China-USA Symposium
For the Advancement of
Earthquake Sciences and Hazard Mitigation Practices

The Conference Center of the National People's Congress
Beijing, China
October 19, 2010

China Academy of Sciences
President Lu Yongxiang and Members of the China Organizing Committee

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夏威夷中華總商會

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April 22, 2011

This Compilation reflects the outcome of the China-USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices, with associated research and government meetings held from October 18-21, 2010 in Beijing and Mianyang, China.

We would like to thank the Honorable Lu Yongxiang, Vice Chairman of the China National Peoples Congress and President of the Chinese Academy of Sciences for his constant support and acceptance of this project. In addition, we are most grateful to our Chinese hosts and organizers, including Organizing Chairman Wang Guantao, Vice Chairmen Peng Gongbing, (China Science Center of International Eurasian Academy of Sciences-CSCIEAS), Dai Feng (CSCIEAS), Zhou Chang (Architectural Society of China-ASC), Wang Jun (China Academy of Building Research), Li Xiaojiang (China Academy of Urban Planning & Design), Shao Yisheng (CSCIEAS), as well as Conference Secretary Generals Zhang Baiping (ASC) and Rao Jie (CSCIEAS) and Secretary General Chen Zhuming and Director Lake Zhao of the China Association for International Friendly Contact.

For the US, the Organizing Committee of Gary Chock, Ivan Wong and Dr. Guangren Yu was instrumental in helping to plan the Symposium and the additional informal meetings with key research and planning organizations. They, along with USA team members Dr. Daniel Abrams, Douglas Bausch, Richard Eisner, Mathew Francis, Marjorie Greene, Dr. Nicolas Luco, Chaoying Luo, Dr. Eduardo Miranda, Dr. Mark Petersen, Dr. Ian Robertson, Dr. J.P. Singh, Dr. Kenneth Stokoe, Dr. Christine Theodoropoulos, Thomas Tobin, and Yumei Wang ably represented the US scientific, engineering and hazard planning community. We were pleased to have the participation and encouragement from Austin Turner, Jeff Graham and David Benner of the U.S. Consulate General. We are thankful to the National Science Foundation and Dr. Joy Pauschke for their support of the research components of this international exchange. The Coastal Zone Foundation and Beatrice M. H. Young Foundation also supported logistics for the US team members. Special thanks go to Chaoying Luo for coordinating the meetings in China and to Gary Chock for his tireless effort in helping to organize all components of this vital exchange, as well as compiling this final report.

To earthquake scientists, engineers, and hazard planners in the US and China, please use this report to contact your counterparts with the goal to increase further collaboration. We know members of the USA team are ready to assist, if it is needed so that both countries can better plan for and recover from future earthquakes.

Dennis J. Hwang
USA Organizing Committee
Immediate Past President, CCCH

L. Thomas Tobin
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Announcement

The CHINA/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices
Week of October 18, 2010

The goal of this symposium is to advance the earthquake sciences and hazard mitigation practices in both China and the U.S. and to enhance cooperation and mutual understanding between the two countries. In this symposium, participating earthquake scientists, engineers, and hazard mitigation practitioners from China and the U.S. will meet and collaborate together in identifying and discussing the approaches taken by both countries to address common issues in seismic hazard mitigation. This first meeting will help facilitate a continuing exchange of useful scientific, engineering, planning knowledge and experience that could lead to safer buildings and reduced casualties in future earthquakes. This symposium should provide an uncommon opportunity to exchange scientific, engineering, and emergency management knowledge with the key agencies in China being assembled together.

There are four main areas that have been proposed for collaboration:

1. Hazard Assessment and Mapping, Geotechnical Hazards and Siting (China Earthquake Administration)
2. Building Codes and Multi-Hazard Design (China Academy of Building Research)
3. Hazard Mitigation of Critical and Important Building Construction (China Academy of Urban Planning & Design)
4. Pre-Disaster Planning and Mitigation and Emergency Response(Ministry of Civil Affairs, Sichuan Province)

Expected outcomes: with each major subject topic there will be:

1. A list of common issues shared by U.S. and Chinese scientists, engineers and practitioners;
2. A technical summary of the approaches or procedures used by each to address those issues;
3. Identification of organizations in both countries that address these issues;
4. Identification of individuals working on these issues with contact information;
5. An agenda for the future, which includes follow-up, further dialogue and meetings; and
6. A report summarizing the meetings or workshops.

Planning for this symposium in China is being lead by institutes and agencies:

- Ministry of Construction
- China Science Center, International Eurasian Academy of Science (IEAS)
- Architectural Society of China (ASC), registered by the Ministry of Civil Affairs, also a member of China Association for Science and Technology
- The China Association for International Friendly Contact

Our hosts are proposing to host a day-long plenary session in Beijing and 2 days in Beichuan County, near the location of the May 12, 2008 M8.0 Sichuan Earthquake. The China organizing committee is lead by Dr. Zhou Chang and Mr. Zhang Baiping of the Architectural Society of China, and representative(s) from the Architects & Scientific Research Institute. Chen Zhuming, Zhao Lei and Martin Zhang of the China Association for International Friendly Contacts will be providing support.

A continuing dialogue is desired that will be fostered that week through individual focus group meetings with key Chinese scientific ,engineering, and planning institutes that can extend into future cooperative conferences or joint research projects on the themes of primary interest. The proposed focus meetings are listed in Attachment A. A list of subjects of particular interest is provided in Attachment B.

The CHINA/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices
Week of October 18, 2010

The Chinese Chamber of Commerce of Hawaii, Earthquake Engineering Research Institute, and the University of Hawaii are the U.S. organizing co-sponsors. The U.S. Embassy will also be a participating agency via their offices in Beijing and Chengdu. Other participating U.S. agencies include the Federal Emergency Management Agency (FEMA) and the U.S. Geological Survey (USGS). The U.S. organizing committee has assembled a diverse group of U.S. researchers and experts that can engage in this exchange of scientific knowledge, engineering codes, standards, and hazard mitigation practices. A summary of the backgrounds of the USA participants is given in the Attachment C biographical sketches.

The U.S. organizing committee for technical coordination consists of:

Dennis Hwang: DJH@opglaw.com, djh@roplaw.com
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Gary Chock: gchock@martinchock.com
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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of any of the host or sponsoring organizations, or the organizations of the participants.

Attachment A

Focus Meetings to be arranged with Agencies and Institutes of China with USA Scientists/Engineers; Week of October 18 2010

October 18 Meetings	
USA Group Number	**Institute / Location**
1 Morning	**China Earthquake Administration** Chunfeng-Hu, Director-General of International Cooperation Department Dr. Chen Yuntai Phone:+86-10-68415370 +86-10-82840007(H) E-mail: chenyt@cea-igp.ac.cn Dean of School of Earth and Space Sciences, Beijing University Dr. Sun Baitao, Institute of Engineering Mechanics sunbt@iem.ac.cn, sunbt@iem.net.cn
Morning	**Institute of Geophysics, China Earthquake Administration** Gao Mengton, gaomt@cea-igp.ac.cn No.5 South Road of China National University, Haidian District, Beijing, China. Zip: 100081
Afternoon	**World Data Center for Seismology Beijing** **Institute of Earthquake Science, China Earthquake Administration** Dr. Liu Refeng , Director E-mail: liufr@csndmc.ac.cn +86 10 880 15 249 No.63, Fuxing Avenue E-mail: Beijing, 100036
2 & 3 Morning	**China Academy of Building Research** Dr. Wang Yayong Tel: 8610-84282354; E-mail: yayongwang@sina.com Institute of Earthquake Engineering 30#, Bei San Huan Dong Lu (North Third Ring Road of Beijing) Beijing, 100013
Afternoon	**China Development Research Foundation of the Development Research Center of the State Council** Diao Linlin, Programme Officer E-mail: diaoll@cdrf.org.cn F4, Tunlien Tower, No. 8 Deshengmen East Avenue, Xicheng District
4 Morning	**Ministry of Civil Affairs, National Disaster Reduction Centre of China** Dr. Wang Zhenyao, Director General Tel: +86 83551201 Email: wangzhenyao@ndrcc.gov.cn Room 1151, Zhongmin Plaza, No.7 Baiguang Road, Xuanwu District, Beijing China 100053

Attachment A

Focus Meetings to be arranged with Agencies and Institutes of China with USA Scientists/Engineers; Week of October 18 2010

October 18 Meetings	
4 Afternoon	**Ministry of Civil Affairs, Disaster Relief Department** Chai Mei, Deputy Director-General Tel 010-58123282 E-mail: chaimei@mca.gov.cn 147 Beiheyan Street, Dongcheng District, Beijing 100721

Focus Meetings to be arranged with Agencies and Institutes of China with USA Scientists/Engineers; Week of October 18 2010

October 22nd Meetings	
Group Number	**Location**
1 Morning	**China Geological Survey - China Institute of Geological Environment Monitoring, Ministry of Land and Resources** Zhou P.G., Chen H.Q. Yin Yueping No. 20 Dahuisi, Haidian district, Beijing 100081, PR China Tel:+86-10-62173424 -
2 & 3 Morning	**Tsinghua University** Lu Xinzheng Email : luxinzheng@sina.com Disaster Prevention and Mitigation Project Research Center School of Civil Engineering, Beijing, PR China,100084
2 Afternoon	**Ministry of Housing and Urban Rural Development** 9 Sanlihe Rd., Beijing 100835 Telephone: 86-10-6839-4114; (operator); 6839-3292 (office) Jiang Weixin, Minister
3 Afternoon	**China Academy of Urban Planning & Design, Ministry of Construction** Mr. Luxin Huang Director, Department of International Cooperation and Development Tel: +8610-58322061 Fax: +8610-58322060 Email: luxinh@163.com No.5 West Beijing, Chegongzhuang PC: 100044 E-mail: caupd@caupd.com Tel: (8610) 58322222 - (Administration), 58323333 - (Technical)
4 Morning	**China Earthquake Administration, Earthquake Relief Department** Prof. Chen Jianmin Director General +86 1088015575 Dr. Mao Chenxi Tel 86-451-86652981; (Harbin) E-mail: maochenxi@iem.ac.cn http://www.cea.gov.cn/ Number 63 Fuxing Avenue. Beijing, 100036 Prof. Chen Jianmin Director General +86 1088015575

Focus Meetings to be arranged with Agencies and Institutes of China with USA Scientists/Engineers; Week of October 18 2010

October 22nd Meetings	
4 Morning	**Academy of Disasters Reduction and Emergency Management (ADREM), Beijing Normal University** Professor Shi Peijun - Executive Vice- President of the Beijing Normal University E-mail: spj@bnu.edu.cn Tel: 86-10-62208179 Zone B, Science and Technology Building, Beijing Normal University No.19 Xinjiekou Wai Street, Haidian District, Beijing, P.R.China. Postcode: 100875 Telephone: 86-010-58802778 Fax: 86-010-58802925
Morning	and **Ministry of Education - Department of International Cooperation and Exchange** JING Wei, Director, Division of Americas and Oceania
Afternoon	**Chinese Academy of Science and Technology for Development** **Ministry of Science and Technology** **Wan Gang - President** Dr. Zhao Yandong Deputy Director of the Institute of Science Email: casted@casted.org.cn Address: No.8 Yuyuantan South Road, Haidian District, Beijing, 100038 Tel: +8610 58884695 58884506
1 Afternoon	**China Civil Engineering Society** Tan Qinglian, President Xila Liu, International Director No. 9 San Li He Road Beijing

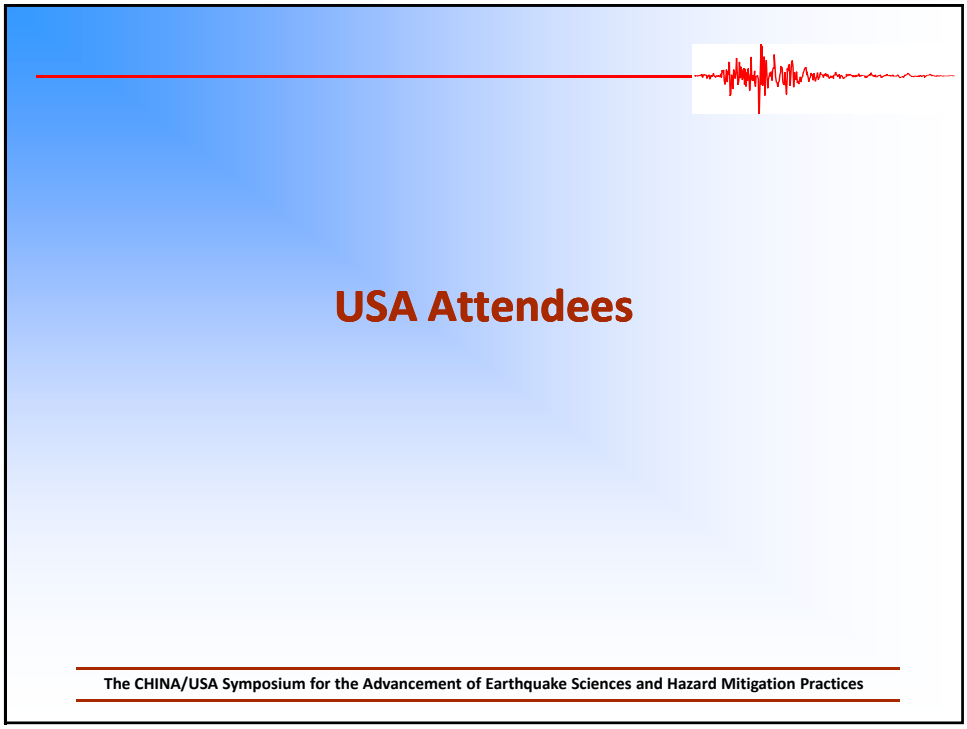
Attachment B

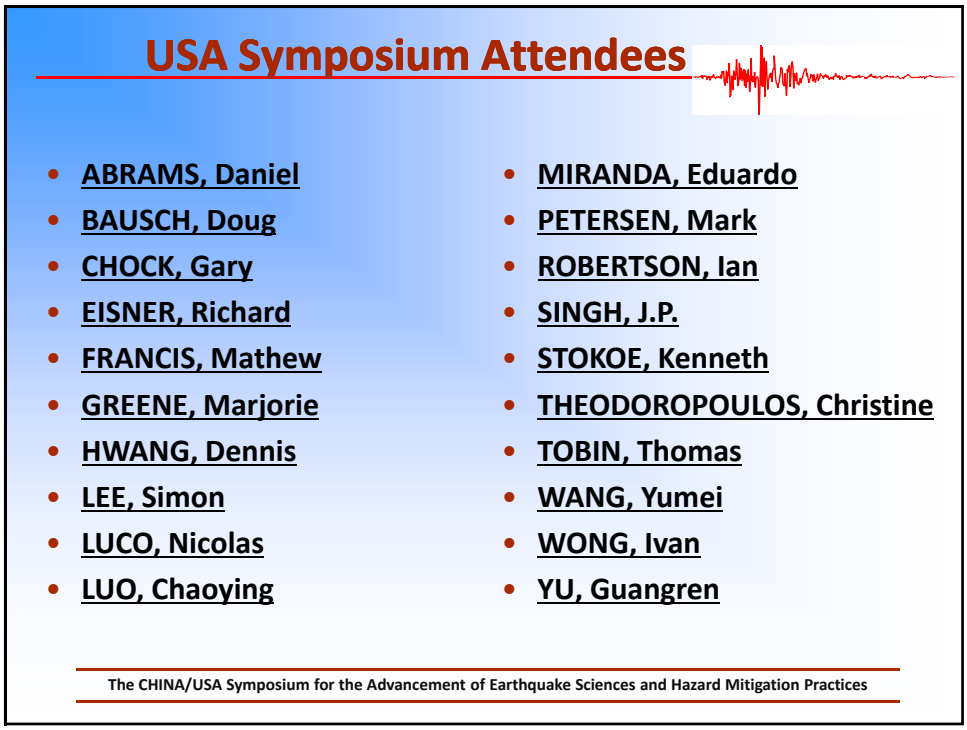
The CHINA/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices

Attachment B: Subjects of interest that the USA participants would like to learn relating to China earthquake science, engineering, and emergency planning and response:

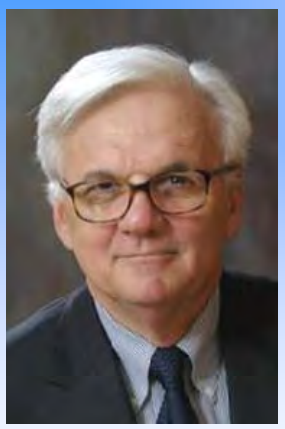
Implementation of the UN International Strategy for Disaster Reduction (ISDR) 2005-2015 Hyogo Framework for Action in Asia
China Earthquake Networks Center and strong ground motion record data
Scientific and analytical basis for the seismic hazard mapping for design standards
China's seismic design and construction codes applicable for: Buildings, Housing, and Urban and Rural development
Earthquake consequence risk analysis for hazard mitigation policies
Land use and development decision-making policies for disaster mitigation
Critical infrastucture protection
Seismic research by major universities
Anticipated needs for future updates to China seismic design maps and codes
Comparisons of the seismic performance of China building construction designed under earlier and modern China seismic building codes
Hazard mitigation of schools and emergency response buildings such as hospitals
Seismic rehabilitation of existing masonry buildings
Multi-hazard design criteria for reliability
Natural disaster reduction in coastal and low-lying areas
China's National Disaster Reduction Commission
China's national disaster management system and the roles of various ministries in emergency response and recovery
Emergency preparedness planning
Use of computer modeling to estimate losses for planning and disaster management
Use of remote sensing for disaster assessment and response
Building safety assessment system
Post-disaster planning for repair, reconstruction, or relocation
Lessons learned from the Wenchuan and Qinghai earthquakes towards improving seismic safety of buildings, including schools and emergency response buildings such as hospitals
Economic losses and societal impacts from earthquakes
Comprehensive policies regarding the earthquake safety of schools including building codes and enforcement, emergency preparedness and exercises, community awareness, risk reduction in existing facilities and curriculum regarding earth science and earthquake engineering
Construction practices and costs in urban and rural areas
Beichuan County abandoned damaged building zones and museum/memorial
Examples of geologic hazards in Beichuan/Sichuan: surface rupture, landslides, and liquefaction, damage to earthern dams

USA Attendees


USA Attendees
The CHINA/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices


USA Symposium Attendees
ABRAMS, Daniel
BAUSCH, Doug
CHOCK, Gary
EISNER, Richard
FRANCIS, Mathew
GREENE, Marjorie
HWANG, Dennis
LEE, Simon
LUCO, Nicolas
LUO, Chaoying
MIRANDA, Eduardo
PETERSEN, Mark
ROBERTSON, Ian
SINGH, J.P.
STOKOE, Kenneth
THEODOROPOULOS, Christine
TOBIN, Thomas
WANG, Yumei
WONG, Ivan
YU, Guangren
The CHINA/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices

ABRAMS, Daniel, Ph.D., P.E.



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Return to List of Attendees

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Return to List of Attendees

Meeting Schedule

Meetings - 10/18		**Group 1** Ivan Wong Mathew Francis Mark Petersen Kenneth Stokoe II Simon Lee* Dennis Hwang	**Group 2** Gary Chock Guangren Yu* Daniel Abrams Nicolas Luco	**Group 3** Ian Robertson Eduardo Miranda JP Singh Christine Theodoropoulos Chaoying Luo*	**Group 4** L Thomas Tobin Richard Eisner Yumei Wang Marjorie Greene Douglas Bausch Staff engineer with Martin Beijing office*
* = translators					
Date	**Time**	**Meeting Track 1**	**Meeting Track 2 and 3**		**Meeting Track 4**
Monday October 18	**7:30 AM**	**All Groups Assemble for Departure in Motorcoach to Meetings**			
	9:00 - 11:30 AM	China Earthquake Administration ***地震局***	China Earthquake Administration ***地震局***		Ministry of Civil Affairs ***民政部***
		Institute of Geophysics - [CEA -IG] (9:30-11:30) ***地球物理研究所*** Su Xiaolan +8610-68417859 suxl@cea-igp.ac.cn **Confirmed**	National Earthquake Response Support Service(NERSS) ***中国地震应急搜救中心*** Wang Juan +8610-59956325 wangjuan0510@263.net **Confirmed**		National Disaster Reduction Centre of China [NDRCC] and Disaster Relief Department [MCA - DRD] ***中国国家减灾中心和灾害救济司*** MA Yunfei +8610-63531082 mayunfei@ndrcc.gov.cn **Confirmed**
		Coordinator: Greene & Wang	Coordinators: Bausch and Chock		Coordinator: Greene & Wang
	Lunch	**Restaurant in the Xicheng District**	Songhelou Restaurant, No. 9 Nanlishi Road ***（松鹤楼，西城区南礼士路乙 9 号 ）+8610-68018956***		
	1:30 - 4:00 PM	China Earthquake Administration ***地震局***	Development Research Center of the State Council ***国务院发展研究中心***		
		China Earthquake Network Center CEA - CENC (2:30 - 3:45 PM) ***中国地震台网中心*** Pang Lina +8610-59959241 pln@seis.ac.cn **Confirmed**	China Development Research Foundation [CDRF] ***中国发展研究基金会*** Feng Wenmeng +8610-84080102 +8610-84080188-8014 13520392713 ~ 2:30 pm: DAI Junwu to meet at CDRF for separate breakout meeting with Dan Abrams and Marjorie Greene **Confirmed**		
		Hai Dian District	Xicheng District		
		Coordinator: Wong	Coordinator: Robertson		
	~5 pm	Meeting with Dr. Lu Yongxiang of CAS - confirmed			
	Dinner 7 pm	Informal Buffet Dinner for USA participants and companions at the NPC hotel			
	8:30 PM	Meeting of the organizing committees and group leaders			

Meetings - 10/22		Group 1	Group 2	Group 3	Group 4
		Ivan Wong	Gary Chock	Ian Robertson	L Thomas Tobin
		Mark Petersen	Guangren Yu*	Eduardo Miranda	Richard Eisner
		Kenneth Stokoe II	Nicolas Luco	Christine Theodoropoulos	Yumei Wang
* = translators		Simon Lee*	JP Singh	Chaoying Luo*	Marjorie Greene
		Douglas Bausch		Daniel Abrams	Dennis Hwang
		Mathew Francis			Staff engineer with Martin Beijing office*

Date	Time	Meeting Track 1	Meeting Track 2 and 3	Meeting Track 4
Friday October 22	7:30 AM	**All Groups Assemble for Departure in Motorcoach to Meetings**		
	9:00 - 11:00 AM	Beijing Normal University ***北京师范大学***	China Academy of Building Research [CABR] ***中国建筑科学研究院***	Beijing Normal University ***北京师范大学***
		Academy of Disaster Reduction and Emergency Management [ADREM] ***防灾与应急管理研究院*** Li Jing +8610 58807163 lijing@ires.cn **Confirmed**	Institute of Earthquake Engineering[IEE] ***工程抗震所*** Huang Shimin +8610-64517435 hsmcabr@yahoo.com.cn **Confirmed**	Academy of Disaster Reduction and Emergency Management [ADREM] **防灾与应急管理研究院** Li Jing +8610 58807163 lijing@ires.cn **Confirmed**
		Coordinators: Greene & Wang	Coordinators: Chock, Theodoropoulos, and Robertson, Yu	Coordinators: Greene & Wang
	Lunch	**Restaurant in the Xicheng District**	Quanjude Roast Duck (Shishahai Branch) ***全聚德什刹海店 西城区地安门西大街 57 号*** +8610-66128557	
	1:30 - 4:00 PM	Chinese Academy of Sciences ***中科院***	Tsinghua University ***清华大学***	Ministry of Science and Technology ***科技部***
		Center for Earth Observation and Digital Earth [CEODE] ***对地观测与数字地球科学中心*** Liu Jie +8610-58887409 liuj@ceode.ac.cn **Confirmed**	Disaster Prevention and Mitigation Project Research Center ***防灾与减灾工程研究中心*** Han Linhai +8610-62797067 lhhan@tsinghua.edu.cn **Confirmed**	Chinese Academy of Science and Technology for Development [CASTD] ***中国科学技术发展战略研究院*** Zhao Yandong +8610-58884656 casted@casted.org.cn **Confirmed**
		Hai Dian District	Hai Dian District (North)	Hai Dian District
		Coordinator: Bausch	Coordinators: Robertson, Miranda, Yu	Coordinator: Greene & Wang
	Dinner	**Restaurant in the Xuanwu District**	Jinyue Seafood (Xibianmen Branch),No. 85 Xibianmennei Street. ***(金悦世界海鲜西便门店 , 西便门内大街 85 号) +8610-63168999***	

Symposium Itinerary

Schedule from Chinese Organizers(10-8-10)
Daily Program for USA Team
Additions from USA Organizing Committee

October 17 (Sunday)

USA team arrives at different times – dinner on own

Travel to Hotel by Organizers provided for October 17 and 18 only.

