

CTBUH



council on tall buildings and
urban habitat presents

breakfast seminar

Recommendations for the Seismic Design of High Rise Buildings

7:15am for 7:30am start
Brisbane Club: Edinburgh room
241 Adelaide St

Friday 1st August 2008

\$40 per person
(tables seat 10)
payment to:
ACTBUH
41 Raff St
Spring Hill 4000

please RSVP:
Michelle O'Keeffe phone: 07 3120 6853
fax: 07 3832 8330



OPUS

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ACTBUH Seismic Seminar - 2008
1st August 2008

**Dr. Andrew Whittaker, Department of Civil, Structural, and
Environmental Engineering, University of Buffalo (UB)**

Dr. Whittaker is a Professor in the Department of Civil, Structural, and Environmental Engineering at the University at Buffalo (UB).

The Seismic Seminar investigates the resurgence in the construction of high-rise buildings around the world, including in many seismically active regions. There are major differences in the approach taken to seismic design in different national jurisdictions. Whilst rigorous performance based assessments are required in Japan and China, many other nations do not require anything other than a 'UBC-style' design based on code spectra and conventional force reduction factors. Some of these simple approaches lead to unsafe and/or uneconomic designs. The objective of this Guide is to set out best practice for the seismic design of high-rise buildings for use in any seismic region of the world.



**AUSTRALIAN COUNCIL ON TALL BUILDINGS & URBAN HABITAT
BREAKFAST SEMINAR BOOKING FORM**

TO REGISTER, please complete the form below and fax back to (07) 3832 8330 or alternatively email to m.okeeffe@ndy.com

Phone 07 3120 6800 Email m.okeeffe@ndy.com
 Fax 07 3832 8330 Post 41 Raff Street
 Spring Hill QLD 4000

CANCELLATIONS MUST BE RECEIVED BY 4.30PM TWO DAYS PRIOR TO THE BREAKFAST. FULL PAYMENT WILL BE REQUIRED FOR ALL CANCELLATIONS RECEIVED AFTER THIS TIME.

PLEASE ADVISE OF ANY MEDICAL DIETARY REQUIREMENTS.

CONTACT DETAILS

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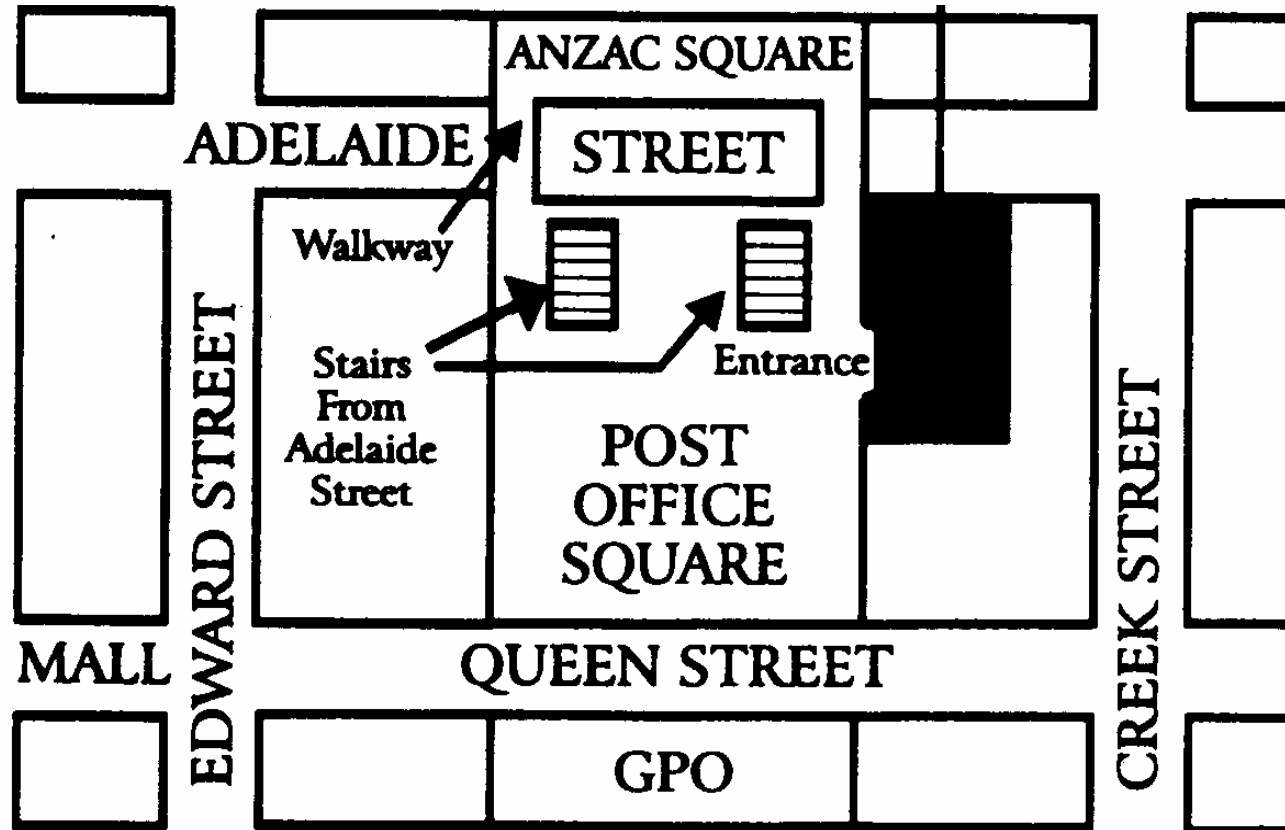
Single Ticket	_____	Table of 10	_____	Qty Purchased	_____
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REGISTRANT DETAILS

	ATTENDEE NAME	COMPANY
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The Australian Council On
Tall Buildings & Urban Habitat
website address is:
www.actbuh.com.au

Location Map



The Club entrance is located on the park level of Post Office Square.

The nearest public car park is the King's Post Office Square Car Park with entrances on both sides of Adelaide Street.

241 Adelaide Street
(GPO Box 2431)
BRISBANE QLD 4001
Telephone +617 3222 8700

CURRICULUM VITAE

Name: Andrew S. Whittaker
Address: 230 Ketter Hall, Buffalo, NY 14260
Phone: 1-716-645-2114 x 2418
Fax: 1-716-645-3733
Email: awhittak@acsu.buffalo.edu

Education

Degree: Ph.D., University of California at Berkeley, 1988
Major: Structural Engineering
Thesis: Seismic behavior of dual steel framing systems
Degree: M.S., Civil Engineering, University of California at Berkeley, 1985
Degree: B.E., Civil Engineering, University of Melbourne, Victoria, Australia, 1977

Professional Registration

Civil Engineer, California, No. C045013
Structural Engineer, California, No. S03618

Employment History

University at Buffalo, Buffalo, New York, Professor, 2004-present
University at Buffalo, Buffalo, New York, Associate Professor, 2001-2004
University of California, Berkeley, California, Associate Director, PEER, 1998-2000
University of California, Berkeley, California, Associate Director, EERC, 1992-1997
Forell/Elsesser Engineers, San Francisco, California, Senior Engineer, 1989-1991
Connell Wagner Group, Melbourne, Australia, Senior Engineer, 1978-1984

Professor, *University at Buffalo, (2004-present)*

Dr. Whittaker is a Professor in the Department of Civil, Structural, and Environmental Engineering at the University at Buffalo (UB). He is the President of the Consortium of Universities for Research in Earthquake Engineering (CUREE), which is a not-for-profit corporation in the United States. The CUREE membership includes 26 research universities and 320+ affiliated faculty. He has served as President of the organization since 2005. Dr. Whittaker has led the development of numerous multi-campus, multidisciplinary proposals including the recently funded, \$30M USD NEHRP Consultants Joint Venture, which is a joint venture of CUREE and the Applied Technology Council. He developed and now leads the University of Buffalo involvement in three Indefinite Delivery Indefinite Quantity (IDIQ) contracts with US federal agencies on topics related to blast engineering and infrastructure protection; the lead organizations for the IDIQ contracts are CUBRC and Black and Veatch. Dr. Whittaker also serves as a member of the Board of Directors for the Earthquake Engineering Research Institute (EERI) and the World Seismic Safety Initiative (WSSI).

Dr. Whittaker's current research interests include

- Blast engineering of buildings and infrastructure: clearing effects; material models at high strain rates; progressive collapse
- Performance-based earthquake engineering: procedures for loss computations; scaling earthquake ground motions; simplified methods of analysis.
- Seismic hazard: characterization for performance-based design; near-fault shaking; site amplification.
- Seismic protective systems: new isolation systems; analytical models for isolators; system response.
- Seismic behavior of squat reinforced concrete walls: rectangular, flanged and barbell walls; performance assessment; predictive equations.
- Nuclear structures: fragility evaluation of conventional and isolated power plants; modular construction for Gen III+ plants; Gen IV power plants.
- LNG tanks: mechanical analogs for schematic-level design; isolated and conventional tanks.

Dr. Whittaker teaches undergraduate and graduate classes at the University at Buffalo, including

- Undergraduate: CIE 423, Structural engineering III
- Undergraduate: CIE 428: Steel design
- Graduate: CIE 500B, Blast engineering
- Graduate: CIE 525, Reinforced concrete
- Graduate: CIE 619, Structural dynamics and earthquake engineering II

Associate Professor, *University at Buffalo, (2001-2004)*

Associate Director, *Pacific Earthquake Engineering Research Center, (1998-2000)*

Dr. Whittaker served as the Associate Director of the Pacific Earthquake Engineering Research (PEER) Center. In this capacity, he served as a member of the Research Executive Committee, worked with the Director and Deputy Director to draft the research and strategic plans for the Center, and directed the PEER Business and Industry Partnership (BIP) program and Implementation Advisory Board.

Associate Director, *Earthquake Engineering Research Center, (1993-1998)*

Dr. Whittaker was the technical director of the Earthquake Engineering Research Center (EERC) from 1993 to 1998, managing research activities and large-scale experimental facilities. He taught graduate and undergraduate classes in the Department of Civil Engineering at the University of California at Berkeley, developed and executed research projects and programs with federal and state agencies and private consortia, participated in workshops and short courses organized by the department and EERC, led the effort to upgrade the Berkeley earthquake simulator, and conducted research on steel structures and protective systems utilizing Center's the large-scale dynamic testing facilities.

Consultant, *(1992-present)*

Dr. Whittaker has provided consulting, peer-review and expert-witness services to private companies, local, state, and federal government agencies in the United States, South America, Europe, United Kingdom, Russia, Australia, and Asia. A focus of his consulting work is the application of performance-based seismic design and advanced blast engineering to tall and ultra-tall buildings, bridges, and power-related infrastructure. Fields of work related to earthquake engineering include historic structures, ultra-high-rise buildings, oil and gas production and transmission infrastructure, nuclear power and waste storage facilities, U.K. MoD marine assets, nuclear-safety-related buildings and dry docks, long- and

short-span bridges, mission-critical buildings and infrastructure, towers, airport infrastructure, and monumental buildings. *Projects include:* **Buildings:** U.S. Court of Appeals Building, San Francisco; New Zealand Parliament buildings, Wellington, New Zealand; San Francisco City Hall, San Francisco, CA; Pioneer Courthouse, Portland, OR; Green Library, Stanford, CA; New Zealand National Museum, Wellington, New Zealand; WDI Disney Resort parking structure, Anaheim, CA; Caltrans OCTMC, Irvine, CA; Santa Clara Police Facility, Santa Clara, CA; Universal headquarters building; Los Angeles, CA; Church of the Year 2000, Rome, Italy; LA Cathedral; Los Angeles, CA; AboveNet web-hosting facility, San Francisco, CA; Maples Pavilion, Stanford, CA; Prada building, San Francisco, CA; Ara Pacis Museum, Rome, Italy; SouthBay Tower, San Jose, CA; Microsoft Gibraltar data center, Seattle, WA; Kourion timber structures, Cyprus; New de Young Museum, San Francisco, CA; King County Courthouse, Seattle, WA; Tarabya Hotel, Istanbul, Turkey; CYTA telecom building retrofit program, Cyprus; Bosphorus residences, Istanbul, Turkey; Nordstrom building, Los Angeles, CA; St. Francis Towers (2×60-story towers), Manila, Philippines; Diamond of Istanbul (65 stories), Istanbul, Turkey; Soyuk Tower (30 stories), Istanbul, Turkey; Los Faros de Panama (1×95 stories, 2×78 stories), Panama City, Panama; Glasgow International Airport, Glasgow, UK (blast analysis and design); Capital Partners Towers (2×42 stories), Almaty, Kazakhstan; Qatar National Bank, Doha, Qatar. **Bridges:** Benicia-Martinez bridge, Benicia, CA; Ferrocarril Viaduct, Caracas, Venezuela; Willamette River bridge, Portland, OR; Stutson Bridge, Rochester, NY; Marcy Bridge, Rome, NY; A30 Autoroute, Montreal, Canada. **Infrastructure:** Trans-Alaskan Pipeline, Alaska; Caltrans SRMD Test Facility, San Diego, CA; San Francisco International Airport terminal, San Francisco, CA; JFK International Airport terminal, NY; HMNB Devonport SRC core pond building, Devonport, UK; BMS (Trident) cradles, Devonport, UK; BMS refit facilities, Devonport, UK; Ataturk International Airport terminal building, Turkey; HMNB Devonport Reactor Access Housing; Devonport, UK; Sutro Tower, San Francisco, CA (1999); Nuclear waste storage facilities, Hunterston, U.K.; Sakhalin I oil platform, Russia; Sakhalin II gas platforms, Russia; ANSTO nuclear reactor, Lucas Heights, Australia; Bakim airplane hangers, Ataturk Airport, Istanbul, Turkey; HMNB Clyde Faslane jetties, U.K.; LNG Tanks, Long Beach, CA.; LNG Tanks, Baja California, Mexico; Petrochemical facilities, Japan; Plum Point power station, Missouri; AWE Facilities, Aldermaston, UK; LNG Tanks, Quoddy Bay, Maine; Columbia Bottoms Well Field, St. Louis, Missouri; Beaver Stadium, PA; Sutro Tower, San Francisco, CA (2008); **Special Structures:** Fabrications, Museum of Modern Art, New York; Hermes Statue, Olympia, Greece; Oakland Cathedral, Oakland, CA.

Associate, Forell/Elsesser Engineers; San Francisco, (1989-1992)

Dr. Whittaker participated in numerous seismic rehabilitation projects including the development of seismic isolation systems for buildings; ground motion criteria for conventional and isolated building structures; peer review of the seismic isolation upgrade of the Parliament Buildings in Wellington, New Zealand; and the preparation of construction documents for the upgrade of the earthquake-damaged Green Library at Stanford University.

Senior Engineer, Connell Wagner Group; Melbourne, Australia, (1978-1984)

Dr. Whittaker's projects with the Connell Wagner Group included the design and construction supervision of the Victorian Arts Center and the Melbourne World Trade Center; design of two high-rise buildings (South Yarra Project); design of a casino and convention center; design of a 52-story building in Kuala Lumpur; and the design of a sports stadium to seat 70,000 patrons (VFL Park, Waverley).

Awards and Honors

- Gold Award, James Lincoln Arc Welding Foundation, 1987
- Outstanding 1998 Journal Paper, *Los Angeles Tall Buildings Structural Design Council*, “Evaluation of pre-Northridge moment resisting frame joints.”
- Outstanding 1998 Journal Paper, *Los Angeles Tall Buildings Structural Design Council*, “Evolution of seismic design practice in Japan.”
- Grand Award, 2002, *American Council of Engineering Companies*, “Seismic modernization of the new Ataturk International Airport, Istanbul, Turkey.”
- Diamond Award 2002, *New York Association of Consulting Engineers*, “Seismic modernization of the new Ataturk International Airport, Istanbul, Turkey.”
- Best Paper Award, 2002, *5th World Congress on Joints, Bearings and Seismic Systems for Concrete Structures*, “Cyclic behavior of high-damping rubber bearings.”
- Outstanding 2003 Journal Paper, *Los Angeles Tall Buildings Structural Design Council*, “Forensic studies of a large cover-plate steel moment-resisting connection.”

Professional Memberships and Committees

Dr. Whittaker is a member of the following professional organizations:

- Member, American Society of Civil Engineers
- Member, American Concrete Institute
- Member, Consortium of Universities for Research in Earthquake Engineering
- Member, Structural Engineers Association of Northern California
- Associate Member, Structural Engineers Association of New York
- Member, Earthquake Engineering Research Institute
- Member, Australian Earthquake Engineering Society
- Member, Japan Society for Seismic Isolation

Dr. Whittaker serves on a significant number of local, state, national, and international committees as listed below, and is an active member of the design professional community in the United States.

