thickness of the steel plate, shear-deflection behavior, shear-axial length behavior and failure mode of the column specimens.

● **6.11-5** Lee, D. L. N., Wight, J. K. and Hanson, R. D., **Repair and rehabilitation of reinforced concrete structures,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings,* 371–396. (For a full bibliographic citation see Abstract No. 1.2–2.)

An investigation on the effectiveness of repaired reinforced concrete exterior beam-column subassemblages is presented. The epoxy injection technique and the removal and replacement technique using different high early strength materials were used to repair the specimens. Details of the repair procedure along with the strength properties of the materials used in the repairs are given. Based on the results, it is concluded that epoxy injection and removal and replacement methods of repair can restore structural integrity to the members.

● **6.11-6** Ramakrishnan, V., **Comparison of three-dimensional analysis of concrete shear wall buildings and their actual behavior,** *Methods of Structural Analysis,* Vol. I, 95–114. (For a full bibliographic citation see Abstract No. 1.2–3.)

This paper presents the results of an extensive experimental and theoretical investigation conducted to determine the lateral load distribution in nonlineal concrete shear wall systems in the precracking stage and the true effect of the flange in flanged shear walls. A comparison of three-dimensional analysis using the finite element method and the actual behavior of large-scale microconcrete models before concrete cracking is presented. Guidelines are also suggested for the design of such concrete shear wall structures.

● **6.11-7** Jimenez, R. *et al.*, **Interface shear transfer and dowel action in cracked reinforced concrete subject to cyclic shear,** *Methods of Structural Analysis,* Vol. I, 457–475. (For a full bibliographic citation see Abstract No. 1.2–3.)

Seismic shear transfer in thick reinforced concrete sections that are precracked by tensile stresses in the reinforcement is treated in this paper. This situation arises in various structures, including reinforced concrete secondary nuclear containment structures, where a combined internal pressurization and seismic loading are considered in design.

Experimental results are reported for several specimen geometries with five different bar sizes (#4, #6, #7, #9 and #14). Each specimen was loaded in fully reversing nondynamic cyclic shear to simulate the effects of seismic action. Selected specimens were built with greased plates at the crack location to eliminate the interface component of shear transfer; hence these specimens (with #4, #6, and #9 bars) transmit shear by dowel action alone. Most specimens had independent external tensile loads applied to the bars during the shear loading.

Measured response includes shear slip vs. shear load, growth of crack width with cycling, degradation characteristics of interface and dowel action, bending effects in the reinforcing, and splitting tendencies produced by combined dowel action and axial tension in the reinforcing.

Experiments involving #7 and larger bars were conducted on specimens with shearing areas on the order of several hundred square inches, while the #4 and #6 bar tests were done at a small scale to study the feasibility of using a new specimen design for large-scale experiments. Additional experiments with #14 bars are currently under way, and the #14 bar results reported here should be considered as preliminary.

6.11-8 Miles, A. W., **Shock-front loading method for studies in dynamic photoelasticity,** *Experimental Mechanics,* **16,** *9,* Sept. 1976, 349–355.

A versatile technique for applying a well-defined dynamic load to models for studies in dynamic photoelasticity is described. The method utilizes the shock front produced in a gas-dynamic shock tube to apply a load to models by direct normal impact. The principles and scope of the method are described and some examples of the dynamic stresses arising from shock-front impact on a low-modulus photoelastic model are presented and discussed. The method is suited to studies where simple variation and accurate determination of the load-cycle parameters, as well as precise reproducibility, are necessary. The method, in addition, permits close-field study of the initial response of materials to dynamic loading to be undertaken.

6.11-9 Styles, D. D. and Dodds, C. J., **Simulation of random environments for structural dynamics testing,** *Experimental Mechanics,* **16,** *11,* Nov. 1976, 416–424.

To successfully reproduce a response under random loading in the laboratory requires an understanding of the applicability of input-output response relationships for the system under study, together with a description of the random environment which provides the excitation. It is demonstrated that, for a multiple or continuous-input system, an environmental description can be obtained from measured field response data. This description will then contain the necessary information to provide excitation signals for a predetermined number of vibrators which will simulate the service response in the laboratory. A digital technique for the simulation of random environments is presented and the results of its application in the case of generating test signals for a simulation test on a multi-wheeled road vehicle are shown.

6.11-10 Wu, J. N. C. and Roman, G. W., **Dynamic modeling of marine boilers,** *Experimental Mechanics,* **16,** *4,* Apr. 1976, 140–145.

Experimental investigation was performed on a simplified scale model of a typical marine boiler. Shaking table tests were performed to determine natural frequencies, and impact tests were used to determine the structural shock response. The dynamic response data have been used to verify analytical results obtained from a three-dimensional beam-element model with the consideration of local flexibility at the nozzle-vessel intersections.

● **6.11-11** Ciongradi, C. and Ciongradi, I., **Influence of infill walls on the earthquake response of framed structures,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 116, 6. (For a full bibliographic citation see Abstract No. 1.2-6.)

A structural model of an 11-story framed building (scaled to 1:4) was tested on a shaking table. After subjecting the model to earthquake motions of increasing intensity, the model was consolidated by infilled masonry walls. The earthquake response, the dynamic characteristics and structural stiffness were determined as a result of static and dynamic tests. Simultaneously, a fragment specimen of a framed structure representing a framing alveole (portal frame), was used to determine response to static reversible loadings. The P-Δ hysteresis curves determined from this research of the behavior of the consolidated model with infilled walls will be used to study the response of this framed structure to an actual recorded earthquake.

● **6.11-12** Mazilu, P. *et al.*, **Types of jointings at large-panelled fabricated constructions in seismic regions,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 96, 12. (For a full bibliographic citation see Abstract No. 1.2-6.)

Loop-jointing tests of large-panel structures subjected to static and dynamic loads are described. Experiments delineated the increased damping properties of reinforced concrete after the appearance of cracks and the dependence of damping on the amplitude of the oscillations. The results attest to the need for improving the design concept of joints used in the construction of large-panel buildings.

● **6.11-13** Apostolov, G., **Dynamic characterizations for multistoreyed buildings with central core and hanged slabs,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 114, 9. (For a full bibliographic citation see Abstract No. 1.2-6.)

In this report, the theoretical and experimental investigations of multistory buildings with central cores and floor-slab structures hung from the top story structure are discussed. The floor-slab structures are soft like a spring connected with a central core. Investigations and determination of dynamic characteristics are conducted using the theoretical model. The effect of hanging of the floor-slab structures and the soft connection with the central core is verified on a steel test model. The resonance curve, the natural frequencies and the mode of vibrations are defined by the testing method.

● **6.11-14** Oberti, G., Castoldi, A. and Mazzieri, C., **Analysis by means of physical models of the seismic behaviour**

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

of concrete arch dams, *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 119, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

The seismic verification of an arch dam, as recently suggested by the most advanced codes, must be carried out by computing the dynamic response of the structure to a design earthquake. The new criteria pose a series of problems not yet completely solved. These include: the interaction between dam and foundation rock, especially for that which concerns the energy radiation; the hydrodynamic pressure and the interaction between the reservoir and the dam's motion; the effect of different movements of the dam's abutments as a consequence of the finite wave length of the seismic acceleration; and the determination of the properties of the material.

This paper shows how a physical model, built on a suitable geometric scale and tested with adequate equipment, can lead to a satisfactory solution for many of the previous problems. Toward this aim, the results obtained at ISMES (Italy) through a model investigation of the Ridracoli arch-dam are reviewed and some aspects of the seismic design are discussed.

● **6.11-15** Izmailov, Yu. V., Il'chenko, E. V. and Tarnovsky, K. I., **Big compound blocks of natural stone with prestressed reinforcement,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 146, 7. (For a full bibliographic citation see Abstract No. 1.2-6.)

Wide use of natural stone in many seismic regions provides an incentive for industrialization of stone building construction. Switching from manual construction to assembling big compound blocks permits more economical construction of stone buildings and increases their seismic stability. One of the methods for producing such blocks is the squeezing of masonry by prestressed reinforcement. In this case, the intensity of the masonry prestressing should be within 0.5 to 1.0 kg/cm^2. The compound blocks can be transported to a building site just after their production for assembling building walls; it is not necessary to wait until the mortar in the masonry joints hardens. Testing the prestressed compound blocks has revealed that they are characterized by considerably higher strength indices in comparison with usual masonry.

● **6.11-16** Diaconu, D. *et al.*, **The comparative seismic response of some eleven-levelled structures of monolith and precast frames,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 62, 14. (For a full bibliographic citation see Abstract No. 1.2-6.)

The paper presents the synthesis of some experimental and theoretical research regarding the behavior of framed structures under strong earthquake ground motion. The eleven-story structures included both monolithic and partially prefabricated ones. The experimental research was carried out on a shaking table.

The study points out some comparative aspects regarding sideway, initial and deteriorated stiffness, the variation of the dynamic characteristics in terms of the working stage of the structures, the adaptation interval, the average instantaneous deformed shapes and the acceleration distribution, retardation in the seismic response and the zones of energy absorption, the values of unitary stresses in the characteristic cross-sections and the cracking as well as the failure peculiarities. Estimated are the elements of the lateral stiffness matrix, which along with the above-mentioned data, contribute to the realization of some typical structures with increased safety.

● **6.11-17** Bukharbaev, T. H., Paramzin, A. M. and Itskov, I. E., **Box-unit dwelling houses in seismic-resistant construction,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 144, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

A system of box-unit houses and a load-test stand for the full-scale testing of large-size structures are considered. Static and dynamic tests of full-size house portions assembled of space members are described. A discrete model method is suggested to be used for the theoretical analysis of the three-dimensional stress-strain condition of box-units.

6.11-18 Anderson, C., **Lateral loading tests on concrete block walls,** *The Structural Engineer,* **54,** 7, July 1976, 239-246.

This paper describes tests carried out on six full-sized single-leaf blockwork walls. The walls were tested to ultimate load and the results compared with values based on the design rules proposed in the British Standards Institution Draft Specification for the Structural Use of Unreinforced Masonry, 74/10483DC.

● **6.11-19** Fiorato, A. E., Oesterle, Jr., R. G. and Carpenter, J. E., **Reversing load tests of five isolated structural walls,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 437-453. (For a full bibliographic citation see Abstract No. 1.2-7.)

An experimental program is being carried out to develop design criteria for reinforced concrete walls used as lateral bracing in earthquake-resistant buildings. Primary items of interest include the ductility, energy dissipation, and strength of the walls.

Tests of five walls are described. The model walls were 15 ft high and 6 ft 3 in. wide. Wall thicknesses were 4 in. All specimens were subjected to in-plane horizontal reversing loads. Controlled variables included the shape of the

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

wall cross-section, the amount of main flexural reinforcement, and the amount of hoop reinforcement around the main flexural reinforcement. Two specimens were subjected to high nominal shear stresses. The failure mode for these specimens was associated with web shear distress. Three specimens were loaded with low nominal shear stresses. Two of these had ordinary column ties. One had lateral confinement reinforcement around the main flexural reinforcement in the boundary elements. Capacities of these specimens were governed by damage to the boundary elements as alternate tensile yielding and compressive buckling of the main flexural reinforcement occurred.

Lateral confinement reinforcement in the boundary elements helped to limit bar buckling and to contain cracked concrete within the core. Confinement provided a wall with somewhat greater ductility, but no significant increase in strength.

6.11-20 Cranston, W. B. and Roberts, J. J., **The structural behaviour of concrete masonry—reinforced and unreinforced,** *The Structural Engineer,* 54, *11,* Nov. 1976, 423–436.

In this paper the behavior of reinforced and unreinforced masonry is considered. Tests on eccentrically loaded unreinforced walls and couplet specimens are reported and a simple theoretical approach for solid block masonry is derived. A method of predicting wall strength is presented. Additional tests are described on reinforced masonry sections subjected to lateral loading only and the simple ultimate load theory used for reinforced concrete is shown to give a good indication of the ultimate strength of the sections. The effect of employing different values of the partial factor of safety for strength of the masonry is considered. It is indicated that present design procedures using permissible stresses result in uneconomic design.

● **6.11-21** Shimazu, T. and Fukuhara, Y., **Experimental study on reinforced concrete truss frames as earthquake resistance elements,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 489–500. (For a full bibliographic citation see Abstract No. 1.2–7.)

More than twenty small one-story and one-span reinforced concrete braced frames were subjected to alternating repeated horizontal loads at the top beam level with a constant axial load at the two tops of the columns. The objective was to obtain basic data on the earthquake-resistant capacities of reinforced concrete truss frames. The variables considered are the slenderness of the frame members, the longitudinal reinforcement ratios of the members, the level of the axial load and the connection reinforcement. The test results show that braced frames have considerable ductility in addition to high stiffness and high strength.

● **6.11-22** du Bouchet, A. V., **Earthquake response of guyed towers,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 513–526. (For a full bibliographic citation see Abstract No. 1.2–7.)

A structural model of a guyed tower (scaled by dimensional analysis principles) is subjected to simulated earthquake ground motion by means of a shaking table. The model has been scaled from a prototype previously reported in the literature. A total of fifteen variables are scaled, including ground and structure acceleration, velocity, and displacement, material constants and density, structure geometry, stress levels and gravitational constant.

● **6.11-23** Umemura, H. *et al.*, **Experimental study on reinforced concrete columns with special web reinforcements,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 527–540. (For a full bibliographic citation see Abstract No. 1.2–7.)

This paper presents the results of experimental studies carried out on reinforced concrete columns with double spiral web reinforcements. Approximately 30 specimens were subjected to alternating repeated antisymmetrical loads with a constant axial load. The variables considered were shear span ratio, axial load level, the amount and diameter of web reinforcement, the angle between web and longitudinal reinforcements, with and without welding between the reinforcements. It was found that double spiral web reinforcements are much more effective for reinforced concrete columns than conventional web reinforcements.

● **6.11-24** Plecnik, J. M. *et al.*, **Epoxy repair of structures,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1023–1036. (For a full bibliographic citation see Abstract No. 1.2–7.)

This paper presents a brief review of a portion of the experimental results obtained in the Structures Lab. at California State Univ., Long Beach. The results deal with the behavior of epoxy repaired structural masonry elements subjected to static and dynamic (seismic) load conditions. The conclusions show that damaged concrete masonry structural elements properly repaired with various epoxy adhesive materials are essentially restored to the strength levels which existed prior to sustained damage. Several aspects concerning epoxy repair procedures are discussed in relation to their effects on the strength of the repaired structural elements. Presented are experimental results demonstrating the behavior and strength properties of epoxy repaired structural masonry elements.

● **6.11-25** Wakabayashi, M. and Minami, K., **Experimental studies on hysteretic characteristics of steel reinforced concrete columns and frames,** *Proceedings of the International Symposium on Earthquake Structural Engineering,*

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

Vol. I, 467–480. (For a full bibliographic citation see Abstract No. 1.2–7.)

In order to obtain information on the inelastic hysteretic characteristics of steel reinforced concrete (SRC) columns and frames, a parametric experimental study was carried out on the strength, deformability, failure mechanism and shapes of hysteresis curves under repeatedly applied, well-defined loads using 27 column and 9 frame specimens. Variables chosen for the experiments were the magnitude of the constant axial load and the composition of column cross section; full-web (H-shaped) steel component, open-web (battened) steel component and reinforced concrete sections without steel component for the comparison of the characteristics with SRC counterparts. All column specimens were of rectangular cross section (15 cm x 15 cm). Well-defined cyclic loading was applied to all of the specimens by controlling the deflection amplitude. The discussion concentrates on the strength, the behavior before and after the attainment of the maximum strength, the failure mechanism and hysteretic characteristics involved in the large deformation range under repeated loading.

6.11-26 Melik-Elchyan, A. G. and Akopyan, K. A., **Reflection coefficients and amplitude curves of reflected cylindrical waves** (Koeffitsienty otrazheniya i amplitudnye krivye otrazhennykh tsilindricheskikh voln, in Russian), *Sbornik trudov Moskovskogo inzhenerno-stroitelnogo instituta, 125-126,* 1975, 183–184.

The effects of various impulse excitation sources (e.g., explosions and earthquakes) on structures are studied. Dynamic photoelasticity techniques are used to investigate reflection of cylindrical stress waves at the boundary in a two-layered medium. Typical alterations in the wave field at the boundary, related to the formation of head waves, are discussed.

● **6.11-27** Dumanoglu, A. A. and Severn, R. T., **The dynamic foundation interaction of multistorey frames,** *Earthquake Engineering and Structural Dynamics,* 4, 6, Oct.–Dec. 1976, 589–608.

This paper discusses the extent to which foundation properties influence the response of some framed structures to earthquakes. Three stages can be isolated, the first of which checks the validity of a theoretical method by means of model studies. Five models were made, a five-story plane frame rigidly fixed at its feet, two models of the same frame but now in association with a linearly elastic isotropic foundation, Adiprene L-100 and L-167, which had *E*-values of 4.4 and 39.7 N/mm^2, respectively. A five-story, asymmetric space frame was also made, with fixed feet and with a foundation of modulus 4.4N/mm^2. In this first stage, resonance tests were made, using MAMA, to obtain frequencies, mode shapes and damping values. Corresponding frequencies and mode shapes were calculated using a finite element idealization.

The second stage uses a proven computer program for a parametric study to obtain a large number of results, which give a good indication of the effect of different foundation conditions on this type of structure. Some calculations are also made in which the foundation is represented by equivalent springs instead of finite elements.

In the third stage dynamic response was considered. A shaking table was built on which the models were subjected to a number of actual earthquake records, which had been suitably scaled and recorded on magnetic tape. The structural response was measured, and compared with calculated values obtained by step-by-step methods and, alternatively, the modal addition approach. For the asymmetric space-frame, particular attention was paid to the torsional effect.

● **6.11-28** Masri, S. F. and Safford, F. B., **Dynamic environment simulation by pulse techniques,** *Journal of the Engineering Mechanics Division, ASCE,* **102,** *EM1,* Proc. Paper 11923, Feb. 1976, 151–169.

The capability for simulating the response of structures to transient dynamic loading is useful for testing structural adequacy, for evaluating mathematical models, and for investigating the response of equipment in a structure. An analytical and experimental investigation of the use of mechanical pulse generators to determine the characteristics of massive structures and to simulate continuous dynamic environments applicable to such structures is described. Theoretical, "criterion" response is computed. A method is presented for determining the optimized pulse train convenient for experimental application. Experimental measurements obtained from a 200,000-lb (92,000-kg) structure are used to generate specifications for pulse simulation of earthquake ground motion. These pulse specifications are shown to be physically practical. Results of in-place tests of the 200,000-lb (92,000-kg) structure by pulse techniques compare favorably with theoretical predictions.

6.11-29 Kartsivadze, G. N., **On methods of analysis of elastoplastic vibrations in structures from seismic excitation** (O methodakh analiza uprugo-plasticheskikh kolebanii sooruzhenii pri seismicheskom vozdeistvii, in Russian), *Prostranstvennye konstruktsii zdanii i sooruzhenii, 2,* 1975, 11–15.

Characteristics of seismic excitations are considered and existing methods for incorporating them into practical design are discussed. Results of experimental investigations of the behavior of reinforced concrete structures subjected to intensive shock or seismic loadings are presented.

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

6.11-30 Asanbekov, Kh. A. and Plotnikov, V. M., **On calculation of loads on building walls from explosion waves** (K opredeleniyu nagruzok na steng zdanii ot vzryvnoi volny, in Russian), *Tekhnicheskie nauki, 15,* 1975, 157–160.

Results of experimental measurements of the intensity of reflected shock waves from explosions are presented. The experimental results are compared to data obtained analytically. The experimental data are analyzed and formulas for the reflection coefficient of the shock waves arriving at the wall are derived.

● **6.11-31** Clough, R. W. and Bertero, V. V., **Laboratory model testing for earthquake loading,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 86–107. (For a full bibliographic citation see Abstract No. 1.2–8.)

The purpose of this paper is to discuss the earthquake response testing of structures and structural components, with emphasis on the techniques and facilities employed in research at the Univ. of California, Berkeley. Two different testing procedures are being used at Berkeley to study the nonlinear seismic response mechanisms: an earthquake simulator and a variety of controlled load systems making use of hydraulic actuators. Each type of system is discussed briefly; its advantages mentioned; and several examples of the use of each system are discussed. It must be emphasized that the primary purpose of such tests is to obtain response data which can be used in verifying or improving mathematical modeling concepts; they are not specifically intended to demonstrate the adequacy of any given design.

● **6.11-32** Bertero, V. V. *et al.*, **Pseudo-dynamic testing of wall structural systems,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 286–297. (For a full bibliographic citation see Abstract No. 1.2–8.)

The ultimate objective of this investigation is to develop practical methods for the aseismic design of combined frame-wall structural systems. To achieve this objective, integrated analytical and experimental studies have been conducted to determine the actual mechanical behavior of wall systems subjected to earthquake-like excitations.

In this paper emphasis is placed on the discussion of the design, construction, and performance of the testing facility used in the experimental studies. Only those analytical results needed for planning the design of the facility and the experimental program, for checking the facility's performance, and for judging the possible aseismic design implications of the behavior observed in these experiments are briefly discussed.

● **6.11-33** Tsunoda, T., Konoue, N. and Shimaguchi, S., **Large shaking table** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 11,* 1975, 185–189.

A large shaking table has been used for experimental research on the structural dynamics of civil engineering works and building structures since it was installed at the institute in 1967. A description of this table was given as a first report just after its completion. A detailed report of improved specifications resulting from recent repair work is presented, along with a summary of the table's application for research studies during the past nine years; this will be a useful guideline for future utilization of the equipment.

● **6.11-34** Hawkins, N. M., Kobayashi, A. S. and Fourney, M. E., **Use of acoustic emission and holographic techniques to detect debonding in cyclically loaded concrete structures,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 532–540. (For a full bibliographic citation see Abstract No. 1.2–8.)

This paper reports a study of the feasibility of using acoustic emission and holographic interferometry techniques to determine the degree and extent of debonding between a reinforcing bar and the surrounding concrete and the bond strength of a bar surviving a cyclic loading that has stressed it inelastically. Tests were made on ten specimens simulating beam to column connections. Only the results for three typical specimens are discussed; complete details of the investigation are contained in two of the references.

● **6.11-35** Fiorato, A. E. *et al.*, **Highlights of an experimental investigation of the seismic performance of structural walls,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 308–317. (For a full bibliographic citation see Abstract No. 1.2–8.)

Because of the lack of information on the deformation capability of structural walls, a combined experimental and analytical investigation of structural walls was undertaken. The overall objective is to develop design criteria for reinforced concrete structural walls used as lateral bracing in earthquake-resistant buildings. Primary items of interest include the ductility, energy dissipation capacity and strength of structural walls.

The experimental portion of the investigation consists of four parts. In Part I, isolated walls are being investigated. These walls are subjected to reversing in-plane loads. Part II is an investigation of structural wall systems. The systems investigation consists of proof tests of coupled walls and frame-wall structures. In Part III, an investigation of the stress versus strain characteristics of confined concrete is being carried out. Part IV is an investigation of the

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

behavior of coupling beams subjected to reversed loading. This paper describes the highlights of the experimental investigation.

● 6.11-36 Huckelbridge, A. A. and Clough, R. W., **Earthquake simulation tests of a steel frame allowed to uplift,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 318–329. (For a full bibliographic citation see Abstract No. 1.2-8.)

This investigation was conducted to investigate the feasibility of designing more economical structures; i.e., structures without supplementary anchorages to prevent overturning and structures having less strength and ductility requirements. A three-story unbraced single-bay steel frame was tested. For comparative purposes, each test was run twice: once with the base constrained against uplift and again with uplifting allowed.

● 6.11-37 Watanabe, S. *et al.*, **Basic studies on dynamic dampers** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 10,* 1975, 30–34.

The studies are concerned with basic experiments on dynamic dampers to be used for the elimination of the vibration of machine foundations resting on the ground and with corresponding theoretical analyses taking dissipation damping into consideration. The effect of vibration elimination of a dynamic damper is because of the mass and frequency ratios between the damper and the machine foundation and because of the damping factors of the damper and the foundation-soil system. The less the damping factor of the damper, the more effective will it be. In the range of mass ratios experimented with, the maximum effects reached about $1/5 \sim 1/20$ in terms of vibration amplitude. It appears that the dynamic damper will be very useful for reduction of vibration, especially in the case of steady state vibration.

● 6.11-38 Freeman, S. A., **Testing wall panels for earthquake response,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 342–351. (For a full bibliographic citation see Abstract No. 1.2-8.)

As part of the structural response research program being conducted for the Nevada Operations Office of the U.S. Energy Research and Development Admin., a testing program was developed and conducted for the investigation of nonstructural wall panels subjected to racking. The objectives of the testing program were to determine thresholds for damage to partitions due to horizontal adjacent story displacement in high-rise buildings and to gather data that can be used to determine the influence of nonstructural partitions on the structural response of high-rise buildings.

In general, the wall panels were constructed to represent typical partitions used in high-rise building construction. Some of the panels were used for special parameter studies or for comparisons with other test programs. A specially designed testing frame simulated cyclic lateral displacement, parallel to the plane of the wall panels, that might be experienced during the response of a building to strong winds or earthquake motion.

● 6.11-39 Elkamshoshy, F. M. and Ward, M. A., **Development of a simple apparatus for studying multi-storey frame connections,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 363–369. (For a full bibliographic citation see Abstract No. 1.2-8.)

In this paper, multistory frame connections are classified as: interior, exterior, top and corner connections. Testing of these connections under gravity loads, lateral effects and their combinations was the principal design requirement. In addition, special consideration has been given to the following: (i) Column axial load and the difference in beam moment are important parameters in the study of connection behavior under lateral loads and hence the apparatus should be able to apply these loads. (ii) The test setup should occupy a minimum of laboratory space. (iii) The design should utilize a conventional compression machine for applying the column axial load.

● 6.11-40 Ernst, G. C. and Smith, G. M., **Pseudo dynamic and earthquake simulation testing,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 370–379. (For a full bibliographic citation see Abstract No. 1.2-8.)

Laboratory tests that purport to simulate the behavior of structural framing during earthquake or cyclonic wind effects are a very necessary aspect of research concerned with the dynamic response of structures. This paper describes the methods of dynamic simulation testing developed at the Univ. of Nebraska in an effort to obtain a basic understanding of the response of reinforced concrete beam-column framing to the lateral load effects resulting from severe earthquake or wind conditions. In general, the approach to the problem has been that of establishing test specimen proportions reasonably representative of actual framing and adaptable to both two- and three-dimensional testing. With the proportions and specimen size determined by monotonic loading of beams and frames in standard universal testing machines, the development of specialized test equipment and procedures was undertaken. These specialized methods are presented in this paper under the headings: displacement vs. force-seeking, horizontal plane tests, and vertical plane tests.

● 6.11-41 Mogami, T. *et al.*, **Experiments on column joints of precast reinforced concrete frames** (in Japanese), *Reports of the Technical Research Institute, Taisei Corporation, 8,* Nov. 1975, 15–26.

The power grip method is a new method for joining steel bars. The structural problems which might arise when this method is used to join the column members of precast reinforced concrete structures are studied. Tests were conducted on nine specimens which were subjected to earthquake loads. In comparison with monolithic specimens, the specimens with joints performed satisfactorily. As a result, the authors recommend the use of the power grip method in the construction of precast reinforced concrete structures.

● **6.11-42** Saito, T., Yoshizaki, S. and Sugita, K., **Experiments on column-slab joints of flat slab structures** (in Japanese), *Reports of the Technical Research Institute, Taisei Corporation, 8,* Nov. 1975, 103–112.

The purpose of these experiments was to investigate the structural properties of flat slab structures with thick column strips similar to girders in frame structures and with square drop panels, preparing for future prefabrication. Four different types of scale models of approximately 1/2.5 were prepared, which represented column strips (mid-span to mid-span including drop panels and columns). Each sectional area of the column strip of three specimens was almost equal, while the width and the thickness were different. The overall thickness of the drop panels was constant. The authors investigated the effects of dimensions and shapes of column strips and drop panels on the strength, rigidity and mechanism of collapse. The remaining specimen was not provided with a drop panel. When precast members are used, drop panels are considered to be fixed at the top of columns, and to serve as supports for column strip panels. Then column strip panels and columns are wet jointed upon the drop panels, and finally middle strip panels are to be placed. Drop panels might be replaced by steel pieces to fix column strip panels to columns. The specimens prepared for these experiments were monolithically cast. As a conclusion, the authors suggest that flat slab structures with wider column strips and drop panels are better than those with narrower column strips.

● **6.11-43** Yoshizaki, S., Nishigaki, T. and Kanoh, Y., **Experiments on slab-column junctions of flat plate structures under the combinations of lateral and vertical loads** (in Japanese), *Reports of the Technical Research Institute, Taisei Corporation, 8,* Nov. 1975, 113–123.

Experimental investigations were conducted to analyze the behavior of column-slab junctions of flat plate structures on which vertical and horizontal loads are applied simultaneously. Five specimens were prepared, one of which was subjected to a vertical load only. Shearing stress intensity of the critical section due to vertical load, 5 kg/cm^2 was applied to two specimens, and 10 kg/cm^2 to the remaining two specimens; then, the horizontal loads were applied, keeping the shearing stresses due to vertical loads unchanged. The authors studied the crack patterns, load-deflection curve, distribution of bending moments, effects of vertical loads on the ultimate strength, ductility capacity and the mechanism of transferring bending moments from columns to slabs by experiments. This report indicated that the evaluation of torsional moment using the hypothesis adopted in ACI 318-71 is considerably different from the experimental results.

● **6.11-44** Otani, S., **Earthquake tests of shear wall-frame structures to failure,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 298–307. (For a full bibliographic citation see Abstract No. 1.2-8.)

This paper describes the experimental investigation and the findings of an earthquake simulator study of the behavior of multistory reinforced concrete shear wall-frame structures.

● **6.11-45** **Failure tests of full-size connections between cast-in-situ diaphragm walls and structural elements of a building** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 10,* 1975, 35–40.

This report is concerned with an experimental study of wall foundations built by the OWS-Soletanche method. In order to study the strengths of the connections between cast-in-situ diaphragm walls designed as seismic walls and structural elements such as footing beams of a building, full-size models were subjected to shear forces and torsional moments to failure. These connections were constructed by a special method, the "JOF" method, and this is used as a prototype construction method for connections. The report compares the strengths of these full-size connections with the value calculated from an empirical equation deduced from previous model tests.

6.11-46 Fainberg, I. I. and Lure, F. M., **On calculation of stresses in members of bar systems from natural frequencies** (K opredeleniyu usilii v elementakh sterzhnevykh sistem po chastote svobodnykh kolebanii, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 2,* 1976, 64–66.

A new method is presented for the experimental determination of stresses in bars. The method is based on the use of supplementary loads. Compared to the method of test loads, the vibration method outlined here leads to more exact stress values. Testing may be carried out without regard to temporary loads and without interruption of the functioning of the systems.

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

● **6.11-47** Sato, K. *et al.*, **Experimental study on beam-to-column connections using cast steel T-stubs,** *KICT Report No. 23,* Kajima Inst. of Construction Technology, Tokyo, Nov. 1976, 32.

Beam-to-column connections of steel frames require not only sufficient strength but also a simplified connection method. This paper describes the structural aspect of a newly developed connection system which meets these requirements. The system is an improved method of the ordinary high-strength bolted T-stub flange-to-column connections, and its distinctive feature is the use of cast steel attachments called HISPLIT. The thickness of the T-stub flange of HISPLIT is tapered from the stub center to the edges to minimize the prying force induced in bolts.

Three series of load tests using full-scale models were conducted to investigate the jointing efficiency of HISPLIT and the structural behavior of steel beam-to-column connections using HISPLIT. Test results showed that due to the effect of the tapered T-stub flange an increase of about 50% in allowable strength could be expected compared with a usual T-stub connection. The HISPLIT connections were found to have stable restoring force characteristics as a moment-resisting rigid connection, and to possess strength, rigidity and ductility superior to the ordinary site-welded connection.

● **6.11-48** Castoldi, A. and Casirati, M., **Experimental techniques for the dynamic analysis of complex structures,** *74,* Ist. Sperimentale Modelli e Strutture, Bergamo, Italy, Feb. 1976, 16.

The experimental methods for the dynamic analysis of complex structures, both by means of models and in situ tests, are illustrated through the description of the testing techniques and equipment, and the review of some of the most important research carried out at ISMES.

With the use of the most sophisticated techniques available today, in particular as far as the data acquisition and processing systems are concerned, the results obtained from the tests are complete and accurate and reliability is easily controlled.

● **6.11-49** Lee, D. L. N., **Original and repaired reinforced concrete beam-column subassemblages subjected to earthquake type loading,** *UMEE 76R4,* Dept. of Civil Engineering, Univ. of Michigan, Ann Arbor, Apr. 1976, 206.

Eight reinforced concrete exterior beam-column subassemblages were designed using the most recent building code recommendations for either seismic or nonseismic areas in order to represent both types of existing structures. The only difference between the two designs was the amount of transverse reinforcement. The specimens were cast and tested to determine their behavior with special attention being focused on the beam-to-column joint. During testing, the specimens were subjected to a loading which simulated the type of motions that could be expected during either a moderate or a severe earthquake to obtain different degrees of damage.

The damaged specimens were repaired using either of two repair techniques depending on the degree of damage. For the moderately damaged specimens, the pressure injection of epoxy was used. The removal of the damaged material and replacement with various high early strength materials was used to repair more severely damaged specimens. The specimens were retested in the same manner as the original test to determine the behavior of the repaired specimens and to compare this behavior with the original behavior.

Based on this investigation, two principal conclusions were made: (1) epoxy injection and removal and replacement techniques of repair can effectively restore structural integrity to damaged members, and (2) the original specimens showed that the concrete in the beam-to-column joint can resist twice the shear force allowed by the ACI 318-71 Building Code.

● **6.11-50** Aristizabal-Ochoa, J. D. and Sozen, M. A., **Behavior of ten-story reinforced concrete walls subjected to earthquake motions,** *UILU-ENG-76-2017, Structural Research Series No. 431,* Univ. of Illinois, Urbana, Oct. 1976, 378.

Tall reinforced concrete structures resist lateral forces as frames (shear beams) or as cantilevers (flexure beams). The tests discussed in this report were designed to investigate the earthquake response of reinforced concrete systems resisting lateral forces primarily in the flexure-beam mode. The small-scale test structures represented slender walls coupled by beams. A secondary but important objective of the experimental program was to demonstrate the consequences of flexural yielding in the wall prior to yielding of the beams.

Studies of the experimental data were made with a view to the development of procedures to determine design forces using modified linear response models.

● **6.11-51** Islam, S. and Park, R., **Tests on slab-column connections with shear and unbalanced flexure,** *Journal of the Structural Division, ASCE,* **102,** *ST3,* Proc. Paper 11972, Mar. 1976, 549–568.

Tests were conducted on eight 1/2-scale models of reinforced concrete interior flat plate-column connections transferring shear and unbalanced moment from gravity and simulated seismic loading. The slab at the connection contained either no shear reinforcement or shear reinforcement in the form of either cranked bars, structural steel

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

shearhead or closed vertical stirrups. The simulated seismic loading was statically applied, either monotonically or cyclically in the inelastic range. The strength and ductility of the connections and the modes of failure were compared. The connections without shear reinforcement failed suddenly in diagonal tension. The use of cranked bars as shear reinforcement increased the strength of the connection but did not increase the ductility. The use of a structural steel shearhead resulted in an increase in strength and in a limited increase in ductility. The use of closed vertical stirrups around the slab bars, which passed through the column, resulted in an increase in the strength and in a substantial increase in the ductility of the connection.

● **6.11-52** Ghali, A., Elmasri, M. Z. and Dilger, W., **Punching of flat plates under static and dynamic horizontal forces,** *Journal of the American Concrete Institute,* **73,** *10,* Title No. 73-47, Oct. 1976, 566–572.

The results of a laboratory investigation on the strength and deformation of flat slab floors at their connection with columns when subjected to static or dynamic horizontal forces are presented. Six full-scale specimens of a slab-column connection were subjected to a constant axial force representing gravity load, and a varying static and dynamic moment transferred between the column and the slab. The amount of the flexure reinforcement in the slab was variable. No shear reinforcement was provided.

Results indicate higher strength and higher energy absorption capacities of the slab in the dynamic tests. The increase in bending reinforcement in both the static and dynamic tests resulted in an increase in strength, but with an important decrease in the energy absorption capacity and the ductility. These two properties are important requirements, particularly for structures designed to resist dynamic loads, such as blast waves or earthquakes.

● **6.11-53** Kahn, L. F., **Reinforced concrete infilled shear walls for aseismic strengthening,** *UMEE 76R1,* Dept. of Civil Engineering, Univ. of Michigan, Ann Arbor, Jan. 1976, 352.

Five half-sized reinforced concrete frames were constructed and tested to determine experimentally the effectiveness of infilled walls in strengthening existing framed structures against earthquake loads. The one-story, one-bay frames which measured 66 in. by 108 in. were tested under static, reversed cycle loads. One specimen was the unstrengthened open frame; the second used a wall cast monolithically with the frame; the third used a wall cast-in-place after the frame was constructed; the fourth used a single precast panel fitted within the frame and mechanically connected to top and bottom beams; and the fifth used a wall made of six small precast panels which were mechanically connected within the frame and then joined together.

Three general conclusions were that cast-in-place walls can provide the same maximum strength as an equivalent, new monolithic wall but with less ductility, that multiple precast panels provide a strong, ductile and easy-to-construct strengthening technique, and that the cyclically degraded load capacity of shear walls should be used in the structural design rather than the virgin, monotonic capacity.

● **6.11-54** Muto, K. *et al.*, **One dimensional vibration test and simulation analysis for HTGR core,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 8/8, 10. (For a full bibliographic citation see Abstract No. 1.2-11.)

The highlight of this paper is to describe the seismic model test of the hexagonal graphite blocks of the General Atomic Co. HTGR core. A straight array across the core was selected as the object of the study. The purposes are to clarify the seismic behavior of the graphite blocks by experiments and to establish the method of computer analyses by feeding back the test results into computer codes.

● **6.11-55** Corazao S. R., M. and Blondet S., M., **Experimental study of the structural behavior of adobe buildings to seismic loads** (Estudio experimental del comportamiento estructural de las construcciones de adobe frente a solicitaciones sismicas, in Spanish), Banco Peruano de los Constructores [Lima], 1973, 55.

● **6.11-56** Clough, R. W. *et al.*, **Experimental study of structural response to earthquakes,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 4/2, 11. (For a full bibliographic citation see Abstract No. 1.2-11.)

The purpose of this paper is to describe the objectives, methods, and some of the principal results obtained from experimental studies of the behavior of structures subjected to earthquakes. Although such investigations are being conducted in many laboratories throughout the world, the information presented here deals specifically with projects being carried out at the Earthquake Engineering Research Center (EERC) of the Univ. of California, Berkeley. A primary purpose of these investigations is to obtain detailed information on the inelastic response mechanisms in typical structural systems so that the experimentally observed performance can be compared with computer-generated analytical predictions. Only by such comparisons can the mathematical models used in dynamic nonlinear analyses be verified and improved.

Two experimental procedures for investigating earthquake structural response are discussed: (1) the earthquake simulator facility which subjects the base of the test structure to acceleration histories similar to those recorded in actual earthquakes, and (2) systems of hydraulic rams which impose specified displacement histories on the test components, equivalent to motions developed in structures subjected to actual earthquakes. The general concept and performance of the 20 ft square EERC earthquake simulator is described, and the testing of a two-story concrete frame building is outlined. Correlation of the experimental results with analytical predictions demonstrates that satisfactory agreement can be obtained only if the mathematical model incorporates a stiffness deterioration mechanism which simulates the cracking and other damage suffered by the structure. Several test facilities, based on servo-controlled hydraulic actuators, that have been developed for testing a variety of structural components are discussed. Tests of two types of components, a spandrel-wall-girder column assemblage and a three-story shear-wall floor-slab system are selected for detailed discussion. Correlation of the results of these tests with analytical predictions has not yet been completed, so the validity of current modeling procedures for such components cannot be verified.

The principal conclusions to be drawn from these investigations is that the current state-of-the-art ability to predict nonlinear earthquake response, particularly of reinforced concrete structures, is limited by insufficient knowledge of the actual seismic behavior. Additional experiments will be required to improve the mathematical idealizations employed in performing such analyses.

● **6.11-57** Popov, E. P., Stephen, R. M. and Philbrick, R., **Capacity of columns with splice imperfections,** *EERC 76-21,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Sept. 1976, 61. (NTIS Accession No. PB 260 378)

The milled or cut surfaces at column splices as a general rule do not make a perfect full and even contact. Recognizing this fact, the AISC Code of Standard Practice accepts a maximum gap of 1/16 in. at the faying surfaces. Data on the behavior of such imperfectly spliced columns are very limited. Therefore, in this investigation the behavior of two W 14x176 columns with the currently allowed 1/16 in. gaps at the splices and two similar columns with 1/4 in. gaps and shims inserted in accordance with the AISC Quality Criteria and Inspection Standards were compared with the behavior of an unspliced column of the same size. Four of the columns were 14 ft 8 in. long; one was 10 ft long. The results showed that the lack of perfect contact at the compression splices of these stubby columns is not serious, provided that the gaps are carefully shimmed and welding is used to maintain sections in alignment. In these tests minimum partial penetration welds only along the flanges were used. The KL/r ratio for the columns tested was approximately 30. Therefore, considerable caution must be exercised in extending the results to the columns having high slenderness ratios.

After completion of the compression tests the specimens were tested in tension. Since only minimum partial penetration welds along the flanges were provided at the splices, all failures occurred through the welds. Some observed lack of uniformity of the weld size suggests the need for a visual inspection of such welds if the members are designed to transmit tensile forces. Tensile tests of these full-size specimens provide data on the behavior of such members for aseismic design. Complete load-deflection diagrams are included in the report. No such data appear to be readily available elsewhere.

● **6.11-58** Williams, D. and Godden, W. G., **Experimental model studies on the seismic response of high curved overcrossings,** *EERC 76-18,* Earthquake Engineering Research Center, Univ. of California, Berkeley, June 1976, 163. (NTIS Accession No. PB 269 548)

An experimental model study relating to the seismic resistance of large multispan curved overcrossings of the type which suffered heavy damage during the 1971 San Fernando earthquake is reported. This report is the fourth in a series to result from the project, "An Investigation of the Effectiveness of Existing Bridge Design Methodology in Providing Adequate Structural Resistance to Seismic Disturbances." The feasibility of developing a model to satisfy the necessary similitude requirements of such a complex structure, and also capable of being tested on the 20 ft x 20 ft (6.1 m) shaking table at the Univ. of California, is outlined. The small amplitude dynamic characteristics of the microconcrete model, a 1/30 true-scale version of a hypothetical prototype, are examined and for this elastic range the experimental results compared satisfactorily with those predicted analytically.

The response of the model is described for a series of progressively more intense simulated seismic excitations applied (i) horizontally in the asymmetric longitudinal direction, and (ii) horizontally in the symmetric direction, both alone and also with simultaneous vertical excitation.

The existence of expansion joints in the bridge deck proved to have great influence on the response of the structure. Despite the inclusion of strong ductile restrainers across these joints, they were subjected to severe damage caused by multiple impacting in both torsional and translational modes. Some recommendations concerning this design are made.

● **6.11-59** Mayes, R. L., Omote, Y. and Clough, R. W., **Cyclic shear tests of masonry piers, Volume I - Test results,** *EERC 76-8,* Earthquake Engineering Research Center, Univ. of California, Berkeley, May 1976, 105. (NTIS Accession No. PB 264 424)

This report presents the results of cyclic in-plane shear tests on a variety of fixed ended masonry piers. The test set-

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

up is designed to simulate, insofar as possible, the boundary conditions the piers would experience in a perforated shear wall of a complete building. Each test specimen was a full-scale panel about 15 ft square consisting of two piers and a top and bottom spandrel. The panels were constructed from 6 in. wide x 8 in. high x 16 in. long hollow concrete block units. The variables included in the investigation were the quantity and distribution of reinforcement including joint reinforcement, the rate of load application, partial grouting and the vertical bearing stress.

The results are presented in the form of hysteresis envelopes, graphs of stiffness degradation properties and tabulated data on the ultimate strength and ductility indicators. Part II of this report, EERC Report No. 76-16, provides a comparison of the results obtained from the double-pier tests with those obtained from a simple diagonal test and with other investigations, as well as a correlation of the test results with theoretically predicted results and comments on the design implications of the test results.

6.11-60 Malyshev, L. K., **Investigations of the earthquake resistance of hydraulic structures on small scale models** (Issledovaniya seismostoikosti gidrosooruzhenii na malomasshtabnykh modelyakh, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh*, 88-93. (For a full bibliographic citation see Abstract No. 1.1-7.)

A technique developed at the Vedeneev Research Inst. for small-scale modeling and experimental investigations of the behavior of tall dams subjected to seismic excitations is presented. This technique combines methods of polarized optics and interferometry and holographic electroacoustical interferometry is utilized to establish the natural frequencies and mode shapes of dams. The experimental tools described were used to solve a series of problems involving the earthquake resistance of hydraulic structures, e.g., earthquake response of canyon walls and massive hydraulic structures, including the dams of the Inguri and Sayan-Sushen hydroelectric power plants.

6.11-61 Airapetyan, B. M., Askov, V. L. and Slovesnyi, B. V., **Experimental model investigations of the earthquake resistance of the piping of the inner perimeter of the Armenian nuclear power plant** (Eksperimentalnye issledovaniya na modeli seismostoikosti truboprovodov pervogo kontura Armyanskoi AES, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh*, 115-117. (For a full bibliographic citation see Abstract No. 1.1-7.)

Methods and results of experimental investigations of the response of the inner perimeter piping of the Armenian nuclear power plant are presented. A 1:12 scale model was used to investigate the behavior of the pipe network with or without hydraulic damping.

6.11-62 Panteleev, A. A., **Application of holographic interferometry for investigations of natural frequencies and mode shapes of hydraulic structures** (Iz opyta primeneniya golograficheskoi interferometrii k issledovaniyu form i chastot sobstvennykh kolebanii gidrosooruzhenii, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh*, 104-108. (For a full bibliographic citation see Abstract No. 1.1-7.)