October 18 (Monday)

Breakfast on own - Confirm start time with hotel[1]

07:30-08:00 - Gather in Lobby for Briefing

08:00 - Leave for Informal Meetings in Vans

09:00 to 11:30 - Morning Meetings

12:00 to 13:00 - Lunch

13:30 to 16:00 - Afternoon Meetings

Return to Hotel - NPC Conference Center

17:00-19:00 Possible 30 minute meeting with Lu Yongxiang – Vice President of National Peoples Congress and President of Chinese Academy of Sciences – USA team only (confirm)

18:00-20:00 Informal Dinner at NPC Conference Center for USA team and accompanying members (confirm)

20:30-21:00 – Organizing meeting – Organizing Committee, Group Leaders

October 19 (Tuesday)

Full day for conference（NPC Conference Center）

09:00-09:20 Opening
Chaired by the organizer
Welcome address by the organizer
Address by the representative of USA Team – Dennis Hwang
Welcome address by the co-organizer

09:20-09:30 Tea Break

Morning Session Chaired by ASC

09:30-10:00 Gao Mengtan, Professor, Deputy Director of Institute of Geophysics, China Earthquake Administration
---- Seismic Risk and Mitigation of Catastrophic Earthquake in China

10:00-10:40 USA Speakers of group (1)
---- Hazard Assessment and Mapping

10:40-11:10 Zhou Xiyuan, Academician of China Academy of Science, Researcher from China Academy of Building Research
---- Seismic Zoning and Earthquake Protection of Building Structures

11:10-11:50 USA Speakers of group (2)
---- Building Codes and Multi-Hazard Design

11:50-12:00 Q & A, summing-up of the morning session

[1] USA team members pay for their own breakfast on mornings of October 18 and 23. Pay for their own lunch on October 18 and 22. Pay for their own dinner on October 17 and 22. Save receipts for all travel expenses, if there is funding assistance from NSF they will be required for reimbursement.

12:00-13:30 Lunch（NPC Conference Center）
Afternoon Session (1) Chaired by the USA Team – Dan Abrams
13:30-14:00 Li xiaojiang, President of China Academy of Urban Planning & Design
---- Post-disaster Reconstruction and Urban Safety
14:00-14:40 USA Speakers of group (3)
---- Hazard Mitigation of Critical and Important Facilities

14:40-15:10 Qiu Jian, Chief Planner, Bureau of Urban & Rural Construction of Sichuan Provincial Government
---- Planning and Design for Post-Wenchuan Earthquake Reconstruction in Urban and Rural Areas of Sichuan
15:10-15:20 Tea Break
Afternoon Session (2) Chaired by CABR
15:20-16:00 USA Speakers of group (4)
---- Pre-Disaster Planning and Mitigation and Emergency Response
16:00-17:00 Q & A, summing-up of the afternoon session
17:00- End of conference
18:00- Welcome Dinner hosted by the organizer and co-organizers (at NPC Conference Center)

October 20 (Wednesday)
Morning: From Beijing to Mianyang by CA1451 (07:45-10:15)
Afternoon: Visit Earthquake Sites and reconstruction of Beichuan County Town.

October 21 (Thursday)
Morning: Roundtable exchange with local professionals – Simon Lee, Chaoying Luo, Guangren Yu – Translators
Afternoon: Visit the reconstruction projects of villages
Evening: Mianyang to Beijing by CA1456 (20:10-22:35)
Hotel – to be confirmed

October 22 (Friday)

Breakfast on own – confirm with hotel start time

08:00 - Leave for Informal Meetings in Vans

09:00 to 11:30 - Morning Meetings

12:00 to 13:00 - Lunch

13:30 to 16:00 - Afternoon Meetings

18:00 Dinner

October 23 (Saturday)

Most USA team members depart
Travel to airport provided by organizers for October 22 and 23 only

Photographs from Meeting with China Academy of Sciences
President Lu Yongxiang and Members
of the China Organizing Committee

Meetings of October 18, 2010

China Earthquake Administration
Institute of Geophysics
63, Fuxing Ave. Beijing 100036

Meeting – October 18, 2010 - 9:00 am to 11:30 am

Present from USA – Dr. Mark **Petersen**, Dr. Ken **Stokoe**, Mathew **Francis**, Dennis **Hwang**, Ivan **Wong**
Present from China – Dr. **Gao** Mengtan - Deputy Director-General (86-10-68415371 – Mobile 13801278023; gaomt@sina.com);
Dr. **Li** Xiaojun– Deputy Director (86-10-68729205 – Mobile 13801384356; beerli@vip.sina.com);
Dr **Yu** Yanxiang – Engineering Seismology – (86-10-68729126; yuyx@cea-igp.ac.cn);
Dr. **Wen** Zengping– (86-10-68729285; zengpingwen@hotmail.com); and
Dr. **Pan** Hua.
Several did not have their business cards so it was difficult to get full contact information.

Introductions

Presentation by Dr. Gao

- Institute consists of many seismologist, geologists, and engineers. They work in seismology, seismic hazards, and disaster mitigation.
- Some pioneering work
  - Seismic microzonation
  - Design ground motions for important structures
  - Strong ground motion simulation
  - Risk assessment with implications to earthquake insurance
  - Disaster management theory – social impacts
- China very active seismically
- They are worried about the big event in populated areas

Presentation by Dr. Yu Yanxiang
Four generations of national hazard maps
1957; 1977; 1990 – probabilistic; 2001 – used in building codes, PGA and TG (see photo DSC_4054); 2011 – Seismic zoning map. Maps are for rock and soil classified into five categories.

- Maps are based on historical seismicity and faults
- Wenchuan earthquake – was in fault model
- Microzonation maps are probabilistic and they consider site effects. The site effects are based on subzones – for large cities it was done, e.g., Kunming and others. Usually based on the city asking them.

Performed site assessment on 20+ sites – many along the coast. Some candidate and real sites.

Fujian – nuclear plant
Purpose to determine design ground motions and identify capable faults.
USA – 10,000-year return period used for nuclear power plants, same in China

Deterministic and probabilistic methods – both used
Maximum considered magnitudes like U.S. use different methods of assessing maximum magnitude.

Design ground motion has a lower threshold 0.15 g

Wenchuan earthquake ground motions
Fault displacement
Significant duration
0.98 g highest PGA on soil

Ground motion prediction empirically-based
Looking at the NGA models

Also looking at ground motion simulations
Fault displacement model also using finite element
Legrange spectral element method – good for irregular interface and topography
Modified generalized reflection/transmission matrices – high frequency (DSC-4059)
One set of simulations have been done for Beijing (DSC_4060)

Site characterization being done for Yunnan – Southwest China (DSC-4073)

- Seismically active region
- 600 portable devices will be deployed
- 4 deep profiles using air gun source and earthquakes
- Crustal velocity model will be developed

Yuxi Basin

- Sediments shed off surrounding mountains
- Middle valley maybe soft
- Lake area – likely for liquefaction

Seismic vulnerability assessment
Fragility curves focus of research

Concern for large events catastrophic events (DSC_4084)
Seismicity distribution - Many large events - Concern high risk in populated areas

USA – 20 magnitude 7s in 100 years – or once every 5 years
China in the last century

- 149 M > 7
- 38 M > 7.5
- 12 M > 8.0

- 2 M > 8.5

China has had many 1906 San Francisco-like earthquakes (DSC-4091)

- 1679 – near Beijing – over 80,000 died
- 1303 Linfen – more then 200,000 died - magnitude 8 earthquake
- 1596 Huaxian – 830,000 died – complicated surface faulting
- On average 3,000 die per year over last 500 years due to earthquakes

Tasks to be performed:

- Historical magnitudes need to reevaluated
- Populated areas a concern
- Seismic hazard maps and one for building codes – same organization
- Soil affects – non-linear
- Urban hazard map – should be used for design

Break - 10:46 am

Presentation by Professor Li

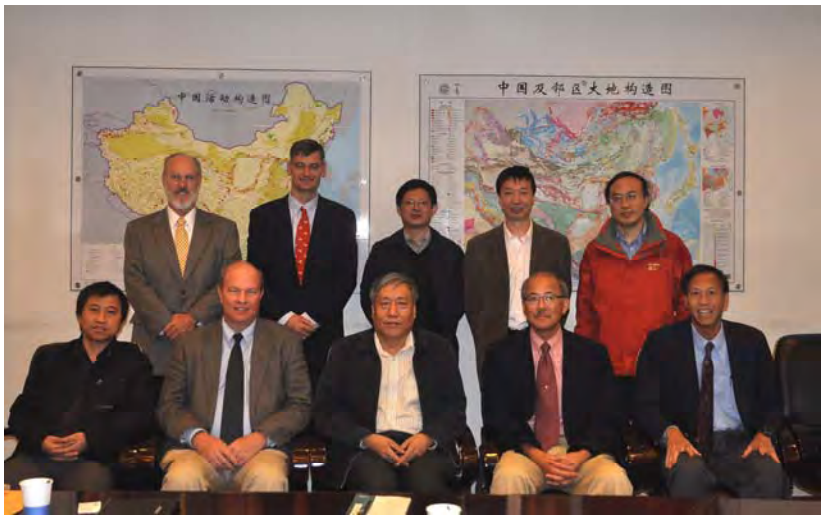
Strong motion observations in the Wenchuan earthquake (DSC-4093)
460 stations recorded the earthquakes
Earthquake was a multiple event **M** 7.6 and **M** 7.5 separated by 40 sec?
Series of reverse faults but second event was a strike-slip event
Will be analyzing records for many years
There is a large amount of strong motion data from this event – more than the USA
The data may be accessible to U.S. researchers – Ivan to request

Potential Collaboration - Many areas they are interested — CEA-IG very well organized with constant funding and considerable monitoring.

1. China – many more big earthquakes – the USA would like to learn more about their data – and what they learned from the data. Ivan requested their data and they are willing to share.
2. Comparisons – in small and large earthquakes – soil nonlinearity – observations very important – Dr. Ken Stokoe
3. Walter Mooney of USGS visits every year
4. NEES umbrella – NSF – and other parts – well instrumented in valley
5. Yuxi Basin Project – Ken and Ivan would be interested in collaboration – CEA-IG has 40 main people and others working on the Project
6. Also would like to collaborate on Yunnan Province on site response analysis
7. Large earthquakes – populated regions – widely distributed in China – not like USA where it is only California and New Madrid

They are interested in aggregated risk
Many people die in China due to collapse of structures
Long-return periods for earthquakes – how to they plan for this?
Going to performance based engineering

Time-dependant hazard – they are looking into it. Still need to account for aftershocks?



Sitting – Left to Right – Dr. YU Yanxiang, Dr. Mark PETERSEN - USGS, Dr. GAO Mengtan, Ivan WONG – URS Corp., Dennis HWANG – Chinese Chamber – University of Hawaii – Sea Grant – NOAA – Standing – Dr. Ken STOKOE – University of Texas, Mathew FRANCIS – URS Corp., Dr. Pan HUA, Dr. LI Xiaojun, Dr. Wen Zengping.

Meeting with National Earthquake Response Support Services [NERSS]
Monday, October 18, 2010

No.1, Yuquan West Street, Shijingshan District, Beijing, 100049
Meeting Minutes

09:00 Welcoming Remarks – by NERSS

09:10 Overview of meeting objective: Identification of Areas for Collaboration - Mr. BAUSCH

09:15 Self-introduction of China and USA participants

Attendees

USA: Douglas Bausch, FEMA
Nicolas Luco, United States Geological Survey
Gary Chock, Martin & Chock, Inc.
Guangren Yu, Martin & Chock, Inc.
Chaoying Luo, John A. Martin & Associates, Beijing
Eduardo Miranda, Stanford University
Daniel Abrams, University of Illinois
Christine Theodoropoulos, University of Oregon
JP Singh, JP Singh & Associates

China: QU Guosheng, Prof. Deputy Director, Chief Engineer of NERSS [Geologist]
Has visited the USA; experience includes Yushu and Wenchuan Team Leader, leads the development teams for their disaster management information systems.
Also Director of Digital Disaster Mitigation and Emergency Management Research Center of Peking University. Had already visited the NEIC and Dave Wald a couple years ago. Will lead the team visiting FEMA office December 8-10
qgsh@263.net Tel +86 10 8825 5929 86 13801225593 mobile

LI Yigang, Dr, Deputy Director of Technique Support Department, Associate Prof., TEL:86-10-59956405 FAX:86-10-59956405
liyig@263.net , lead author on their papers concerning the Global Earthquake Disaster Alert System (GEDAS) and the Earthquake Disaster Management Information System in China, Rapid Assessment for Earthquake Response and Recovery; experience includes Haiti Search and Rescue

SHANG Hong, Director of Technique Support Department, Associate Prof. [also equipment]
ZHENG Li, Deputy Director of Training Department, Associate Prof. , hpuzheng@gmail.com, attended Friday farewell banquet and Bausch has had continued discussion on development of a HAZUS pilot in SW China [experience includes Wenchuan earthquake]
ZHANG He, Director of Information Support Department, Associate Prof.
NING Baokun, Dr, Deputy Director of Information Support Department, Associate Prof. [geologist - presented her work associated with the Wenchuan earthquake]

ZHANG Xiaoyong, Dr, Information Support Department, Associate Prof.
SUI Jianbo, Dr, Technique Support Department, Associate Prof.
FENG Jun, Dr, Engineering Department, Associate Prof.
LI Yangfeng, Dr, Technique Support Department, Associate Prof. [geologist]
DU Xiaoxia, Dr, Technique Support Department, Engineer. [aerospace technology]
SUN Gang, Information Support Department, Engineer.
CHEN Siyu, Training Department, Engineer. [attended banquet]
LIU Jingjing, Information Support Department, Engineer.
ZHANG Yuan, Technique Support Department, Engineer.
YU Xi, student.

09:20 Role and Capabilities of the NERSS

- Presentation by Dr. QU Guosheng and video of NERSS [*NERSS Impressions* brochure was also distributed]

NERSS was established in October 2004 within the China Earthquake Administration. It has a total staff of approximately 150. It has both domestic and international Search & Rescue teams. It also establishes the standards for provincial S&R teams.

1. Technology Support
    - Warning
    - Disaster Evaluation and Rescue Command System
    - Emergency Projects
    - City Shelter construction
2. Information Support (includes use of high resolution imagery)
    - National Emergency Response Resources
    - Estimation of Losses
    - Briefings to Authorities
    - Decision Making System
    - Operating Emergency Response
    - Risk Analysis
3. Equipment and Logistic Support & Supplies
    - Managing Procurement of Equipment
    - Deploying
    - Logistics of Search and Rescue
4. Training & Support Base
    - Training Command System
    - Training S&R

- Training for Other Countries
- Training for First Responders

International Response:

Earthquake Level ≥ 7

Response: A quick report is developed using Pager within ½ hour for CEA, and within another ½ hour for the National Office for Emergencies. Reports later developed for the State Council and Military, and the Ministry of Foreign Affairs

There are about 36 such responses each year, with 1-2 international deployments of the S&R teams [China International Search and Rescue]

Class 1 Strong Earthquake, no disaster

Class 2 Strong Earthquake, light disaster

Class 3 Strong Earthquake, heavy disaster [generally > 2000 fatalities estimated]

Domestic Response – UN certified

Note that within ½ hour of the Great Wenchuan earthquake, over 30,000 fatalities were estimated.

Different classification designations are used for domestic earthquakes

Disaster planning: Since 1995, 50 cities have been studied for urban planning and emergency planning, and search and rescue. Zones are delineated urban suburban and S&R

In each studied

1. Risk Analysis of Seismicity and Site Effects
2. Vulnerabilities of Buildings [7 types of buildings]
3. Vulnerabilities of Lifelines
4. Bridges and Roadways
5. Secondary Effects
6. Casualties
7. Mitigation
8. Modeling Simulations

Research Areas:

1. Study cases of earthquake EM and S&R performance
2. Active fault detection
3. Loss estimation of Dccision Wupport
4. Early Warning Systems
5. Emergency response techniques
6. S&R Technicques
7. Training

8.

Q&A:

- Question regarding use of ground-truthed data and modeling sensitivity

  Sensitivity to fault mechanism is an issue; more data on this is needed sooner after an event

- What are the 7 types of buildings that are modeled for fragility?

  Further work on this is needed; some of those generically included are wood, brick, reinforced concrete, steel, factory buildings.

09:40 Earthquake Loss and Search and Rescue Estimation in the U.S. (HAZUS and PAGER) and development of International Applications through Remote Sensing Mr. BAUSCH and discussion

USGS Loss PAGER provides "leaning-forward" estimates of losses and fatalities in about 20 minutes after an earthquake based on ground motion data.

HAZUS MH provides more detailed loss estimates with a ShakeMap about 1 hour after an earthquake. ($40 million was spent in its development). There is a technique for creating an international region; population density can be used to develop a surrogate building inventory. HAZUS is consequence driven. Quality building data will include Seismic Design Level as well as structural system data. There are about 24 counties using HAZUS outside of the USA. See Natural Hazards Review paper by Bausch.

There are 10 FEMA regions in the United States.

Level 1 National activation with losses greater than $1 Billion

Level 2 Divisional activation with losses in the $100M to $1B range

Level 3 Regional Activation with losses in the $1M to $!00M range

These levels are not well correlated with earthquake magnitude, nor well correlated with earthquake fatalities. These levels correlated well with Earthquake Damage.

HAZUS can be used to determine anticipated S&R teams based on damage for certain classes of buildings

In 2011 there will be a National Level Earthquake Exercise for the greater New Madrid.

Q&A: There is a need to for building data in HAZUS.

10:00 Earthquake Loss Estimation in China with GEDAS and ArcGIS – Presentation by NERSS and discussion

-Presentation by Dr. LI Yigang

GEDAS is tool that was developed after the 2008 Wenchuan earthquake, incorporating earthquake information and casualty loss estimation for China International Search and Rescue (CISAR) decisions. Geologic data and population data estimated from Landscan imagery is utilized. Earthquake and Tsunamis are included.

Alerts include short text messages, multimedia messages, and email messages similar to but less detailed than PAGER

National Earthquake Damage Estimation System Applications for China:

More detailed data

Losses and damage probabilities

Landslides

Fires

Dams

Fatalities

Urban Area Earthquake Disaster Information Management System: Risk and Vulnerability Analysis for a combined hazard mitigation and emergency operations plan

10:25 Lessons from Past Earthquakes for Improving Disaster Response– -Presentation by Dr. NING Baokun

10:45 Visiting NERSS

There have been about 150 earthquake responses by NERSS since its inception

There is about a 24 hour period after an major earthquake before CISAR is deployed

11:00 Presentation of Future Work towards New Applications and Tools– by NERSS

Discussion and plans for future contact and research collaboration areas– Lead by Mr. QU Guosheng

A. New Global USGS Loss PAGER System and related activation levels for
    a. domestic China application with data needs identified.
    b. Response of FEMA, theory and practice of Search and Rescue, and mechanism of Management & Training
B. Use of Twitter feeds for rapid earthquake notification and situational awareness and case examples from the USA
    a. Relationship between PAGER and Did You Feel It?
C. Methodology of Loss Estimation, Impact Analysis and Applications in the USA and China
    a. Early warning estimation, faster time estimates during response, operations, and ground-truthing, and dealing with data gaps
D. HAZUS applications in China
    a. Cases of applications in emergency management and Search and Rescue in the USA and elsewhere
    b. There is a lack of building information in rural areas.

Mr. BAUSCH

- Loss Estimation
- Loss Pager – Interpretation of Pager with China building data
- Ground Motions for Scenarios
- Continual updating of loss estimates with greater detail

11:15 Wrap-up comments by NERSS and USA team leaders

<u>Discussion of future earthquake conferences where further collaborative planning meetings leading towards joint papers can occur</u>

Doug Bausch prepared an invitation letter for Dr Qu and his colleagues to visit the FEMA facilities in Denver and continue collaboration on the loss modeling potential. A visit to the NEIC will also be incorporated.

A joint workshop in the USA in August-2011 was proposed, perhaps in conjunction with a NorthCOM conference in Denver or Colorado Springs. A mid-July 2011 Natural Hazards Conference at the University of Colorado, Boulder. Topics:

- Emergency Management
- Search & Rescue
- Loss Assessment
- Establishing training for provincial teams and certification

Areas of possible collaborative research:
A joint MOU will need to be drafted for presentation to the China Earthquake Administration. (The task of preparing the first draft was later requested by Dr. QU to be done by the USA.)

At the banquet we discussed collaborating with Beijing Normal University on a demonstration project in Southwest China that integrates HAZUS

11:40 Adjournment and informal individual discussions thereafter

11:45 Departure

Additional Contact Information:

XU Zhizhong, Department of S&T and International Cooperation, China Earthquake Administration, xuzhizhong@gmail.com , Tel: +86 10 88015535

Douglas Bausch douglas.bausch@dhs.gov (303) 263-0949

Gary Chock gchock@martinchock.com (808) 521-4513

Chaoying Luo cy@johnmartin.com

Meeting with National Earthquake Response Support Services [NERSS]
Monday, October 18, 2010

Professor Qu and one of the NERSS S&R team members during a tour of their ready to go supply area

Meeting with National Disaster Reduction Center of China (NDRCC)
Monday, October 18, 2010

Attendees:
From China:
Suju LI, Deputy Director (lisuju@ndrcc.gov.cn)
Fan Yida, Professor, Expert Committee of China National Committee for Disaster Reduction Secretary-General (fanuyida@ndrcc.gov.cn)
Wu Wei, Remote Sensing Department, Office of China National Committee for Disaster Reduction (wuwei@ndrcc.gov.cn)
Zhang Yunxia, Deputy Director, Disaster Information Department National Disaster Reduction Center of China (zhangyunxia@ndrcc.gov.cn)

From US:
Tom Tobin
Rich Eisner
Yumei Wang
Marjorie Greene
Chao Ying Luo

Professor Fan led the meeting. He began by making a brief presentation on the role of the National Disaster Reduction Center –they operate a disaster data center, satellite operations center and international cooperation. In China there are 34 departments or agencies involved in disaster management. There is a General Office, with a Board of Experts that feeds into the NDRCC, which is in turn part of the National Commission. They operate a Satellite Operations Center for Disaster Reduction, and a National Natural Disaster Database.

