

**PROCEEDINGS
OF THE
EIGHTH WORLD
CONFERENCE on
EARTHQUAKE
ENGINEERING**

Vol. 4

TU352.1-53

E12

1984

V.4

8962061

p315.9-53

E12.2

1984

V.4

PROCEEDINGS

OF THE

**EIGHTH WORLD
CONFERENCE on
EARTHQUAKE
ENGINEERING**



July 21-28, 1984
San Francisco
California
U.S.A.



E8962061

VOLUME IV

Response of Structures

PRENTICE-HALL, INC., Englewood Cliffs, New Jersey

8863081
Library of Congress Catalog Card Number: 84-640235

PRENTICE-HALL STAFF:

Editorial/production supervision and

interior design: *Ros Herion and Barbara Palumbo*

Manufacturing buyer: *Anthony Caruso*

Acquisition editor: *C. M. Iossi*

©1984 by **Earthquake Engineering Research Institute**

All rights reserved. No part of this book may be reproduced, in any form or by any means, without permission in writing from the Earthquake Engineering Research Institute.

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

ISBN 0-13-246398-9

Prentice-Hall International, Inc., London
Prentice-Hall of Australia Pty. Limited, Sydney
Editora Prentice-Hall do Brasil, Ltda., Rio de Janeiro
Prentice-Hall Canada Inc., Toronto
Prentice-Hall of India Private Limited, New Delhi
Prentice-Hall of Japan, Inc., Tokyo
Prentice-Hall of Southeast Asia Pte. Ltd., Singapore
Whitehall Books Limited, Wellington, New Zealand

The Earthquake Engineering Research Institute (EERI), the International Association for Earthquake Engineering (IAEE), and the Steering Committee of the 8th World Conference on Earthquake Engineering are not responsible for the statements made in the papers of these proceedings; any opinions expressed are those of the individual authors.

The material contained herein reflects reproduction and reduction from original materials submitted by the individual authors. The variable quality of the copy is unavoidable due to the scope of the project. Interested readers should contact the individual authors for necessary clarification.

VOLUME IV — CONTENTS

ORIGINAL PAGE IS
OF POOR QUALITY

6. RESPONSE OF STRUCTURES 1

6.1 Response Spectra and Input Motions 5

Hall, W.J.,* Nau, J.M., Zahrah, T.F.	Scaling of Response Spectra and Energy Dissipation in SDOF Systems	7
Zhou, X.,* Wang, G., Su, J.	Seismic Design Response Spectra Considering Intensity, Epicentral Distance and Site Condition	15
Prince, J.,* Alonso, L.	Some Comments on the Relation Between the Acceleration Response Spectra of Real Earthquakes and the Design Spectra of Building Code Provisions	23
Singh, M.P.*	Extended Applications of Relative Acceleration and Velocity Spectra as Seismic Design Inputs	29
Chang, F.K.*	Analysis of Strong-Motion Data from the New Hampshire Earthquake of 18 January 1982	37
Pauschke, J.M.,* Krishnamurty, S.	Peak Vs. Root-Mean Square (RMS) Acceleration as a Response Parameter	45
Westermo, B.D.*	The Dependence of Structural Response Upon Strong Ground Motion Characterization	53
Corsanego, A., Del Grosso, A.,* Solari, G., Stura, D.	Some Considerations About Site Effects During the Irpinia Earthquake of November 23, 1980	59
Ohi, K.,* Tanaka, H.	Frequency-Domain Analysis of Energy Input Made by Earthquakes	67
Fajfar, P.,* Fischinger, M.	Parametric Study of Inelastic Response to Some Earthquakes Recorded in Southern Europe	75
Nishikawa, T.,* Hayama, S., Seki, T.	Normalization Parameters of Maximum Values of Earthquake Motion for Non-Linear Response Analyses of Structure	83
De Luca, A.,* Palazzo, B.	Inelastic Spectra for Geometrical and Mechanical Deteriorating Oscillator	91