The applications of the simplest variant of holographic interferometry (the averaged hologram exposure method) are illustrated using small-scale models of several hydraulic structures. This technique is used to investigate natural frequencies and mode shapes of vibrations of hydraulic structures of various degrees of complexity.

● **6.11-63** Muto, K. *et al.*, **One dimensional vibration test and simulation analysis for HTGR core** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 227, 759-766. (For a full bibliographic citation see Abstract No. 1.2-9.)

● **6.11-64** Tamura, C. and Morichi, S., **Dynamic stress analysis with model made of gelatin gel** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 255, 983-990. (For a full bibliographic citation see Abstract No. 1.2-9.)

In examination of the earthquake resistance of a structure, it is important to have information on the dynamic stress distribution in the structure. Model experimentation is often used for this purpose. Usually dynamic model analysis is more difficult for massive structures than for flexible structures because of the high natural frequency and the high rigidity of a massive model. Gelatin gel has a very low velocity of propagation of S-wave (2-3 m/sec), and extremely high photoelastic sensitivity. Thus, gelatin gel is useful as a material for the photoelastic analysis of massive structures.

In this report, the use of gelatin gel for dynamic photoelastic analysis is demonstrated by some applications. The gel is used to inspect the dynamic stress distribution around an opening in a soft layer over a rigid ground. The experimental results are examined theoretically.

● **6.11-65** Hisada, T. *et al.*, **The bi-axial shaking table and its dynamic characteristics** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 258, 1007-1014. (For a full bibliographic citation see Abstract No. 1.2-9.)

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

A shaking table with plan dimensions of 4 x 4 m has been constructed at the Kajima Inst. of Construction Technology, Chofu, Tokyo. The table has the following characteristics: (1) It has one horizontal and the vertical degrees-of-freedom. (2) It is made of welded and bolted aluminum plates. (3) The system can test specimens weighing up to 20 tons. The horizontal actuators can accelerate the table up to 1.2 g, and the vertical actuators, up to 2 g. (4) The stroke of the actuators are ± 15 cm for the horizontal direction and ± 7.5 cm for the vertical. However, the horizontal actuators are limited to displacements of ± 13.5 cm in order to improve the resolution of table motion. (5) The measurement system includes accelerometers, dynamic strain meters and displacement meters, and can simultaneously record 80 channels from the sensors. A minicomputer is used to analyze the data which are acquired during and after a test.

Tests with no load and with 20 tons load were performed using sinusoidal waves, and the dynamic characteristics of the system were investigated. In the case of a test using a compensated command signal, the response of the table followed the command signal with sufficient accuracy.

● **6.11-66** Matsuzaki, A., Hirai, H. and Kumagai, H., **Development of earthquake simulator (Part 2. Acceleration control type earthquake simulator)** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 257, 999–1006. (For a full bibliographic citation see Abstract No. 1.2-9.)

Since earthquakes are usually recorded with acceleration wave-forms, reproduction of the recorded accelerations with a shaking table is an important problem in earthquake simulation tests. Some displacement-control-type earthquake simulators have already been put to practical use for earthquake simulation tests. But, even a small distortion of table displacement causes a large distortion to table acceleration. Therefore, it is very difficult to reproduce the recorded acceleration with a shaking table. In this paper, one method for realizing acceleration control is discussed. It is shown that an acceleration control system with good stability, fast response, and no displacement drift can be obtained by adding displacement, velocity, and acceleration input signals simultaneously at a proper rate as well as by adding their feedback signals. This method is confirmed by experimental results obtained using a shaking table weighing one ton.

● **6.11-67** Matsuzaki, A., Hirai, H. and Yoneda, T., **Development of earthquake simulator (Part 1. Effects of test structure and their compensation method)** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 256, 991–998. (For a full bibliographic citation see Abstract No. 1.2-9.)

The increased size of structural models used recently for earthquake simulator tests have had serious effects on the control characteristics of simulators.

When a test structure with a large mass is mounted on a shaking table, the motion of the simulator tends to be oscillatory. A readjustment of the feedback gain of a control system is required whenever the load mass is varied. This paper clarifies the relation between load mass and optimum feedback gain of a control system and shows how feedback gain can be adjusted automatically.

An additional problem encountered is that most test structures are generally poorly damped and have some resonant frequencies. In an earthquake simulation test, it is important to examine the response of the test structures in the vicinity of their resonant frequencies. However, when an oscillatory structure is tested in the vicinity of its resonant frequency, the motion of the shaking table is disturbed by a reaction force from the test structure. A theoretical method for compensating for this phenomenon is presented. Some experimental results are shown to verify the validity of the method and practical applications of the method are discussed.

● **6.11-68** Suzuki, K. and Sato, H., **A study on the multi-dimensional spectral analysis for response of a piping model with two-seismic inputs,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 7/1, 12. (For a full bibliographic citation see Abstract No. 1.2-11.)

A medium-scale model of a piping system subjected to two seismic inputs was studied using a multidimensional power spectrum analysis. The system was attached to a three-story concrete structural model, which was excited by earthquake motions on a shaking table. The inputs to the piping system were recorded at the second floor and at the ceiling of the third floor where the system was attached to the structural model. The power spectrum method proved to be reliable for identifying the vibration characteristics of the multi-input structural system.

6.12 Deterministic Methods of Dynamic Analysis

● **6.12-1** Arvidsson, K., **Non-uniform shear wall-frame systems with elastic foundations,** *Proceedings, The Institution of Civil Engineers,* 59, Paper 7778, Mar. 1975, 139–148.

A practical method is presented for lateral load analysis of interacting shear walls and frames of variable stiffness. The method is based on the continuous theory of shear wall-frame systems. The structure is divided into a number of uniform elements. The solution to the problem

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

is then obtained by a simplified iteration procedure. Secondary design effects, such as shear deformations, column shortening in the frame and elastic foundation conditions, are considered for the system. Two examples are analyzed by the proposed method and by a discrete frame analysis to illustrate the accuracy of the method.

● **6.12-2** Bayulke, N., **Evaluation of response of a structural system to an earthquake ground motion by using the modal superposition method** (Yapilara gelen maksimum deprem etkilerinin "mod superpozisyonu" metodu ile hesaplanmasi, in Turkish), *Deprem Arastirma Enstitusu Bulteni*, **2**, *6*, July 1974, 91–112.

The equation of motion of an n-degree-of-freedom system is formulated, and the solution of the equation by modal superposition is explained. The maximum response of the system with respect to an earthquake ground motion using the response spectra is developed. A numerical example is also given using the method.

● **6.12-3** Citipitioglu, E. and Celebi, M., **An approximate method for analysis of multistory structures subjected to horizontal loads** (Cok katli perdeli yapilarin yatay yuklere gore yaklasik hesap metodu, in Turkish), *Deprem Arastirma Enstitusu Bulteni*, **2**, *7*, Oct. 1974, 31–40.

An approximate method of lateral load analysis for shear wall systems is presented. The method makes use of computer solutions of shear wall systems for which a set of orthogonal axes can be defined. The procedure is dependent on the possibility of the shear wall system being separated into planar frames. The compatibility of the uppermost floor displacement is used to divide the lateral load in one direction among the frames in the same direction. Shear center is defined, and in case of torsion, distribution of torsional moments is approximated.

● **6.12-4** Chowdhury, P. C., **An alternative to the normal mode method**, *Computers and Structures*, **5**, *5/6*, Dec. 1975, p. 315.

The Lanczos vector method is proposed as an alternative to the normal mode method. The advantage in using Lanczos vectors is that they make far less demands on computer storage and computer time. The disadvantage of using these vectors is that they accomplish only a partial decoupling of the equations of motion where the normal modes achieve complete decoupling. All of the limitations (e.g., linearity) of the normal mode method also apply to the Lanczos method.

● **6.12-5** Alarcon C., J. A. *et al.*, **Stress analysis of structure by computer with dynamic option**, *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering*, **11**, 1975, 106–146.

Described are two computer programs (FRAME 1 and FRAME 2) which can be used for the stress analysis of structures subjected to horizontal and vertical loads. Included in this paper are descriptions of the purpose of the programs, the theoretical methods used, the program block charts, the user's manual and an example application.

● **6.12-6** Quispe S., A. E., San Bartolome R., A. F. and Zedeno C., J. C., **Dynamic analysis for lumped mass systems using the computer program**, *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering*, **11**, 1975, 147–170.

A program which can be used for the dynamic analysis of lumped mass systems is described. Initially, this program was prepared to be used on an IBM 360/195 computer. To enable the program to be run on the computer of the International Inst. of Seismology and Earthquake Engineering, an overlay technique was used. After conversion of the program in this way, some examples that were calculated using the IBM computer were compared with examples calculated using the smaller computer, with the same results obtained.

The program described in this paper can be used alone if all of the necessary data are given, or it can be used in conjunction with FRAME 1 and FRAME 2 when the stiffness matrix of general structures is needed as data.

The theoretical methods used in the program are explained in Section I; the block chart of the program and the overlay diagram are shown in Section II; the user's manual and the explanation of the input data are treated in Section III.

● **6.12-7** Buch, D. T., **Dynamic analysis of a gravity dam profile including observations on its dynamic behaviour**, *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering*, **11**, 1975, 171–191.

Dams with heights exceeding 100 m represent special earthquake design hazards. The gravity dam profile of the Tagokura Dam in Japan is studied. The dynamic analysis is performed considering the dam as a nonuniform cantilever beam after incorporating the effects of shear deflection and rotary inertia. The results of the dynamic analysis are compared with the observational behavior available for this dam. The method presented is a simple and accurate method which can be used with or without the use of a computer.

● **6.12-8** Nishikawa, T., Batts, M. E. and Hanson, R. D., **Nonlinear building response by the characteristics method**, *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering*

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

with Emphasis on the Safety of School Buildings, 310–332. (For a full bibliographic citation see Abstract No. 1.2–2.)

The characteristics method partially accounts for stiffness interaction but does not include the flexural behavior of the structure. The structure is treated as a continuous shear beam with distributed mass coupled in two ways with a lumped mass bending beam. The resulting hyperbolic partial differential equations for the shear beam are solved by the method of characteristics. In this paper, results of the characteristics method solution for two different structures will be compared with the results of a member-by-member nonlinear analysis using DRAIN-2D and a special purpose computer program.

● **6.12-9** Cook, R. D., **Review of selected topics in finite element analysis,** *Methods of Structural Analysis,* Vol. I, 535–548. (For a full bibliographic citation see Abstract No. 1.2–3.)

The following topics are discussed: tests of element quality, avoiding computational failures caused by defects in elements, the quadratic isoparametric element and its modified forms, an improved mass matrix for dynamic problems, and taking advantage of symmetry and repetition in structural form. The author believes that wider appreciation of these concepts would lead to more effective and economical finite element analyses.

● **6.12-10** Tseng, G. *et al.,* **Elastic and elasto-plastic computerized dynamic analysis of frame structures subjected to blast overpressure,** *Methods of Structural Analysis,* Vol. II, 977–995. (For a full bibliographic citation see Abstract No. 1.2–3.)

DYNFA (Dynamic Inelastic Frame Analysis), a computer program developed to obtain the response of general types of frame structures subjected to arbitrary blast loads, is described. The program can be used to determine the overall motions of a building as well as local displacements of the frame components. Although DYNFA was developed primarily for use in structural steel frame buildings, it can also be used for the analysis of reinforced concrete frame structures. Selected numerical results for two frame structures are presented.

● **6.12-11** Rosenblueth, E., **The six components of earthquakes,** *Proceedings of the Australian and New Zealand Conference on the Planning and Design of Tall Buildings,* 63–81. (For a full bibliographic citation see Abstract No. 1.2–1.)

This paper deals with the effects of translational and rotational components of earthquakes, treating the base of a structure as a rigid body. Only relatively firm ground is examined. Soil-structure interaction is disregarded; and, for the most part, buildings are treated as uniform shear beams within the range of linear behavior.

● **6.12-12** Naumovski, N. and Petrovski, D., **Earthquake response of continuous media using dynamic relaxation,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 24, 5. (For a full bibliographic citation see Abstract No. 1.2–6.)

This paper presents and elaborates upon the use of the dynamic relaxation method to analyze the linear earthquake response of continuous media. Generally, the method is used numerically to solve a differential equation, or a system of differential equations of higher order, by application of a special technique of central finite differences. The main characteristic of the method is that the differential equation which should be solved is transformed to a damped wave equation adding damping and inertia terms. The wave equation solution can be made by its expanding into a system of simpler differential equations and by expressing these equations further in the form of central finite differences. The evaluation of the mesh for variables takes into consideration the initial and boundary conditions. The evaluating points are alternatively placed in time and space. The variables are defined by an iterative approach where the convergency depends upon the damping coefficient.

The above procedure refers to the application of the dynamic relaxation method to static problems. However, in dynamic problems the boundary conditions vary in time and disable the relaxation. In this paper, the authors use the same technique which is applied to static problems with the exception of boundary conditions.

● **6.12-13** Celebi, M. and Citipitioglu, E., **An approximate method of lateral load analysis for multi-story shear wall structures,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 77, 9. (For a full bibliographic citation see Abstract No. 1.2–6.)

Application of exact methods of elastic analysis to shear wall structures still remains academic due to the amount of input data and the large number of equations involved. Consequently, approximate methods appear to be the only tools available to design engineers.

The method presented in this paper is applicable to multistory shear wall structures whose shear walls are parallel to a set of orthogonal axes. The structure is divided into an appropriate number of planar shear wall frames in each principal direction. Each planar shear wall frame is then analyzed for lateral loads following the pattern of the lateral load acting on the whole structure by using a computer program developed for planar shear wall frames. Once the solution of each assumed planar frame is obtained, then the compatibility of the uppermost story

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

displacements is used to determine the lateral load distribution factors for each frame.

● **6.12-14** Santhakumar, A. R., **Analysis of non-uniform coupled shear walls with two rows of openings,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1249–1262. (For a full bibliographic citation see Abstract No. 1.2–7.)

The finite difference method is applied to the solution of coupled shear walls with two or more rows of openings in which properties of beams and walls may vary with height. The method would be useful in analyzing shear walls with different boundary conditions, flexible beam wall joints and different patterns of equivalent lateral loads associated with seismic-resistant shear wall design. The order of errors introduced in static design quantities is less than 5% for normal coupled shear walls in which the number of stories is more than six.

6.12-15 Zienkiewicz, O. C., Brotton, D. M. and Morgan, L., **A finite element primer for structural engineering,** *The Structural Engineer,* **54,** *10,* Oct. 1976, 387–397.

The purpose of this short paper is to describe in a simple way the operation of the finite element method and to indicate the principles involved. This has been approached by a description of the general processes of structural analysis by the stiffness method using simple matrices when their use is advantageous. The finite element method is presented as an approximation in which a continuum is replaced by a number of discrete elements and an indication is given as to how the engineer can satisfy himself as to the accuracy of his results. It has not been possible to discuss the suitability of types of elements for particular purposes but details of some of the commonly used elements with appropriate references and comments have been given. Reference has also been made to the use of the infinite element applications of computers.

● **6.12-16** Hadjian, A. H. and Atalik, T. S., **Discrete modeling of symmetric box-type structures,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1151–1164. (For a full bibliographic citation see Abstract No. 1.2–7.)

The dynamic modeling of box-type structures with simple lumped mass models is evaluated. Shear deformations, rotatory inertia and shear lag effects are important contributions to the overall response, depending on the characteristics of the structure. A simplified procedure is described to routinely incorporate these effects. The effects of shear deformation and rotatory inertia effects on the mass properties of the structure are accounted for by heuristically reducing the consistent mass matrix of a beam element into a diagonal form. These effects are then isolated and checked against the analytical solutions with acceptable results. The incorporation of shear lag effects is approached from a static point of view. Based on a bending theory developed by Reisner, the stiffness of the beam is modified so that the use of the elementary bending theory would correctly predict deflections of beams with significant shear lag effects. The effect of shear lag on the inertial properties is investigated in only a few test cases. The procedure developed is tested by comparing the results with those from a finite element model of a structure the properties of which were intentionally selected to accentuate those under investigation.

● **6.12-17** Celebi, M., **On the shear pinched hysteresis loops,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1195–1205. (For a full bibliographic citation see Abstract No. 1.2–7.)

The dependence of shear pinching on high nominal shear stresses acting on critical regions of reinforced concrete beams is discussed. Samples of shear pinched hysteresis loops are presented. The shear pinching phenomenon is discussed in terms of energy absorption and instantaneous stiffness. The representation of shear pinched hysteresis loops with mathematical models is reviewed. The existing model is compared with a new model based on a Ramberg-Osgood curve.

● **6.12-18** Meyer, K. J. and Oppenheim, I. J., **Torsional response at large eccentricities,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 541–549. (For a full bibliographic citation see Abstract No. 1.2–7.)

The induced torsional response of a one-story structure was studied. The authors proposed and tested a simplified analytical technique. The technique properly recreated the periodicity of the torsional motion, but was disappointing in not accurately predicting the peak response. Examination of these somewhat "negative" results still revealed some interesting patterns of behavior. The main positive results are an extension of some well-known earlier work, and an insight into probable response at large eccentricities.

● **6.12-19** Teraszkiewicz, J. S., **Seismic dynamic parametric study on finite element model of nuclear power plant facility,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 945–959. (For a full bibliographic citation see Abstract No. 1.2–7.)

This paper presents the steps taken to establish a finite element model for the seismic dynamic analysis of a nuclear power plant facility embedded 72 ft in a sandstone site. A parametric study was undertaken to establish the extent of the rock to be included in the model, as well as

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

the distribution and number of dynamic degrees-of-freedom.

● **6.12-20** Lin, Y. J. and Hadjian, A. H., **Discrete modeling of containment structures,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 899–912. (For a full bibliographic citation see Abstract No. 1.2–7.)

In practice the dynamic response of nuclear power plant containment structures is generally obtained by modeling the structures as either a lumped mass or a finite element model. The choice of model depends on the object of the analysis. This paper investigates the validity of the choice of a model to represent the actual shell structure. Cylindrical, hemispherical and containment vessel shapes are considered. The criteria for a minimum number of nodal points is also determined for both methods of analysis. Treating the containment structure as a hollow cantilever beam of a length measured to the top of the dome, the Timoshenko beam equation predicts the structure frequencies with reasonable accuracy for a beam type mode ($n = 1$) up to the 3rd mode, while the bar theory predicts the fundamental frequency of the axisymmetric mode ($n = 0$) with equally acceptable accuracy. The simplicity of this approach is highly recommended since standard published curves and simple equations may be used as a means for a reliable prediction of containment natural frequencies.

● **6.12-21** Gould, P. L., Sen, S. K. and Suryoutomo, H., **Seismic analysis of hyperbolic cooling towers by the response spectrum method,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 987–1005. (For a full bibliographic citation see Abstract No. 1.2–7.)

A free vibration finite element analysis for rotational shells is developed and applied to the seismic analysis of hyperbolic cooling towers. In the numerical studies, particular attention is drawn to the influence of the system of supporting columns on the dynamic stresses and deformations.

● **6.12-22** Morris, N. F., **Dynamic analysis of elastic-plastic space frames,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 285–298. (For a full bibliographic citation see Abstract No. 1.2–7.)

A method is presented for the nonlinear dynamic analysis of three-dimensional space structures stressed into the elastic-plastic range. The procedure is an extension and modification of previously published static analyses. These modifications take place in the description of the stiffness matrix and in the interaction equations required for three-dimensional elastic-plastic flow. The modal superposition method is used to reduce the order of the nonlinear dynamic equations to a more manageable form.

● **6.12-23** Kounadis, A. N., **Dynamic response of cantilever beam - columns with attached masses supported on a flexible foundation,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 305–314. (For a full bibliographic citation see Abstract No. 1.2–7.)

In this paper, the dynamic response of steel multistory buildings with a concrete core, supported on a flexible foundation and subjected to an arbitrary dynamic force or to a horizontal movement of the ground induced by an earthquake, is established by analyzing an equivalent continuous model. This model consists of a cantilever with translational and rotational springs at its support, carrying n concentrated masses at the floor levels. The influence of the rotatory inertia of the masses as well as of an initial constant compressive force acting at the free end of the cantilever is also included. The free and forced motion of the model is investigated, using generalized functions.

It is found that: (a) the effect of the translational spring on the eigenfrequencies of the first three modes is considerably higher than that of the rotational spring; (b) the effect of the translational and the rotatory inertia of the mass of the foundation on the frequency of the fundamental mode is appreciable.

● **6.12-24** Goldberg, J. E., **A new method for numerical integration of equations of motion,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 413–422. (For a full bibliographic citation see Abstract No. 1.2–7.)

The purpose of this presentation is to describe, in the context of earthquake engineering problems, a new method for numerical integration of differential equations. The new method appears to have certain advantages over some of the methods that are currently in use.

6.12-25 Wahed, I. F. A. and Bishop, R. E. D., **On the equations governing the free and forced vibrations of a general non-conservative system,** *The Journal of Mechanical Engineering Science,* **18,** *1,* Feb. 1976, 6–10.

An expression is derived for the steady forced response of a system. The theory is an adaptation and exploration of previous work by Woodcock. His studies were published in the Hamiltonian form, while in the present paper, the Lagrange approach is used.

6.12-26 Mahalingam, S., **Dynamic characteristics of a structure with modifications at its supports,** *The Journal of Mechanical Engineering Science,* **18,** *3,* June 1976, 113–120.

The paper is concerned with the free and forced vibrations of an undamped system in which rigid supports are removed or replaced by new subsystems. Since the modifications involve the constraints of the system, special techniques based on the receptances and transfer ratios associated with displacement excitation at a support are employed. The results are formulated in the modal parameters of the whole of the original unmodified system and any added subsystems; the characteristics of the removed subsystem play no part in the solution. Starting with the problem of the removal of one or more rigid supports, the analysis is extended to modifications of a greater complexity at the supports.

6.12-27 Nikolaenko, N. A., Bagmanyan, A. L. and Ulyanov, S. V., **Analog computer applications in problems of vibrating non-linear and parametric systems subjected to dynamic excitations** (Ispolzovanie AVM v zadachakh kolebanii nelineinykh i parametricheskikh sistem pri dinamicheskikh vozdeistviyakh, in Russian), *Trudy TsNII stroitelnykh konstruktsii, 44,* 1975, 4–29.

Current problems in earthquake engineering involving sample trajectories of nonlinear and parametric systems subjected to dynamic excitations are investigated using analog computers. A method is developed for constructing dynamic memories with running phase coordinates. Accumulation of excitations and the problem of finding the worst kind of excitation for the class of dynamic systems under consideration are considered. The motions of systems with variable structure (e.g., systems with disengaging joints, elastoplastic and combined systems) are analyzed in the cases of determinate or random dynamic excitations. The results of this analysis are used to evaluate the adaptability and feasibility of the models considered.

6.12-28 Chikovani, N. S., **Calculations of earthquake resistance of cable networks using the finite difference method** (Opredelenie seismostoikosti vantovykh pokrytii metodom konechnykh raznostei, in Russian), *IX obedinennaya sessiya nauchnoissledovatelskikh institutov zakaukazskikh respublik po stroitelstvu,* Aiastan, Erevan, Vol. 1, 1975, 107–109.

Natural frequencies and mode shapes as well as forced vibration amplitudes of cable networks are calculated. Finite difference methods are employed. The fundamental recurrence formulas for displacements along one of the axes of an orthogonal cable network of arbitrary shape and contour are derived. Variations in curvature during the deformation process are calculated using the z-coordinate of the initial shape and normal displacements.

● **6.12-29** Hinton, E., Rock, T. and Zienkiewicz, O. C., **A note on mass lumping and related processes in the finite element method**, *Earthquake Engineering and Structural Dynamics,* **4,** *3,* Jan.-Mar. 1976, 245–249.

The general problem of mass lumping and related processes in the finite element method are discussed. A mass lumping scheme is presented for parabolic isoparametric elements. Examples are presented to show the good accuracy which can be obtained in linear and nonlinear dynamic problems using the scheme.

● **6.12-30** Beredugo, Y. O., **Modal analysis of coupled motion of horizontally excited embedded footings**, *Earthquake Engineering and Structural Dynamics,* **4,** *4,* Apr.-June 1976, 403–410.

A modal analysis formulation of the equations of motion of horizontally excited embedded footings is presented. Numerical solutions obtained with these equations are compared with the results obtained from direct solutions. It is shown that the two methods of solution are in good agreement for frequencies near to the first resonance.

● **6.12-31** Chokshi, N. C. and Lee, J. P., **Shear coefficient and shear force distribution in nuclear power plant structures due to seismic loading**, *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 629–642. (For a full bibliographic citation see Abstract No. 1.2-7.)

In the earthquake-resistant design of nuclear power plant facilities, structures are sometimes modeled by the lumped-mass method. Due to this simplification, the shear coefficient has to be calculated and the total shear forces properly distributed. The shear coefficient is important because the deformations due to shear effects are generally significant. The distribution of the total shear force is a highly statically indeterminate problem and requires solutions of a large number of simultaneous equations for complex wall configurations.

In this paper, the results of shear coefficient and shear distribution calculations using both the thin wall beam theory method and the rigidity method are presented for several elementary structural shapes. These results are compared with those obtained by Cowper through the integration of the equations of three-dimensional elastic theory. A dynamic analysis is performed on a two-story structure using the above two approaches to generate a lumped-mass model. The results of the dynamic analysis are compared with those obtained using a finite element model. The dynamic analysis is performed in two orthogonal directions. The results and applicability of each approach are discussed.

● **6.12-32** Hinton, E., **A note on a finite element method for the free vibrations of laminated plates**, *Earthquake Engineering and Structural Dynamics,* **4,** *5,* July–Sept. 1976, 515–516.

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

The object of this note is to investigate the use of a parabolic plate bending element for the free flexural vibration analysis of symmetrically laminated plates in which transverse shear deformation and rotatory inertia effects are considered. The basic theory and examples used are identical to those used in a similar study involving the finite strip method.

● **6.12-33** Hinton, E., **A note on a thick finite strip method for the free vibration of laminated plates,** *Earthquake Engineering and Structural Dynamics,* **4,** *5,* July–Sept. 1976, 511–514.

The finite strip method, which was introduced by Cheung, has recently been extended to cater for transverse shear deformation effects and it has been shown that the method can be used to solve a range of important problems in an economic manner. The object of this note is to investigate the use of this "thick" finite strip approach for the free flexural vibration analysis of symmetrically laminated plates.

● **6.12-34** Tamura, C. and Okamoto, S., **On earthquake resistant design of a submerged tunnel,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 809–822. (For a full bibliographic citation see Abstract No. 1.2-7.)

A mathematical model for the earthquake-resistant design of a submerged tunnel is presented. Data obtained from a dynamic response analysis of the tunnel subjected to typical earthquake motions in various ground conditions are presented. A comparison between observations and a numerical analysis using the presented data is made. A practical method to estimate the stresses in a tunnel during earthquakes is given.

● **6.12-35** Ungureanu, N., **A new structural model for shear walls analysis,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1277–1291. (For a full bibliographic citation see Abstract No. 1.2-7.)

A new model is presented for analyzing shear walls with openings which are subjected to horizontal seismic loads. The horizontal elements that couple the vertical members are replaced by an equivalent continuous connection of variable stiffness according to a periodic law. The model by which the horizontal coupling elements are replaced by a continuous connection of constant stiffness is well known. The proposed model takes into account more efficiently the local effects of the joints between the horizontal and vertical elements. A differential equation describing the shear wall deformation is derived.

Some quantitative and qualitative differences between the two models are discussed using a numerical example of a shear wall having one row of openings. Experimental data show that the proposed model more closely approximates the actual physical phenomenon.

● **6.12-36** Masri, S. F., **Response of beams to propagating boundary excitation,** *Earthquake Engineering and Structural Dynamics,* **4,** *5,* July–Sept. 1976, 497–509.

An exact solution is presented for the transient response of viscously damped Bernoulli-Euler beams with arbitrary boundary conditions that are subjected to directly applied dynamic loads in addition to arbitrary support motion. It is shown that, for certain system characteristics, the wave-like progression of the disturbance may have a significant influence on the structural response of such beams.

● **6.12-37** Clough, R. W. and Mojtahedi, S., **Earthquake response analysis considering non-proportional damping,** *Earthquake Engineering and Structural Dynamics,* **4,** *5,* July–Sept. 1976, 489–496.

Nonproportional damping may be defined as a form of linear viscous damping which introduces coupling between the undamped modal coordinate equations of motion. The standard modal superposition method of earthquake response analysis, therefore, cannot be employed with nonproportionally damped structures. In this paper, several methods for analyzing the dynamic response of nonproportional damped structures are outlined. It is concluded that the most efficient procedure is to express the response in terms of a truncated set of undamped modal coordinates and to integrate directly the resulting coupled equations. The effectiveness of the method is demonstrated by a numerical example.

● **6.12-38** Castellani, A., Castoldi, A. and Ionita, M., **Numerical analysis compared to model analysis for a dam subject to earthquakes,** *83,* Ist. Sperimentale Modelli e Strutture, Bergamo, Italy, Sept. 1976, 9. (Reprint of Paper 10 from the *Proceedings of the Fifth International Conference on Experimental Stress Analysis,* Udine, Italy, 1974.)

The finite element approach in the analysis of the static behavior of both arch and gravity dams has by now produced reasonable agreement with experimental results. Until fairly recently, however, discrepancies of up to 100% were not unknown. Some of these discrepancies still exist. The compliance of dam supports and the elastic moduli of materials still lead to uncertainties in both the numerical and the experimental approach. From the dynamic point of view, at least two more topics should be raised: how to take into account displacements in different phases of dam supports and water effects. The resulting problems considerably limit the reliability of experiments on shaking tables; hence, the interest in developing them theoretically and numerically. Difficulties in differentiating between the damping properties of concrete, water and the surrounding soil lead to further limits on experiments; but the scarcity of relevant data reduces the possible advantages of the numerical approach. This paper discusses the state-of-the-art of these topics in relation to the seismic behavior of dams; and two approaches are presented, one using models and the other using finite elements. The latter uses a shallow rectangular shell element developed by Connor and Brebbia. A generalized Lanczos method is used to calculate frequencies and mode shapes, taking advantage of the band shape of the stiffness and mass matrices. A helpful aspect of this problem is the reasonable agreement between these two approaches when the same boundary conditions are applied.

● **6.12-39** Shantaram, D., Owen, D. R. J. and Zienkiewicz, O. C., **Dynamic transient behaviour of two- and three-dimensional structures including plasticity, large deformation effects and fluid interaction,** *Earthquake Engineering and Structural Dynamics,* **4,** *6,* Oct.-Dec. 1976, 561-578.

The finite element method is employed in the prediction of the dynamic transient response of two- and three-dimensional solids exhibiting geometric (large deformations) and material (elasto-plastic) nonlinearities. Explicit time marching schemes are adopted for integration of the dynamic equilibrium equation and a diagonal "lumped" mass matrix is employed with a special procedure applicable to parabolic isoparametric elements. A variety of problems are presented including a solid/fluid interaction situation, and the method is shown to be of use in solving economically many problems of a dynamic or a catastrophic nature which can occur in such structures as nuclear reactors, containment vessels, etc.

● **6.12-40** Distefano, N. and Pena-Pardo, B., **System identification of frames under seismic loads,** *Journal of the Engineering Mechanics Division, ASCE,* **102,** *EM2,* Proc. Paper 12047, Apr. 1976, 313-330.

In this paper, system identification algorithms are employed to construct appropriate nonlinear models of real structures, undergoing seismic disturbances. A three-story, half-scale steel frame of the moment-resisting type is modeled as a "shear" frame. The data for this frame were obtained from the Earthquake Engineering Research Center of the Univ. of California. The restoring forces in this model are assumed to be of the viscous differential type, containing four unknown parameters. The solution of the problem, that is, the identification of state parameters, is sought by nonlinear filtering methods. The invariant imbedding filter is presented as a special case of a novel dynamic programming filter. In a purely experimental fashion, it is shown that the adopted model is identifiable and stable by utilizing simulated and real data. Abundant numerical experiments are performed; some of the results are presented. By adding corrective nonlinear terms to the basic linear model, the predictive ability of the model is demonstrated.

6.12-41 Ivovich, V. A., **Dynamic analysis of suspended structures** (Dinamicheskii raschet visyachikh konstruktsii, in Russian), STROIIZDAT, Moscow, 1975, 191.

Basic principles of the dynamic analysis of suspended systems are presented from a nonlinear viewpoint. Actual problems in the dynamics of geometrically nonlinear suspended bars, cable trusses, membranes and cable nets in free and forced vibration are considered. Steady vibrations of suspended systems are analyzed as well as stationary and transient vibration modes due to random excitations.

● **6.12-42** Hart, G. C. and Yao, J. T. P., **System identification in structural dynamics,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 61-85. (For a full bibliographic citation see Abstract No. 1.2-8.)

● **6.12-43** McNiven, H. D. and Matzen, V. C., **Identification of the energy absorption characteristics of an earthquake resistant structure: Description of the identification method,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 402-411. (For a full bibliographic citation see Abstract No. 1.2-8.)

The purpose of this research is to use data from experiments to formulate a mathematical model that will predict the nonlinear response of a single story steel frame to an earthquake input. The process used in this formulation is system identification. The form of the model is a second order nonlinear differential equation with linear viscous damping and Ramberg-Osgood type hysteresis. The damping coefficient and the three parameters in the hysteretic model are to be established. An integral weighted mean squared error function is used to evaluate the "goodness of fit" between the model's response and the structure's response when both are subjected to the same excitation. The function includes errors in displacement and acceleration and is integrated from zero to a time T, which may be the full duration of the recorded response or only a portion of it. The parameters are adjusted using a modified Gauss-Newton method until the error function is minimized.

The computer program incorporating these steps in the system identification process is verified with simulated data. Results given in the paper show that in every case the program converges in few iterations to the assigned set of parameters.

● **6.12-44** Adham, S., Bhaumik, A. and Isenberg, J., **Reinforced concrete constitutive relations,** *AFWL-TR-74-72,* Agbabian Assoc., El Segundo, California, Feb. 1975, 358. (NTIS Accession No. AD-A 007 886)

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

A mathematical model of reinforced concrete is derived from stress-strain relations of reinforcing steel and plain concrete and from consideration of slip in bond between them. The stress-strain relations are nonlinear because of cracking and the inelasticity of the concrete and steel. They are presented in the form of a variable modulus model for use in a finite element code. The stress-strain relations for plain concrete are based on experimental data obtained under uniaxial, biaxial and triaxial states of stress. Additional laboratory experiments were performed to investigate the bond-slip relation in tension and in compression. The model stress-strain relation in each principal stress direction is affected by the other two principal stresses. The form of the stress-strain relation and the manner in which it is affected by the lateral principal stresses are different in tension and compression. Until cracking occurs, properties of the model depend on the entire stiffness of steel and concrete. After cracking, a composite modulus is used which reflects the combined stiffness of steel and concrete and takes into account the extent to which the bond between steel and concrete is broken. This model is incorporated in a dynamic inelastic finite element code and is used to analyze the response of reinforced concrete members such as beams, deep beams, beam columns, and ring beams, subjected to static and dynamic loading. The results of analysis are in general agreement with available experimental observations. Recommendations for improvement in the material model are made as a result of the correlation studies.

● **6.12-45** Caravani, P., Watson, M. and Thomson, W. T., **Recursive least squares time domain identification of dynamic structures,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 391–401. (For a full bibliographic citation see Abstract No. 1.2–8.)

The identification of building parameters from earthquake response has interested structural engineers during the past few years. The approach taken by most investigators has been in the frequency domain using Fourier methods. For some time, it has been felt by the authors of this paper that a time domain approach would be superior to that of the frequency domain; and the investigations carried out in this direction substantiate this belief.

The approach described in this paper preassumes a model for the structure, and the parameters of the model are determined from a series of time measurements of the response taken at various points on the structure. The response measured at the various points of the structure is the acceleration resulting from an excitation such as an earthquake, and a mathematical algorithm developed for the digital computer successively takes this data at progressive time increments to converge to the most probable values of the parameters. The algorithm is written for efficient computation and avoids the necessity of inverting large matrices.

● **6.12-46** Matzen, V. C. and McNiven, H. D., **Identification of the energy absorption characteristics of an earthquake resistant structure: Identification of parameters from shaking table experiments,** *Dynamic Response of Structures: Instrumentation, Testing Methods and System Identification,* 330–341. (For a full bibliographic citation see Abstract No. 1.2–8.)

The purpose of this research is to use data from experiments to formulate a mathematical model that will predict the nonlinear response of a single-story steel frame to an earthquake input. The process used in this formulation is system identification.

In experiments performed on a shaking table, the frame was subjected to two earthquake motions at several intensities. In each case the frame underwent severe inelastic deformation. A computer program which incorporates the concepts of system identification makes use of the recorded data to establish four parameters in a nonlinear mathematical model. When different amounts of data are used in the program, parameter sets are established which give the best model response for that amount of test data. The resulting sets of parameters reflect the way in which the properties of the structure change during the excitation. However, when the full durations of the different excitations are used, the sets of parameters are almost identical. For each of these sets of parameters, the correlation of the computed accelerations with the measured is excellent, and the shape of the computed displacement response compares very well to the measured response, although the permanent offset of the displacements is not computed exactly.

Suggestions are given on how to overcome this deficiency in the mathematical model.

● **6.12-47** Omote, Y. and Takeda, T., **Theoretical and experimental study on the moment-curvature characteristics of reinforced concrete cylinders subjected to reversal of bending moment under constant axial load** (in Japanese), *Report of the Technical Research Institute, Ohbayashi-Gumi, Ltd., 10,* 1975, 1–5.

The object of this study is to establish the moment-curvature (M-$1/\rho$) relationship of reinforced concrete cylinders subjected to reversal of bending moment under constant axial load. Both analytical and experimental studies are conducted. The method of analysis is based on the stress-strain relationship of concrete and reinforcement. The results of this analysis agree well with experimental results. In addition, the energy absorption characteristic of the M-$1/\rho$ hysteresis loop is also discussed.

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

6.12-48 Romanov, A. A., **Calculation of natural frequencies and mode shapes of plates using the successive approximation method** (Opredelenie chastot i form svobodnykh kolebanii plastin metodom posledovatelnykh priblizhenii, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 3,* 1976, 57–59.

Plates supported identically along opposite edges are analyzed by means of the operational-variational technique for solving the differential equations of bending. The successive approximation method is employed. The example of a quadratic plate with clamped edges is used to demonstrate the high degree of accuracy of the method presented.

6.12-49 Khilchevskii, V. V. and Dubenets, V. G., **On a possible construction of mechanical hysteresis loop equations for cyclic vibrations** (Ob odnoi vozmozhnosti postroeniya uravnenii petli mekhanicheskogo gisterezisa pri tsiklicheskikh kolebaniyakh, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii, 2,* 1976, 57–60.

The behavior of a nonlinear, nonelastic material is analyzed using a series with coefficients dependent on the sign and direction of deformations. A method for obtaining the parameters in the formulas for the series coefficients is described.

● 6.12-50 Takizawa, H., **Biaxial effects in modelling earthquake response of R/C structures** (Technical Note), *Earthquake Engineering and Structural Dynamics,* 4, 6, Oct.–Dec. 1976, 609–616.

● 6.12-51 Nathan, N. D., MacKenzie, J. R. and McKevitt, W. E., **Structural response to translational and rotational ground motions,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 3, 1975, 105–116. (For a full bibliographic citation see Abstract No. 1.2–6.)

Records of torsional ground motion are developed for various types of earthquakes, using methods proposed by Newmark. Response spectra are presented and used to check bounds obtained by Newmark. Multidegree-of-freedom analysis is discussed, and some results are presented.

● 6.12-52 White, W., Valliappan, S. and Lee, I. K., **A unified boundary for finite dynamic models,** *UNICIV Report No. R-150,* School of Civil Engineering, Univ. of New South Wales, Kensington, N.S.W., Australia, Feb. 1976, 23.

The finite element analysis of dynamic problems in an infinite, isotropic medium is discussed. To simulate the physically infinite system by a finite model, an energy-absorbing boundary is proposed. This boundary is frequency independent and proves to be very efficient in absorbing stress waves. The boundary constants are calculated for the particular cases of plane strain and axisymmetry.

● 6.12-53 Matsushima, Y., **Spectra of spatially variant ground motions and associated transfer functions of soil-foundation system,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 145, 351–358. (For a full bibliographic citation see Abstract No. 1.2–9.)

The movement of ground surface during an earthquake would not be identical even in a relatively limited plane, but it is possible to have spatial variation. Mathematical expressions of cross-spectral density functions among such ground motions have been investigated from various standpoints from which associated transfer functions of a soil-foundation system have been analytically derived. The spectral expression of ground motions which have a statistical correlation depending only on distance and the associated transfer function will be recommended as the most simple and realistic simulation of the actual phenomenon, although there are not enough data available either quantitatively or qualitatively to state a definite conclusion. The single parameter in this case is a constant called "space correlation index," the value of which has been estimated.

● 6.12-54 Nilsson, L., **Nonlinear static and dynamic analysis of reinforced concrete plates subjected to in-plane loads,** *75: 10,* Dept. of Structural Mechanics, Chalmers Univ. of Technology, Goteborg, Sweden, 1975, 35.

This paper presents a model for nonlinear static and dynamic analysis of reinforced in-plane loaded concrete plates. Cracking, as well as the nonlinear stress-strain relationships for the two materials, is considered.

The numerical solutions are based on the finite element method. An isoparametric biquadratic in-plane element and a linear rod element are utilized in order to simulate concrete and reinforcement steel. A nonlinear secant constitutive relation and Mohr-Tresca's fracture criterion are chosen to yield the constitutive relation for concrete. The stress-strain test curve for reinforcement steel is approximated by successive Hermitian polynomials. The coupled system of nonlinear equations of motion is integrated in time and approximately satisfied via variable stiffness iterations.

Two numerical examples are considered. Results obtained by the present method are compared with experimentally obtained results.

● 6.12-55 Pilkey, W. D. and Chen, Y. H., **The use of general purpose computer programs to derive equations of motion for optimal isolation studies,** *ESS-4085-112-75,*

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

Research Labs. for Engineering Sciences, Univ. of Virginia, Charlottesville, 1975, 28.

Techniques are developed which permit general purpose structural analysis computer programs to be used to generate the equations of motion necessary for limiting performance studies. The limiting performance characteristics of a system are useful in analyzing the optimal behavior of a dynamic system. In particular, the limiting performance characteristics are the essential ingredients in an efficient optimal design method for isolation systems.

● **6.12-56** Adeli, H., **Solution techniques for linear and nonlinear dynamics of structures modeled by finite elements,** *23,* The John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, June 1976, 283.

The objectives of this project are to determine the most efficient techniques for linear and nonlinear dynamic analysis of structures modeled by finite elements. The selection of solution techniques to be compared is based on the information available in the literature. The accuracy, stability, and efficiency of the solution techniques are examined by comparing the results from a plane stress sample problem.

For linear analysis of the sample problem, results for the following solution techniques are compared: (1) direct linear extrapolation with the trapezoidal rule, (2) central difference predictor, (3) two-cycle iteration with the trapezoidal rule, and (4) normal mode method.

For nonlinear analysis, both material and geometric nonlinearities are included in the finite element formulation. Three implicit solution techniques are investigated in this work. They are (1) Newmark-Beta method, (2) Houbolt's method, and (3) Park's stiffly-stable method. In addition, the following explicit methods are compared: (1) central difference predictor, (2) two-cycle iteration with the trapezoidal rule, and (3) fourth-order Runge-Kutta method.

Algorithms for these solution techniques are developed and are implemented in three computer programs. The first program is for linear analysis, the second is for nonlinear analysis by implicit methods, and the third is for nonlinear analysis by explicit methods.

● **6.12-57** Maidanik, G., **Response of coupled dynamic systems,** *Journal of Sound and Vibration,* **46,** *4,* June 22, 1976, 561-583.

A complex dynamic system can often be modeled in terms of coupled basic dynamic systems. A basic dynamic system is a system whose response can be specified in terms of a scalar quantity. A general formalism, dealing with the response of a complex dynamic system, is developed. The formalism spans several previous formalisms and encompasses new material that has not been previously considered, e.g., direct couplings between the ribs on a panel. The format is chosen so that it provides for consideration of elements of statistical energy analysis. Thus, for example, the expression for the frequency spectral power flow between two basic dynamic systems is derived and cast in a modal form. In particular, various conditions and approximations under which cross-modal terms vanish in the expression are specified and interpreted. Modal densities are defined and used to obtain further reductions in the expression for the power flow between two multimodal basic dynamic systems.

● **6.12-58** Maidanik, G., **Variations in the boundary conditions of coupled dynamic systems,** *Journal of Sound and Vibration,* **46,** *4,* June 22, 1976, 585-589.

The paper is a sequel to the paper cited in Abstract No. 6.12-57. In that paper, isolation of the basic dynamic systems was achieved by imposing uncoupled boundary conditions in which the coupling impedances were removed. It is illustrated that alternate isolations, involving different boundary conditions, can be imposed. In particular, the modification introduced in the formalism when blocked boundary conditions are substituted for the uncoupled boundary conditions is discussed in some detail.

● **6.12-59** Endo, M. and Taniguchi, O., **An extension of the Southwell-Dunkerley methods for synthesizing frequencies, Part I: Principles,** *Journal of Sound and Vibration,* **49,** *4,* Dec. 22, 1976, 501-516.