American Concrete Institute (ACI)

- Member, Committee 349, Reinforced Concrete Nuclear Structures, 2001-present

American Institute of Steel Construction

- Member, Subcommittee for Modular Composite Construction, 2006-present

American Society of Civil Engineers (ASCE)

- Member, ASCE Seismic Isolation Testing Standards Committee, 1995-2004
- Member, ASCE Task Committee on Seismic Isolation, 1996-2004
- Member, Steering Committee, Structural Engineers World Congress, 1997-1998
- Member, ASCE Task Committee on Supplemental Damping Systems, 1999-2004
- Member, Seismic Task Committee, ASCE Standard 7, 2000-present
- Member, ASCE Blast Standards Committee, 2003-present
- Co-Guest Editor, *Journal of Structural Engineering*, Vol. 134, No. 1, 2008

Applied Technology Council (ATC)

- Member, Technologies Team, ATC-33: Seismic Rehabilitation of Buildings, 1992-1997
- Member, Analysis Team, ATC-33: Seismic Rehabilitation of Buildings, 1992-1997

Project Director, ATC-34: Study of *R* Factors and Critical Code Issues, 1993-2002
 Member, Steering Committee, ATC-15-8, US-Japan Workshop, August 2000
 Structural Products Team Leader, ATC-58: Performance based earthquake engineering, 2002-present
 Member, Steering Committee, ATC-29-2 Seminar, October 2003

Building Seismic Safety Council (BSSC)
 Member, BSSC, PUC Technical Subcommittee 12, 1992-2005
 Corresponding Member, BSSC, Technical Subcommittee 2, 2006-present
 Member and Subgroup Leader, Issue Team 4, Seismic Design Procedures, 2006-present

California Department of Transportation (Caltrans)
 Member, Caltrans SRMD Peer Review Panel, 1997-2000
 Member, Caltrans Statewide Seismic Program Advisory Board, 1998-2006

Consortium of Universities for Research in Earthquake Engineering (CUREE)
 Member, Board of Directors, 2001-present
 Chair, CUREE Future Research Projects Committee, 2001-present
 Vice President, 2003-2004
 President, 2005-2009
 Member, CUREE-Kajima, Joint Venture Management Committee, 2006-present
 Member, NEHRP Consultants (ATC-CUREE) Joint Venture Management Committee and Program Committee, 2007-present

Department of Homeland Security (DHS)
 Member, Peer Review Panel, Blast tolerance of steel building structures, 2004-present

Earthquake Engineering Research Institute (EERI)
 Co-chair, US-Australia Bilateral Commission on Earthquake Engineering, 2004-present
 Coordinator, International Programs, 8th US National Conference on Earthquake Engineering, 2005-2006
 Member, Board of Directors, 2007-present

National Institute of Standards and Technology (NIST)
 Member, Oversight Committee, Guidelines for Testing Passive Energy Dissipation Devices, 1998-2004

Structural Engineers Association of California (SEAOC)
 Member, Ad-Hoc Energy Dissipation Systems Committee, 1995-1999

Structural Engineers Association of Northern California (SEAONC)
 Member, Board of Directors, 1996-1998
 Chair, Protective Systems Subcommittee, 1992-1999

University of California, Berkeley (UCB)
 Member, University of California at Berkeley Seismic Review Committee, 1996-2000

United States Geological Survey (USGS)
 Alternate Member, ANSS National Steering Committee, 2001-present
 Chair, USGS_ANSS Structural Instrumentation Committee, 2004-2005

World Seismic Safety Initiative (WSSI)

Member, Board of Directors, 2008-2011

Other

Member, International Scientific Advisory Committee, International Conference on Computational Methods for Smart Structures and Materials, Rome, Italy, 1998

Member, International Advisory Committee, Third International Conference on Behavior of Steel Structures in Seismic Areas, Montreal, Canada, 2000

Member, International Advisory Committee, Fourth International Conference on Behavior of Steel Structures in Seismic Areas, Naples, Italy, 2003

Member, International Advisory Committee, Fifth International Conference on Behavior of Steel Structures in Seismic Areas, Lehigh University, United States of America, 2008

Member, International Advisory Committee, Eighth International Conference on Shock and Impact on Structures, University of Adelaide, Australia, 2009

Professional Service

Dr. Whittaker reviews research proposals for U.S. National Science Foundation, Canadian Natural Sciences and Engineering Research Council, and the Australian Research Council. He reviews manuscripts for the American Society of Civil Engineers (Journals of Structural Engineering, Engineering Mechanics, and Wind Engineering & Industrial Aerodynamics), the Earthquake Engineering Research Institute, Earthquake Engineering and Structural Dynamics, the Journal of Earthquake Engineering, Nuclear Engineering and Design, the Structural Design of Tall Buildings, and the Journal of Sound and Vibration; and reviews papers for national and international conferences on earthquake, blast and structural engineering.

Dr. Whittaker serves on the International Editorial Board of the archival Wiley journal, The Structural Design of Tall Buildings and the Editorial Board of the Electronic Journal of Structural Engineering.

University Service

Member, University of California at Berkeley Seismic Review Committee, 1996-2000

Reviewer, National Science Foundation, Research proposals, 2000-present

Reviewer, Research Program, Department of Structural Engineering, Tokyo Institute of Technology, Yokohama, Japan, 2001

Reviewer, Research Program, Department of Civil and Environmental Engineering, University of Melbourne, Australia, 2001, 2003

Member, University at Buffalo Faculty Senate Tenure and Privileges Committee, 2002-present

Chair, External Advisory Board, UCSD-NEES project, University of California, San Diego, 2002-2004.

Peer Review, USAID and ACEC, Washington, D.C., Applications for University Partnerships to Reduce Vulnerability to Seismic Hazards, 2003, 2003

Member, University at Buffalo Centers and Institutes Task Group, 2004-2005

Reviewer, National Science Foundation, Engineering Research Centers, 2005

College Service

SEAS Academic Infraction Appeals Committee, 2002-present

Departmental Service

Chair, CSEE Educational Laboratories Committee, 2001-2005.
Member, CSEE Undergraduate Studies Committee, 2001-2005.
Coordinator, CSEE Ph.D. Qualifying Examination, 2002-present
Faculty Advisor, UB EERI Student Chapter, 2003-present
Member, CSEE Search Committee, 2003-2004
Deputy Director, Structural and Earthquake Engineering Simulation Laboratory, 2005-2007
Member, CSEE Graduate Studies Committee, 2005-present
Chair, Computational Mechanics Search Committee, 2006

Research Supervision

Ph.D. Degree, Advisor

Oscar Ramirez, University at Buffalo, co-advised with M. Constantinou (May 2000)
Position: Professor, Technical University of Panama
Taejin Kim, UC Berkeley, co-advised with B. Stojadinovic (May 2003)
Position: Professor, SungKyunKwan University, Korea
Fei Deng, University at Buffalo (July 2004)
Position: World Bank, Washington, D.C.
Gordon Warn, University at Buffalo (June 2006)
Position: Post-doctoral researcher, University at Buffalo
Claudia Marin, University at Buffalo (November 2006)
Position: Post-doctoral researcher, University at Buffalo
Yin-Nan Huang, University at Buffalo (Expected May 2008)
Cevdet Gulec, University at Buffalo (Expected December 2008)

Ph.D. Dissertation Committees

Oscar Ramirez, May 2000, (Member)
Taejin Kim, May 2003 (Co-chair)
Eric Wolff, August 2003 (Member)
Ani Natali Sigaher-Boyle, June 2004 (Member)
Fei Deng, July 2004 (Chair)
Panayiotis Roussis, September 2004 (Member)
Eleni Pavlou, May 2005 (Member)
Methee Chiewanichakorn, December 2004 (Member)
Jun Wang, May 2005 (Member)
Wasim Bahram, May 2005 (Member)
Darren Vian, December 2005 (Member)
Jeff Berman, February 2006 (Member)
Khalid Al-Gahtani, May 2006 (Member)
Wael Alnahhal, October 2006 (Member)

Xiaoyun Shao, December 2006 (Member)
Mehdi Ahmadizadeh, September 2007 (Member)
Xiaobo Luo, December 2007 (Member)
Hongbo Wang, December 2007 (Member)
Mohamad Abdulhamid, Expected May 2008 (Member)
Elvira Elvira, Expected May 2008 (Outside Examiner, University of Melbourne)
Alper Ucak, Expected May 2008 (Outside Examiner, Catholic University of America)
Daniel Fenz, Expected May 2008 (Member)

M. S. and M. Eng Degree, Advisor

Andrew Thompson, U.C. Berkeley (May 1999)
Position: Associate, Arup Consulting, San Francisco, London
Troy Morgan, U.C. Berkeley (May 2000)
Position: PhD student, University of California, Berkeley
Taejin Kim, U.C. Berkeley (May 2000)
Despoina Tsamandoura, University at Buffalo, December 2002)
Hiram Badillo, University at Buffalo (August 2003)
Position: PhD student, University of Barcelona, Spain
Janet Lane, University at Buffalo (August 2003)
Position: Engineer, US Army Corps of Engineers
Edgard Escobar, University at Buffalo (May 2004)
Position: Consulting engineer, Managua, Nicaragua
Michael Astrella, University at Buffalo (December 2004)
Position: Structural engineer, Weidlinger Associates, New York
Ryan Cyr, University at Buffalo (January 2005)
Cevdet Gulec, University at Buffalo (June 2005)
Position: PhD student, University at Buffalo
Erick Burgos, University at Buffalo (July 2006)
Position: Consulting engineer, San Salvador, El Salvador
Ionnis Christovasilis, University at Buffalo (August 2006)
Position: PhD student, University at Buffalo
Nicholas Kipfer, University at Buffalo (May 2007)
Position: Structural engineer, Birdair Associates, New York
Toshi Yoza, University at Buffalo (June 2007)
Position: Structural engineer, Arup, Los Angeles
Graeme Ballantyne, University at Buffalo (August 2007)
Position: Structural engineer, Thornton-Tomasetti, Philadelphia
Brian Regan, University at Buffalo (Expected May 2008)
Daniel Gavahi, University at Buffalo (Expected December 2008)

Post-Doctoral Fellows and Research Engineers

Dr. Amir Gilani, Research Engineer; UC Berkeley, 1996-2000

Position: Senior Engineer, Caltrans, Sacramento
 Dr. Juan Chavez, Research Engineer; UC Berkeley, 1996-1998
 Position: Senior Engineer, ABS Consulting, San Francisco
 Dr. Shakzod Takhirov, Research Engineer; UC Berkeley, 1997-2000
 Position: Research Engineer, University of California, Berkeley
 Mr. Hidemi Nakashima, Visiting Scholar, Shimizu Corporation; UC Berkeley, 1999
 Position: Senior Engineer, Shimizu Corporation, Japan
 Dr. Michio Yamaguchi, Post Doctoral Fellow, Tokyo Institute of Technology; UB, 2002-2003
 Position: Senior Engineer, Nippon Steel Corporation, Japan
 Dr. Taejin Kim, Visiting Scholar, SungKyunKwan University, Korea; UB 2008-2009
 Position: Professor, SungKyunKwan University, Korea

Teaching

2000-2001: CIE 423, Structural Engineering III
 CIE 619, Earthquake Engineering and Structural Dynamics II

2001-2002: CIE 525, Reinforced Concrete (incl. Enginet)
 CIE 619, Earthquake Engineering and Structural Dynamics II (incl. Enginet)

2002-2003: CIE 361, Civil Engineering Laboratory
 CIE 428, Steel Structures
 CIE 525, Reinforced Concrete (incl. Enginet)
 CIE 619, Earthquake Engineering and Structural Dynamics II (incl. Enginet)

2003-2004: CIE 525, Reinforced Concrete (incl. Enginet)
 CIE 619, Earthquake Engineering and Structural Dynamics II (incl. Enginet)

2004-2005: CIE 525, Reinforced Concrete (incl. Enginet)
 CIE 428, Steel Structures
 CIE 619, Earthquake Engineering and Structural Dynamics II

2005-2006: CIE 525, Reinforced Concrete
 CIE 428, Steel Structures
 CIE 619, Earthquake Engineering and Structural Dynamics II

2006-2007: CIE 428, Steel Structures
 CIE 500B, Blast Engineering
 CIE 525, Reinforced Concrete
 CIE 619, Earthquake Engineering and Structural Dynamics II

2007-2008: CIE 500B, Blast Engineering
 CIE 525, Reinforced Concrete (incl. Enginet)

Publications

Textbooks and Textbook Chapters

- (T1) Bruneau, M., C. M. Uang, and A. S. Whittaker, *Ductile Design of Steel Structures*, McGraw-Hill, New York, N.Y., September 1997.
- (T2) Uang, C. M., A. S. Whittaker, M. Bruneau and K. C. Tsai, *Chapter 8, Seismic design of steel structures*, in *The Seismic Design Handbook*, F. Naeim (ed.), Kluwer Academic Publishers, Boston, MA, January 2001.
- (T3) Warn, G., J. W. Berman, A. S. Whittaker, and M. Bruneau, *Investigation of a damaged high-rise building near Ground Zero*, Chapter in "Beyond September 11th: An Account of Post Disaster Research," Special Publication No. 39, Natural Hazards Research and Applications Information Center, University of Colorado, Boulder, CO., pp. 199-240, July 2003.
- (T4) Whittaker, A. S. and M. C. Constantinou, *Chapter 12, Seismic energy dissipation systems for buildings*, in *Earthquake Engineering*, Bozorgnia and Bertero (eds), CRC Press, Boca Raton, FL, March 2004.
- (T5) Thompson, A. C. T., A. M. Kammerer, G. M. Katzman and A. S. Whittaker, *Chapter 7, Natural Hazards*, in *Extreme Event Mitigation in Buildings*, Meacham (ed), NFPA, Quincy, MA., April 2006

Refereed Journals

- (R1) Whittaker, A. S., C. M. Uang, and V. V. Bertero, "Experimental behavior of a dual steel system," *Journal of the Structural Division*, ASCE, 115(1), January 1989.
- (R2) Whittaker, A. S., V. V. Bertero, C. L. Thompson, and L. J. Alonso, "Seismic testing of steel-plate energy dissipating devices," *Earthquake Spectra*, Vol. 7, No. 4, November 1991.
- (R3) Aiken, I. D., D. K. Nims, A. S. Whittaker, and J. M. Kelly, "Testing of passive energy dissipation systems," *Earthquake Spectra*, Vol. 9, No. 3, Earthquake Engineering Research Institute, CA, August 1993.
- (R4) Whittaker, A. S., J. P. Moehle, and M. Higashino, "Evolution of building seismic design practice in Japan," *The Structural Design of Tall Buildings*, 7, 93-111, John Wiley, 1998.
- (R5) Whittaker, A. S., M. C. Constantinou, and P. Tsopelas, "Displacement estimates for performance-based earthquake engineering," *Journal of Structural Engineering*, Vol. 124, No. 8, pp. 896-905, ASCE, Washington, D.C., August 1998.
- (R6) Makris, N., Y. Roussos, A. S. Whittaker, and J. M. Kelly, "Viscous heating of fluid dampers II: large-amplitude motions," *Journal of Engineering Mechanics*, Vol. 124, No. 11, ASCE, Washington, D.C., November 1998.
- (R7) Whittaker, A. S., A. Gilani, and V. V. Bertero, "Evaluation of pre-Northridge steel moment-resisting frame joints," *The Structural Design of Tall Buildings*, 7 (4), pp. 263-284, John Wiley, December 1998. **Best Paper Award**
- (R8) Whittaker, A. S., M. C. Constantinou, and P. Tsopelas, "Nonlinear procedures for the seismic evaluation of buildings," *The Structural Design of Tall Buildings*, 8 (1), pp. 1-13, John Wiley, March 1999
- (R9) Whittaker, A. S., C. Rojahn, and G. C. Hart, "Seismic response modification factors," *Journal of Structural Engineering*, Vol. 125, No. 4, ASCE, Washington, D.C., April 1999.
- (R10) Whittaker, A. S. and M. C. Constantinou, "Supplemental damping for new and retrofit construction." *Revista De Ingenieria Sismica*, Vol. 61, Sociedad Mexicana de Ingenieria Sismica A.C., Mexico City, December 1999.

- (R11) Gilani, A. S.J. and A. S. Whittaker, "Fatigue-life evaluation of steel post structures, part I: background and analysis." *Journal of Structural Engineering*, Vol. 126, No. 3, ASCE, Washington, D.C., March 2000
- (R12) Gilani, A. S. J. and A. S. Whittaker, "Fatigue-life evaluation of steel post structures, part II: experimentation." *Journal of Structural Engineering*, Vol. 126, No. 3, ASCE, Washington, D.C., March 2000
- (R13) Gilani, A. S. J., A. S. Whittaker, and G. L. Fenves, "Seismic evaluation and retrofit of porcelain transformer bushings." Volume 17, No. 4, *Earthquake Spectra*, EERI, Oakland, CA, November 2001.
- (R14) Chang, S.-P., N. Makris, A. S. Whittaker, A. C. T. Thompson, "Experimental and analytical studies on the performance of hybrid isolation systems." Volume 31, No. 2, *Earthquake Engineering and Structural Dynamics*, Wiley, London, pp 421-443, December 2001
- (R15) Kim, T., A. S. Whittaker, A. S. J. Gilani, V. V. Bertero, and S. M. Takhirov, "Experimental evaluation of plate-reinforced steel moment-resisting connections." *Journal of Structural Engineering*, Vol. 128, No. 4, ASCE, Washington, D.C., pp 483-491, April, 2002
- (R16) Kim, T., A. S. Whittaker, A. S. J. Gilani, V. V. Bertero, and S. M. Takhirov, "Cover-plate and flange-plate steel moment-resisting connections." *Journal of Structural Engineering*, Vol. 128, No. 4, ASCE, Washington, D.C., pp 474-482, April, 2002
- (R17) Uriz, P. and A. S. Whittaker, "Retrofit of pre-Northridge steel moment-resisting frames using fluid viscous dampers." *The Structural Design of Tall Buildings*, Volume 10, No. 5, John Wiley, London, pp 371-390, December 2001 **Best Paper Award**
- (R18) Whittaker, A. S., A. S. J. Gilani, S. Takhirov, and C. Ostertag, "Forensic studies of a large cover-plate steel moment-resisting connection." *The Structural Design of Tall Buildings*, John Wiley, 2000, *The Structural Design of Tall Buildings*, Volume 11, No. 4, John Wiley, London, pp 265-283, December 2002. **Best Paper Award**
- (R19) Ramirez, O. M., M. C. Constantinou, J. D. Gomez, A. S. Whittaker, and C. Z. Chrysostomou, "Evaluation of simplified methods of analysis of yielding structures with damping systems." Volume 18, No. 3, *Earthquake Spectra*, EERI, Oakland, CA, pp. 501-530, August 2002.
- (R20) Ramirez, O. M., M. C. Constantinou, A. S. Whittaker, C. A. Kircher, and C. Z. Chrysostomou, "Elastic and inelastic seismic response of buildings with damping systems." Volume 18, No. 3, *Earthquake Spectra*, EERI, Oakland, CA, pp. 531-547, August 2002.
- (R21) Sezen, H., A. S. Whittaker, K. J. Elwood, and K. M. Mosalam, "Performance of reinforced concrete buildings during the August 17, 1999 Kocaeli, Turkey earthquake, and seismic design and construction practice in Turkey." Volume 25, No. 1, *Engineering Structures*, Elsevier Science, London, pp 103-115, January 2003.
- (R22) Whittaker, A. S., M. C. Constantinou, O. M. Ramirez, M. W. Johnson, and C. Z. Chrysostomou, "Equivalent lateral force and modal analysis procedures of the 2000 NEHRP Provisions for buildings with damping systems," Volume 19, No. 4, *Earthquake Spectra*, Oakland, CA, pp. 959-980, November 2003.
- (R23) Ramirez, O. M., M. C. Constantinou, A. S. Whittaker, C. A. Kircher, M. W. Johnson, and C. Z. Chrysostomou, "Validation of the 2000 NEHRP Provisions equivalent lateral force and modal analysis procedures for buildings with damping systems," Volume 19, No. 4, *Earthquake Spectra*, Oakland, CA, pp. 981-999, November 2003.
- (R24) Berman, J., G. Warn, A. S. Whittaker, and M. Bruneau, "Reconnaissance and preliminary analysis of a damaged building near Ground Zero, *The Structural Design of Tall and Special Buildings*, Volume 12, pp. 371-391, December 2003.