* Presenting Author

<i>Sotoudeh, V.,* Boissonnade, A.</i>	Probabilistic Study of the Dynamic Response of a Stiffness-Degrading Single Degree of Freedom Structure Excited by a Strong Ground Motion with Specific Probabilistic Characteristic	99
<i>Minami, T.*</i>	Potential Destructiveness of Strong Earthquakes	107
<i>Parducci, A., Mezzi, M.*</i>	Elasto-Plastic Response Spectra of Italian Earthquakes Taking into Account the Structural Decay	115
<i>Wong, J.P.,* Paz, M.M.</i>	A Short Duration Equivalent Earthquake	123
<i>Chen, Y-q.*</i>	Selection of Accelerograms and Evaluation of Reliability by Step-by-Step Integration	129
<i>Azevedo, J.J.*</i>	Towards an Improvement on Loading Criteria	137
<i>Takeuchi, M., Kotoda, K., Kamaza, S., Atobe, Y.,* Hayakawa, K.</i>	Input Earthquake Waves as Deduced from the Measured Response of a Building	145

6.2 Analytical Procedures 153

<i>Lutes, L.D.</i>	Effects of Model Coupling on Dynamic Response	155
<i>Gupta, A.K.*</i>	Modal Combination in Response Spectrum Method	163
<i>Tsai, N.C.*</i>	A New Method for Spectral Response Analysis	171
<i>Amini, A.,* Trifunac, M.D.</i>	A Statistical Basis For Spectrum Superposition in Response to Earthquake Excitation	179
<i>Riddell, R., Vasquez, J.*</i>	Existence of Centers of Resistance and Torsional Uncoupling of Earthquake Response of Buildings	187
<i>Takizawa, H.*</i>	Coupled Lateral and Torsional Failure of Buildings under Two-Dimensional Earthquake Shakings	195
<i>Fao, W.K.,* Sadek, A.W.</i>	Inelastic Response of Eccentric Buildings Subjected to Bi-Directional Ground Motions	203
<i>Pan, T.-C.,* Kelly, J.M.</i>	Coupled Lateral-Torsional Response of Base-Isolated Structures	211
<i>de Bejar, L.A.,* Gergely, P.</i>	Linear Response of Torsionally Coupled Buildings for Multicomponent Earthquake Excitations	219
<i>Gergely, P.,* de Bejar, L.</i>	Nonlinear Response of Torsionally Coupled Buildings for Multicomponent Earthquake Excitations	227
<i>Kung, S.Y.,* Pecknold, D.A.</i>	Seismic Response of Torsionally Coupled Single Storey Structures	235
<i>Kato, D.,* Katsumata, H., Aoyama, H.</i>	Effect of Wall Base Rotation on Behavior of Reinforced Concrete Frame-Wall Buildings	243
<i>Koh, A.S.,* Spanos, P-T.D.</i>	Seismically Induced Rocking of Rigid Structures	251
<i>Baba, K.,* Nakashima, H.</i>	Seismic Response of Uplifting Shear Wall-Flexural Frame Interaction System	259
<i>Ishiyama, Y.*</i>	Criteria for Overturning of Rigid Bodies by Sinusoidal and Earthquake Excitations	267
<i>Ylm, S.C.S.,* Chopra, A.K.</i>	Earthquake Response of Buildings on Winkler Foundation Allowed to Uplift	275
<i>Chen, D.*</i>	Sliding-Uplifting Response of Flexible Structures to Earthquakes	283
<i>Psycharis, I.N.,* Jennings P.C.</i>	Rocking, Tipping and Upthrow of Simple Structures by Horizontal Motion	291
<i>Allen, R.H.,* Oppenheim, I.J., Bielak, J.</i>	Rigid Body Mechanisms in Structural Dynamics	299
<i>Beliveau, J.G.,* Chater, S.</i>	System Identification of Structures from Ambient Wind Measurements	307