A new method for synthesis of isolated frequencies of composite vibrating systems is presented. First, from an analogy with single-degree-of-freedom systems composed of springs and masses, the essential patterns of synthesis are clearly recognized in regard to the composite, continuous systems to which the well-known Southwell-Dunkerley methods are applicable. Then, in a converse manner, another fundamental pattern of synthesis is formulated for a single-degree-of-freedom model with springs in series, and this leads to a general formulation of the new synthetic method for continuous systems. It can predict a lower limit of the true frequency for such vibrating systems having a series-type coupling of restoring elements. Like the Southwell-Dunkerley methods, it is based on Rayleigh's principle, but in order to obtain an approximate value very close to the correct frequency one further needs another condition, which can be provided on the basis of a perturbation technique, at least in the most general cases. When applied to an ideal composite system whose restoring elements are coupled exactly in series, the present method proves to be essentially equivalent to the previous Southwell-Dunkerley methods in the sense that the additional approximate error, characteristic of the present method, is stationary with respect to slight differences of deflection curves among all isolated systems, as well as the error associated with the Rayleigh approximation. Upon adding the present method to a class of the previous synthetic methods, it becomes possible to cover all the synthetic patterns of isolated frequencies for any continuous system whose essential structure is fundamentally analogous to that for a composite single-degree-of-freedom model. Thus, a combined synthetic method for all such continuous systems is formulated, which may be regarded as an extension of the previous Southwell-Dunkerley methods.

● 6.12-60 Endo, M. and Taniguchi, O., **An extension of the Southwell-Dunkerley methods for synthesizing frequencies, Part II: Applications,** *Journal of Sound and Vibration,* **49,** *4,* Dec. 22, 1976, 517–533.

The series-type synthetic method of obtaining frequencies and the combined synthetic one are examined mainly from the practical point of view, for some typical vibrating models. In section 2, the fundamental frequency of a two-degree-of-freedom system with two springs and two masses, connected alternately in series, is first discussed, and the accuracy of the approximate solutions is investigated without the influence of the error associated with Rayleigh's principle, which is completely eliminatable for such discrete systems. The convergence of the approximate solutions as finite power-series expansions in the perturbation parameter is also studied. Secondly, for two kinds of fairly complicated models composed of a beam, springs and concentrated masses as examples, a study is presented of the degree of the error of approximation accumulated when synthesizing many isolated frequencies on the basis of the series-type synthetic method or the combined synthetic one. This study shows that in almost all cases the lower limit of the true frequency obtained by the present methods is very close to the true frequency and the error due to the procedure of synthesizing isolated frequencies is smaller than that associated with Rayleigh's principle. In sections 3 and 4, it is shown that in elastic continua such as bars, beams and plates the bending deformation and the transverse shear one, or the former and the torsional one, if related, are coupled in series, so that one can utilize the concept of the series-type synthetic method to obtain an approximate frequency of composite systems with such deformations.

● 6.12-61 van der Burgh, A. H. P., **On the asymptotic approximations of the solutions of a system of two nonlinearly coupled harmonic oscillators,** *Journal of Sound and Vibration,* **49,** *1,* Nov. 8, 1976, 93–103.

A procedure, closely related to the averaging method, is given for the construction of asymptotic approximations for the solutions of a Lagrangian system.

● 6.12-62 Jacquot, R. G., **The response of a system when modified by the attachment of an additional sub-system,** *Journal of Sound and Vibration,* **49,** *3,* Dec. 8, 1976, 345–351.

A technique is developed by which the effect of the attachment of a sub-system on frequency domain and time domain responses may be evaluated. This involves working with driving point and transfer functions in the frequency domain. Transition to the time domain is accomplished by use of the fast Fourier transform algorithm. The technique developed is applied to find the optimal damping for a dynamic vibration absorber attached to the tip of a forced elastic cantilever beam.

● 6.12-63 Sinha, S. C. and Chou, C. C., **An approximate analysis of transient response of time-dependent linear systems by use of orthogonal polynomials,** *Journal of Sound and Vibration,* **49,** *3,* Dec. 8, 1976, 309–326.

The paper deals with the approximate analysis of second-order linear systems with variable coefficients through the application of orthogonal polynomials. The time-dependent functions appearing as coefficients in the system equations may be periodic, nonperiodic or can have multiple turning points. These variable coefficients are replaced by simple functions, viz. a constant, a linear or a quadratic function, and orthogonal polynomial expansions are used in the desired time interval so that the approximate differential equations thus obtained have known closed-form solutions. In particular, expansions in ultraspherical polynomials have been treated in detail, which include the Chebyshev and Legendre polynomials as special cases. If the time-function is approximated by a constant, the approximate solutions are the sine and cosine functions, which a linear approximation leads to a solution in terms of Bessel functions of 1/3 order or Airy functions. The quadratic approximation of the function results in Weber's equations and the solutions are parabolic cylindrical functions.

In the case of periodic coefficients, the functions are approximated so that the periods of the original and the approximate functions remain the same. The method has been applied to an equation with two turning points and to Mathieu's equation and the results are compared with numerical solutions. The well-known WKBJ results are also presented for comparison. Results obtained by the present approach agree more accurately with numerical solutions, depending on the choice of orthogonal polynomials used in the expansions. Moreover, in the case of turning point problems the approach is simpler as compared to other methods available in the literature and uniformly valid solutions are obtained without any difficulty.

● 6.12-64 Sakata, T., **A reduction method for problems of vibration of orthotropic plates,** *Journal of Sound and Vibration,* **48,** *3,* Oct. 8, 1976, 405–412.

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

It is shown that the problem of vibration of an orthotropic plate can be reduced to that of another orthotropic plate by a simple coordinate transformation, and reduction formulas are obtained. To justify the reduction formulas, fundamental natural frequencies of orthotropic rectangular plates with various boundary conditions and of a clamped orthotropic elliptical plate are discussed. As an example, an exact natural frequency of a simple supported generally orthotropic skew plate with special flexural rigidities is obtained from that of a simply supported isotropic rectangular plate.

● **6.12-65** Hassab, J. C., **A generalized approach to the solution of variable systems subjected to arbitrary source functions and boundary conditions,** *Journal of Sound and Vibration,* **48,** *2,* Sept. 22, 1976, 277–291.

Under study are layered inhomogeneous systems with or without forcing functions as represented by sources and boundary conditions. Under a forced or unforced state, such systems pervade the fields of sound and vibration. A common formulation to the constraints and physical laws that apply is given by using the Fredholm integral equation. A unified and versatile solution is developed analytically to treat these problems under forced or unforced conditions. Then the approach is dissected to implement the results on the computer or to treat, at the outset, the lumped approximation of the distributed system. This development modifies, extends, and generalizes previous studies that have been applied to a restricted class of systems. Here the treated systems need not be limited to those described by a strictly bilinear or symmetric Green function. Also, the source function and boundary conditions are not limited to those of special type or form. Throughout, examples are given to illustrate the analysis.

● **6.12-66** Hinton, E., **The dynamic transient analysis of axisymmetric circular plates by the finite element method,** *Journal of Sound and Vibration,* **46,** *4,* June 22, 1976, 465–472.

The linear elastic, dynamic transient analysis of some circular plate bending problems is considered by using axisymmetric, parabolic isoparametric elements with an explicit time marching scheme. The effects of rotatory inertia and transverse shear deformation are included. A special mass lumping scheme and the use of a reduced integration technique allow the treatment of thin as well as thick plates. Several numerical examples are presented and compared with results from other sources.

● **6.12-67** Mahalingam, S., **A joint relaxation technique for the receptance solution of structural vibration problems,** *Journal of Sound and Vibration,* **47,** *1,* July 8, 1976, 115–124.

A well-established technique for the analysis of a complex vibrating system is to cut it into a convenient number of simpler subsystems. An alternative approach, suggested by recent studies of displacement excitation, is to convert the system into a set of independent subsystems by clamping it at a sufficient number of coordinates. Exact solutions for free and forced vibration are then obtained by considering the relaxation of the clamps. Vibration analysis data are used for the numerical solution of framed structures by this method. This displacement approach is in some cases simpler than the standard methods and leads to smaller frequency determinants.

● **6.12-68** Sakata, T., **Eigenvalues of orthotropic continuous plates with two opposite sides simply supported,** *Journal of Sound and Vibration,* **47,** *4,* Aug. 22, 1976, 577–583.

In the present paper, a simple reduction method is proposed for evaluating the eigenvalues of an orthotropic continuous plate with two simply supported opposite sides from that of the isotropic continuous plate with the same boundary conditions by the extension of Rajappa's work. Furthermore, calculations are performed for the simply supported orthotropic and isotropic continuous plates with two intermediate supports to justify the reduction method.

● **6.12-69** Westbrook, D. R., **Small strain non-linear dynamics of plates,** *Journal of Sound and Vibration,* **44,** *1,* Jan. 8, 1976, 75–82.

Equations of motion are obtained for the nonlinear vibration of plates, under an assumption of small strains, by the application of perturbation theory with multiple timing to the three-dimensional dynamic equations of elasticity. The main equations obtained by this process are not new but the method gives added insight into the nature of plate vibrations and the errors involved in the standard equations.

● **6.12-70** Aksu, G. and Ali, R., **Determination of dynamic characteristics of rectangular plates with cutouts using a finite difference formulation,** *Journal of Sound and Vibration,* **44,** *1,* Jan. 8, 1976, 147–158.

The paper describes a method for the prediction of the dynamic characteristics of rectangular plates with cutouts. The method is based on the use of variational principles in conjunction with the finite difference technique. A concept of interlacing grids has been developed to express the strain energy of nodal subdomains into which the plate is divided. The use of this idea has been demonstrated in relation to internal and boundary nodes. Natural frequencies and corresponding mode shapes of rectangular plates with one and two cutouts have been predicted and experimentally verified.

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

● **6.12-71** Bailey, C. D., **Exact and direct analytical solutions to vibrating systems with discontinuities,** *Journal of Sound and Vibration,* **44,** *1,* Jan. 8, 1976, 15–25.

Direct analytical solutions, i.e., analytical solutions without any reference to the theory of differential equations, are given for the vibration frequencies and modes of beams with discontinuities in moment and shear. The calculated displacement, slope, moment and shear are given. In every case, these data are compared to corresponding data from the rigorously exact solution to the differential equation subjected to the rigorously imposed boundary conditions. The results show that, contrary to the approximation that would be obtained from the Rayleigh-Ritz method when there are discontinuities in the higher derivatives, the direct solution converges to the exact solution as defined by the mathematician; i.e., the solution that satisfies the differential equation of equilibrium throughout the domain and the conditions on the boundary of the domain.

● **6.12-72** Ramakrishnan, R. and Kunukkasseril, V. X., **Free vibration of stiffened circular bridge decks,** *Journal of Sound and Vibration,* **44,** *2,* Jan. 22, 1976, 209–221.

An analytical method for determining the free vibration frequencies of stiffened curved bridge decks is presented. The bridge deck is idealized as a system consisting of a number of concentric annular plate and circular ring segments rigidly connected to each other. From the closed-form solutions for free vibration of the individual plate segments and rings, the frequency of the system is obtained by imposing the edge and continuity conditions. Results for several cases are furnished and a comparison with experimental results is also presented.

● **6.12-73** Hallquist, J. O., **An efficient method for determining the effects of mass modifications in damped systems,** *Journal of Sound and Vibration,* **44,** *3,* Feb. 8, 1976, 449–459.

An analytical procedure is presented for determining the effects of mass modifications in viscously damped vibratory systems. A very general but straightforward formulation is given which simplifies considerably for positive definite systems with distinct eigenvalues, the most common case. The procedure permits successive modifications, is reversible, provides accurate results, and significantly reduces computation time. The complete solution of the unmodified system is not a prerequisite for applying the method, although if it is available an exact solution for the modified system can be obtained. A stable numerical scheme for locating the complex roots of the characteristic equation is given, and numerical results are provided to demonstrate the theory.

● **6.12-74** Elishakoff, I. and Wiener, F., **Vibration of an open shallow cylindrical shell,** *Journal of Sound and Vibration,* **44,** *3,* Feb. 8, 1976, 379–392.

A method is presented for analyzing the vibration of open shallow cylindrical shells with general boundary conditions at all four edges. An approximate solution is formulated consisting of two Voigt-Levy type problems and a postulated eigenfrequency/wave-number relationship. The set of possible eigenfrequency/wave-number relations is obtained by considering the problems capable of exact solution and generalizing the resulting eigenfrequency/wave-number relations in such a way that the approximate solution will always reduce to the exact solutions for the appropriate boundary conditions. This method allows calculation of eigenfrequencies where Bolotin's asymptotic method fails due to degeneracy of the dynamic edge effect.

● **6.12-75** Nayfeh, A. H. *et al.,* **Vibrations of nearly annular and circular plates,** *Journal of Sound and Vibration,* **47,** *1,* July 8, 1976, 75–84.

A general procedure is presented to determine the natural frequencies and mode shapes of nearly annular and circular plates. A straightforward perturbation procedure is used with a transfer of the boundary conditions to obtain solutions given by simple expressions. As well as yielding good accuracy quantitatively, the method accurately predicts qualitative behavior. Numerical results are presented for clamped elliptical and square plates.

● **6.12-76** Mazumdar, J. and Coleby, J. R., **Simplified approach to the vibration analysis of elastic plates due to sonic boom,** *Journal of Sound and Vibration,* **45,** *4,* Apr. 22, 1976, 503–512.

A theoretical study of the response of a flat plate to a sonic boom excitation is presented. For such a study, the problem of transient vibrations of elastic plates having clamped or simply supported boundary conditions under a pulse load in the shape of a capital N corresponding to a typical far-field sonic boom disturbance is discussed in a new fashion by using the concept of iso-amplitude contour lines on the surface of the plate. Series solutions consisting of products of eigenfunctions times functions of time are employed to analyze the motions. As an illustration of the technique, an elliptical plate subjected to a typical N wave arriving at normal incidence is chosen as a model because this involves a curvilinear boundary of a relatively simple shape, yet has no simple exact solution. Closed-form solutions are obtained for both clamped as well as simply supported edges. The results have technical importance for the prediction of response of window panes and wall-panels to sonic boom. All details are explained by graphs.

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

● **6.12-77** Rutenberg, A., **A lower bound for Dunkerley's formula in continuous elastic systems,** *Journal of Sound and Vibration,* **45,** *2,* Mar. 22, 1976, 249-252.

Dunkerley's formula is shown to yield a lower bound for the fundamental frequency of vibration of a continuous elastic system whose flexibility is separable into a number of distinct components. The use of the formula is illustrated by considering a uniform cantilever and a three-layer sandwich beam.

● **6.12-78** Wilken, I. D. and Soedel, W., **Simplified prediction of the modal characteristics of ring-stiffened cylindrical shells,** *Journal of Sound and Vibration,* **44,** *4,* Feb. 22, 1976, 577-589.

Two simplified means of predicting the modal characteristics of ring-stiffened circular cylindrical shells are developed. These approaches are based on the receptance method and use the modal characteristics of the unstiffened cylinder and of the rings as inputs. In the first approach simplicity is achieved while retaining accuracy by confining the geometry to a cylindrical shell with simply supported ends stiffened by identical, equally spaced rings. For this not uncommon configuration, a single non-matrix frequency equation is developed which can be solved surely and rapidly by a numerical method. The second approach is more general and provides insight into the effects of ring stiffeners. The results are not as precise as the first approach, but the calculations are simple enough to be carried out at one's desk given the modal characteristics of the unstiffened cylindrical shell and of the rings.

● **6.12-79** Wilken, I. D. and Soedel, W., **The receptance method applied to ring-stiffened cylindrical shells: Analysis of modal characteristics,** *Journal of Sound and Vibration,* **44,** *4,* Feb. 22, 1976, 563-576.

The receptance method is applied to determine the natural frequencies and mode shapes of circular cylindrical shells stiffened by rings. The receptances of a cylindrical shell and of a ring to forces in the radial and circumferential directions are derived in terms of the modal characteristics of each. A matrix equation of free vibration, which must be solved by an iterative technique, results by eliminating the angular variable. An iterative solution is practical, since the size of the matrices remains at two times the number of stiffening rings, regardless of the number of modes of the unstiffened cylinder and rings included in the solution. The validity of the method is demonstrated by comparing results for specific cases with the results obtained theoretically and experimentally by others. When various stiffener configurations are being considered for a given cylindrical shell, the modal characteristics of the shell without stiffeners may be calculated once and used repeatedly to calculate the frequencies of the stiffened shell configurations. The form of the results offers potential for simplifications which are presented in a companion paper.

● **6.12-80** Parnell, L. A. and Cobble, M. H., **Lateral displacements of a vibrating cantilever beam with a concentrated mass,** *Journal of Sound and Vibration,* **44,** *4,* Feb. 22, 1976, 499-511.

The displacement equation for a uniform cross-section, cantilever-type beam carrying a concentrated mass at one end is solved under the most general conditions of an arbitrary distributed lateral load and arbitrary boundary and initial conditions. The method employs complex variable residue theory to determine the inversion integral for the Laplace-transformed solution of the boundary value problem. An example problem is solved and the displacement is shown graphically at several points along the beam for two values of the concentrated mass.

● **6.12-81** Kreyszig, E., **On approximation by cylinder functions,** *Journal of Sound and Vibration,* **45,** *1,* Mar. 8, 1976, 1-4.

This paper is concerned with two approximation methods for solving linear vibrational systems with time-dependent parameters which were recently proposed by Srinivasan and Sankar and discussed in connection with two linear differential equations. It is shown that, in principle, the methods involve certain practical difficulties and that for the equations proposed by Srinivasan and Sankar there are different approaches which may be preferable. However, the latter apply only to certain classes of vibrational problems, whereas the methods proposed by Srinivasan and Sankar are universal.

● **6.12-82** Greif, R. and Mittendorf, S. C., **Structural vibrations and Fourier series,** *Journal of Sound and Vibration,* **48,** *1,* Sept. 8, 1976, 113-122.

A method is introduced for vibration analysis of a wide class of beam, plate and shell problems including the effects of variable geometry and material properties. The method is based on the discrete technique of component mode analysis. For each of these components the mode shapes are written in terms of Rayleigh-Ritz expansions involving simple Fourier sine or cosine series. Due to the nature of these series, special attention must be given to end point behavior in the modal expansions and in the derivatives of these modal expansions. This is done via the mechanisms of Stokes's transformation. Continuity between components is enforced with Lagrange multipliers. The resulting frequency equation is exact and the associated eigenvector contains a combination of force- and displacement-type terms. Numerical solutions are found by truncating the series and monitoring the frequency determinant on a computer.

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

● **6.12-83** Darwin, D. and Pecknold, D. A., **Analysis of RC shear panels under cyclic loading,** *Journal of the Structural Division, ASCE,* **102,** *ST2,* Proc. Paper 11896, Feb. 1976, 355–369.

A nonlinear constitutive model for plain concrete subjected to cyclic biaxial stresses is described in brief. The model takes account of the compressive softening of concrete prior to reaching maximum compressive stress. Two reinforced concrete shear wall structures, one loaded monotonically and the second subjected to large cyclic load reversals are analyzed and compared with test data. Simulation of cyclic loading response is greatly improved compared to previous elastoplastic models. In addition to the improved material characterization in compression, the treatment of tensile cracking is felt to be a significant factor in the good match obtained with experimental data.

● **6.12-84** Morris, N. F., **Analysis of cable-stiffened space structures,** *Journal of the Structural Division, ASCE,* **102,** *ST3,* Proc. Paper 11998, Mar. 1976, 501–513.

A method is presented for computing the nonlinear dynamic response of three-dimensional cable-stiffened structures. The nonlinear dynamic equations are reduced to a smaller system by expanding the unknown variables as a series of mode shapes which were found by an eigenvalue analysis of the linear dynamic equations. The method is applied to a single plane cable-stayed bridge. Results are obtained for linear and nonlinear dynamic response due to earthquake, vortex excitation, and wind gusting. It is confirmed that a linear analysis is suitable for cable-stayed bridges.

● **6.12-85** Belytschko, T., Chiapetta, R. L. and Bartel, H. D., **Efficient large scale non-linear transient analysis by finite elements,** *International Journal for Numerical Methods in Engineering,* **10,** *3,* 1976, 579–596.

Finite element methods appear to be a promising means for studying transient phenomena such as dynamic structure-media interaction with seismic and blast loadings. However, particularly for nonlinear materials such as soil, many of the techniques currently employed are quite inefficient, so large-scale analyses are very uneconomical. In this paper, the effectiveness of various transient analyses for nonlinear problems is reviewed and some features of an efficient computer program for this class of problems are described. An application to a structure-media interaction problem is presented and compared with experimental results.

● **6.12-86** Corr, R. B. and Jennings, A., **A simultaneous iteration algorithm for symmetric eigenvalue problems,** *International Journal for Numerical Methods in Engineering,* **10,** *3,* 1976, 647–663.

A FORTRAN IV algorithm is presented for determining sets of dominant eigenvalues and corresponding eigenvectors of symmetric matrices. It is also extended to the solution of the equations of natural vibration of a structure for which symmetric stiffness and mass matrices are available. The matrices are stored and processed in variable bandwidth form, thus enabling advantage to be gained from sparseness in the equations. Some of the procedures may also be used to solve symmetric positive definite equations such as those arising from the static analysis of structures loaded within the elastic range.

● **6.12-87** Holmes, P. J. and Rand, D. A., **The bifurcations of Duffing's equation: An application of catastrophe theory,** *Journal of Sound and Vibration,* **44,** *2,* Jan. 22, 1976, 237–253.

The existence and stability of solutions of Duffing's equation are investigated and their characteristic bifurcations are studied. It is shown how catastrophe theory provides a natural synthesis between the practical and theoretical aspects of the problem. In so doing, ways are indicated in which the mathematical methods of differential dynamics might be of use to the vibration engineer, particularly in the treatment of nonlinear problems.

● **6.12-88** McDaniel, T. J. and Murthy, V. R., **Solution bounds for varying geometry beams,** *Journal of Sound and Vibration,* **44,** *3,* Feb. 8, 1976, 431–448.

The theory of differential and integral inequalities is applied to obtain upper and lower bounds to the transfer matrix for beams with varying geometry. Various techniques of generating and refining these bounds are investigated. Numerical results indicate that these bounds can be refined to produce numerical agreement of the upper and the lower bound to a given number of significant digits.

Proceeding from bounds on the transfer matrix elements a theory is developed for determining upper and lower bounds on the natural frequencies and mode shapes and on the solution state vector for static loading of such beams. This procedure is then extended to the analysis of multispan beams with varying geometry. Numerical results are presented for various configurations.

● **6.12-89** Goodno, B. J. and Gere, J. M., **Analysis of shear cores using superelements,** *Journal of the Structural Division, ASCE,* **102,** *ST1,* Proc. Paper 11837, Jan. 1976, 267–283.

A number of multistory buildings, containing concrete shear cores to house vertical services, have sustained major damage in recent earthquakes. Simplified analytical models for the shear cores cannot account for the relative stiffness of intersecting walls and for the influence of openings on the wall stiffness. Wall stress calculations are also beyond the capabilities of many of these continuum models. To remedy this, a three-dimensional shear core analytical model composed of two-dimensional rectangular plane stress and plate bending finite elements was developed. A subassemblage of finite elements forms a superelement and a stack of superelements is assembled in series elimination fashion to model the core tower. Determination of vibration frequencies, mode shapes, and nodal displacements for several isolated shear cores demonstrates the capabilities of the model. This general purpose analytical model can be readily incorporated into existing multistory-building frame models, and can serve as a basis for evaluation of simpler continuum models.

● **6.12-90** Benson, P. R. and Hinton, E., **A thick finite strip solution for static, free vibration and stability problems,** *International Journal for Numerical Methods in Engineering,* **10,** *3,* 1976, 665–678.

A finite strip method for the analysis of plate bending problems is described. This method, which takes into account the effects of transverse shear deformation, is applied to the static analysis of a curved plate and then to the free vibration and stability of thick and thin plates.

● **6.12-91** Datta, S., **Large amplitude free vibrations of irregular plates placed on an elastic foundation,** *International Journal of Non-Linear Mechanics,* **11,** *5,* 1976, 337–345.

A unified method for determining the lowest natural frequency of large amplitude free vibrations of thin elastic plates of any shape and placed on an elastic foundation is given. The conformal mapping technique is introduced and Galerkin's method is used to calculate approximate values of the lowest natural frequency. Time periods for circular, square, and cornered plates placed on elastic foundations have been determined for simply supported and clamped edge boundary conditions. Practical values have also been determined experimentally. The results are presented in the form of graphs and they are compared with other known results.

● **6.12-92** Bojadziev, G. N., **Non-linear vibrating systems in resonance governed by hyperbolic differential equations,** *International Journal of Non-Linear Mechanics,* **11,** *6,* 1976, 347–354.

The asymptotic solutions of second-order hyperbolic differential equations with weak nonlinearities in the case of internal and external resonance are found. The method used is an extension of the Krylov-Bogoliubov-Mitropolskii method. An application is made to the longitudinal vibrations of a rod in which nonlinear elastic behavior and linear viscoelastic damping occur.

● **6.12-93** Hughes, T. J. R., **Reduction scheme for some structural eigenvalue problems by a variational theorem,** *International Journal for Numerical Methods in Engineering,* **10,** *4,* 1976, 845–852.

An accurate reduction scheme for structural eigenvalue problems is deduced from a variational theorem in which the displacement, velocity and/or momentum fields are taken to be independent.

● **6.12-94** Chriss, S., **Frame interaction in nonorthogonal grids,** *Journal of the Structural Division, ASCE,* **102,** *ST4,* Proc. Paper 12031, Apr. 1976, 739–757.

A method, based on the theorem of minimum total potential, is proposed for the analysis of nonorthogonal grids subjected to a set of static, horizontal forces arbitrary in magnitude and direction. Effects of interaction resulting from unsymmetrical bending of columns common to nonorthogonal intersecting frames are duly taken into account. Shear walls may be included in the analysis. Stiffness matrices of the individual stiffness elements and a matrix comprising the force set are utilized as basic input information. The method ultimately results in a system of linear algebraic equations from which translational and rotational displacements of the rigid floor plates are determined. Subsequently, translational and flexural deformations of the stiffness elements are computed, from which stress resultants may be determined. Part one covers the formulation of the method of analysis through the development of equilibrium, compatibility, and force (moment) deformation relationships for subsequent utilization according to the minimum total potential theorem. In part two, a numerical application is presented.

● **6.12-95** Arora, J. S., **Survey of structural reanalysis techniques,** *Journal of the Structural Division, ASCE,* **102,** *ST4,* Proc. Paper 12056, Apr. 1976, 783–802.

The behavior of the structure is assumed to be described by a finite element model. Several techniques for computing static response of modified structures are available in the literature. These are initial strain concept of reanalysis, techniques based on the Sherman-Morrison identity, some general techniques of structural modifications, Taylor series approach, iterative techniques, reduced basis methods, and some other techniques. Some new approaches based on the reduced basis method are tried and their results are summarized. For frequency response of modified structures, three basically different techniques are available. In the first one, modifications to the eigenvalues and eigenvectors are computed directly by using Taylor series expansion. In the second one, locally modified systems are treated in an exact manner, and in the third technique component mode substitution methods are viewed as reanalysis methods.

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

● **6.12-96** Chang, A. T., **Improved quadratic elements,** *International Journal for Numerical Methods in Engineering,* **10,** *6,* 1976, 1379-1387.

A general method to formulate improved quadratic elements is presented. Derivation of the method is based on more accurate shape functions that take into account effects of governing differential equations. These new shape functions have the same form as those of the standard eight-node quadratic element. Therefore, they may be easily adapted into existing programs. The new quadratic element is compared with both standard and standard condensed quadratic elements. To show relative merits of different quadratic elements eigenvalue tests are performed. Several examples ranging from field problems, plane stress and bar vibration are used to demonstrate the applicability of this approach.

● **6.12-97** Jain, M. K., Iyengar, S. R. K. and Lone, A. G., **Higher order difference formulas for a fourth order parabolic partial differential equation,** *International Journal for Numerical Methods in Engineering,* **10,** *6,* 1976, 1357-1367.

In this paper, we have derived some new higher-order difference formulas for the solution of a fourth-order parabolic partial differential equation governing transverse vibrations of a uniform flexible beam in one and two space dimensions using Richtmyer's approach and a direct approach. Two examples illustrate the utility of the new difference methods.

● **6.12-98** Dawson, B. and Davies, M., **An extended matrix transfer method with an automatic root search capability,** *International Journal for Numerical Methods in Engineering,* **10,** *1,* 1976, 67-76.

An "extended matrix transfer method" is presented which has an automatic root search capability that can be guaranteed to determine all the roots of the problem, with the exception of those roots lying within prescribed tolerance bandwidths. The power and generality of the method are demonstrated by application to a specially synthesized problem.

● **6.12-99** Akesson, B. A., **PFVIBAT–A computer program for plane frame vibration analysis by an exact method,** *International Journal for Numerical Methods in Engineering,* **10,** *6,* 1976, 1221-1231.

The described program PFVIBAT uses the exact displacement method to perform free and forced vibration analysis entirely within the differential equation theory of beams, thus avoiding assumed modes and lumped masses. The frame may contain rigid bodies. Clamped, hinged, guided and rolling connections are provided for. Consideration of rotatory inertia, shear deformation and second-order bending moments and shear forces as caused by static axial load is optional. Eigenfrequencies and modal masses are calculated with an accuracy that may be specified. Displacement and moment modes are plotted. Transient vibrations are studied.

● **6.12-100** Chugh, A. K. and Biggers, S. B., **Stiffness matrix for a non-prismatic beam-column element,** *International Journal for Numerical Methods in Engineering,* **10,** *5,* 1976, 1125-1142.

An algorithm is presented which generates an element stiffness matrix for nonprismatic beam-column members using Newmark's numerical procedure of successive approximations. The resulting element stiffness matrix on element coordinates is found to be in excellent agreement with those available for limiting cases. An approximate stability analysis conducted on the convergence of the numerical scheme shows that the proposed algorithm is stable. The critical buckling loads for various end conditions are computed as part of the computational scheme. A computer program listing in FORTRAN IV is included which will handle essentially any order and/or kind of nonprismaticity of beam elements. The results are presented in the conventional and convenient coefficient format.

● **6.12-101** Jones, R., **Approximate expressions for the fundamental frequency of vibration of several dynamic systems,** *Journal of Sound and Vibration,* **44,** *4,* Feb. 22, 1976, 475-478.

An approximate formula for the frequency of vibration of several dynamic systems is presented. This approximation is an extension of the existing approximate formulas for vibrating plates. The formula is applied to the problem of a vibrating membrane.

● **6.12-102** Gorman, D. J., **Free vibration analysis of cantilever plates by the method of superposition,** *Journal of Sound and Vibration,* **49,** *4,* Dec. 22, 1976, 453-467.

The method of superposition is employed to analyze the first five symmetric and antisymmetric free vibration modes of a cantilever plate for a wide range of aspect ratios. It is shown that this method provides a simple, straightforward and highly accurate means of solution for this family of problems. Convergence to exact values is shown to be remarkably rapid. The first two symmetric and antisymmetric modal shapes for a square plate are accurately described by means of contour line drawings. The numerous advantages of this method over previously used methods are discussed. It is shown that it lends itself readily to the entire family of rectangular plates with classical edge conditions; i.e., clamped, simply supported, and free. Its applicability to a wide family of rectangular plates with

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

boundary conditions other than the classical type is also discussed.

● **6.12-103** Bendat, J. S., **System identification from multiple input/output data,** *Journal of Sound and Vibration,* **49,** *3,* Dec. 8, 1976, 293–308.

For stationary random or transient data representing multicorrelated (multicoherent) input/output data occurring in physical systems, iterative computational algorithms are developed to identify the frequency response functions of optimum constant parameter linear systems connecting this data. Results are obtained from Fourier transform methods and optimum least-squares prediction techniques by changing original arbitrary input records into ordered sets of conditioned input records. These procedures provide the basis for efficient digital computer analysis of general multiple input/output problems. The Appendix contains useful error analysis results for the optimum frequency response estimates determined from measured data.

● **6.12-104** Kitagawa, H. and Mochizuki, T., **On the conversion of a hysteretic structure into the model with equivalent viscous-damping–Fundamental studies on the approximate function of restoring force characteristics of pile** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 164, 503–510. (For a full bibliographic citation see Abstract No. 1.2-9.)

In this paper an attempt is made to convert the restoring force characteristics obtained from a static test into an equivalent vibrational model.

In general, it is difficult to formalize the hysteresis curve obtained from a static test, but the skeleton curve and the area surrounded by the hysteresis curve may be formalized readily as a function of displacement amplitude. Here, by using the skeleton curve and the area, the force-deflection relation having a hysteresis loop could be converted into the restoring force model expressed in a power function. The following two assumptions are constructed to approach the magnitude of damping quantity and spring characteristics: (i) The area of the hysteresis loop for a static test is equal to that of the restoring force model. (ii) The skeleton curve of the restoring force model passes the top of the hysteresis curve of the static test.

In Section 2, the steady-state response to sinusoidal excitation of a structure having a nonlinear hysteretic force-deflection relation of a power function is investigated by energy methods and by the method of slowly varying parameters to obtain the resonant amplitude and frequency response. The relation between the response and the nonlinear parameter for the force level of the excitation is shown.

A few examples for conversion are mentioned. Under the above assumptions, the restoring force characteristics for structural members of reinforced concrete and a pile obtained from the response curves are shown.

● **6.12-105** Rao, G. V., Raju, I. S. and Raju, K. K., **A finite element formulation for large amplitude flexural vibrations of thin rectangular plates,** *Computers & Structures,* **6,** *3,* June 1976, 163–167.

Large amplitude flexural vibrations of rectangular plates are studied in this paper using a direct finite element formulation. The formulation is based on an appropriate linearization of strain displacement relations and uses an iterative method of solution. Results are presented for rectangular plates with various boundary conditions using a conforming rectangular element. Whenever possible, the present solutions are compared with those of earlier work. This comparison confirms the superiority of the proposed formulation over the earlier finite element formulation.

● **6.12-106** Frank, R. A., **Dynamic modeling of large precast panel buildings using finite elements with substructuring,** *Seismic Resistance of Precast Concrete Panel Buildings, No. 2, R76-36,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Aug. 1976, 162.

At the present time little is known about the dynamic behavior of large panel precast concrete buildings (LPPB). The present research is a preliminary investigation of the dynamic response characteristics of these systems. The structure is assumed to respond elastically and is modeled using statically condensed superelements to represent the panels and anisotropic finite elemtnts to model the connections. A typical building system is defined and the sensitivity of the dynamic response to several parameters examined. These parameters include the height of the structure, the width of the panel, the relative stiffness of the connection, the per cent critical damping, and the variability in the expected ground motion.

From these studies it was determined that the linear dynamic response of LPPB systems is approximately that for a shear wall type structure. Response was found to be primarily in the first mode of vibration for shorter structures, while for taller structures the higher modes became important. The relative stiffness of the connections (after significant degradation) was also found to have a significant influence on the nature of the response. This influence was greatest in the shorter structures and higher modes of vibration. Displacement demands on the connections were also significantly influenced by the relative stiffness of the connection. This influence, however, was greatest in the first mode of response.

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

● **6.12-107** Reisman, H. and Tendorf, Z. A., **Dynamics of initially stressed plates,** *Journal of Applied Mechanics,* **43,** Series E, 2, June 1976, 304-308.

A formalism is presented for the solution of supported plates of bounded extent, subjected to time-dependent transverse forces and boundary conditions. Initially, and during the course of the motion, the plate is assumed to be in an arbitrary (stable) state of membrane stress. An example of a suddenly loaded, simply supported, rectangular plate is presented. The membrane prestress in the example problem is assumed to be constant and parallel to two opposite edges of the plate.

● **6.12-108** Rock, T. A. and Hinton, E., **A finite element method for the free vibration of plates allowing for transverse shear deformation,** *Computers & Structures,* **6,** *1,* Feb. 1976, 37-44.

An isoparametric quadrilateral plate bending element is introduced and its use for the free vibration analysis of both thick and thin plates is examined. Plates of rectangular planform and of orthotropic materials are analyzed and excellent results are obtained. The element performance is assessed by comparison with well-established analytical and numerical solutions based on Mindlin's thick plate theory, three-dimensional elasticity solutions and solutions based on thin plate theory. The ease with which the element may be implemented is stressed. The use of an eigenvalue economizer which produces considerable economy in the computer solution is demonstrated. Various mass lumping schemes and numerical integration rules used in the construction of the element mass matrix are also examined.

● **6.12-109** Shibata, A., **Equivalent linear models to determine maximum inelastic response of nonlinear structures for earthquake motions,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 236, 831-838. (For a full bibliographic citation see Abstract No. 1.2-9.)

An equivalent linear model to simulate the maximum inelastic response of a hysteretic single-degree-of-freedom system is discussed. A comparison of the maximum inelastic responses of nonlinear systems and corresponding equivalent linear systems is included. An interpretation of the general trends of inelastic earthquake response in terms of equivalent linear response and the shape of the earthquake response spectrum is presented.

● **6.12-110** Chowdhury, P. C., **The truncated Lanczos algorithm for partial solution of the symmetric eigenproblem,** *Computers & Structures,* **6,** *6,* Dec. 1976, 439-446.

The Lanczos method is programmed in a truncated version where the generalized eigenvalue problem is transformed into a standard eigenproblem of a tridiagonal matrix of reduced order. Recent developments have removed a long-standing objection to this method on the grounds of numerical instability and it is now a very efficient method for the partial eigensolution of large, sparse, symmetric matrices. The program is flexible enough to allow the user to define any storage mode that particularly suits the sparsity pattern in each problem. A numerical example is presented to illustrate the power of the method and to compare it with the simultaneous iteration method.

● **6.12-111** Kadar, I., **Three-dimensional structural programs in every day usage,** *Computers & Structures,* **6,** *6,* Dec. 1976, 481-487.

This paper describes recent experiences with the usage of three-dimensional programs and gives some guidelines for their selection. It also will show advantages in their use. The need for analyses of complex, irregularly shaped structures frequently arises. To solve the limitation of two-dimensional and axisymmetrical programs, previously used in analyses of the nuclear industry, many three-dimensional programs have become available. These structural programs offer a practical method for the analyses.

A wide range of occasions exist for use of three-dimensional programs in the various approximate analyses of nuclear structures. The descriptions of four approximate analyses are given. The medium-sized models utilized plate bending elements and provided timely results in less than ten engineering days. Some analyses included nonlinear approaches to simulate the cracking of the concrete.

For the detailed analysis of an entire complex structure, the use of the three-dimensional structural programs is even more advantageous. Rotated shapes integrated with rectangular structures cannot be easily analyzed using only two-dimensional or axisymmetrical programs. The detailed analyses for two complex structures are described. A large size model was prepared for the analysis of each entire structure; then several partial details were analyzed using smaller, more refined models. Boundary conditions for the detailed models were taken from the analyses of the entire complex structure. Both horizontal and vertical seismic loads were considered for one of the structures.

There are several aspects to consider in the selection of three-dimensional programs. They include: program availability, analysis method, element type, computer economy and engineering time. Three-dimensional structural programs are now readily available to provide reliable analyses for many design problems encountered in the nuclear industry. It is the hope of the author that this paper will help extend their usage to everyday engineering applications.

● **6.12-112** Bailey, C. D., **Hamilton, Ritz, and elastodynamics,** *Journal of Applied Mechanics,* **43,** Series **E,** *4,* Dec. 1976, 684–688.

The theory of Ritz is applied to the equation that Hamilton called the "law of varying action." Direct analytical solutions are obtained for the transient motion of beams, both conservative and nonconservative. The results achieved are compared to exact solutions obtained by the use of rigorously exact free-vibration modes in the differential equations of Lagrange and to an approximate solution obtained through the application of Gurtin's principles for linear elastodynamics. A brief discussion of Hamilton's law and Hamilton's principle is followed by examples of results for both free–free and cantilever beams with various loadings.

● **6.12-113** Vujanovic, B., **The practical use of Gauss' principle of least constraint,** *Journal of Applied Mechanics,* 43, Series E, *3,* Sept. 1976, 491–496.

In this paper, Gauss's principle of least constraint is used to obtain approximate solutions of conservative and nonconservative dynamic systems. The main feature of the method is that every particular problem is reduced to an algebraic problem of minimizing a quadratic form with respect to the physical components of the acceleration vector of the system, or with respect to the components of a generalized force. The method is illustrated by solving several problems. The method is equally applicable to ordinary as well as partial differential equations. A brief criticism of the least-squares method, as a method of solving differential equations, is given.

● **6.12-114** Khan, A. H. and Stafford Smith, B., **A simple method of analysis for deflection and stresses in wall-frame structures,** *Building and Environment,* **11,** *1,* 1976, 69–78.

A simplified method of analysis for tall shear wall-frame structures with regular window openings is proposed. The method idealizes a basic structure into an assemblage of "analogous plate-modules" whose stiffness properties are evaluated from finite element computer analyses. The idealized structure, an unperforated cantilever wall with equivalent stiffness properties, is then analyzed by hand using the theory of bending for design deflections and stresses.

● **6.12-115** Danay, A., **A general element for analysis of asymmetric multi-storey buildings with varying cross-section,** *Building and Environment,* **11,** *1,* 1976, 57–67.

The paper presents a finite element method for analysis of asymmetric multistory buildings with varying cross section. The basic structural component is a rectangular thin panel bounded between floors and vertical edges. Its behavior is governed by the conventional axial, bending and shear assumptions of beam theory. The element displacement vector consists of four corner axial movements and top and bottom floor translation and rotation. Two additional displacements, related to the compatibility along the vertical sides, are temporarily included prior to the condensation of the stiffness matrix of shear wall substructures of floor height. This approach allows a uniform type of solution for all common components, e.g. open, closed or mixed cross-section coupled shear walls and frames.

Since the conventional assumptions of the open and closed shear wall theories are included, this finite element method provides identical numerical results. As a computer program basis, it has the following advantages: (a) minimum amount of data due to the absence of conventional sectional properties, (b) uniform solution for common structural components, (c) inclusion of varying cross-section and different foundation types, (d) direct output of stresses for each nodal point.

● **6.12-116** Oran, C. and Kassimali, A., **Large deformations of framed structures under static and dynamic loads,** *Computers & Structures,* **6,** *6,* Dec. 1976, 539–547.

With reference to the problem of large deformations and stability of elastic framed structures, this paper explores the computational capabilities of a general beam-column type method which was recently developed by the senior author. The method is flexible in that the coordinate system used may be either Eulerian or Lagrangian. In addition, various types and levels of consistent approximations can be introduced into the analysis in a rather routine fashion.

In an effort to evaluate the merits of the method in the static case, extensive numerical studies were carried out on a group of specially selected and relatively simple structural systems. In formulating the dynamic case, use was made of a well-known numerical integration technique, namely, the so-called "Newmark β method". Again numerical studies were carried out, although on a smaller scale than in the static case. These studies clearly indicate that the suggested method is both practical and highly accurate.

● **6.12-117** Henghold, W. M. and Russell, J. J., **Equilibrium and natural frequencies of cable structures (a nonlinear finite element approach),** *Computers & Structures,* **6,** *4/5,* Aug.–Oct. 1976, 267–271.

This paper concerns the finite element method as applied to cable structures. A family of nonlinear elements is developed. The class of elements developed retains all geometric nonlinearities and allows for any elastic deformation. The problems of static deflection and natural frequency determination for small oscillations about the

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

nonlinear equilibrium position are investigated for single-span cables.

● **6.12-118** Watanabe, H., **The verification of reliability of a numerical method of seismic analyses for rock and earth fill dams through both model tests and observation of earthquake on an actual dam,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 222, 719–726. (For a full bibliographic citation see Abstract No. 1.2-9.)

● **6.12-119** Capurso, M., **Displacement bounding principles in the dynamics of elastoplastic continua,** *Journal of Structural Mechanics,* 3, *3,* 1974–1975, 259–281.

General bounds on the total displacements of structures subjected to any dynamic loading process are developed for an elastic perfectly plastic material. These bounds are subsequently extended to linear kinematic hardening materials. Previously developed bounds for the dynamics of impulsively loaded structures are recognized to be particular cases of the present formulation. A simple example indicates that the proposed technique is relatively easy to use for numerical computations.

● **6.12-120** Szilard, R., **A numerical procedure for independent check of finite element solutions,** *Computers & Structures,* **6**, *4/5,* Aug.-Oct. 1976, 291–296.

This paper deals with the following problems: Given a matrix-displacement solution of a structural system, (1) how can the analysis be tested for its correctness; (2) how can the total error of the finite element solution be estimated and (3) its convergence accelerated? The proposed technique is essentially a finite-difference-based variational approach which utilizes displacements (computed by an F.E. approach) in higher-order finite difference expressions for the total potentials pertinent to individual nodal subdomains. Numerical examples illustrate the effectiveness of the proposed technique. Although these sample problems are limited to static, linear-elastic, small-deflection structural theories, the present method has much broader applicability.

● **6.12-121** Hughes, T. J. R., **Stability, convergence and growth and decay of energy of the average acceleration method in nonlinear structural dynamics,** *Computers & Structures,* **6**, *4/5,* Aug.-Oct. 1976, 313–324.

The subject of this paper is the stability, convergence and growth and decay of energy of the average acceleration method applied to a class of linear and nonlinear elastic problems encountered in structural dynamics. A discrete energy identity is obtained and the cause of the spurious growth and decay of energy, noted in nonlinear problems, is exhibited. A notion of stability in energy is defined which guarantees that for small time steps energy is asymptotically conserved and for large time steps amplification of higher modes does not occur. By way of the energy identity, the average acceleration method is proved to be stable in that sense. Furthermore, convergence is proved and the rate of convergence is shown to be second order, with respect to time step, for both displacements and velocities.

● **6.12-122** Carroll, W. E., **Inclusive criteria for optimum grid generation in the discrete analysis technique,** *Computers & Structures,* **6**, *4/5,* Aug.-Oct. 1976, 333–337.

A majority of the literature dealing with optimum idealization geometry has been confined to a consideration of the elastostatic displacement formation. Primary to this work has been the recognized dependence of system potential energy on both displacements and grid geometry and subsequent optimization. Recent work by the author has extended the concept of an optimum idealization geometry to include a general class of problem based on considering the Lagrangian a function of grid geometry. A variational formulation is shown to yield more inclusive criteria.

The main focus of this paper is the establishment of criteria for selecting "optimum grids" for this broader class of problems with emphasis on the elastodynamic displacement formation. Based on this discussion, guidelines are presented along with the results of an investigation dealing with elementary problems of the elastodynamic class. Conclusions indicate improved values of eigenvalues for the free vibration analyses.

● **6.12-123** Duffey, T. A., Romesberg, L. E. and Schreyer, H. L., **The construction and use of N-dimensional lower bound failure surfaces,** *Computers & Structures,* **6**, *4/5,* Aug.-Oct. 1976, 355–361.