They hope to train up to 700,000 information officers by 2015. They deal with three types of damage assessment—risk assessment, loss assessment and working assessment for disaster relief. There are four levels of disaster. The highest or most severe is the first grade, involving the vice premier of the state council. The second level involves the minister of civil affairs. The third level involves the vice minister of civil affairs, and the 4th level involves the Department of Disaster and Social Relief. For each level of response, there are different actions.

They are interested in exploring space technology and risk assessment, early warning, monitoring and damage assessment. In September 2008 they launched two satellites, and have been conducting joint monitoring in Africa and Australia.

They also have a group that does disaster reduction policy research. And they are interested in international exchanges and cooperation.

There was discussion of seismic design for buildings at the end of the meeting. Seismic designs apply across the country. For schools and hospitals there are different standards.

The U.S. and China share a similar problem in that owners do not want to upgrade their buildings. In China the government is forcing schools and hospitals to upgrade. In Beijing all the schools are upgraded. The Ministry of Education oversees school retrofit. They are spending up to a trillion yuan over 5 years for the retrofit of schools and hospitals, in different departments and different programs.

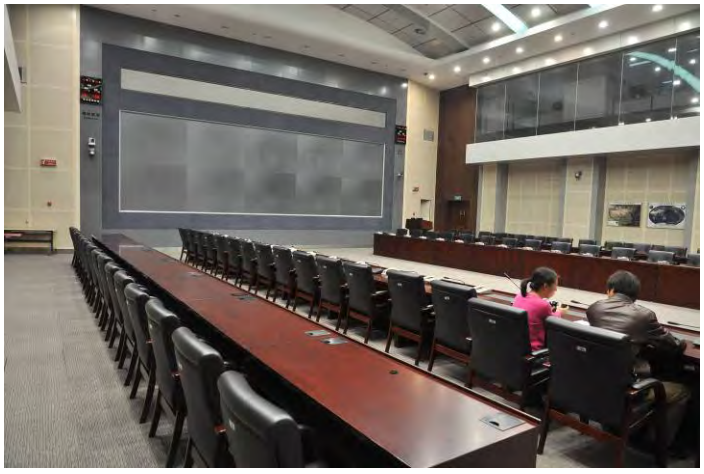
From left to right, back row: Marjorie Greene, Tom Tobin, Zhang Yunxia, Rich Eisner, Fan Yida, Chao Ying Luo
From row, l to r: Wu Wei, ???, Yumei Wang, ???, Suju Li

China Earthquake Administration
China Earthquake Network Center (CENC)

Meeting – October 18, 2010 - 1:30 pm to 3:00 pm

Present from USA - Mark Petersen, Ken Stokoe, Mathew Francis, Dennis Hwang, Ivan Wong
Present from China – Deputy Director HE Qin, 5 Nanheng St. Sanlihe, Beijing 10045, P.R. China – Tel: - 86-10-59959205, 58320605 Fax: 86-10-59959214 – Mobile: 13910879374; heqincn@yahoo.com.cn

Introductions – Deputy Director HE briefed the USA team members. Most of his colleagues and senior staff were tied up with current emergency matters. Meeting was in the Emergency Control Center (see Photo). The control room is impressive in its size and complexity – multiple large video screens, data feeds and communications capabilities. We are uncertain if a similar combined facility exists in the U.S. for emergency response. The complex provides a range of earthquake disaster services from collecting and evaluating seismic data to coordinating emergency response and rescue, akin to a combination of FEMA, USGS and municipal OEM offices.



The Control Center helps coordinate functions at the National level between the National Government and local government after an earthquake. This Center is devoted solely for earthquakes. It accommodates combined jurisdictions within the control room akin to the NORTHCOM/ NORAD control room (i.e., many seats in the center for operations CENC personnel and provincial / local government officials).

CENC serves as an official government clearinghouse of multiple data sources, including their own monitoring stations. They receive and process raw data and from multiple sources and provide data analysis and forecasting. They host a 24 hour hotline and data center for the seismic feeds. They disseminate processed seismic data to local fire, police and military officials. They also collect first responder data and victim reports and coordinate between the responding parties. Thus, they aid in determining the most damaged areas to direct resources to that area. Having a single joint disciplinary and operational center dedicated to earthquakes is a sound strategy given the high vulnerability and frequent seismic events throughout the country as compared to the USA.

Left to Right - Matt Francis, Dr. Mark Petersen, Deputy Director HE Qin, Dennis Hwang, Dr. Ken Stokoe, and Ivan Wong.

The meeting in the Control Center, this was followed by a brief tour of the building, which included its structural framework, largely underground for security. The building has a reinforced concrete frame, shear walls and a multi-layer rubber bearing base isolation system. The building is design to withstand and remain operational following a large, as a designated piece of critical infrastructure. The building is new; we believe it opened in 2010.

The briefing was followed by a tour of the data collection center that monitors earthquake activity 24/7. There 5-10 people in data processing and 5-10 in first responder call center all the time. One of the scientists/observers explaining the level of earthquake activity in China in real time. Data was provided about the number of monitoring stations established throughout China, and broadcasting of geological information and evaluation reports to interested or affected parties.

They are also involved in forecasting with an entire floor devoted to this activity, but we did not visit the forecasting floor. CENC has an active network monitor livestock, water pressure from groundwater and other criteria, which is fed into predictive probabilistic and deterministic models. They recognize the importance of forecasting within broad limitations of accuracy, adopting a philosophy is to get the word out and respond, even if there are false alarms, versus not responding at all. They have many resources devoted to forecasting and their center is well funded.

The USA team learned of the different structure for earthquake response from the CENC (multi-disciplinary for one hazard versus a single discipline but multiple hazards in the US). Areas of future research and collaboration include determining the advantages and disadvantages of the different models and adopting the strengths of each system. One limitation may be inflexibility in incorporating third party subsequent evaluations to revise official data conclusions, since CENC has a monopoly of authority. Unfortunately, there were no first responders from the USA team at the meeting. FEMA first responders dealing with earthquakes would be a good target for future collaboration with CENC, as would animal scientists and groundwater hydrologists evaluations the seismic prediction program.

Suggested Additional Follow-up includes work on developing parallel forecast models for tsunamis and earthquakes. These models are evolving and not widely accepted in the US, and could develop useful calibrations between work products by USGS/NOAA and CENC, well as developing joint understandings of the relationship between local and national earthquake response operations to military support, such as NORTHCOM and the US National Incident Management System (NIMS).

Meeting with China Development Research Foundation [CDRF]

Monday, October 18, 13:30 – 16:00

Meeting Agenda

13:45 Welcome – Dr. TANG
CDRF is a "GONGO", that is, a government and corporate sponsored NGO that conducts policy research.

13:55 Overview of meeting objective – Mr. CHOCK

14:00 Self-introduction of China and USA participants
Attendees:

China: Dr. TANG, Min [economist] CDRF Deputy Secretary-General tangmin@cdrf.org.cn 86 10 84080188 – ext 8015
Dr. FENG, Wenming fengwm@cdrf.org.cn 86 10 84080188 – ext 8014
Ms. DIAO, Linlin [Intl relations] diaoll@cdrf.org.cn 86 10 84080188 – ext 8052
Mobile 13911006630

Guest:
Dr. DAI, Junwu CEA Institute of Engineering Mechanics
junwudai@126.com Tel 0451-86652663, mobile 13796094076
Head of the Division of Science and Technology

USA: Mr. CHOCK, Gary
Mr. TOBIN, Thomas
Mr. BAUSCH, Douglas
Dr. ABRAMS, Daniel
Mr. EISNER, Richard
Ms. GREENE, Marjorie
Dr. LUCO, Nicolas
Ms. LUO, Chaoying
Dr. MIRANDA, Eduardo
Dr. SINGH, J. P.
Dr. THEODOROPOULOS, Christine
Ms. WANG, Yumei
Dr. YU, Guangren

14:15 China's seismic design and construction codes applicable to buildings, housing, urban and rural development – Presentation by Mr. CHOCK

14:30 Hazard mitigation of schools and emergency response buildings such as hospitals – Presentation by Dr. MIRANDA

14:45 Role of NGO's in earthquake response – Discussion by Dr. TANG

Compared to the USA, the role of NGO's in Chinese society is rather limited. However, after the Great Wenchuan earthquake, many NGO's became involved. NGO's contributed about RMB 30B, which required coordination from the central government.

Building performance in rural areas was rather poor, although confined masonry had better performance. A Chinese rural house may cost between $500 to $5000. Annual average wages in rural areas is just $200 to $600. Therefore, simple solutions for improving seismic safety are needed. There is no earthquake insurance in China.

15:10 Seismic retrofit of rural residences in Tibet – Presentation by Dr. FENG and discussion
Dr. FENG is responsible for a multi-year program of earthquake awareness training for mayors, and is involved since September 2009 in the pilot implementation of "PP" band wrapping of masonry walls per the retrofit technique created by Kimio Meguro of the University of Tokyo

The project is located in Lhasa, Tibet in which 10 to 15 homes are expected to be retrofitted sometime in 2010 or 2011. (None have yet been done.)
Work has been under the guidance of consultant Dr. Meguro, who recommended this technique after China sent a report of existing conditions of home construction techniques in this area.
There were 7 prototypes tested for up to 1.2g at the IEM in Harbin [a written report was said to be available]
The "PP" band is actually a woven plastic packaging mesh applied on both sides of a unreinforced masonry wall with through-ties to each mesh inserted through drilled holes in the wall. The plastic mesh is protected from UV by 3 mm mortar skim coat.
Installed cost is anticipated to be $100 for a 90 square meter house.
The technique *will not* prevent structural collapse but may delay it, with the intent being for the occupants to escape from the building.
There are possible large-scale applications of this technique.

15:40 Discussion of potential research collaboration – Lead by Mr. Tobin

Richard Eisner discussed the VOAD [Voluntary Organizations Active in Disaster] as a model for how NGO's are utilized in disaster response and recovery in the United States.
- A webcast link on this subject would be sent to Dr. Tang.

Marjorie Greene expressed an interest in Tibetan home construction and the PP Band retrofit technique for adobe and brick construction for the EERI World Housing Encyclopedia.
- More information and the test reports were requested from Dr. Feng.

Daniel Abrams suggested that the Shake Table at NEES@UI could be used to study this technique further and whether it had any applications to URM walls in the USA.

16:15 Wrap-up comments by China and USA team leaders – Dr. TANG and Mr. CHOCK

16:30 Adjourn

Contact Information:

CHOCK, Gary, gchock@martinchock.com, Tel: 1-808-521-4513
TOBIN, Thomas, lttobin@aol.com

Seismic Retrofit of Rural Residence in Tibet

Wenmeng Feng

China Development Research Foundation

2010.10.18

Background 1

Tibet

- Location:
  Southwest of China
- Altitude:
  the “Roof of the World” with average altitude of 4,000 meters
- Area:
  1.2 million square kilometers
- Population:
  2.81 million (the end of 2006)

Buildings in Tibet

- The prevalence of masonry houses in rural Tibet…
- And with low earthquake-resistant capability…
- However, the local economic conditions are still not good…
- How to retrofit the existing masonry houses in an economical way?

Background 3

CDRF Training Program in Japan

- Time:
  September, 2009;
- Location:
  University of Tokyo
- Participants:
  Municipal Secretary of CPC or mayors of cities with higher probabilities of the happening of an earthquake
- One of the three topics:
  combating earthquakes.

Background 4

Introduction of PP-band Technology

- Technical Point:
  Using PP-bands to retrofit existing masonry structures

- Proposed by:
  Professor Kimiro MEGURO, ICUS, IIS, University of Tokyo

- Technical Feature:
  Local Applicability (technically easy, economically cheap, culturally acceptable, etc.)

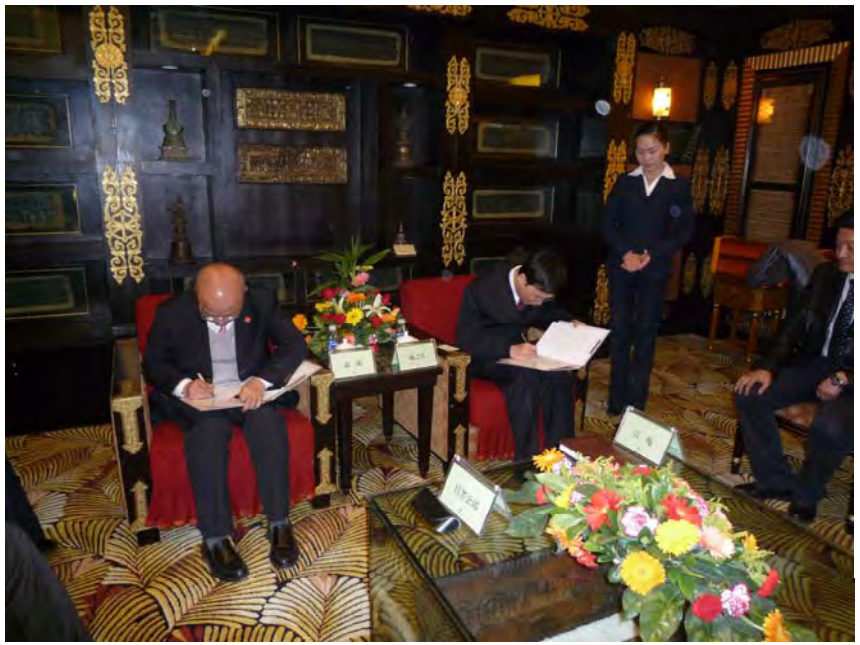
- Why PP-band?
  1) Cheap;
  2) Worldwide available;
  3) Tolerate large deformations;
  4) Durable;
  5) Easy to handle and transport

Pilot Project in Tibet

- Goal:
  Retrofit rural residence in Tibet using PP-band Technology

- Triggering:
  Upon the request of Lhasa government, CDRF planned, organized and participated directly the implementation of this pilot project;

- Three Phases:
  1) Field Investigation;
  2) Experiment;
  3) Pilot project in Lhasa rural areas



Field Investigation in Lhasa - 1

- Time:
  December, 2009

- Participants:
  1) Lu Mai, Secretary General, CDRF;
  2) Guoqing Gao, Office Director, CDRF;
  3) Wenmeng Feng, Program Officer; CDRF.

- Purpose:
  To Investigate the architecture features of rural houses in Lhasa

- Outcome:
  Information regarding the architecture features of more than 16 rural houses were collected; communication with Professor MEGURO's research team.

Field Investigation in Lhasa -2

- Time:
  April, 2010;

- Participants:
  1) kimiro Meguro,
  Professor, University of Tokyo;
  2) Koichi, Numada,
  Research Assistant, University of Tokyo;
  3) Wenmeng Feng,
  Program officer CDRF.

- Outcome:
  Furthered the understanding regarding the architecture features and the local geographical characteristics.

Experiment

- Period:
  April 2010 to August 2010

- Purposes:
  1) to test the applicability and effectiveness of PP-band technology in retrofitting the rural residence in Tibet;
  2) to provide technical training to the local engineers

- Location:
  Institution of Engineering Mechanics, China Earthquake Administration, Harbin, Heilong Jiang province.

- Participants:
  1) CDRF
  2) IEM, CEA;
  3) Lhasa government
  4) MEGURO Team,

- Outcome:
  1) testified the effectiveness of PP-band technology in retrofitting the rural residence in Tibet ;
  2) worked out an operational instructions in the implementation of the PP-band technology

Current Status of the Pilot Project

- Introduction to the local residents and the trial on the spot;
- Manufacturing of the first machine to produce PP-mesh;
- Implementation of the Pilot Project in 2010:

  1) PP-band technology is to be applied to 10-15 houses in the retrofitting of rural residence in the coming days;

  2) more applications are expected in 2011.

Thank you for your attention!

China-US Symposium Programme October 19, 2010

中美地震科学与减灾学术研讨会

China-USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices

会议手册
PROGRAMME

2010年10月19日
中国 北京 全国人大会议中心

October 19, 2010 Beijing, China
The Conference Center of the National People's Congress

主办单位 Organizer
国际欧亚科学院中国科学中心
China Science Center of International Eurasian Academy of Sciences

承办单位 Co-organized by
中国建筑学会
The Architectural Society of China (ASC)
中国建筑科学研究院
China Academy of Building Research (CABR)
中国城市规划设计研究院
China Academy of Urban Planning & Design (CAUPD)

支持单位 Supported by
中国国际友好联络会
China Association for International Friendly Contact
夏威夷中华总商会
Chinese Chamber of Commerce of Hawaii

Daily Program for USA Team

October 18 (Monday)

Full day: Arrival of USA Team, stay at NPC Conference Center (hotel)
18:00-20:00 Informal Dinner at NPC Conference Center

October 19 (Tuesday)

Full day for conference (NPC Conference Center)
09:00-09:20 Opening
Chaired by the organizer
Welcome address by the organizer
Address by the representative of USA Team
Welcome address by the co-organizer
09:20-09:30 Tea Break

Morning Session Chaired by ASC

09:30-10:00 Gao Mengtan, Professor, Deputy Director of Institute of Geophysics, China Earthquake Administration
— Seismic Risk and Mitigation of Catastrophic Earthquake in China
10:00-10:40 USA Speakers of group (1)
— Hazard Assessment and Mapping
10:40-11:10 Zhou Xiyuan, Academician of China Academy of Science, Researcher from China Academy of Building Research
— Seismic Zoning and Earthquake Protection of Building Structures
11:10-11:50 USA Speakers of group (2)
— Building Codes and Multi-Hazard Design
11:50-12:00 Q & A, summing-up of the morning session
12:00-13:30 Lunch (NPC Conference Center)

Afternoon Session (1) Chaired by the USA Team

13:30-14:00 Li xiaojiang, President of China Academy of Urban Planning & Design
— Post-disaster Reconstruction and Urban Safety
14:00-14:40 USA Speakers of group (3)
— Hazard Mitigation of Critical and Important Facilities
14:40-15:10 Qiu Jian, Chief Planner, Bureau of Urban & Rural Construction of Sichuan Provincial Government
— Planning and Design for Post-Wenchuan Earthquake Reconstruction in Urban and Rural Areas of Sichuan
15:10-15:20 Tea Break

Afternoon Session (2) Chaired by CABR

15:20-16:00 USA Speakers of group (4)
— Pre-Disaster Planning and Mitigation and Emergency Response
16:00-17:00 Q & A, summing-up of the afternoon session
17:00- End of conference
18:00- Welcome Dinner hosted by the organizer and co-organizers (at NPC Conference Center)

October 20 (Wednesday)

Morning: From Beijing to Mianyang by CA1451 (07:45-10:15)
Afternoon: Visit Earthquake Sites and reconstruction of Beichuan County Town

October 21 (Tuesday)

Morning: Roundtable exchange with local professionals
Afternoon: Visit the reconstruction projects of villages
Evening: Mianyang to Beijing by CA1456 (20:10-22:35)

October 22 (Friday) Departure

Master List of USA Symposium Papers by Group Session

Group 1	**Hazard Assessment, Mapping, and Siting**
Ivan Wong:	Executive Summary of Symposium Papers: Hazard and Risk Assessment, Mapping, and Siting
Kenneth Stokoe II:	Experience with nees@UTexas Large-Scale Mobile Shakers In Earthquake Engineering Studies
Mark Petersen:	Seismic Hazard Mapping in China and the United States
Ivan Wong:	Development of Urban Earthquake Hazard Maps in the United States
Mathew Francis:	Geological Hazards for Siting Consideration (Landslides, Liquefaction, Surface Faulting, Ground Rupture)
Douglas Bausch:	Earthquake Scenarios and HAZUS Applications in the U.S.
Dennis Hwang:	Key Concepts in Implementing Hazard Mitigation Practices
Group 2	**Building Codes**
Gary Y.K. Chock:	Executive Summary of Symposium Topic Papers: Building Codes
Gary Y.K. Chock:	Overview of Current USA Seismic Design Provisions for New Construction
Guangren Yu, et al:	Comparison of USA and China Seismic Design Procedures
James Harris:	Target Seismic Reliability against Collapse in USA Codes and Assessment of Variations in Expected Performance
Nicolas Luco:	Preparation of USA Seismic Design Maps and Associated Web Application
Daniel Abrams:	USA Seismic Rehabilitation Methodologies for Unreinforced Masonry Buildings
Group 3	**Hazard Mitigation of Critical and Important Building Construction**
Ian Robertson:	Executive Summary of Symposium Papers: Hazard Mitigation of Critical and Important Building Construction
Ian Robertson:	Current Technologies and Future Research Trends for Seismic Hazard Mitigation of Critical and Important Building Construction
Eduardo Miranda:	Building-Specific Loss Estimation for Performance Based Design
M.Walker, et al, and J.P. Singh:	Site-Specific Ground Motion Criteria for Performance Based Design for Critical Facilities
Kit Miyamoto:	Collapse Hazard and Design Process of Essential Buildings with Dampers
Christine. Theodoropoulos:	Implementation of Seismic Regulations for Nonstructural Components in Essential and Important Buildings in the United States
Group 4	**Pre-Disaster Planning, Mitigation and Emergency Response**
L. Tom Tobin:	Executive Summary: Pre-Disaster Planning, Mitigation and Emergency Response
L. Tom Tobin:	Risk Reduction and Management Responsibilities in the United States
Richard Eisner:	Emergency Preparedness and Planning in the USA National Incident Management System and the Primary Role of Local and State Governments
Yumei Wang:	Earthquake Risk Management Approaches for Civic and Critical Lifeline Infrastructure:Applications in Oregon
Marjorie Greene:	The Role and Importance of an Independent Multidisciplinary Technical Society, with Examples of the Benefits to the Earthquake Professions
L. Tom Tobin:	Community Action Plan for Seismic Safety (CAPSS) Project

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Executive Summary of Symposium Papers: HAZARD AND RISK ASSESSMENT, MAPPING, AND SITING

Ivan G. Wong

The first step in effective earthquake hazard mitigation is the identification and quantification of seismic hazard and risk. Of course, unless this type of information is conveyed effectively to stakeholders and decision-makers, mitigation efforts will unlikely be implemented either at all or in a meaningful way. Siting is an important tool in hazard mitigation. The following series of papers describes and summarizes the approaches used in the U.S. to evaluate earthquake hazards and risk and to communicate that information to those who can implement it.

Experience With nees@UTexas Large-Scale Mobile Shakers in Earthquake Engineering Studies (Kenneth Stokoe, II)

The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) is a US-wide program that is supported by the National Science Foundation. NEES is composed of a network of fifteen testing facilities, called Equipment Sites, that are spread across the United States. The Equipment Site specializing in mobile, geotechnical, field equipment was developed at the University of Texas at Austin named nees@UTexas. Operational since October 2004, nees@UTexas is a 50% shared-use facility. In the past three years, nees@UTexas has conducted nine shared-used projects and numerous non-shared-use projects. Experience with the shakers is discussed for: (1) deep shear wave velocity profiling in the Mississippi Embayment, (2) in-situ nonlinear shear modulus measurements of soil, (3) field dynamic tests of 1/4-scale bridge bents founded on drilled shafts, and (4) in-situ liquefaction tests in Imperial Valley, CA. Test arrangements and representative results from these projects will be presented.

Seismic Hazard Mapping in China and the United States (Mark Petersen and Mengtan Gao)

China and the United States share similar seismotectonic characteristics that lead to significant seismic hazard and risk in highly populated urban areas. During the past few decades several large earthquakes have inflicted billions of U.S. dollars/China Yuan in losses and caused many casualties, injuries, and societal problems within the nearby impacted areas. China and the U.S. have taken important steps in risk mitigation by developing new national seismic hazard maps and tools for rapidly assessing ground shaking and losses following an earthquake. These hazard maps are based on the “best available science” and form the framework of building design codes that when properly applied can mitigate the building collapses that cause most casualties and losses. Rapid assessments of ground shaking and losses can help officials in emergency response following a large, damaging earthquake. The international seismic hazard community should continue to share strong-motion data, hazard and risk methodologies, and collaborate in setting standards for urban hazard models and design guidelines.