<i>Udwadia, F.E.*</i>	Optimal Sensor Locations for Geotechnical and Structural Identification	315
<i>Tomizawa, M.*</i>	Identification of Structural Parameters and Aseismic Control of the Building	323
<i>Hakuno, M.,* Iida, M., Iwashita, K.</i>	Estimation of Building Response due to Large-Scale Earthquake from Observed Response Records to Small Earthquakes	331
<i>Saito, Y.,* Uchida, N., Aoyagi, T., Kawamura, M.</i>	Simulation Analysis on High-Rise Building Behavior by the Use of Strong Earthquake Motions Actually Observed	339
<i>Beck, J.L.,* Park, H.</i>	Optimal Algorithms for Calculating the Response of Linear Oscillators to Digitized Ground Accelerations	347
<i>Wu, S.T.,* Leyendecker, E.V.</i>	Dynamic Response of Structural Systems Subjected to Horizontal Propagating Shear Waves	355
<i>Miller, R.K., Heidari, M.A.*</i>	Approximate Analysis of Earthquake Response of Impacting Structures	363
<i>Matsushima, Y.*</i>	Optimum Distribution of Shear Coefficients for Multi-Degree-of-Freedom Systems Subjected to White Excitations	371
<i>Delinic, K.*</i>	Dynamical Response of Non-Proportionally Damped Dynamical Systems	379
<i>Freystatter, S.,* Schmitz, C., Arnold, J.P., Taud-Turnovsky, J.</i>	Influence of Seismic and Site Conditions on Equipment Response	387
<i>Yang, T.Y.,* Kapania, R.K., Saigal, S.</i>	Linear and Nonlinear Dynamic Response Analysis of Complex Shell Structures	395
<i>Mau, S.T.*</i>	Structure Identification Using Classical Normal Modes	403
<i>Takita, M.,* Izumi, M., Ito, K., Katsukura, H.</i>	A Study on Modal Coupling Analysis of Structures by the Component Mode Method	411
<i>Ito, K.,* Izumi, M., Katsukura, H., Takita, M.</i>	A Study on Application of the Component Mode Method to the Structures Constructed from Components with Different Damping	419
<i>Monge, J.*</i>	An Accurate Estimation of the Fundamental Period of Regular Tall Buildings	427
<i>Chavez, M.,* de Leon, D.</i>	Reliability of Nonlinear Systems with Uncertain Parameters and Random Seismic Excitation	435
<i>Tsotsos, S.S.,* Liolios, A.A.</i>	Dynamic Response of Pile Subjected to Lateral Loading—A Parametric Study	443
<i>Capatina, D.,* Titaru, E.</i>	Possible Extension of the Structural Seismic Analysis	451
<i>Suzuki, Y.,* Manai, R.</i>	A Method of Seismic Response Analysis of Hysteretic Structures Based on Stochastic Differential Equations	459
<i>Qin, Q.*</i>	Reliability of Randomly Excited and Strongly Deformed Hysteretic Oscillators	467
<i>Row, D.,* Schrieker, V.</i>	Seismic Analysis of Structures with Localized Nonlinearities	475
<i>Villaverde, R.*</i>	Response Spectrum Method for the Analysis of Nonlinear Multistory Structures	483
<i>Wakabayashi, M., Nakamura, T., Iwai, S.,* Hayashi, Y.</i>	Effects of Strain Rate on the Behavior of Structural Members Subjected to Earthquake Force	491
<i>Zingone, G.,* Papia, M.</i>	Energy Dissipation Capacity of Stiffened Steel Systems Under High Intensity Earthquake	499

6.3 Analysis of Building Structures 507

<i>Teramoto, T., Asano, M., Kitamura, H.*</i>	A Study of the Collapse Mechanism of Rigid Frames by Analysis of the Elasto-Plastic Seismic Response Using a Flexural Model	511
---	---	-----