This paper describes a technique for constructing and using lower bound (conservative) interaction surfaces for yielding or failure of structural elements in terms of generalized stresses. The generation scheme makes use of any available one, two or higher dimensional interaction data for the structural element of interest and the resulting surfaces inscribe the actual (unknown) interaction hypersurface which is assumed to be convex. Due to the large quantity of lower dimensional interaction data available for reinforced concrete, the method is particularly suited for the development of multidimensional interaction surfaces for this material. When used in conjunction with large computer programs capable of accurately predicting the multidimensional state of generalized stress, these higher dimensional interaction surfaces elevate the determination of yielding or failure in terms of generalized stress to a more rational basis. The technique for utilizing these surfaces in conjunction with a finite element program for demonstrating structural adequacy is outlined. The use of the method with the shock spectra approach for the

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

seismic analysis of structures and with buckling analyses of structures under combined loads is also presented.

● **6.12-124** Barber, R. B. and Blotter, P. T., **Component mode analysis of frames with shear walls,** *Computers & Structures,* **6**, *4/5,* Aug.-Oct. 1976, 397-403.

A direct solution for the dynamic analysis of multistory frames with shear walls using finite element modeling techniques may exceed the size limitations of the computer and/or lead to errors in numerical calculations and long computer times. The application of component mode dynamic analysis techniques for the analysis of this type of structure was evaluated in this study. The accuracy of the results obtained, the comparative costs, and the advantages and disadvantages of the component mode method were investigated.

A computer program which utilizes finite element modeling techniques and component mode dynamics analysis was written as a part of the study. Multistory plane frames with shear walls were investigated using both standard and component mode methods of dynamic analysis. A refined plane stress finite element was utilized to model the shear walls.

The results of the investigation showed that excellent frequency accuracy can be obtained using component mode methods for both the two- and three-substructure cases studied. The first two lateral mode shapes were accurately predicted for the models studied, and good response results were obtained for both a step function and a low frequency cyclic base excitation. Good results were obtained even when the normal modes of each substructure were severely truncated (truncation of the substructure normal modes is basic to the method). It was determined that computer costs could be reduced if a sufficient number of normal modes were truncated. The relative length of the substructures used to define the plane frame structure was found to have little effect on the predicted frequencies. However, the substructure lengths did affect the mode shapes. The component mode method of dynamic analysis was found to be a very useful tool in the analysis of multistory structures.

● **6.12-125** Rao, C. V., Raju, K. K. and Raju, I. S., **Finite element formulation for the large amplitude free vibrations of beams and orthotropic circular plates,** *Computers & Structures,* **6**, *3,* June 1976, 169-172.

A finite element formulation for the large amplitude free oscillations of beams and orthotropic circular plates is presented in this paper. The present formulation does not need the knowledge of longitudinal-inplane forces developed due to large displacements and thus avoids the use of corresponding geometric stiffness matrices, which were used in earlier finite element formulations. The convergence of the results obtained by using the present formulation is very good. Comparison of the present results with earlier work wherever possible confirms the reliability and effectiveness of the present finite element formulation.

● **6.12-126** Tsipouras, P., **Triangular finite elements for Poisson's equation with nodal derivatives,** *Computers & Structures,* **6**, *3,* June 1976, 173-176.

Explicit values are given for the element stiffness matrices of two triangular finite elements for Poisson's equation in the plane: one with four nodal points including derivatives as nodal values at the vertices and another without a central point. These provide $O(h^6)$ and $O(h^4)$ accuracy in the energy, respectively.

● **6.12-127** Bathe, K.-J. and Ozdemir, H., **Elastic-plastic large deformation static and dynamic analysis,** *Computers & Structures,* **6**, *2,* Apr. 1976, 81-92.

The problem of formulating and numerically implementing finite element elastic-plastic large deformation analysis is considered. In general, formulations can use different kinematic descriptions and assumptions in the material law, and analysis results can vary by a large amount. In this paper, starting from continuum mechanics principles, two consistent formulations for elastic-plastic large deformation analysis are presented in which either the initial configuration or the current configuration is used for the description of static and kinematic variables. The differences between the formulations are clearly identified and it is established that, depending on the elastic-plastic material description, identical numerical results can be obtained. If, in practice, certain constitutive transformations are not included, the differences in the analysis results are relatively small in large displacement but small strain problems. The formulations have been implemented and representative sample analyses of large deformation response of beams and shells are presented.

● **6.12-128** Parameswaran, M. A. and Sukumaran, K., **A lumped mass vibration model of a slender latticed cantilever,** *Computers & Structures,* **6**, *2,* Apr. 1976, 107-109.

A relatively simple numerical iterative procedure for estimating the normal modes of flexural vibrations of a slender, multipanel latticed cantilever, tapered or straight, is developed. The cantilever is reduced to an N-mass system and the influence coefficients are derived with due consideration to the shear flow through the diagonal bracings. Experimental and computer results of a model are compared.

● **6.12-129** Reddy, J. N., **Modified Gurtin's variational principles in the linear dynamic theory of viscoelasticity,** *International Journal of Solids and Structures,* **12**, *3,* 1976, 227-235.

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

Using Vainberg's theory of potential operators, variational principles are developed for the linear dynamic theory of viscoelasticity. The Euler equations of the functional developed herein are the governing field equations, including the boundary and initial conditions, as opposed to the equivalent set of integro-differential equations of Gurtin's method.

● **6.12-130** Penzes, L. E., Chang, K. H. and Lee, G. E., **Seismic model of the gas cooled fast breeder reactor core support structure,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 8/10, 10. (For a full bibliographic citation see Abstract No. 1.2-11.)

The modeling technique for the seismic analysis of the core support structure of a gas-cooled fast breeder reactor is developed. The core support structure consists of the support cylinder and a perforated grid plate from which 265 fuel and blanket elements are suspended as cantilevered beams. Due to limitations of computer storage and considering the large number of core elements, a well-planned seismic modeling technique is very important to obtain a realistic analysis. The analysis of the core support structure consists of three steps: (a) analysis of the grid plate, (b) analysis of the core elements, and (c) modal synthesis. The dynamic theory of the grid plate is developed by generalizing Reissner-Mindlin thick plate theory with orthotropic constants and then modifying the formulations of the rotary inertia expressions to include the rotary inertia effects of the core elements. In this general case, the differential equation for this problem can be solved by numerical techniques. However, applying the effective elastic constants of the perforated plate in the customary fashion, the solution can be determined analytically in terms of Bessel functions.

By applying the present technique, it is shown that the grid plate fundamental frequency is in the range of the fundamental frequencies of the core elements so that a dynamic coupling effect exists. Due to this dynamic coupling effect, the grid plate cannot be considered a rigid plate for the purposes of seismic analysis of the gas-cooled fast breeder reactor. Hence, a simple spring mass seismic model is inadequate and a more elaborate finite element model applying plate and shell elements is used instead. The technique of modal synthesis is then applied to determine the effects of dynamic coupling and to study the seismically induced motions of the core elements in a realistic manner.

● **6.12-131** Mukherjee, S., **Matrix of transmission in structural dynamics,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 4/4, 13. (For a full bibliographic citation see Abstract No. 1.2-11.)

The problem of close-coupled systems and cantilever-type buildings can be treated efficiently by means of the very general and versatile method of transmission matrix. The expression "matrix of transmission" is used to point out that the method to be described differs fundamentally from another method related to matrix calculus, and also successfully used in vibration problems. In this method, forces and displacements are introduced as the unknowns of the problem. The matrix of transmission relates these quantities at one point of the structure to those at the neighboring point. Results of analysis of a typical nuclear building by this method show very close agreement with the results obtained by using the ASKA and SAP IV programs.

6.12-132 Black, D. C., Pulmano, V. A. and Kabaila, A. P., **Flat plates supported on walls,** *Mémoires Abhanlungen,* 36-I, 1976, 79-91.

In this paper values of the bending stiffness of slabs in cross-wall structures subjected to lateral loads are presented. The cross sectional dimensions of the walls and the dimensions of the slab are fully taken into account. The case investigated is an interior bay of a regular cross-wall building, having a large number of bays in the longitudinal direction and one transverse bay. The walls are subjected to a simultaneous rotation in the same direction about their center lines in the longitudinal direction. From considerations of symmetry only a quarter of the bay is analyzed.

The stiffness values are obtained from elastic analyses of the slab using meshes of compatible quadrilateral plate bending finite elements. With these elements quite coarse meshes may be used. In regions of rapidly changing curvatures, such as near the wall, fine mesh is used. The transition from fine to coarse mesh is facilitated using a mesh grading technique. This technique allows two or more small elements to abut the side of a larger element without violating interelement compatibility. In this manner the monotonic convergence characteristics of compatible elements are maintained in an unorthodox arrangement.

The results are presented as a series of graphs giving the variation of the nondimensional slab stiffness with the aspect ratio of the slab, the span and the thickness of the wall. Curves giving the variation of the effective width of an "equivalent beam" are also given. In addition some results showing the distribution of the moments in the slab are also presented.

● **6.12-133** Bervig, D. R. and Chen, C., **Stability and toe pressure calculation of a reactor building subject to seismic disturbance,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 3/7, 12. (For a full bibliographic citation see Abstract No. 1.2-11.)

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

At the present time, the stability and toe pressure calculation of a reactor building subject to seismic disturbance is still based on the equivalent inertial force method applied statically. Even though it has long been recognized that this method sometimes gives unrealistically high response, especially when uplift is considered, it is still used by the industry due to the lack of better alternatives.

First of all, the equivalent static method fails to admit the fact that the inertial force acts cyclicly instead of constantly in one direction. Second, the maximum inertial force used to calculate stability and toe pressure lasts only a small fraction of a second according to the equivalent linear time history analysis. Of course, the validity of the linear analysis is in doubt when the resulting maximum inertial force predicts extensive uplift. Third, when the maximum inertial force dictates a large amount of uplift, the static force method fails to consider the energy required to raise the center of gravity of a relatively rigid building.

In order to obtain a more realistic response, a more sophisticated model is required in the dynamic analysis. One way of doing it is to use the finite element method and represent the soil by either plane strain or 3-D elements. However, most general purpose finite element programs cannot handle the problem of separation between soil and foundation mat in the dynamic analysis or the nonlinear force displacement curve for the soil. Even if a special finite element program were written for this purpose, the computation cost could be very high due to the nonlinear nature.

It is the intention of this paper to introduce a numerical scheme to handle this nonlinear dynamic problem with reasonable computation cost. A set of nonlinear differential equations is derived by coupling the modal information of a free-free building model with the compression-only nonlinear force displacement curve representing the soil. This formulation has several advantages. These are (1) a rigid body large displacement rotational mode is included in the analysis to account for the uplift, (2) the compression-only nonlinear force displacement curve can be defined at several control points along the building soil interface, (3) the mode shapes used in the analysis are free-free. This allows for a better estimate of the importance of the building flexibility effects on soil pressure since the rigid body modes and flexible modes are separated, and (4) the boundary restraints imposed on the rigid body or free-free modes are a function of the relative motion between the structure and soil.

The set of nonlinear differential equations is solved using a digital computer code that functions as an analog computer. By using this code, the compression-only nonlinear force displacement curve for the soil can easily be handled. A parametric study is conducted to evaluate the importance of uplift, building flexibility and the nonlinear force displacement curve. The results obtained are also compared with the conventional linear dynamic analysis.

● **6.12-134** Rukos, E., **Continuous finite elements,** *E14,* Inst. de Ingenieria, Univ. Nacional Autonoma de Mexico, Mexico City, May 1975, 42.

The standard finite element analysis makes use of the full discretization of the spatial variables in the media, resolving the solution of a complicated boundary value problem formed by one or more partial differential equations into a much simpler one: the solution of a set of algebraic equations whenever only the spatial variables appear.

The discretization of the media at all coordinates but one is presented. This partial discretization leads to continuous finite elements as opposed to fully discrete ones. The elements are continuous in the direction of the nondiscretized coordinate. Due to this partial discretization the problem resolves, for the cases presented, into a set of linear differential equations rather than algebraic equations. The general problem of first derivative functionals in elastostatics is considered and it is shown, in general, how the continuous finite elements required for the solution may be obtained. Plane stress, plane strain, axisymmetric and three-dimensional continuous elements are obtained to illustrate application to particular cases.

Different methods of solution for the set of differential equations are discussed, and the relation of this local partial discretization with existing and widely used techniques is stressed. Infinite and semi-infinite media problems can be directly solved, avoiding the use of fictitious boundaries which can unnecessarily increase the size of the discrete problem and, in some cases, cause the solution to deteriorate.

Simple numerical examples, one finite and the other semi-infinite, are solved to demonstrate the good comparison obtained between the numerical and the exact solutions, even in the case of very coarse discretizations.

● **6.12-135** Lee, T. H. and Wesley, D. A., **Nonlinear seismic response of a series of interacting fuel columns consisting of stacked elements,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 8/5, 10. (For a full bibliographic citation see Abstract No. 1.2-11.)

A theoretical investigation of the dynamic response of an HTGR core during a seismic disturbance has been conducted by developing a nonlinear dynamic model to characterize the motion of the fuel elements in a vertical plane of the core. The analytical model considers a series of fuel columns placed in a plane with boundary structures at

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

the two ends simulating the reflector columns which are elastically supported by the prestressed concrete reactor vessel. Each column is formed by a series of stacked fuel elements constrained by dowels which restrict the relative horizontal movement but allow vertical and rocking motions between elements. The fuel columns are separated from one another by gaps. The motions of the doweled elements are interacting with those of the adjacent columns or boundary structures through the phenomena of impact.

The solution to the problem was made computationally feasible by using only the rigid-body displacements of each individual fuel element as coordinate variables and thereby minimizing the total number of degrees-of-freedom required. The elements are treated as rigid bodies with only surface flexibility characterized by discrete spring elements. For the two-dimensional problem considered here, each element has two translational displacement coordinates and one rotation coordinate. The nonlinear governing equations were derived, using the Lagrangian formulation, with consideration of large rotation effects.

Numerical results are presented for the motions of the fuel elements. Both the free-vibration responses and the forced motions due to boundary excitations resulting from earthquake motion are discussed. Computations were made for problems involving a single column as well as multiple columns. In the multi-column problems, both staggered and nonstaggered configurations were studied.

Some experimental results of the fuel element motions are also discussed. For the simpler problems in which the response quantities could be accurately measured, good correlation between the theoretical results and experimental values has been achieved. The results of this investigation have indicated that the idealization adopted in the fundamental modeling of stacked elements is reasonably accurate in predicting the dynamic behavior of the fuel columns during earthquakes.

● 6.12-136 Leonard, J. W., **An improved modal synthesis method for the transient response of piping system,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 7/2, 10. (For a full bibliographic citation see Abstract No. 1.2-11.)

In this work is explored the feasibility of employing the modal-acceleration method as an improved modal-synthesis method for the dynamic analysis of piping systems. In the modal-acceleration method, the equivalent static responses to transient loadings are combined with the partial sum of superposed modes, each mode being weighted by a participating factor for the transient loading under consideration. Thus the modal-acceleration method can be considered as a refinement of the classical method of modal superposition.

The two basic techniques in current use to predict the forced dynamic response of structural systems are (1) the direct time integration of the equations of motion and (2) the modal-superposition method. The modal-superposition method has the relative advantage of using a single set of basic information describing the dynamic characteristics of the structural system, i.e., the natural modes and frequencies, to generate with slight additional computation the solutions to a multiplicity of different forcing functions for the same structure.

There have been two compounding disadvantages to the successful application of the modal-superposition method computationally. First, for complicated forcing functions, or for forcing functions which tend to excite the higher modes of vibration (as in the case of fluid transients in piping systems), it is often necessary to include the effects of numerous natural modes in the superposition in order to obtain sufficient accuracy. Secondly, there are no current methods of efficiently obtaining uniform accuracy of modal shapes for all the desired modes for a given analysis. The compounding effect of these two disadvantages is that it is the additional higher modes of vibration desired for additional accuracy in the modal superposition that are the most inaccurate. Even if accurate frequencies are calculated for the higher modes, the corresponding mode shapes are usually inaccurate.

One method of alleviating these difficulties is to modify the modal-superposition method so as to require a lesser number of mode shapes to represent the forced response for a given set of transient loadings. There would be additional benefit on a computational-cost basis in that, since less modes are required, the expense of calculating the higher modes could be eliminated. One method which requires less modes in the dynamic analysis is the modal-acceleration method.

In this work the fundamentals of the modal-superposition method are briefly reviewed for a damped multidegree-of-freedom system. Then the modification by inclusion of equivalent static displacement shapes is detailed and used to develop the modal-acceleration method for damped multidegree-of-freedom systems. The potential application of this method in the numerical calculation of forced responses of computer idealizations of multidegree-of-freedom structural systems is explored.

● 6.12-137 Shaw, D. E., **Seismic structural response analysis for multiple support excitation,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 7/3, 8. (For a full bibliographic citation see Abstract No. 1.2-11.)

In the seismic analysis of nuclear power plant equipment such as piping systems, situations often arise in which piping systems span between adjacent structures or between different elevations in the same structure. Owing to the differences in the seismic time history response of different structures or different elevations of the same structure, the input support motion will differ for different supports. If a time history analysis is used to determine the seismic response of a piping system subject to multiple support excitation, the appropriate time histories may simply be used as displacement input time histories at the various supports and the matrix equations of motion integrated directly.

However, the seismic response of nuclear power plant equipment is typically performed using response spectra techniques where the multiply excited structure is characterized by different response spectra at the various supports resulting from the different support time histories. Present state-of-the-art methods for considering this problem are not entirely satisfactory since typically the response is determined by deriving response spectra which can be used at every support. These fictitious response spectra are determined by either enveloping the various support spectra or using the largest of the support spectra. The latter technique is often used for piping systems spanning different elevations in the same structure since floor response spectra typically become greater at the higher elevations.

Both of the above techniques are somewhat arbitrary. The major problem arising from multiple support excitation as characterized by differing support spectra is twofold. First, classical response spectra techniques typically admit to only one response spectrum describing the seismic excitation. Second, the phase relationships of the various support excitations which are present in time history representations are lost in the determination of the support spectra. The consequences of this latter problem are illustrated by a piping system between two supports each having identical time histories except one lags the other by a finite time difference. Both response spectra will be the same so that without consideration of the time lag only symmetric modes of the piping system would be excited, whereas both symmetric and antisymmetric modes would be excited by a time history analysis.

Utilizing classical equations of motion, this paper develops the concept of a frequency dependent participation factor and rotational response spectra accounting for phase differences between support excitations to formulate the seismic response of a structure subjected to multiple support excitation. The essence of the method lies in describing the seismic excitation of a multiply excited structure in terms of translational and rotational spectra used at every support and a frequency dependent spatial distribution function derived from the phase relationships of the different support time histories. In this manner it is shown that frequency dependent participation factors can be derived from the frequency dependent distribution functions.

Examples are shown and discussed relative to closed-form solutions and the state-of-the-art techniques presently being used for the solution of problems of multiply excited structures.

● **6.12-138** Scavuzzo, R. J. and Lam, P. C., **Effect of torsional excitation on equipment seismic loads,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 7/4, 10. (For a full bibliographic citation see Abstract No. 1.2-11.)

It is the purpose of this study to determine the effect of torsional vibration modes on the seismic response of nuclear power plants. Often it is necessary to design a containment structure which has a center of mass eccentric to its geometric center. Under these conditions, torsional vibration modes are excited from lateral seismic ground motions. Specifically, the problems investigated in this study are to determine the response of a structure internal to the containment vessel as a function of mass eccentricity.

The dynamic analysis of the nuclear power plant structure is based on three-dimensional normal mode theory. Modal structural damping is included in the model. Forces and moments to the ground are determined from normal mode methods. Using this approach, ground-structure interaction is represented by six integrodifferential equations, one for each degree-of-freedom. These equations are solved by numerical iteration techniques. In this manner radiation damping caused by ground-structure interaction effects is separated from the smaller structural damping.

Using this mathematical model, two parametric studies are conducted on a three-mass structural model which consists of a containment vessel mass, a base mass and an internal structure mass. By moving the internal structure away from the geometric center of this system, the effects of torsional excitation on the seismic response of the system are studied. Two parametric studies are based on two types of input motions. In the first study, only lateral motion in one direction is input to the system. In the second study, lateral seismic motion in two perpendicular directions and vertical seismic motion are input simultaneously. Results are presented as graphs of the response of internal structure and containment structure as a function of mass eccentricity.

● **6.12-139** Lee, J. P. and Chen, C., **Vertical response of nuclear power plant structures subject to seismic ground motions,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 5/3, 7. (For a full bibliographic citation see Abstract No. 1.2-11.)

In the seismic analysis of nuclear power plant structures, it is generally assumed that the floor slab is "rigid" in its own plane. However, the slab may be quite flexible in the direction perpendicular to the plane of the slab. Thus, two pieces of equipment located at different locations of the same floor may be subjected to two different excitations at their supports, due to vertical ground input. If a simplified stick model with one lumped mass at each floor elevation is used, the effect of the flexibility of the floor on the structural dynamic responses is not taken into account.

There are several methods available to treat this problem related to extra amplification due to floor flexibility. The first method is to use the cascade approach. In this approach, the responses obtained from the stick model are used as input motion to each of the separate flexible floor models. This method is straightforward and the amount of work depends on the degree of sophistication of the flexible floor model. The shortcoming of this method is that the energy feedback from the floor to the building is not taken into account and therefore the resulting responses may be overestimated.

The second method is to model the flexible floor with plate bending elements and combine them with the rest of the building. This integrated model is then treated as a system and subjected to ground excitation. By doing this, the energy feedback of the floor during vibration is automatically taken into account. Consideration of the interaction between the floor and the rest of the structure generally yields structural responses lower than those obtained from the cascade approach. However, the computer cost of this analysis is very high especially in generating the floor response spectra for equipment design.

The third alternative as introduced here is to represent the building by a composite lumped model in which the floor is also represented by lumped masses. The stiffness of the interconnecting spring between mass points is computed from the physical properties of the corresponding floor slab. The advantages of this method are that the feedback effect is properly included and the computer cost is significantly reduced.

In this paper, techniques to model the building and the methods used to obtain the spring constants are presented and discussed. The results obtained using the composite lumped mass model approach and those obtained using the finite element method are compared. Various composite lumped mass models and modeling techniques are recommended for future engineering applications.

● **6.12-140** Stoykovich, M., **Development and use of seismic instructure response spectra in nuclear plants,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 5/4, 12. (For a full bibliographic citation see Abstract No. 1.2-11.)

This paper encompasses methods for the development of instructure response spectra as well as the use of these spectra in the seismic design and analysis of nuclear plant components.

The time history modal analysis, which is the most commonly used method to generate instructure response spectra in the United States, is described. This includes the effects of rigid body transformation associated with angular accelerations of the lumped mass nodal points due to eccentric locations of the equipment or system support points. When the locations of the support points are known, the instructure response spectra are simply generated at these points taking into account translational and angular accelerations in a straightforward manner as far as the formulation is concerned. On the other hand, when the locations of the support points are unknown, a general way of generating and using the instructure response spectra associated with both translational and angular input motions is presented. In this case the instructure response spectra due to translational excitations are used in conjunction with the one due to rotational excitations.

Various numerical techniques for the integration of differential equations of motions are outlined. The time interval to be used in each method of numerical integration is chosen so as to avoid mathematical instability and inaccuracy. Comparison of the results using different techniques for the numerical integration of a sample problem, for the purpose of verifying solution accuracy, is provided. Methods of developing instructure response spectra other than the time history method are discussed. The use of three-dimensional instructure response spectra developed for each of the three orthogonal translational directions of ground motion is presented. Since the records show that earthquake motions occur in all three directions simultaneously, without consistent relations among them, the evaluation of the combined effects of these motions on equipment, systems and other components is described.

● **6.12-141** Kost, G., Tsui, E. Y. W. and Krutzik, N., **Axisymmetric finite element analyses of the KKP-II containment and reactor pressure vessel structures,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 6/2, 10. (For a full bibliographic citation see Abstract No. 1.2-11.)

Two refined axisymmetric finite element models were used for the dynamic seismic analyses of the KKP-II containment and RPV structures, using a postulated ground motion time history. One model was established primarily for the response of the containment structure, whereas the other was used for the response of the reactor pressure vessel plus internals.

In the first model, refined axisymmetric thin shell and solid elements were used for the containment components,

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

while fluid elements were employed to represent the hydrodynamic effects of the fluid entrapped between the steel shells. Effects of the reactor building, RPV and internals, foundation mat, as well as soil-structure interaction, are included, using equivalent cylindrical or solid elements and suitable classical solutions of rigid plates on an infinite halfspace. Eigenvalues of the structural components of this model were generated and compared with those of similar but three-dimensional models established for KKP-I. The correlations were quite satisfactory.

In the second model, both refined beam and shell elements were used to represent the internals and pressure vessel, while fluid elements were used for the water contained within the RPV. Whenever hinged boundary conditions were encountered, the corresponding rotational degree-of-freedom was suppressed. Effects of the reactor building, concrete and steel containments, foundation mat and soil-structure were likewise considered in this model, using relatively coarser equivalent finite elements. To solve the resulting consistent mass matrices efficiently, the determinant search eigenvalue extraction iterative technique was utilized.

The modal superposition procedure was used to generate most of the solutions of the present analyses, applying the recently updated digital program ASHSD3. For the purpose of determining the stress distributions within the internals more critically, a beam element and several special boundary conditions have been incorporated in this program. It now accepts four different types of elements, i.e., shell, solid, fluid and beam, and is capable of producing desirable force resultants and stresses, either by the isotropic beam theory or orthotropic shell or solid theory. To ensure that the dynamic characteristics of the present models are accurate enough to provide meaningful response, eigenvalues and vectors of these models have also been compared with those of similar three-dimensional beam models. It was found that both results show good agreement especially concerning the fundamental frequencies.

6.12-142 Stanisic, M. M., **Convergence of an iterative solution for a class of nonlinear vibration problems,** *The Journal of the Acoustical Society of America,* **59**, *5*, May 1976, 1180–1183.

A nonlinear equation describing the motion of a nonlinear oscillator has been reduced by proper substitution to an integro-differential equation and then solved by means of an iterative technique for an arbitrary forcing function. The effect of the nonlinear terms on the convergence has been studied. It has been shown that such a solution converges sectionally in an interval $\Delta\tau$. An inequality has been determined which yields a maximum $\Delta\tau$ regardless of the form of the forcing function if $\epsilon = 0$. However, for a nonzero ϵ the interval of convergence is highly dependent on the form of the forcing function.

6.12-143 Malyshev, L. K. and Shulman, S. G., **On the seismic response of massive structures** (K raschetu massivnykh sooruzhenii na seismicheskie vozdeistviya, in Russian), *Izvestiya VNII gidrotekhniki, 108,* 1975, 168–178.

Stresses and strains in massive hydraulic structures subjected to seismic excitations are investigated. Various techniques are employed to study the two-dimensional problem for a rectangular block on an elastic base. Stresses and strains are calculated using statistical and spectral methods of seismic analysis, analog accelerograms and stress wave propagation models. Experimental investigations using polarized optical methods and interferometry are also reported. Both horizontal and vertical seismic excitations are considered. The results obtained by the above methods are compared and analyzed. It is demonstrated that the critical excitation phase as described in the wave framework is characterized by stresses not predicted by existing methods in the theory of earthquake resistance.

● **6.12-144** Paz, M. and Wong, J., **Response of self strained structures to multiple time-phased seismic excitation,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 4/8, 8. (For a full bibliographic citation see Abstract No. 1.2-11.)

In a recent publication the authors presented a parametric study of the seismic response of simple structures as affected by the existence of axial forces. The fundamental dynamic characteristics such as the natural frequencies and mode shapes are influenced by the presence of axial forces. As a consequence, the response changes to the extent that the influence of these forces is relevant in the interaction of a particular structure and a given ground motion.

This paper presents a further development of the previous study and considers the response of self-strained structures subjected to multiple time-phased seismic excitation. The objective is to determine the effect of ground motion on a structure subjected to a time-phased ground motion at multiple supporting points and also subjected to self-straining which may be induced by temperature gradients, mechanical actions, or prestressing.

The structure is discretized and analyzed by the finite element method. The governing equations of motion are expressed in terms of stiffness, mass, and geometric matrices and a parameter accounting for the self-strain effect. The homogeneous solution of these equations leads to an eigenvalue problem from which the natural frequencies and the corresponding mode shapes can be obtained. These results are used to write the modal equations, and the time-phased ground motion is applied to these equations. The

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

solution of the modal equations is obtained for the specific ground motion using a piecewise linearized accelerogram. The final time response is then obtained by the superposition of the corresponding modal equations. Several typical ground motions including the well-known El Centro earthquake of 1940 are applied to several structures in which the amount of self-strain as well as the time-phased multiple excitation is varied parametrically. The final results are plotted to illustrate both the effects of self-straining and time-phased excitation on the structural response and the interaction between structure and a given ground motion.

6.12-145 Monakhenko, D. V., **On the methodology of modeling earthquake response of dams** (O metodiki modelironvaniya seismostoikosti plotin, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh*, 78–83. (For a full bibliographic citation see Abstract No. 1.1-7.)

Fundamental problems in the methodology of investigations of the earthquake resistance of dams using models are discussed, including problems in the analysis of equations, dimensions, choice of model scale, the modeling of seismic events and the effects of differing properties of the material of the model and the object investigated.

● **6.12-146** Malik, L. E. and Bertero, V. V., **Contribution of a floor system to the dynamic characteristics of reinforced concrete buildings,** *EERC 76-30*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Dec. 1976, 290.

A practicable and sufficiently accurate stiffness matrix method for estimating the contribution of a floor system to the overall elastic stiffness of moment resisting space frames is developed. The floor system considered consisted of a two-way reinforced concrete slab supported on beams between columns. This stiffness matrix method is achieved by performing extensive parametric finite element analyses to identify the main parameters affecting and therefore controlling the stiffness of individual floor panels of the floor system. The stiffness of a two-way slab floor panel has been investigated by establishing an 8 x 8 panel stiffness matrix based on two rotational degrees of freedom (DOF) at each panel support. Stiffness matrix elements are determined by computing the moments necessary to produce a unit rotation at one support DOF while restraining the other seven DOF in the panel. Existing finite element computer programs are used in these computations. A series of rectangular finite elements model the bending and membrane stress-strain relations of the floor slab. The beams are modeled as uniaxial, prismatic members, connected by rigid links to the slab finite element nodes along the beam's centerline. Analytical tests confirm this method's accuracy in estimating the beam-slab composite action in flexible floors.

Floor panels are classified in different categories according to their location in the floor system. To identify the principal parameters controlling the stiffness of these different types of floor panels, a total of 122 two-way slab floor panels, including 70 single panels, 14 corner panels, 28 interior panels and 1 exterior panel, are analyzed. The range of parameters included in the investigation encompasses most of the two-way reinforced concrete floors to be encountered in practice.

The stiffness matrix method, which is based on the results of parametric studies, estimates the elastic rotational stiffness of a floor as that of equivalent, uniaxial memebers between adjacent column floor supports. This method does not identify a physical cross section for the equivalent members; rather, it establishes a procedure by which the position of the neutral axis of the member in relation to the top of the slab and the member stiffness matrix is computed directly from a set of graphs. Each equivalent member has a 3 x 3 stiffness matrix based on one torsional and two flexural DOF.

The accuracy and practicability of the stiffness matrix method, as well as of those methods currently in use, such as the ACI 318-71 equivalent frame method and an effective slab width method for predicting the lateral stiffness of moment-resisting space frames, is evaluated by applying all these methods to 27 single-story, single-panel structures and one single-story, multipanel structure. The results are compared with those from analyses using a finite element method. These methods, with the exception of the finite element method, are also used to predict the dynamic response of two multistory buildings. The results obtained raise serious questions as to the accuracy of equivalent frame and effective slab width methods for such predictions. The developed stiffness matrix method is found to be not only sufficiently accurate, but also simple and economical to use in practice because it can be applied directly in existing frame analysis computer programs or in manual calculations using techniques such as moment distribution. A number of recommendations for improving the method developed herein as well as for extending it to other reinforced concrete floor systems are also suggested.

● **6.12-147** Hilber, H. M., **Analysis and design of numerical integration methods in structural dynamics,** *EERC 76-29*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Nov. 1976, 102. (NTIS Accession No. PB 264 410)

The objective of the present work is to develop one-step methods for the integration of the equations of structural dynamics which (a) are unconditionally stable, (b) have an order of accuracy not less than two, and (c) possess numerical dissipation which can be controlled by a parameter other than the time-step size. In particular, no numerical dissipation must be included. Four new families of

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

algorithms are discussed from this point of view, and compared with algorithms, such as the Newmark, Wilson and Houbolt methods, which are commonly used in structural dynamics and which do not achieve these requirements.

The algorithms introduced first are derived from the Newmark formulas by adding step-size-dependent viscous damping terms in the discrete equations of motion. The analysis reveals that the artificial viscosity of these schemes does not effectively filter out undesirable high-frequency modes. In fact, it is shown that the qualitative behavior of artificial and real viscous damping terms is essentially the same, inasmuch as both are practically ineffective in high-frequency modes. Based on this experience a one-parameter family of algorithms is developed with properties (a) to (c). Some members of this family more accurately integrate the low-frequency modes than the Wilson methods, yet are more strongly dissipative in the high-frequency modes. The new methods have commensurate storage and computational efforts when compared with Newmark and Wilson methods.

The third family of algorithms discussed in this work is based on equilibrium collocation and can be viewed as a generalization of the Wilson methods. Schemes are identified which achieve requirements (a) to (c), which are optimal with regard to dissipative and dispersive characteristics, and which possess improved properties compared to the Wilson method. However, large peak-amplitude errors occur when the step size is greater than the smallest period of the system; hence, collocation methods (including the Wilson methods) are not recommended for most problems of structural dynamics.

Finally, a set of higher-order algorithms is analyzed. They are unconditionally stable, have an order of accuracy not less than three with respect to the undamped and the damped equations of motion, and do not generate a response which goes beyond the exact solution. The price for these improvements is increased storage requirements and higher computational costs per time step in comparison with the previously considered methods.

● **6.12-148** Srichatrapimuk, T., **Earthquake response of coupled shear wall buildings,** *EERC 76-27,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Nov. 1976, 138. (NTIS Accession No. PB 265 175)

An efficient analytical technique for determining linear and nonlinear responses of coupled shear wall structures is developed. Walls are assumed to be nonyielding with all inelastic action confined to coupling beams. Structural displacements are then represented as a linear combination of the first few natural mode shapes in both lateral and longitudinal (vertical) vibration of individual walls which are treated as independent cantilevers. The number of degrees-of-freedom of the system is thereby substantially reduced. With such a reduction technique, vertical inertia need not be neglected and any mechanical model for coupling beams may be incorporated into the analysis.

The effectiveness and flexibility of this general approach in reducing the number of degrees-of-freedom are demonstrated. The technique results in a considerable reduction in computational effort when compared to standard programs used to analyze inelastic structural response.

The analytical technique is implemented in earthquake response analyses of two coupled shear wall systems; analytical results are then correlated with observations of earthquake damage in these structures. The earthquake response of coupled shear walls is then interpreted, and design considerations for efficient earthquake-resistant shear wall systems are suggested.

● **6.12-149** Matzen, V. C. and McNiven, H. D., **Investigation of the inelastic characteristics of a single story steel structure using system identification and shaking table experiments,** *EERC 76-20,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Aug. 1976, 143. (NTIS Accession No. PB 258 453)

In this report, system identification is used to formulate a realistic nonlinear mathematical model to represent the seismic behavior of a single-story steel structure. With this model and the parameters established for it, the energy absorbing characteristics of the structure are investigated. During this study, system identification itself is examined to determine how it can be better utilized in structural engineering.

There are three major parts to this research. The first is the mathematical development of system identification to meet the particular needs of this problem. This development involves the formulation of a second-order nonlinear differential equation with linear viscous damping and Ramberg–Osgood type hysteresis. The equation contains four independent parameters: the viscous damping coefficient and the three Ramberg–Osgood parameters. All four are left open to be established in the identification process. To integrate the equation an iterative routine that uses linear acceleration and residual load correction is developed. An integral squared error function is used to evaluate the "goodness of fit" between the model's response and the structure's response when both are subjected to the same excitation. The function includes errors in both displacements and accelerations and is integrated from zero to a time T, which may be the full duration or only a portion of it. The error function is minimized using a modified Gauss-Newton method. The set of parameters that define the minimum squared error is the best set possible for the model and test data.

The computer program which incorporates the system identification process is verified by using simulated data. A variety of numerical experiments are tried, and in every case the program converged in very few iterations to the minimum error.

The second part of the research involved shaking table experiments in which a single-story steel frame was subjected to several earthquake excitations. The tests were designed to give specific information about the structure: how its behavior depends on the particular excitation, and how the previous loading history affects its subsequent behavior.

The last part of the research is the use of test data in the identification program to establish the four parameters in the mathematical model. When different values are used for T, parameter sets are established which give the best model response for that amount of test data. The resulting sets of parameters reflect the way in which the properties of the structure change during the excitation.

When a virgin structure is tested, the hysteretic behavior in the first few seconds is approximately elastic, perfectly-plastic. Beyond that time, the hysteretic behavior stabilizes and the loops become more rounded. Even when the structure was no longer virgin, there were two distinct phases of response. For small values of T, the parameters reflect the initial phase of response, which appears to be different for different loading histories and different earthquake motions. As T was increased the influence on the parameters of the first phase diminished. When the full duration was used, the parameters reflect the stable hysteretic behavior almost exclusively.

A surprising result of this work is that the parameters found from the full durations of the three different excitations were almost identical. For each of these sets of parameters, the correlation of the computed accelerations with the measured is excellent, and the shape of the computed displacement response compares very well to the measured response, although the permanent offset of the displacement is not computed exactly.

Suggestions are given on how to overcome this deficiency in the mathematical model. Also, several ideas on how to make system identification more useful to structural engineers are given as topics for future research.

● **6.12-150** Ray, D., Pister, K. S. and Polak, E., **Sensitivity analysis for hysteretic dynamic systems: Theory and applications,** *EERC 76-12,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1976, 61. (NTIS Accession No. PB 262 859)

Sensitivity analysis, calculation of the rate of change of response variables with respect to design variables, is a critical component in the process of reanalysis for improvement of trial designs or in seeking an optimum design. This report presents necessary theorems and provides details for numerical computation of sensitivity matrices for spatially discretized structural systems subjected to dynamic excitation. General results are presented for nonlinear (hysteretic) structures and explicit numerical examples illustrate the methodology applied to multistory shear frames whose force-displacement relationship is bilinear hysteretic.

6.12-151 Atrakhova, T. S., Golubyatnikov, V. L. and Nikiforova, M. M., **Prediction of dam response to seismic excitation** (Prognoz reaktsii plotin pri seismicheskom vozdeistvii, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 118–121. (For a full bibliographic citation see Abstract No. 1.1-7.)

A technique is presented to process weak earthquake records and to obtain artificial records of strong earthquakes in the same region by extrapolation. The technique is applied to predict the response of the dam of the Golovnaya hydroelectric power plant. The response to the artificial accelerogram is calculated using the finite element method. The results are compared to real experimental data obtained during a strong earthquake.

6.12-152 Ostroverkh, B. N., **Numerical dynamic model of inhomogeneous elastic base for massive hydraulic structures** (Chislennaya dinamicheskaya model uprugogo neodnorodnogo osnovaniya dlya massivnykh gidrosooruzhenii, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 15–18. (For a full bibliographic citation see Abstract No. 1.1-7.)

A model of inhomogeneous material is constructed by means of the finite difference method using a lattice with variable dynamic parameters at each node. Propagation of stress waves in a finite section of the base arising from impulse loading at the surface is investigated.

● **6.12-153** Akagi, T., **A method of determining viscoelasticity as damping estimation by forced vibration** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 234, 815–822. (For a full bibliographic citation see Abstract No. 1.2-9.)

● **6.12-154** Nakamura, M. and Matsuoka, O., **Earthquake response analysis considering building size** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 231, 791–798. (For a full bibliographic citation see Abstract No. 1.2-9.)

In this paper structural response when different ground motions occur at each part of a building base is investigated. Acceleration, velocity and displacement of the ground motion are analyzed using spectral and time history methods. It is concluded that when ground motions are different at each part of a building base the response of a system cannot be accurately obtained by considering only acceleration. All inputs should be considered. The difference in the responses changes depending upon the conditions of the structural system. It is further concluded that the ratio of velocity input to total input is very small.

● **6.12-155** Nikolaenko, N. A., Nazarov, Yu. P. and Ulyanov, S. V., **Non-linear space problems in structural earthquake resistance theory,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 263, 1039–1050. (For a full bibliographic citation see Abstract No. 1.2-9.)

This paper discusses problems of constructing a new spatial model for the aseismic design of a structure. Aspects of constructing mathematical models of nonlinear spatial oscillations of the model are considered. The mathematical models are constructed in terms of Lagrangian equations of the second order with application of vector analysis and tensor calculus. To determine the potential energy of spatial-distorted elastic bracing of discrete dynamic systems, design models of elastic bracing are proposed. Agreement between the mathematical model obtained and linear systems of differential equations, well known in the field of earthquake engineering and on which the codes of practice of the U.S.S.R., U.S.A., Japan and other countries are based, is illustrated by some examples.

● **6.12-156** Brusa, L. *et al.*, **A numerical method for vibration analysis of composite structures with different damping capacities,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 4/5, 10. (For a full bibliographic citation see Abstract No. 1.2-11.)

The most important computational problem for vibration analysis of structures is the solution of the eigenvalue problem: $K\delta + \lambda C\delta + \lambda^2 M\delta = 0$ (1). If the structure consists of materials with different damping capacities, it is not always possible to define a similarity transformation which simultaneously diagonalizes matrices K, C and M. In this case the solution of problem (1) is reduced to the solution of the problem: $Ay = \lambda y$ (2). Well-known numerical methods are available for the computation of the complete eigensystem of problem (2) which can be conveniently used for small-size problems.

For large-size problems, such as those arising from finite element applications, the number of eigenvalues and eigenvectors required is usually much smaller than the order of the matrices, so that the solution of problem (2) can be restricted to the evaluation of a few dominant modes.

This paper presents a numerical method for the computation of the first p eigenvalues of the smallest modulus of problem (1), and corresponding vectors. This method is based on the simultaneous iteration concept.

A computer program based on this numerical model and using the finite element method is described.

● **6.12-157** Brusa, L. *et al.*, **A computational method for direct integration of motion equations of structural systems,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 4/6, 8. (For a full bibliographic citation see Abstract No. 1.2-11.)

The dynamic analysis of structural systems requires the solution of a matrix equation. Many numerical methods are available for direct integration of the equation and their efficiency is due to the fulfillment of the following requirements: a reasonable order of accuracy must be obtained for the approximation of the response relevant to the first modes; and the modal contributions relevant to the eigenvalues with large real part must be essentially neglected.

This paper presents a step-by-step numerical scheme for the integration of the equation which satisfies these requirements. The efficiency of the numerical scheme described in the paper has been evaluated by comparing it with some widely used direct integration methods.

● **6.12-158** Kobayashi, S., Fukui, T. and Azuma, N., **An analysis of transient stresses produced around a tunnel by the integral equation method** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 211, 631–638. (For a full bibliographic citation see Abstract No. 1.2-9.)

The paper describes an application of the integral equation method to the analysis of the transient stresses produced around a tunnel. The method used consists of devising a solution for the transient problem for the superposition of appropriate steady-state solutions.

● **6.12-159** Kadar, I., **Approximate and detailed analyses for structures of reactor containment buildings, using three-dimensional computer program,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 6/3, 10. (For a full bibliographic citation see Abstract No. 1.2-11.)

Structural finite element programs are commonly used in the design of nuclear reactor building structures. In several cases, the usual two-dimensional and axisymmetrical programs have not proven to be adequate for the analysis of nonsymmetrical structures or nonsymmetrical loadings. Three-dimensional programs were developed and proved to be fast and reliable tools for the analysis in each phase of the design. During the design of nuclear power plants, there are several occasions when approximate analyses are sufficient: in preliminary designs; in selections between proposed alternatives; in detailed analysis to provide boundary conditions; in case of independent checking analyses; in test analyses with simplified models.

Short descriptions and size of models used are given for the following analyses: (1) preliminary analysis for all structures of a BWR reactor containment building, (2) preliminary analysis for selection of structural solution of a reactor pedestal structure, (3) independent checking analysis for the primary containment structures of a BWR, (4) independent checking analysis of a reactor shield structure, (5) test analysis with a simplified model for the seismic response analysis of a reactor drywell structure.

In the detailed analysis of complex structures, the use of a three-dimensional program is indispensable. Description of analysis and model sizes for two complex structures is given: (1) building structure of a breeder reactor with detailed nonlinear analysis of the internal support structure for 30 million pound hypothetic accident loads. Model sizes: 1570 and 1032 nodes respectively, and (2) drywell structure, which serves as a primary containment and also carries the weight of the upper fuel pools. Loading conditions include internal and external pressures, thermal, seismic, and other loads. Model size: 1350 nodes.

The following conclusions have been drawn: The three-dimensional structural programs are useful tools in every phase of the design of nuclear power plants. Nonlinear and dynamic analyses may also be performed with three-dimensional models. Analyses with simplified models are the best way to test a structural program. The plotting subprograms facilitate the creation of the mathematical model and the evaluation of the output of loading analyses. Familiarity of the engineer with a three-dimensional program increases the speed and effectiveness of the design.

● 6.12-160 Tsushima, Y., Jido, J. and Abe, Y., **Aseismic design of structures with nuclear reactors: Method of earthquake response analysis for reactor internals,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 8/1, 13. (For a full bibliographic citation see Abstract No. 1.2-11.)

The authors have studied and developed analytical techniques for the seismic-resistant design of nuclear power plant structures and have applied these techniques to the analysis of existing structures. Presented is a new method for analyzing the dynamic response of lightweight structures, such as fuel assemblages and shell structures, including drywells, which have dynamic membranous properties and which must be analyzed using multidegrees-of-freedom. General descriptions are provided of analytical investigations using the new method.