- (R25) Whittaker, A. S., G. L. Fenves, and A. S. J. Gilani, "Earthquake performance of porcelain transformer bushings," Volume 20, No. 1, *Earthquake Spectra*, Oakland, CA, pp. 1-19, February 2004.
- (R26) Mosqueda, G., A. S. Whittaker and G. L. Fenves, "Characterization and modeling of Friction Pendulum bearings subjected to multiple components of excitation," *Journal of Structural Engineering*, Volume 140, No. 3, pp. 433-442, March 2004.
- (R27) Warn, G. and A. S. Whittaker, "Performance estimates in seismically isolated bridges," *Engineering Structures*, Vol. 26, No. 9, pp. 1261-1278, July 2004.
- (R28) Grant, D., G. L. Fenves and A. S. Whittaker, "Bidirectional modeling of high-damping rubber bearings," *Journal of Earthquake Engineering*, Vol. 8, Special Issue 1, pp 161-185, September 2004.
- (R29) Sezen, H. and A. S. Whittaker, "Seismic performance of industrial facilities affected by the 1999 Turkey earthquake," *Journal of Constructed Facilities*, Vol. 20, No. 1, ASCE, pp. 28-36, February 2006.
- (R30) Kim, T., B. Stojadinovic and A. S. Whittaker, "Seismic performance of welded steel beam moment connections to built-up box columns," *Journal of the Earthquake Engineering Society of Korea*, Vol. 10, No. 1, pp. 25-31, February 2006 (in Korean)
- (R31) Warn, G. and A. S. Whittaker, "Property modification factors for seismically isolated bridges," *Journal of Bridge Engineering*, Vol. 11, No. 3, ASCE, pp. 371-377, May 2006.
- (R32) Escobar-Sandoval, E., A. S. Whittaker, and G. F. Dargush, "Concentrically loaded circular steel plates bearing on plain concrete," *Journal of Structural Engineering*, Vol. 132, No. 11, ASCE, pp. 1784-1792, November 2006.
- (R33) Badillo, H., A. S. Whittaker, and A. M. Reinhorn, "Seismic fragility of suspended ceiling systems," *Earthquake Spectra*, Vol. 23, No. 1, February 2007.
- (R34) Warn, G., A. S. Whittaker and M. C. Constantinou, "Vertical stiffness of elastomeric and lead-rubber seismic isolation bearings," *Journal of Structural Engineering*, Vol. 133, No. 9, ASCE, pp. 1227-1236, September 2007.
- (R35) Huang, Y.-N., A. S. Whittaker, M. C. Constantinou and S. Malushte, "Seismic demands on secondary systems in isolated nuclear power plants," *Earthquake Engineering and Structural Dynamics*, 36, pp. 1741-1761, October 2007.
- (R36) Whittaker, A. S., G. L. Fenves and A. S. J. Gilani, "Seismic evaluation and analysis of high-voltage disconnect switches," *Engineering Structures*, Vol. 29, No. 12, pp. 3538-3549, December 2007.
- (R37) Symans, M. D., F. A. Charney, A. S. Whittaker, M. C. Constantinou, C. A. Kircher, M. W. Johnson and R. J. McNamara, "Energy dissipation systems for seismic applications: current practice and recent developments," *Journal of Structural Engineering*, Volume 134, No. 1, ASCE, pp. 1-21, January 2008.
- (R38) Kim, T., B. Stojadinovic and A. S. Whittaker, "Seismic performance of pre-Northridge welded steel moment connections to built-up box columns," *Journal of Structural Engineering*, Volume 134, No. 2, ASCE, pp. 289-299, February 2008.

Refereed Journal Articles Submitted for Review/In Press

- (R39) Warn G. and A. S. Whittaker, "Vertical earthquake loads on seismic isolation systems in bridges," In Press, *Journal of Structural Engineering*.
- (R40) Christovasilis, I. and A. S. Whittaker, "Seismic analysis of conventional and isolated LNG tanks using mechanical analogs," In Press, *Earthquake Spectra*.

- (R41) Gulec, K., A. S. Whittaker and B. Stojadinovic, "Shear strength of squat rectangular reinforced concrete walls," In Press, *ACI Structural Journal*.
- (R42) Huang, Y.-N., A. S. Whittaker and N. Luco, "Maximum spectral demands in the near-fault region," In Press, *Earthquake Spectra*.
- (R43) Yoza, T. and A. S. Whittaker, "Seismic performance of code-compliant Japanese buildings," Paper submitted for review and possible publication, *Architectural Institute of Japan*, submitted July 2007.
- (R44) Gulec, K., A. S. Whittaker and B. Stojadinovic, "Shear strength of squat reinforced concrete walls with boundary elements," Paper submitted for review and possible publication, *ACI Structural Journal*, submitted October 2007.
- (R45) Marin, C. C, A. S. Whittaker and M. C. Constantinou, "Experimental study of the XY-Friction Pendulum bearing for bridge applications," Paper submitted for review and possible publication, *Journal of Bridge Engineering*, submitted October 2007.
- (R46) Marin, C. C, A. S. Whittaker and M. C. Constantinou, "Analytical and numerical studies of the XY-Friction Pendulum bearing," Paper submitted for review and possible publication, *Engineering Structures*, submitted October 2007.
- (R47) Kim, T., B. Stojadinovic and A. S. Whittaker, "Brittle fracture of pre-Northridge fully restrained moment connections to box columns," Paper submitted for review and possible publication, *Engineering Structures*, submitted November 2007.
- (R48) Jones, J., C. Wu, D. J. Oehlers, A. S. Whittaker, S. Marks, and R. Coppola, "Finite difference analysis of RC panels for blast effects," Paper submitted for review and possible publication, *International Journal of Impact Engineering*, submitted March 2008.
- (R49) Kim, T., B. Stojadinovic and A. S. Whittaker, "Post-fracture seismic performance of welded steel moment connections," Paper submitted for review and possible publication, *Journal of Construction Steel Research*, submitted March 2008.

Refereed Journal Articles in Preparation

- (R50) Wu, C., D. J. Oehlers, M. Reberstrost, J. Leach, and A. S. Whittaker, "Blast testing of ultra-high performance and FRP-retrofitted reinforced concrete slabs," *International Journal of Impact Engineering*, to be submitted April 2008.
- (R51) Ballantyne, G, A. S. Whittaker, A. Aref and G. Dargush, "Clearing effects of air blast loadings on rigid reflecting surfaces," *Journal of Structural Engineering*, to be submitted April 2008.
- (R52) Ballantyne, G, A. S. Whittaker, A. Aref and G. Dargush, "Air-blast loadings on structural shapes," *International Journal of Impact Engineering*, to be submitted May 2008.
- (R53) Huang, Y.-N., A. S. Whittaker and N. Luco, "Site amplification and the NGA relationships," *Earthquake Spectra*, to be submitted May 2008
- (R54) Huang, Y.-N., A. S. Whittaker and N. Luco, "Selection and scaling of earthquake ground motions in support of performance-based design," *Journal of Structural Engineering*, to be submitted May 2008
- (R55) Ngo, T., P. Mendis and A. S. Whittaker, "A rate-dependent constitutive model for normal, high and ultra-high strength concrete," *ACI Materials Journal*, to be submitted May 2008
- (R56) Ngo, T., P. Mendis and A. S. Whittaker, "Lattice models for analysis of reinforced concrete components subjected to blast loading," *Engineering Structures*, to be submitted June 2008
- (R57) Burgos, E. A., Y.-N. Huang, A. S. Whittaker, and R. O. Hamburger, "Seismic performance of buildings with hybrid lateral force resisting systems," *Earthquake Spectra*, to be submitted July 2008.

Refereed Conference Proceedings and Manuscripts

- (C1) Bertero, V.V., C.M. Uang, and A.S. Whittaker, "Test structures: experimental response and code compliance," *Proceedings*, ASCE Specialty Conference, Orlando, FL, August, 1987.
- (C2) Bertero, V. V., C. M. Uang, and A. S. Whittaker, "Earthquake simulator testing of a concentrically braced steel structure," *Proceedings*, Ninth World Conference on Earthquake Engineering, Tokyo, Japan, August, 1988.
- (C3) Whittaker, A. S., C. M. Uang, and V. V. Bertero, "Experimental seismic response of steel dual systems," *Proceedings*, Fourth U.S. National Conference on Earthquake Engineering, Palm Springs, CA, May 1990.
- (C4) Uang, C. M., V. V. Bertero, and A. S. Whittaker, "Seismic response correlation of full-scale and 0.3-scale models tested by different dynamic testing techniques," *Proceedings*, Fourth U.S. National Conference on Earthquake Engineering, Palm Springs, California, May 1990.
- (C5) Walters, M. T., E. Elsesser, and A. S. Whittaker, "Seismic isolation: an emerging rehabilitation technique," *Proceedings*, 9th ASCE Structures Congress, Indianapolis, Indiana, May 1991.
- (C6) Elsesser, E. and A. S. Whittaker, "Earthquake response of San Francisco freeway structures during the October 17, 1989 earthquake," *Proceedings*, Third U.S. Conference on Lifeline Earthquake Engineering, Los Angeles, California, August, 1991.
- (C7) Whittaker, A. S. and E. Elsesser, "Seismic design criteria for transportation structures," *Proceedings*, Third U.S. Conference on Lifeline Earthquake Engineering, Los Angeles, California, August, 1991.
- (C8) Whittaker, A. S., I. D. Aiken, D. Bergman, P. W. Clark, J. Cohen, J. M. Kelly, and R. E. Scholl, "Code requirements for design and implementation of passive energy dissipation systems," *Proceedings*, ATC-17-1 Seminar on Seismic Isolation, Passive Energy Dissipation, and Active Control, Applied Technology Council, San Francisco, California, March, 1993.
- (C9) Clark, P. W., A. S. Whittaker, I. D. Aiken, and J. A. Egan, "Performance considerations for isolation systems in regions of high seismicity," *Proceedings*, ATC-17-1 Seminar on Seismic Isolation, Passive Energy Dissipation, and Active Control, Applied Technology Council, San Francisco, California, March, 1993.
- (C10) Whittaker, A. S. and I. D. Aiken, "Passive energy dissipation systems for earthquake-resistant design," *Proceedings*, 11th ASCE Structures Congress, Irvine, California, April, 1993.
- (C11) Whittaker, A. S. and I. D. Aiken, "Passive control of structural systems," *Proceedings*, 12th ASCE Structures Congress, Atlanta, GA, April 1994.
- (C12) Rojahn, C. and A. S. Whittaker, "A critical review of current approaches to earthquake-resistant Design," *Proceedings*, 13th ASCE Structures Congress, Boston, MA, April 1995.
- (C13) Whittaker, A. S., M. C. Constantinou, and C. A. Kircher, "Seismic rehabilitation using supplemental damping systems," *Proceedings*, Eleventh World Conference on Earthquake Engineering, Acapulco, Mexico, June 1996.
- (C14) Whittaker, A. S. and M. C. Constantinou, "Constitutive modeling of energy dissipation devices for the seismic analysis of buildings," *Proceedings*, 12th ASCE Engineering Mechanics Conference, San Diego, CA, May 1998.
- (C15) Rojahn, C. and A. S. Whittaker, "A proposed framework for performance-based design of new buildings," *Proceedings*, 6th U.S. National Conference on Earthquake Engineering, Seattle, WA, June 1998.
- (C16) Makris, N., Y. Roussos, A. S. Whittaker, and J. M. Kelly, "Seismic protection with fluid dampers," *Proceedings*, Structural Engineers World Congress, San Francisco, CA, July 1998.

- (C17) Fujisaki, E., E. Matsuda, G. L. Fenves, and A. S. Whittaker, "Seismic qualification and fragility testing of porcelain transformer bushings," *Proceedings*, 5th U.S. Conference on Lifeline Engineering, Seattle, WA, August 1999
- (C18) Thompson, A., A. S. Whittaker, G. L. Fenves, and S. A. Mahin, "Property modification factors for elastomeric bearings," *Proceedings*, Twelfth World Conference on Earthquake Engineering, Auckland, New Zealand, January 2000.
- (C19) Huang, W.-H., G. L. Fenves, A. S. Whittaker, and S. A. Mahin, "Characterization of seismic isolation bearings from bi-directional testing," *Proceedings*, Twelfth World Conference on Earthquake Engineering, Auckland, New Zealand, January 2000.
- (C20) Anderson, E.L., S. A. Mahin, G. L. Fenves, and A. S. Whittaker, "An evaluation of the AASHTO uniform load method for estimating forces and deformations in seismically isolated bridge systems," *Proceedings*, Twelfth World Conference on Earthquake Engineering, Auckland, New Zealand, January 2000.
- (C21) Kim, T., A. S. Whittaker, and V. V. Bertero, "Reinforced steel moment-resisting joints," *Proceedings*, Third International Specialty Conference on the Behavior of Steel Structures in Seismic Areas, STESSA 2000, Montreal, Canada, August 2000.
- (C22) Whittaker, A. S., "Earthquake engineering into the next millennium," *Journal of Architecture and Building Science*, Architectural Institute of Japan, Vol. 116, No. 1465, Tokyo, Japan, January 2001.
- (C23) Whittaker, A. S., G. L. Fenves, and A. S. J. Gilani., "Evaluation of seismic qualification procedures for high-voltage substation equipment," *Proceedings*, ASCE Structural Engineering Congress, Washington, May, 2001.
- (C24) Constantinou, M. C., A. S. Whittaker, and E. Velivasakis, "Seismic evaluation and retrofit of the Ataturk International Airport Terminal building," *Proceedings*, ASCE Structural Engineering Congress, Washington, May, 2001.
- (C25) Morgan, T., A. S. Whittaker, and A. C. Thompson, "Cyclic behavior of high-damping rubber bearings," *Proceedings*, Fifth World Congress on Joints, Bearings and Seismic Systems for Concrete Structures, American Concrete Institute, Rome, Italy, October 2001. **Best Paper Award**
- (C26) Whittaker, A. S., Ed. "Guidelines for testing large seismic isolator and energy dissipation devices," CERF Report No. 40600, Civil Engineering Research Foundation, Washington, D.C., January 2002.
- (C27) Kim, T., B. Stojadinovic, and A. S. Whittaker, "Behavior of steel moment connections between a wide-flange beam and a box column," *Proceedings*, Seventh U.S. National Conference on Earthquake Engineering, Earthquake Engineering Research Institute, Boston, May 2002.
- (C28) Mosqueda, G., A. S. Whittaker, G. L. Fenves, and D. Mellon, "Performance characterization of fluid viscous dampers," *Proceedings*, Seventh U.S. National Conference on Earthquake Engineering, Earthquake Engineering Research Institute, Boston, July 2002.
- (C29) Bruneau, M., A. M. Reinhorn, A. S. Whittaker, M. C. Constantinou, S. Thevanayagam, S.-Y. Chu, M. C. Pitman, and K. Winter, "A versatile high-performance testing facility towards real-time dynamic hybrid testing," *Proceedings*, Seventh U.S. National Conference on Earthquake Engineering, Earthquake Engineering Research Institute, Boston, July 2002
- (C30) Ballantyne, J. R., M. L. Chapman, C. A. Hughes, and A. S. Whittaker, "Seismic base isolation-a cost effective means of upgrading UK nuclear structures," *Proceedings*, 12th European Conference on Earthquake Engineering, Paper 403, Elsevier Science, London, UK, September 2002