Kawano, A.*	Inelastic Behavior of Low-Rise Steel Frame Based on a Weak Beam-to-Column Connection Philosophy to Earthquake Motion	519
Hilmy, S.I.,* Abel, J.F.	Material and Geometric Nonlinear Earthquake Analysis of Steel Frames Using Computer Graphics	527
Meyer, C.,* Roufaiel, M.S.L.	Reliability of Damaged Reinforced Concrete Frames	535
Noguchi, H., Naganuma, K.*	Nonlinear Finite Element Analysis of Restoring Force Characteristics of Reinforced Concrete Beam-Column Joints	543
Ötani, S.*	Hysteresis Models of Reinforced Concrete for Earthquake Response Analysis	551
Aranda, H.G.R.*	Ductility Demands for R/C Frames Irregular in Height	559
Caşciati, F.,* Faravelli, L.	Plastic Zone Spread and Seismic Reliability of R.C. Frames	567
Raga, G.,* Vestroni, F., Vulcano, A.*	On the Relationship between Overall and Local Ductility Demand for Plane Frames Subjected to Earthquakes	575
Sano, T., Vitiello, E.*	Low Intensity Earthquakes on Multi-Storey R.C. Buildings: Records, Identification and Modelling	583
Rivero, C.E.,* Walker, W.H.	An Analytical Study of the Interaction of Frames and Infill Masonry Walls	591
Kikuchi, K.,* Yoshimura, K.	Effect of Vertical Component of Ground Motions and Axial Deformation of Columns on Seismic Behavior of R/C Building Structures	599
Fintel, M.,* Ghosh, S.K.	Earthquake Resistance of Multistory Building Structures Designed for Wind	607
Jurukovski, D.,* Tashkov, L., Trajkovski, V.	Mathematical Model Formulation of a Fourteen Storey R/C Building Using Strong Motion Records and Parameter System Identification	615
Liau, T.C.,* Kwan, K.H.	New Development in Research of Infilled Frames	623
Irie, Y.*	Dynamic Characteristics of R.C. and S.R.C. Apartment Buildings	631
Fujiwara, T.,* Kitahara, A.	On the Aseismic Safety of Space Structures Under Bi-Directional Ground Motion	639
Kawamura, H.,* Yamada, M., Tani, A., Fujitani, H.	Regional Evaluation of Seismic Damages of Reinforced Concrete Buildings—Case Study: Standard R/C School Building in Hyogo Prefecture, Japan	647
Khachian, E.E., Shapinian, S.G.,* Ambartsumian, V.A., Melkumian, M.G.	A Study in Seismic Resistance of Frame Structures	655
Naik, T.R., Kaliszky, S., Soltis, L.A.*	Lateral-Torsional Response of Low-Rise Timber Buildings	663
Keintzel, E.*	Ductility Requirements for Shear Wall Structures in Seismic Areas	671
Bernardini, A., Giuffre, A., Modena, C.*	Reinforced Hollow Clay Brick Masonry Shear Walls Under Seismic Actions	679
El Kamshoshy, F.,* Pister, K.S.	A Mixed Finite Element Method for Dynamic Analysis of Seismically Loaded Structures—Application to Coupled Shear Walls	687
Keshavarzian, M.,* Schnobrich, W.C.	Computed Nonlinear Analysis of R/C Coupled Shear Walls	695
Malhas, F.A.*	Preliminary Correlations for Shaking Table Tests of Precast Panel Walls	703
McNary W.S., Atkinson, R.H.,* Abrams, D.P., Noland, J.L.	Basic Properties of Clay-Unit Masonry Stack-Bond Prisms in Compression	711
Mills, R.S.,* Igusa, T.	Seismic Response Assessment for a Masonry High-Rise Building	719