Development of Urban Earthquake Hazard Maps in the United States (Ivan Wong)

In the past decade, earthquake ground shaking hazard maps for urban areas in the U.S. have been developed by the U.S. Geological Survey and URS Corporation. These maps illustrate the intensity and variability of ground shaking at a microzonation scale due to the local site response of both soil and rock. Both earthquake scenario and probabilistic maps generally for the building code probabilities of 10% and 2% exceedance in 50 years (return periods of 475 and 2,475 years, respectively) have been developed. Ground motions are generally expressed in terms of peak horizontal acceleration and the building code-specified spectral accelerations at periods of 0.2 and 1.0 second. The maps are and can be used in a number of ways such as increasing general public awareness of earthquake hazards, urban planning, selecting facility sites, providing a basis for whether site-specific hazard evaluations should be performed, aiding emergency preparedness and response, and loss estimation.

Geologic Hazards for Siting Considerations (Mathew Francis)

Seismic hazard mitigation for infrastructure requires identifying hazards (both variety and scale) and implementing correlating protections (i.e., modification to infrastructure) within constraints of functional

objectives and feasible siting. Mitigation constraints and opportunities vary significantly depending upon the scale of potential damages and the siting flexibility among three classes of mitigation: 1) new developments; 2) existing developments; and 3) disaster recovery.

A logical planning sequence for each class of problem requires using best available hazard and siting data at the earliest possible stage of development. Initial hazard and site screening should always precede detailed studies, which then can be focused upon aspects of greatest uncertainty or consequence. Modifying existing developments poses the greatest constraints to siting mitigations and therefore usually focuses more upon structural mitigations, though no site is exempt from relocation in the face of excessive hazard(s).

Varying uncertainties among hazards requires judgment to consider combinations of hazards and potential interactions for each site. This paper presents an overview of the following siting practices: 1) current U.S. approach to geologic hazards input for siting requirements; 2) current U.S. practices for evaluating predominant geologic hazards of earthquakes; and 3) recent advances in site hazard screening with desktop-level mapping and analysis using abundant digital data and "off the shelf" geographic information system (GIS) web tools.

The third topic is presented with greater emphasis in this paper to advocate initiating multi-hazard risk management practices across local or regional infrastructure portfolios. GIS-based interactive screening includes both new mapping and digitized old maps. Digital data can be efficiently combined for "layered" geohazard evaluations and computations giving rapid low cost preliminary risk evaluations over large areas. This provides a badly needed resource to aid developing nations in remote resource-limited locations of risk across the full range of infrastructure.

Earthquake Scenarios and HAZUS Applications in the U.S. (Douglas Bausch)

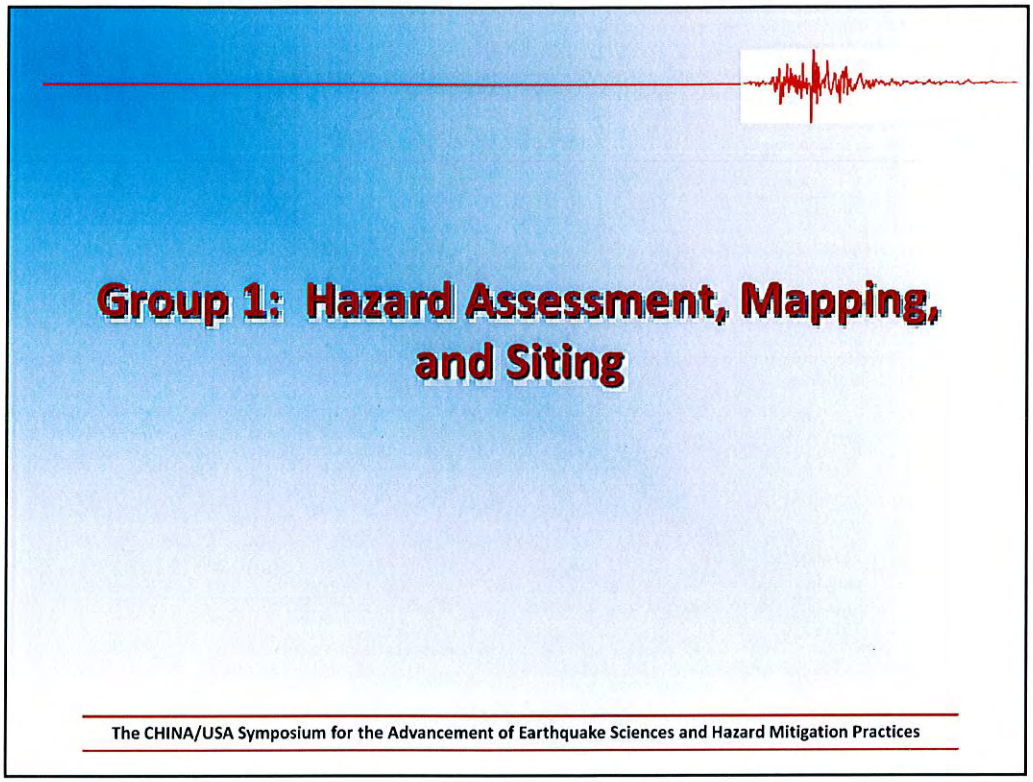
The Federal Emergency Management Agency (FEMA) developed the loss estimation software HAZUS and released the earthquake version in 1997. Since then FEMA has added flood loss and hurricane loss capabilities while continuing to improve the earthquake model. For more than a decade, a broad range of applications have emerged including the development of mitigation strategies, scenario driven catastrophic planning, exercise support, recovery and preparedness planning. This paper will introduce several potentially valuable applications for implementation in China.

HAZUS runs some 247 modules that estimate losses ranging from building damage to social losses including casualties and displaced households. Since HAZUS operates in a powerful GIS platform, it can display a variety of results with critical base layers. These maps and results can effectively communicate risk before the earthquake happens, as well as immediately after the earthquake for response and recovery applications. Some example applications of HAZUS that help identify vulnerabilities and develop mitigation strategies, as well as potential response and recovery needs will be discussed in this paper. While HAZUS can provide probabilistic results based on 8 different return periods or annualized results, scenario applications have helped support a broad range of emergency management activities. FEMA has coordinated with the U.S. Geological Survey (USGS) on the development of new products that support an extensive library of ShakeMap scenarios, largely based on the USGS National Hazard Map. The Earthquake Scenario Project (ESP), though still under development, is a forward-looking project, estimating earthquake hazard and loss outcomes as they may occur one day. For each scenario event, fundamental input includes i) the magnitude and specified fault mechanism and dimensions, ii) regional Vs30 values for site amplification, and iii) event metadata.

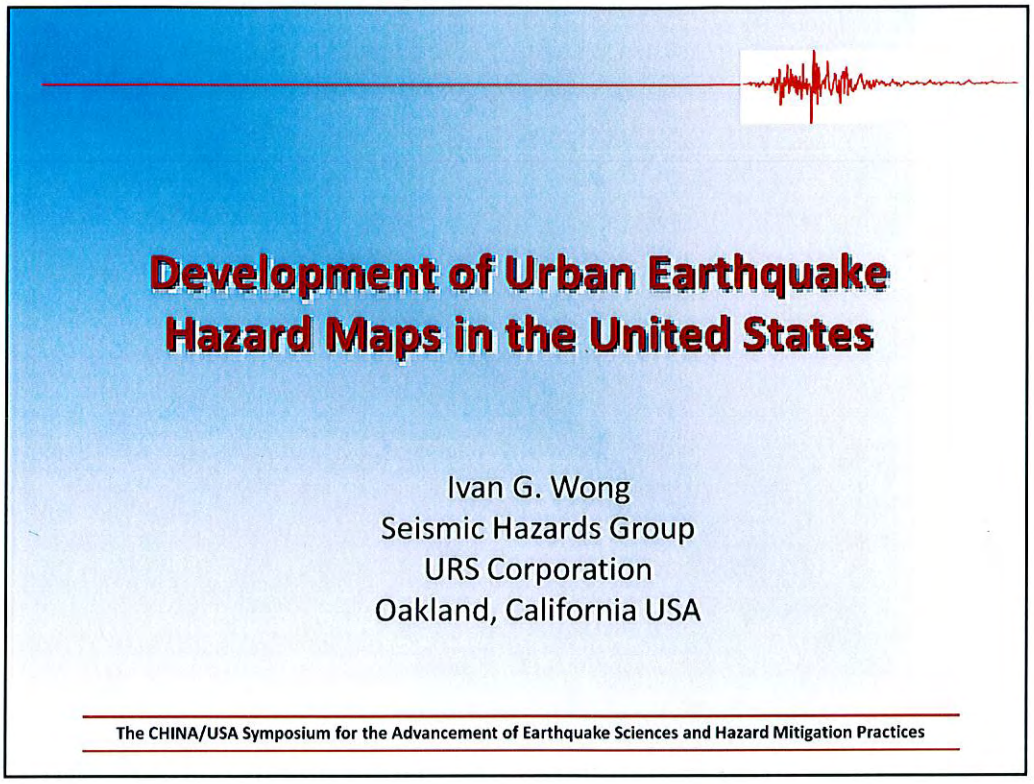
Key Concepts in Implementing Hazard Mitigation Practices (From Siting and Construction to Preparation and Response) (Dennis Hwang)

One of the greatest challenges for scientists, engineers and other technical professionals is to have their findings, recommendations or studies incorporated into the real world decisions of a community. For those practicing in the area of earthquake science and engineering, the goal of successful implementation is even more vital considering the potential risk to life and property for communities without proper design and hazard mitigation protection. In this paper, several concepts developed in the Hawaii Coastal Hazard

Mitigation Guidebook (Hwang, 2005), and later for Indonesia after the December, 26, 2004 tsunami (Hwang et al., 2005) and for Louisiana after Hurricane Katrina (Wilkins et al., 2008) are discussed for areas relevant to earthquake hazard mitigation. Three concepts covered in this paper relate to: (i) Multi-Hazard Design, (ii) Utilizing all tools for Hazard Mitigation including siting, and most importantly (iii) the Key Elements of Implementation. The concepts are universal and if applied, should lead to greater success with implementation and thus communities that are better protected from natural hazards. These concepts are later discussed in the context of the earthquake in Haiti and many of the works of authors on the USA team.



I will introduce the Group 1 participants and our topics. We will discuss hazard assessment, mapping, and siting practices in the United States.


Development of Urban Earthquake Hazard Maps in the United States
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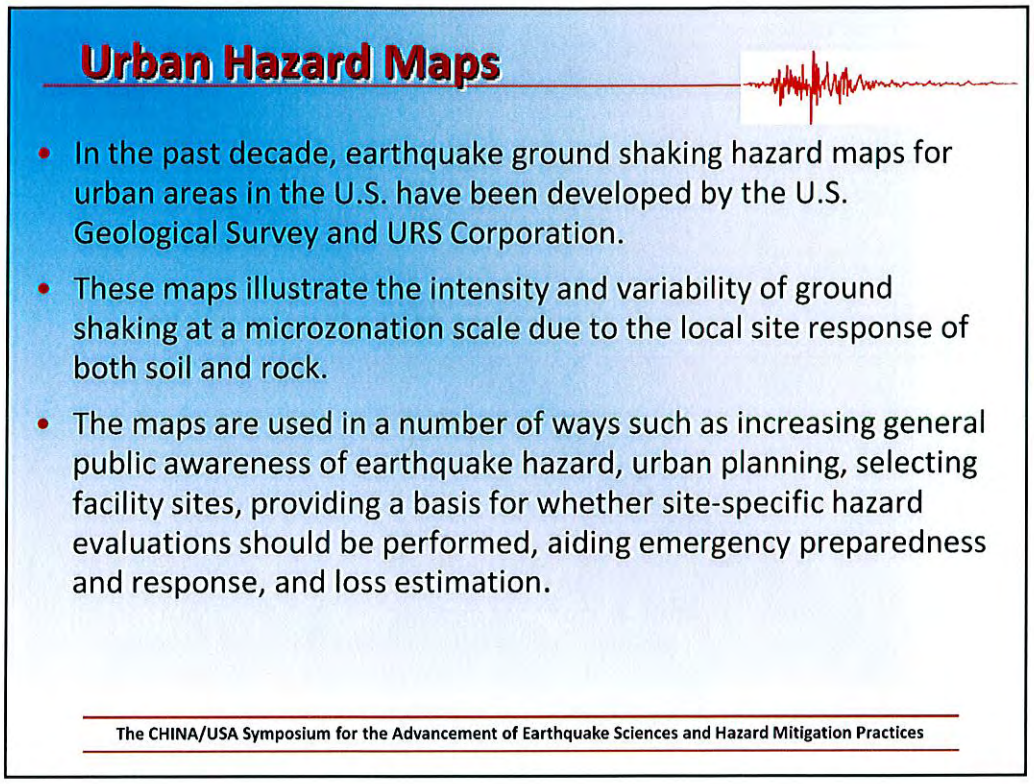
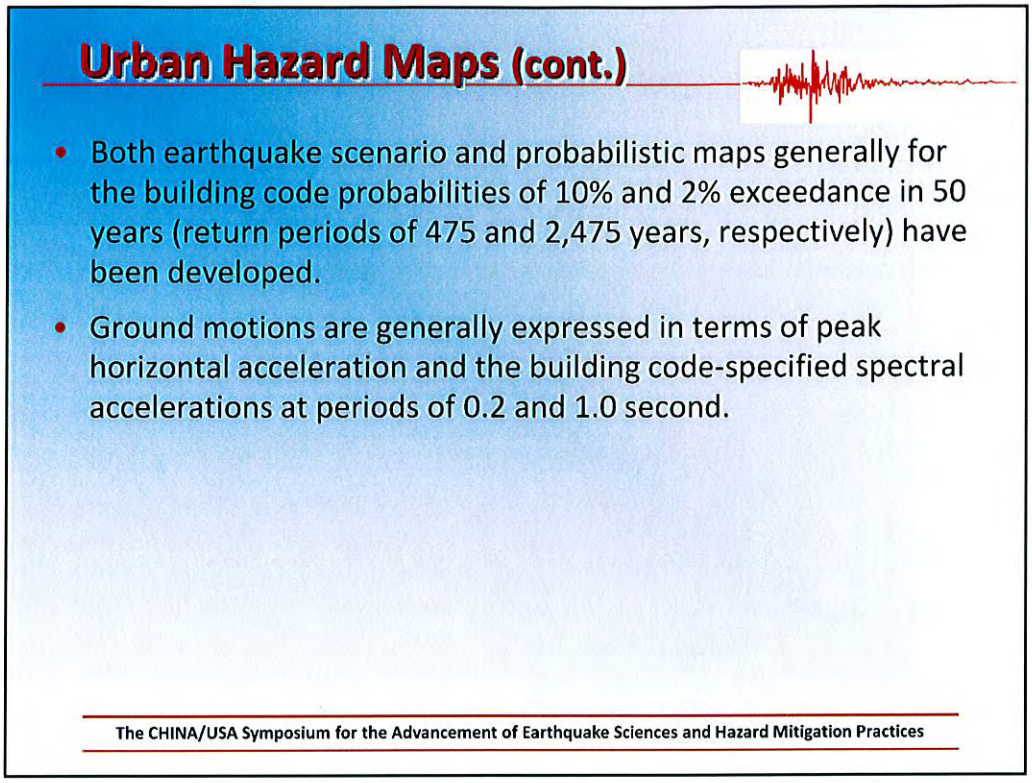
Seismic Hazards Group
URS Corporation
Oakland, California USA
The CHINA/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices



In the past decade, earthquake ground shaking hazard maps for urban areas in the U.S. have been developed by the U.S. Geological Survey and URS Corporation.

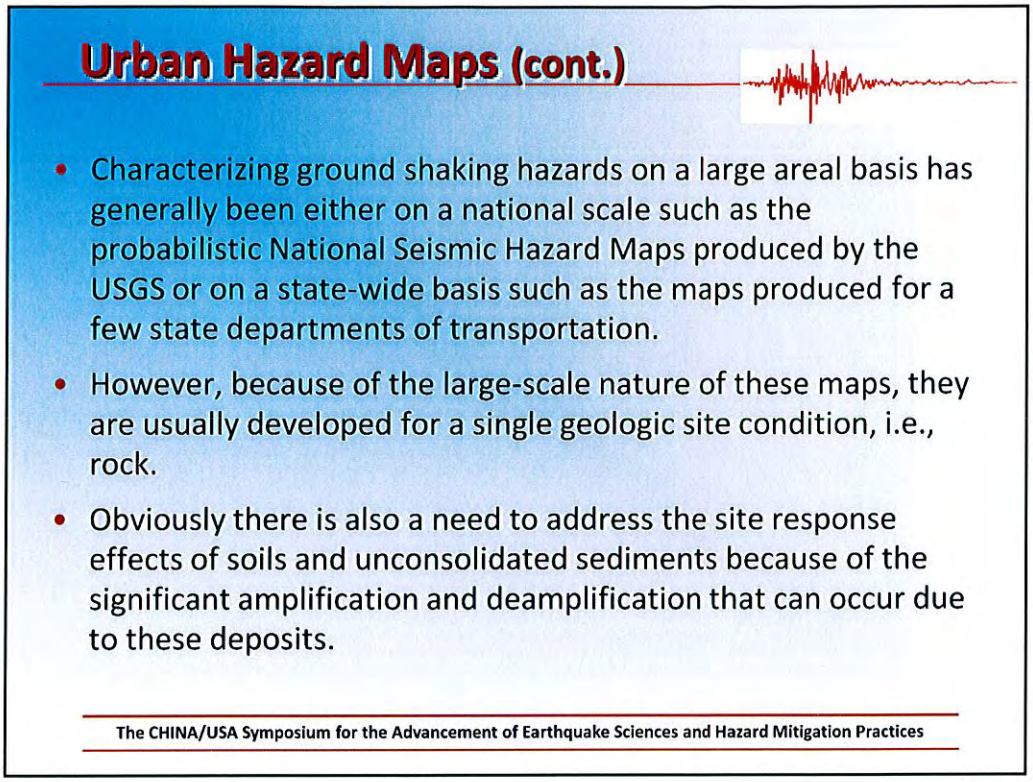
These maps illustrate the intensity and variability of ground shaking at a microzonation scale due to the local site response of both soil and rock.

The maps are used in a number of ways such as increasing general public awareness of earthquake hazard, urban planning, selecting facility sites, providing a basis for whether site-specific hazard evaluations should be performed, aiding emergency preparedness and response, and loss estimation.



Both earthquake scenario and probabilistic maps generally for the building code probabilities of 10% and 2% exceedance in 50 years (return periods of 475 and 2,475 years, respectively) have been developed.

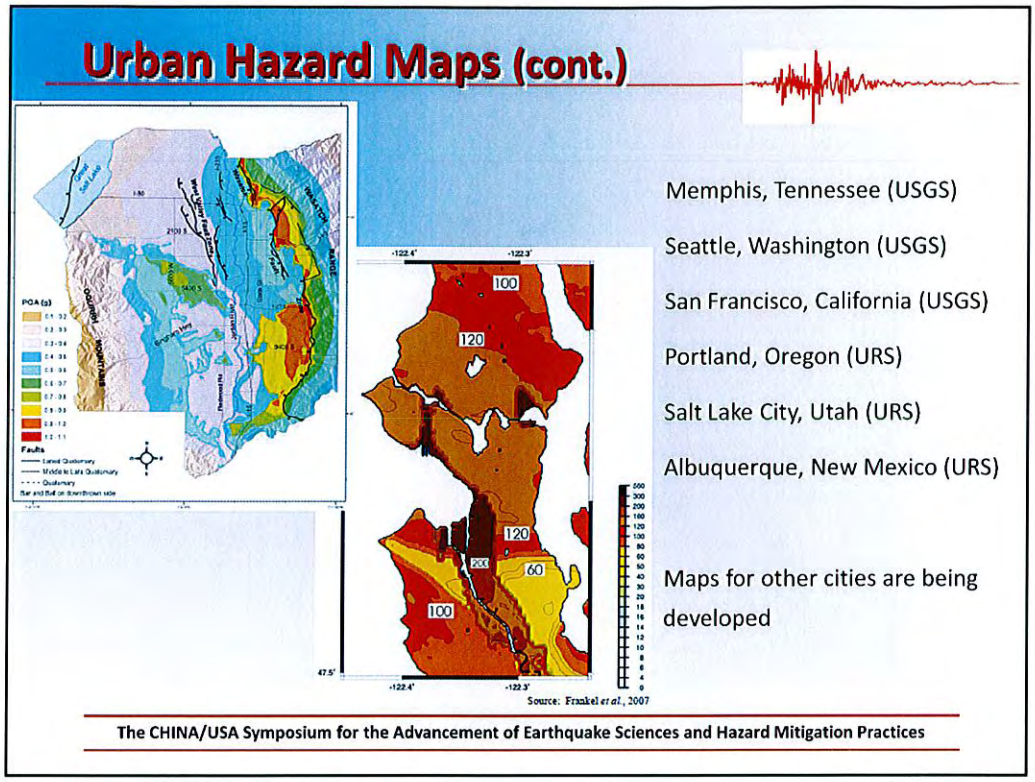
Ground motions are generally expressed in terms of peak horizontal acceleration and the building code-specified spectral accelerations at periods of 0.2 and 1.0 second.



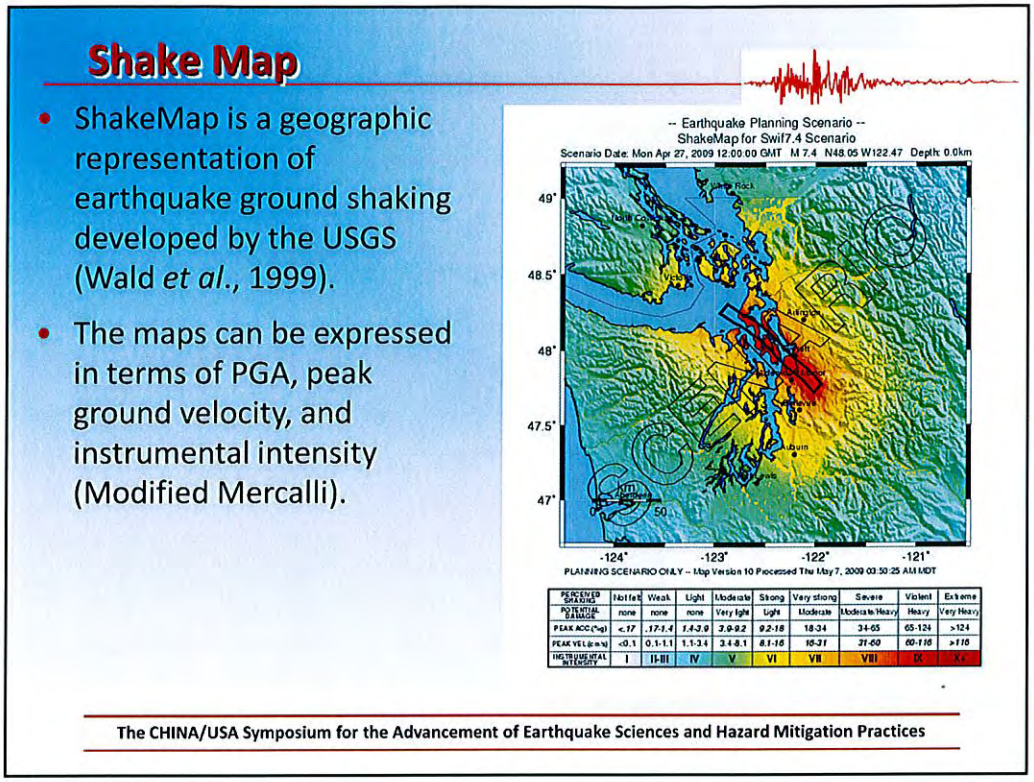
Characterizing ground shaking hazards on a large areal basis has generally been either on a national scale such as the probabilistic National Seismic Hazard Maps produced by the USGS or on a state-wide basis such as the maps produced for a few state departments of transportation.