6.13 Nondeterministic Methods of Dynamic Analysis

● 6.13-1 Collins, J. D., **Structural system failure analysis in a high load environment,** *Methods of Structural Analysis,* Vol. I, 39-53. (For a full bibliographic citation see Abstract No. 1.2-3.)

A methodology is developed for treating the failure of a structure and its critical contents as a system. Fault trees are used to compute failure of elements and link the elements where coupling or sequential failure is significant. Loads are modeled probabilistically and the failure sequence is incorporated into a Monte Carlo simulation to derive component and system failure probability.

● 6.13-2 Wan, F. Y. M., **Dynamical problems of continuous media with random boundary data,** *International Journal of Solids and Structures,* **10,** *1,* Jan. 1974, 35-44.

A spatial correlation method is formulated for linear dynamic problems in continuum mechanics with random boundary data. The essential feature of the method is the formulation of a nonstochastic mixed initial-boundary value problem for the matrix spatial correlation function of the vector state variable. Whenever Green's function of the stochastic problem cannot be obtained in terms of known functions, a numerical solution of the mean-square response and other second-order response statistics by the spatial correlation method are several hundred times more efficient than any other available method. Further improvements in the computational efficiency of the method for a steady-state stationary response process also are noted.

● 6.13-3 Nickolaenko, N. A. *et al.,* **Non-linear parametrical problems in the theory of seismic structures,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 75, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

Consideration is given to the problems of construction of the methods of statistical analysis for essentially nonlinear parametric systems under random seismic actions. The calculation results, required for determining the conditions of dynamic stability and safety estimation for the main characteristics of nonlinear parametric system fluctuations are adduced. Kolmogorov's method for calculating and solving the corresponding equations forms the basis for the analysis. The vibration analysis methods for spatial systems, systems with suspended equipment and bar (internal) systems are considered. For systems with one and two degrees-of-freedom, the phenomena of the main and composite resonances under parametric disturbances of a seismic type are analyzed.

● **6.13-4** Gazetas, G. and Vanmarcke, E. H., **Approximate random vibration analysis of elastoplastic multi-degree-of-freedom structures,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 961–974. (For a full bibliographic citation see Abstract No. 1.2–7.)

The paper presents a probabilistic dynamic analysis of the inter-story displacement response to earthquake-like excitation of multistory, elastoplastic, shear structures. The paper consists of two parts. In the first part, time-histories of story distortions of a 4-dof structure excited by simulated earthquake motions are presented and the effects of yielding on the apparent mode of vibration of the various stories and on the amount of energy dissipated are shown. In the second part, two mathematical models, predicting the expected values of story ductility factors, are presented. The crude, "independent-springs" model gives rough, upper bound solutions, which appear to be too conservative for very stiff structures. The "improved" model combines the elastic random vibration theory of multidegree-of-freedom structures, the elastoplastic random-vibration theory of simple oscillators, and accounts for the effects that the yielding of a story has on the other stories. The results of the method for these 4-dof structures compare very well with the statistics from 15 simulated motions.

● **6.13-5** Atalik, T. S. and Utku, S., **Stochastic linearization of multi-degree-of-freedom non-linear systems,** *Earthquake Engineering and Structural Dynamics,* **4,** *4,* Apr.-June 1976, 411–420.

An equivalent linearization technique to obtain the response of nonlinear multidegree-of-freedom dynamic systems to stationary gaussian excitations is developed. The nonlinearities are assumed to be single-valued functions of accelerations, velocities and displacements. Using a property of gaussian vector processes, the closed forms of the coefficients of the equivalent linear system are obtained by the direct application of partial differentiation and expectation operators to the nonlinear terms. It is shown that when the nonlinearities possess potentials, the linear system has symmetric coefficient matrices. A geometrical interpretation of the linear coefficients, in connection with the original nonlinearities, is presented. The accuracy is investigated by means of examples.

6.13-6 Makarov, V. P., Kirikov, B. A. and Novozhilov, A. V., **On random vibrations of elastoplastic systems caused by seismic excitations** (O sluchainyk kolebaniyakh uprugoplasticheskikh sistem pri seismicheskikh vozdeistviyakh, in Russian), *Trudy TsNII stroitelnykh konstruktsii, 44,* 1975, 83–87.

An analytical representation is found for the nonlinear relationship between restoring force and displacement. The reliability of a system subjected to random excitations is evaluated by means of static methods. The possibility of an analytical solution for strongly nonlinear problems is demonstrated.

● **6.13-7** Singh, M. P. and Chu, S. L., **Stochastic considerations in seismic analysis of structures,** *Earthquake Engineering and Structural Dynamics,* **4,** *3,* Jan.-Mar. 1976, 295–307.

A method is presented for stochastic modelling of a design earthquake by a power spectral density function for seismic analysis of structures. The method can be adopted with information currently available in the form of design response spectra for earthquake motion. Accurate seismic responses of structures can be easily obtained using such stochastic models. The methods for accurate response analysis of structures with closely spaced modes and for generation of floor response spectra of a building using a prescribed ground response spectrum directly are also presented. The hypothesis that a design earthquake can be modelled by a power spectral density function is used only implicitly in developing these methods.

● **6.13-8** Nikolaenko, N. A. and Burgman, I. N., **Earthquake resistance of structures with suspended masses,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 683–698. (For a full bibliographic citation see Abstract No. 1.2–7.)

This paper deals with the earthquake resistance of structures with suspended masses. Provided are results obtained in studies of linear and nonlinear vibrations of such structures subjected to horizontal seismic loads assumed to be a random process. Damping is considered in the linear analysis. The steady and transfer states of vibrations of frameworks with suspended masses were studied using correlation theory. The statistical analysis was performed using a computer to calculate the dynamic characteristics for different designs. When considering nonlinear problems of the system vibrations, equations with viscous damping and with a nonlinear-elastic diagram of a soft type approximated by a cubic parabola were studied. Differential equations were solved using the statistical linearization method.

● **6.13-9** Kobori, T. and Takeuchi, Y., **On non-stationary spectrum and mean square response of a simple structural system to earthquake excitation,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 857–868. (For a full bibliographic citation see Abstract No. 1.2–7.)

A method for evaluating the nonstationary spectral characteristics of earthquake excitation is presented, using the concept of the nonstationary spectral density under the assumption that the earthquake excitation may be considered as a nonstationary stochastic process. In this paper, the nonstationary spectral density is defined by the finite time-averaged variance of output process of the narrow band filter taking account of the resolution in the frequency and time domains. As to the characteristics of the narrow band filter, the transfer characteristics of a one-mass-system can be made available. The physical interpretation of this nonstationary spectral density is discussed, and the numerical calculations are carried out for several recorded accelerograms. The evaluation of the mean square response of the lumped mass system for the nonstationary spectral density is examined, relating to the procedure of evaluating the maximum structural response from the response spectrum; and the numerical results with regard to the lumped mass type structural models are presented.

● **6.13-10** Wen, Y.-K., **Method for random vibration of hysteretic systems,** *Journal of the Engineering Mechanics Division, ASCE,* **102,** *EM2,* Proc. Paper 12073, Apr. 1976, 249-263.

Based on a Markov-vector formulation and a Galerkin solution procedure, a new method of modeling and solution of a large class of hysteretic systems (softening or hardening, narrow or wide-band) under random excitation is proposed. The excitation is modeled as a filtered Gaussian shot noise allowing one to take the nonstationarity and spectral content of the excitation into consideration. The solutions include time histories of joint density, moments of all order, and threshold crossing rate; for the stationary case, autocorrelation, spectral density, and first passage time probability are also obtained. Comparison of results of numerical examples with Monte Carlo solutions indicates that the proposed method is a powerful and efficient tool.

● **6.13-11** Paez, T. L. and Yao, J. T. P., **Probabilistic analysis of elastoplastic structures,** *Journal of the Engineering Mechanics Division, ASCE,* **102,** *EM1,* Proc. Paper 11914, Feb. 1976, 105-120.

An efficient method for performing first passage analyses and inelastic response analyses is presented. The first passage problem is solved by discretizing the equation of motion for the structure in space and in time to obtain the transition probabilities for the displacement of the structure. The response of elastoplastic structures to stationary excitation is characterized by the probability distributions of cumulative plastic deformation and permanent set. The response process of the structure is discretized in time and in space, and an equivalent vibration process is obtained. The half-cycle information is used to predict response information over a given length of time. Results of numerical examples indicate that the accumulation of plastic displacements differs only slightly between the zero-start case and the stationary-start case for elastoplastic structures.

● **6.13-12** Chokshi, N. C. and Lutes, L. D., **Maximum response statistics for yielding oscillator,** *Journal of the Engineering Mechanics Division, ASCE,* **102,** *EM6,* Proc. Paper 12632, Dec. 1976, 983-993.

Results are presented from an empirical (Monte Carlo) study of the extreme values (i.e., maximum values over an interval of time) of the response of yielding oscillators excited by a random process. An electronic differential analyzer analog computer was used to perform the Monte Carlo simulation. The oscillators considered are of the single-degree-of-freedom type with a bilinear hysteretic restoring force, and the excitation used is stationary normal white noise. The probability-distribution of the extreme value of response of a given system to a given level of excitation is obtained for time intervals ranging at 0.5-10 periods of the response. In addition to results for the zero-start situation, some data for stationary response are included. Because of the close fit of most of the data to the Gumbel distribution, it is possible to characterize the extreme value distribution by plots of the mean and variance of the extreme value versus the length of the time interval used.

● **6.13-13** Yamada, M. and Kawamura, H., **Probabilistic approach to ultimate aseismic safety of structures,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 975-985. (For a full bibliographic citation see Abstract No. 1.2-7.)

In this paper, "steady-state forced vibration" is adopted as a medium to make possible the direct comparison between earthquake loads, dynamic response and ultimate states of structures. First, ultimate state criteria of structures subjected to regulated cyclic loads are given by probabilistic descriptions with the following three random variables: resonance capacity relating to hysteretic energy absorption, deformation amplitude (or equivalent natural period) and number of cycles. Second, it is shown that the characteristics of earthquake loads and structural dynamic response can be expressed by probabilistic distributions of regulated waves and illustrated in the space with acceleration amplitude, period and number of waves.

Finally, combining both the probabilistic properties of ultimate state conditions and the dynamic responses of structures, their ultimate seismic safety is evaluated as a probability of survival. It is emphasized here that fracture conditions of structures should be based on experimental results and that the probability of survival should be used as an objective function in ultimate aseismic optimum design.

6.13-14 Rzhanitsyn, A. R., **Analysis of the combination of time-variant loads** (Uchet sochetanii nagruzok, peremennykh vo vremeni, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii,* 2, 1976, 15-19.

A stochastic analysis of the combination of random loads is presented. The calculation uses only the peak values of loads. The expected duration of simultaneous peak loads and the probability of simultaneous excitation within a given period are calculated. The technique presented here may lead to substantial savings in cases involving several time-variant loads. In practice the simultaneous presence of three or more peak loads may be disregarded and only certain combinations taken into account. In the absence of a full set of statistical data, a rough estimate of the chief parameters is sufficient in most cases.

● **6.13-15** de Silva, C. W., **Optimal estimation of the response of internally damped beams to random loads in the presence of measurement noise,** *Journal of Sound and Vibration,* **47,** *4,* Aug. 22, 1976, 485–493.

A technique is suggested to determine an optimal estimate of beam response to random loads when a set of response measurements with random measurement noise is available. A beam with internal damping represented by a frequency dependent Kelvin-Voigt model is considered. This model introduces both viscoelastic and hysteretic internal damping. Kalman filter theory is used in solving the stochastic estimation problem. A numerical example is given at the end to illustrate the effectiveness of the proposed method.

● **6.13-16** Iyengar, R. N. and Dash, P. K., **Random vibration analysis of stochastic time-varying systems,** *Journal of Sound and Vibration,* **45,** *1,* Mar. 8, 1976, 69–89.

The analysis of the free and forced vibration of a randomly time-varying system is the subject matter of this paper. This is a complicated problem which has received relatively little discussion in the literature. Herein two methods are presented, apart from the digital simulation technique, of finding the response moments. The first one is a series technique which can be considered as a generalization of the well-known Galerkin method. The second method belongs to the class of closure techniques. Upon presuming some of the joint distributions to be Gaussian, equations are derived for the first two response moments. It is shown further that the non-Gaussian output density can be approximately predicted by a simple transformation. Detailed numerical results are obtained and compared with computer-simulated response statistics. It is demonstrated that the methods developed here are highly efficient. In particular it is found that the Gaussian closure approximation has a wide range of application.

● **6.13-17** Roberts, J. F., **First passage time for the envelope of a randomly excited linear oscillator,** *Journal of Sound and Vibration,* **46,** *1,* May 8, 1976, 1–14.

The problem of predicting the probability of first passage failure, P_f, for a linear oscillator excited by white noise is discussed. Two methods are compared, both of which depend on the Markov character of the envelope of the response process; in one a continuous time envelope process is studied whereas in the other the envelope process is considered only at discrete, equi-spaced times. A close relationship between these approaches is demonstrated and the extent to which they offer useful estimates of P_f is assessed by a comparison with simulation results, and with results obtained by an independent method.

● **6.13-18** Holland, C. J., **Stationary small noise problems,** *International Journal of Non-Linear Mechanics,* **11,** *1,* 1976, 41–47.

An approximation technique is demonstrated for estimating stationary averages for a mildly nonlinear dynamic system perturbed by additive white noise with a small coefficient. Numerical examples illustrating the effectiveness of this technique are given.

● **6.13-19** Dimentberg, Jr., M. F., **Response of a nonlinearly damped oscillator to combined periodic parametric and random external excitation,** *International Journal of Non-Linear Mechanics,* **11,** *1,* 1976, 83–87.

An analytical solution, using the Fokker–Planck–Kolmogorov equation, is obtained for the problem of response of a nonlinearly damped oscillator to combined periodic parametric and random external excitation. The solution yields first-order probability densities of amplitude and phase. These expressions are employed to distinguish between oscillations excited by external and parametric periodic forces in the presence of additional broadband random external excitation. Through decoupling of fast and slow motions an approximate expression is obtained for expected value of time to phase "switch".

● **6.13-20** Gazetas, G., **Random vibration analysis of the inelastic multi-degree-of-freedom systems subjected to earthquake ground motions,** *Evaluation of Seismic Safety of Buildings, No. 7, R76-39,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Aug. 1976, 319.

A random vibration method is presented to predict the probability distribution of the maximum inelastic response of deterministic, multidegree-of-freedom, elastoplastic systems subjected to earthquake ground motions described by a single power spectral density function and a strong-motion duration. Extensive simulation studies are used as a guide for the development of the theory, since these studies yield a better understanding of the elastoplastic dynamic behavior of multistory systems.

The theory is evaluated by comparing its response predictions with statistics from multiple time-integration analyses. Various two- and four-degree-of-freedom struc-

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

tures and motions with different frequency content and motion duration are used for this evaluation.

● **6.13-21** Hadjian, A. H. and Hamilton, C. W., **Impact of soil-structure interaction on the probabilistic frequency variation of concrete structures,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 3/8, 10. (For a full bibliographic citation see Abstract No. 1.2-11.)

Earthquake response of equipment in nuclear power plants is characterized by floor response spectra. Since these spectra peak at the natural frequencies of the structure, it is important, both from safety and cost standpoints, to determine the degree of the expected variability of the calculated structural frequencies. The present paper extends a previous work on the variability of the natural frequencies of structures due to the variations of concrete properties and presents a rigorous approach to evaluate frequency variations based on the probability distributions of both the structural and soil parameters and how they jointly determine the distributions of the natural frequencies. The impact of soil properties on the structural frequencies stems from the fact that soil-structure interaction is an important consideration for massive structures.

Although adequate data on the variability of concrete properties exists, very little is known concerning the exact probability distributions of those soil properties that determine the foundation impedance coefficients. To illustrate the methodology used, it is assumed that the soil-structure interaction coefficients are normally distributed. As data on soil property variations become available, the methodology developed here is capable of readily incorporating such data.

The methodology used and the results obtained are discussed. With the proper choice of coordinates, the simultaneous random variations of both the structural properties and the interaction coefficients can be incorporated in the eigenvalue problem. The key methodology problem is to obtain the probability distribution of eigenvalues of matrices with random variable elements. Since no analytic relation exists between the eigenvalues and the elements, a numerical procedure had to be designed. Since accuracy is most important at the extreme high and low fractile values, the Monte Carlo simulation technique was eliminated. It was found that the desired accuracy can be best achieved by splitting the joint variation into two parts: the marginal distribution of soil variations and the conditional distribution of structural variations at specific soil fractiles. Then, after calculating the actual eigenvalues at judiciously selected paired values of soil and structure parameters, this information is recombined to obtain the desired cumulative distribution of natural frequencies.

The study indicates that, unlike fixed base structures, the frequency variation of structure-soil systems for any given exceedance level is not the same for all frequencies. Furthermore, the assumed variability of the impedance coefficients may increase or decrease the over-all frequency variation fractiles from those of the fixed-base structure. As expected, the soil variability impacts only on the interacted frequencies. These frequencies are easily identified from the conditional cumulative distributions and other relationships presented in the paper.

● **6.13-22** Reese, R. C. *et al.*, **Probabilistic approaches to structural safety,** *Journal of the American Concrete Institute,* 73, *1,* Title No. 73-4, Jan. 1976, 37-49.

This is a collection of discussions and opinions based on a forum sponsored by Committee 114, Research and Development, and Committee 348, Structural Safety, at the ACI 1973 fall convention in Ottawa. Realizing the variability in the parameters utilized, accounting for it, and collecting additional data toward an increasing degree of precision are courses of action proposed by proponents of probability.

The authors reviewed the history, accomplishments, and possible directions to take, as well as requirements for probabilistic approach and model analysis.

The following are the discussion titles and authors: *Introduction,* Reese, R. C.—*Background,* Allen, D. E.—*Requirements for probabilistic approach,* Cornell, C. A.—*Ideas for a research program in the reliability of reinforced concrete structures,* Esteva, L.—*Model tests on complete structures,* White, R. N.—*Benefits of the proposed research,* Sexsmith, R. G.—*Probability workshop—Oral summary,* Winter, G.—*Summary,* Reese, R. C.

● **6.13-23** Scanlan, R. H. and Sachs, K., **Floor response spectra for multi-degree-of-freedom systems by Fourier transform,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 5/5, 11. (For a full bibliographic citation see Abstract No. 1.2-11.)

The earthquake response spectrum has become a standard tool in earthquake engineering. This is especially true in nuclear engineering where response spectra are extensively used for the analysis of the structure as well as light equipment.

This paper describes a method of generating floor response spectra from a given ground response spectrum. This time-saving approach makes use of Fourier spectrum techniques and the randomness of phase angles. Good agreement with time history methods is obtained. This method is much faster than time history methods, which are being used in most applications.

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

● **6.13-24** Grossmayer, R., **On the reliability of a simple model under nonstationary earthquake excitation,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 4/7, 17. (For a full bibliographic citation see Abstract No. 1.2-11.)

The aim of the paper is to determine the reliability of an earthquake-excited structure. In contrast to the time history and response spectrum analysis, a stochastic approach is preferred, thus emphasizing the random feature of the nonstationary excitation process.

Seismic response of the structure is analyzed for reliability. The structure is called reliable if a characteristic value $X(+)$ does not exceed a critical level within the lifetime of the structure. The probability of this event is calculated by determining the probability of the disjoint event of first passage.

For exact determination of the first passage probability, a partial differential equation with time-dependent coefficients exists. However, no solution is known because of the complex initial and boundary conditions. Therefore, an approximate solution of the problem must be performed. It can be done by determining upper and lower bounds for the first passage probability according to a formula by Shinozuka. The method is demonstrated with an elastic clamped-free bar model with small viscous damping and makes use of modal analysis. The suspension point of the bar is subjected to a nonstationary excitation process. The procedure followed was executed for various values of the parameters of the bar (stiffness ratio, damping ratio) and the following tendencies were noticed: the stronger the damping in the bar, the closer the upper and lower bounds; the lower the eigenfrequencies of the bar, the closer the upper and lower bounds. However, one has to keep in mind the assumption of elastic behavior with small deflections.

The investigations were completed by generating 30 earthquake sample processes on a digital computer. The so-determined first passage probability fits excellently within the two bounds and divides the interval between them nearly into two halves. Only for higher eigenfrequencies do the numerical values tend closer to the upper bound. The demonstrated procedure permits the determination of sufficiently close bounds for the probability of the reliability for a simple clamped-free bar under nonstationary earthquake excitation, and can also be applied to a finite-element structure, if modal analysis is assumed.

● **6.13-25** Ishimaru, S., **Ductility factor control method,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 238, 847-854. (For a full bibliographic citation see Abstract No. 1.2-9.)

This paper presents a procedure for obtaining the yield strength of a building which is satisfied when the response ductility factors of the members approach the specified values against a design earthquake. A lumped mass system and a framed system are examined. The procedure consists of a nonlinear response spectrum and the equivalent linearization method. The yield strengths of the members can be estimated by using the method of the square root of the sum of the squares. After obtaining the yield strengths, these values are checked by the response analysis.

● **6.13-26** Shibata, H., **On response analysis for structural design and its reliability,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 4/3, 12. (For a full bibliographic citation see Abstract No. 1.2-11.)

This paper deals with the reliability of response analysis for predicting the behavior of structures to strong earthquakes. Although the accuracy of response analysis seems to have increased recently, the accuracy relates only to the time-history records of past strong earthquakes. Predictions of the time histories of future earthquakes can only be made using a stochastic approach. If response analysis is treated in a stochastic sense, factors which affect the reliability of the analysis must be noted. The author discusses some practical ways to achieve this based upon theoretical and computer simulation analyses and model tests on shaking tables and field experiments. Two additional problems are discussed. One is the analysis of the response of structures (including piping systems) to vertical ground motion. The other is the analysis of elasto-plastic structural response.

● **6.13-27** Tani, S. and Hiramatsu, A., **Earthquake responses by the restoring force characteristics to ultimate collapse** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 251, 951-958. (For a full bibliographic citation see Abstract No. 1.2-9.)

In this paper, a simple idealized model of the restoring force characteristics covering the overall range of structural behavior is assumed for brittle and ductile structures. The earthquake response, the histogram of damage due to structural failure or entire collapse and the average and the standard deviation of the displacement are discussed using nonstationary random processes as input ground accelerations.

● **6.13-28** Yamazaki, Y., **Study on earthquake response of structures by considering non-deterministic variables,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 241, 871-878. (For a full bibliographic citation see Abstract No. 1.2-9.)

Vibrational properties of structures subjected to earthquake ground motions have been investigated by utilizing the concept of random vibration. The theory of random

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

vibration for dynamic responses of structures is based on the stochastic point of view that earthquake ground motions cannot be essentially predicted as deterministic phenomena and that vibrational behavior of structures during earthquakes must be analyzed stochastically. However, it is also true that a structure cannot be treated as a deterministic system, because the dynamic properties of an actual structure, such as masses, spring constants and damping constants, cannot be evaluated deterministically when a structure is designed. Hence, a structure must be designed by considering the nondeterministic properties of the structure as well as those of earthquake ground motions. There have been many papers written concerning the dynamic response of a structure subjected to earthquake ground motions by application of the theory of random vibration. The theory for the stationary random response of a linear lumped-mass system has been studied by the author. Expansion of this theory is carried out in this paper, in which all variables are regarded as nondeterministic ones. The fundamental formula obtained by Taylor's series of a function f(r) of the vector of random variables r is applied to this expansion. This expansion is used to obtain the seismic response of a structure.

● **6.13-29** Charlwood, R. G., Anderson, D. L. and Chapman, C. B., **Sensitivity analyses of a seismic response event tree model of a nuclear plant safety system,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 7/11, 14. (For a full bibliographic citation see Abstract No. 1.2-11.)

Combined probability predictions for earthquake-initiated failure of a typical three-component nuclear plant safety system were computed for a New Brunswick site. The purpose was to establish a basis for investigating a currently proposed earthquake design code for nuclear plants constructed in Canada. Sensitivity analyses were carried out on the probabilistic input data using an event tree and on possible design decisions, in order to establish a quantitative basis for comparison of their relative contributions and the effect of uncertainties on the combined failure probability predictions. Sufficient conditions for the model system to achieve a combined failure probability of 10^{-5} to 10^{-6} per annum are identified.

The event tree includes the Dept. of Energy, Mines and Resources of Canada ground motion probability distribution predictions, a probability distribution of response spectra, and failure probability distributions for three components in series. Combined failure probabilities are computed for various possible design basis earthquakes (DBE).

It is shown that the predicted probabilities of earthquakes greater than 0.5 g are large enough to dominate the results. The significance of this effect is shown by considering various "maximum possible" ground accelerations, above which the probability of occurrence is considered negligible.

The effect of variations in component failure distributions was, as expected, found to be major. Four linear distributions were considered. It was shown that the decrease in failure probability for a three-component series system from a single-component system was not as large as might be expected owing to the common mode of failure.

In summary it is shown that combined system seismic failure probabilities in the range 10^{-5} to 10^{-6} could conceivably be achieved. However, to do so it appears necessary to be able to establish either a maximum possible earthquake or demonstrate a large reserve of component strength above the DBE. The effect of uncertainty in the ground motion and in the response spectra are relatively unimportant when compared to other uncertainties. The effect of common mode failure must be considered in the seismic analysis.

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

7. Earthquake-Resistant Design and Construction and Hazard Reduction

7.1 General

● **7.1-1** Jennings, P. C., **Strong ground motion and seismic design criteria,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings,* 1-11. (For a full bibliographic citation see Abstract No. 1.2-2.)

The purpose of this paper is to summarize the status of measurements of strong ground motion in the United States and to discuss how the data are being used to determine seismic design criteria. The statistical data concerning the strong-motion records and the measurement programs are drawn from a series of papers by D. E. Hudson and his coworkers at the California Inst. of Technology. Almost all of the accelerograph networks in the United States are maintained by the Seismic Engineering Branch of the U.S. Geological Survey, or are coordinated with the program of this agency. The instruments are owned by a wide variety of organizations, including federal and state agencies, universities, public utilities and building owners. The Seismic Engineering Branch, however, services many of the instruments owned by others and acts as a central repository for the records and the digitized data.

● **7.1-2** Bresler, B., Okada, T. and Zisling, D., **Assessment of earthquake safety and of hazard abatement,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings,* 188-209. (For a full bibliographic citation see Abstract No. 1.2-2.)

Methods for assessing the seismic safety of structures are discussed, and procedures for establishing priorities for evaluating and abating hazards are indicated. Field evaluation, code compliance evaluation, and maximum tolerable earthquake intensity evaluation are summarized, and results of a pilot study to identify possible hazards and levels of seismic resistance in several reinforced concrete frame buildings are reported.

● **7.1-3** Hoshiya, M., Kusano, N. and Ishii, K., **Characteristics of earthquake intensity,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 3, 12. (For a full bibliographic citation see Abstract No. 1.2-6.)

The method of average response spectrum plays an important role in present aseismic design. The procedure is based on an intuitive and rough assumption that the normalization gives a set of equivalent data or, more clearly, a set of sample data of an ensemble of earthquake accelerations. But if this assumption cannot be supported, this approach becomes of little significance. In this investigation a comparative study is carried out to search for the best parameter among several alternatives which would allow the averaging operation over response spectra which are essential in design.

● **7.1-4** Eisenberg, J. M., **Changing over system of seismic structural protection,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 74, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

In this paper and in the author's other mentioned works, it is shown that, in those cases when seismic effects with different spectral characteristics are expected or when the information on the characteristics is uncertain, a significant reduction of the seismic effect can be achieved and

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

the optimum decision of the earthquake protective system can be approached by using earthquake protective systems with dynamic properties which change during an earthquake within the predicted range. Systems with variable parameters are also efficient when in addition to the seismic load the wind load is taken into account.

7.1-5 Dowrick, D. J., **Overall stability of structures,** *The Structural Engineer,* 54, *10,* Oct. 1976, 399–409.

A definition of structural stability is given in terms of the sensitivity of structures to variations of the design parameters. The problem of overall stability is then considered, as distinct from local member stability, and two main modes of overall instability are identified, namely lateral and torsional instability. Each of these modes of overall instability are then examined in terms of some of the main factors involved, particularly the variability of live loads, stiffness and geometry, and the influence of geometrical changes during live loading and differential settlements. Statistical methods have been used where appropriate.

The size of some of these variations from normal design assumptions is considered for some typical buildings. Some of these factors are normally neglected in design, and it has been shown that this can lead to significantly underestimating the design forces. Design criteria are suggested for various factors not normally considered, and derivations of these criteria are given in the appendix. The deliberate use of such criteria in design could eventually be coupled with appropriate reductions of the partial safety factors in current use, but more work on a wider range of loads and structures is required.

● 7.1-6 Bertero, V. V., **Establishment of design earthquakes–Evaluation of present methods,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 551–580. (For a full bibliographic citation see Abstract No. 1.2-7.)

This paper evaluates the reliability of current methods of establishing design earthquakes for structures located at sites near potential source(s) of major earthquakes. Problems associated with the establishment of such earthquakes are reviewed and present methods are summarized. Emphasis is placed on assessing the reliability of the method which derives inelastic design response spectra directly from a linear-elastic design response spectrum. The suggested spectra are compared with response spectra, computed for accelerograms derived from records obtained near the fault rupture of the 1971 San Fernando earthquake. The aseismic design implications of the results of this comparison are evaluated on the basis of the dynamic responses of single and multiple degree-of-freedom systems subjected to available accelerograms of near-fault ground motions. Guidelines for improving present methods of establishing design earthquakes are suggested and recommendations for future research are offered.

● 7.1-7 Nuttli, O. W., **On the specification of a design earthquake,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 1–19. (For a full bibliographic citation see Abstract No. 1.2-7.)

This paper discusses some of the more common means of specifying the design earthquake motion at a site. They include: estimation of the peak acceleration or the modified Mercalli intensity at the site, selection of an existing strong-motion accelerogram which is scaled up or down to give the proper peak acceleration at the site, calculation of response spectra and/or Fourier spectra from the selected strong-motion records, construction of typical response spectra which are scaled up or down so that their zero-period level corresponds to the expected peak acceleration, estimation of the sustained levels and the durations of ground acceleration, velocity and displacement at discrete frequencies, selection of an existing strong-motion accelerogram which is scaled up or down to fit the sustained acceleration levels, and construction of synthetic time histories of the ground motion by making use of mathematical-physical models of the earth structure and of the earthquake source mechanism.

● 7.1-8 Mahin, S. A. and Bertero, V. V., **Problems in establishing and predicting ductility in aseismic design,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 613–628. (For a full bibliographic citation see Abstract No. 1.2-7.)

Ductility factors are commonly used in inelastic analyses of building structures to quantitatively describe maximum deformations. Improved methods based on such factors have recently been suggested for preliminary seismic-resistant design and for detailing of critical regions. Definitions of several basic ductility factors are examined in detail in this paper, noting problems that may be encountered in applying them to real structural systems. Alternative definitions are suggested for systems subjected to reversed plastification. The reliability of curvature ductility estimates obtained using conventional lumped, rather than more realistic spread, plasticity models is investigated. Systematic errors introduced by two-component models are examined. The implications of these results for the analysis and design of seismic-resistant structures are discussed.

7.1-9 Pestryakov, V. A. and Burmistrova, G. N., **Effects of technological and structural factors on dynamic behavior of EKG-8I power shovel under seismic loads** (Vliyanie nekotorykh tekhnologicheskikh i Konstruktivnykh faktorov na dinamiku ekskavatora DKG-8I pri seismichekom nagruzhenii, in Russian), *Sbornik nauchnykh trudov Magnito-*

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

gorskogo gorno-metallurgicheskogo instituta, 155, 1975, 24–27.

The dynamic response of the EKG-8I power shovel to seismic excitations is analyzed.

● 7.1-10 Gupta, A. K. and Chu, S. L., **A unified approach to designing structures for three components of earthquake,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 581–596. (For a full bibliographic citation see Abstract No. 1.2-7.)

This paper addresses itself to the design of structures subjected to three components of an earthquake when the analysis is carried out by the response spectrum method. It is a common practice to calculate the maximum probable value of any response as the square root of the sum of the squares of the responses obtained in various modes of vibration for the three components of an earthquake (a coupling matrix is introduced when the modes have closely spaced frequencies). In many design problems, the strength criterion is based on values of more than one quantity at an instance. However, the above procedure gives the maximum probable value of each of the quantities which do not occur simultaneously. In many current design practices, the structure is conservatively designed as if these probable maximum values were occurring simultaneously.

A theory has been presented which postulates simultaneous variation in various responses of a structure. It is also shown that the response in several modes of vibration under three components can be represented by the response in a small number of equivalent modes, thus reducing the number of calculations required in the design analysis. Modal space and subspace have been defined. The response values which are expected to occur simultaneously and to cause an extreme probable effect lie on an interaction surface in the modal subspace.

With the theories presented in this paper, one should be able to design any type of structure analyzed by the response spectrum method. Application of these theories to some frequently encountered design problems is illustrated.

● 7.1-11 Vitiello, E. and Pister, K. S., **Optimal earthquake-resistant design: A reliability-based, global cost approach,** *Computer Methods in Applied Mechanics and Engineering,* 8, 1976, 277–299.

This paper presents a methodology for incorporating into the decision-making process of design the explicit consideration of possible future performance of the designed structure in the presence of uncertainty in both loading and structural parameters assumed in the design process. Design is viewed as an optimization problem, taking into account as a merit function terms related to building cost as well as possible future damage. Randomness of loads, load effects, structural resistances and structural parameters affecting response are considered. In this framework a method suited both to linear as well as nonlinear structural behavior is presented. Approximate expressions of the probabilities of the above random variables as functions of the central moment of their distributions are introduced. Together with a first-order expansion of the input-output response function characterizing the structural model, this procedure gives computational feasibility for actual design applications. An example is included to clarify the methodology proposed and to illustrate typical features of problem formulation and solution.

● 7.1-12 Christian, J. T., **Relative motion of two points during an earthquake** (Technical Note), *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT11,* Proc. Paper 12513, Nov. 1976, 1191–1194.

● 7.1-13 Shah, H. C. *et al.*, **A study of seismic risk for Nicaragua, Part II, Summary,** *12B,* The John A. Blume Earthquake Engineering Center, Stanford Univ., Stanford, California, Mar. 1976, 44.

The purpose of this summary is to provide an overview of the methodology and results of a proposed design procedure based upon seismic risk analysis. Topics to be covered are seismic hazard zoning, design objectives, definition of structure importance or use classes, definition of the type of structural system, definition and formation of the design spectra, the structural design procedure based on the response spectrum method, an equivalent static force method, design examples.

In this brief overview, the important terms and concepts are referenced to their relevant chapters in the final report *A Study of Seismic Risk for Nicaragua, Part II, Commentary,* (see Abstract No. 3.4-7).

7.1-14 Sinitsyn, A. P., **Optimization method for earthquake-resistant structures** (Metodika optimizatsii seismostoikikh konstruktsii i sooruzhenii, in Russian), *Voprosy inzhenernoi seismologii, 18,* 1976, 115–130.

The principle of balanced risk is utilized as the starting point for the optimization method for earthquake-resistant structures. Economic optimization principles are taken into consideration by comparing the additional expenditures for seismic-resistant design features with the cost of reconstruction following an earthquake. The solution for the optimization problem is obtained by means of successive approximations.

● 7.1-15 Oshiro H., F., **Seismic-resistant theory** (Teoria antisismica, in Spanish), Editorial Universo S.A., Lima, Peru, 1976, 275.

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

● **7.1-16** Rosenblueth, E., **Towards optimum design through codes,** *Journal of the Structural Division, ASCE,* **102,** *ST3,* Proc. Paper 11999, Mar. 1976, 591-607.

The main purpose of codes should be to produce optimum structures. Within one plausible system of ethics one should optimize for all of society, including future generations, taking into account protection of property, not only of life. Wide uncertainties demand use of probability theory, particularly Bayesian statistics. Limit-state design, split factors, characteristic values, semiprobabilistic codes, and second-moment formats approximate reliability level design. This familiarizes engineers with probability theory but overemphasizes the influence of uncertainties and of statistical correlation and does not reflect the economic framework. Intuitive adjustments of reliability levels are unsatisfactory. Advent of optimization codes should be accelerated.

● **7.1-17** Hall, W. J., Mohraz, B. and Newmark, N. M., **Statistical studies of vertical and horizontal earthquake spectra,** *NUREG-0003,* Nathan M. Newmark Consulting Engineering Services, Urbana, Illinois, Jan. 1976, 128. (NTIS Accession No. PB 248 232)

The study reveals that there is no well-defined dependence of normalized seismic design response spectra on the earthquake ground acceleration level. Recommendations for horizontal design response spectra are close to those given in Regulatory Guide 1.60. Recommendations for vertical response spectra are somewhat lower than Regulatory Guide 1.60 provisions in the frequency range 2 to 30 Hz approximately. The results are based on seismic information recorded along the west coast of the United States and are directly applicable to that region only.

● **7.1-18** Stockdale, W. K., **Modal analysis methods in seismic design for buildings,** *M-132,* Construction Engineering Research Lab., Champaign, Illinois, June 1975, 36. (NTIS Accession No. AD A012 732)

This report is the first step in preparing a change to the tri-services manual TM 5-809-10, *Seismic Design for Buildings.* Changes in this manual are necessary to provide guidance for the design of critical military facilities which must remain functional after subjection to strong earthquakes. This report describes and discusses modal analysis methods used in the dynamic analysis of structures in conjunction with the earthquake response spectra and time history methods. Elastic and inelastic conditions are discussed, as well as structural damping and assumptions and limitations of the methods. Example calculations are included.

● **7.1-19** **Architects and earthquakes: Research needs,** AIA Research Corp., Washington, D.C., 1976, 247.

The purpose of this report is to provide a systematic approach to the identification, organization and implementation of seismic research needs relevant to the architectural and other design professions. The report is comprised of five sections. Descriptions of the sections follow: (1) ten state-of-the-art papers presenting background information on earthquakes and the built environment; (2) lists of research recommendations developed by the AIA/RC Seismic Safety Research Workshop; (3) a research agenda categorizing the research needs and highlighting major areas where more information is needed; (4) a discussion of the problems faced in the dissemination and utilization of seismic research information by the architectural profession; goals, objectives, requirements and strategies for successful seismic information utilization by architects are presented in a program outline; (5) an outline of future steps which should be taken to transform the research agenda into a comprehensive research program.

The report includes a noncomprehensive listing of reports and projects that are usable by the architectural profession in earthquake-resistant design.

● **7.1-20** Nelson, F. C., **Techniques for the design of highly damped structures,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 7/10, 9. (For a full bibliographic citation see Abstract No. 1.2-11.)

It is the purpose of this paper to discuss ways to design a structure that will provide the amount of damping desired. In particular, ways to design structures with a high degree of damping are presented.

There are four principal sources of structural damping: the damping inherent in the material, energy dissipation at joints, energy dissipation in the surrounding fluid, and radiation of energy away from the structure. Many engineers mistakenly assume that the damping of a structure is determined by the choice of its material when in fact the inherent damping of the material is usually the least important source. The joints of a structure are usually the controlling factor in determining the structure's damping. This paper will review the various energy dissipation mechanisms associated with the motion of dry interfaces. The paper will then discuss the extent to which lubricants and layers of interfacial material (such as polymer films or metal foils) can be used to increase the damping at joint interfaces.

Certain viscoelastic polymers possess material damping which is much larger than that of metals or concrete. This suggests that if they can be incorporated into the elements which form the structure the damping of the structure will be significantly increased. An effective way of doing this is to apply layers of high-damping polymers to the surfaces of structural elements or to insert polymer layers within the structural elements. Recently, these techniques have been successfully used for large-scale, low-frequency structures. The paper will discuss two examples of the application of this technique to large-scale structures: a concrete bridge deck and a metal frame-type machinery foundation.

While increasing the damping, the use of the above techniques can reduce the stiffness of a structure. To avoid this, a parallel arrangement of components can be used: one component to provide stiffness and the other component to absorb energy. The energy-absorption component can operate as a dynamic absorber or a damped absorber. The primary interest of the paper will be on damped absorbers which have been used to augment the structural damping of large structures during seismic events by the plastic deformation of bars or strips of steel. Some mention is made of the use of multiple damped dynamic absorbers.

7.2 Building Codes

● **7.2-1** Corns, C. F., **The national dam inspection program,** *Civil Engineering, ASCE,* **45,** *4,* Apr. 1975, 75–77.

As a result of recent legislation, the Corps of Engineers is initiating a national inspection program of dams to provide protection for human life and property. This paper summarizes the Corps' activities and the guidelines and decisions used by the Corps to assess dam adequacy.

● **7.2-2** Wakabayashi, M., **Recent Japanese developments in mixed structures,** *Methods of Structural Analysis,* Vol. I, 497–515. (For a full bibliographic citation see Abstract No. 1.2-3.)

In 1975, the Architectural Inst. of Japan published revised design specifications for steel-reinforced concrete (SRC) structures. Discussed in this paper are the revised design formulas for SRC members and connections under shear. In addition, the recent developments in the research and use of the prefabricated SRC system, composite beams and concrete-steel tube members are introduced.

● **7.2-3** Freeman, S. A., **Evaluation of an existing building complex for earthquake response,** *Methods of Structural Analysis,* Vol. II, 781–795. (For a full bibliographic citation see Abstract No. 1.2-3.)

The Veterans Admin. (VA), Office of Construction, has been conducting a program to evaluate the earthquake resistance of their hospital facilities. Phase I of this program involves field inspection of selected buildings and analysis of their structural and nonstructural components with the aid of available drawings, photographs, and other records. Each structure is classified as conforming or nonconforming to the criteria of VA Handbook H-08-8, *Earthquake Resistant Design Requirements for VA Hospital Facilities.* This paper presents an example of such an evaluation for an existing multistory complex. The structure is Building No. 1 of the Veterans Admin. Cochran Div. Hospital, located in St. Louis, Missouri.

The hospital is a complex building which is large, irregular in plan, and which has setbacks and expansion joints. The predetermined scope and budget of the analysis precluded complex, detailed analytical procedures, so approximate analytical procedures were developed for estimating various damage threshold levels determined by the capacities of the various building materials, both structural and nonstructural. The analysis included the participation effects of the nonreinforced brick masonry, the concrete fireproofing, and the structural steel. Representative frames were mathematically modeled and analyzed with computer aid. Basic dynamic characteristics were determined, although some material properties had to be assumed to approximate yield and ultimate strength limits of structural and nonstructural elements.

Results were used to predict failure patterns at various amplitudes of earthquake motion and to determine whether the building conformed to governing earthquake criteria. The evaluation was based on experience, judgment, and common sense rather than on a strict interpretation of building code requirements.

7.2-4 Mattock, A. H., Li, W. K. and Wang, T. C., **Shear transfer in lightweight reinforced concrete,** *Journal of the Prestressed Concrete Institute,* **21,** *1,* Jan.-Feb. 1976, 20–39.

A study is reported of the single-direction shear transfer strength of lightweight aggregate concrete. Push-off tests were carried out on specimens made from sanded lightweight concrete, two types of all-lightweight concrete and sand and gravel concrete. Both initially uncracked specimens and specimens cracked in the shear plane before being subjected to shear were tested. It was found that the shear transfer strength of light-weight concrete is less than that of sand and gravel concrete having the same compressive strength.

The shear-friction provisions of Section 11.15 of ACI 318-71 may be used in the design of connections in lightweight concrete providing the value of the coefficients of friction μ, contained in Section 11.15.4, are multiplied by the following factors: (a) For all-lightweight concrete having a unit weight not less than 92 lb per cu ft, multiply μ by 0.75. (b) For sanded lightweight concrete having a unit weight not less than 105 lb per cu ft, multiply μ by 0.85.

7.2-5 Speyer, I. J., **Considerations for the design of precast concrete bearing wall buildings to withstand abnormal loads,** *Journal of the Prestressed Concrete Institute,* **21,** *2,* Mar.-Apr. 1976, 18–51.

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

Presents design guidelines for precast bearing wall buildings subject to abnormal loadings. Emphasizes horizontal, vertical, and peripheral ties sufficient to provide interaction between all building elements. Empirical design approaches, based on various reports, are suggested and some examples are provided in the appendix.

● 7.2-6 Shepherd, R., **New Zealand earthquake provisions,** *Proceedings of the Australian and New Zealand Conference on the Planning and Design of Tall Buildings,* 82–95. (For a full bibliographic citation see Abstract No. 1.2-1.)

The 1973 draft New Zealand seismic loading code, a revision of the 1965 code, is examined. The code specifies that one of three methods (equivalent static, spectral modal analysis, using the functions of the horizontal seismic design coefficient as response spectra, or numerical integration response) must be used to determine minimum earthquake effects. The changes which the draft code requires in the use of these three methods are discussed. In addition, such special considerations as horizontal torsional and overturning moments and setbacks are described. A comparison is included of seismic design coefficients specified by the 1965 and the 1973 codes for typical New Zealand buildings.

● 7.2-7 Umemura, H., **The development of dynamic design of buildings in Japan,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 122, 11. (For a full bibliographic citation see Abstract No. 1.2-6.)

The following areas of the design of buildings in Japan are covered: static design, development of dynamic design, dynamic design of low-rise buildings and dynamic modification of static design.

● 7.2-8 Clark, S. H., **California Coastal Commission accepts advice from ASCE on earthquake design controversy,** *Civil Engineering, ASCE,* **46**, *5*, May 1976, 85–87.

A case history is described of an ASCE section (San Francisco) causing a public agency to change its position with respect to earthquake design criteria. The California Central Regional Coastal Commission adopted an unrealistically severe earthquake design requirement for a shopping center in Seaside, California. The requirement—to resist 2/3 g lateral acceleration—was an unacceptable misinterpretation of some geologic data, and was protested by several professional groups. If such a requirement were literally enforced, unnecessary additional expense of 30% to 40% could have been incurred with no guarantee of greater earthquake safety. The San Francisco section organized an ad hoc committee of representatives of four professional groups, and the committee was able to convince the Commission to use the Uniform Building Code earthquake design provisions rather than to establish their own criteria.