Hernandez-Basilio, O.*	Structural Behavior of Concrete Walls with Shear Failure	727
Nakashima, M., Huang, T., Lu, L.-W.*	Effect of Diaphragm Flexibility on Seismic Response of Building Structures	735
Jain, S.K.,* Jennings, P.C.	Continuous Models for Frame and Shear-Wall Buildings with Flexible Floors	743
Roper, S.C.,* Iding, R.H.	Appropriateness of the Rigid Floor Assumption for Buildings with Irregular Features	751
Button, M.R.,* Kelly, T.E., Jones, L.R.	The Influence of Diaphragm Flexibility on the Seismic Response of Buildings	759
Nakano, K.,* Awano, Y., Sugano, S., Tomita, K., Suitsu, H., Shindo, A.	A Survey of Building Damages During the El-Asnam, Algeria Earthquake of October 10, 1980	767
Cartin, J.F.*	Performance of School Canopies during the October 10, 1980 El-Asnam, Algeria Earthquake	775
Mallick, D.V.*	Engineering Studies of Building Response During El-Asnam Earthquake of October 10, 1980	783
Tagikuchi, K.,* Ichinose, T., Yoshii, M., Kubo, T., Iwashita, T.	Analysis of R/C Structures Damaged by the 1980 South Italy Earthquake	791
Foutch, D.A.,* Barenberg, M.E.	Earthquake Response of a Four-Story RC Building	799
Pardoen, G.C.,* Shepherd, R.	Experimental and Analytical Studies of the Imperial County Services Building	807
Kreger, M.E.*	Evaluation of the Response of the Imperial County Services Building	815
Zeris, C.A.,* Altmann, R.	Implications of Damages to the Imperial County Services Building for Earthquake-Resistant Design	823
Trigos, J.L.,* Hentschel, W.	Response of Two Reinforced Concrete Buildings in Mexico City during the Petatlan Earthquake of March 14, 1979	831
Lara, O.*	Seismic Resistant Implications of the 1980 Guayaquil, Ecuador Earthquake	839
Onose, J.-i.*	Prediction of Damage Ratio of Reinforced Concrete Buildings due to Earthquake and Comparison with Actual Damage Ratio	847
Wada, A.,* Shinozaki, Y., Hakamura, N.	Collapse of Building with Expansion Joints through Collision Caused by Earthquake Motion	855
Kato, K.,* Kawaji, M., Matsumura, A., Endo, T., Iguchi, T.	Damage to a Concrete-Block Masonry House Due to the 1982 Urakawa-Oki Earthquake	863
Kamil, H.,* Sharpe, R.L., Chen, M.-C., Algire, W.K.	Seismic Risk Study of the Palo Alto Civic Center	871
Hom, S.,* Manrod, W.E., Sharpe, R.L.	Considerations in Predicting Earthquake Damage to Industrial Facilities	879
Krawinkler, H.*	Damage Assessment in Steel Structures Subjected to Severe Earthquakes	887
Hughes, R.E.*	A Methodology for Surveying Earthquake Damage to Vernacular Buildings	895
Nason, R.*	Brick Building Damage in Ground Failure Areas in the 1906 San Francisco Earthquake	903
Gong, S.,* Fan, X., Gu, D.	A Study on the Energy Method for Seismic Design of Structures	905

6. RESPONSE OF STRUCTURES



New steel-frame buildings rise amid building rubble in San Francisco following the 1906 earthquake and fire. (From the files of H.J. Degenkolb)

6.1 Response Spectra and Input Motions

Available for public use at the discretion of the National Archives and Records Administration

SCALING OF RESPONSE SPECTRA AND ENERGY DISSIPATION IN SDOF SYSTEMS

W. J. Hall (I)

J. M. Nau (II)

T. F. Zahrah (III)

Presenting Author: W. J. Hall

SUMMARY

This paper contains summaries of two studies recently completed at the University of Illinois, one on response spectra and one on energy absorption. Design spectra are commonly normalized by peak ground motions. In the current study alternative scaling factors were evaluated. It was found that a three parameter system of spectrum intensities may afford a better means for scaling spectra. The study on energy absorption focused on the total amount of energy imparted to a simple structure, and the dissipative mechanisms including the number of yield excursions and reversals. Also an effective motion criterion was identified.