However, because of the large-scale nature of these maps, they are usually developed for a single geologic site condition, i.e., rock.

Obviously there is also a need to address the site response effects of soils and unconsolidated sediments because of the significant amplification and deamplification that can occur due to these deposits.

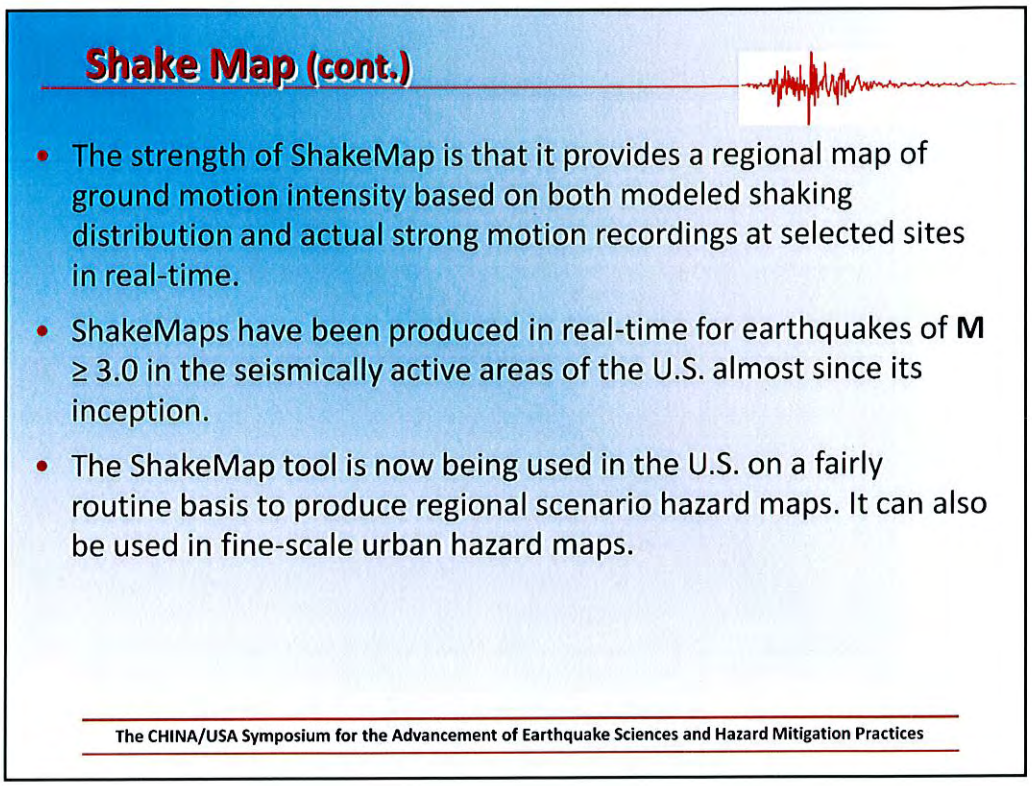


Several urban hazard maps have been developed in the U.S. by the USGS and URS Corporation. These include maps for Memphis, Tennessee; Seattle, Washington; San Francisco, California; Portland, Oregon; and Albuquerque, New Mexico. New urban maps are being prepared for Evansville, Illinois and revised maps for Portland, Oregon and Salt Lake City, Utah.



ShakeMap is a geographic representation of earthquake ground shaking developed by the USGS (Wald *et al.*, 1999).

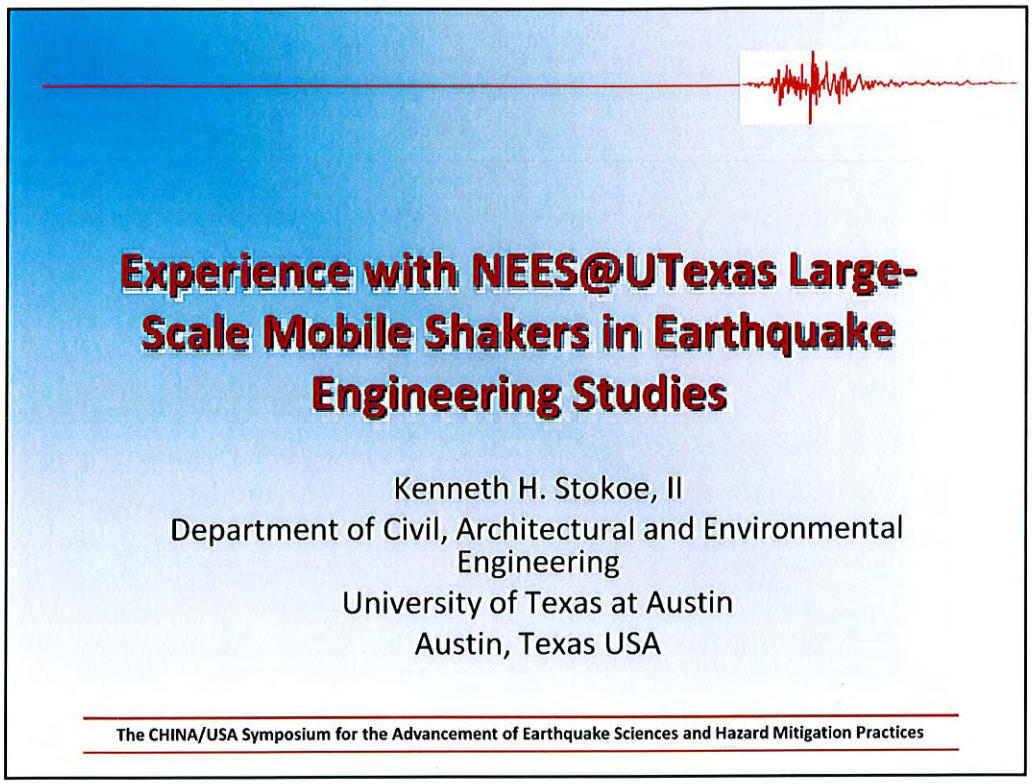
The maps can be expressed in terms of PGA, peak ground velocity, and instrumental intensity (Modified Mercalli).

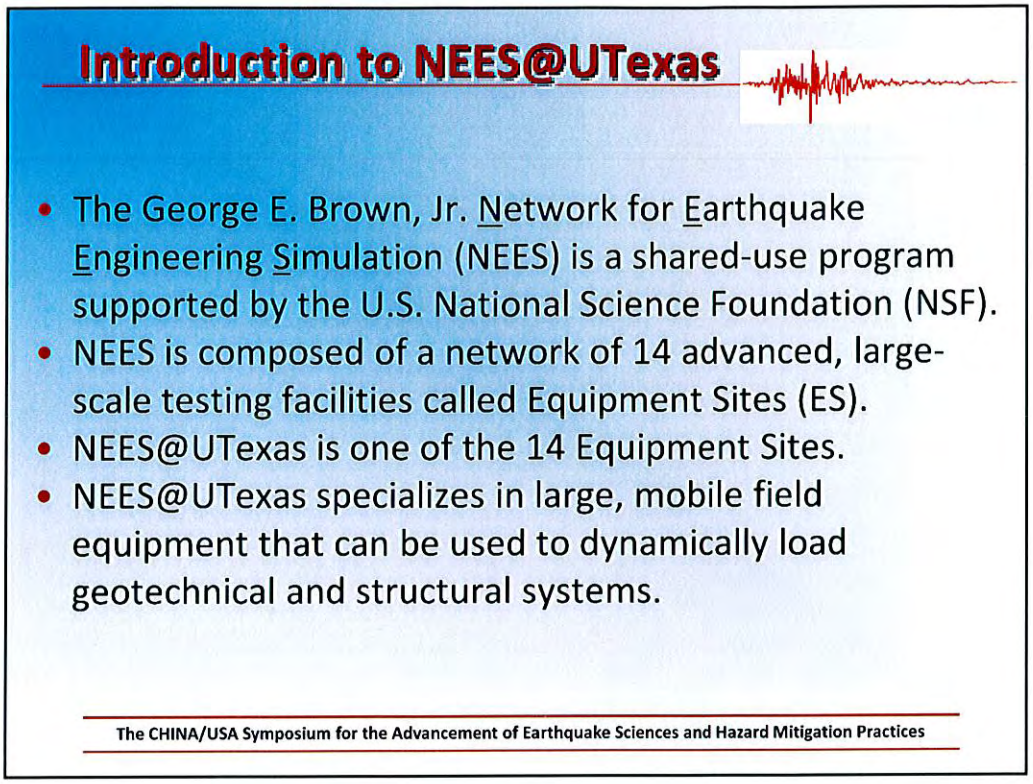


The strength of ShakeMap is that it provides a regional map of ground motion intensity based on both modeled shaking distribution and actual strong motion recordings at selected sites in real-time.

ShakeMaps have been produced in real-time for earthquakes of **M** ≥ 3.0 in the seismically active areas of the U.S. almost since its inception.

The ShakeMap tool is now being used in the U.S. on a fairly routine basis to produce regional scenario hazard maps. It can also be used in fine-scale urban hazard maps.


Experience with NEES@UTexas Large-Scale Mobile Shakers in Earthquake Engineering Studies
Kenneth H. Stokoe, II
Department of Civil, Architectural and Environmental Engineering
University of Texas at Austin
Austin, Texas USA
The CHINA/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices

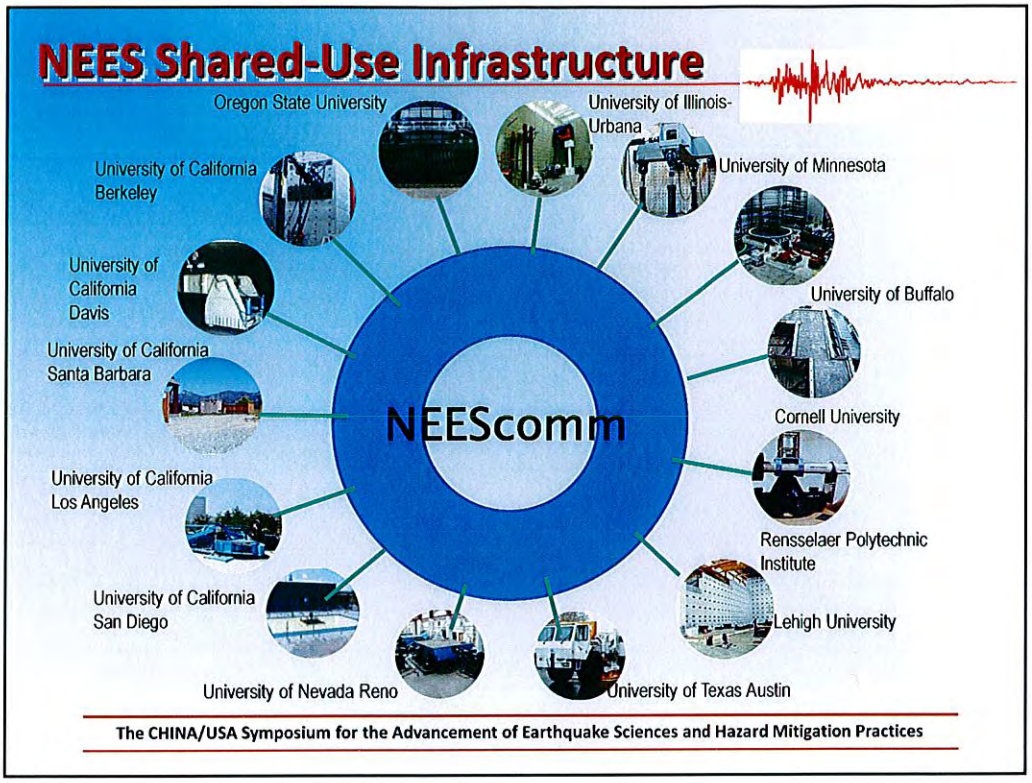


The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) is a shared-use program supported by the U.S. National Science Foundation (NSF).

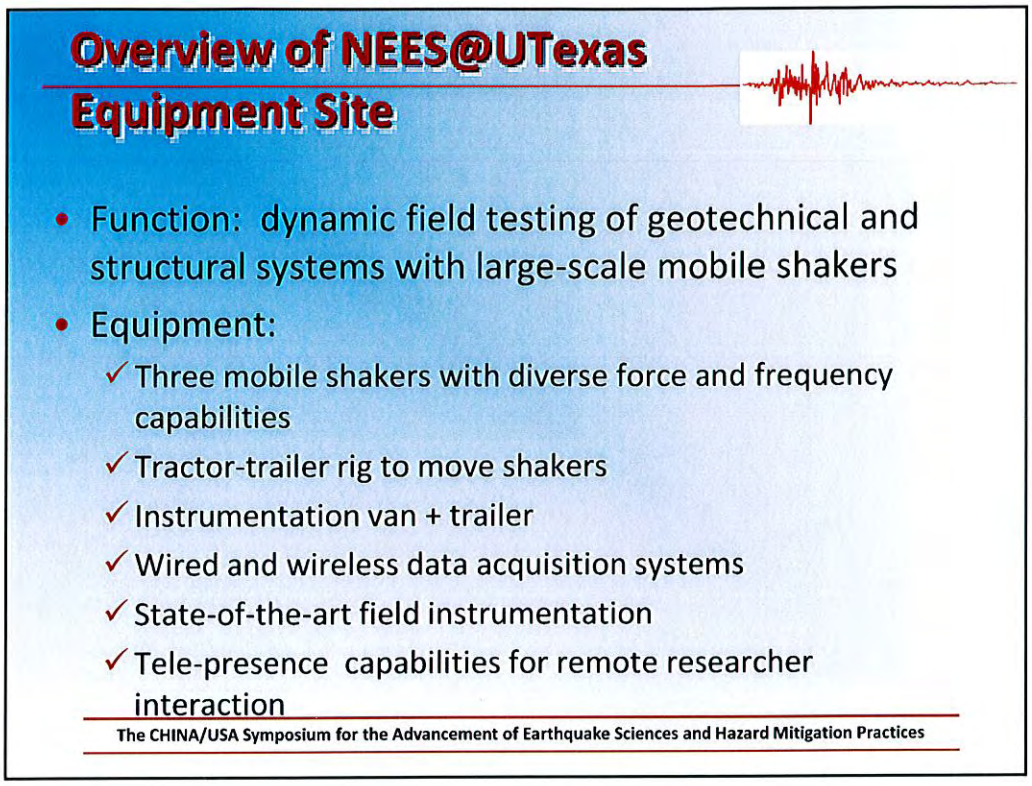
NEES is composed of a network of 14 advanced, large-scale testing facilities called Equipment Sites (ES).

NEES@UTexas is one of the 14 Equipment Sites.

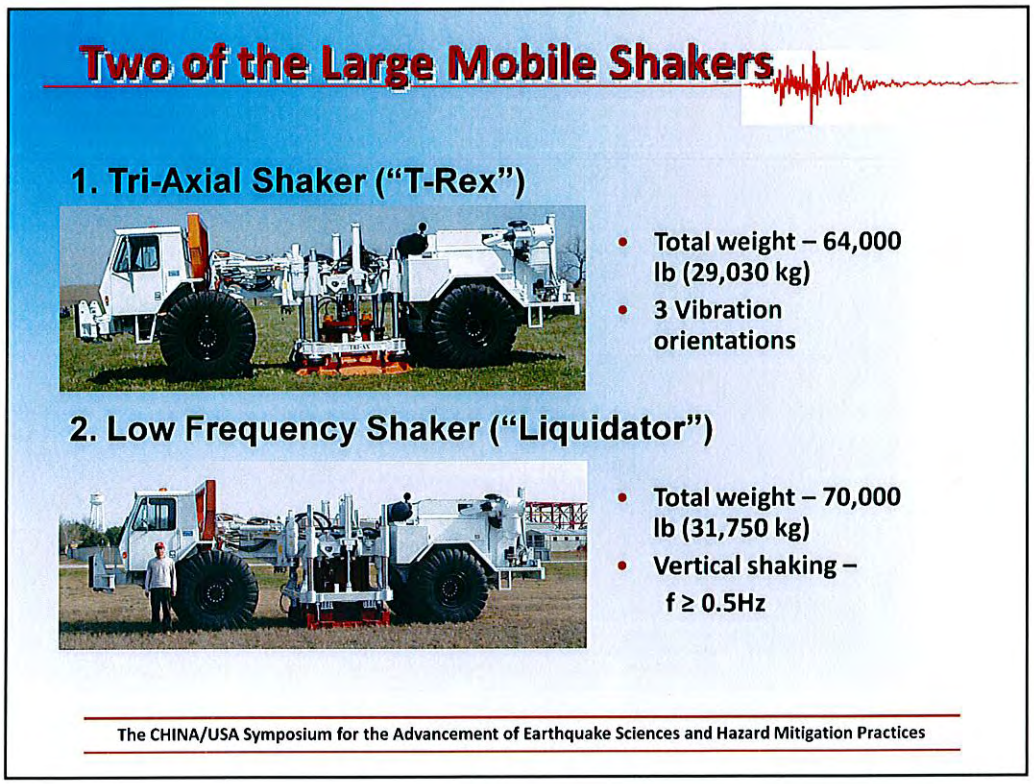
NEES@UTexas specializes in large, mobile field equipment that can be used to dynamically load geotechnical and structural systems.



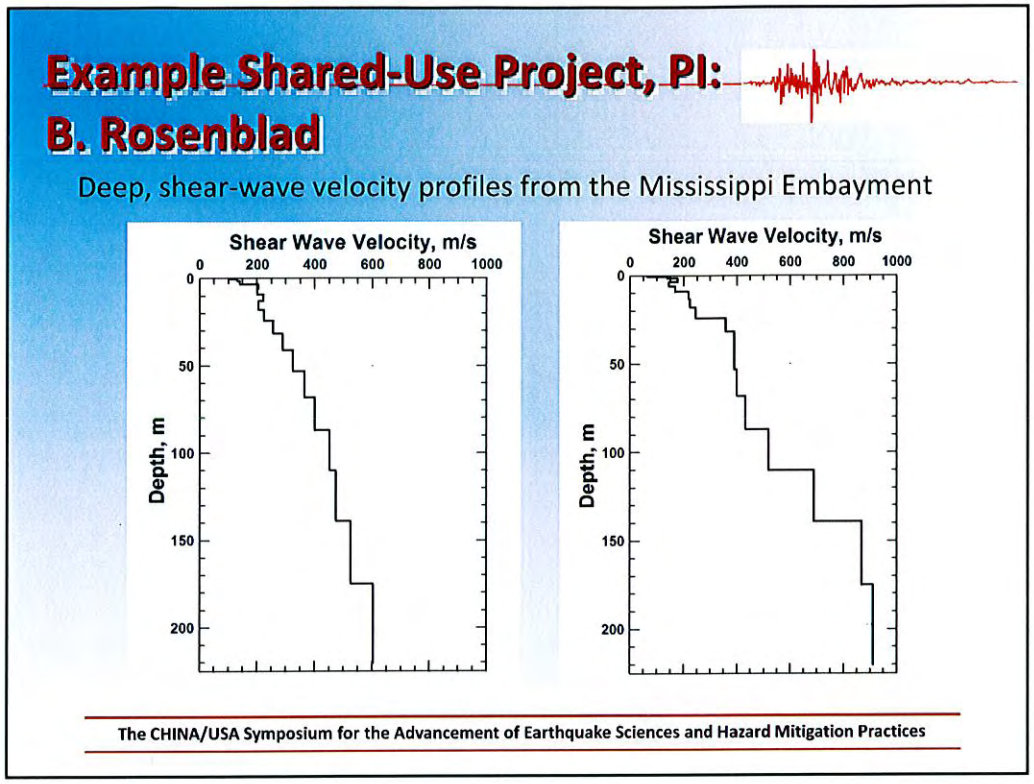
The 14 shared-used equipment sites are shown on this slide. The 14 sites are located at many different universities around the United States and are managed by an organization called NEEScomm. NEEScomm is located at Purdue University in Indiana. The 14 equipment sites cover a range in capabilities that include multi-directional shake tables, large reaction walls and controlled loading systems, geotechnical centrifuges, a tsunami wave basin, and field experimentation facilities.



The function of the NEES@UTexas equipment site is to provide the capabilities for dynamic field testing of geotechnical and structural systems. These capabilities are in the form of three large-scale mobile shakers, associated support equipment, data acquisition systems and field instrumentation.



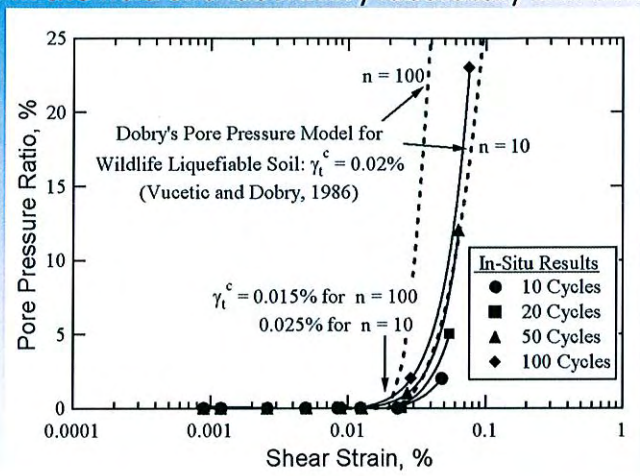
The two largest mobile shakers are shown here. They are called "T-Rex" and "Liquidator." T-Rex can be used to excite systems in three different directions with a peak force of 267 kilo-Newtons at frequencies above 12 cycles per second. Liquidator is a unique mobile shaker which can excite systems with frequencies down to 0.5 cycles per second.



An example of some results from one shared-use project using Liquidator is shown on this slide. Deep, shear-wave velocity (Vs) profiles in the Mississippi Embayment were determined using nonintrusive surface waves at very low frequencies. Profiles to depths exceeding 200 m were cost-effectively determined for earthquake site-response studies. Deep Vs profiles were previously lacking in this area.