- (C31) Gallocher, S. C., C. I. Robertson, and A. S. Whittaker, "Application of the capacity spectrum method to jetty structures," *Proceedings*, 12th European Conference on Earthquake Engineering, Paper 123, Elsevier Science, London, UK, September 2002
- (C32) Bruneau, M., A. M. Reinhorn, M. C. Constantinou, S. Thevanayagam, A. S. Whittaker, S.-Y. Chu, M. C. Pitman, and K. Winter, "The University at Buffalo node of the NEES network-a versatile high-performance testing facility towards real-time dynamic hybrid testing," *Proceedings*, 12th European Conference on Earthquake Engineering, Paper 823, Elsevier Science, London, UK, September 2002.
- (C33) Chrysostomou, C. Z., M. C. Constantinou, and A. S. Whittaker, "Energy dissipation devices for structural design and retrofit," *Proceedings*, FIB Symposium on Concrete Structures in Seismic Regions, Athens, Greece, May 2003.
- (C34) Badillo, H., A. S. Whittaker, and A. M. Reinhorn, "Performance characterization of suspended ceiling systems," *Proceedings*, ATC-29-2 Seminar on the Seismic Design, Performance and Retrofit of Nonstructural Components in Critical Facilities, Irvine, CA, October 2003.
- (C35) Whittaker, A. S. and T. T. Soong, "An overview of nonstructural research at three U.S. Earthquake Engineering Research Centers", *Proceedings*, ATC-29-2 Seminar on the Seismic Design, Performance and Retrofit of Nonstructural Components in Critical Facilities, Irvine, CA, October 2003.
- (C36) Bachman, R. E., R. O. Hamburger, C. D. Comartin, C. Rojahn, and A. S. Whittaker, "ATC-58 framework for performance-based design of nonstructural components", *Proceedings*, ATC-29-2 Seminar on the Seismic Design, Performance and Retrofit of Nonstructural Components in Critical Facilities, Irvine, CA, October 2003
- (C37) Whittaker, A. S., R. O. Hamburger, C. Comartin, R. Bachman and C. Rojahn, "Performance based engineering of building structures," *Proceedings*, 73rd Shock and Vibration Symposium, SAVIAC, San Diego, CA, October 2003.
- (C38) Kim, T., B. Stojadinovic and A. S. Whittaker, "Seismic performance of US steel box column connections," *Proceedings*, 13th World Conference on Earthquake Engineering, Paper 981, Vancouver, B.C., Canada, August 2004.
- (C39) Badillo, H., A. S. Whittaker and A. M. Reinhorn, "Seismic qualification and fragility testing of suspended ceiling systems," *Proceedings*, 13th World Conference on Earthquake Engineering, Paper 1053, Vancouver, B.C., Canada, August 2004.
- (C40) Sezen, H. and A. S. Whittaker, "Performance of industrial facilities during the 1999 Kocaeli, Turkey, earthquake," *Proceedings*, 13th World Conference on Earthquake Engineering, Paper 282, Vancouver, B.C., Canada, August 2004.
- (C41) Warn, G. and A. S. Whittaker, "Energy-related demands on seismic isolators in bridges," *Proceedings*, 13th World Conference on Earthquake Engineering, Paper 3250, Vancouver, B.C., Canada, August 2004.
- (C42) Bruneau, M., A. M. Reinhorn, M. Constantinou, A. S. Whittaker, and S. Thevanayagam, "The UB-NEES versatile high-performance testing facility," *Proceedings*, 13th World Conference on Earthquake Engineering, Paper 1577, Vancouver, B.C., Canada, August 2004.
- (C43) Hamburger, R. O., C. Rojahn, J. Moehle, R. Bachman, C. Comartin and A. S. Whittaker, "Development of next-generation performance-based earthquake engineering design criteria for buildings," *Proceedings*, 13th World Conference on Earthquake Engineering, Paper 1819, Vancouver, B.C., Canada, August 2004.
- (C44) Whittaker, A. S. et al., "Guideline for ANSS seismic monitoring of engineered civil systems – version 1.0." Open-File Report 2005-1039, United States Geological Survey, Reston, VA, March 2005.

- (C45) Whittaker, A. S., M. C. Constantinou and S. Malushte, "Building structures with damping systems: from research to design practice," *Proceedings*, Structures Congress, ASCE, New York, April 2005.
- (C46) Whittaker, A. S. and R. L. Nigbor, "Guideline for ANSS seismic monitoring of engineered civil systems," *Proceedings*, Annual Meeting of the Seismological Society of America, Incline Village, NV, April 2005.
- (C47) Deng, F., A. S. Whittaker and S. Chen, "An overview of expert and decision-support system approaches for cash flow prediction and project financing," *Proceedings*, CEIS 2005 Conference on Civil Engineering Infrastructure Systems, Beirut, Lebanon, June 2005.
- (C48) Huang, Y.-N., A. S. Whittaker, M. C. Constantinou and S. Malushte, "Seismic protection of secondary systems in nuclear power plant facilities," *Transactions*, 18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18-K11-7), Beijing, China, August 2005.
- (C49) Malushte, S. and A. S. Whittaker, "Survey of past base isolation applications in nuclear power plants and challenges to industry/regulatory acceptance," *Transactions*, 18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18-K10-7), Beijing, China, August 2005.
- (C50) Huang, Y.-N., A. S. Whittaker and M. C. Constantinou, "Seismic demands on secondary systems in conventional and isolated nuclear power plants," *Proceedings*, 8th US National Conference on Earthquake Engineering, San Francisco, California, April 2006.
- (C51) Whittaker, A. S., "Seismic protection of mission-critical infrastructure," *Keynote Address and Proceedings*, Fourth World Conference on Structural Control and Monitoring, San Diego, California, July 2006.
- (C52) Constantinou, M. C., A. S. Whittaker, D. M. Fenz and G. Aposotolakis, "Seismic isolation of bridges," Report to the California Department of Transportation, Sacramento, CA, June 2007.
- (C53) Gulec, K., A. S. Whittaker and B. Stojadinovic, "Shear strength of squat reinforced concrete walls with flanges and barbells," *Transactions*, 19th International Conference on Structural Mechanics in Reactor Technology (SMiRT 19), Toronto, Canada, August 2007.
- (C54) Huang, Y.-N. and A. S. Whittaker, "Scaling of earthquake records for the design of safety-related nuclear facilities," *Transactions*, 19th International Conference on Structural Mechanics in Reactor Technology (SMiRT 19), Toronto, Canada, August 2007.
- (C55) Huang, Y.-N. and A. S. Whittaker, "Mapping seismic hazard for maximum demands in near-fault regions," *Transactions*, 19th International Conference on Structural Mechanics in Reactor Technology (SMiRT 19), Toronto, Canada, August 2007.

Technical Reports and Non-Refereed Manuscripts

- (T1) Bertero, V.V., C.M. Uang, A.S. Whittaker, and C.R. Llopiz., "Progress report on the earthquake simulation tests and associated studies of 0.3-scale models of the six-story steel test structure," *Proceedings*, Sixth Joint Technical Coordinating Committee Meeting, U.S.-Japan Cooperative Research Program Utilizing Large-Scale Testing Facilities, Maui, Hawaii, June 1985.
- (T2) Whittaker, A.S., C.M. Uang, and V.V. Bertero, "Earthquake Simulation Tests and Associated Studies of a 0.3-Scale Model of a Six-Story Eccentrically Braced Steel Structure," Report No. UCB/EERC-87/02, Earthquake Engineering Research Center, University of California, Berkeley, CA, June, 1987.
- (T3) Whittaker, A.S., C.M. Uang, and V.V. Bertero, "Implications of recent research on current seismic regulations pertaining to steel dual systems," *Proceedings*, Conference on Tall Buildings in Seismic Regions, Council for Tall Buildings and Urban Habitat, Los Angeles, CA, February, 1988.

- (T4) Aktan, H.M., A.S. Whittaker, and V.V. Bertero, "Non-buckling slip braces for seismic rehabilitation," *Proceedings*, Second U.S.-Japan Workshop on Urban Hazard Reduction, Tokyo, Japan, July, 1988.
- (T5) Whittaker, A.S., C.M. Uang, and V.V. Bertero, "An Experimental Study of the Behavior of Steel Dual Systems," Report No. UCB/EERC-88/14, Earthquake Engineering Research Center, University of California, Berkeley, CA, September, 1988.
- (T6) Whittaker, A.S., V.V. Bertero, L.J. Alonso, and C.L. Thompson, "Earthquake Simulator Testing of Steel Plate Added Damping and Stiffness Elements," Report No. UCB/EERC-89/02, Earthquake Engineering Research Center, University of California, Berkeley, CA, December, 1988.
- (T7) Whittaker, A.S., V.V. Bertero, L.J. Alonso, and C.L. Thompson, "Passive energy dissipation using steel -plate Added Damping and Stiffness Elements," *Proceedings*, International Conference on Base Isolation and Passive Energy Dissipation, Assisi, Italy, June, 1989.
- (T8) Giacchetti, R., A. S. Whittaker, V. V. Bertero, and H. M. Aktan, "Seismic response of a DMRSF retrofitted with friction-slip devices," *Proceedings*, International Conference on Base Isolation and Passive Energy Dissipation, Assisi, Italy, June, 1989.
- (T9) Bertero, V. V. and A. S. Whittaker, "Seismic upgrading of buildings," *Proceedings*, Fifth Chilean Conference on Seismology and Earthquake Engineering, Santiago, Chile, August, 1989.
- (T10) Nims, D. K., E. Miranda, I. D. Aiken, A. S. Whittaker, and V. V. Bertero, "Collapse of the Cypress Street Viaduct as a Result of the Loma Prieta Earthquake," Report No. UCB/EERC-89/16, Earthquake Engineering Research Center, University of California, Berkeley, CA, November, 1989.
- (T11) Whittaker, A. S. and V. V. Bertero, "Earthquake simulator testing of ADAS elements," *Proceedings*, U.S./P.R.C. Workshop on Base Isolation and Passive Energy Absorption, Earthquake Engineering Research Center, University of California, Berkeley, May, 1990.
- (T12) Whittaker, A. S., V. V. Bertero, and R. E. Scholl, "Cyclic testing of steel-plate energy dissipaters," *Proceedings*, U.S./P.R.C. Workshop on Base Isolation and Passive Energy Absorption, Earthquake Engineering Research Center, University of California, Berkeley, May, 1990.
- (T13) Walters, M. T., E. Elsesser, and A. S. Whittaker, "Base isolation: an innovative seismic upgrading strategy," *Proceedings*, U.S./P.R.C. Workshop on Base Isolation and Passive Energy Absorption, Earthquake Engineering Research Center, University of California, Berkeley, May, 1990.
- (T14) Elsesser, E., A. S. Whittaker, et al., "The repair of five historic buildings damaged by the Loma Prieta earthquake," *Proceedings*, Seismic Retrofit of Historic Buildings Conference, National Parks Service, San Francisco, California, November, 1991.
- (T15) Walters, M. T., Sattary, V. and A. S. Whittaker, "Seismic isolation of the U.S. Court of Appeals, San Francisco," *Proceedings*, 44th Annual Meeting, Earthquake Engineering Research Institute, Oakland, California, February 1992.
- (T16) Whittaker, A. S., D. A. Friedman, and E. Elsesser, "Loma Prieta Earthquake repair of the Stanford University Green Library West," *Proceedings*, 44th Annual Meeting, Earthquake Engineering Research Institute, Oakland, California, February 1992.
- (T17) Whittaker, A. S., "Tentative general requirements for the design and construction of structures incorporating discrete passive energy dissipation devices," ATC 15-4, *Proceedings*, Fifth U.S.-Japan Workshop on the Improvement of Structural Design and Construction Practices, San Diego, California, September, 1992.
- (T18) Whittaker, A. S. and R. C. Krumme, "Structural Control Using Shape-Memory Alloys," E*Sorb Systems Report No. 93-01, Berkeley, California, April, 1993.

- (T19) Sharpe, R. S., A. S. Whittaker, and V. Sattary, "Design of a Tridirectional Reaction Frame for Comparative Dynamic Testing of Base Isolation Systems," USACERL Technical Report FM-93/04, U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, IL, April, 1993.
- (T20) Aiken, I.D. and A. S. Whittaker, "Development and application of passive energy dissipation techniques in the U.S.A.," *Proceedings*, International Post-SMiRT Conference Seminar on Isolation, Energy Dissipation, and Control of Vibrations of Structures, Capri, Italy, August 1993.
- (T21) Whittaker, A. S., "Passive control: analysis and design," *Proceedings*, Advances in Earthquake Engineering Practice, Earthquake Engineering Research Center, University of California, Berkeley, CA, June 1994.
- (T22) Whittaker, A. S., "Future directions for seismic codes," *Proceedings*, Advances in Earthquake Engineering Practice, Earthquake Engineering Research Center, University of California, Berkeley, CA, June 1994.
- (T23) Whittaker, A. S., "Seismic retrofit using protective systems," *Proceedings*, Advances in Earthquake Engineering Practice, Earthquake Engineering Research Center, University of California, Berkeley, CA, June 1994.
- (T24) Whittaker, A. S., "Supplemental damping design issues," *Proceedings*, UOA/UOM/UCB Earthquake Engineering Short Course, University of Adelaide, Australia, July 1994.
- (T25) Whittaker, A. S., "Protective systems for seismic retrofit," *Proceedings*, UOA/UOM/UCB Earthquake Engineering Short Course, University of Adelaide, Australia, July 1994.
- (T26) Aiken, I., A. S. Whittaker, P. W. Clark, J. Inaudi, and M. Higashino, "Passive energy dissipation techniques," *Proceedings*, SEAONC Fall Seminar Series-The Developing Art of Seismic Engineering, Structural Engineers Association of Northern California, San Francisco, CA, November 1994.
- (T27) Whittaker, A. S. and D. Clyde, "Testing of FIP Proprietary Shock Transmission Units: Marquam Bridge Retrofit Project," Report No. EERCL-STI/94-01, Earthquake Engineering Research Center, University of California, Berkeley, CA, December 1994
- (T28) Whittaker, A. S., "Testing of FIP Proprietary Seismic Isolation Hardware: Marquam Bridge Retrofit Project," Report No. EERCL-STI/94-02, Earthquake Engineering Research Center, University of California, Berkeley, CA, December 1994
- (T29) Whittaker, A. S., J. P. Moehle, and M. Higashino, "Evolution of Japanese and United States seismic codes," *Proceedings*, SEAONC Spring Seminar Series—The Great Hanshin Earthquake Disaster, Structural Engineers Association of Northern California, San Francisco, CA, May 1995.
- (T30) Griffith, M. C. and A. S. Whittaker, "Seismic isolation in regions of low seismicity," *Proceedings*, Ninth Pacific Conference on Earthquake Engineering, Melbourne, Australia, November 1995.
- (T31) Moehle, J. P., A. S. Whittaker, et al., "Seismological and Engineering Aspects of the 1995 Hyogoken Nanbu Earthquake," Report No. UCB/EERC-95/10, Earthquake Engineering Research Center, University of California, Berkeley, CA, November 1995.
- (T32) Whittaker, A. S., G. Hart, et al., "Structural Response Modification Factors," Report ATC-19, Applied Technology Council, Redwood City, CA, December 1995.
- (T33) Whittaker, A. S. et al., "A Critical Review of Current Approaches to Earthquake-Resistant Design," Report No. ATC-34, Applied Technology Council, Redwood City, CA, December 1995.
- (T34) Lynn, A., J. P. Moehle, and A. S. Whittaker, "Evaluation of an existing, seven-story, reinforced-concrete building," *Proceedings*, Seventh U.S.- Japan Workshop on Improvement of Structural Design and Construction Practices, Kobe, Japan, January 1996.

- (T35) Whittaker, A. S. "Testing of FIP Proprietary Damper Units: Hood River Bridge Retrofit Project," Report No. EERCL-STI/96-01, Earthquake Engineering Research Center, University of California, Berkeley, CA, April 1996.
- (T36) Whittaker, A. S. and A. Gilani, "Cyclic Testing of Steel Beam-Column Connections," Report No. EERCL-STI/96-04, Earthquake Engineering Research Center, University of California, Berkeley, CA, May 1996.
- (T37) Whittaker, A. S., V. V. Bertero, and A. Gilani, "Full-scale seismic testing of steel moment-frame connections," Report to the SAC Joint Venture, Earthquake Engineering Research Center, University of California, Berkeley, CA, June, 1996.
- (T38) Whittaker, A. S., "Testing and inspection of passive energy dissipation devices," *Proceedings*, Symposium on Passive Energy Dissipation Technology, County of Los Angeles, Alhambra, July 1996.
- (T39) Whittaker, A. S. and J. P. Moehle, "Performance-based earthquake engineering," *Proceedings*, Australian Earthquake Engineering Society Annual Meeting, Adelaide, Australia, September 1996.
- (T40) "NEHRP Guidelines for the Seismic Rehabilitation of Buildings," FEMA Reports 273 and 274, Federal Emergency Management Agency, Washington, D.C., October 1996
- (T41) Moehle, J. P. and A. S. Whittaker, *Editors*, "Performance-Based Seismic Design: An Action Plan for Future Studies," FEMA Report 283, Federal Emergency Management Agency, Washington, D.C., October 1996.
- (T42) Whittaker, A. S., S. A. Mahin, et al., "Testing of protective systems and hardware for bridge applications," *Proceedings*, Fourth U.S.-Japan Workshop on Earthquake Protective Systems for Bridges, Osaka, Japan, December 1996.
- (T43) Whittaker, A. S. and S. A. Mahin, "Seismic evaluation and repair of steel buildings," *Proceedings*, Chinese Earthquake Engineering Society Seminar on the Northridge Earthquake Disaster, Taipei, Taiwan, December 1996.
- (T44) Whittaker, A. S., A. Gilani, and V. V. Bertero, "Cyclic testing of cover-plated steel moment connections," *Proceedings*, Japan-U.S. Workshop on Fractures of Steel Buildings in Earthquakes, San Francisco, CA, January 1997.
- (T45) Whittaker, A. S., et al., "Implementation of passive energy dissipation devices," *Proceedings*, Bertero Symposium, Report No. UCB/EERC-97/04, Earthquake Engineering Research Center, University of California, Berkeley, CA, April 1997.
- (T46) Whittaker, A. S., "Evaluation of steel moment-resisting connections," *Proceedings*, International Symposium on Experimental Research for Structural Performance, Advanced Structure Research Station, Hanyang University, Seoul, Korea, June 1997.
- (T47) Eberhard, M. O., A. Matamoros, and A. S. Whittaker, "Cyclic Testing of Reinforced Concrete Captive Columns, Report No. EERCL-STI/97-01, Earthquake Engineering Research Center, University of California, Berkeley, CA, June 1997
- (T48) Whittaker, A. S., "Development of analysis procedures and design guidelines for supplemental damping devices," *Proceedings*, International Post-SMiRT Conference on Seismic Isolation, Passive Energy Dissipation and Active Control of Seismic Vibrations of Structures," Taormina, Italy, August 1997.
- (T49) Tsopelas, P, M. C. Constantinou, C. A. Kircher, and A.S. Whittaker, "Simplified Methods of Analysis for Yielding Structures," NCEER Report 97-0012, National Center for Earthquake Engineering Research, Buffalo, New York.