SCALING METHODS FOR EARTHQUAKE RESPONSE SPECTRA

Introduction

Early recommendations for earthquake design spectra were published by Housner, and by Newmark and Hall. In 1973 the results of companion statistical studies by Newmark and Blume were reported, which together form the basis for much of the current design practice (Ref. 1). In current practice, the earthquake hazard at a site is characterized by estimates of the expected peak values of ground acceleration, velocity, and displacement. The corresponding design spectra are constructed by amplifying these ground motion maxima by appropriate factors determined from the previously reported statistical studies. In the roughly ten years since the development of these design procedures, two important observations have been made. First, from the statistical studies themselves, it has been noted that the dispersion or scatter in the data is large. For example, coefficients of variation exceeding 50 percent have resulted when spectra are normalized or scaled by peak ground motion values. Secondly, from observations following actual earthquakes, it has been noted that levels of damage are inconsistent with large ground motion maxima. That is, greater levels of damage might have been expected had the peak instrumental ground motions been known beforehand. Of course, these peak parameters convey little or no information regarding the earthquake duration and frequency content, two important elements

(I) Professor of Civil Engineering, Univ. of Illinois, Urbana,
Illinois, USA

(II) Assistant Professor of Civil Engineering, North Carolina State
University, Raleigh, North Carolina, USA

(III) Engineer, Agabian Associates, El Segundo, California, USA

affecting damage. The conclusion is that ground motion maxima, alone, are poor indicators of earthquake damage potential or earthquake strength.

The objective of this study (Ref. 2) is to evaluate the current practice of scaling earthquake response spectra by the three peak ground motions. Other investigators such as Mahin and Bertero have suggested such studies, and, Cornell, Banon, and Shakal have reported results in which response spectra were scaled by mean Fourier amplitudes of acceleration. In this study, alternative scaling techniques are investigated in greater detail than heretofore considered. The approach, simply stated, is to statistically evaluate normalizing factors which have been proposed over the years, with the goal of reducing (ideally, minimizing) the dispersion or scatter encountered in current scaling methods.

Statistical Evaluation

The normalizing factors considered in this study are categorized into two groups, one based on ground motion data and the other on response-related quantities. The parameters within the group based on recorded ground motions are the integrals of the squared ground motions, and the root-square, mean-square, and root-mean-square motions. Those in the response-related category include the spectrum intensity and the amplitudes of the Fourier spectrum of ground acceleration. A three-parameter system of spectrum intensities, computed from the 2 percent damped elastic pseudovelocity spectrum, is developed. The spectrum intensities are determined within low, intermediate, and high ranges of frequency, appropriately selected to provide the least average dispersion in the corresponding frequency regions of the elastic spectra. A similar set of three mean Fourier amplitudes is derived.

In the statistical analysis, spectra for elastic and inelastic systems, computed from an ensemble of 12 earthquake accelerograms, are considered. The group of ground motions was selected to encompass a wide variety of conditions such as geographical location, earthquake magnitude, epicentral distance, and amplitude and duration of strong shaking. The response spectra, computed for displacement ductilities of 1 (elastic), 1.5, 2, 3, 5, and 10 included those for elastoplastic systems with 2, 5, and 10 percent damping. Bilinear systems with 5 percent damping and 2, 5, and 10 percent strain-hardening were also considered.

Results

The results of the study of alternative scaling procedures for earthquake response spectra may be summarized as follows.

1. For elastic spectra, the root-square displacement offers moderate reductions in scatter compared with that which results from normalization by the peak ground displacement. In the low frequency region, between 0.07 and 0.2 HZ the root-square displacement provides, on the average, about a 30 percent decrease in the coefficient of variation for the normalized spectra.