Shared-Use Project,
PIs: K. Stokoe, and E. Rathje

In-Situ Liquefaction: Comparison of pore water pressure generation curves in the field and laboratory laboratory and field tests



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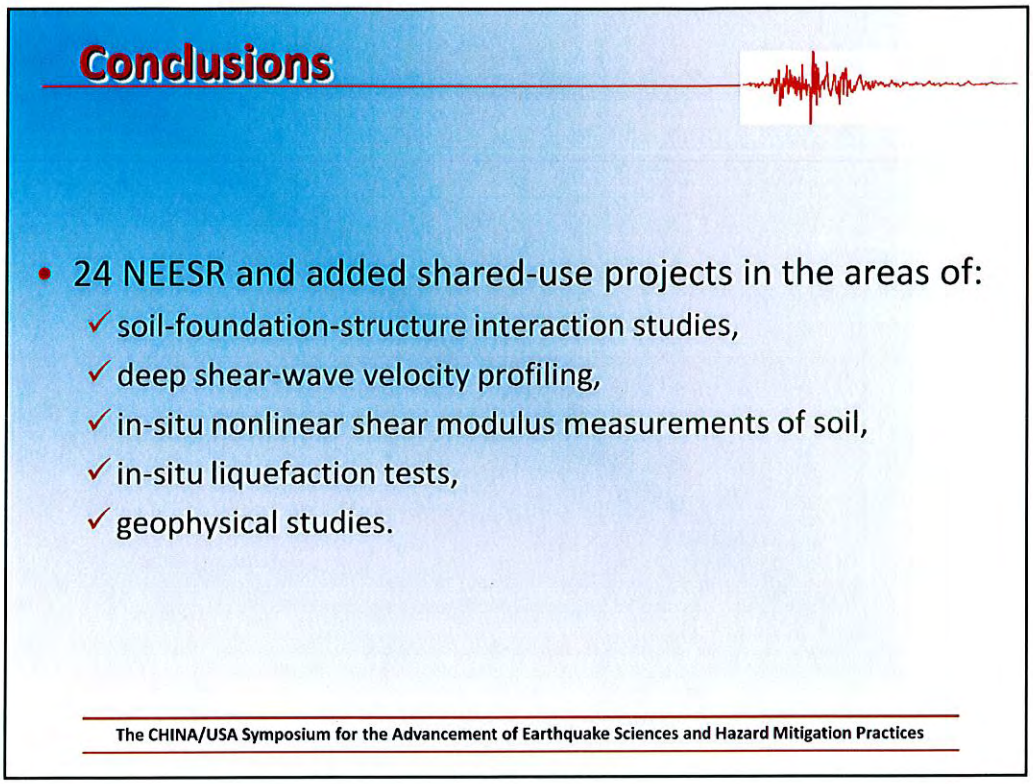
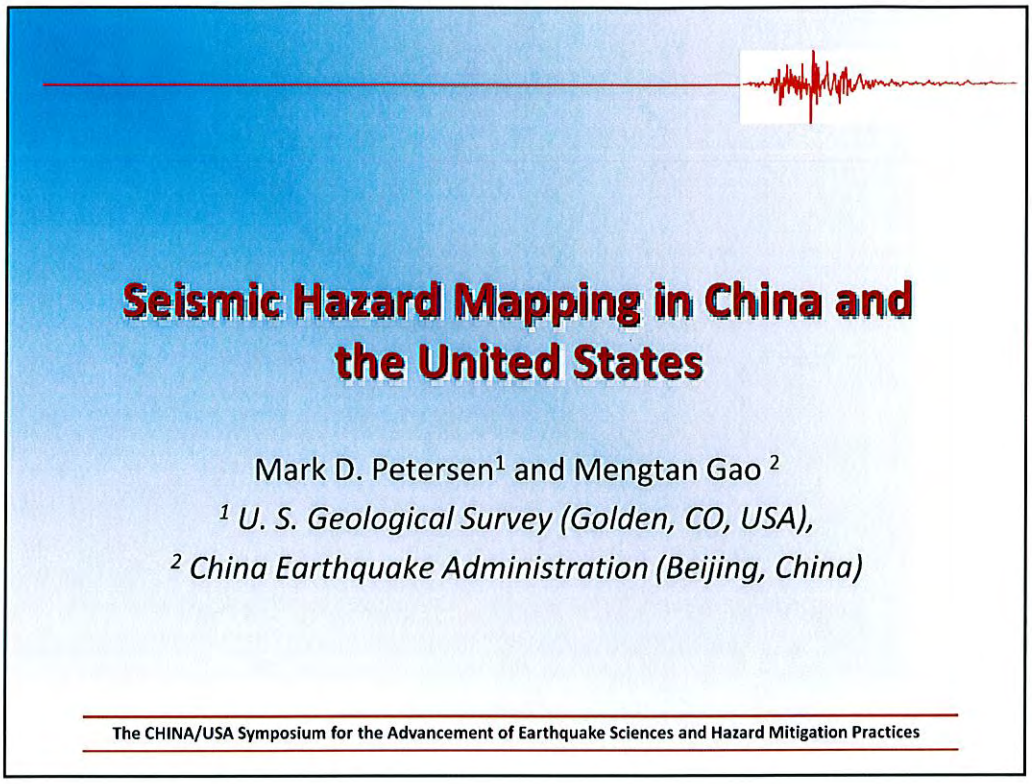
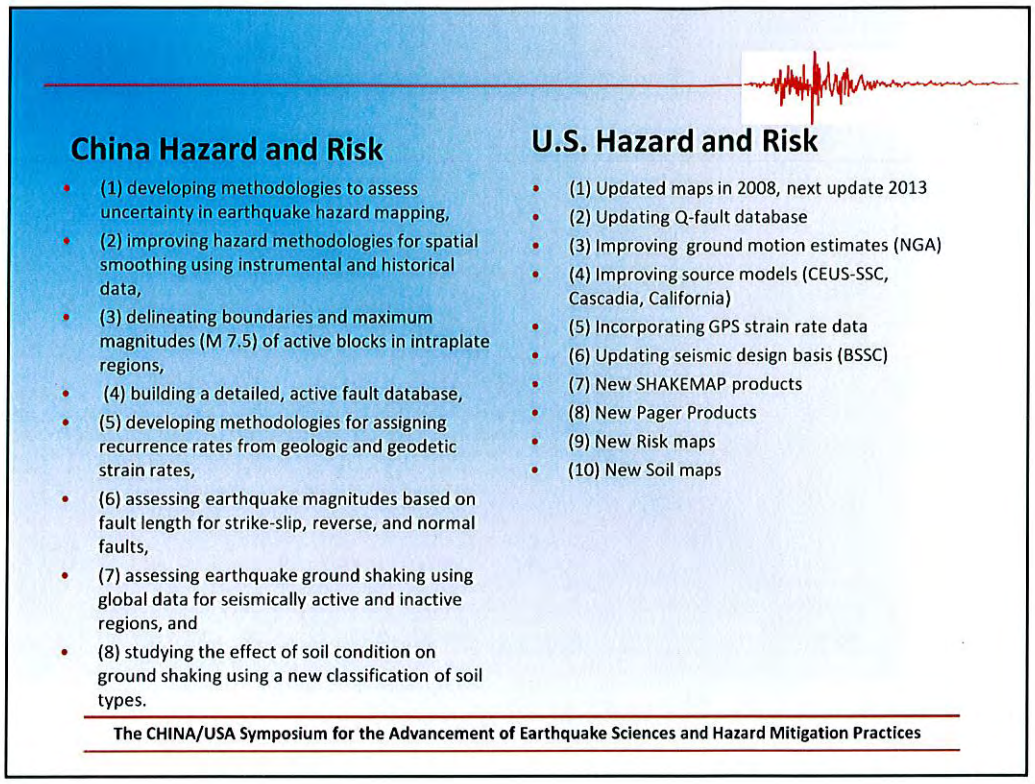
In this second example of a shared-use project, T-Rex was used to study liquefaction of a natural sand deposit. The controlled horizontal shaking of T-Rex created the onset of pore water pressure generation which was leading to the in-place liquefaction of the deposit. This work represented the first time a controlled liquefaction experiment was conducted in the field. The field results compare well with earlier laboratory tests with intact samples recovered from the site, confirming the field testing approach. This approach will be used in the future to test gravelly soils and silts with plasticity.



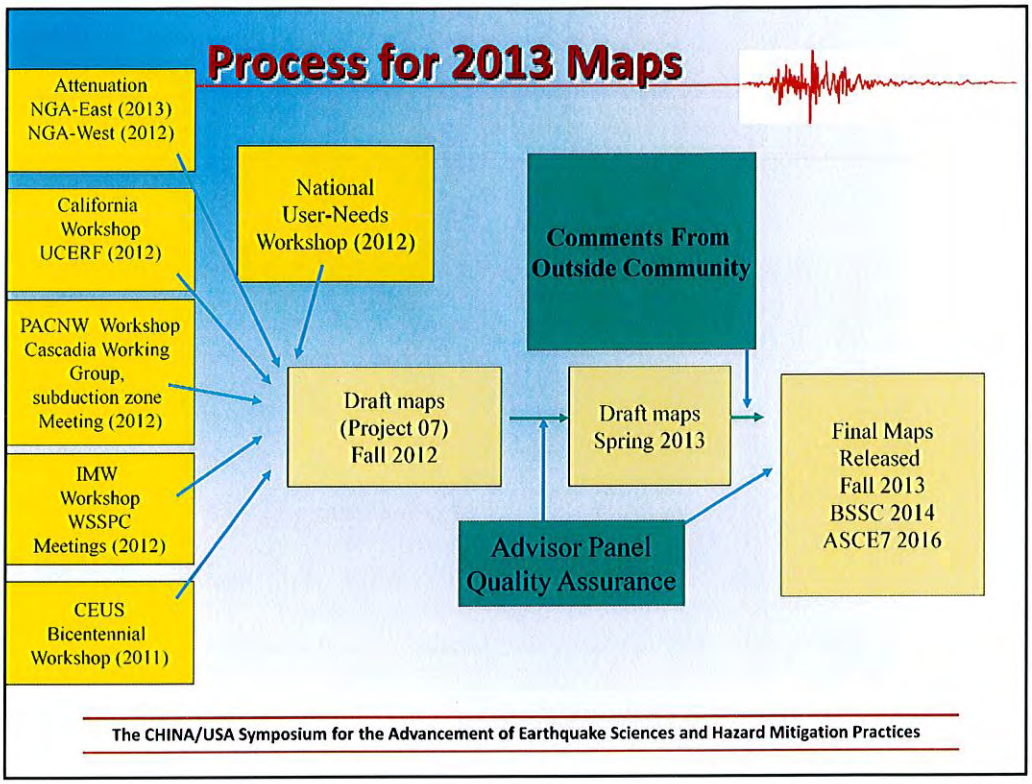
More than 24 shared-use projects have been conducted with the NEES@UTexas equipment site. More than 160 shared-use projects have been conducted with the 14 NEES equipment sites. This work has contributed to advancing education, understanding and improved solutions in earthquake engineering.



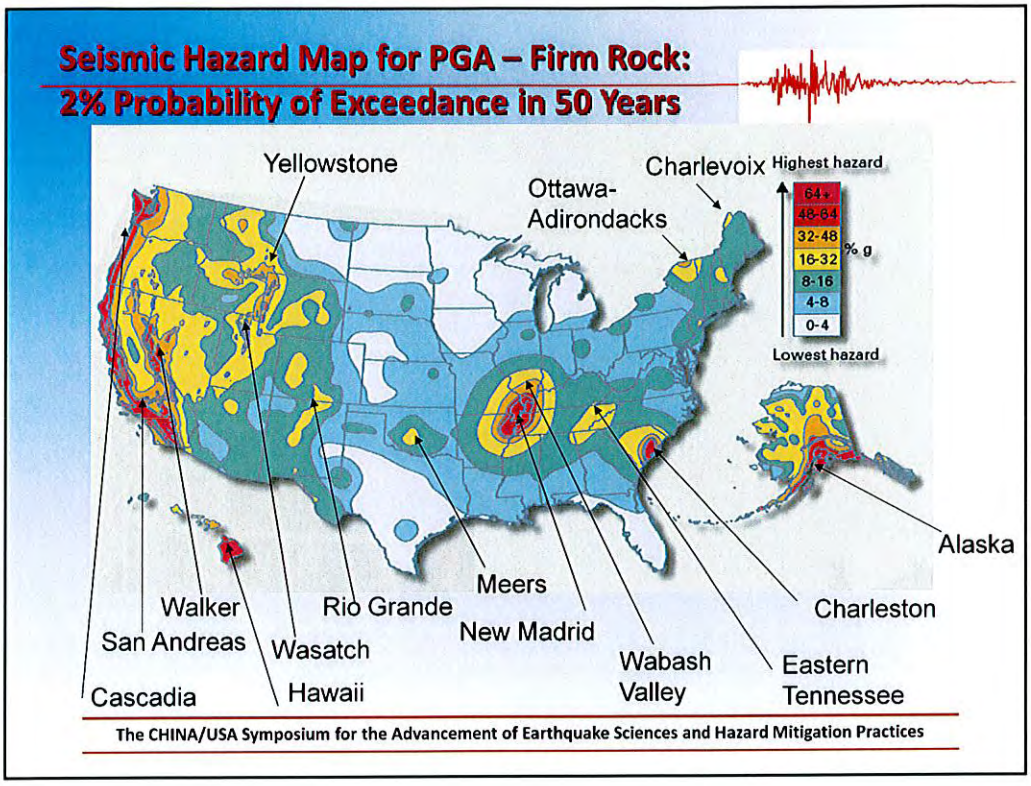
Today I would like to discuss the Seismic Hazard Mapping in China and the United States. We have been cooperating with Dr. Mengtan Gao and his colleagues at the China Earthquake Administration for the past several years on developing better hazard maps that are applied in building codes. I know that we at the USGS have benefited from these discussions. Today I would like to talk about some of the seismic hazard issues facing both countries and some paths that may help us develop better hazard maps and facilitate better risk reduction in China and the U.S.



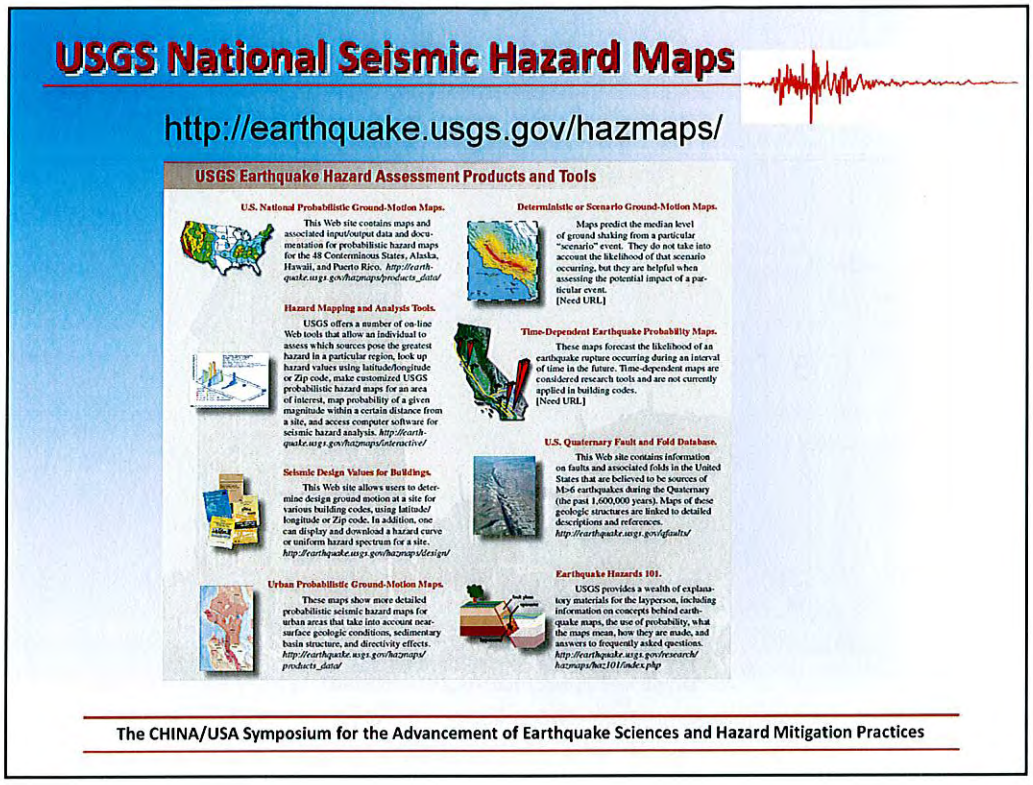
China has been very active in developing new models for earthquake hazard and risk which include: (1) developing methodologies to assess uncertainty in earthquake hazard mapping, (2) improving hazard methodologies for spatial smoothing using instrumental and historical data, (3) delineating boundaries and maximum magnitudes (M 7.5) of active blocks in intraplate regions, (4) building a detailed, active fault database, (5) developing methodologies for assigning recurrence rates from geologic and geodetic strain rates, (6) assessing earthquake magnitudes based on fault length for strike-slip, reverse, and normal faults, (7) assessing earthquake ground shaking using global data for seismically active and inactive regions, and (8) studying the effect of soil condition on ground shaking using a new classification of soil types. The USGS has worked on similar problems and has: (1) Updated maps in 2008, next update 2013, (2) Updated Q-fault database, (3) Improved ground motion estimates (NGA), (4) Improved source models (CEUS-SSC, Cascadia, California), (5) Incorporated GPS strain rate data, (6) Updated the seismic design basis (BSSC), (7) Developed New SHAKEMAP products, (8) Developed New Pager Products, (9) Developed New Risk maps, and (10) Developed New Soil maps.



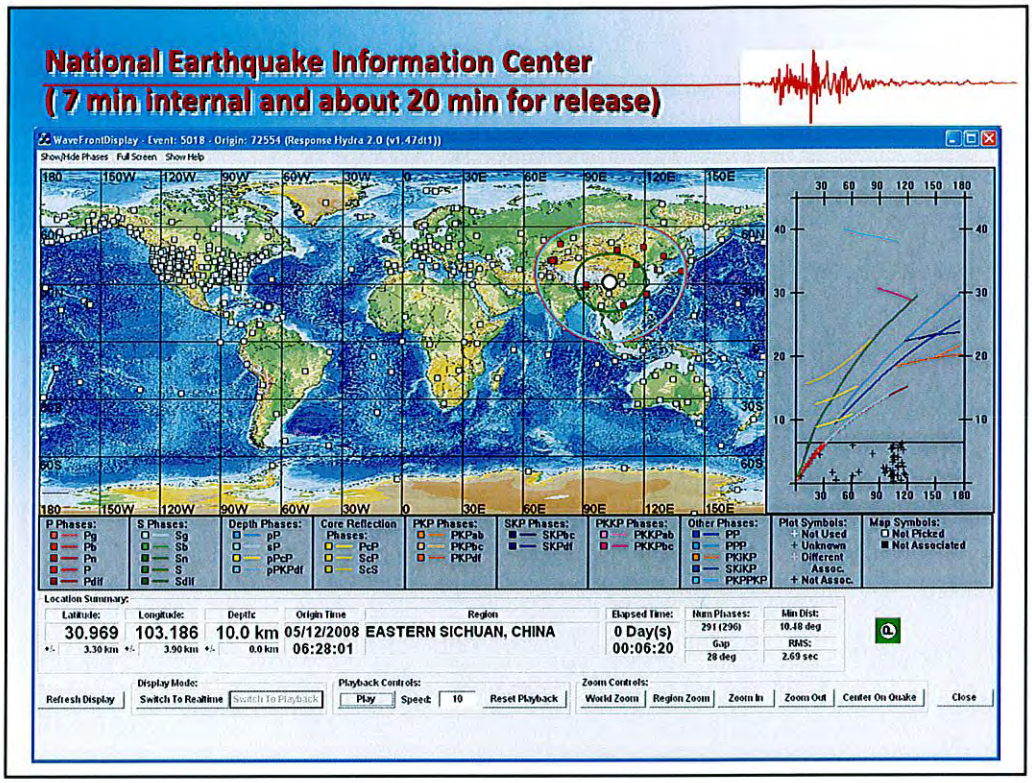
In the U.S. we have an extensive process to incorporate hazard information for building codes. For each update including the next one that is due in 2013 we hold several regional, topical, and user workshops shown in dark yellow boxes, convene scientific review panels to examine the input data and methods shown in green boxes, and release several products shown in light yellow boxes. This process helps us develop consensus in the science community so that we can provide the "best available science" for building design.



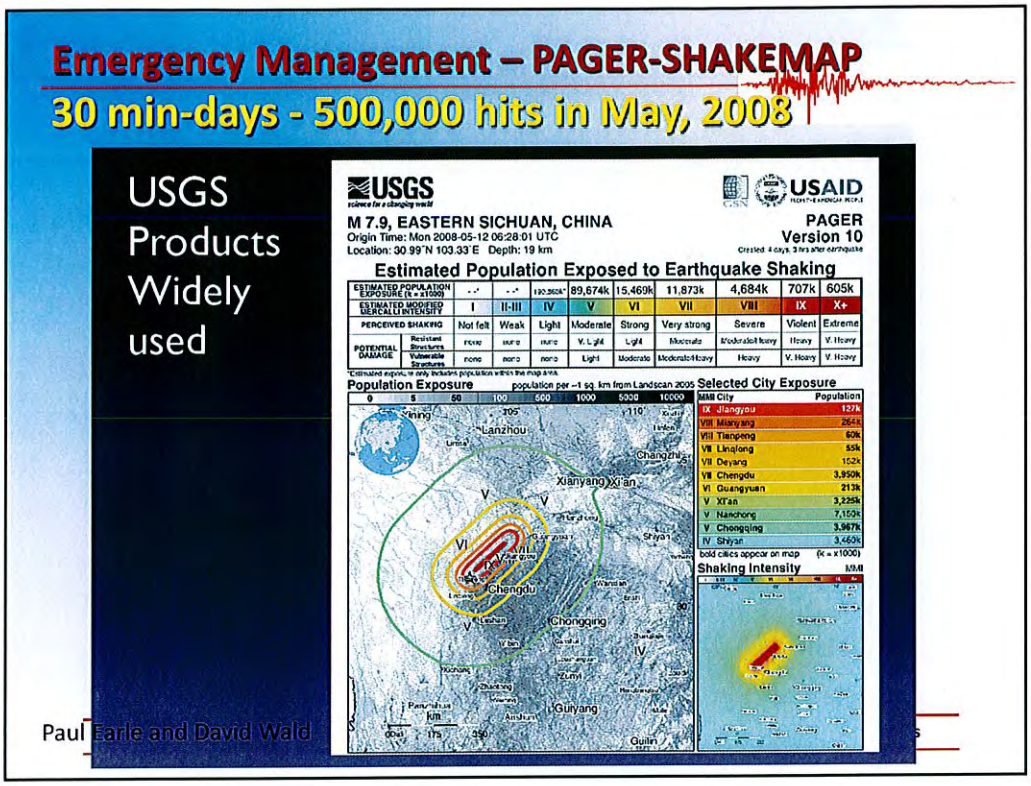
This figure shows the 2008 hazard maps for peak ground acceleration on uniform firm rock site conditions. This map is for a hazard of 2% probability of exceedance in 50 years which is the basis for building codes in the U.S. Hazard in the U.S. includes earthquakes in the western U.S. near plate tectonic boundaries and earthquakes in the middle of the continental plate. In the western U.S. , it is easy to observe faulting in images from space. However, faulting in the eastern U.S. is more difficult to understand. We hope that we can solve some of these problems through collaboration with our partners in China.