- (T50) Gilani, A. S., J. W. Chavez, and A.S. Whittaker, "Fatigue-Life Evaluation of CMS Structures, Volume 1: As-Built Specimens," Report No. UCB/EERC-97/10, Earthquake Engineering Research Center, University of California, Berkeley, CA, September 1997.
- (T51) Whittaker, A. S., P. W. Clark, and J. M. Kelly, "Cyclic Testing of Full-Size Unison Seismic Isolation Bearings," Report No. EERCL-STI/97-02, Earthquake Engineering Research Center, University of California, Berkeley, CA, October 1997.
- (T52) Whittaker, A. S. and M. C. Constantinou, "New analysis methods and design procedures for supplemental damping devices," *Proceedings*, SEAONC Fall Seminar Series, Structural Engineers Association of Northern California, San Francisco, CA, November 1997.
- (T53) Whittaker, A. S., "Seismic protective systems for building and bridge applications," *Proceedings*, EERI Regional Seminar Series, Earthquake Engineering Research Institute, New York, NY, November 1997.
- (T54) Makris, N., Y. Roussos, A. S. Whittaker, and J. M. Kelly, "Viscous Heating of Fluid Dampers During Seismic and Wind Applications," Report No. UCB/EERC-97/11, Earthquake Engineering Research Center, University of California, Berkeley, CA, December 1997.
- (T55) Gilani, A. S., J. W. Chavez, and A. S. Whittaker, "Fatigue-Life Evaluation of CMS Structures, Volume 2: Retrofit Specimens," Report No. UCB/EERC-97/13, Earthquake Engineering Research Center, University of California, Berkeley, CA, December 1997.
- (T56) Whittaker, A. S., "FEMA 273 analysis procedures for supplemental damping devices", *Proceedings*, SEAONC Spring Seminar Series, Structural Engineers Association of Northern California, San Francisco, CA, March 1998.
- (T57) Constantinou, M. C. and A. S. Whittaker, "Seismic protective systems for bridges in the United States", *Proceedings*, US-Italy Workshop on Seismic Protective Systems for Bridges, New York, N.Y. April 1998.
- (T58) Fenves, G. L., W-H Huang, A.S. Whittaker, P. W. Clark, and S. A. Mahin, "Modeling and characterization of seismic isolation bearings", *Proceedings*, US-Italy Workshop on Seismic Protective Systems for Bridges, New York, N.Y.
- (T59) Fenves, G.L. A. S. Whittaker, W-H Huang, and S. A. Mahin, "Analysis and testing of seismically isolated bridges under biaxial excitation," *Proceedings*, 5th Caltrans Seismic Research Workshop, California Department of Transportation, Sacramento, June 1998.
- (T60) Makris, N. and A. S. Whittaker, "Viscous heating in fluid dampers," *Proceedings*, 5th Caltrans Seismic Research Workshop, California Department of Transportation, Sacramento, June 1998.
- (T61) Gilani, A., J. Chavez, G. L. Fenves, and A.S. Whittaker, "Seismic Evaluation of 196 kV Porcelain Transformer Bushings," Report No. UCB/PEER-98/02, Pacific Engineering Research Center, University of California, Berkeley, CA, June 1998.
- (T62) Whittaker, A. S., "The practice of earthquake engineering," *Proceedings*, International Standards for Structural Design, National University of Singapore, Singapore, July 1998.
- (T63) Whittaker, A. S., "Performance based engineering of new buildings," *Proceedings*, 2nd U.S.-Japan Workshop on Performance Based Design, San Francisco, CA, July 1998.
- (T64) Whittaker, A. S., "The role of protective systems in performance-based seismic engineering of new buildings." *Proceedings*, Arup Partnerships Seismic Seminar, Osaka, Japan, October 1998.
- (T65) Whittaker, A. S., "Design guidelines and testing requirements for passive supplemental dampers." *Proceedings*, MANSIDE Workshop, Italian Seismic State Agency, Rome, Italy, January 1999.
- (T66) Gilani, A., A. S. Whittaker, and G. L. Fenves, "Seismic Evaluation of 550 kV Porcelain Transformer Bushings," Report No. UCB/PEER-99/05, Pacific Engineering Research Center, University of California, Berkeley, CA, October 1999.

- (T67) Gilani, A. S. J, A. S. Whittaker, G. L. Fenves, and E. Fujisaki, "Seismic Evaluation and Retrofit of 230-kV Porcelain Transformer Bushings," Report No. UCB/PEER-99/14, Pacific Engineering Research Center, University of California, Berkeley, CA, December 1999.
- (T68) Wallace, J., J. Stewart, and A. S. Whittaker, "Building vulnerability studies: modeling and evaluation of tilt-up and steel reinforced concrete buildings," Report No. UCB/PEER-1999/13, Pacific Engineering Research Center, University of California, Berkeley, CA, December 1999.
- (T69) Kim, T., A. S. Whittaker, and V. V. Bertero, "Large scale testing of reinforced steel moment-resisting connections," *Proceedings*, U.S.-Japan Workshop on Seismic Fracture Issues in Steel Structures, San Francisco, California, February 2000.
- (T70) Whittaker, A. S. and M. C. Constantinou, "Fluid viscous dampers for building construction." *Proceedings of the 1st International Symposium on Passive Control*, Tokyo Institute of Technology, Tokyo, March 2000.
- (T71) Gilani, A. S. J, A. S. Whittaker, G. L. Fenves, C.-H. Chen, H. Ho, and E. Fujisaki, "Seismic Evaluation and Analysis of 230-kV Disconnect Switches," Report No. UCB/PEER-00/06, Pacific Engineering Research Center, University of California, Berkeley, CA, July 2000.
- (T72) Clyde, D. and A. S. Whittaker, "Full-Scale Dynamic Testing of Expansion Joints for Seismically Isolated Bridges," Report No. EERCL/2000-1, Pacific Engineering Research Center, University of California, Berkeley, CA, September 2000.
- (T73) Kim, T., A. S. Whittaker, A. S. J. Gilani, V. V. Bertero, and S. Takhirov, "Cover-Plate and Flange-Plate Reinforced Steel Moment-Resisting Connections," Report No. UCB/PEER-2000/07, Pacific Engineering Research Center, University of California, Berkeley, CA, September 2000.
- (T74) Whittaker, A. S., "Passive seismic control of building structures." *Proceedings of the MEDAT-2 Workshop*, Multi-disciplinary Center for Earthquake Engineering Research, Buffalo, New York, December 2000.
- (T75) Ramirez, O. M., M. C. Constantinou, A. S. Whittaker, M. W. Johnson, and J. D. Gomez, "Development and Evaluation of Simplified Procedures for Analysis and Design of Buildings with Passive Energy Dissipation Systems," Technical report MCEER-00-0010, Multi-disciplinary Center for Earthquake Engineering Research, Buffalo, New York, December 2000.
- (T76) Sezen, H., K. J. Elwood, A. S. Whittaker, K. M. Mosalam, J. W. Wallace, and J. F. Stanton, "Structural Engineering Reconnaissance of the August 17, 1999 Earthquake: Kocaeli (Izmit), Turkey," Report No. UCB/PEER-2000/09, Pacific Engineering Research Center, University of California, Berkeley, CA, December 2000.
- (T77) Whittaker, A. S., "Seismic Protective Systems," Workshop on Seismic Isolation and Structural Control, Korean Institute of Machinery and Materials, Taejon, South Korea, April 2001.
- (T78) Whittaker, A. S., "Seismic Isolation Systems," International Seminar on Seismic Isolation, Unison Industrial Company, Seoul, South Korea, April 2001.
- (T79) Whittaker, A. S. (Editor). "Effects of Near Field Earthquake Shaking," Report No. UCB/PEER-2000/07, Pacific Engineering Research Center, University of California, Berkeley, CA, May 2001.
- (T80) Huang, W. H., G. L. Fenves, A. S. Whittaker, and S. A. Mahin, "Development and Experimental Calibration of Models for Elastomeric Isolation Bearings of Bridges," *Proceedings*, Caltrans Seismic Workshop, California Department of Transportation, Sacramento, CA, June 2001
- (T81) Anderson, E. A., S. A. Mahin, G. L. Fenves, and A. S. Whittaker, "Effect of Configuration on Seismically Isolated Bridges," *Proceedings*, Caltrans Seismic Workshop, California Department of Transportation, Sacramento, CA, June 2001

- (T82) Whittaker, A. and T. Kim, "Performance evaluation for reinforced steel moment-resisting connections," *Proceedings*, US-Japan Seminar on Advanced Stability and Seismicity Concepts for Performance-Based Design of Steel and Concrete Structures, NSF-JSPS Joint Program, Kyoto, Japan, July 2001
- (T83) Lee, P. L., A. Mazeika, C. Hartman, A. S. Whittaker, and M. C. Constantinou, "Seismic isolation of an Internet service exchange facility: AboveNet ISX-SFI," *Proceedings*, 2001 SEAOC Convention, Structural Engineers Association of California, Sacramento, CA, September 2001.
- (T84) Whittaker, A. S., M. C. Constantinou, and C. Z. Chrysostomou, "Seismic Energy Dissipation Systems for Buildings," *Proceedings*, Passive Energy Dissipation Symposium, Tokyo Institute of Technology, Yokohama, Japan, December 2001.
- (T85) Badillo, H., D. Kusumastuti, A. M. Reinhorn, and A.S. Whittaker, "Seismic qualification of suspended ceiling systems," Technical Report UB CSEE/SEESL-2002-01, Vol. 1., Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, March 2002.
- (T86) Bruneau, M., A. M. Reinhorn, M. C. Constantinou, S. Thevanayagam, A. S. Whittaker, S.-Y. Chu, M. Pitman, and K. Winter, "Versatile Shake Tables and Large-Scale High-Performance Testing Facility Towards Real-Time Hybrid Seismic Testing," *Proceedings*, ASCE Structures Congress, Denver, CO, April 2002.
- (T87) Bruneau, M., A. S. Whittaker, and A. M. Reinhorn, "Overview of Damage to Buildings near Ground Zero", Technical Report MCEER-02-SP02, Multi-disciplinary Center for Earthquake Engineering Research, Buffalo, New York, April 2002.
- (T88) Berman, J. W., G. Warn, A. S. Whittaker, and M. Bruneau, "Reconnaissance and Preliminary Assessment of a Damaged Building Near Ground", Technical Report MCEER-02-SP03, Multi-disciplinary Center for Earthquake Engineering Research, Buffalo, New York, April 2002.
- (T89) Kusumastuti, D., H. Badillo, A. M. Reinhorn, and A.S. Whittaker, "Seismic qualification of suspended ceiling systems," Technical Report UB CSEE/SEESL-2002-01, Vol. 2., Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, April 2002.
- (T90) Robertson C I, E. P. Lavery, N. C. Sanders, and A. S. Whittaker, "Site storage of intermediate level radioactive waste in the United Kingdom," *Proceedings*, ATC-17-2 Seminar on Response Modification Technologies for Performance Based Seismic Design, Applied Technology Council, Los Angeles, California, May 2002.
- (T91) Viti, S., A. M. Reinhorn, and A. S. Whittaker, "Retrofit of structures: strength reduction with damping enhancement," *Proceedings*, KEERC-MCEER Joint Seminar on Contributions to Earthquake Engineering, Multi-disciplinary Center for Earthquake Engineering Research, Buffalo, New York, July 2002.
- (T92) Warn, G. and A. S. Whittaker, "Performance estimates in seismically isolated bridges," *Proceedings*, Fourth China-Japan-US Trilateral Symposium on Lifeline Earthquake Engineering, Qingdao, PRC, October 2002.
- (T93) Bruneau, M., Whittaker, A., Reinhorn, A., Berman, J., Warn, G., Huyck, C., Adams, B., "Engineering and Organizational Issues Related to the World Trade Centre Terrorist Attack", *Proceedings*, International Conference on Protection of Structures Against Hazards, Singapore, November 2002, pp. 1-10.
- (T94) Kim, T., B. Stojadinovic, and A. S. Whittaker, "Physical and numerical performance evaluation of steel moment-resisting frames," Report to the California Department of Transportation, Pacific Earthquake Engineering Research Center, University of California, Berkeley, December 2002.

- (T95) Badillo, H., A. S. Whittaker, and A. M. Reinhorn, "Testing for seismic qualification of suspended ceiling systems, Part 3" Technical Report UB CSEE/SEESL-2003-01, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, February 2003.
- (T96) Badillo, H., A. S. Whittaker, and A. M. Reinhorn, "Testing for seismic qualification of suspended ceiling systems, Part 4" Technical Report UB CSEE/SEESL-2003-02, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, May 2003.
- (T97) Repp, J., H. Badillo, A. S. Whittaker, and A. M. Reinhorn, "Seismic qualification of suspended ceiling systems, Part 5" Technical Report UB CSEE/SEESL-2003-03, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, September 2003.
- (T98) Repp, J., H. Badillo, A. S. Whittaker, and A. M. Reinhorn, "Seismic qualification of suspended ceiling systems, Part 6" Technical Report UB CSEE/SEESL-2003-03, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, November 2003.
- (T99) Repp, J., A. S. Whittaker, and A. M. Reinhorn, "Performance of suspended ceiling systems for blast-type loadings," Technical Report UB CSEE/SEESL-2003-05, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, November 2003.
- (T100) Whittaker, A. S., R. O. Hamburger, and M. Mahoney, "Performance based engineering of buildings and infrastructure for extreme events," *Proceedings*, AISC-SINY Symposium on Resisting Blast and Progressive Collapse, American Institute of Steel Construction, New York, New York, December 2003.
- (T101) R. O. Hamburger, and A. S. Whittaker, "Considerations in performance-based blast resistant design of steel structures," *Proceedings*, AISC-SINY Symposium on Resisting Blast and Progressive Collapse, American Institute of Steel Construction, New York, New York, December 2003.
- (T102) Warn, G, M. C. Constantinou and A. S. Whittaker, "Statue of Hermes, Friction Pendulum bearing testing report," Technical Report UB CSEE/SEESL-2004-01, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, February 2004.
- (T103) R. O. Hamburger, and A. S. Whittaker, "Design of steel structures for blast-related progressive collapse resistance," *Proceedings*, National Steel Construction Conference, American Institute of Steel Construction, Long Beach, CA, March 2004. **T. R. Higgins Award, 2005**
- (T104) Warn, G, A. S. Whittaker and M. C. Constantinou, "Exxon Mobil multi-stage rubber bearing Sakhalin I platform, prototype bearing test report," Technical Report UB CSEE/SEESL-2004-02, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, March 2004.
- (T105) Mosqueda, G., A. S. Whittaker, G. L. Fenves and S. A. Mahin, "Experimental and analytical studies of the Friction Pendulum system for the seismic protection of bridges," Report No. EERC 2004/01, Earthquake Engineering Research Center, University of California, Berkeley, CA, May 2004.
- (T106) Astrella, M. and A. S. Whittaker, "Changing the paradigm for performance-based seismic design," *Proceedings*, International Workshop on Performance Based Seismic Design, Report PEER 2004/05, Pacific Earthquake Engineering Research Center, Bled, Slovenia, June 2004.

- (T107) Filiatrault, A., A. Aref, M. Bruneau, M. Constantinou, G. Lee and A. S. Whittaker, "MCEERs research on the seismic response modification of structural and nonstructural systems and components in hospitals," *Proceedings*, SEAOC Annual Convention, Monterey, CA, August 2004. (also presented at the International Conference in Commemoration of 5th Anniversary of the 1999 Chi-Chi Taiwan Earthquake, in Taipei in September 2004).
- (T108) Hamburger, R. O., C. Rojahn, J. P. Moehle, R. E. Bachman, C. Comartin and A. S. Whittaker, "Development of next-generation performance-based earthquake engineering design criteria for buildings," *Proceedings*, SEAOC Annual Convention, Monterey, CA, August 2004.
- (T109) Cyr, R., A. S. Whittaker, and A. M. Reinhorn, "Seismic qualification of suspended ceiling systems, Part 6," Technical Report UB CSEE/SEESL-2004-04, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, December 2004.
- (T110) Astrella, M. and A. S. Whittaker, "The role of protective systems in performance-based earthquake engineering," *Proceedings*, ISEE Conference Commemorating the 10th Anniversary of the 1995 Kobe Earthquake, Awaji, Japan, January 2005.
- (T111) Astrella, M., A. S. Whittaker and M. C. Constantinou, "Protective technologies and performance-based earthquake engineering," *Proceedings*, KEERC International Seminar on Innovative Concepts and Technologies in Seismic Analysis and Design of Building Structures, Seoul National University, Seoul, South Korea, February 2005.
- (T112) Gulec, K., A. S. Whittaker, and A. M. Reinhorn, "Seismic qualification of suspended ceiling systems, Part 7," Technical Report UB CSEE/SEESL-2005-1, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, July 2005.
- (T113) Astrella, M, J, and A. S. Whittaker, "The performance-based design paradigm," MCEER Technical Report MCEER-05-0011, Multidisciplinary Center for Earthquake Engineering Research, University at Buffalo, Buffalo, New York, December 2005.
- (T114) Badillo-Alvarez, H., A. S. Whittaker, A. M. Reinhorn and G. P. Cimellaro, "Seismic fragility of suspended ceiling systems," MCEER Technical Report MCEER-06-0001, Multidisciplinary Center for Earthquake Engineering Research, University at Buffalo, Buffalo, New York, February 2006.
- (T115) Gulec, K., A. S. Whittaker, and A. M. Reinhorn, "Seismic qualification tests of ceiling systems, Part 8, a study for Armstrong Building Operations," Technical Report UB CSEE/SEESL-2005-6, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, March 2006
- (T116) Gulec, K. and A. S. Whittaker, "Seismic qualification tests of ceiling systems and ceiling system-sprinkler assemblies, Part 9, a study for Armstrong Building Operations," Technical Report UB CSEE/SEESL-2006-2, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, March 2006.
- (T117) Gulec, K. and A. S. Whittaker, "Seismic qualification of FlexHead sprinkler systems tested with Seismic Design Category D, E and F ceiling systems," Technical Report UB CSEE/SEESL-2006-3, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, May 2006.
- (T118) Gulec, K. and A. S. Whittaker, "Seismic qualification tests of ceiling systems, Part 10, a study for Armstrong Building Operations," Technical Report UB CSEE/SEESL-2006-7, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, July 2006.
- (T119) Warn, G. P. and A. S. Whittaker, "A study of the coupled horizontal-vertical behavior of elastomeric and lead-rubber seismic isolation bearings," Technical Report MCEER-06-0011,

Multidisciplinary Center for Earthquake Engineering Research, University at Buffalo, Buffalo, New York, December 2006.