● 7.2-9 Kawasaki, I. and Kuribayashi, E., **On specifications for earthquake-resistant design of the Honshu-Shikoku bridges (JSCE-1974),** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 711–725. (For a full bibliographic citation see Abstract No. 1.2-7.)

● 7.2-10 Kawakami, K. *et al.*, **On specifications for earthquake-resistant design of highway bridges (January 1971),** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 771–781. (For a full bibliographic citation see Abstract No. 1.2-7.)

● 7.2-11 Cheng, P. H., **Comparison of aseismatic steel building design practice in Japan and U.S.A.,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 727–744. (For a full bibliographic citation see Abstract No. 1.2-7.)

Current seismic-resistant building codes, steel structural design specifications and construction practices and the seismology and geology of Japan and the west coast of the United States are reviewed and compared. A sample building design is calculated in accordance with the building codes of both countries and is presented in detail. The result indicates that the degree of safety provided by the codes of both countries for seismic-resistant steel structures correlates reasonably well with historical earthquake magnitudes. A study is recommended to more closely correlate safety codes with expected magnitudes as the basis for an international seismic-resistant building code.

● 7.2-12 Ramesh, C. K. and Fadnis, P. V., **Response of reinforced concrete chimneys to earthquake forces,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1293–1309. (For a full bibliographic citation see Abstract No. 1.2-7.)

Reinforced concrete chimneys have not received as much attention as that of building or other tower frames for the evaluation of their response to impulsive lateral forces arising as a result of ground motions, although many codes of practice do provide some guidelines —not always reliable— for estimating these forces and the corresponding displacements of such systems. The present study attempts to be a step in this direction by providing some data on the dynamic behavior of two reinforced concrete chimneys. The analysis is performed by applying the step-by-step numerical integration procedure to a digitized forcing function of an actually recorded acceleration spectrum. The results show the need for a revision of the relevant clauses of some codes of practice.

● 7.2-13 Celebi, M., **Comparative study of the new Turkish earthquake resistant design code,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 745-757. (For a full bibliographic citation see Abstract No. 1.2-7.)

Some highlights of the new 1975 Turkish Earthquake Resistant Design Code are compared with other major codes. The seismic zoning factors are increased in the new code; therefore, the resulting seismic coefficients are higher than the 1968 code and the 1970 UBC.

A new seismic-coefficient spectrum factor is formulated; the factor is a function of the natural periods of vibration of both the structure and the underlying soil layer. The inclusion of the natural period of vibration of soil into the spectrum factor is discussed in light of recent research results and investigations of the causes of past earthquake damage. The methods of determination of the natural period of structures are reviewed. Conclusions are drawn as a result of the comparisons made.

● 7.2-14 de Neufville, R., **How do we evaluate and choose between alternate codes for design and performance?,** *Seismic Design Decision Analysis, No. 17, MIT-CE R75-3,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Feb. 1975, 38.

The choice of a design code depends on the values we place on the benefits or 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 varies between different elements of society. As shown by a case study, these facts mean that the most commonly discussed methods of evaluation for seismic codes—benefit-cost or risk-of-death analysis—may lead to incorrect and unacceptable recommendations. We propose criteria 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.

● 7.2-15 Hisada, T., **Earthquake loading and seismic code requirements for tall buildings,** Kajima Inst. of Construction Technology, Tokyo, Aug. 1976, 19.

The following sections are contained in this report: Horizontal earthquake force and its distribution; Vertical earthquake force; Seismic regionalization; Importance of the structure as related to its use; Subsoil conditions; Types of construction related with ductility; Drift limitations; Horizontal torsional moments; Overturning moment; Allowable stresses and load factors; Dynamic analysis.

● 7.2-16 Noland, J. L., Feng, C. C. and Pyle, D., **Building code requirements for reinforced concrete (ACI 318-71) in decision logic table format,** *Journal of the American Concrete Institute,* 73, *8,* Title No. 73-34, Aug. 1976, 445-446.

In a Ph.D. dissertation by the senior author, ACI 318-71 has been converted into a new format using decision logic tables to present the portions of the code which require logical analysis in order to determine their meaning. In the dissertation, the portions of the code which are general are presented as narrative statements. The decision logic tables and narrative statements are linked together to form a complete system which enables the user to determine requirements applicable to a given design in a more precise manner. The new form is a direct translation of the code as presently written. The decision logic table form of the code should be of value to practicing engineers, computer program developers, educators, and to those who prepare design specifications. This brief paper summarizes the work reported in the dissertation.

● 7.2-17 Gates, J. H., **California's seismic design criteria for bridges,** *Journal of the Structural Division, ASCE,* **102,** *ST12,* Proc. Paper 12636, Dec. 1976, 2301-2313.

An earthquake design criteria developed for bridges in California is presented. The criteria considers the proximity of maximum credible seismic events, local soil conditions, dynamic structural characteristics, ductility, and risk. The rationale for development of a flexible criteria which permits future revisions is given. The development of a map of maximum bedrock accelerations for California is examined. The development of response spectra at the bedrock level based on actual recorded events is presented. A method for considering the effects of soils at a site is developed and incorporated into the criteria. Four sets of soil curves are shown to represent the majority of bridge sites in California. The rationale behind the ductility and risk reductions for modern California bridges is described. Recent dynamic analysis applications and approximate methods of analysis are presented, as well as future directions of seismic bridge design.

● 7.2-18 **Proposed revisions to: Building code requirements for reinforced concrete (ACI 318-71),** *Journal of the American Concrete Institute,* 73, *1,* Title No. 73-1, Jan. 1976, 15-25.

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.

● 7.2-19 Husid, R. and Neumann, J. V., **Critical analysis of Chapter IV, Title V of the national building code: Safety against the destructive effect of earthquakes** (Anali-

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

sis critico del Capitulo IV, Titulo V del reglamento nacional de construcciones: Seguridad contra el efecto destructivo de los sismos, in Spanish), Dept. de Ingeniera, Pontificia Univ. Catolica del Peru, Lima, Oct. 1975, 53.

● 7.2-20 Mayes, R. L. *et al.*, **Expected performance of Uniform Building Code designed masonry structures,** *EERC 76-7*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Sept. 1976, 91. (NTIS Accession No. PB 270 098)

This report presents an evaluation of the seismic design sections of the 1972, 1973, 1974 and 1976 versions of the *Uniform Building Code* and the "Recommended Comprehensive Seismic Design Provisions for Buildings," prepared by the Applied Technology Council. In order to evaluate the various codes a three-, a nine-, and a seventeen-story building of similar floor plan were studied. The seismic design stresses in these buildings were calculated by the specified code procedures as well as the stress state predicted by a realistic dynamic earthquake response procedure. The adequacy of the codes was then evaluated by comparing the two types of stress predictions.

The conclusion of the study was that the increasing conservatism of the more recent codes is justified and that greater conservatism is necessary in the most recent codes for buildings of moderate height such as the nine- and seventeen-story buildings considered in the study.

● 7.2-21 Irvine, H. M., **The centre of earthquake loading on tall buildings,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* 9, 4, Dec. 1976, 195-198.

A response spectrum technique is applied to two well-known linear elastic continuous models of slender highrise buildings in order to obtain likely positions for the centers of earthquake loading. The models are the uniform cantilever shear beam and the uniform cantilever shear wall, which represent the two extremes of pure shear deformation and pure flexural deformation, respectively. The results obtained are at variance with the static provisions of the current New Zealand code; this is especially so in the case of the shear wall. On the basis of these findings, a tentative suggestion is made for a change to the familiar equivalent static lateral load distribution specified at present by the code.

● 7.2-22 Kolston, D., **Parts and portions of buildings,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* **9**, *1*, Mar. 1976, 74-78.

This paper discusses clause 3.4.9 of the New Zealand NZS 4203 *Code of Practice for General Structural Design and Design Loadings.* The clause pertains to the parts of buildings not related to the building structure. An appendix gives examples of calculations of the seismic force for a reinforced concrete boundary wall, a cantilevered reinforced concrete column, and a boiler.

● 7.2-23 Larrabee, R. D. and Whitman, R. V., **Seismic design decision analysis - Report No. 28: Costs of reinforcing existing buildings and constructing new buildings to meet earthquake codes,** *MIT-CE R76-25,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, May 1976, 86.

The costs of constructing new buildings according to seismic codes are reviewed. A particular building, designed with and without seismic loads, is examined; the design for seismic loads increased the construction cost by 2.8 per cent. Under more general circumstances, cost increases would be one per cent or less. Some consequences of the implementation of a new seismic code are discussed.

Methods of reinforcing existing buildings are discussed. Estimated costs for reinforcing 156 buildings are presented. Reinforcing costs are on the order of $5 to $18 per square ft for masonry bearing wall buildings. Costs are lower for other structural types or buildings with previous seismic design. Costs are higher for older buildings, smaller buildings, and historic buildings. The percentage of older existing buildings is estimated; an examination of U.S. codes illustrates how few existing buildings were designed for seismic loads.

7.3 Design and Construction of Buildings

● 7.3-1 Wood, R. H. and Roberts, E. H., **A graphical method of predicting sidesway in the design of multistorey buildings,** *Proceedings, The Institution of Civil Engineers,* **59**, Paper 7808, June 1975, 353-372.

Since the advent of limit state design, considerable advances have been made in simplifying collapse-design procedures to the level of graphical desk methods, especially in the field of column design and frame instability. The corresponding simplified treatment of the other limit state of permissible sidesway has been rather neglected, partly because of confusion as to what the design criterion should be. To help to speed up the design process, and to emphasize the importance of stiffening of frames by composite action, a completely graphical method is devised for estimating sidesway of multistory buildings.

● 7.3-2 Gupta, S. C., **Model aseismic analysis and design of multistoried R.C.C. building,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* **11**, 1975, 207-225.

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

A model design is presented for an 11-story reinforced concrete building including penthouse and basement with core shear walls and open frames. The design includes all stages from the so-called "thumb-rule sizes" of members to the final stages of dynamic response analysis. The design can be carried out manually in all stages except in the dynamic response analysis stage.

Included are comparisons of (a) Indian and Japanese practice, (b) shear forces due to the Koyna earthquake response spectrum prescribed by I.S. 1893–1970, (c) shear forces without the inclusion of shear walls in the design, and (d) computed dynamic response with actual data. In addition, the selection of a mathematical model of the building is examined. The detailed design calculations are not included in the paper.

● 7.3-3 Arioglu, E. and Anadol, K., **Resistance of Suleymaniye Mosque against earthquakes** (Tarihsel perspektifte Suleymaniye Camii'nin depremlere mukavemeti, in Turkish), *Deprem Arastirma Enstitusu Bulteni*, **2**, *6*, July 1974, 1–11.

The Suleymaniye Mosque was built in Istanbul during the reign of Magnificent Suleyman by the head architect of the period, Mimar Koca Sinan, between the years 1549 – 1557. The mosque up to the present time has been subjected to 89 earthquakes with intensities greater than VI (MM scale) and has shown perfect structural performance. In this paper the successful earthquake response of the structure is analyzed and discussed in relation to its determined structural and dynamic characteristics.

● 7.3-4 Hirosawa, M. *et al.*, **An evaluation method of earthquake resistant properties of existing reinforced concrete school buildings**, *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings*, 174–187. (For a full bibliographic citation see Abstract No. 1.2-2.)

This paper presents a method for evaluating the earthquake-resistant properties of existing reinforced concrete school buildings. First of all, the lateral resistance of a building is evaluated using a simple calculation. If the lateral strength is not sufficient for the force expected during a strong earthquake, the building should be investigated as to whether or not its columns will fail as a result of the shear force. Buildings with columns having shear failure modes should be investigated further. Buildings found to be unsafe against a future strong earthquake should be strengthened by an appropriate method.

● 7.3-5 Okada, T. and Bresler, B., **Seismic safety of existing low-rise reinforced concrete buildings–Screening method**, *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings*, 210–246. (For a full bibliographic citation see Abstract No. 1.2-2.)

This paper describes a methodology for evaluating the seismic safety of low-rise reinforced concrete buildings and its application to existing school buildings. The method classifies buildings according to three types of failure mechanisms; the criteria by which buildings are judged consider nonlinear behavior in response to two levels of earthquake motion. The overall method consists of a sequence of procedures which are repeated in successive cycles using more refined idealizations of behavior in each cycle. The first cycle of the procedure is called the "first screening" and is the cycle described in this paper.

● 7.3-6 Murakami, M. and Penzien, J., **Nonlinear response spectra for probabilistic seismic design of reinforced concrete structures**, *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings*, 247–273. (For a full bibliographic citation see Abstract No. 1.2-2.)

In the investigation reported herein, twenty each of five different types of artificial earthquake accelerograms were generated for computing nonlinear response spectra of five structural models representing reinforced concrete buildings. To serve as a basis for probabilistic design, mean values and standard deviations of ductility factors were determined for each model having a range of prescribed strength values and having a range of natural periods. Adopting the standard design philosophy, i.e., only minor damage is acceptable under moderate earthquake conditions and total damage or complete failure should be avoided under severe earthquake conditions, required strength levels were investigated for each model. Selected results obtained in the overall investigation are presented and interpreted in terms of prototype behavior.

● 7.3-7 Shibata, A. and Sozen, M. A., **Use of linear models in design to reflect the effect of nonlinear response**, *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings*, 274–290. (For a full bibliographic citation see Abstract No. 1.2-2.)

A method to determine design forces for earthquake-resistant design of reinforced concrete structures is described. The method, which recognizes energy dissipation in the nonlinear range of response, utilizes linear models and response spectra. The paper contains discussions of (1) equivalent linear earthquake response of single-degree-of-freedom hysteretic systems, (2) description of the substitute structure method, and (3) a design example using the method.

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

● 7.3-8 Higashi, Y. and Kokusho, S., **The strengthening methods of existing reinforced concrete buildings,** *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings,* 333–351. (For a full bibliographic citation see Abstract No. 1.2–2.)

In order to investigate the effects of strengthening methods, several tests were made as follows: (1) Strengthening by solid walls poured in place under a certain pressure within the existing frames; (2) strengthening by adding reinforced concrete or precast concrete wing walls at the sides of the existing columns, or precast concrete panels within the existing frames; (3) strengthening the existing columns with welded wire fabrics and mortar. The results of these tests are described in this paper.

● 7.3-9 Nicoletti, J. P., Jhaveri, D. P. and Emkin, L. Z., **Computer-aided structural analysis and design of the 37-story Bonaventure Hotel,** *Methods of Structural Analysis,* Vol. II, 796–835. (For a full bibliographic citation see Abstract No. 1.2–3.)

This paper briefly describes and summarizes computer-aided analyses and design for a complex convention hotel structure, located in downtown Los Angeles. The analyses included static analyses for gravity and lateral (wind and seismic) loads in accordance with the *Los Angeles City Building Code* and dynamic analyses for two postulated levels of seismic ground motion. Concurrently with the analyses, a design program was developed in accordance with the established design criteria for column selection and design of connection details to ensure ductile response of the principal frame elements.

● 7.3-10 Smith, I. C., **The design and construction of the Bank of New Zealand, Wellington, New Zealand,** *Proceedings of the Australian and New Zealand Conference on the Planning and Design of Tall Buildings,* 424–444. (For a full bibliographic citation see Abstract No. 1.2–1.)

The design of the Bank of New Zealand is presented. At the time of construction, the bank was the tallest building in New Zealand (30 stories; 374 ft from basement to roof). A sophisticated analysis involving real time earthquake motion was used to achieve an economic structure tuned to suit the earthquake response. This analysis is described.

7.3-11 Spencer, R. A. and Neille, D. S., **Cyclic tests of welded headed stud connections,** *Journal of the Prestressed Concrete Institute,* **21,** *3,* May-June 1976, 70–83.

Simulated earthquake loading was applied to a type of welded headed stud connection used in precast box-type buildings. Load-deflection hysteresis loops were obtained, and the actual strength of each connection under cyclic loading was compared with the static ultimate design strength.

Although the design strength was exceeded by up to 30 percent in the initial cycles, the strength began to fall as the number of load cycles increased, and was generally well below the design strength at failure. Deflections at failure were from seven to twenty-four times the theoretical elastic deflection at the design ultimate strength, but because the connections lose both strength and stiffness before failure, their ductility does not justify any reduction in the lateral forces used for earthquake-resistant design. If the connections are properly designed and detailed, they should perform satisfactorily in buildings designed as box systems.

7.3-12 Tso, W. K. and Bergmann, R., **Dynamic analysis of an unsymmetrical high rise building,** *Canadian Journal of Civil Engineering,* 3, *1,* Mar. 1976, 107–118.

A complete time history response dynamic analysis is carried out to establish the design seismic loading for the Harbour Centre building in Vancouver. The building has an elevated observation deck and restaurant offset from the center of the structure. The paper describes the steps and considerations involved in the dynamic analysis, such as the dynamic modelling of the structure, the choice of input ground records and the interpretation of the computed results. Whenever possible, the calculated values are compared with the 1975 National Building Code of Canada requirements to provide a proper perspective of the various approaches in establishing design loads for this building.

7.3-13 Diamant, R. M. E., **System building–Italian style,** *Civil Engineering, 826,* June 1975, 30–31.

"Structurapid," an Italian system for constructing precast concrete structures, is described. For structures in areas of high seismic risk, Structurapid employs an earthquake-resistant frame capable of resisting lateral stress. During a February 1972 earthquake in Ancona, Italy, a partially constructed Structurapid multistory building experienced no damage.

● 7.3-14 Tzenov, L. and Baltov, A., **Optimal height of tall buildings under seismic loading,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 167, 5. (For a full bibliographic citation see Abstract No. 1.2–6.)

The objective of this paper is to determine the degree to which increasing the number of stories of buildings in seismic regions is reasonable. A criterion is assumed and the optimal number of stories is determined in the case of seismic loading only. Analysis of the results is performed and practical application of the criterion is discussed.

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

● **7.3-15** Brankov, G. and Boncheva, H., **Determination of the optimal structural system for seismic regions,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 161, 7. (For a full bibliographic citation see Abstract No. 1.2-6.)

In Bulgaria different structural systems are used in residential buildings and it is very important from the earthquake point of view to know which of the applied systems is the most suitable (the type of structural system, number of stories, etc.). In this paper, the authors, using damage potential, offer methods for determining the optimal selection of the basic parameters characterizing the structures, taking into account their different deformations as a result of seismic action and local ground conditions.

● **7.3-16** Izmailov, U. V. and Chuprina, A. A., **Designing and construction of stone-frame buildings,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 143, 6. (For a full bibliographic citation see Abstract No. 1.2-6.)

A combination of stone masonry with a monolithic reinforced concrete frame represents a structure characterized by rather high resistance to the action of seismic forces. This is confirmed by the behavior of framed buildings with stone masonry subjected to earthquakes and by the results of special experimental investigations. Among the latter is testing of stone-frame wall fragments for shear in their plane. The strength and stiffness design of stone-frame walls can be carried out through the use of the obtained analytical expressions or by using the finite element method.

● **7.3-17** Polyakov, S. V., **Some structural solutions of buildings with walls of brick and natural stone and large-panel buildings for mass construction in seismic regions,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 142, 12. (For a full bibliographic citation see Abstract No. 1.2-6.)

The paper presents some solutions of one- to five-story buildings being constructed in seismic regions. The buildings had walls of brick and natural stone and some were large-panel buildings. Test data characterizing resistance of structures strengthened with brick and stone walls are given. Described are three recent earthquakes in the U.S.S.R. when large-panel buildings proved their earthquake resistance.

● **7.3-18** Kilimnik, L. Sh., Zharov, A. M. and Burgman, I. N., **Limit state analysis and synthesis of seismic design,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 132, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

Some basic problems of seismic-resistant structural design are discussed. Included are discussions of instrumental recording analysis, selection of seismic design models, the study of parameters, the basic principles of the estimation of the limit state of high-rise frame buildings, the optimum parameter study of seismic frame buildings, and principles for synthesizing the construction solution of buildings under actual seismic conditions with limit state parameters being specified.

● **7.3-19** Venkayya, V. B. and Cheng, F. Y., **Resizing of frames subjected to ground motion,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 597-612. (For a full bibliographic citation see Abstract No. 1.2-7.)

A design procedure is presented based on optimality criteria, treating the expected ground motion as a dynamic force on the structure. Elastic systems are designed for minimum weight while satisfying all the design requirements. The design requirements are strength and stiffness under all loading conditions including those resulting from expected ground motion.

● **7.3-20** Holmes, W. T., **Seismic design of the Veterans Administration Hospital at Loma Linda, California,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 823-841. (For a full bibliographic citation see Abstract No. 1.2-7.)

The 500-bed Veterans Admin. Hospital in Loma Linda, California, now under construction, lies in a region of high seismicity and was designed for the new VA criteria of remaining operational after a major earthquake. Extensive studies were performed to determine site characteristics and, as a result, design lateral forces on the structure were significantly larger than required by conventional codes. This paper summarizes the design procedure used and describes the resulting structure.

● **7.3-21** Ricart Nouel, A. A., **Sheraton Hotel in Santo Domingo, Dom. Rep.: Analysis, design, and construction techniques,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 423-436. (For a full bibliographic citation see Abstract No. 1.2-7.)

Analysis and design techniques are described for an 11-story reinforced concrete building, part of the Sheraton Hotel project in Santo Domingo. Construction methods are briefly outlined. Main features of the structure are typical nine-story-high pierced shear walls on top of two-story frames.

Wind forces, UBC earthquake forces, and those obtained from an elasto-dynamic analysis were compared. The equivalent half frame method was used for lateral load

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

analysis, and the design was based on the ACI 318-71 Building Code.

● 7.3-22 Paramasivam, P., Nasim, S. and Lee, S. L., **Modal analysis and seismic design of tall building frames,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 73-82. (For a full bibliographic citation see Abstract No. 1.2-7.)

An iterative method for the modal analysis of tall building frames based on lumped mass idealization is presented. The method takes into consideration the flexibility of the horizontal members and allows distinct rotations of the joints in each story. The iteration converges rapidly and the required computation can be carried out using a small computer. The application of the proposed method to the seismic design of tall buildings is illustrated with the aid of an earthquake response spectrum. The effect of damping and the contributions of the lower modes to the seismic response of the structures are investigated. The story shear coefficients obtained verified the whipping action observed on the top few stories. The design procedure is simple and practical.

● 7.3-23 Nassonova, T. I. and Fraint, M. J., **On the limit analysis of box-unit buildings under static and dynamic effects,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 299-304. (For a full bibliographic citation see Abstract No. 1.2-7.)

Some simple examples are given to show how the limit equilibrium extreme principles of elastic-plastic systems can be used to calculate box-unit buildings. The box-unit buildings are presented in the form of a system with single-side ties.

● 7.3-24 Sokolov, M. E. and Glina, Yu. V., **Development in structural solutions of multi-storey seismicproof frameless buildings of in-situ reinforced concrete in U.S.S.R.,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 83-89. (For a full bibliographic citation see Abstract No. 1.2-7.)

The report deals with the main preconditions of in-situ housing development in seismic regions of the U.S.S.R. as well as with a short survey of the subject. Included are principal structural solutions for in-situ seismic-resistant buildings without frames; these include solutions for walls, floor slabs and methods of reinforcement. The experience of designing such buildings in the field is described, with particular attention to static and dynamic calculations.

● 7.3-25 Paulay, T., **Some design considerations of earthquake resistant reinforced concrete shear walls,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 669-681. (For a full bibliographic citation see Abstract No. 1.2-7.)

The possible failure modes in cantilever shear walls are examined, in particular from the point of view of the energy-dissipation capacity and the suitability of the mechanisms involved in earthquake-resistant buildings. Design recommendations with respect to flexure, instability, diagonal tension and sliding shear are made. The introduction of concepts of energy dissipation by shear along a vertical fiber of a cantilever shear wall leads to the examination of coupled shear walls. Using the evidence obtained from extensive tests, the author shows that with the dispersal of and intelligent hierarchy in suitable energy-dissipating mechanisms, achieved with relative ease in practice, coupled shear walls can be made to possess all the desirable features of an efficient earthquake-resistant structure. To illustrate this, a comparison between two coupled shear wall models, one with conventionally and the other with diagonally reinforced coupling beams, is made in terms of strength degradation and cumulative energy absorption during progressive reversed cyclic loading.

7.3-26 Kulygin, Yu. S., **Design features contributing to plastic deformations in reinforced concrete frame buildings subjected to alternating loads** (Konstruktivnye meropriyatiya obespechivayushchie razvitiya plasticheskikh deformatsii v zhelezobetonnykh karkasnykh zdaniyakh pri znakoperemennykh vozdeistviyakh, in Russian), *Trudy TsNII stroitelnykh konstruktsii, 45,* 1975, 20-24.

Design features contributing to the formation of plastic sections and zones in frame buildings are analyzed and recommendations are given. The recommendations are based on an analysis of earthquake-resistant frame design methods and observation of earthquake effects.

7.3-27 Moskalenko, A. S. and Kazina, L. N., **Calculation of free flexural vibration frequencies of columns of industrial buildings subjected to the effects of dynamic torsional moments** (Opredelenie chastot svobodnykh izgibnykh kolebanii kolonn promyshlennykh zdanii podverzhennykh vozdeistviyu dinamicheskikh krutyashchikh momentov, in Russian), *Stroitelstvo shakht, rudnikov i podzemnykh sooruzhenii,* Sverdlovskii gornyi institut, Sverdlovsk, Vol. 1, 1975, 76-79.

Design of industrial buildings whose foundations are subjected to the effects of dynamic torsional moments is discussed.

7.3-28 Borodin, L. A., **Response of steel building frames with plastic reserve capacity to seismic loads** (Raschet metallicheskikh karkasov zdanii na seismicheskuyu nagruzku s uchetom plasticheskikh rezervov, in Russian), *Materialy po metallicheskim konstruktsiyam, 18,* 1975, 109-122.

Vibrations of elastoplastic systems caused by seismic excitations are considered. Response of energy-absorbing

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

structures is calculated using experimental data on the carrying capacity of frame members. Recommendations are given for the design of steel frames for seismic loads using plastic joints. Frames with stiffening elements which can undergo significant plastic deformations are considered.

● 7.3-29 Sasaki, T. *et al.*, **An experimental study on earthquake resistant fortification work for already constructed reinforced concrete buildings,** *KICT Report No. 20,* Kajima Inst. of Construction Technology, Tokyo, June 1975, 21.

Damage resulting from the Tokachi-oki earthquake of 1968 demonstrated that some code-designed reinforced concrete buildings did not have adequate earthquake resistance. A survey conducted following the earthquake revealed that there were a considerable number of reinforced concrete buildings with poor earthquake resistance.

The object of this investigation is to present a practical method for the strengthening of these weak buildings. The method investigated herein is to cover an existing concrete column by a thin steel plate and to grout the clearance between the column and the steel plate with nonshrink cement mortar. The test was performed by applying repeated alternate distortions to the column specimen, simulating the effects of earthquakes. It was confirmed from the test results that this fortification method, in spite of being easy to use and economical, gives remarkable effects.

● 7.3-30 Polak, E., Pister, K. S. and Ray, D., **Optimal design of framed structures subjected to earthquakes,** *Engineering Optimization,* 2, 1976, 65-71.

This paper treats the following design problem: find the set of design parameters which minimizes the cost of an idealized multistory framed structure, subject to constraints that the relative displacements between adjacent story levels do not exceed preassigned limits when the structure is subjected to ground motion of a design earthquake. The design problem has the format of a state-constrained optimal control problem, which is solved by an algorithm based on a recent paper of Polak and Mayne. Because of hysteresis in the operator equation describing system dynamics, directional derivatives of the constraints cannot be calculated by standard techniques. Formulas for calculating the required derivatives appearing in the basic algorithm are presented and discussed.

● 7.3-31 Muto, K. *et al.*, **Aseismic design and study of tall reinforced concrete buildings,** Kajima Inst. of Construction Technology, Tokyo, July 1975, 21.

● 7.3-32 Haviland, R. W., Biggs, J. M. and Anagnostopoulos, S. A., **Inelastic response spectrum design procedures for steel frames,** *Evaluation of Seismic Safety of Buildings, No. 8, R76-40,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, Sept. 1976, 140.

Reported herein is an evaluation of aseismic design procedures based upon inelastic response spectra. Steel frames of different heights are designed for a desired level of yielding using elastic modal analysis. Responses in terms of maximum ductility ratios are computed for simulated ground motions derived from the design spectrum. Both shear beam models and point hinge models are utilized and compared. Results are given in terms of maximum local and story ductility ratios as compared with the design values. The effect of gravity loads on the computed response and the effect of including such loads in the design procedure are investigated. In general, local ductility ratios exceed the desired design level. The use of seismic load factors to improve performance is investigated. It is concluded that the inelastic response spectrum approach is promising, but that further study and development are necessary before it could be adopted with confidence.

● 7.3-33 **Low-cost construction resistant to earthquakes and hurricanes,** *ST/ESA/23,* Dept. of Economic and Social Affairs, United Nations, New York, 1975, 205.

This paper deals with the technological aspects of design and construction which must be taken into account when putting up new low-cost buildings and auxiliary structures in areas subject to earthquakes and strong winds. Its purpose is to set forth principles and basic techniques which can serve as a guide to administrators and technicians to enable them to prevent substantial damage to structures subjected to stresses resulting from earth tremors or violent movements of air masses.

The section on earthquakes places particular emphasis on the design, construction and repair of low-cost one-story or multi-family dwellings.

● 7.3-34 Stea, W. *et al.*, **Overturning and sliding analysis of reinforced concrete protective structures,** *Technical Report 4921,* Ammann & Whitney, New York, Feb. 1976, 279. (NTIS Accession No. AD A022 619)

This report presents design procedures and the computer program written to implement them for determining the gross motions of protective structures subjected to blast effects of high-explosive detonations. These procedures are intended to supplement the design methods of the triservice design manual *Structures to Resist the Effects of Accidental Explosions.*

The material presented includes dynamic analysis techniques for determining the gross motions of the structure on its supporting soil, methods for computing the time history of the blast load on the structure, and criteria and procedures for designing the foundation of the structure. A

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

system of classification of various soils is given together with a tabulation of critical soil properties. Documentation of the computer program is provided by means of descriptions of the required input parameters, definitive illustrations of the coded input card formats, illustrations of input deck structures, the FORTRAN listing for the CDC 6600 computer, and sample problems.

● 7.3-35 Ohmori, N. *et al.*, **Studies on the reinforced concrete slitted shear walls,** *KICT Report No. 21,* Kajima Inst. of Construction Technology, Tokyo, Feb. 1976, 109.

A slitted wall has vertical slits at certain intervals at mid-height in the wall. These slits are complete breaks not only in concrete but also in reinforcements so as to change the shear wall to a series of flexural wall-columns. The slitted wall is capable of such a large deformation angle that it can be used in high-rise buildings. It meets the requirements of a high-rise building system, in that it is flexible and ductile when subjected to seismic activity, and it is rigid and stiff against winds. The slitted wall tends to swell in plastic range with crack development, which exerts a confining force to the wall-columns. This reduces the reinforcement ratio of a wall-column, with quick closing of the cracks.

The objective of this study is to establish the design procedure for a slitted wall. This report deals mainly with experiments and research studies for the design method.

● 7.3-36 Feng, T. T. and Arora, J. S., **Optimization of beam type structures under dynamic input,** *22,* Intertech Corp., Iowa City, Feb. 1976, 10.

This report presents optimal design of cantilever beams subjected to dynamic input. The beams have radial ribs, and the depth of the ribs are considered as design variables. A lumped mass is placed at the free end of the cantilever beams and its effect on the dynamic response is studied. Numerical results for two examples are obtained and discussed.

● 7.3-37 Cheng, F. Y. and Botkin, M. E., **Nonlinear optimum design of dynamic damped frames,** *Journal of the Structural Division, ASCE,* **102,** *ST3,* Proc. Paper 11993, Mar. 1976, 609-627.

A method to optimize the weight of plane frames subjected to dynamic loads is presented. Various considerations for rigid frame design include damping, the $P\Delta$ effect, static girder loads, static column loads and girder shears transferred to the columns. A finite difference approach is presented to evaluate a shock spectrum which is used in conjunction with modal superposition to obtain the peak upper bound dynamic displacements and stresses for multistory and multibay frames. The displacement method is used for the structural matrix formulation from which the optimization process is shown in relation to the change of the design variables in the condensed stiffness matrix. A direct, nonlinear mathematical programming method of feasible directions is used to minimize the weight of the structure subject to the aforementioned linear and nonlinear constraints. Several applications of the proposed method are presented to show the design process related to the active constraints and the significant effects of various considerations on optimum design.

● 7.3-38 Rosenblueth, E. and Asfura, A., **Optimum seismic design of linear shear buildings,** *Journal of the Structural Division, ASCE,* **102,** *ST5,* Proc. Paper 12119, May 1976, 1077-1084.

An iteration procedure is described for the optimum design of shear buildings that behave linearly and have infinitely stiff and sufficiently strong beams. The design spectrum is assumed to be given. The procedure involves a modal analysis in each cycle. It converges rapidly if the design velocity spectrum increases with period in the neighborhood of the fundamental period and it can be adapted to cases in which the spectrum decreases in this range. The proposed approach insures at least one active restriction per story.

● 7.3-39 Shibata, A. and Sozen, M. A., **Substitute-structure method for seismic design in R/C,** *Journal of the Structural Division, ASCE,* **102,** *ST1,* Proc. Paper 11824, Jan. 1976, 1-18.

A method is proposed to determine design forces for earthquake-resistant design of reinforced concrete structures. The method uses a modified linear model of the structure and recognizes the effect of energy dissipation in the nonlinear range of response. Thus, the designer is provided with a procedure, at the level of linear spectral response analysis, with explicit options about the levels of inelastic response in different elements of a multistory reinforced concrete structure. The paper contains analytical tests of two-story to 10-story frames designed according to the proposed method.

7.3-40 Bljuger, F., **Determination of deformability characteristics of vertical shear joints in precast buildings,** *Building and Environment,* **11,** *4,* 1976, 277-282.

A classification and an analysis are presented for the deformability characteristics of the common types of vertical wall joints. A unified approach with practical recommendations is outlined for their determination in elastic and elasto-plastic design of multistory structures.

● 7.3-41 Velkov, M., **Seismic stability of reinforced concrete structural members of high-rise buildings and design of a twenty two story large panel building constructed in seismic zone,** Inst. of Earthquake Engineering and Engi-

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

neering Seismology, Univ. Kiril & Metodij, Skopje, Yugoslavia, Sept. 1975, 107.

Aseismic design of structures is impossible without detailed experimental and theoretical investigations which provide adequate explanation of the behavior of structures during earthquakes. This paper reviews the most characteristic experiments carried out in the world in order to provide an explanation of the behavior of certain structural members and systems. Described are experiments on beams, columns, shear walls, joints and full-scale structures. An interpretation of the results of these experiments is presented and conclusions are drawn. In the second section, the design of a tall large panel building is described.

● 7.3-42 Gallo, M. P. and Ang, A. H.-S., **Evaluation of safety of reinforced concrete buildings to earthquakes,** *UILU-ENG-76-2018, Structural Research Series No. 433,* Univ. of Illinois, Urbana, Oct. 1976, 114.

A model is developed that provides the basis for the determination of the levels of risk implicit in current earthquake-resistant design procedures. The basic variabilities in the loads and structural properties, as well as the errors in the mathematical models used to predict these quantities in design, are carefully examined and assessed from available information. These uncertainties lead to risk estimates that are consistent with the present state of knowledge. Only linear structures are considered; thus the failure probabilities calculated herein must be regarded as an indication of the likelihood of a structure (or a structural member) being stressed beyond the elastic range, and not necessarily that collapse, or even serious structural damage, will occur.

The levels of risk implicit in the 1974 SEAOC Code for bending, shear, and axial load are evaluated. This is accomplished by examining specific typical structures designed according to the code.

● 7.3-43 Kamil, H., **A computer-oriented deterministic-cum-probabilistic approach for the extreme load design of complex structures,** *Computers & Structures,* 6, *4/5,* Aug.-Oct. 1976, 375-379.

To obtain a rational, economical and reliable structural design under extreme loading conditions, a combination of deterministic and probabilistic approaches need to be used. Computers can be effectively used to combine these two approaches and to apply them to the design of structures.

State-of-the-art techniques are reviewed first for the deterministic and the probabilistic methods. It is emphasized that the development and use of probabilistic techniques for direct use in engineering design has been slow, partly due to the fact that no serious attempt has been made to use computers for this purpose. Computers can be used for the application of a combined deterministic-cum-probabilistic approach in the following two areas: (1) determination of design loads for multiple load cases by combining the individual load cases probabilistically outside the structure-foundation system and then determining the element load cases deterministically inside the system; (2) determination of the reliability of the foundation-structure system by first modeling the member property variations at the element level and then generating the system reliability using matrix algebra techniques, along with the system stiffness matrix.

Methodologies are presented to describe how the above objectives can be achieved. Limitations of the proposed methodologies are described and recommendations for future studies are made.

● 7.3-44 Wood, R. H. and Roberts, E. H., **A graphical method of predicting side-sway in the design of multistorey buildings,** *CP53/75,* Great Britain Building Research Establishment, Garston, England, June 1975, 14. (For an additional reference see Abstract No. 7.3-1.)

Since the advent of limit-state design, considerable advances have been made in simplifying collapse design procedures to the level of graphical desk methods, especially in the field of column design and frame instability. The corresponding simplified treatment of the other limit state of permissible sidesway has been rather neglected, partly because of confusion as to what the design criterion should be. To help speed up the design process, and to emphasize the importance of stiffening of frames by composite action, a completely graphical method is devised for estimating sidesway of multistory buildings.

● 7.3-45 de Clercq, H. and Powell, G. H., **Analysis and design of tube-type tall building structures,** *EERC 76-5,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1976, 207. (NTIS Accession No. PB 252 220)

Tube-type structures for tall buildings generally consist of large numbers of members connected at an equally large number of joints. This causes the exact analysis of such structures to be expensive and manual sizing of members during design to be tedious.

In this report, a method called the "Macroelement Method," is presented for the approximate analysis of three-dimensional tube-type frames consisting of horizontal beams and vertical columns connected at rigid joints. A linear elastic three-dimensional analysis can be performed very economically by this method for buildings of arbitrary plan, including such structures as bundled tube frames. The macroelement method is a variation of the finite element method, in which a single element embraces a rectangular portion of frame consisting of several columns and several beams. Elements are connected at a small number of nodes. Shape functions are assumed over the region of each element to express the displacements of the beam-column joints in terms of the displacements of the nodes. Numerical results are presented to show that an analysis by this method can yield results which are close to those obtained by an exact analysis, using a fraction of the computer time.

In the second part of the report a method for automated design and optimization is presented. This method is a combination of the "Optimality Criterion Method," which ensures satisfaction of displacement constraints, and the fully stressed design process. The cost, area and other properties of a member are expressed in terms of its moment of inertia through families of linear functions. This allows complex relationships to be treated. Numerical examples indicate that the proposed method is well suited for obtaining feasible and inexpensive designs. Convergence to the final design essentially occurs in the first three iteration steps, and each step entails only a few calculations beyond those required for a static analysis. When used with the macroelement method, an optimized design can be obtained for less than the cost of a single exact analysis.

● 7.3-46 Okada, T. and Bresler, B., **Strength and ductility evaluation of existing low-rise reinforced concrete buildings–Screening method,** *EERC 76-1,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1976, 234. (NTIS Accession No. PB 257 906)

This report describes a methodology for evaluating the seismic safety of lowrise reinforced concrete buildings and its application to existing school buildings. The method classifies buildings according to three types of failure mechanism. In the criteria for evaluating buildings, nonlinear response to two levels of earthquake ground motion is considered. The overall method consists of a sequence of procecures which are repeated in successive cycles, using more refined idealizations of behavior in each cycle. The first cycle of this procedure is called the first screening and is the cycle described in this report.

7.3-47 Radchenko, A. P. and Krasulin, N. N., **On restoration of reinforced concrete structures damaged in earthquakes** (K voprosu vosstanovleniya zhelezobetonnykh konstruktsii, poluchivshikh povrezhdeniya v rezultate seismicheskogo vozdeistviya, in Russian), *Stroitelstvo i arkhitektura Uzbekistana, 10,* 1976, 6-9.

The possibilities of using epoxy compounds to restore reinforced concrete structures following damage from seismic loadings are discussed. Gaps, plastic deformation zones and broken concrete members may be restored using epoxy compounds. In all of the cases investigated, the reliability of structures following restoration using these materials has led to significant economic results.

● 7.3-48 Sato, T. and Hanmuki, T., **The static-reliability of multi-story frames subjected to large lateral forces,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 240, 863-870. (For a full bibliographic citation see Abstract No. 1.2-9.)

This paper describes a direct computational method for analyzing the probability of safety of structures when multistory frames are subjected to relatively large lateral design forces.

● 7.3-49 Paulay, T., **Moment redistribution in continuous beams of earthquake resistant multistorey reinforced concrete frames,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* 9, *4,* Dec. 1976, 205-212.

To allow a more uniform and efficient distribution of load resistance in reinforced concrete frames that may be subjected to seismic excitation well beyond the range of elastic response, the concepts of moment redistribution, used frequently for the plastic design of steel structures, are reexamined. The aims of moment redistribution, with particular reference to earthquake loading, are stated and relevant terms are defined. To allow advantageous but static adjustments of moments (derived from an elastic analysis) to be made, the requirements of equilibrium and lateral load resistance are assembled into a set of simple rules. Some limits for redistribution, which appear to be reasonable considering current provisions for structural ductility are proposed. A simple technique, suitable for use in a design office, is presented. The technique is applied to an example.

7.4 Design and Construction of Nuclear Facilities

● 7.4-1 Shibata, H., **Anti-earthquake design of industrial facilities,** *Technocrat,* 8, *11,* Nov. 1975, 12-21.

Designing industrial facilities for earthquake resistance is reviewed. A flow chart of design considerations for nuclear power plants is presented. In addition, the modes and mechanisms of industrial building failure and the seismic coefficient and the response spectrum methods of design are discussed.

● 7.4-2 Zendehrouh, S. and Shinozuka, M., **A structural design decision methodology for nuclear power plants,** *Methods of Structural Analysis,* Vol. I, 517-534. (For a full bibliographic citation see Abstract No. 1.2-3.)

The purpose of this study is to extend the existing methods of reliability analysis and design decision making in order to devise a design decision methodology suited for nuclear power plant facilities. The proposed methodology

(a) uses a reasonable practical measure of safety to indicate the integrity level of structural and equipment design under severe environmental and other hazardous conditions such as earthquakes, tornadoes, missiles and floods; (b) correlates this measure with the radioactivity release in probabilistic terms; and (c) ultimately identifies the appropriate level of design for a particular nuclear power plant facility. Application of the methodology is illustrated for the case of earthquakes.

● 7.4-3 Mehta, D. S. and Meyers, B. L., **Application of structural, mechanical and electrical codes and standards in the design of safety related structures, components and systems for nuclear power plants,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 759–769. (For a full bibliographic citation see Abstract No. 1.2-7.)

This paper identifies and provides a brief summary of the codes, standards and code of federal regulations currently being used in the design of safety-related structures, components and systems for nuclear power plants. Discussed also are the current requirements that must be applied prior to issuance of a construction permit and operating license for nuclear power plants. The current status and brief summaries of the codes and standards are presented.

7.4-4 Pavlyk, V. S. and Vasyunkin, A. N., **Aseismic design features of nuclear power plants** (Meropriyatiya po seismozashchite konstruktsii atomnoi elektrostantsii, in Russian), *Trudy TsNII stroitelnykh konstruktsii, 45,* 1975, 13–19.

Aseismic design features of the central structures of nuclear power plants—the reactor building and primary systems—are discussed using data on aseismic nuclear power plant design available in the U.S.S.R. as well as from an analysis of foreign publications. Directions of ongoing investigations intended to put aseismic nuclear power plant design on a scientific basis are described.

● 7.4-5 Yanev, P. I., Mayes, R. L. and Jones, L. R., **Seismic review of existing nuclear power plants,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper 1/5, 10. (For a full bibliographic citation see Abstract No. 1.2-11.)

Because of developments in the fields of earthquake and structural engineering over the last two decades, the codes, standards and design criteria for nuclear power plants and other critical structures have changed substantially. As a result, plants designed only a few years ago do not satisfy the requirements for new plants. Accordingly, regulatory agencies are requiring owners of older nuclear power plants to re-qualify the plants seismically, using codes, standards, analytical techniques and knowledge developed in recent years. Seismic review consists of three major phases: (1) establishing the design and performance criteria, (2) re-qualifying the structures, and (3) re-qualifying the equipment.

The design criteria and the levels of earthquake excitation are dependent on the presence of soil-structure interaction, particularly for soft soil sites and embedded structures. The original design spectra may be significantly altered in such cases. Structural design codes, and particularly mechanical and pressure vessel codes, have changed significantly in recent years and present some difficult problems for re-qualification and design.

Structural re-qualification consists primarily of analytical studies of the existing structures. Several factors aid the analysis—the configurations are fixed, tests can be easily performed to obtain more accurate material properties, and forced vibration testing can be performed to establish dynamic properties. Equipment and piping systems re-qualification involves analysis and extensive in-situ, forced vibration test programs. A combination of the methods appears to be most desirable, particularly for structurally complex or rigid equipment.

Some of the difficulties encountered in the seismic review are the verification of as-built structural and equipment configurations, the extent of nonlinear effects such as cracking of concrete members, selection of performance criteria for electrical equipment, and lack of access because of high radiation exposures.

● 7.4-6 Newmark, N. M., **A response spectrum approach for inelastic seismic design of nuclear reactor facilities,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 5/1, 14. (For a full bibliographic citation see Abstract No. 1.2-11.)

From consideration of the effect of suddenly initiated pulses of displacement, velocity, or acceleration on simple inelastic systems, bounds on the seismic response of such systems can be inferred. The results are consistent with observations and calculations that have been made of the time-history seismic response of elastoplastic systems, and permit generalization and extrapolation to more complex stress-strain or force-deformation relations.

With these observations as a base, design criteria for use with response spectrum methods are developed for systems in which only a limited amount of inelastic action can be permitted, as is the case in general with nuclear reactor facilities.