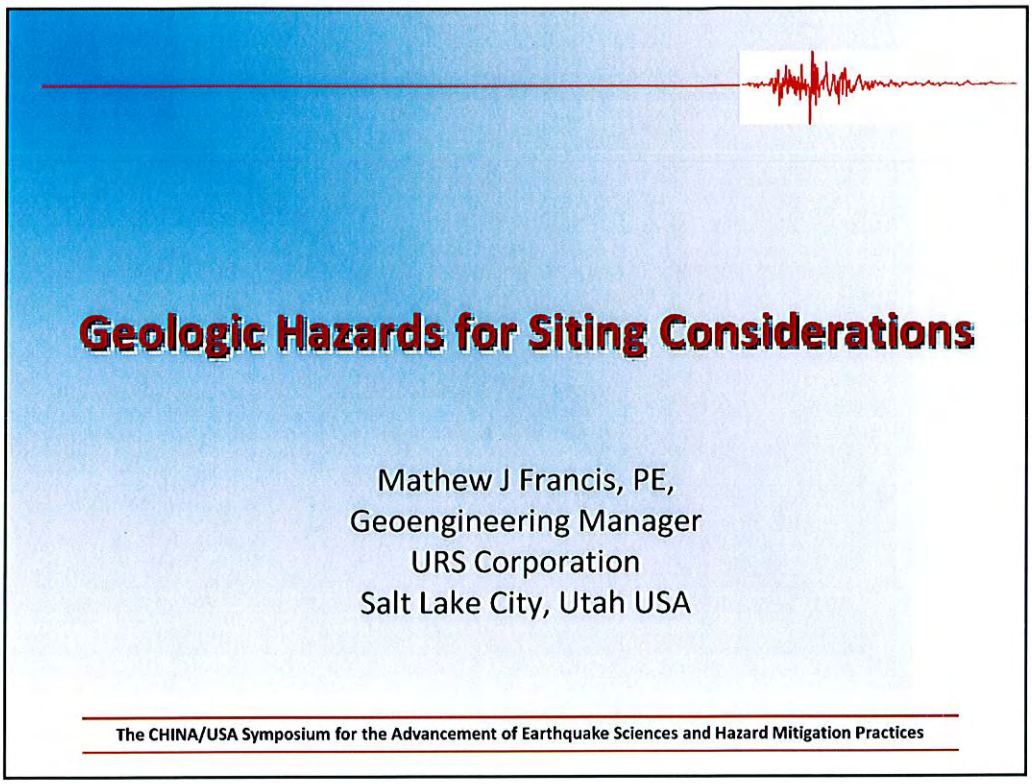
On our website we allow access to all of the input data, computer codes, and tools that help the engineer to design buildings. We have all of the background information used to develop the U.S. National Seismic Hazard Maps, tools to take apart the hazard and determine which sources are most important, GIS tools to examine details of the hazard, engineering tools that provide information for building design, scenario maps to help planners understand the consequences of an earthquake, time-dependent probability maps, urban hazard maps that incorporate computer simulations of ground motions, Quaternary fault databases, and basic information on how to assess hazards.



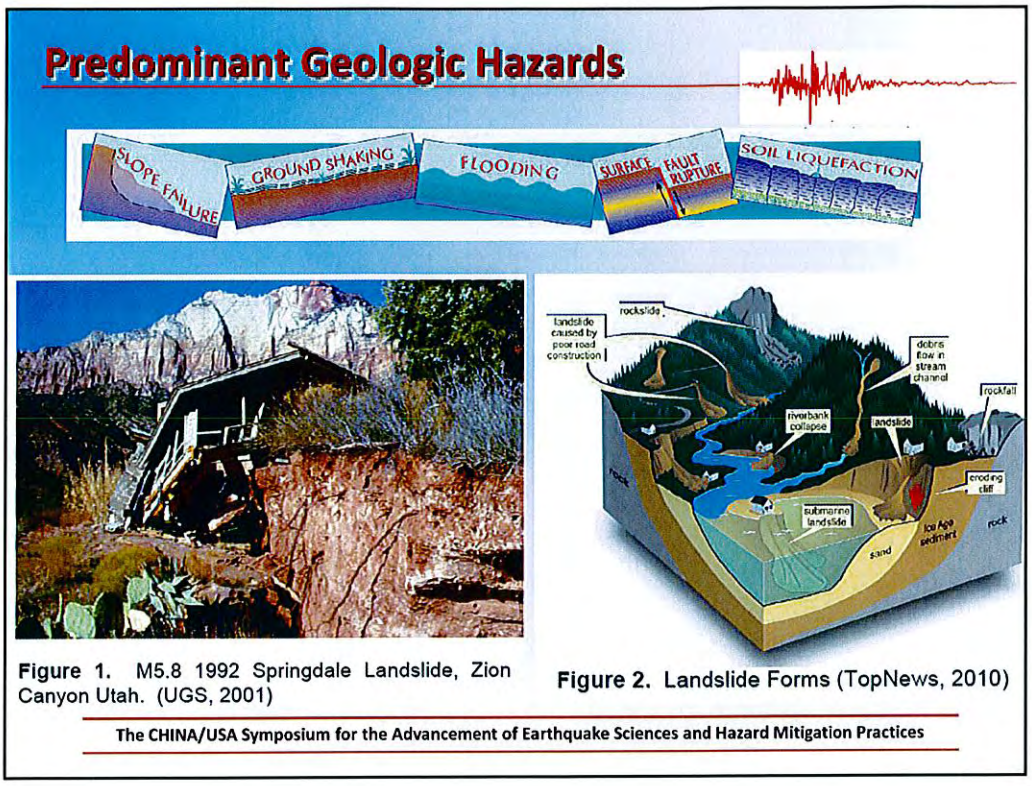
In addition our office at the USGS has developed tools for locating and assessing the size of global earthquakes. This figure shows the phase data (mostly p and s-wave data) used to locate the Wenchuan earthquake in 7 minutes. These locations are checked by an individual and then sent out to thousands of users on the email list in about 20 minutes. The rapid assessment allows quicker and more effective response and should help reduce risk from damaging earthquakes.



This map shows an example of the USGS PAGER –SHAKEMAP tool output that rapidly calculates the shaking intensity, population exposure, and the number of people that are within each intensity zone. The USGS updates the locations as new information becomes available and this map shows version 10 information that was released 4 days following the Wenchuan earthquake. Recently we updated the page to include potential losses (casualties and economic). This should help responders focus efforts quickly. I hope that we will continue to cooperate with the CEA and others who are interested in reducing earthquake risk.



Introduction: Mathew Francis will be present an overview of USA practices in geologic hazards for siting considerations, including GIS modeling of landslide susceptibility.



Seismic siting hazards include slope failure, ground shaking, flooding, surface fault rupture and soil liquefaction.

Figure 1 is the 1992 Springdale Landslide in Utah triggered by topographic amplification of a distant earthquake.

Figure 2 shows landslides induced by seismic activity: riverbank collapse, eroding cliffs, debris flow, rockfall and poor road construction. Mitigations vary widely.

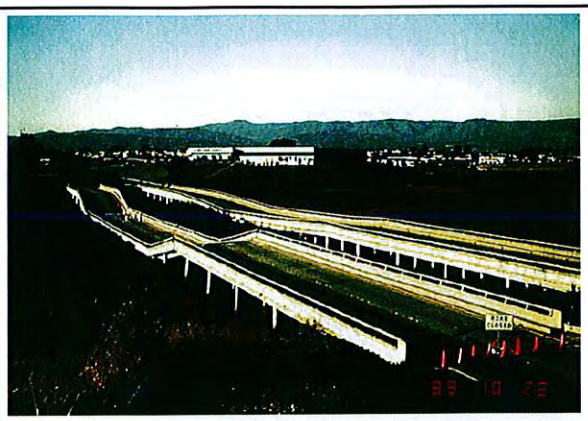


Figure 4. M6.9 1983 Loma Prieta EQ Induced Liquefaction, Highway 1, Near Watsonville, CA. (USGS, 2010)

Figure 5. M9.2 1964 Alaska Earthquake, Turnagain Heights Lateral Spread, (USGS, 2010)

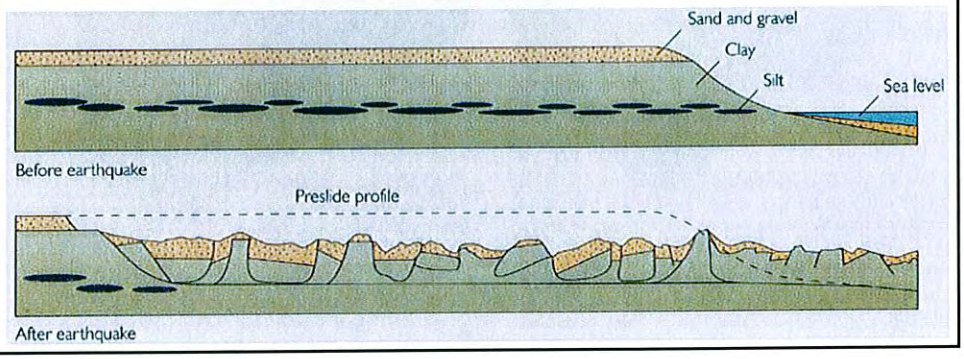


Figure 1 is a highway liquefaction failure 100km south of San Francisco during the 1983 Loma Prieta earthquake.

Figure 2 is a profile of the Turnagain Heights lateral spread from the 1964 Alaska earthquake. A layer of liquefiable silt spread up to 600m.

Mitigation of liquefaction and lateral spread is mandatory under US building codes. Current best practice is the simplified method by Boulanger & Idriss. The most popular mitigations are stone columns and soil mixing.

Figure 7. M7.9 2002 Denali EQ, Alaska (USGS, 2010)

Figure 8. Transcanada Pipeline Fault Crossing (USGS, 2010)

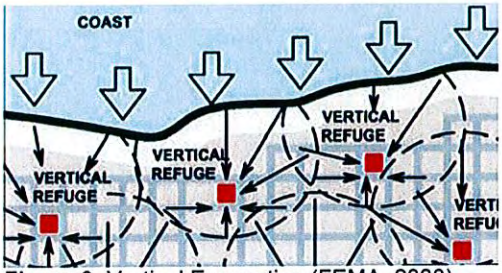
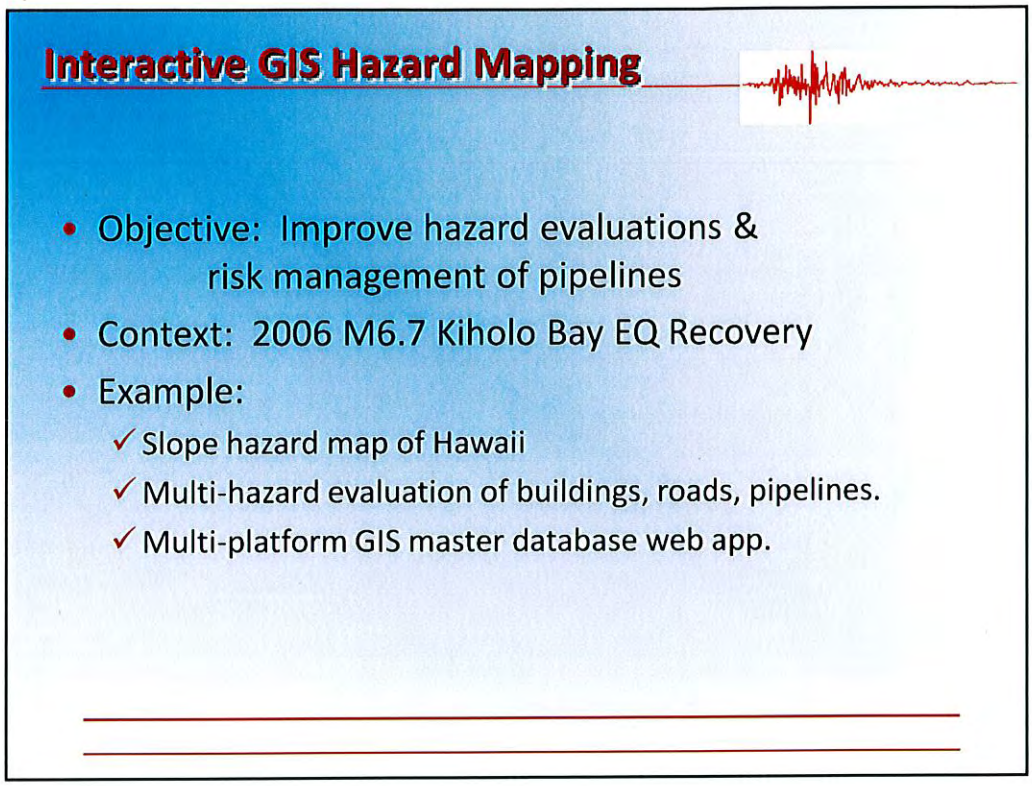


Figure 9. Vertical Evacuation (FEMA, 2008)

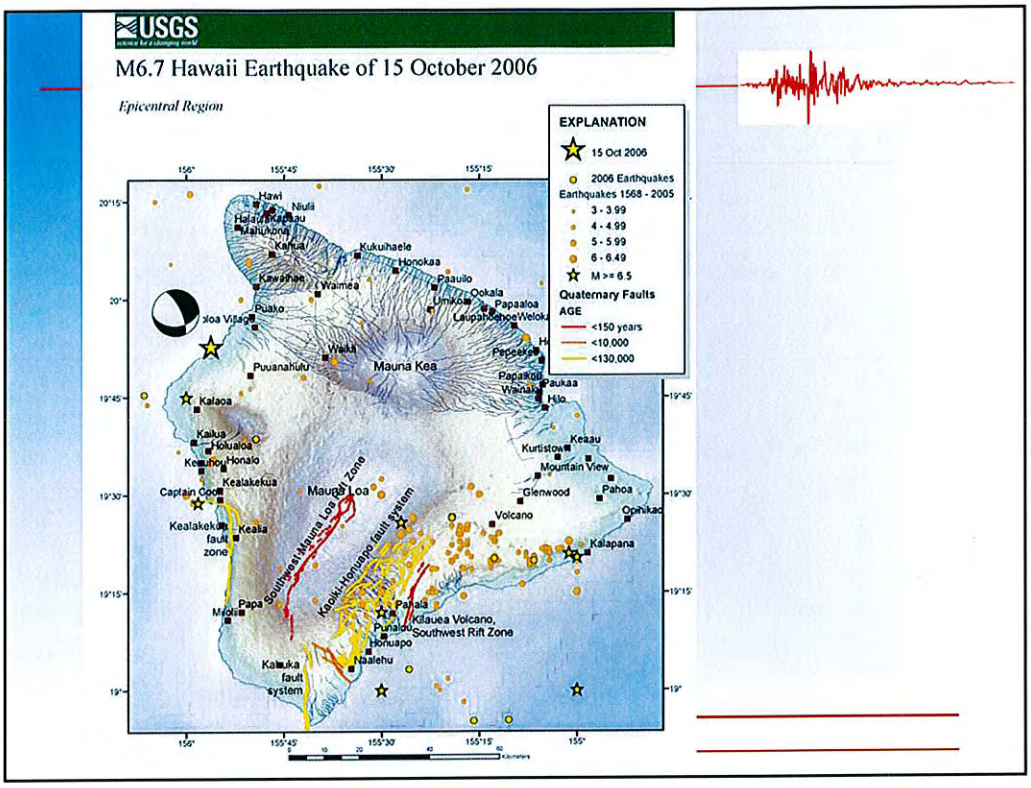
Figure 10. Tsunami Inundation. (EERI, 2006)

Figures 7 and 8 show surface fault rupture common with large earthquakes in the Western US. Trench studies have been used to develop fault rupture hazard maps and setback guidance. Pipeline fault crossings include ductile joints and slider bearings.

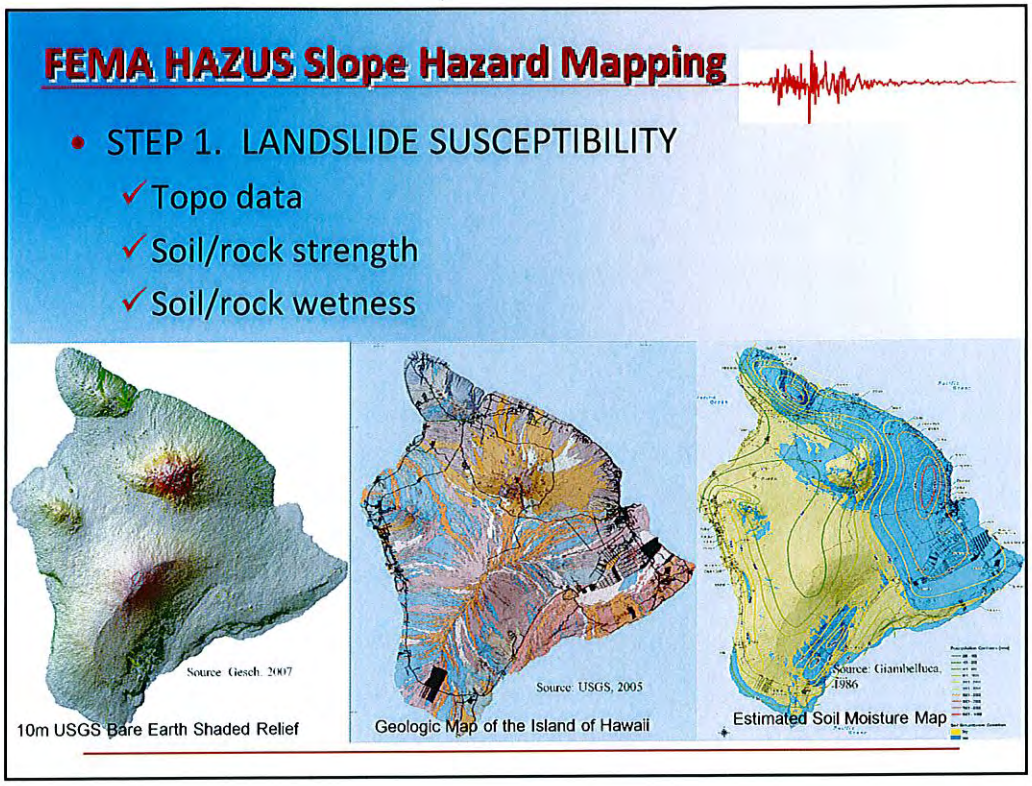
Figures 9 and 10: Tsunami flood mapping and mitigation criteria have been in Hawaii building codes for 30 years. Updates since the 2004 Tsunami include probabilistic tsunami hazard assessments (PTHA) and improved structural analysis for vertical evacuation being adopted by Honolulu and Oregon.



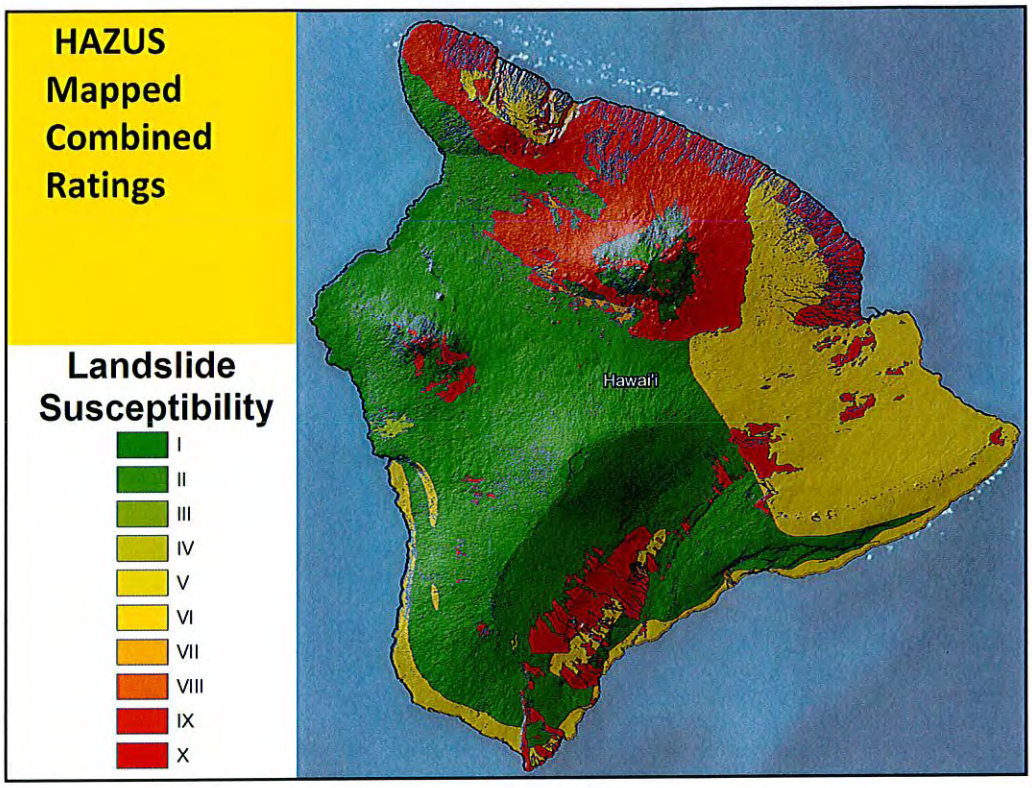
New hazard mapping is being done using interactive GIS. An example for landslides is presented from the 2006 M6.7 Hawaii Earthquake, including loss modeling of buildings, roads and pipelines with GIS master database applications.



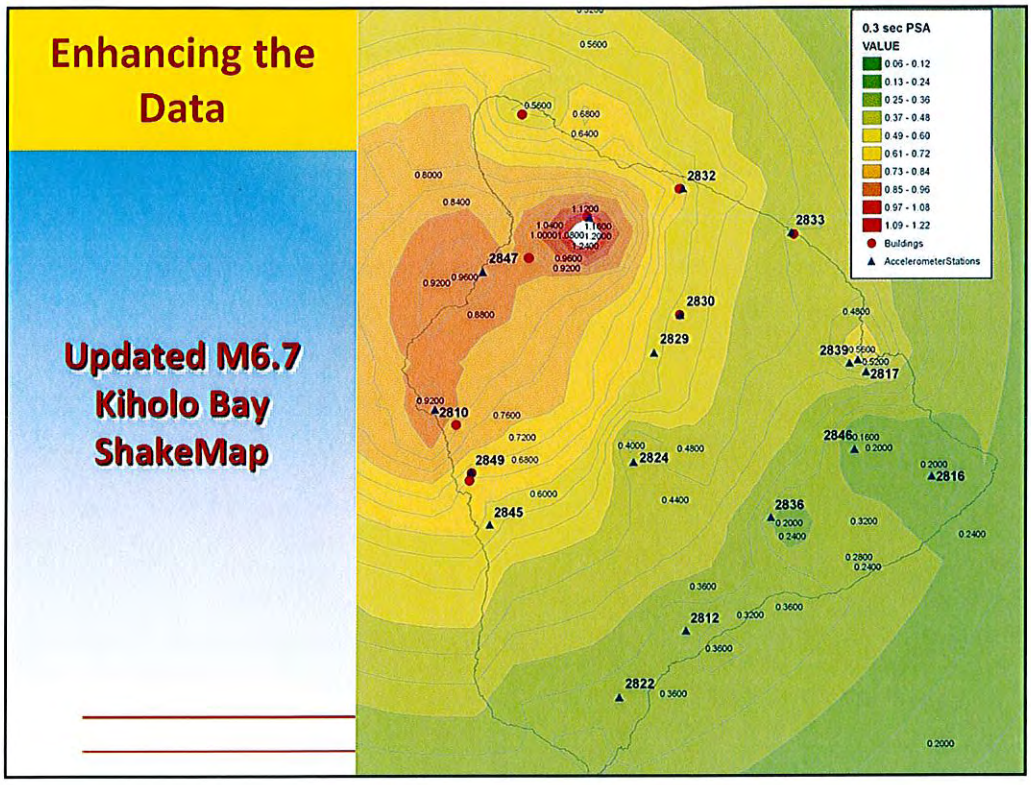
This map shows historic earthquakes. The 2006 event occurred west of the island, away from the historic source of dominant seismicity at Kilauea volcano. It caused significant infrastructure damage.