- (T120) Kafali, C., S. Fathali, M. Grigoriu and A. S. Whittaker, "Static and kinetic coefficients of friction for rigid blocks," Technical Report MCEER-07-001, Multidisciplinary Center for Earthquake Engineering Research, University at Buffalo, Buffalo, New York, March 2007.
- (T121) Marin, C., A. S. Whittaker and M. C. Constantinou, "Experimental and analytical study of the XY Friction Pendulum bearing," Technical Report MCEER-07-007, Multidisciplinary Center for Earthquake Engineering Research, University at Buffalo, Buffalo, New York, March 2007.
- (T122) Gulec, K., and A. S. Whittaker, "Seismic qualification tests of ceiling systems, Part 11, a study for Armstrong Building Operations," Technical Report UB CSEE/SEESL-2007-3, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, May 2007.
- (T123) Gulec, K., and A. S. Whittaker, "Seismic qualification tests of ceiling systems, Part 1, a study for USG Interiors, Inc.," Technical Report UB CSEE/SEESL-2007-4, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, New York, May 2007.
- (T124) Constantinou, M. C., A. S. Whittaker, Y. Kalpakidis, D. M. Fenz and G. P. Warn, "Performance of seismic isolation hardware under service and seismic loading," Technical Report MCEER-07-0012, Multidisciplinary Center for Earthquake Engineering Research, University at Buffalo, Buffalo, New York, March 2007.
- (T125) Dusenberry, D. O, W. G. Corley, J. P. Hobelmann, L. Lin, P. Mlakar, J. Schmidt, R. Smilowitz, S. Smith and A. S. Whittaker, "Voluntary standard for blast protection," *Proceedings*, Protect 2007, University of British Columbia, BC, Canada, August 2007.
- (T126) Reitherman, R. and A. S. Whittaker, "An inventory of academic and research organizations related to natural disaster risk reduction," CUREE Report to the United Nations ISDR, Consortium of Universities for Research in Earthquake Engineering, Richmond, CA, August 2007
- (T127) Huang, Y.-N., A. S. Whittaker and R. O. Hamburger, "Scaling earthquake ground motion records for performance-based assessment of buildings," *Proceedings*, SEAOC 2007 Convention, Structural Engineers Association of California, Sacramento, CA, September 2007.
- (T128) Whittaker, A. S., R. O. Hamburger and Y.-N Huang, "Building-specific seismic loss estimation," *Proceedings*, 2007 AEES Conference, Wollongong, NSW, Australia, November 2007. **Keynote address.**
- (T129) Whittaker, A. S., R. O. Hamburger and Y.-N Huang, "Next-generation performance-based earthquake engineering," *Proceedings*, 1st International Conference on Modern Design, Construction and Maintenance of Structures, Hanoi, Vietnam, December 2007. **Keynote address.**
- (T130) Warn, G. P. and A. S. Whittaker, "Performance estimates for seismically isolated bridges," Technical Report MCEER-07-0024, Multidisciplinary Center for Earthquake Engineering Research, University at Buffalo, Buffalo, New York, December 2007.
- (T131) Reitherman, R. and A. S. Whittaker, "An outline of a strategic plan for the global partnership of universities, academic institutions and research organizations for disaster risk reduction," CUREE Report to the United Nations ISDR, Consortium of Universities for Research in Earthquake Engineering, Richmond, CA, January 2008.
- (T132) Willford, M., A. S. Whittaker and R. Klemencic, "Guidelines for the seismic design of tall buildings," *Draft for Review*, Council for Tall Buildings and Urban Habitat, New York, March 2008.



Recommendations for the Seismic Design of High-rise Buildings

Draft for Comment - 1
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APPENDIX 1 - Damping of Tall Buildings

1.0 Introduction and Background

1.1 Overview

There is a resurgence of construction of high rise and ultra-high rise buildings around the world. The design of these tall buildings in seismically active regions varies dramatically from region to region. Whereas rigorous performance-based assessments are required in some countries, including Japan and China, many other countries do not require anything beyond a traditional design based on force reduction factors.

The objective of this Guide is to set out best practice for the seismic design of high-rise buildings anywhere in the world. Best practice for high-rise buildings is not represented by the traditional design codes such as the Uniform Building Code [ICBO, 1997] or its successor, the International Building Code [ICC, 2006]. Whilst these codes are referenced for the design of high-rise buildings in many countries, in part because the UBC still forms the basis for many national building codes, they are not suitable for the design of high-rise buildings for the following reasons:

- 1) They were developed for application to low and medium-rise buildings [and the framing systems used in those buildings] and not for the modern generation of tall buildings.
- 2) They permit only a limited number of structural systems for buildings taller than 49m in height, which are not economic for buildings of significantly greater height, and do not include systems that are appropriate for many high rise buildings
- 3) Rules appropriate at or below 49m are not necessarily valid at 100+m in height
- 4) The use of elastic response analysis with force reduction factors (denoted R in the United States) for strength design is inappropriate for buildings where several modes of vibration contribute significantly to the seismic response along each axis of a building.

1.2 International Context

A performance based philosophy is consistent with the best international practice, and has been explicitly required by regulatory authorities in Japan for buildings exceeding 60m since 1981. In China, height limits on tall buildings are set out in the Chinese code for seismic design of buildings GB50011-2001 and depend on the seismic zone, the structural material and the structural systems adopted. For instance, in China's highest seismic zone (seismic intensity 9, equivalent to UBC zone 4), the maximum height for code-designed reinforced concrete structures is 80m and for steel structures is 180m. For buildings with heights in excess of these limits, a performance-based approach must be adopted to demonstrate satisfactory seismic performance and the design must pass an expert panel review.

Building codes in the United States such as the Uniform Building Code (ICBO, 1997) and International Building Code (ICC, 2006) and other national codes based on these documents permit performance-based design but provide little-to-no specific guidance. The direct application of the standard design procedures in these codes can lead to poor structural forms, relatively uneconomic structural designs, and, in some cases, to buildings that will not

perform well in moderate and severe earthquakes. The methods of Eurocode 8 (European Standards, 2004) are not performance based and not well suited to high-rise construction.

Performance-based methods require the designer to assess how a building will likely perform under earthquake shaking and their correct use will help to identify unsafe designs. At the same time this approach enables arbitrary restrictions to be lifted and provides scope for the development of safer and more cost-effective structural solutions. Much of the framework for performance-based design in the USA can be traced to Vision 2000 (SEAOC, 1995), ATC 40 (ATC, 1996) and FEMA 356 (FEMA, 2000). More recently, guidelines for performance based seismic design of high-rise buildings have been issued by regulatory bodies in Los Angeles (LATBSDC, 2006) and San Francisco (SEAONC, 2007)

1.3 Scope of this Guide

This document aims to provide guidance and minimum standards for the designers of tall buildings in seismically active regions anywhere in the world. A tall building is defined herein as a building of sufficient height for the period of the first translational mode of vibration to exceed 4 seconds or for its height to exceed 50m. However, the guidance can also be used to assess the performance of medium-rise buildings where this is needed.

The Guide draws upon best current and emerging practice from different countries and research bodies. It is not intended to replace any national code or other design recommendations, but rather sets out issues to be considered by designers, peer reviewers and regulators.

2.0 Design Objectives and Philosophy

2.1 Overview of Performance Objectives

Performance objectives relevant for high rise buildings are based upon the performance expectations embedded in the prescriptive provisions of most building design codes. Implicit within the seismic design procedures of American, Japanese, Chinese, New Zealand codes and Eurocode 8 is the expectation that a building designed in conformance with the provisions will:

1. Resist a minor level of earthquake ground shaking without damage
2. Resist the design level of earthquake ground shaking with damage (which may or may not be economically repaired) but without causing extensive loss of life
3. Resist the strongest earthquake shaking expected at the site without total collapse, but potentially with extreme damage

These performance objectives have formed the basis of structural design of countless high rise buildings worldwide over the last several decades, although the three performance levels are rarely verified explicitly.

Whilst designing a high rise building to achieve superior performance to low-rise buildings is possible, and may be desirable for certain buildings, fundamental economic and societal pressures suggest that these traditional design objectives strike a reasonable balance between construction cost and risk of damage. Building codes sometimes specify an importance factor for high occupancy or mission-critical buildings, which results in higher design strength than the code minimum for ordinary construction. A similar approach could be adopted for high-rise buildings of substantial social and economic value but with the importance factor replaced by component checking for a more stringent performance level (e.g., collapse prevention and its associated acceptance criteria replaced by life safety and its attendant acceptance criteria). Japanese practice sets significantly more onerous performance targets for high-rise buildings than for normal occupancy buildings.

2.2 Minimum Design Objective Recommendations

Whereas traditional code procedures attempt to satisfy implicitly all three objectives by designing to prescriptive rules for a single (design) level of seismic hazard, performance based design of high rise buildings should investigate at least two performance objectives explicitly. There is reasonable agreement between current practice in Japan (), China (2001) and the United States (LATBSDC 2007, SEAONC, 2007) as to what these should be, namely:

1. Negligible damage in once-in-a-lifetime earthquake shaking demands having a return period of about 50 years (30 years to 72 years depending on jurisdiction and building importance). This objective is achieved by designing for essentially elastic structural response and limiting the storey drifts to minimise damage to non-structural components such as cladding and internal walls. Herein, this performance objective is termed the service-level assessment.
2. Collapse prevention under the largest earthquake demands that may occur at the site. This earthquake demand is often taken as that with a return period of approximately 2500

years (sometimes limited by a deterministic cap in regions of high seismicity). Collapse prevention is achieved by demonstrating that a) inelastic deformation demands in all the structural elements are smaller than their deformation capacities taking appropriate account of gravity loads, second-order effects and deterioration of stiffness and strength due to cyclic loading, b) story deformations are sufficiently small so as to prevent catastrophic damage to non-structural elements. Herein, this design objective is termed the collapse-level assessment.

2.3 Additional Design Objectives

The assessments of Section 2.2 are incorporated into Japanese and Chinese high-rise design practice, and also in the emerging performance based practice on the West coast of the United States. However, the approach in Japan does not assign return periods to the specified seismic hazards, and the collapse-prevention assessment is more stringent in terms of maximum storey drift than practice in the United States.

Some other jurisdictions require an assessment for seismic demands associated with an intermediate return period of 475 years. In China, the intention is that the damage in such shaking is repairable. For buildings exceeding the code height limits and for complex buildings (e.g., those having high level gravity transfer structures, towers connected at high levels or having long cantilevers) expert review panels in China may require the designer to demonstrate that critical members remain elastic under the intermediate earthquake.

In California, building officials expect to see a ‘Code’ justification of a tall building albeit with some relaxation of the required minimum base shear. This is intended to ensure conformity with ‘previous experience’, but the logic for this is not clear since there is no previous experience of the performance of very tall buildings designed to Californian practice in earthquakes of design-level magnitude. Since the structural systems of very tall modern buildings will likely not be any of those prescribed in the code the Engineer has to define and justify an appropriate R factor for this assessment. However, designing for seismic load effects reduced by a global force reduction factor is not a suitable approach for non-linear multi-mode systems such as high-rise buildings.

2.4 Deformation Based Design Philosophy

Deformation is the key parameter in performance-based seismic design rather than *force or strength* that is used in conventional code design approaches because performance is characterised by the level of damage and damage is related to the degree of elastic and inelastic deformation in components and systems.

Deformations can be classified into three types:

1. Overall building movements
2. Story drifts and other internal relative deformations
3. Inelastic deformations of structural components and elements

Overall building movement enables a qualitative assessment of building performance only. Although total building deformation can provide some measure of the significance of $P - \Delta$

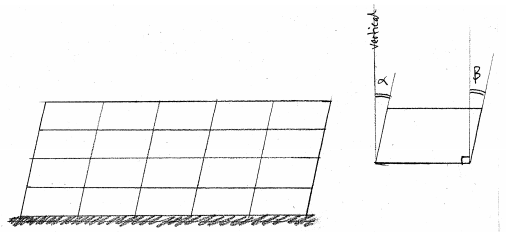
effects on the response of a building, this is of limited value since peak deflection is transitory.

Story drift, which is defined here as the relative horizontal displacement of two adjacent floors, can form the starting point for assessment of damage to non-structural components such as facades and interior partitions. However, it is more informative in high-rise buildings to assess these relative movements in each story as components due to:

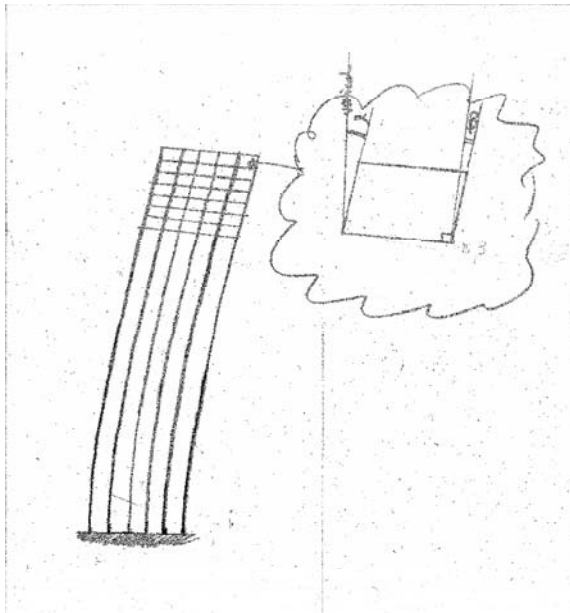
1. *rigid body* displacement
2. *racking (shear)* deformation

Rigid body displacement is associated with the 'rotation' of the building as a whole at upper levels due to vertical deformations in the columns below, and induces no damage. Racking shear deformation (β) is a measure of the angular in-plane deformation of a wall or cladding panel. This will in general vary at different positions on a floor, and may exceed the story drift ratio (α) in some locations, (e.g. partition panels spanning between a core and a perimeter column). These distinctions are illustrated in the three panels of Figure 1.

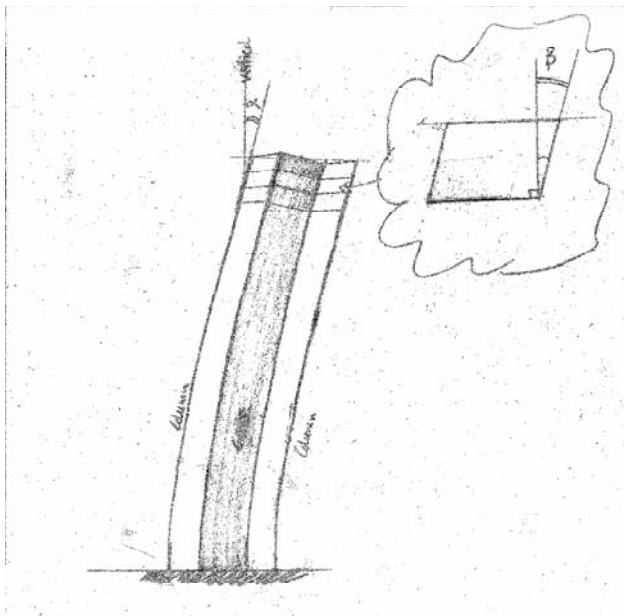
Inelastic element deformations form the basis for assessment of *structural damage* and potential for *structural collapse*. Assessments are generally performed one component at a time by comparing deformation demands with permissible values (e.g., maximum plastic hinge rotations) that are based on structural details (e.g. tie spacing in concrete elements) and co-existing member forces.



a) *Low rise building: racking deformation angle equals storey drift ratio*



b) *'Tube' high-rise building: racking deformation angle is smaller than the storey drift ratio*



c) *Wall-frame high-rise building: racking deformation angle can exceed storey drift ratio*

Figure 1 – Deformation parameters for tall buildings

2.5 Performance Criteria

Establishing quantitative acceptance criteria for performance-based design is the subject of on-going debate. Although great strides have been made in the past decade, much work remains. One challenge faced by the designer is to establish a balance between construction cost and risk of damage (and associated cost) for a design problem with many sources of uncertainty in all steps of the design solution. Examples of the uncertainties include:

1. Spectral demand given a recurrence interval for the site.
2. Representation of the spectral demand using ground shaking records.
3. Prediction of global and local response of the structure to given ground shaking records due to imperfect numerical representation of building behavior, the influence of underlying soils and foundations on ground shaking, the impact of non-structural systems such as cladding on global response, inaccurate constitutive models for common structural elements under cyclic loading and material and construction variability.
4. Translation of component inelastic demands (e.g., shear deformations in walls) into quantitative descriptions of damage suitable for performance assessment and aggregation of component-level damage to form a global description of damage.

Extensive work is underway in the USA (through the ATC 58 project) on the assessment of risk of unacceptable performance (direct economic loss, downtime and casualties) through Monte Carlo simulations of structural response that address each source of uncertainty. Assessment procedures have been developed for intensity, scenario and time-based characterizations of seismic hazard. The assessment procedures are computationally intensive and corresponding *design* procedures have not yet been developed.