● 7.4-7 Miller, C. A. and Costantino, C. J., **Facility design constraints for combined seismic and thermal loading,** *Transactions of the 3rd International Conference on Struc-*

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

tural Mechanics in Reactor Technology, Vol. 4, Paper K 7/8, 8. (For a full bibliographic citation see Abstract No. 1.2–11.)

The primary coolant in breeder reactors is liquid sodium with the system operating at temperatures of about 1000°F. The design of piping systems and their support structure must include sufficient flexibility to accommodate thermal growth and yet be stiff enough to withstand seismic-induced loadings. This paper describes some of the problems which arose in satisfying these conflicting requirements for the dump heat exchanger (DHX) of the Fast Flux Test Facility. Based upon this experience, criteria are suggested for the design of liquid sodium piping systems subjected to both seismic and thermal loadings.

The tube bundle of the DHX contains 66 serpentines arranged side by side and supported from a structural framework which is about 15 ft by 40 ft in plan and 40 ft high. Air flows vertically through the tube bundle providing cooling. Each serpentine of the tube bundle contains four 30 ft horizontal pipes connected with pipe bends. Liquid sodium enters and exits from the serpentines through headers. All of the horizontal pipes and headers are supported from the main structure which is thermally insulated from the hot interior. Thermal stresses are induced in the piping because the pipe bends expand more than the support structure. Consideration of thermal stresses alone would suggest that the number of pipe support points be minimized but this solution leads to high seismic-induced stresses. The final design utilizes four supports; a trial design of seven supports was found unacceptable because of the large thermal stresses. This solution was reached through a trial and redesign process.

To circumvent the necessity of this iterative design process, solutions are developed giving the optimal number and location of supports for given thermal and seismic loadings. The horizontal pipe is considered as a continuous beam with end moment springs representing the pipe bends. The number and location of supports is calculated so that the maximum bending moment in the pipe is minimized. Charts are given in nondimensional form which allow the designer to select the proper number of supports depending on the relative severity of the thermal and seismic loads, and on the pipe geometry. Application of this criteria to the DHX would indicate that the optimal support condition is four as was used in the design.

The design of the supports for piping systems subjected to severe thermal and seismic loadings should be based upon a tradeoff between each of the loadings. Both loadings must be considered simultaneously and the support locations selected to minimize the combined effects. A rational procedure for doing this is given in the paper and results are presented which are applicable for most piping systems.

● 7.4-8 Skinner, R. I., Tyler, R. G. and Hodder, S. B., **Isolation of nuclear power plants from earthquake attack,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* 9, 4, Dec. 1976, 199–204.

The analysis of one- and two-mass models indicates that the earthquake-generated horizontal forces and deformations of the main structures of a nuclear power plant can be reduced by a factor of about ten times by mounting the overall power plant building on a recently developed base-isolation system. The very high forces which this resonant appendage effect may induce in some critical components (such as fuel elements, control rods and essential piping) may be reduced by a factor of 40 or more times by the isolation system. The parameters of the isolation system have been chosen as appropriate to the level of protection which should be provided for a nuclear plant in a seismically active area. Consideration is given to flexible mounts and dampers suitable for such an isolator.

● 7.4-9 Smith, C. B., **The state-of-the-art for seismic design of nuclear power plants—An assessment,** *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology,* Vol. 4, Paper K 4/1, 10. (For a full bibliographic citation see Abstract No. 1.2–11.)

The results of an assessment of the state-of-the-art for the seismic design of nuclear power plants are described and those areas of seismic design and analysis requiring further work are delineated. The study was conducted by a private firm and was based on the experience of the firm's personnel in the field as well as the efforts of specialists from industry and government.

Three general areas were investigated: soils, siting and seismic ground motion specification; soil-structure interaction; and the response of major nuclear power plant structures and components. In addition, a sample of industry experts was polled in an effort to establish industry concerns.

Major findings include the necessity of improving knowledge of seismicity and soil dynamic parameters; improved specification of seismic inputs used for design (the safe shutdown earthquake and the operating basis earthquake) and validation of models and methods used for soil-structure interaction calculations. Also considered important are the acquisition of additional experimental data on equipment and structures; certain changes to regulations and standards; and the development of simplified design methods suitable for industry-wide application.

Substantial conservatism in seismic design appears to be present in many areas; in others, the reliability and uncertainty of the design needs quantification. There is industry concern for the lack of skilled manpower with seismic design experience. Among the respondents to the questionnaire, there was nearly unanimous agreement as to the urgent need for preselected, preapproved sites with preestablished seismic design criteria for nuclear power plants. Furthermore, the role of the licensing and regulatory agencies has been questioned. At least in the United States, it appears that more emphasis should be placed on licensing and regulation and less on attempts to tell the industry what methods should be used for design and analysis.

The quantity of experimental data existing in the world today—from both tests and actual earthquakes—is so small as to be cause for concern. Additional work in this area is urgently needed, particularly on full-scale structures and at high levels of response.

● 7.4-10 Danisch, R. and Labes, M., **Aseismic design of turbine houses of nuclear power plants** (in German), *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology*, Vol. 4, Paper K 6/6, 14. (For a full bibliographic citation see Abstract No. 1.2-11.)

The turbine house does not belong to the safety-related parts of equipment of a nuclear power plant. A special protection against earthquakes is not demanded by the seismic codes as long as it is proven that safety-related parts of equipment will not be restricted in their function by a collapse of the turbine house. The degree of an aseismic design is largely up to the customer who has to weigh the benefits aagainst the additional costs necessary to strengthen the turbine foundation against earthquakes.

In comparison to the high-tuned turbine foundations in use in the U.S.A. today, low-tuned turbine foundations with helical-spring supports, which are constructed by the KWU exclusively, pose special problems in aseismic design. This is discussed herein.

The spring-supported mass constitutes about a quarter of the building mass. For mechanical reasons, the spring elements are chosen in such a way that the turbine foundation has a natural frequency of ~3 Hz. Thus it remains within the same frequency range as the turbine house and within that range which is particularly amplified by an earthquake. It is therefore likely that resonance effects as well as oscillation effects may occur.

The standardized calculation methods for conventional buildings without safety functions, such as DIN 4149 (Germany) or SIA 162 (Switzerland), do not cover the oscillation conduct of such a complicated structure as nuclear power plants. Information about possible relative displacements between the building and the turbine foundation (hammering-effect) and about the stresses on the turbine and other components is determined only by dynamic calculation methods such as the time-history or the response-spectrum method.

If an operating basis earthquake is assumed, the following strengthening measures will be necessary: (1) Small earthquakes ($<0.05g$)—reinforcement of the building structure; the concept of the building structure may be kept unchanged. (2) Medium earthquakes—reinforcement of the building structure, slight alterations of the building concept; installation of damping elements at the spring assemblies; reinforcement of the turbine foundation without changing the concept. (3) Strong earthquakes ($>0.15g$)—essential alteration of the building concept such as light steel construction or altering the machine hall, additional shear-walls, deeper foundation level of the building; installation of damping elements at the spring assemblies; reinforcement of turbine bearings; modified design of the turbine foundation. The acceleration values given above are only a rough evidence, since the stresses are largely dependent on the soil conditions and the response spectra at a site.

● 7.4-11 Baccarini, L. *et al.*, **Seismic qualification tests of electric equipment for Caorso nuclear plant: Comments on adopted test procedure and results**, *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology*, Vol. 4, Paper K 7/9, 10. (For a full bibliographic citation see Abstract No. 1.2-11.)

The seismic tests on Class I electric equipment for the nuclear power plant of ENEL at Caorso have been carried out at the Ist. Sperimentale Modelli e Strutture for the last two years. The testing procedure is mainly based on the IEEE Guide, Std. 344-1971, and is summarized as follows: Complete panels (fully equipped with operated and nonoperated devices): resonance search at low acceleration level; determination of amplification and damping at the found resonances; vibration tests at the resonance frequencies (continuous sine) with acceleration to be related to the floor response spectrum (f.r.s.) on the basis of the results of the previous tests; devices (operated and monitored): resonance search as above; vibration tests at the resonance frequencies, or at 33 Hz if resonances are not found, with increasing acceleration until the device ceases to perform.

Without going into details as to the reliability of the f.r.s., a proper correlation between the results of the resonance search tests and the f.r.s. is easily made if a panel can be considered as a single-degree-of-freedom, linear and viscously damped system. Actually, almost all panels show a very complex behavior with numerous resonances, which, in turn, is highly nonlinear. Te determine the damping value is then an almost unsolvable problem, and the correlation between the test acceleration and the f.r.s. is very difficult. As regards the responses recorded in points of the panel, high accelerations are due to local resonances of small nonstructural parts, so that gage points should be selected very carefully when the overall behavior is to be determined. The meaning of "structural integrity" as a criterion of seismic adequacy is debatable. Structural damage occurs very seldom, and affects parts of the panel of low importance unless fatigue effects, unlikely to play a noticeable role during an earthquake, are introduced. On the other hand, structural damage may not affect the performance of the devices placed in the panel, whereas their poor performance may occur without structural damage to the panel itself. The influence of the mounting (weldings, boltings, connections) greatly affects the dynamic behavior of the panels, especially when the first resonance frequency is concerned.

On the basis of these considerations, a more reliable testing procedure would be: a continuous frequency sweep at low acceleration (sinusoidal) to record the behavior of the most significant points; a random excitation whose spectrum matches with the given f.r.s., or, for a more general test procedure, envelops a number of expected earthquake spectra; to repeat the frequency sweep to make evident possible differences in the panel behavior due to important structural failures. Criteria for the correct choice of a specimen panel to be tested are discussed in detail.

As regards the devices, the determination of the resonant frequencies is sometimes difficult (due to the small dimensions of the device its behavior might be modified by the presence of the pick-up mass), and in most cases, it has no meaning. In effect, a bad performance of a device is mainly due to local resonances (of springs, contacts, connections) which can be discovered only by monitoring.

The tests at 33 Hz when resonances are not found have little meaning. This is mainly due to the nonlinear behavior of contacts and other moving parts of the devices (switch on–switch off positions) when bad performance may occur suddenly at any frequency for lower acceleration levels.

A better testing technique seems then to be to test the device, its performance being monitored with continuous sweeps in the frequency range of interest and increasing the acceleration until it ceases to perform correctly.

7.5 Design and Construction of Miscellaneous Structures

● 7.5-1 Ramirez Sanchez, S., **Design of bridge substructures on pile foundations,** *Individual Studies by Participants at the International Institute of Seismology and Earthquake Engineering,* **11,** 1975, 226-239.

The procedures used to design a prestressed concrete bridge are described, assuming the substructures to be resting on ordinary soil. The design computations of prestressed concrete piles of 60 cm diameter for apartments and cast-in-place concrete piles of 100 cm diameter for pier substructures were based on the Japan Industrial Standard and on specifications of the Japan Road Assn. It was assumed that piles of varying diameters might be utilized depending on soil conditions and the type of substructure. The seismic coefficient method was used in the design of the substructures. As far as the superstructure was concerned, only a general study was made of the design of the prestressed concrete girders.

● 7.5-2 Chang, D. J., **Guide criteria to bridge and permit loads,** *Methods of Structural Analysis,* Vol. I, 170-188. (For a full bibliographic citation see Abstract No. 1.2-3.)

The current practice of bridge design and rating, based on the assumption that every engineering phenomenon is without uncertainty, does not always guarantee safe and long-term economic solutions. The application of probabilistic theories instead should provide a rational basis in the decision process over the "life" of any structure. A uniform treatment of dynamic disturbances to a structure is presented as examples.

● 7.5-3 Kapsarov, H., **Seismic stability of the supporting structure for a spherical tank, volume 2000 m^3,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 1, Paper No. 82, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

A supporting structure for a tank located in the vicinity of Skopje, a seismically active region, is analyzed. The tank is for storage of explosive materials.

● 7.5-4 Tamura, C. and Okamoto, S., **A study on the earthquake resistant design of subaqueous tunnels,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 121, 13. (For a full bibliographic citation see Abstract No. 1.2-6.)

Following a mathematical model previously developed by them, the authors calculate the response of underwater tunnels, having a typical cross section and typical ground conditions, to different seismic waves. In these calculations, much attention was given to the influence of the predominant period of the ground, the length of the slope of the channel and the rigidity of the subgrade over the maximum axial and bending stresses occurring in underwater tunnels during earthquakes.

● 7.5-5 Kubo, K., **Fundamental concept of aseismic design of underground piping system,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 123, 8. (For a full bibliographic citation see Abstract No. 1.2-6.)

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

The results of research on the relation between seismic damage to water pipes and soil conditions are explained. Data of the damage to water pipes in Tokyo obtained during the 1923 Kanto earthquake were used. The main finding was that water pipes constructed in transient soil conditions were most heavily damaged. The effect of ground acceleration upon the damage ratio of underground structures is shown. To compare damage ratios obtained from two earthquakes, data on the damage to water pipes in Los Angeles obtained during the 1971 San Fernando earthquake were used.

An outline of the tentative draft (1973) of the Japanese design codes for the seismic-resistant design of underground oil pipelines is presented. In addition, the author comments upon the fundamental concept used to design underground piping systems for earthquake resistance.

● 7.5-6 Fujiwara, T., **Some problems in counterplans to earthquake on new high speed railway lines,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 150, 5. (For a full bibliographic citation see Abstract No. 1.2-6.)

Discussed are four seismic-resistant safety measures for trains operated at high speeds on structures built on very soft ground. First, it is appropriate to construct a bridge on such ground if the bridge has a long span or if it is on floating piles. Second, in the case of a floating pile structure, the earthquake motion of the ground upon which each of the piers stands is difficult to assess since the motion is heavily affected by the inclination of the boundary layer. Third, in order to stop moving trains as soon as possible, the idea of the conventional earthquake-motion detecting system should be reviewed. Fourth, the track structure should be designed so that a train, even when derailed, may not be overturned.

● 7.5-7 Bickovski, V. and Petrovski, J., **Optimum arch dam shape definition for earthquake load,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 166, 7. (For a full bibliographic citation see Abstract No. 1.2-6.)

Selection of proper geometry and cross section of an arch dam to satisfy safety criteria for static and particularly extreme earthquake loads is a complex but very important step in the seismic analysis of this type of structure.

The procedure of "envelope structural response" for the purpose of preliminary analyses of an arch dam is described and compared with the classical modal superposition method of analysis. Using this procedure, fast correction of the geometry and cross sections could be provided on the basis of extreme stress and deformation value calculation for any moment of the time history.

● 7.5-8 Carlson, L. A., Dreyer, R. C. J. and Platzke, R., **First bridge across the Yukon River,** *Civil Engineering, ASCE,* **46,** *8,* Aug. 1976, 47-51.

Until recently, the Yukon River was a major obstacle in constructing a roadway to the oil-rich North Slope of Alaska. But on Oct. 10, 1975, that obstacle was hurdled when the first bridge across the Yukon was open to traffic. This new $30,000,000 crossing is located 100 miles northwest of Fairbanks. The remote location, extremely cold climate, and other environmental factors called for unusual design and construction. Twin orthotropic steel box girders support a 30 ft wide roadway. Later, the bridge will carry two 48 in. crude oil pipelines. The bridge's reinforced concrete piers are secured to bedrock on the river bottom with prestressed rock anchors. Because of the very low ambient temperatures, brittle fracture was an overriding concern. Exceptionally tough A537 steel (pressure vessel steel) was used in all major tension areas of girders. Toughness requirements were so stringent that only Japanese producers would quote on the project.

● 7.5-9 Longinow, A. *et al.,* **Seismic retrofitting for highway bridges,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 37-50. (For a full bibliographic citation see Abstract No. 1.2-7.)

The San Fernando earthquake of Feb. 9, 1971, has demonstrated that bridges located in high risk seismic zones which were designed in accordance with the then-prevailing AASHO design criteria may not possess adequate seismic resistance. This paper describes an effort which was undertaken to develop a set of practical retrofit measures that can be employed on existing bridges so as to reduce damage and minimize the threat to life should an earthquake occur. The process leading to the identification of potential bridge weaknesses, selection of a retrofit measure and verification of its adequacy is illustrated using both detailed and simplified analysis procedures.

● 7.5-10 De Capua, N. J. and Liu, S. C., **Protection of communications facilities in earthquake areas,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 253-268. (For a full bibliographic citation see Abstract No. 1.2-7.)

The continued reliable operation of telephone equipment in earthquake-prone areas depends on the equipment's ability to survive earthquakes of a realistic magnitude. This paper presents a procedure for developing regional earthquake protection practices in a cost-effective manner.

Maintaining system reliability requires extensive knowledge of the earthquake environment of a particular area and the response-damage-failure mechanism of the equipment and its supporting frame during earthquakes.

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

The earthquake environment is determined by a regional microzonation analysis, which is translated into isoseismic acceleration maps of the area being studied. The seismic response of the communications equipment is determined by a comprehensive analysis of the coupled foundation-building system and dynamic testing of the equipment assembly, employing a regional test environment. The procedure is applied to electronic, electromechanical, and reserved-power equipment for both a single system and multiple systems within an earthquake area.

● 7.5-11 Merz, K. L., **Earthquake dynamic environment within buildings,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 795-808. (For a full bibliographic citation see Abstract No. 1.2-7.)

An understanding of building response to earthquake ground motion is necessary for nonstructural designers to prepare specifications for equipment manufacturers and suppliers. The proper design of equipment anchorage and the interconnection of non-structural components within a building requires knowledge of the magnitude of the forces induced in equipment and the deformations imposed upon the components. The present paper provides a review of the actual building motions recorded during the 1971 San Fernando earthquake to allow realistic estimation of the distribution of floor acceleration and building drifts over a building height. Peak floor amplification factors are presented for a sample of 49 high-rise buildings. The statistics of floor acceleration peaks over the time duration of motion are also examined for an example building to provide some information about the probability of exceeding a given value of peak acceleration. The analysis of the records recorded during the 1971 San Fernando earthquake provide data in the form of floor response spectra. This data is reviewed to provide guidance for the design of typical spring-mounted (vibration-isolated) building service equipment. The relative deflection between floors of a building, or story drift, is a critical parameter. The drift response determined from a recorded building motion is examined to provide guidance for the realistic estimation of building drifts, which are the result of the nonlinear response behavior of buildings.

● 7.5-12 Robinson, W. H. and Greenbank, L. R., **An extrusion energy absorber suitable for the protection of structures during an earthquake,** *Earthquake Engineering and Structural Dynamics,* **4,** *3,* Jan.-Mar. 1976, 251-259.

A structure moving under the influence of an earthquake is normally required to absorb its own energy of motion. However, in many cases it is possible to attach to the structure energy-absorbing devices which absorb most of its energy of motion. One such device is an energy absorber which works by extruding lead back and forth through an orifice. On being extruded the deformed lead recrystallizes immediately, thereby recovering its original mechanical properties before the next extrusion or stroke. Accordingly, the amount of energy absorbed is not limited by work hardening or fatigue of the lead, but rather by the heat capacity of the device, the melting point of lead being the upper limit to the operating temperature. Furthermore, the device is able to absorb energy during a large number of earthquakes.

A number of 20 kN x 2 cm stroke to 200kN x 26 cm stroke extrusion energy absorbers have been tested at rates of 10^{-6} to 3.6 x 10^{3} cm/min. They behaved as "plastic solids" or "coulomb dampers" with nearly rectangular hysteresis loops and little rate dependence.

7.5-13 Pestryakov, V. A., **Determination of seismic safety zones for excavators on the basis of permissible dynamic loads** (Opredelenie zony seismicheskoi bezopasnosti ekskavatorov po dopustimoi dinamicheskoi nagruzke, in Russian), *Sbornik rauchnykh trudov Magnitogorskogo gornometallurgicheskogo instituta, 155,* 1975, 22-24.

Criteria for evaluating seismic effects of explosions on excavators in open-pit mines on the basis of permissible dynamic loads are established.

● 7.5-14 Wang, P. C. *et al.,* **Critical excitation and response of free standing chimneys,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. I, 269-284. (For a full bibliographic citation see Abstract No. 1.2-7.)

This paper deals with the problem of the seismic design of free-standing chimneys, of constant as well as tapered cross sections. It is shown that seismic designs based on the critical excitations of these structures are conservative, but not overly so, and that such designs should be appropriate either for localities in which ground motion records are scarce or for structures, the loss of which would have serious economic or social consequences. This conclusion is based on computed "critical design factors," which are the ratios of the response peaks generated by a critical excitation to those produced by an actual ground acceleration of the same intensity. These factors were found to be in the order of 0.93 to 1.3 for at least one structural design variable of each of the two structures, implying that design based on the critical excitation method would be slightly more conservative than one based on an already observed ground motion. Design calculations for the additional steel reinforcement implied by those factors confirm this conclusion.

● 7.5-15 Chen, P. C. and Barber, R. B., **Seismic design of liquid storage tanks to earthquakes,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1231-1247. (For a full bibliographic citation see Abstract No. 1.2-7.)

Bauer's rigorous and experimentally verified technique, which can be used to solve the Laplace equation and which satisfies the boundary conditions for hydrodynamic problems, was compared with current tank seismic design procedures developed by Housner. These design procedures were developed using an approximate approach which did not consider the usual procedures for determining velocity potentials for hydrodynamic problems; the approach only considered the first mode frequency of fluid oscillation.

Factors included in the comparison were fluid oscillation frequencies, fluid dynamic pressures, equivalent mechanical models, and tank base moments. The NRC seismic design spectra were used in the comparison as the design earthquakes. The results show that for cylindrical tanks the current design approach generally gives smaller tank base moments than the rigorous approach. For rectangular tanks, the differences in tank base moments between these two approaches are small.

Based upon the above results, improved techniques were developed for tank seismic design. These simplified techniques use the rigorous approach for tank analysis and consider higher mode frequencies of fluid oscillation. Parameter charts were also developed which greatly facilitate the seismic analysis and design of liquid storage tanks.

● **7.5-16** Eisenberg, I. M., **Safety of seismic protective systems with reserve elements,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 927-943. (For a full bibliographic citation see Abstract No. 1.2-7.)

Some results of an approximate analysis of the safety of earthquake protective systems with reserve disengaging elements are presented. Systems with one and several reserve elements are considered. The overshoot random vibration theory is used for analysis. A wide-band random vibration approximation—a white noise process—is assumed as a mathematical model of earthquake ground motion. A numerical example is given. It is shown that the failure probability of reserve element structures is considerably lower and that such structures are more safe than structures without reserve elements.

● **7.5-17** Sakurai, A., Kurihara, C. and Iwatate, T., **Aseismic design examples of prestressed concrete water tank,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1263-1276. (For a full bibliographic citation see Abstract No. 1.2-7.)

Seismic-resistant designs of prestressed concrete water tanks contain interesting problems not only of hydroelasticity but also of design and construction of thin-walled prestressed concrete shell structures. Examples of seismic-resistant design of three prestressed concrete surge tanks of hydroelectric power stations are presented in connection with discussions of the virtual mass effect of the inner water of a flexible tank and discussions of the relative merits of stress analysis methods used in these designs. These methods are reviewed by model test and field research on an actual tank during surging tests. Utilization of these examples seems especially appropriate when seismic-resistant designs of thin-walled water tanks are required.

7.5-18 Bulson, P. S., **Lightweight underground structures,** *The Structural Engineer,* **54,** *9,* Sept. 1976, 321-327.

The behavior of simple thin-walled structures under soil cover and surface pressure has been examined by the author and others, using statically and dynamically loaded models. The results are summarized and used as a basis for presenting fundamental equations that might be used for initial design calculations. Particular reference is given to strength, stability and safety, and to the ways in which flexible substructures differ fundamentally from more conventional rigid forms.

It is concluded that lightweight structures can be used successfully and economically in an underground environment, provided that the soil conditions are known, and that emplacement is carefully conducted.

● **7.5-19** Konishi, I., **World's third longest cantilever bridge,** *Civil Engineering, ASCE,* **46,** *2,* Feb. 1976, 84-86.

This report includes the planning, design and construction procedure of the world's third longest double deck, cantilever bridge, Osaka Port Bridge, which was completed in July 1974 in Osaka City, Japan. The geographical and meteorological characteristics at the site presented difficult foundation problems and design problems against strong earthquakes and winds. Weldable super high-strength steels, 114,000 psi (80 kg/mm^2) up to 2.95 in. (75 mm) thickness, were newly produced for this bridge. It took only 3.5 hours to lift the 610 ft (186 m) suspended truss span weighing 4200 tons from the sea to a height of 197 ft (60 m).

● **7.5-20** **California soon to have platform in 850 ft of water,** *Civil Engineering, ASCE,* **46,** *4,* Apr. 1976, 49-50.

Exxon's oil drilling and production platform, to be placed off Santa Barbara, California, will stand in water twice as deep—850 ft versus about 420 ft—as any other such platform. The jacket, standing about 900 ft high, has piles driven through its eight legs that are about 1250 ft high, surely a record; but the portion of the pile above seabed acts not as pile but as leg. The jacket is being fabricated in two pieces, top and bottom, which will be joined near the site. Hydraulic connectors, each consisting of hydraulic cylinders arrayed radially around each leg, lock the two halves together until they are welded. For upending and submerging in a controlled manner, the tall legs

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

must be sealed off at intermediate points; unique bridge plugs do this.

● **7.5-21** Lee, K. L. and Focht, Jr., J. A., **Closure of: Liquefaction potential of Ekofisk tank in North Sea,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *CT1,* Proc. Paper 11816, Jan. 1976, p. 113. (*By Lee, K. L. and Focht, Jr., J. A., Proc. Paper 11054, Jan. 1975.)

7.5-22 Petrov, A. A. and Efremov, M. M., **On design of suspended systems for seismic excitations** (K raschetu visyashehikh sistem na seismicheskie vozdeistviya, in Russian), *Stroitelnaya mekhanika i raschet sooruzhenii,* 2, 1976, 61-64.

The effects of seismic excitation on the supporting cables of suspended systems are evaluated in the case of horizontal displacement at the base. The presence of a phase shift due to the approximate equality of the seismic wave length and the dimensions of the structure is assumed. Seismic excitation is considered as a stationary stochastic process. The most dangerous case involving base displacement along the longitudinal axis of a large-span structure subjected to a random traveling wave is discussed. The results have practical applications in evaluating seismic loads on bridges, overpasses and roofs.

● **7.5-23** **Earthquake damage evaluation and design considerations for underground structures,** American Society of Civil Engineers, Los Angeles, Feb. 1974, 102.

Underground structures are used to convey most of our daily necessities, the most important of which is water supply. These structures also include utilities such as telephone, gas, oil, electricity and storm and sanitary sewer systems. Following the 1971 San Fernando earthquake, the Los Angeles Section of the American Society of Civil Engineers established a committee to coordinate studies undertaken by the various utilities to review earthquake design criteria used for such facilities and to formulate recommendations to minimize expected damage. This report presents the results of those studies.

● **7.5-24** **A review of earthquake resistant design of dams** (Une revision du calcul sismique des barrages, in French and English), *Bulletin 27,* Committee on Earthquakes, International Commission on Large Dams, Paris, Mar. 1975, 106.

The Committee on Earthquakes studied the influence of earthquakes on dams and collected the available information on the subject. This report presents a brief summary of world practice and indicates the design practice, standards and construction procedures used in various countries.

● **7.5-25** **Report concerning earthquake resistant design advances for State highway and bridge construction,** *Third Biennial Report,* Business and Transportation Agency, California Dept. of Transportation, Sacramento, Oct. 1976, 31.

This is a report on earthquake-resistant design advances for State highway and bridge construction and on remedial actions completed, in progress or contemplated, aimed at increasing the earthquake-resistant characteristics of existing State highway facilities. This is the third biennial report and covers progress from Oct. 1972 through Oct. 1976.

● **7.5-26** Van de Vegte, J. and de Silva, C. W., **Design of passive vibration controls for internally damped beams by modal control techniques,** *Journal of Sound and Vibration,* 45, *3,* Apr. 8, 1976, 417-425.

Modern modal control techniques are applied to the design of dynamic absorbers for the control of transient vibrations of internally damped thin uniform beams. Parameters and locations of single and dual absorbers are chosen so that the overall system approximates a desired characteristic polynomial.

● **7.5-27** Takada, S. and Nagao, S., **Efficiency of joint parts for aseismic strength of buried pipelines** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 217, 679-686. (For a full bibliographic citation see Abstract No. 1.2-9.)

In this report, an analytical method is proposed for the aseismic design of buried pipelines, taking into consideration that the ground was elastic-plastic. The numerical method is based on the displacement method. It is assumed that the seismic wave propagating in the surface layer is similar to the sine wave. Parameters for these calculations were the relative displacement between the pipes and the soil and the maximum friction acting on the pipe. About 100 cases were analyzed.

● **7.5-28** Noda, S. and Uwabe, T., **Relation between seismic coefficient and ground acceleration for gravity quaywall,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 203, 575-582. (For a full bibliographic citation see Abstract No. 1.2-9.)

Using the present design standard for port and harbor structures, the seismic coefficients corresponding to the severity of ground motions were obtained for 129 gravity quaywalls in 49 ports damaged by 12 earthquakes. The maximum ground accelerations in the ports were estimated by calculating the ground response during the earthquakes with reference to the attenuation curves of the base rock acceleration based on the accelerograms in the port areas. The seismic coefficients varied up to 0.25. The upper limit of the relation between the coefficient and the maximum ground acceleration is expressed by an equation.

● 7.5-29 Dracup, J. A., Duke, C. M. and Jacobsen, S. E., **Optimization of water resource systems incorporating earthquake risk,** *36,* California Water Resources Center, Univ. of California, Davis, Sept. 1976, 45.

This six-year study of the optimization of water resource systems incorporating earthquake risk was undertaken as an interdisciplinary effort. The chief accomplishment was the providing of a procedure with which to incorporate seismic risk into the optimal planning of a large-scale water resource system (Part I). In Part II, the philosophy and evolution of the new field of lifeline earthquake engineering are outlined. Part III includes the project objectives, accomplishments and bibliography. The main contributions are listed in the bibliography, in which it is seen that the items overlap among the fields of earthquake engineering, water resource systems and operations research.

7.5-30 Thomas, H. H., **The engineering of large dams,** Wiley-Interscience, New York, 1976, 2 vols., 777.

This book is a reference on the engineering of large dams covering major factors of investigation, including hydrology, geology, and the conception of the project of design—both mathematical and model analyses—and of various construction techniques with special reference to their effect on design. Coverage includes environmental effects of large reservoirs, the possibility of induced seismic activity, and overall water resource planning.

● 7.5-31 Baccarini, L. *et al.*, **Seismic qualification tests of electric equipment for Caorso nuclear plant: Comments on adopted test procedure and results,** *84,* Ist. Sperimentale Modelli e Strutture, Bergamo, Italy, Sept. 1976, 12.

7.5-32 Sinitsyn, A. P., **The balanced risk method and the reliability of hydraulic structures** (Metod sbalansirovannogo riska i nadezhnost gidrotekhnicheskikh sooruzhenii, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 73–77. (For a full bibliographic citation see Abstract No. 1.1-7.)

The balanced risk method is employed to calculate the reliability of hydraulic structures. It is found that uniform risk for all structures of a hydroelectric power plant complex may be achieved provided that the design parameters of each structure are adjusted to take into account the service life, the importance, the dangers from failure and the cost of reconstruction of each structure. The maximum possible and maximum likely earthquake intensity is calculated. The concept of risk is defined and formulas for calculating it are presented. A method for calculating design intensities is described.

7.5-33 Savinov, O. A., **Operational methods for increased earthquake resistance of large dams** (Ekpluatatsionnye sposoby povysheniya seismostoikosti bolshikh plotin, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 69–73. (For a full bibliographic citation see Abstract No. 1.1-7.)

Methods for increasing the earthquake resistance of large dams utilizing special aeration and filtration devices switched on automatically by signals from a seismic telemetric network are described. The efficiency of such methods is analyzed and data supporting their feasibility are presented.

7.5-34 Ivanishchev, V. F. and Natarius, Ya. I., **Design of concrete gravity dams in seismic regions** (Opyt proektirovaniya betonnykh gravitatsionnykh plotin v seismicheskikh raionakh, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh,* 44–50. (For a full bibliographic citation see Abstract No. 1.1-7.)

Strength and stability requirements of concrete gravity dams in seismic regions are discussed. It is found that the requirement of the absence of tensile stresses under a particular load combination implies dam profiles with height to width ratios up to 1.0. A correction in building codes is suggested. The response of a dam with a triangular profile to an intensity 9 earthquake is calculated.

● 7.5-35 Baron, F. and Pang, S.-H., **Determination of seismic design criteria for the Dumbarton Bridge replacement structure, Vol. 1: Description, theory, and analytical modeling of bridge and parameters,** *EERC 75-1,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1975, 309. (NTIS Accession No. PB 259 407)

This report deals with the first phase of an extensive seismic investigation that is being made of a long multispan bridge proposed for a crossing of the lower arm of the San Francisco Bay. In this phase, a preliminary design is investigated and a set of seismic design criteria are established. The bridge is 7400 ft long and is composed of 43 spans founded on various soil conditions, including thick-mud and deep-water sections. Parametric studies are performed (a) to determine and explore the critical questions of design, (b) to define the parameters that need to be considered in the analyses, and (c) to establish seismic design criteria for the final phase of design. Among the parameters studied are those associated with five different earthquakes, two soil columns, the interaction of the various footings and piling groups with varying water and soil conditions,

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

and the properties of the structural elements along the bridge. Based on these studies, seismic design criteria are established in the form of design spectra for both strong and moderately strong earthquake motions.

● 7.5-36 Baron, F. and Pang, S.-H., **Determination of seismic design criteria for the Dumbarton Bridge replacement structure, Vol. 2: Numerical studies and establishment of seismic design criteria**, *EERC 75-2*, Earthquake Engineering Research Center, Univ. of California, Berkeley, Feb. 1975, 186. (NTIS Accession No. PB 259 406)

See abstract No. 7.5-35 for an abstract of this report.

7.6 Design and Construction of Foundations, Piles and Retaining Walls

● 7.6-1 Naik, T. R. and Peyrot, A. H., **Analysis and design of laterally loaded piles and caissons in a layered soil system**, *Methods of Structural Analysis*, Vol. II, 589-606. (For a full bibliographic citation see Abstract No. 1.2-3.)

A method, based on Broms's method, is proposed for the analysis and design of piles and caissons under heavy lateral loadings. The numerical procedure was specially developed for a layered soil system. The proposed theory is compared with other published studies. A computer program has been developed to design a most economical caisson foundation for a given set of loads and soils data. Several examples are presented to evaluate the effects of various variables. The consequences of improper soils data evaluation also are discussed.

● 7.6-2 Martynova, L. D. *et al.*, **On the use of precast pile-foundations in construction of earthquake-proof large-panel buildings**, *Proceedings of the International Symposium on Earthquake Structural Engineering*, Vol. I, 161-168. (For a full bibliographic citation see Abstract No. 1.2-7.)

7.6-3 Gulyaev, E. A., **Seismic response of flexible and rigid retaining walls** (Raschet na seismicheskie vozdeistviya gibkikh i zhestikikh podpornykh stenok, in Russian), *Sovershenstvovanie metodov rascheta i proektirovaniya gidrotekhnicheskikh sooruzhenii vozvodimykh v seismicheskikh raionakh*, 214-218. (For a full bibliographic citation see Abstract No. 1.1-7.)

Design of flexible and rigid retaining walls for seismic regions is discussed.

7.7 Design and Construction of Soil and Rock Structures

● 7.7-1 Rieder, U. G. and Staggl, H., **Discussion of: Seismic design of reinforced earth walls,*** *Journal of the Geotechnical Engineering Division, ASCE*, 102, *GT3*, Proc. Paper 11949, Mar. 1976, 262-264. (*By Richardson, G. N. and Lee, K. L., Proc. Paper 11143, Feb. 1975.)

● 7.7-2 Heinz, R. A., **Hydraulic fill dams earthquake stability**, *Civil Engineering, ASCE*, 46, 5, May 1976, 55-60.

The 1971 San Fernando earthquake near Los Angeles generated concern for the stability of hydraulic fill dams. Two dams located near the fault were damaged severely. The shaking effect of the earthquake caused liquefaction and partial collapse. The water levels behind these dams had been lowered before the quake so overtopping did not occur. The state of California had the owners of all the hydraulic fill dams in critical locations evaluate their structures with modern dynamic techniques. Four dam-owning agencies report the corrections required.

● 7.7-3 Vaidya, N. R., Ries, E. R. and Kissenpfennig, J. F., **Seismic resistant design of a nuclear Category I earth dam**, *Transactions of the 3rd International Conference on Structural Mechanics in Reactor Technology*, Vol. 4, Paper K 6/9, 11. (For a full bibliographic citation see Abstract No. 1.2-11.)

An integral part of many nuclear power plants is the ultimate heat sink (UHS), the purpose of which is to retain and deliver a supply of service water to the plant when water from the primary circulating water system is not available. Obviously, all structures comprising the UHS must be designed to withstand the safe shutdown earthquake (SSE) postulated for the plant site. The earth dam described in this paper is designed to retain the reservoir for the UHS of a nuclear power plant in southern Europe.

In the seismic design of an earth dam, normal static design criteria are not sufficient. For an earthquake-resistant dam, a few wide zones consisting of well-graded material are preferable to many narrow, uniformly graded zones such as may be found in dams for which seismic loadings were not considered. A high degree of compaction is, of course, necessary to provide shear strength and to preclude liquefaction of granular zones. Additional aspects which do not increase the calculated factor of safety, but do add to the conservatism of the design, are a wide crest, a large amount of freeboard and riprap on the crest of the dam as well as on both faces.

Further, the stability of an earth dam designed to resist earthquakes is assessed with due consideration given to the dynamic nature of forces encountered during earthquakes. The usual pseudo-static analysis is only as good as the estimate for the seismic coefficient used to compute an equivalent horizontal static force on a potential sliding mass. In view of the importance of this Category I structure, as is the case of the earth dam considered herein, a more rigorous method is warranted to analyze the behavior of the earth dam to seismic loading or at least to make a more accurate computation of the seismic coefficients. A two-dimensional dynamic finite element analysis is made to predict the response of the earth dam to a safe shutdown earthquake excitation which is in the form of a time history of accelerations appropriately deconvoluted from the surficial time history and applied at the base of the model. The material properties such as shear modulus and damping are adjusted to be compatible with the level of strain obtained.

Thus, nonlinear behavior of the soil is considered in the analysis and a more realistic response is predicted. Acceleration and stress are determined throughout the dam and are used to compute a seismic coefficient for a pseudostatic stability analysis and the dynamic strength to stress ratios at several points in the body of the dam. Finally, the paper presents a design for a dam to resist a progressive erosion accident resulting from postulated concentrated leaks. This is accomplished by providing a wide, well-graded core protected by wide transition cores also heavily compacted.

●7.7-4 Richardson, G. N. and Lee, K. L., **Closure of: Seismic design of reinforced earth walls,*** *Journal of the Geotechnical Engineering Division, ASCE,* **102**, *GT9*, Proc. Paper 12363, Sept. 1976, p. 1024. (*By Richardson, G. N. and Lee, K. L., Proc. Paper 11143, Feb. 1975.)

7.7-5 Thompson, C. D. and Emery, J. J., **Geotechnical design aspects for large gravity retaining structures under seismic loading,** *Canadian Geotechnical Journal,* **13**, *3*, Aug. 1976, 231-242.

Large wharf gravity retaining walls are often constructed in areas of Canada where seismic activity of a level that has damaged marine structures in other countries can be anticipated. From a geotechnical viewpoint, much of this damage is related to the liquefaction of sands and silts in foundations or backfills. It is critical that zones of potential liquefaction be detected, and this may require more extensive field and laboratory testing than for static designs. Simplified procedures for evaluating the liquefaction potential of sands and silts are presented, and some guidelines for sensitive clays are discussed. Since hydraulic fill is often used, remedial measures and specifications to avoid liquefaction of backfills are described. These include densification of the soil and provision of materials outside the gradation range that is most susceptible to liquefaction. While tsunamis arrive after the strong shaking, they can be the source of significant damage in areas where they might occur. Conservative earth pressure parameters are given for areas exposed to tsunamis, and these may be employed for initial assessment of potential problems from offshore earthquakes. The various geotechnical aspects considered must be closely related to other design factors such as seismic exposure, earth pressures, and allowable short-term safety factors.

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

8. Earthquake Effects

8.1 General

8.1-1 Karapetyan, B. K., **Damage to structures with aseismic design features** (Povrezhdeniya zdanii s antiseismicheskimi meropriyatiyami, in Russian), *Seismicheskaya shkala i metody izmereniya seismicheskoi intenzivnosti*, NAUKA, Moscow, 1975, 110–111.

Supplementary data useful for evaluating seismic intensity from damage to structures with aseismic design features are presented.

● 8.1-2 Berg, G. V., **Historical review of earthquakes, damage, and building codes,** *Methods of Structural Analysis*, Vol. I, 387–402. (For a full bibliographic citation see Abstract No. 1.2–3.)

This paper reviews the effects of some past earthquakes (the 1906 San Francisco, the 1908 Messina-Reggio and the 1923 Tokyo earthquakes), some successes and failures of structures to withstand earthquakes, and the development of building codes to regulate the design and construction of facilities to minimize the earthquake hazard.

● 8.1-3 Tissell, J. R., **Troika for earthquake-resistant building design, engineer - building code - contractor,** *Proceedings of the International Symposium on Earthquake Structural Engineering*, Vol. II, 1051–1064. (For a full bibliographic citation see Abstract No. 1.2–7.)

A team of structural engineers from the American Plywood Assn. investigated the behavior of plywood systems in the San Fernando earthquake of Feb. 9, 1971. They found that the good performance of schools showed that current design and careful building techniques could produce plywood and wood buildings that performed well, even in a high-intensity earthquake. Poor performance of some industrial buildings showed that less careful design and construction were soon reflected in performance. Performance of hospitals demonstrated than an "importance factor" should be applied to such buildings. A comparison of earthquake durations, together with the exemplary performance of well-built buildings, showed that the duration-of-load adjustment for wood under seismic load should be raised from 1.33 to 1.75.

● 8.1-4 Hsu, D. S., Gaunt, J. T. and Yao, J. T. P., **Structural damage and risk in earthquake engineering,** *Proceedings of the International Symposium on Earthquake Structural Engineering*, Vol. II, 843–856. (For a full bibliographic citation see Abstract No. 1.2–7.)

In this paper a methodology is presented for the evaluation of structural damage and risk in earthquake engineering. For the purpose of illustration, three types of structures and five levels of damage (including no damage) are considered. Results of this study indicate that it is possible to assess the seismic risk of a certain type of structure in a given region with past earthquake records.

● 8.1-5 Creegan, P. J., **A California structural engineer shares three years of on-site experiences in the design of reparations for buildings in Managua,** *Proceedings of the International Symposium on Earthquake Structural Engineering*, Vol. II, 1037–1050. (For a full bibliographic citation see Abstract No. 1.2–7.)

The author summarizes the events of Dec. 23, 1972, at Managua and indicates how a rating on the Richter scale can be misleading to the engineer. Also discussed are the "politico-engineering decisions" related to recovering from the effects of the earthquake: fire, building code, insurance surveys, surveys for owners, economics of reparation, inflation, special comments on torsion, excessive frame deflections, soft story, yielding in the plastic range, elevators,

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

secondary damage, progressive failures, epoxy for concrete cracks, specifications and inspection.

● 8.1-6 Coffman, J. L., comp., **Catalog of earthquake photographs,** *Key to Geophysical Records Documentation No. 7,* National Geophysical and Solar-Terrestrial Data Center, Boulder, Colorado, Dec. 1976, 63.

This publication is a revision and update of *Catalog of Earthquake Photographs,* KGRD No. 3, Revised 1975 Edition. It is a collection of earthquake damage photographs obtained from 63 different government and private sources. It lists chronologically approximately 750 photographs on the subject of earthquakes and contains descriptions and examples of the collection. Many of the photographs are views of toppled buildings and collapsed bridges and dams; others show spectacular landslides, rifts, and ground cracks resulting from damaging shocks. An index to the photographs is included.

8.2 Studies of Specific Earthquakes

● 8.2-1 Olsen, P. G. and Sylvester, A. G., **The Santa Barbara earthquake, 29 June 1925,** *California Geology,* **28,** *6,* June 1975, 123–131.

This paper is a review of some interesting aspects of the June 29, 1925, Santa Barbara earthquake. Included are photographs of damage, a summary of important earthquakes of the Santa Barbara area, a summary of the current investigations of the structure, seismicity and tectonics of the Santa Barbara Channel region, a map showing principal faults and fault zones in the Santa Barbara Channel region, a list of selected references on the geology and seismicity of the Santa Barbara Channel region and an isoseismal map for the 1925 earthquake. Also included are data gathered from questionnaires and interviews with more than 400 citizens who experienced the earthquake.

● 8.2-2 Singh, S. *et al.*, **Preliminary report on the January 19, 1975 Kinnaur earthquake in Himachal Pradesh,** *Bulletin of the Indian Society of Earthquake Technology,* **12,** *1,* Paper No. 151, Mar. 1975, 1–57.

An earthquake causing strong ground motion occurred in the border districts of Himachal Pradesh on Jan. 19, 1975. The earthquake caused considerable loss of life and different degrees of damage to various structures in the area. Traditional construction in the area was nonseismic and had little resistance against the lateral forces. In recent construction in the area, the walls were constructed of random rubble masonry and such structures suffered extensive damage. Landslides, rockfalls and avalanches caused considerable damage to the Hindustan-Tibet Road and other important roads in the area. Extensive fissures in the ground were developed in the epicentral tract. The maximum observed intensity in the region exceeded VIII and reached IX on the Modified Mercalli intensity scale. The Richter magnitude, as calculated from macroseismic data, was about 6.7. Greater damage to the ground and buildings was noted along the N-S trending Kaurik-Chango Fault following Parachu and Spiti river valleys, suggesting its genetic interrelationship with the earthquake.

● 8.2-3 Husid, R. and Espinosa, A. F., **Seismological and engineering aspects of the March 6, 1974, Carazo earthquake (Nicaragua),** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 137, 6. (For a full bibliographic citation see Abstract No. 1.2-6.)