For the foreseeable future, performance-based *design* will involve:

1. Selection of recurrence intervals at which one or more performance levels are to be met
2. Computation of expected structural response for earthquake shaking associated with those recurrence intervals
3. Assessing element and building deformations against limiting values corresponding to the chosen performance level(s)
4. Assessing element component strengths to ensure that non-ductile failure modes are prevented using capacity design principles

In setting the numeric values for the limiting values of response (i.e., acceptance criteria), account must be taken of the consequence of the specified shaking intensity being exceeded and the uncertainties in the performance-prediction process. In this context it should be borne in mind that response spectra adopted for design often represent median *estimates* of demand that by definition have a 50% probability of being exceeded. For 84th percentile spectral demands (16% probability of exceedance), the predicted deformations will typically range between 1.5 and 2 times the median demands.

The modelling and analytical processes together with the natural variability of structural performance introduce further uncertainty into the effects predicted to be induced in a

building. Reconciliation of the appropriate combination of input ground motions, analytically predicted response and true building performance will improve in time as benchmarking continues.

All said, however, a performance based design approach to the design of tall buildings is a significant improvement over prescriptive code-based designs which fail to recognize the unique characteristics of these buildings. A performance based design provides the designer with greater insight into the likely response of the building to strong ground shaking, and greater control of the desired outcomes.

2.6 Design Issues

The economic structural design of high-rise buildings is a complex technical challenge, with requirements for lateral stiffness, strength and deformation under wind and earthquakes compounding gravity and constructability issues.

In general, as buildings grow taller and more slender, wind loading effects become more significant in comparison to earthquake effects. This is because whilst the wind overturning moment will typically increase as height cubed, the elastic seismic base moment is unlikely to increase at more than height raised to the power 1.25. Accordingly, in regions of moderate seismic hazard, a building structure designed to resist wind effects may require only modest (although vitally important) modifications to meet seismic performance targets. In contrast the design of the lateral force resisting system in a low-rise building at the same site would be entirely governed by seismic requirements.

Critical issues for the design of high-rise buildings in regions prone to significant wind and seismic effects typically include:

1. High base overturning moment and foundation design (wind, seismic)
2. High shear capacity requirements near base (seismic)
3. High gravity stresses in the vertical elements (and use of high-strength materials) to minimise structural sizes for economic structural design and to maximize net floor area
4. Development of ductility in elements at the base of a structure under high compressive gravity stress (seismic)
5. Controlling lateral accelerations (wind)
6. Controlling storey drift (wind and seismic)
7. Controlling damage so as to permit repair (seismic)
8. Ensuring ductile energy dissipation mechanisms and preventing brittle failures (seismic)

2.7 Project Seismic Design Basis

The engineer of record for the building design should develop a Seismic Design Basis document that presents the following information as a minimum:

- Building description
- Description of the seismic resisting systems
- Sample drawings of the building

- Performance objectives for the building including expectations for non-structural components and systems
- Summary results of the seismic hazard study
- Summary results of the wind loading/response study
- Methods of analysis
- Modeling procedures, material properties, damping specification etc.
- Structural component models, component acceptance criteria
- Test data in support of new component models, new software and alternate acceptance criteria.
- Drift limits (if any)
- Seismic design criteria for non-structural components and systems

The Seismic Design Basis document should be developed at the beginning of the project and transmitted to the peer review panel (see Section 2.8) for review and comment. The document should be updated over the course of the project to reflect changes in the design. A final (as-built) version of the document should be prepared.

2.8 Peer Review

Independent, project-specific peer review is a growing trend in many regions of moderate and high seismic hazard. Such peer reviews are conducted by either an individual practitioner, a firm, or by an expert panel. In Japan, China and selected cities on the West Coast of the United States, it is common practice for a building of significant height to be reviewed in detail by an expert panel or consultancy with expertise in the seismic analysis and design of tall buildings.

It is imperative that the peer review team include experts in high-rise building design, performance-based earthquake engineering, non-linear dynamic analysis, geotechnical engineering, and seismic hazard analysis.

2.9 Construction Observation

Appropriate construction observation by the Engineer-of-Record is important to ensure that construction is executed in a manner consistent with the design intent and in conformance with the construction documents. Regular site visits to observe the progress of construction are encouraged. The Engineer-of-Record should visit the site and make a detailed report of all observations when elements key to the overall stability of the building are being installed.

3.0 Seismic Hazard Assessment

3.1 Introduction

The conventional description of a seismic hazard for design is a pseudo-acceleration response spectrum. It is important for the structural designer to understand how such a spectrum is derived, what it represents, and the uncertainties in the reported seismic demand.

A site-specific seismic hazard assessment is recommended for most high-rise building projects, particularly in locations where the extent of previous study and codified guidance are limited. It should be borne in mind that code response spectra are focused on building periods of 3 seconds and less, and that site specific studies are often required to characterize the seismic demand for periods of 3 seconds and greater, which is the period range of interest for many tall buildings.

3.2 Response Spectra

A site specific acceleration response spectrum represents the peak spectral acceleration of an elastic single-degree-of-freedom oscillator at the site for a given probability of exceedance in a selected time period. Site-specific spectra are generally developed by probabilistic seismic hazard analysis that generates a family of seismic hazard curves, which plot annual frequency of exceedance versus 5% damped spectral acceleration for a large number of values of structural period.

The structural engineer should be cognizant of the following:

1. The seismic response of tall buildings can be influenced by multiple modes, with peak modal responses occurring in second or higher translational modes. Spectral demands at periods smaller than the fundamental period may be more critical in terms of design actions and deformations than first mode demands.
2. Site-specific spectra are developed on the basis of an understanding of the seismo-tectonic environment of the region, instrumental recordings of relatively recent earthquakes, physical examination of faults by trenching (where surficial expression of faults is available), estimates of the temporal distributions of earthquake shaking on nearby faults, alternative attenuation functions, local site effects and other factors. Spectra are typically represented by median (50th percentile) values and dispersions about the median, where the dispersions capture the epistemic (model) uncertainty. Depending on the tectonic setting, soil type, period and selected annual frequency of exceedance, 84th percentile spectral demands can be twice the median demands.
3. A design spectrum is typically associated with 5% of critical damping. The structural engineer should exercise care in selecting an appropriate damping level consistent with the structural form of the building and the likely response level of the structural system. . The literature (e.g., ASCE 7, EuroCode 8) provides equations and tables to transform 5% damped spectral accelerations for lower levels of damping, should this be deemed appropriate.
4. The peak accelerations of different elastic single-degree-of-freedom systems will generally not result from the same earthquake event. For example, the greatest spectral demands in longer period buildings will often be associated with infrequent large

magnitude earthquakes whereas the peak spectral demands at short periods are often associated with frequent smaller magnitude earthquakes close to the site.

5. Probabilistic seismic hazard analysis, which is used to generate spectra for different annual frequencies of exceedance, utilizes ground motion attenuation functions. Most of these functions are valid in the period range of 0 to 4 seconds and only a small number have been developed for periods up to 10 second. Site specific spectra developed for the period range of 0 to 4 seconds are often extended to longer periods (which are of interest for the analysis and design of tall buildings) by assuming that spectral acceleration is inversely proportional to period and anchoring spectral demand at a period of 3 or 4 seconds.
6. Near source effects can have a significant impact on spectral demands in the long period range. Care must be taken to adequately account for these effects for sites situated near known active faults.

3.3 Site Response

A standard seismic hazard assessment produces estimates of free-field motions, where the influence of soil type (shear wave velocity) is captured in the attenuation functions. For hard and soft rock sites, site effects are generally assumed to be small and are ignored in the hazard assessment. For firm soil and soft soil sites, a more robust procedure for establishing seismic demands is to conduct a site response study, wherein bedrock motions are transmitted upwards by vertically propagating shear waves through nonlinear soil layers. More sophisticated (and computationally intensive) 3-dimensional methods simulating the entire wave propagation process from fault to site are now beginning to emerge.

For the purposes of the design of major structures such as high rise buildings on softer sites with deep and massive foundations and basements one key issue is what motions are appropriate to the design of the building, given the variation of motions with depth in the ground. This is discussed further in section 4. These so-called foundation motions may be substantially different from the free-field surface motions predicted by a seismic hazard assessment.

A site response study should also identify the potential for liquefaction at depth, slope instabilities and other geo-seismic hazards.

3.4 Selection and Modification of Earthquake Histories for Response Analysis

Although acceleration response spectra can be used directly for elastic design, nonlinear response-history analysis requires the use of sets of ground motion records. Some modification of recorded real ground motions is generally necessary to assess the performance of a high-rise building because of the importance of multiple modes in the response of tall buildings.

Existing ground motion records can be either amplitude scaled or spectrally matched. No fewer than seven, two-component sets of ground motion time series should be used for each performance assessment; requiring that 14 sets of ground motion time series be developed if a response-history analysis is to be conducted for both the service-level and collapse prevention level assessments.

The modification process typically generates a family of ground motion records that have response spectra similar to the target spectra over a wide range of natural periods. This process is often conservative because a target spectrum is generally composed of spectral contributions from multiple sources, earthquake magnitudes, and site-to-source distances—no single combination of source, magnitude, and distance dominates the entire spectrum in most cases.

There is no consensus on the best procedures for the selection and scaling of earthquake ground motion records (time series). The topic is the subject of significant study at this time and results will vary with the degree of inelastic response in the building for the chosen level of seismic hazard. Herein, it is assumed that the degree of inelastic response is limited and is less than that assumed for low- and medium-rise code compliant buildings subjected to maximum earthquake shaking.

One procedure is presented for the selection and modification of horizontal earthquake ground motions for the purpose of design, namely, spectral matching. The engineer may consider alternative selection and scaling procedures and the use of a family of conditional mean spectra (Baker and Cornell, 2006) to which the motions are scaled

Spectrally matched ground motion records should produce the same spectral response (+10%, -5%) as the target spectrum for all the important translational modes of a high-rise building. The ground motions should be matched in the time domain from a period of 0 second to a period of 1.5 times the fundamental translational period. The seed ground motions for spectral matching should be selected on the basis of the (magnitude, distance, epsilon) deaggregation of the target spectrum at the period of the building that produces the largest modal contribution to the elastic global overturning moment, which will generally be the first translational period.

Although spectral matching is an easily understood procedure for scaling ground motion records for response analysis, all dispersion in the ground motion, and much of the dispersion in the building response is lost as a result of spectral matching. Amplitude scaling of recorded ground motions to a given spectral ordinate is also convenient but care must be taken to select ground motions with appropriate spectral shape so as not to substantially overestimate or underestimate spectral demands at periods remote from the target spectral ordinate used for scaling.

Site-specific hazard analysis will return geometric mean demands of horizontal earthquake shaking. The geometric mean demands are neither maximum nor minimum demands and may underestimate median maximum demands by 30+% (Huang et al., 2008). Consideration should be given to the use of median maximum and minimum spectra for spectral matching, together with the use of conditional mean spectra. If maximum and minimum spectra are developed for the purpose of design, one of the horizontal components should be matched to the maximum spectrum and the other to the minimum spectrum. The components of ground motion should be applied to the building analysis model at orientation angles that are selected at random. However, where the building site is located within 5 km of a fault capable of generating moderate-to-large magnitude earthquakes, median maximum and median minimum spectra should be developed and at least three of the seven sets of ground motion time series for the collapse prevention level assessment shall account for forward rupture-directivity effects and applied to the building analysis model accordingly.

4.0 Foundation Effects

4.1 Overview

The soils at a site and the form of a building's foundation can affect the seismic response and performance of the building in several ways, including:

- a) modification of the seismic inputs to the building from those predicted at the free field or at depth in a soil column
- b) adding flexibility and damping to the soil-foundation-building system, which will elongate the period of the building and modify demands.

These effects are more pronounced on soft sites.

4.2 Geotechnical parameters

There is always an element of uncertainty in the properties of the soils beneath a building irrespective of the extent and detail of any site investigation and material testing. For this reason the effects of credible variations in the assessed soil properties should always be considered. The extent of the credible variation should take account of the level of detail in the site investigation.

4.3 Rocking and Translation

For a tall building, the lateral deflection of the building in an earthquake will be very much larger than the lateral translation of its foundation and so the horizontal deformation of the foundation system can usually be ignored. However, a small rotation at the base of a building due to soil-foundation flexibility can result in a significant lateral deflection at the top of a building and such flexibility should be considered in analysis and design.

4.4 Soil-structure interaction

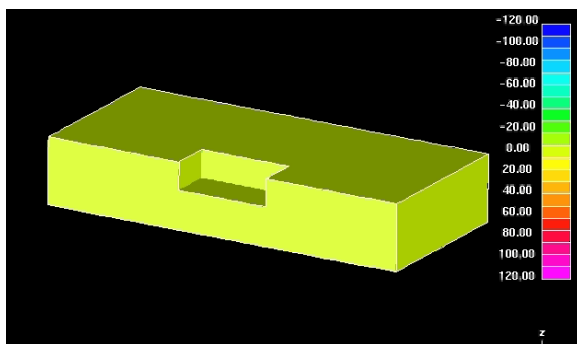
Soil-structure interaction is the term commonly used to describe the effect of the foundation and soil on the behaviour of the structure. In general, there are three principal effects

1. The soil-foundation system will have some mass and flexibility in sliding and rocking that will affect the natural periods and mode shapes of the building.
2. Vibration energy from the structure can be transmitted into the ground and dissipated by the soil materials (material damping) and by radiation of energy away from the foundation in stress waves (radiation damping). Radiation damping is generally very low for foundation rocking at long periods and is generally ignored for tall buildings.
3. The embedment and stiffness of the foundation will affect the seismic motions transmitted to the building. This is caused by kinematic interaction whereby ground motion waves do not meet the foundation at all points simultaneously and so there is some base-slab averaging of the action over the foundation. This causes reduction in the effective input for shorter wavelength (shorter period) motions.

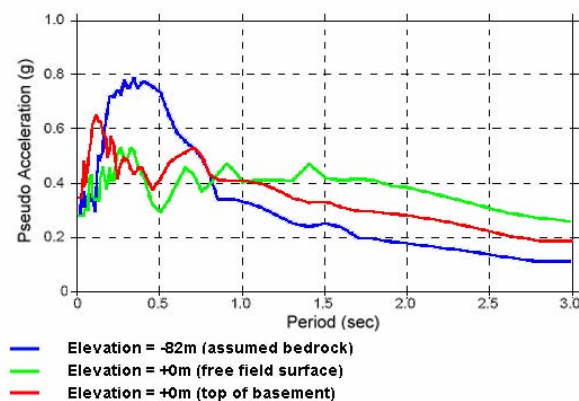
4.5 Foundation embedment

For many buildings it is reasonable and practical to assume that the effective ground motion exciting the structure is the predicted free-field motion. However, for high-rise buildings, foundations are usually massive and extend to considerable depth, and often include several levels of basement beneath and around a tower. In some layered soils these features can significantly affect the motions transmitted to the building.

Basements often form relatively stiff structural boxes extending several storeys below surrounding grade. Since the building is excited by the motions of the basement in these circumstances, it is prudent to assess the likely motion of the basement structure. The difference between basement and free-field motions are most pronounced where the surface soils are weak and soft. Frequency domain analysis methods assume linear response and are not particularly useful in these circumstances since the soil beneath the basement will typically respond far into the nonlinear range for maximum earthquake shaking. In this case, iterative solutions involving linearized soil properties will be required. For analysis of highly nonlinear soils, it is prudent to assess the expected effect by performing a fully coupled nonlinear response-history analysis of soil-foundation-structure system. An example of this type of analysis is illustrated in Figure 2, in which a non-linear site response analysis is performed on a 3-D model of the soil above bedrock with a structural model of the basement incorporated.



a) 3-D non-linear analysis model of layered soils and basement structure



b) Comparison of response spectra at different positions

Figure 2 – Site response analysis incorporating basement structure

Due to the uncertainties present in defining soil parameters and how they relate to modelling assumptions, the structural engineer should exercise care if soil-structure interaction is to be considered. Parametric studies to characterize the sensitivity of the analysis results to key modelling assumptions (e.g. upper and lower bound estimates of soil properties) should be undertaken.

5.0 Structural Analysis and Modeling Procedures

5.1 General

Different types of analysis can be employed for the multiple design assessments identified in Section 2.2. Detailed 3-dimensional finite element models should be prepared for analysis to capture translational and torsional effects.

Elastic analysis is appropriate for the service-level assessment because component responses are generally smaller than those that cause yielding. Nonlinear response-history analysis is required for the collapse prevention level assessment unless it can be demonstrated that all structural components do not yield for maximum earthquake shaking. Vertical excitation should be considered in combination with the bi-directional horizontal excitation discussed above unless it can be shown to have insignificant effect. (If tri-directional earthquake shaking is considered, the ground motion scaling guidance provided above must be extended to address vertical shaking.)

Nonlinear static analysis (pushover) should not be used for analysis of tall buildings because this method of analysis cannot capture the higher mode effects and torsion that are important in such structures and cannot be easily extended to accommodate supplemental damping devices.

5.2 Basic Modelling Principles

Basic principles for modelling structural components in tall buildings are introduced here. The numerical model of the building should be sufficiently detailed so as to enable consideration of the interaction of all structural and non-structural elements that affect significantly the linear and nonlinear response of the building.

5.2.1 Mass

The reactive mass included in the model should be the best estimate of the structural mass, the permanent imposed mass including cladding, finishes, mechanical equipment and fixed furniture. Some jurisdictions will require a small proportion of the live load to be included as a permanent load.

5.2.2 Component force versus displacement relationships

The cyclic force-displacement relationships (mechanical properties) of steel and reinforced concrete components should be determined in the presence of gravity load effects.

For steel components, initial stiffness should be based on gross section properties. For reinforced concrete and steel reinforced concrete, initial stiffness should consider the effects of cracking up to the point of yielding. The guidance provided in ASCE-41 on initial stiffness of concrete elements may be adopted or first principles analysis of cracked section properties can be used to determine values of initial stiffness.

Component yield strengths or yield surfaces must be established considering interaction between shear, axial and flexural forces. The post-yield force-displacement response should be based on industry standard relationships (e.g., ASCE 41) where they exist and are

appropriate. Deterioration of component strength and stiffness with repeated cycling should be modelled explicitly using industry-accepted models if the loss of maximum strength exceeds 20% of the peak strength. For non-linear response history analysis the properties should be based upon expected material strengths and not the reduced nominal strengths used for conventional design.

Modern high-rise buildings employ structural forms, materials and loading regimes that are not common in other seismic resisting structures. Examples include:

- a. Walls and columns constructed of very high-strength concrete (and steel reinforced concrete) – often subjected to high gravity axial stresses
- b. Shear walls with deep coupling beams
- c. Reinforced concrete outrigger walls
- d. Deep steel beams, trusses and stocky columns in tubular construction.

For such members the numerical models and deformation acceptance criteria in existing documents may not be appropriate nor relevant. In such cases, numerical models should be based on test data or first principles engineering mechanics. Such models and their technical basis must be described and validated in the Seismic Design Basis document per Section 2.7.

Regardless of the structural material, the influence of finite joint size, beam-column joint flexibility, and the effect of secondary structural elements (e.g. floor beams and slabs) should be explicitly considered in the development of the numerical model.

Particular difficulties apply to the modelling of reinforced concrete structures because of the dependence of flexural stiffness and shear resistance on axial stress. The columns in moment-resisting frames and the wall components in coupled shear walls can experience very significant variations in axial stress in response to an earthquake and the ‘acceptable’ plastic hinge rotation and the shear resistance therefore vary during an event. It is therefore advisable to check the acceptability of these parameters at each time-step as a function of instantaneous axial stress and not check only the maximum absolute values that occur during the time-series analysis.

Fibre and lumped plasticity elements have both advantages and drawbacks for the modelling of columns, walls and beams. If fibre elements are used, it is necessary to check that the number of elements within the plastic hinge zone is adequate to capture the non-linear variation in strain along the hinge length, otherwise the accumulated plastic rotation will be in error, and the fibre element will not report the maximum strain level. Further, fibre elements cannot consider the effect of high in-plane shear on flexural resistance or ductility. The acceptable plastic hinge rotation associated with a lumped plasticity element must be determined taking account of the length of the hinge zone and the stress-strain characteristics of the reinforcing steel and concrete, together with the concurrent shear and axial force. The hinge rotations suggested in ASCE 41 are for members conventionally proportioned for low to medium rise construction, and are not necessarily suitable for columns and walls of high strength concrete in high-rise construction. The modelling technique employed should be validated using relevant physical test data.

5.2.3 Damping

Damping in high-rise buildings varies depending on the selection of materials, structural system geometry, and types of architectural finishes. Further, the level of damping varies depending on demand level as in a concrete structure where concrete cracking and reinforcing steel yielding may occur even under service level gravity loads. The structural engineer should carefully consider each of these factors when selecting a damping level for the analysis level under consideration. Whilst five percent of critical damping has traditionally been assumed for buildings designed to code provisions there is indisputable evidence that this is generally too high for modern tall buildings. Further discussion of this matter is given in Appendix 1

When modelling damping care should be taken regarding the energy dissipated by the damping procedure in the non-linear response range, and in higher modes. Linear viscous damping provides excessive dissipation in non-linear response; viscous damping proportional to instantaneous tangent stiffness is more appropriate. The response in higher modes is much more significant in high-rise buildings than conventional low- to medium-rise buildings. Stiffness proportional damping is proportional to frequency and so higher modes can be over-damped; Rayleigh damping will also over-damp modes above a certain frequency.

5.3 Elastic Analysis

Response spectrum and response-history analysis are both acceptable elastic analysis procedures for tall buildings. Elastic analysis is appropriate if the demand on each structural component is less than its nominal strength and will generally only be valid for the service-level assessments. Modal damping should be carefully considered as described in Section 5.2.3

If response-spectrum procedures are used for analysis, a sufficient number of modes must be included to capture 95% of the total building mass above the level at which the earthquake shaking is input to the building along each axis of the building, the CQC method should be used to combine modal responses, and the effects of multidirectional loading should be considered.

5.4 Non-linear Response History Analysis

Nonlinear response-history (NLRH) analysis should be used for all assessments that involve significant nonlinear response in structural components. Nonlinear analysis will generally be necessary for the collapse prevention level assessment of Section 2.2. Second order ($P-\Delta$) effects that include all of the building dead load and permanent live load need to be included in the NLRH analysis.

Although a number of finite element codes have capabilities for this type of analysis the results obtained can be strongly affected by the designer's choice of element type, mesh refinement, time-step, damping specification, etc.

The designer should demonstrate to the peer review panel that the type of modelling adopted in the selected software is capable of reproducing the results of relevant cyclic physical tests of components of similar general characteristics to those proposed for the design, and should document the technical basis for the numerical models of all components that are modelled as

nonlinear elements and undergo inelastic response at the chosen level(s) of seismic hazard in the Seismic Design Basis (see Section 2.7).

5.5 Analysis and Performance Assessment Procedures

5.5.1 Elastic analysis

Response spectrum analysis should be performed in accordance with the guidance presented above and following industry standards. Accidental torsion need not be considered. Peak component demands, story deformations, floor accelerations and roof displacement should be reported and used for component assessment and other performance assessments.

For certain types of element, such as reinforced concrete walls and columns, the element resistances in flexure and shear depend upon the concurrent axial force. Since response spectrum analysis returns only positive values for seismic load effects careful consideration may be required to determine where the use of negative values may be more critical

Linear response-history analysis should be performed in accordance with the guidance presented above and following industry standards. Accidental torsion need not be considered. Maximum values of peak component force demands, story deformations, floor accelerations and roof displacement for the seven analyses should be reported and used for component assessment and other performance assessments.

The building structure should be assessed component-by-component. Calculated component actions should generally be less than or equal to component strengths calculated per industry standards. The concept of “essentially elastic” performance is the underlying design objective. Some amount of yielding and force redistribution is acceptable at service levels, but care must be taken to ensure the elastic analysis procedures are not invalid.

For certain types of elements, it might not be prudent to use the maximum values of response for component checking because individual component element resistances depend upon the concurrent values of a number of load effects. It may therefore be necessary to assess performance against criteria at many time steps. An example of this is the dependency on the flexural resistance of a reinforced concrete wall or column on the axial load occurring at the same time. One way to perform a complete check is to plot the (N, M) pairs at each time instant of the response history within the design N-M interaction chart for the element, as shown in Figure 3.

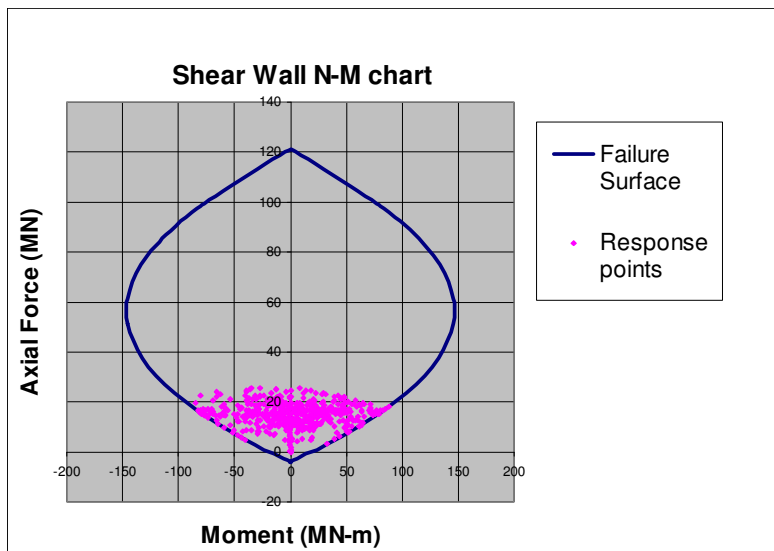


Figure 3 Response history results for reinforced concrete wall plotted within N-M strength interaction surface

The shear resistance of such a wall or column depends on both the axial load and bending moment, and so it may be necessary to compare a plot of shear demand with shear capacity over the duration of the event.

The peak story drifts [or racking deformations] and floor accelerations experienced by non-structural elements should also be reported. Demands on non-structural components should generally be less than limiting values established by the Architect as being consistent with service-level performance. These limiting values should be documented in the Seismic Design Basis and form part of the specification for the design, supply and installation of the non-structural components.

5.5.2 Nonlinear Response-History Analysis

Nonlinear response-history analysis (NLRH) should be performed in accordance with the guidance presented above and following industry standards. Accidental torsion need not be considered.

For design, it is impractical to simulate the dispersion of predicted responses in a statistically meaningful way by means of a limited number (e.g. seven) of response history analyses. In any case, it is known that the dispersion of the ground motions alone is very high. For this reason we recommend that the mean of seven NLRH results should be adopted for the assessment of element and building deformation effects, and that acceptance criteria be set accordingly to recognise the high dispersion. Non-ductile (force-controlled) behavior should be prevented by capacity design.

The building structure shall be assessed component-by-component. All calculated component actions and deformations should be less than or equal to component capacities established using industry standards (e.g., ASCE 41), representative test results or first principles engineering mechanics. As noted previously criteria appropriate to the performance of some types of construction will not be contained in ASCE 41 or other documents and it will be necessary to make reference to tests and/or specific calculations.

For members designed for and exhibiting some ductility it is necessary to assess whether the ductile demand exceeds the deformation limits. Where deformation capacity depends upon a number of concurrent element load effects (e.g. axial and shear stress) this must be taken into account.

For effects that are not ductile (e.g. shear failure in a reinforced concrete column or shear wall) a degree of over-strength should be provided to ensure this failure mode is protected against. One way in which this can be achieved is to determine the shear demand (based on best-estimate strength properties) and to design for this demand using code material strengths and strength reduction factors. Again, in this context the shear capacity itself varies during the event and the assessments for required shear reinforcement need to be evaluated at all times in the response history.

Non-structural components should be assessed for average story drifts [racking deformations] and floor accelerations. Demands on non-structural components should generally be less than the limiting values established by the designer as being consistent with the collapse prevention performance level. These limiting values should be documented in the Seismic Design Criteria.

6.0 Energy dissipation components (dampers)

Energy dissipation components (also known as dampers) and systems can be used to mitigate the effects of earthquake shaking and wind-induced vibration.

Traditional systems for reducing wind-induced vibrations in high-rise buildings such as tuned-mass dampers and tuned liquid dampers are generally unsuitable for mitigating earthquake-induced response because they are tuning-sensitive and will not provide reliable control when the building suffers significant yielding and period elongation. In addition they generally cannot generate high levels of damping and are difficult to design to accommodate the very high responses associated with strong earthquakes.

Energy dissipation components based on the yielding of metals, developed for earthquake engineering applications, are unsuitable for mitigating wind-induced motion because the serviceability wind-induced forces on the components will be lower than their yield forces. They will therefore not dissipate energy in serviceability wind events when damping is required to satisfy occupant comfort criteria. Similar comments apply to friction dampers.

Energy dissipation components using viscous fluids (e.g. fluid viscous dampers) can sometimes be used to mitigate both earthquake and wind effects. Advantages of such components and systems include:

1. System performance is somewhat independent of changes in the dynamic properties of the building
2. Response in multiple modes can be mitigated (rather than just in the fundamental mode as is the case with tuned mass and liquid dampers)
3. Large displacement capacity (stroke) for mitigating earthquake effects and high fatigue life for mitigating wind effects.

Viscoelastic solid dampers can be used in some circumstances to control wind and seismic responses. However, they present some design challenges since their properties require modification during a wind or seismic event to account for the effect of viscous heating and the consequent loss of force output for a given stroke and velocity. Damper manufacturers should be consulted for appropriate numerical models for visco-elastic dampers subject to large-cycle wind loading.

Nonlinear mathematical models for metallic yielding, friction and viscoelastic dampers are available in the literature (e.g., ASCE 41) for earthquake applications.

Damper performance should be confirmed by full-scale testing under maximum earthquake and maximum wind loadings. Procedures for testing dampers for earthquake effects can be found in US codes, guidelines and standards (e.g., ASCE 41). Procedures for testing dampers for wind effects should be developed on a project-specific basis considering demands (displacement, velocity and number of cycles) associated with the response of the building to wind during its lifetime. Fatigue and seal wear accumulate during even modest windspeeds and may be critical to the design of the components. It should also be appreciated that performance at windspeeds well below the design value may be critical for occupant comfort.

7.0 References

ASCE 41 (2006)

Applied Technology Council (ATC), *Seismic Evaluation and Retrofit of Concrete Buildings*, ATC-40, November 1996

Applied Technology Council (ATC), FEMA 356

Baker and Cornell, 2006

Chinese Code for Seismic Design of Buildings, GB 50011 (2001)

European Standard EN1998-1:2004 'Eurocode 8: Design of structures for earthquake resistance', 2004

Huang, Y.-N., A. S. Whittaker and N. Luco, "Maximum spectral demands in the near-fault region," In Press, *Earthquake Spectra*.

International Building Code [ICC, 2006].

Los Angeles Tall Buildings Structural Design Council, '*Alternative Procedure for Seismic Analysis and Design of Tall Buildings Located in the Los Angeles Region*', *Consensus Document*, 2006

SEAONC, 'Recommended Administrative Bulletin on the Seismic Design and Review of Tall Buildings using Non-Prescriptive Procedures', for City of San Francisco Department of Building Inspection, April 2007

Structural Engineers Association of California (SEAOC), *Vision 2000*, 1995

Uniform Building Code [ICBO, 1997]

APPENDIX 1

DAMPING OF TALL BUILDINGS

The intrinsic damping of a tall building is a key design input. Whilst the effect of damping is less dominant for seismic response than it is for dynamic wind response, it is significant and the damping values selected should be considered properly.

However, the choice of damping parameter is not easy, if only because there have until very recently been very few measurements on very tall buildings, some of which are of dubious quality. Current ‘recommendations’ made are based on the more numerous measurements made over many years on less tall buildings.

Considerable progress has been made in the last ten years in understanding the levels of damping that are to be expected, largely due to the careful work on high-quality measurements in Japan (Satake et al, 2003).

In general, Tamura (2007) has concluded that, except at very small amplitudes, damping in tall buildings does not increase significantly with the level of response until yielding mechanisms are mobilised. Since energy dissipation associated with yielding and damage is directly accounted for in nonlinear response-history analysis, the intrinsic damping of a structure should not be increased for this effect. The Japanese database (Satake 2003) provides damping measured at significant response levels in wind or earthquake as a function of building type, height and natural period. This forms the basis of figure A1, which also includes further published and unpublished measurements.

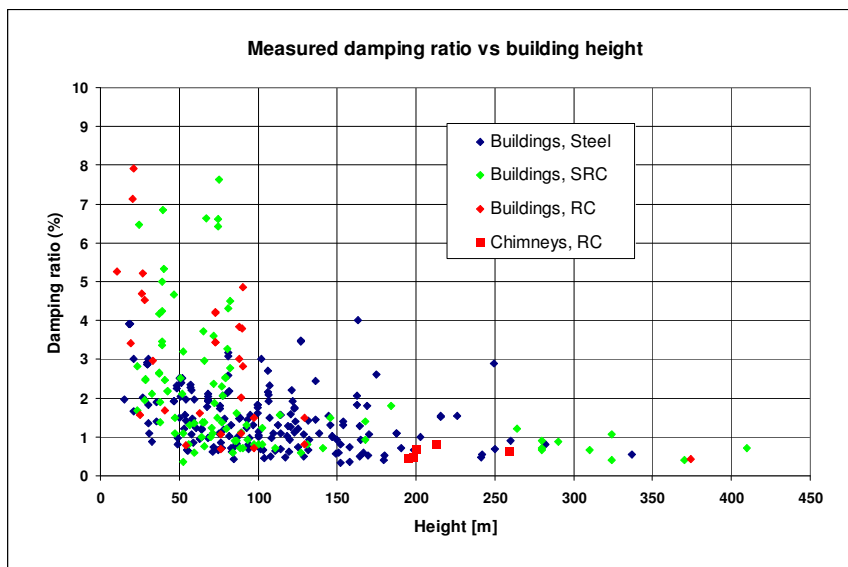


Figure A1 - Measured damping ratio vs building height

There are two clear observations that can be made. Firstly, the intrinsic damping of buildings has high variability, and secondly, the trend is for expected damping to reduce with building height. There are rational reasons why this trend is observed.

1. The basic structural elements of a tall building (e.g. core walls, columns) are very stiff in relation to the cladding and fit out elements, much more so than in low-rise buildings with much smaller structural elements. For this reason whatever energy dissipation there is in the non-structural components will make relatively less contribution to the overall damping of the building.
2. Taller buildings tend to have more highly engineered cladding and fit-out systems that provide less opportunity for energy dissipation
3. The radiation damping from the foundations of high rise buildings would be expected to be very small since the frequencies are very low and the predominant mode is rocking rather than translation.

With these observations in mind it might be expected that the intrinsic damping of a very tall building, prior to the onset of yielding mechanisms, might approach that of the basic structural framing itself.

Selected References

Li QS, Fang JQ, Jeary AP, Wong CK, Liu DK, 'Evaluation of wind effects on a super-tall building based on full scale measurements', *Earthquake Engineering and Structural Dynamics*, 2000, 29:1845-1862, Wiley

Satake N, Suda K, Arakawa T, Sasaki K and Tamura Y, 'Damping evaluation using full scale data of buildings in Japan', *ASCE Journal of Structural Eng*, April 2003.

Tamura Y, 'Amplitude dependency of damping in buildings and estimation techniques', 12th International Conference on Wind Engineering, Cairns, 2007

Wood G (University of Sydney), Private correspondence

Xu YL, Zhan S, 'Field measurements of Di Wang Towers during typhoon York', *Journal of Wind Engineering and Industrial Dynamics* 89 (2001) 73-93