The Mar. 6, 1974, earthquake, which occurred at 01:40:26 UTC at 12.3N and 86.4W, caused extensive damage in the cities of Diriamba, Jinotepe, Dolores, San Marcos and Masatepe, Nicaragua. The maximum Mercalli intensity was VII in Diriamba and Jinotepe. The earthquake was felt throughout Nicaragua and in Costa Rica, Guatemala, and Panama. Small landslides occurred near the city of Leon. Poorly constructed buildings of taquezal and adobe were heavily damaged and some collapsed; poorly designed buildings of reinforced concrete nearly collapsed. This paper documents earthquake damage sustained by both poorly built and well-built structures.

● 8.2-4 Espinosa, A. F., Husid, R. and Algermissen, S. T., **Seismological and engineering features of the October 3, 1974, Lima, Peru earthquake,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 2, Paper No. 141, 6. (For a full bibliographic citation see Abstract No. 1.2-6.)

The Oct. 3, 1974, earthquake, which occurred at 14:21:31 UTC at 12.2S and 77.6W, with a depth of 22 km and magnitude of 7.7, caused extensive damage in the city of Lima and vicinity. The modified Mercalli intensity ranged from V to VIII in the city. The epicenter was 81 km west of Lima. The maximum horizontal acceleration recorded in downtown Lima was 0.19 g with a predominant period of 0.35 sec and a total time duration of 99 sec. Pockets of higher intensities in La Molina, Chorrillos, and Barranco are correlated with ground amplification effects. Slumping was observed along the coastal road south of Lima. Subsidence and liquefaction were observed along the coast.

The earthquake produced severe damage to adobe and quincha construction, and also to some masonry and reinforced-concrete structures. Most of the damage in well-built structures was due in part to lack of lateral resistance in the design and in part to the 0.35 sec predominant period of this earthquake, which nearly matched the natural periods of some of those structures. A building code was implemented after the 1970 Peru earthquake, but most of

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

the structures that were damaged had been designed before 1970. Damage to reinforced concrete structures occurred in Callao, northwest of the city, where a four-story building and the upper part of a concrete silo collapsed; in La Molina, to the northeast, many buildings suffered serious damage and collapsed. Shear walls had been omitted in many reinforced concrete buildings; therefore, short columns were left to resist the inertial loads in their weak directions.

● **8.2-5** Kuhl, D. J., **Evaluation of the Point Mugu earthquake,** *CA-DOT-TL-2140-1-75-08,* Transportation Lab., California Dept. of Transportation, Sacramento, Jan. 1975, 17.

This report presents a summary of damage caused by the Feb. 21, 1973, earthquake near Point Mugu, California, to existing highway facilities in the area. Also presented are the results of a computer analysis of the ground motion and a prediction of the damage this earthquake would have caused at a proposed interchange between Routes 101/232/1 now under design.

● **8.2-6** Moran, D. *et al.*, **Engineering aspects of the Lima, Peru earthquake of October 3, 1974,** Earthquake Engineering Research Inst., Oakland, California, May 1975, 85.

At about 9:21 a.m., Thursday, Oct. 3, 1974, a strong earthquake caused a total of 70 deaths in Lima, Peru, and in several small villages to the south. The Geophysical Inst. of Peru reports property damage of 200 million dollars.

This report summarizes the gathered data, observations, and conclusions of the EERI Reconnaissance Team (RT). The conclusions are limited to engineering aspects since these reflect the expertise of the members of the RT. Some of the data and conclusions presented in this report must be considered preliminary since research is currently being conducted by the USGS, the Geophysical Inst. of Peru, and others. Some building regulations exist in Peru; however, aseismic design provisions for specific buildings are largely left to the discretion of the responsible engineer.

The objectives of this report are to present and discuss the lessons learned from this earthquake in order to mitigate the effects of future shocks.

● **8.2-7** Sozen, M. A. and Matthiesen, R. B., **Engineering report on the Managua earthquake of 23 December 1972,** National Academy of Sciences, Washington, D. C., 1975, 111.

The inspection of Managua was sponsored by the Panel on Earthquakes of the Committee on Natural Disasters. Included as an introduction and as background information is an abstract of a presentation on the seismicity of Nicaragua given in 1972 prior to the earthquake.

● **8.2-8** Youd, T. L. and Hoose, S. N., **Liquefaction during 1906 San Francisco earthquake,** *Journal of the Geotechnical Engineering Division, ASCE,* **102,** *GT5,* Proc. Paper 12143, May 1976, 425–439.

Liquefaction-induced ground failures caused major damage during the 1906 San Francisco earthquake. An analysis of published reports shows that lateral-spreading landslides were the most pervasive and most damaging type of ground failure associated with liquefaction. Bridges, roadways, pipelines, and buildings suffered considerable damage. Pipeline failures were particularly critical in San Francisco, cutting off the water supply to the city and thus indirectly contributing to the substantial post-earthquake fire damage. Flood plain, deltaic, and loose sand fill deposits were particularly vulnerable to lateral spreading failure. Recent borehole data from four lateral spreading locations show that loose, saturated sand underlies each site at shallow depths. Flow landslides developed on several sandy slopes but did little damage because of sparse development in the affected areas. No clear evidence of bearing capacity failures beneath buildings was found; however, settlement of several embankments may have been a consequence of liquefaction.

● **8.2-9** Arioglu, E. and Anadol, K., **Response of rural dwellings to Lice earthquake Sept. 6, 1975 - Turkey,** *Proceedings, Fifth European Conference on Earthquake Engineering,* Vol. 3, 1975, 97–102. (For a full bibliographic citation see Abstract No. 1.2–6.)

Information is given concerning the earthquake which occurred on Sept. 6, 1975, in Lice, Turkey. The characteristics and earthquake response of the structures in the region are presented. Criteria for constructing earthquake-resistant rural dwellings are proposed.

● **8.2-10** **Report on the Sept. 6, 1975 Lice Earthquake** (6 - Eylul - 1975 Lice depremi raporu, in Turkish with English summary), Earthquake Research Inst., Turkey, Ministry of Reconstruction, Ankara, Feb. 1976, 75.

The Sept. 6, 1975, Lice earthquake caused 2,385 fatalities and 8149 houses were destroyed or were damaged beyond repair. The magnitude was 6.9 and the epicenter was located a few kilometers away from Lice in the northeast direction. Included in this report are the following sections: Population, economic and social conditions of the earthquake region; Geology of the earthquake region and field observations; Seismicity and earthquake history of Lice and surrounding area; Structural damage.

● **8.2-11** Sherburne, R. W. and Hauge, C. J., eds., **Oroville, California, earthquake, 1 August 1975,** *Special*

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

Report 124, California Div. of Mines and Geology, Sacramento, 1975, 151.

This is a collection of preliminary data collected by individuals from a number of public agencies and private organizations that are investigating the Oroville earthquake of Aug. 1, 1975. It is expected that additional data collected in the future will enable investigators to draw more definitive conclusions about the earthquake and its effects.

The report is organized into 4 sections. The first contains papers about the earthquake from the point of view of city and state officials and the media. The second section discusses the geology and structure of the area. The third section discusses the damage that occurred in Oroville and surrounding area, and the fourth section discusses the seismology of the area, the earthquake, and its foreshocks and aftershocks.

● 8.2-12 Ambraseys, N., Lensen, G. and Moinfar, A., **The Pattan earthquake of 28 December 1974**, *RP/1975-76/2.222.3*, UNESCO, Paris, 1975, 53.

On Dec. 28, 1974, the Swat and Hazara districts of the Northwest Frontier Province of Pakistan were affected by an earthquake of magnitude 6.0. A UNESCO earthquake reconnaissance mission arrived in Pakistan on Jan. 23, 1975, and in cooperation with the Army Engineers and the Geological Survey of Pakistan, spent three weeks studying the effects of the earthquake. The principal task was to study the effects of the earthquake on buildings and public works. In view of the mountainous nature of the terrain affected by the earthquake, the mission was asked to make a special study of the rockfalls and landslides which it triggered. This report contains a description of the observed damage and some recommendations regarding future building in the area. A summary of information and data on the past seismicity of the region also is included.

● 8.2-13 Espinosa, A. F., ed., **The Guatemalan earthquake of February 4, 1976: A preliminary report**, *Professional Paper 1002*, U.S. Geological Survey, Washington, D.C., 1976, 90.

This is a preliminary report of a series of closely related studies of the Guatemalan earthquake of Feb. 4, 1976. The following papers are included: Tectonic setting and seismicity; Instrumentally recorded seismic activity prior to the main event; Main event and principal aftershocks from teleseismic data; Main-event source parameters from teleseismic data; Strong-motion recordings of the main event and February 18 aftershock; Aftershocks from local data; Geologic effects; Intensity distribution and source parameters from field observations; Damage and engineering implications; and Structural engineering observations in Guatemala City. In addition, a chronological historical record of damaging earthquakes which have occurred in Guatemala between 1526-1976 is included.

8.2-14 Weichert, D. H., **Earthquake reconnaissance: Guatemala, February 1976**, *Geoscience Canada*, 3, 3, Aug. 1976, 208-214.

Seismological knowledge often advances discontinuously after the occurrence of a major earthquake and much can be learned from field investigations. In Canada, magnitude 7 to 8 earthquakes have occurred in the past, in both the east and west, and are likely to recur. For this reason, the Seismological Service of Canada has contingency plans for fast deployment of manpower and instruments following a large Canadian earthquake.

Within the framework of these plans, arrangements had been made with the Earthquake Engineering Research Inst. (EERI) of the U.S. to participate in one of their post-earthquake expeditions. When the magnitude 7.5 earthquake struck Guatemala on Feb. 4, 1976, the writer followed the EERI invitation and joined their reconnaissance team. This paper is basically an account of this earthquake, its seismic effects and the early investigations; but it is also meant as an illustration and reminder of the tasks that would face the Canadian seismological community and especially the Seismological Service in the case of a significant Canadian earthquake.

● 8.2-15 Sozen, M. A. and Roesset, J., **Structural damage caused by the 1976 Guatemala earthquake**, *UILU-ENG-76-2003*, Univ. of Illinois, Urbana, Mar. 1976, 81.

This report has been prepared to provide a preliminary description of the response of engineered construction in Guatemala City to the earthquakes of Feb. 4 and 6, 1976, as evaluated from the authors' observations made during the period Feb. 8 to 14, 1976.

The technical information contained in the report is limited primarily to photographic evidence. No quantitative analysis is included. It is believed that an early release of the available information will be of value to emphasize some of the structural phenomena which do not need analysis and to put into perspective the level of damage experienced in the city.

● 8.2-16 Moinfar, A. A., **The earthquake of Sarkhun (Bandar-Abbas, Iran) of March 7, 1975** (in Persian with English Summary), *46*, Technical Research & Standard Bureau, Iran Plan and Budget Organization, Tehran, June 1975, 42.

The magnitude of the earthquake was 5.6; the focal depth was 27 km. Several aftershocks occurred following the main shock. In the most seriously damaged area, the maximum intensity was between VI and VII on the Modi-

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

fied Mercalli Scale. No faulting was observed, however, rockfalls occurred in a few areas. There were three strong-motion accelerographs and one seismoscope in the area at the time of the earthquake; the records obtained from these instruments are described.

The earthquake did not seriously affect the city of Bandar-Abbas, but some cracks occurred in a few masonry buildings. Bandar-Abbas airport, the most important reinforced concrete structure in the area, experienced some cracks during the earthquake. The damage which occurred to adobe and concrete block masonry buildings in Sarkhun and Ghadhad is described.

● 8.2-17 Okamoto, S. and Sawada, K., **Damage due to Izuhanto-oki earthquake** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 260, 1023–1030. (For a full bibliographic citation see Abstract No. 1.2-9.)

On May 7, 1974, an earthquake occurred in the south Izu area of Japan. The city of Nagaki was buried by a landslide and many people were injured. The residents of Ochii had to move to a safer area because it was feared that it, too, would be hit by a landslide. Many houses and embankments on the fault were damaged. Settlement of the foundations of houses occurred on Iruma sand fill. Steel and concrete structures experienced little damage.

This report is a summary of an investigation conducted immediately after the earthquake and of an investigation conducted one year later. The damage occurring to structures resting on different soil types is described and the importance of maintaining slope stability is discussed.

● 8.2-18 Ohtani, K. *et al.*, **Damage of structures caused by the Izuhanto-oki earthquake 1974** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975*, Paper No. 259, 1015–1022. (For a full bibliographic citation see Abstract No. 1.2-9.)

The southern part of the Izu Peninsula in Japan was shaken on May 9, 1974, by a strong earthquake which caused considerable damage to residential structures. The numbers of completely and partially destroyed houses were 122 and 247, respectively. The main causes of damage were landslides, ground movement, and vibration of structures. This paper discusses the structural damage which occurred.

8.3 Effects on Buildings

● 8.3-1 Umemura, H., **Aseismic measures for reinforced concrete structures—In view of damage from Oita earthquake of 1975**, *Proceedings of the Review Meeting, U.S.-Japan Cooperative Research Program in Earthquake Engineering with Emphasis on the Safety of School Buildings*, 164–173. (For a full bibliographic citation see Abstract No. 1.2-2.)

The Oita earthquake occurred in Japan on Apr. 21, 1975. During that earthquake, part of a reinforced concrete hotel with a basement and four stories collapsed. This paper presents an outline of the damage to that building, the causes of the damage and points requiring attention in the future.

● 8.3-2 Arcia R., J. and Malaver R., A., **Structural reparations of damaged buildings Caracas earthquake of July 29, 1967**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 134, 13. (For a full bibliographic citation see Abstract No. 1.2-6.)

This paper is a part of a final report, prepared by the Venezuelan Oficina Técnia Especial del Sismo. The department carries out projects as well as supervises the reparation of buildings damaged by by the 1967 Caracas earthquake.

In this work, a representative sample of repairs is shown. The original buildings were of reinforced concrete frame construction. For all building samples, plant shape, typical damage, interpretation of damage and structural descriptions before and after structural repair are shown in drawings.

● 8.3-3 Wood, J. H., **Earthquake response of a steel frame building**, *Earthquake Engineering and Structural Dynamics*, 4, 4, Apr.-June 1976, 349–377.

A study has been made of the response, during the Feb. 9, 1971, San Fernando earthquake of the nine-story steel frame Building 180, located at the California Inst. of Technology, Jet Propulsion Lab., Pasadena. The analysis throws light on the actual dynamic properties of the building during the earthquake, and also demonstrates that it is possible, when the ground motion is specified, to make accurate predictions of building motions during moderate earthquakes by using a linear viscously damped model.

Methods of evaluating the lower mode periods and damping ratios from the earthquake records are described, and the values obtained are compared with results from dynamic testing before and after the earthquake and with the periods computed from computer models of the building. Although no structural damage occurred and computed stresses in the steel frame were less than yield stresses, the periods measured by an ambient vibration test after the earthquake were of the order of 10 per cent higher than the pre-earthquake values. The maximum periods during the earthquake were found to be about 30 per cent higher than the post-earthquake periods.

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

● 8.3-4 Estrada-Uribe, G., **Behavior of reinforced concrete structures during the Managua earthquake,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1095–1108. (For a full bibliographic citation see Abstract No. 1.2-7.)

The experience that the author gathered on the site of the Managua earthquake and the results of laboratory tests of samples of construction materials used in Managua are presented. The characteristics of the earthquake and the ground acceleration in the city are discussed. Typical failures of reinforced-concrete structures are illustrated to show the advantages and disadvantages of design and construction practices currently used in several seismic areas around the world and to show the need for revising such procedures.

● 8.3-5 Mahin, S. A. *et al.,* **Response of the Olive View Hospital main building during the San Fernando earthquake,** *EERC 76-22,* Earthquake Engineering Research Center, Univ. of California, Berkeley, Oct. 1976, 321.

This report presents the results of an extensive field and analytical investigation of the structural performance of the main building of the Olive View Hospital Medical Treatment and Care Facility during the 1971 San Fernando earthquake. This modern, six-story, cast-in-place, reinforced concrete building suffered such severe structural and nonstructural damages that it had to be demolished after the earthquake. The observed structural damages are compared with those predicted in a series of quantitative elastic and nonlinear dynamic analyses of the building in order to: (1) reassess current seismic-resistant design practices; (2) identify the principal parameters that controlled the response of the building; and (3) evaluate the ability of currently available analytical methods to predict seismic behavior.

The relatively irregular and complex structural system employed in the building is described in detail in this report along with the original design criteria. The building had four wings located around a central courtyard. Numerous structural (shear) walls were located in the upper four stories, but these did not continue down through the bottom two stories to the foundations.

Damage to the building was particularly severe in the bottom two stories, including story drifts exceeding 30 in. at some locations, substantial inelastic deformations in slabs and columns, and the failure of numerous tied columns which resulted in the collapse of some parts of the building. The main features of the damage appear to be a consequence of ground shaking and not of faulty materials or poor workmanship.

Since no ground motion records were obtained near the building site, several accelerograms were numerically simulated or taken from recordings obtained at other sites in order to perform the desired seismic response analysis. Ground motions obtained near the fault rupture are shown to contain relatively high amplitude, long-duration acceleration pulses, which could partially account for the type of damage observed.

A complete three-dimensional mathematical model of the building is analyzed for biaxial horizontal ground accelerations to assess the structure's overall dynamic characteristics and to identify the initial member failures. This analysis, in conjunction with member capacity studies, identifies the concentration of deformations in the bottom two stories and the brittle type of failure observed in the tied columns. The elastic results were, however, unable to predict the severity and distribution of the inelastic deformations and the large lateral displacements that were observed in the building.

Since the elastic results indicate that the horizontal, translational degrees-of-freedom of the building are essentially uncoupled and that torsion did not have a significant effect on the overall response, a two-dimensional nonlinear model of a part of the building is developed to obtain guidelines regarding the effect of inelastic action on the response of the building. In the first series of nonlinear analyses, the possibility of member failure is disregarded. But in the second series such features as member spalling or failure and hammering of the building against adjacent structures is explicitly considered.

The inelastic analyses reveal that the building was designed to be very strong in comparison with building code specifications, but that for some members (notably the tied columns and flat slabs in the bottom two stories) the required inelastic deformations are larger than they could develop according to their detailing. The inelastic analyses also indicate that the relatively small strength and stiffness of the bottom two stories resulted in a partial sidesway collapse mechanism which concentrated drifts and inelastic deformations in these two stories. The displacements predicted by the inelastic analyses, although generally larger than those predicted by the elastic analyses, were smaller than the permanent displacements observed in the building. While this may be partially due to the simplifications introduced in the inelastic analyses, the results indicate that the response is only moderately affected by changes in the modeling parameters. On the other hand, the inelastic response is found to be very sensitive to the ground motion record used. In particular, records that contain severe, long-duration acceleration pulses like those obtained near the fault rupture result in very large lateral displacemnts when a collapse mechanism forms.

It is believed that the overall poor performance of this building was due to the combination of an inadequate structural system, the poor detailing of some members and the severe ground motions experienced at the site. Addi-

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

tional conclusions regarding the adequacy of the structural system, the adequacy and reliability of analytical methods for predicting seismic behavior, and the effect of detailing and workmanship on seismic performance are offered in the report along with a number of recommendations for improving seismic-resistant design practices.

8.4 Effects on Miscellaneous Structures and Systems

● 8.4-1 Bayulke, N., **The effect of earthquakes on industrial structures** (Depremlerin endustri yapilari, enerji uretim ve dagitim tesisleri ve yapilarin tasiyici olmayan kisimlari uzerindeki etkileri, in Turkish), *Deprem Arastirma Enstitusu Bulteni, 2, 7,* Oct. 1974, 9-16.

This paper deals with earthquake damage to industrial structures, utility production and distribution systems and nonstructural parts in general and measures used to prevent earthquake damage to those structures.

● 8.4-2 Kobayashi, Y., **Hazards from earthquake faulting in Japan,** *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 109, 65-72. (For a full bibliographic citation see Abstract No. 1.2-9.)

Dimensions, displacements and other aspects of surface faults caused by earthquakes in Japan since the 1891 Nobi earthquake are investigated, and various features of damage caused by faulting are summarized. The horizontal displacement is predominant in most earthquake faults in this country. In general, plural faults move in an earthquake, and a belt 0.4 to 3 km wide on both sides of a postulated fault as well as conjugate faults crossed by the latter are at risk. Some examples of damage such as graben, mole track, tension cracks en echelon, or gentle flexure of land surface are presented. In an earthquake of M=7.0 to 7.5, a region within 5 to 10 km from the fault line may suffer more than 30% houses destroyed. A possibility of relatively gentle movement of a fault wall during an earthquake is suggested.

● 8.4-3 Kubo, K., Katayama, T. and Sato, N., **Quantitative analysis of seismic damage to buried pipelines** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 214, 655-662. (For a full bibliographic citation see Abstract No. 1.2-9.)

In spite of their great importance for the mitigation of earthquake disasters and the establishment of post-earthquake rehabilitation programs, quantitative descriptions of earthquake damage to buried utility pipelines are rare. This paper describes some of the quantitative results obtained from past earthquake reports on the seismic damage to underground utility pipelines. Average numbers of breaks per unit length of piping are summarized for water and gas distribution systems. Comments are made on the effect of pipe diameter on damage. By referring to the quantitative data of buried pipeline damage caused by the 1971 San Fernando earthquake, damage is discussed in relation to faulting and intensity of ground motion. Results of quantitative analysis on the relation between seismic damage to water pipes and ground condition are reported.

● 8.4-4 Ekizian, Jr., H., **Anchorage port survives nature,** *Civil Engineering, ASCE, 46, 12,* Dec. 1976, 64-67.

At the time of the Mar. 1964 earthquake, one of the greatest in recorded history, the first element of the terminal had been in service four years. The earthquake had its epicenter about 75 mi (120 km) from Anchorage and a magnitude between 8.4 and 8.6 on the Richter scale. Parts of the city of Anchorage were destroyed. The entire zone around the marine terminal subsided about 3 ft (0.9 m) and the wharf moved about 1 ft (0.3 m) horizontally. The Port of Anchorage, the only usable marine terminal left in south-central Alaska, was back in service about 36 hours after the earthquake, following emergency repairs to the electrical system, and repositioning of the cranes which had been jolted off their rails.

● 8.4-5 Hein, K. H. and Whitman, R. V., **Effects of earthquakes on system performance of water lifelines,** *MIT-CE R76-23,* Dept. of Civil Engineering, Massachusetts Inst. of Technology, Cambridge, May 1976, 82.

Several past earthquakes and their impact on water systems are described, and characteristic damage is pointed out. Because of the importance of water lifeline networks following earthquakes, a method for analyzing the impact of earthquakes on their system performance is developed. The part of this analysis which deals with ground failure-induced damage to pipes in poor soil is applied to the water system of the Metropolitan District Commission, Commonwealth of Massachusetts. Various levels of pipe damage are simulated, and the impact of these damage levels on system performance is evaluated.

● 8.4-6 Committee on Failures and Accidents to Large Dams, U. S. Committee on Large Dams, **Lessons from dam incidents, USA,** American Society of Civil Engineers, New York, 1975, 387.

This report covers dam incidents (failures, accidents, including accidents to reservoirs, damage during construction and major repairs) that occurred from Jan. 1, 1966, to Dec. 31, 1972. Its purpose is to: (1) present available data to the profession; (2) analyze data from questionnaires with respect to type of incident, frequency and trend and (3) develop conclusions and recommendations.

Appendix A is the questionnaire. Appendix B contains an index and a summary sheet for each dam incident

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

reported. The summary sheets contain: data pertaining to each incident, descriptions of the dam and the incident; remedial measures and a bibliography. In addition, photographs and drawings are included for some of the dams.

Mentioned in the report are the Pacoima and the Upper and Lower San Fernando Dams that were subjected to earthquakes.

8.5 Effects and Near Surface Geology

● 8.5-1 Guha, S. K. *et al.*, **Studies on damage pattern in some recent Indian earthquakes**, *Proceedings, Fifth European Conference on Earthquake Engineering*, Vol. 2, Paper No. 139, 4. (For a full bibliographic citation see Abstract No. 1.2-6.)

Microdamage surveys after recent Indian earthquakes show influences of thick soil cover, deep alluvial tract and slumpy soil in enchancing earthquake intensity and consequent damage. These damage data and their dependence on foundation conditions are corroborated from microtremor, forced vibration and velocity response spectra studies.

● 8.5-2 Krinitzsky, E. L. and Bonis, S. B., **Notes on earthquake shaking in soils, Guatemala earthquake of 4 February 1976**, Soils and Pavements Lab., U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Aug. 1976, 33.

A reconnaissance examination was made of earthquake effects in soils resulting from the Feb. 4, 1976, earthquake in Guatemala. The earthquake was caused by strike-slip movement along a discrete fault plane in the Motagua Valley with a length of about 200 km. The Motagua Valley is determined by a zone of active faults that date back to Cretaceous time or older. Several distinct faults are recognizable on air photos but others may have been obscured by alluviation. The valley is a zone of active faults. Although movement was along only one plane, the entire mapped length of the Motagua fault zone participated in the movement. Extensive landslides were induced in deposits of pumice ash. Liquefaction is a probable contributing factor to at least two of the larger landslides in which entire valleys were blocked with debris. In alluvial soils, there were very pronounced sand blows, fissures, land spreading, and land sinking along shores as a result of earthquake shaking of a low order, MM intensity VI. It appears that these effects were restricted to very young sediments. Somewhat older deposits were stable, possibly because of a stabilization by recurrent earthquake shaking in the past. At Puerto Barrios there is a suggestion that liquefaction occurred in sands at 70 to 100 ft below the surface. Again, the liquefaction was associated with very light earthquake shaking.

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

9. Earthquakes as Natural Disasters

9.1 Disaster Preparedness and Relief

● 9.1-1 Tanaka, T., **Broadcasting service in earthquake emergency,** *Technocrat,* 8, *7,* July 1975, 18–24.

Described in this paper is the role of Japan's public broadcasting organization during emergencies. Specific examples are presented of the organization's efforts following the 1964 Niigata, the 1968 Tokachi-oki, and the 1975 Kanto earthquakes.

9.1-2 Davis, I., **Disaster housing: A case study of Managua,** *Architectural Design,* XLV, *1,* 1975, 42–47.

After first describing the relief programs which took place immediately following the Managua, Nicaragua, earthquakes of Dec. 23, 1972, the author gives general conclusions concerning these activities. The last part of the paper includes a list of necessary housing criteria following natural disasters. The list applies to areas where: (a) There is no exposure risk. (b) There is a tropical or subtropical climate. (c) There is a developing situation with extreme poverty. (d) There is an existing predisaster housing shortage.

● 9.1-3 Mann, O. C., **Safety of cities during severe earthquakes,** *Proceedings of the International Symposium on Earthquake Structural Engineering,* Vol. II, 1065–1078. (For a full bibliographic citation see Abstract No. 1.2–7.)

The safety of modern cities during a severe earthquake is explored using simulation methods. The loss parameters were derived from recent earthquakes. The population and construction were modeled in accord with recent demographic projections for the area. The simulation indicates that 1.5% of the population may die or be seriously injured in a severe earthquake unless earthquake-resistant structures are built. Before a higher level of safety is attained, the public must accept its responsibility to pay more for safer structures.

● 9.1-4 Ayre, R. S., **Earthquake and tsunami hazards in the United States: A research assessment,** Inst. of Behavioral Science, Univ. of Colorado, Boulder, 1975, 150.

The contents of this report are as follows: Part I: Earthquakes—Chapter I. Dimensions of the earthquake problem in the United States; II. Simulation of earthquake loss management; III. Research recommendations. Part II: Tsunamis—Chapter IV. Dimensions of the tsunami hazard in the United States; V. Futures: Simulation and scenario; VI. Research recommendations.

● 9.1-5 Culver, C. G. *et al.*, **Natural hazards evaluation of existing buildings,** *NBS BSS-61,* National Bureau of Standards, U.S. Dept. of Commerce, Washington, D.C., Jan. 1975, 958.

A methodology is presented for the surveying and evaluation of existing buildings to determine the risk to the safety of lives under natural hazard conditions and to estimate the amount of expected damage. Damage to both structural and nonstructural building components resulting from the extreme conditions encountered during earthquakes, hurricanes and tornadoes is considered. The methodology has the capability of treating a large class of structural types, including braced and unbraced steel frames, concrete frames with and without shear walls, bearing wall structures, and long-span roof structures. Three independent but related sets of procedures for estimating damage for each of the natural hazards are included in the methodology. The first set of procedures provides a means for qualitatively determining the damage level on the basis of data collected in field surveys of a building. The second set utilizes a structural analysis of the building to determine the damage level as a function of the behavior of

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

critical elements. The third set is based on a computer analysis of the entire structure. All three sets of procedures are based on the current state-of-the-art. The procedures are presented in a format which allows updating and refining. Numerical examples illustrating application of the procedures are included.

● 9.1-6 Hisada, T., **Preparations for facing an earthquake disaster,** Kajima Inst. of Construction Technology, Tokyo, Sept. 1976, 12.

The urgent need for implementing earthquake countermeasures in Japan is discussed. Some of the most dangerous hazards in Japan include: (1) the location of many large cities on soft alluvial ground; (2) the large number of wooden buildings; and (3) the subsidence of the ground below sea level, which has been caused by the pumping of ground water. For several representative cities (Tokyo, Yokohama, Nagoya and Osaka), estimates are made of the number of lives that might be lost and the extent of damage that might occur during a large earthquake. A summary is presented of the various earthquake disaster plans which have been enacted since 1961 by the Japanese government and by prefectures and municipalities. Described are some of the specific preventive measures which have been implemented in Japan; these include: an earthquake prediction project; the establishment of refuge centers; the protection of public buildings, communications facilities, utilities, etc.; protection against fire; evacuation procedures; and the dissemination of information to the public on earthquake disaster prevention.

● 9.1-7 Haas, J. E. and Mileti, D. S., **Consequences of earthquake prediction on other adjustments to earthquakes,** *Bulletin of the New Zealand National Society for Earthquake Engineering,* 9, *4,* Dec. 1976, 187-194.

Earthquake prediction is a new technology soon to be added to the other measures which can be used by a community to cope with the earthquake hazard. Government and business organizations will be faced with new challenges when a specific earthquake prediction is issued for their area. Research on organizational response to such a prediction indicates that there will be significant positive and negative consequences. With an extended lead time of several years, the risk of death and injury can be brought to near zero but the resulting local economic recession will be major proportions.

9.2 Legal and Governmental Aspects

● 9.2-1 Baker, E. J. and McPhee, J. G., **Land use management and regulation in hazardous areas: A research assessment,** Inst. of Behavioral Science, Univ. of Colorado, Boulder, 1975, 124.

Many communities in the United States have a natural hazard problem, whether from flood, hurricane or earthquake. Until recently, relatively little consideration was given to land use management as a tool to protect life and property from those hazards. This volume explores some of the specific problems land use management poses as an adjustment to natural hazards. It examines the factors that enter into defining appropriate land management, including the legal considerations, and then reviews alternative levels and techniques for management. It concludes with suggestions of ways in which research could help improve the present situation.

● 9.2-2 Lemke, R. W., **Reconnaissance engineering geology of the Ketchikan area, Alaska, with emphasis on evaluation of earthquake and other geologic hazards,** *Open-file Report 75-250,* U.S. Geological Survey, 1975, 65.

The Alaska earthquake of Mar. 27, 1964, dramatically emphasized the need for engineering geology studies of urban areas in seismically active regions. A reconnaissance study of the Ketchikan area in southeastern Alaska is part of a program to evaluate earthquake and other geologic hazards in most of the larger Alaska coastal communities. These evaluations in the Ketchikan area should provide broad guidelines useful in city and land-use planning.

The following sections are contained in the report: Geography; Glaciation and associated land- and sea-level changes; Descriptive geology; Structure; Earthquake probability; Inferred effects from future earthquakes; Inferred future effects from geologic hazards other than those caused by earthquakes; Recommendations for additional studies.

● 9.2-3 Hart, E. W., **Fault hazard zones in California, Alquist-Priolo Special Studies Zones Act of 1972 with index to special studies zones maps,** *Special Publication 42, rev. ed.,* California Div. of Mines and Geology, Sacramento, Jan. 1976, 27.

The Alquist-Priolo Geologic Hazard Zones Act, SB520, went into effect Mar. 7, 1973. The purpose of the Act is to provide for public safety in hazardous fault zones. The Act requires the delineation of potential damage areas, called "special studies zones," along known active faults throughout California. It requires local governments to withhold approval of construction permits in those zones until geologic investigation has determined, using the available evidence and up-to-date methods, that the site is not threatened by surface displacement from future faulting.

This publication describes the actions taken to implement the Act from its inception to the present; the status of special studies zones already delineated; and the expected future course of actions to be taken under the Act. This is

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

basically a progress report, because the program to delineate special studies zones along as-yet-unzoned potentially active faults will continue for some years, and because details of the various requirements of the Act are still undergoing modification and refinement.

9.3 Socio-Economic Aspects

● 9.3-1 Ohta, Y., **A questionnaire survey into human psychology and behavior during an earthquake** (in Japanese), *Proceedings of the Fourth Japan Earthquake Engineering Symposium-1975,* Paper No. 107, 51–58. (For a full bibliographic citation see Abstract No. 1.2–9.)

To aid in the construction of seismic zoning maps, the author conducted surveys of residents in Kawasaki, Nemuro, Kushiro, Obihiro, Hiroo and Urakawa following several earthquakes. The responses for each event are compared with both JMA and MM intensities.

● 9.3-2 Kulhanek, O. and Bath, M., **Earthquake insurance coefficients with application to some South-Central American capitals,** *8-76,* Seismological Inst., Uppsala, Sweden, 1976, 57.

Collected seismological information is used to determine earthquake insurance coefficients, defined as the annual premium normalized by the value of the insured property. In formulas developed for insurance coefficients, the extent of the damage as well as the time element and the building type are considered. Numerical estimates are given for the capital areas of Santiago, Lima-Callao, Bogota, Caracas, Managua and Mexico, D.F.

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

List of Titles

Numbers used are abstract numbers.

SECTION 1. General Topics and Conference Proceedings

1.1 General

1.2 Proceedings of Conferences

SECTION 2. Selected Topics in Seismology

2.1 Seismic Geology

2.2 Wave Propagation

2.3 Source Mechanisms

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

2.5 Studies of Specific Earthquakes

2.6 Seismic Water Waves

2.7 Artificially Generated Ground Motions or Seismic Events

2.8 Earthquake Prediction

2.9 Special Topics

SECTION 3. Engineering Seismology

3.1 General

3.2 Strong Motion Records, Interpretation, Spectra

3.3 Artificial and Simulated Earthquake Records

3.4 Seismic Zoning

3.5 Influence of Geology and Soils on Ground Motion

3.6 Seismic Site Surveys

SECTION 4. Strong Motion Seismometry

4.1 Instrumentation

4.2 Regional Data Collection Systems

SECTION 5. Dynamics of Soils, Rocks and Foundations

5.1 General

5.2 Dynamic Properties of Soils, Rocks and Foundations

5.3 Dynamic Behavior of Soils and Rocks

5.4 Dynamic Behavior of Soil and Rock Structures

5.5 Dynamic Behavior of Foundations, Piles and Retaining Walls

5.6 Experimental Investigations

SECTION 6. Dynamics of Structures

6.1 General

6.2 Dynamic Properties of Materials and Structural Components

Interception methods based on vibration damping wall in the ground-Outdoor experiments on ordinary street, 6.2–14
Frequency-independent internal friction in materials and Focht's hypothesis, 6.2–15
Dynamic strength of concrete subjected to repeated loadings, 6.2–16
Investigation of resonances in forced coupled vibrations of a flexible cable, 6.2–17
Free vibrations of a quadratic plate supported by bars at the four corners, 6.2–18
An analytical model for uniaxial cyclic inelastic behavior of reinforced concrete, 6.2–19
Elastodynamics; Vol. II: Linear theory, 6.2–20
Elastodynamics; Vol. I: Finite motions, 6.2–21
Frequency analysis of tapered rectangular plates by the finite strip method, 6.2–22
Vibrations of an initially stressed thick plate, 6.2–23
Application of the extended Kantorovich method to the vibration of clamped rectangular plates, 6.2–24
Analysis of the vibration of box beams, 6.2–25
Dynamic stability of circular cylindrical shells under periodic shearing forces, 6.2–26
Free vibration of non-circular cylindrical shell panels, 6.2–27
Natural patterns of vibration of building frames, 6.2–28
Free vibrations of a beam-mass system with elastically restrained ends, 6.2–29
Transverse vibrations of tapered beams, 6.2–30
Axisymmetric vibrations of circular plates including the effects of geometric non-linearity, shear deformation and rotary inertia, 6.2–31
Transverse vibrations of pre-twisted sandwich beams, 6.2–32
Forced axisymmetric response of circular plates, 6.2–33
On the non-linear vibrations of elastic circular plates of variable thickness, 6.2–34
Free vibrations of circular cylindrical shells, 6.2–35
Free vibration analysis of stiffened plates using finite difference method, 6.2–36
Free vibration analysis of a composite rectangular membrane consisting of strips, 6.2–37
Effect of longitudinal or inplane deformation and inertia on the large amplitude flexural vibrations of slender beams and thin plates, 6.2–38
The free vibrations of elastically connected circular plate systems with elastically restrained edges and radial tensions, 6.2–39
Damping properties of layered cylindrical shells, vibrating in axially symmetric modes, 6.2–40
Large deflection vibration of cross-ply laminated plates with certain edge conditions, 6.2–41
The forced vibration of singly modified damped elastic surface systems, 6.2–42
Non-linear vibrations of three-layer beams with viscoelastic cores I. Theory, 6.2–43
Influence of physical non-linearity on the dynamic behaviour of composite plates, 6.2–44
Generalized non-linear free vibrations of prestressed plates and shells, 6.2–45
Dynamic response analysis of systems with non-proportional damping, 6.2–46
Seismic stresses of piping systems and equipment on heat exchanger supporting structures, 6.2–47
Earthquake response characteristics of three spans continuous truss bridge with high piers, 6.2–48
An analytical study on restoring force characteristics of reinforced concrete framed structures, 6.2–49
A proposal for the wave propagation in gridworks, 6.2–50

6.3 Dynamic Properties of Linear Structures

Statics and dynamics of thin shell structures, 6.3–1
Instability analysis of columns subjected to seismic excitation, 6.3–2
Determination of the natural modes of a complex elastic structure in terms of the natural modes of the unconstrained components, 6.3–3
Seismic effects on rheologically non-homogeneous structures, 6.3–4
Analysis of earthquakeproofness of thin-walled spatial systems, 6.3–5
Response of an empty cylindrical ground supported liquid storage tank to base excitation, 6.3–6
Vibrations of a nuclear power station charge hall, 6.3–7
On the problem of the role of non-elastic resistance in the analysis of foundation-structure interaction during earthquakes, 6.3–8
On some features of the behavior of systems in transition stage subjected to random excitations, 6.3–9
Evaluation of seismic safety of buildings - Report No. 5: A study of the uncertainties in the fundamental translational periods and damping values for real buildings, 6.3–10
Stability analysis of the periodic solution of a piecewise-linear non-linear dynamic system, 6.3–11
Aseismic capacity of buildings—Based upon resonance-fatigue-characteristics, 6.3–12
Identification of viscous damping in structures from modal information, 6.3–13
On the natural period in actual buildings, 6.3–14
An evaluation method for the earthquake resistant capacity of reinforced concrete and steel reinforced concrete columns, 6.3–15

6.4 Deterministic Dynamic Behavior of Linear Structures

The behaviour of building structures under lateral loads, 6.4–1
Consideration on resistant dams in seismic areas, 6.4–2
Response of highway bridges under dynamic load, 6.4–3
Seismic stability of massive structures, 6.4–4
Dynamic earthquake analysis of a bottom supported industrial boiler, 6.4–5
Dynamic response of bridge grid under moving force, 6.4–6
On the dynamic response of a suspended cable, 6.4–7
Earthquake response of a tall multi-flue stack, 6.4–8
Finite element analysis of a seismically excited cylindrical storage tank, ground supported, and partially filled with liquid, 6.4–9
Seismic resistance of precast concrete panel buildings Report No. 1: Joints in large panel precast concrete structures, 6.4–10
Three-dimensional seismic structural analysis of Letterman Hospital, 6.4–11

6.5 Nondeterministic Dynamic Behavior of Linear Structures

6.6 Deterministic Dynamic Behavior of Nonlinear Structures

6.7 Nondeterministic Dynamic Behavior of Nonlinear Structures

6.8 Soil-Structure Interaction

6.9 Fluid-Structure Interaction

6.10 Vibration Measurements on Full Scale Structures

6.11 Experimental Facilities and Investigations

6.12 Deterministic Methods of Dynamic Analysis

6.13 Nondeterministic Methods of Dynamic Analysis

SECTION 7. Earthquake-Resistant Design and Construction and Hazard Reduction

7.1 General

7.2 Building Codes

7.3 Design and Construction of Buildings

7.4 Design and Construction of Nuclear Facilities

7.5 Design and Construction of Miscellaneous Structures

Critical excitation and response of free standing chimneys, 7.5–14
Seismic design of liquid storage tanks to earthquakes, 7.5–15
Safety of seismic protective systems with reserve elements, 7.5 16
Aseismic design examples of prestressed concrete water tank, 7.5–17
Lightweight underground structures, 7.5–18
World's third longest cantilever bridge, 7.5–19
California soon to have platform in 850 ft of water, 7.5–20
Closure of: Liquefaction potential of Ekofisk tank in North Sea,° 7.5–21
On design of suspended systems for seismic excitations, 7.5–22
Earthquake damage evaluation and design considerations for underground structures, 7.5–23
A review of earthquake resistant design of dams, 7.5–24
Report concerning earthquake resistant design advances for State highway and bridge construction, 7.5–25
Design of passive vibration controls for internally damped beams by modal control techniques, 7.5–26
Efficiency of joint parts for aseismic strength of buried pipelines, 7.5 27
Relation between seismic coefficient and ground acceleration for gravity quaywall, 7.5–28
Optimization of water resource systems incorporating earthquake risk, 7.5–29
The engineering of large dams, 7.5–30
Seismic qualification tests of electric equipment for Caorso nuclear plant: Comments on adopted test procedure and results, 7.5–31
The balanced risk method and the reliability of hydraulic structures, 7.5–32
Operational methods for increased earthquake resistance of large dams, 7.5 33
Design of concrete gravity dams in seismic regions, 7.5–34
Determination of seismic design criteria for the Dumbarton Bridge replacement structure, Vol. 1: Description, theory, and analytical modeling of bridge and parameters, 7.5–35
Determination of seismic design criteria for the Dumbarton Bridge replacement structure, Vol. 2: Numerical studies and establishment of seismic design criteria, 7.5–36

7.6 Design and Construction of Foundations, Piles and Retaining Walls

Analysis and design of laterally loaded piles and caissons in a layered soil system, 7.6–1
On the use of precast pile-foundations in construction of earthquake-proof large-panel buildings, 7.6–2
Seismic response of flexible and rigid retaining walls, 7.6–3

7.7 Design and Construction of Soil and Rock Structures

Discussion of: Seismic design of reinforced earth walls,° 7.7–1
Hydraulic fill dams earthquake stability, 7.7–2
Seismic resistant design of a nuclear Category I earth dam, 7.7–3
Closure of: Seismic design of reinforced earth walls,° 7.7–4
Geotechnical design aspects for large gravity retaining structures under seismic loading, 7.7–5

SECTION 8. Earthquake Effects

8.1 General

Damage to structures with aseismic design features, 8.1 1
Historical review of earthquakes, damage, and building codes, 8.1–2
Troika for earthquake-resistant building design, engineer - building code - contractor, 8.1–3
Structural damage and risk in earthquake engineering, 8.1–4
A California structural engineer shares three years of on-site experiences in the design of reparations for buildings in Managua, 8.1–5
Catalog of earthquake photographs, 8.1 6

8.2 Studies of Specific Earthquakes

The Santa Barbara earthquake, 29 June 1925, 8.2–1
Preliminary report on the January 19, 1975 Kinnaur earthquake in Himachal Pradesh, 8.2–2
Seismological and engineering aspects of the March 6, 1974, Carazo earthquake (Nicaragua), 8.2–3
Seismological and engineering features of the October 3, 1974, Lima, Peru earthquake, 8.2–4
Evaluation of the Point Mugu earthquake, 8.2–5
Engineering aspects of the Lima, Peru earthquake of October 3, 1974, 8.2–6
Engineering report on the Managua earthquake of 23 December 1972, 8.2–7
Liquefaction during 1906 San Francisco earthquake, 8.2–8
Response of rural dwellings to Lice earthquake Sept. 6, 1975 - Turkey, 8.2–9
Report on the Sept. 6, 1975 Lice Earthquake, 8.2 10
Oroville, California, earthquake, 1 August 1975, 8.2 11
The Pattan earthquake of 28 December 1974, 8.2–12
The Guatemalan earthquake of February 4, 1976: A preliminary report, 8.2–13
Earthquake reconnaissance: Guatemala, February 1976, 8.2–14
Structural damage caused by the 1976 Guatemala earthquake, 8.2–15
The earthquake of Sarkhun (Bandar-Abbas, Iran) of March 7, 1975, 8.2–16
Damage due to Izuhanto-oki earthquake, 8.2–17
Damage of structures caused by the Izuhanto-oki earthquake 1974, 8.2–18

8.3 Effects on Buildings

Aseismic measures for reinforced concrete structures—In view of damage from Oita earthquake of 1975, 8.3–1
Structural reparations of damaged buildings Caracas earthquake of July 29, 1967, 8.3–2
Earthquake response of a steel frame building, 8.3–3

8.4 Effects on Miscellaneous Structures and Systems

8.5 Effects and Near Surface Geology

SECTION 9. Earthquakes as Natural Disasters

9.1 Disaster Preparedness and Relief

9.2 Legal and Governmental Aspects

9.3 Socio-Economic Aspects

Author Index

Numbers used are abstract numbers.

Subject Index

Numbers used are abstract numbers. Items in **boldface** refer to sections or subsections of the Journal. Items in *italics* refer to other references in the Subject Index.