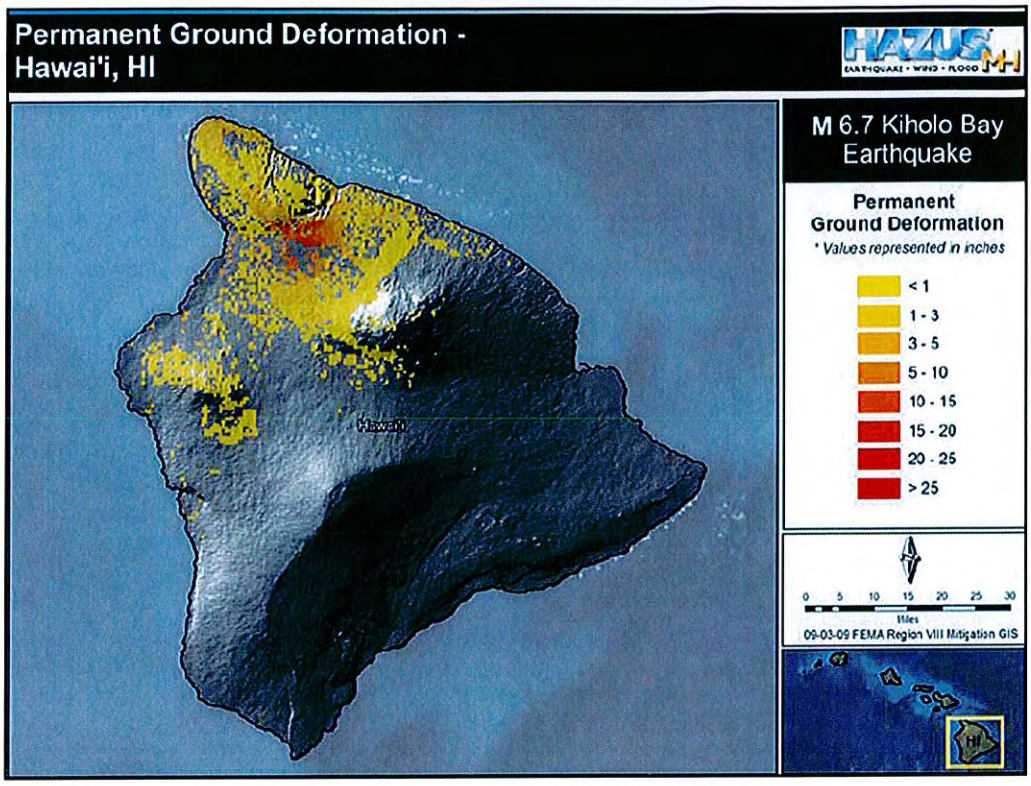
FEMA HAZUS loss modeling software provides a simple method for mapping landslide risk after Keefer (1984). Step 1 is to use digital site topography, geology and moisture maps to assign primary slope stability inputs of slope angle and soil/rock strength.



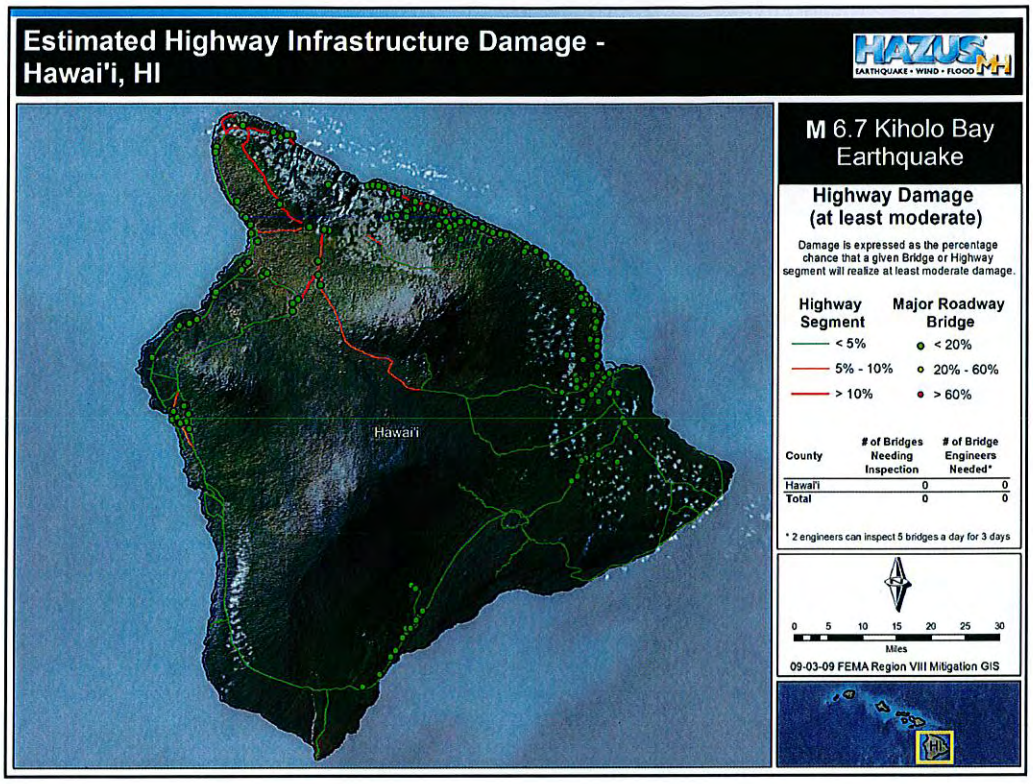
Step 2. is to combine Step 1 data into grouped Landslide Susceptibility Ratings 1 to 10. A rating of 1 is for flat dry strong slopes, and a rating of 10 is for steep wet weak slopes. Each rating has an assigned critical peak ground acceleration (PGA) for "triggering" a landslide.



Step 3 is to model the PGA produced by the earthquake from strong motion records with the program SHAKEMAP. Enhancements include shear wave velocity profile (Vs30) modeling. For future event scenarios, a code earthquake map could be used.

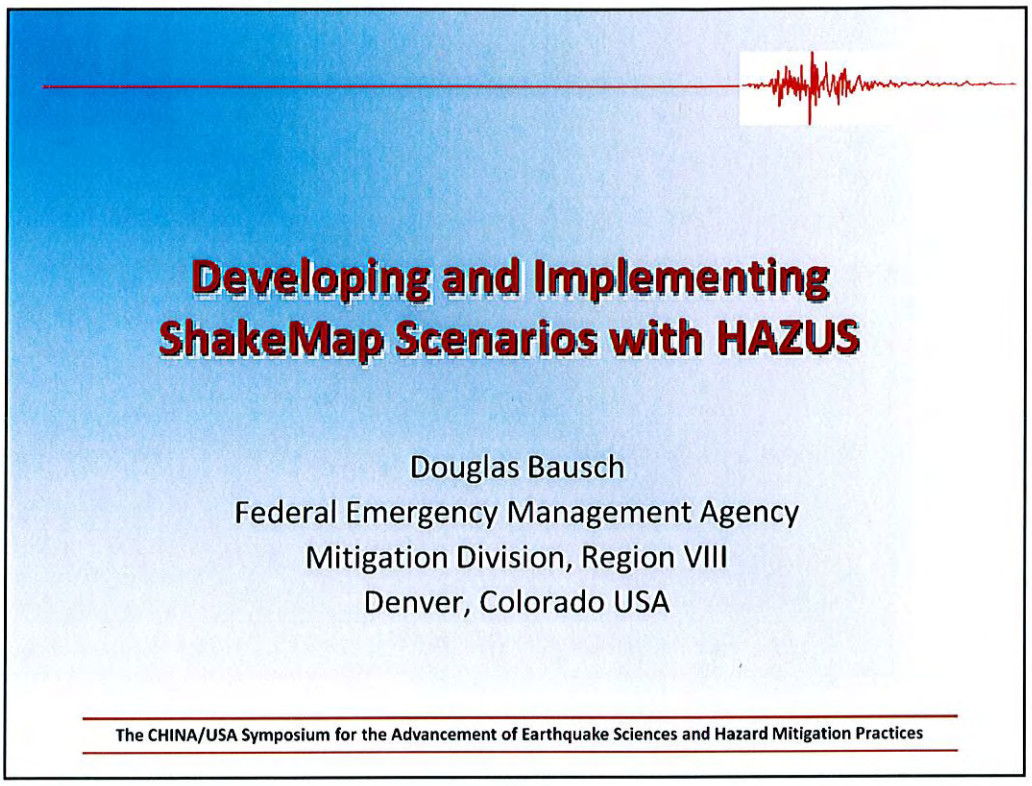


Step. 4 is to estimate landslide movements comparing Step 2 triggering PGA with Step 3 event PGA. The FEMA HAZUS program calculates permanent ground deformations based upon ratios of these two PGA values. For this event, the HAZUS model results matched the event well.



HAZUS then computes infrastructure loss estimates from permanent ground deformations, including buildings, pipelines, and roads/bridges. The robust HAZUS database and other similar GIS platforms now allow for rapid accurate loss estimation and data sharing in planning, maintenance and disaster response activities. Other examples are given in the paper accompanying this presentation.

Thank you.


Developing and Implementing
ShakeMap Scenarios with HAZUS
Douglas Bausch
Federal Emergency Management Agency
Mitigation Division, Region VIII
Denver, Colorado USA
The CHINA/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices

HAZUS Risk Assessment Tool

- Earthquake, flood and hurricane wind modules
- Developed in conjunction with the National Institute of Building Sciences
- Runs on ESRI ArcGIS 9.3 platform
- **Salt Lake Region ATC-13 was HAZUS Predecessor**
- Over 200 data layers – all open source
- Results identify specific and general vulnerabilities for mitigation strategies, numbers increase awareness and trigger action

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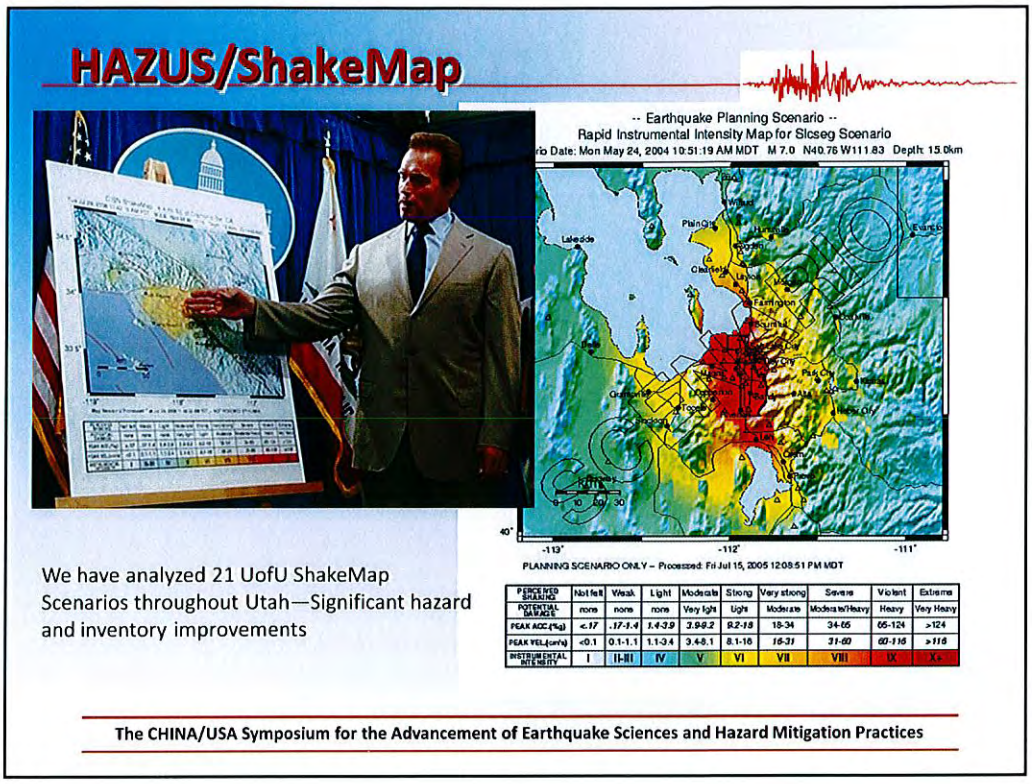
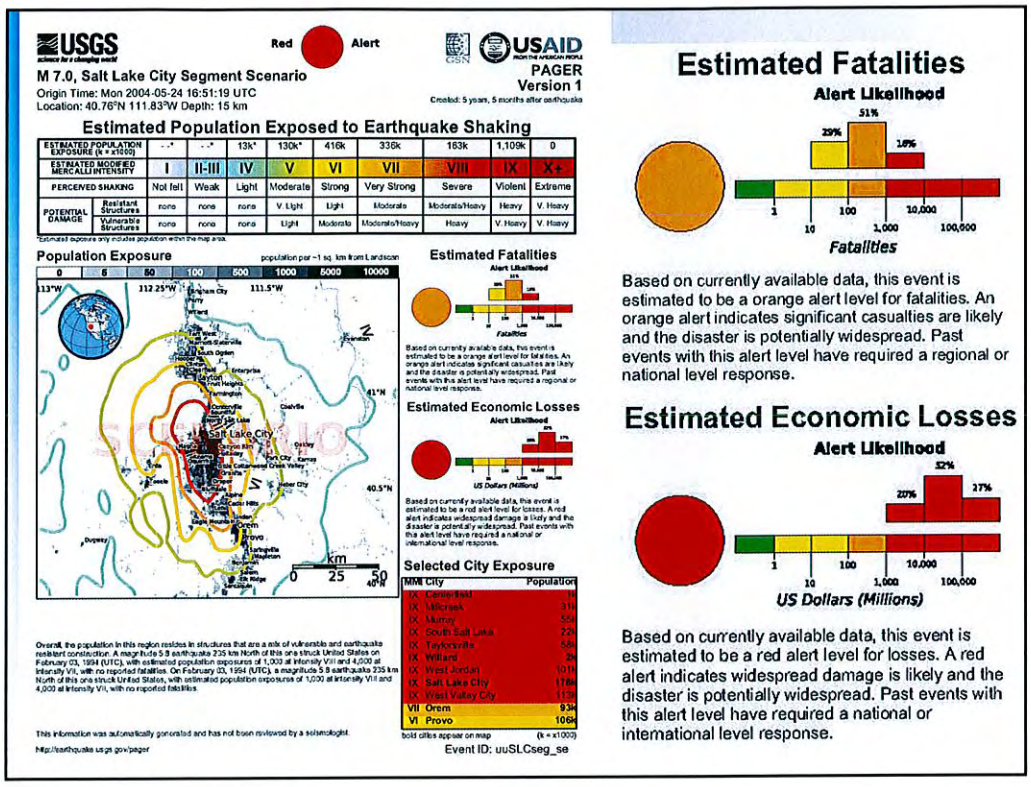
HAZUS is a software package developed by FEMA that allows us to estimate losses for earthquakes, floods and hurricane winds. HAZUS has a broad variety of applications, including supporting the evaluation of mitigation strategies (building codes, retrofits, etc.), loss estimates to support response and recovery following disasters, and the ability to model scenarios for preparedness and mitigation planning.

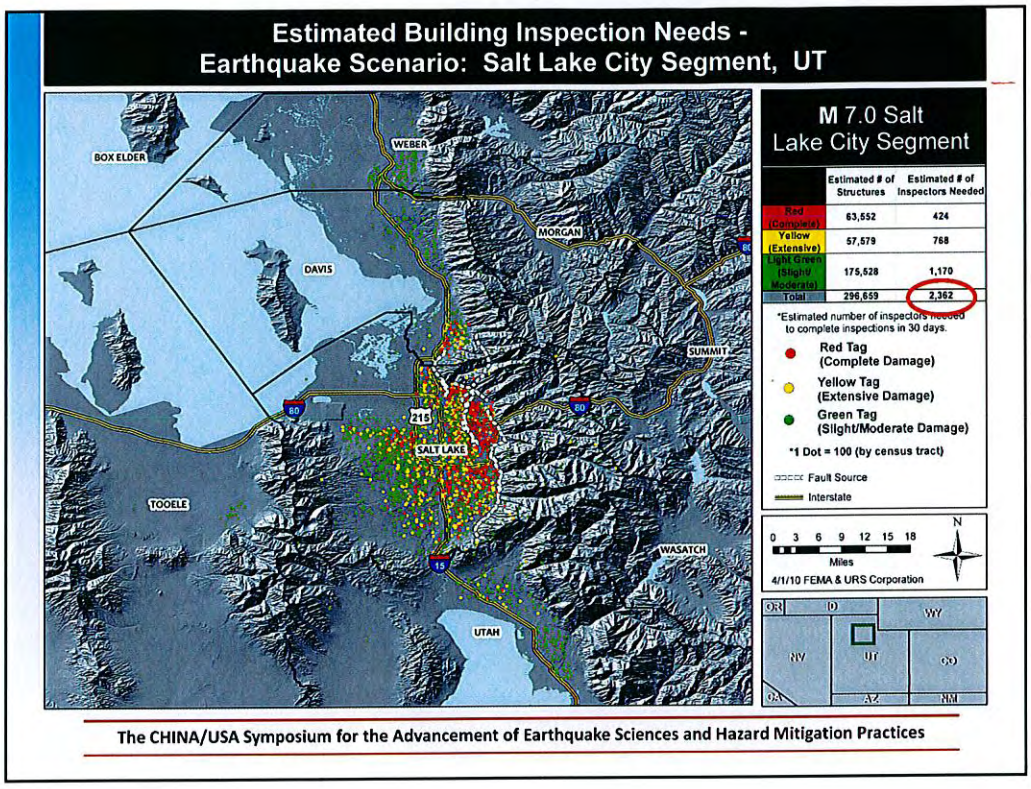
We first released the software in 1997 and have worked to continually enhance the methodology, as well as improve the extensive databases of buildings, infrastructure and demographics.



Although HAZUS has the capability to model ground motions from point or line sources and to use a wide variety of attenuation functions, we more frequently use the more sophisticated USGS ShakeMap products. This also ensures that a broad variety of or users, including public officials, will be familiar with the products when real earthquakes occur.

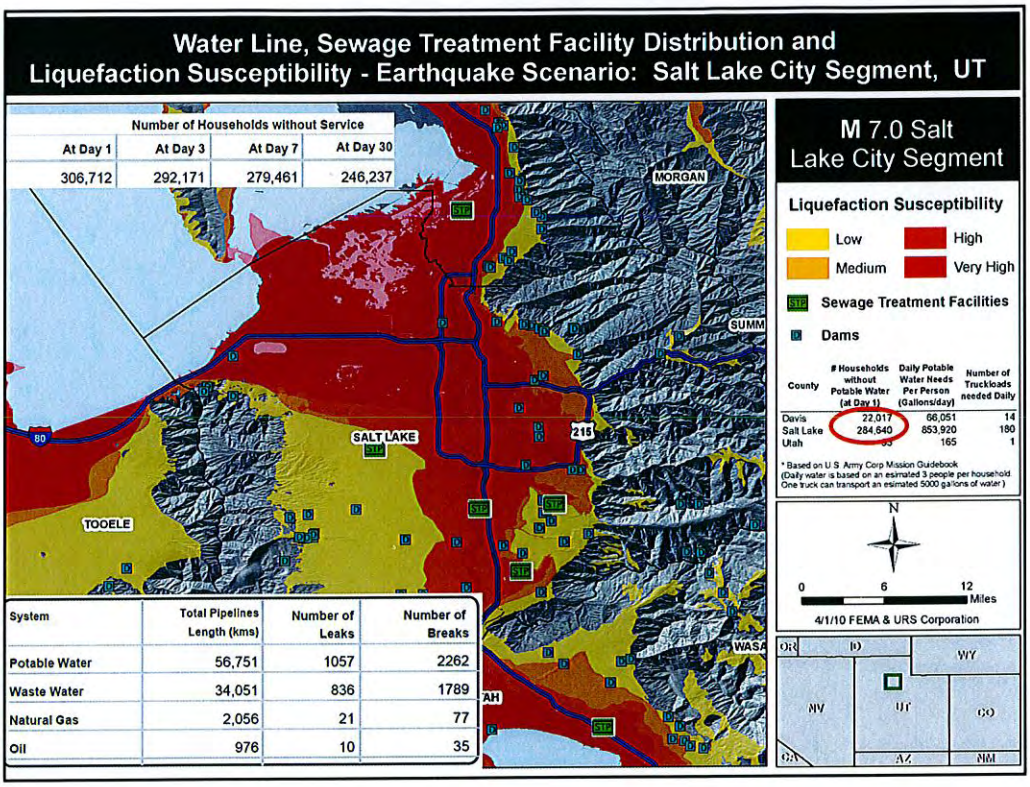


The most rapid first look at potential impacts any where in the world will be provided by the new USGS lossPAGER product within about 20 minutes of an earthquake. We have worked closely with the USGS to create actionable alert levels based on earthquakes dating back to 1960, as well as modeled scenario earthquakes using HAZUS. As a result, FEMA will follow prescripted actions based on these alert levels for the first few hours following an event—before ground-truthed situation reports begin to arrive from the field. This product is primarily an empirical product whereas HAZUS is an analytical product. However, lossPAGER does an outstanding job representing uncertainty and providing rapid actionable information.

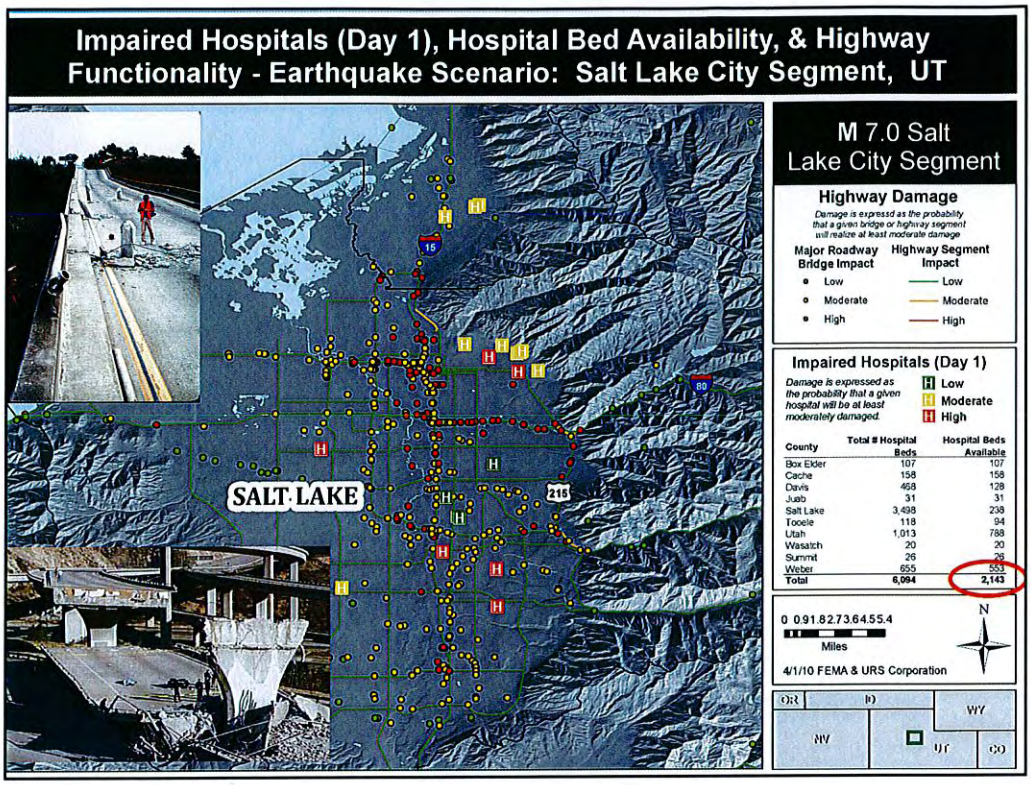


We have developed a suite of HAZUS map products based on ShakeMaps that support the needs of our emergency management programs. These examples are from the Salt Lake region of Utah. This is an area where the earthquake threat was not widely recognized until the mid 1970's and as a result, many of the older buildings do not incorporate earthquake building codes, including a large number of Unreinforced Masonry Buildings. Most the population of Utah lives on or near the Wasatch fault system and much of the area is subject to liquefaction and landslide hazards.

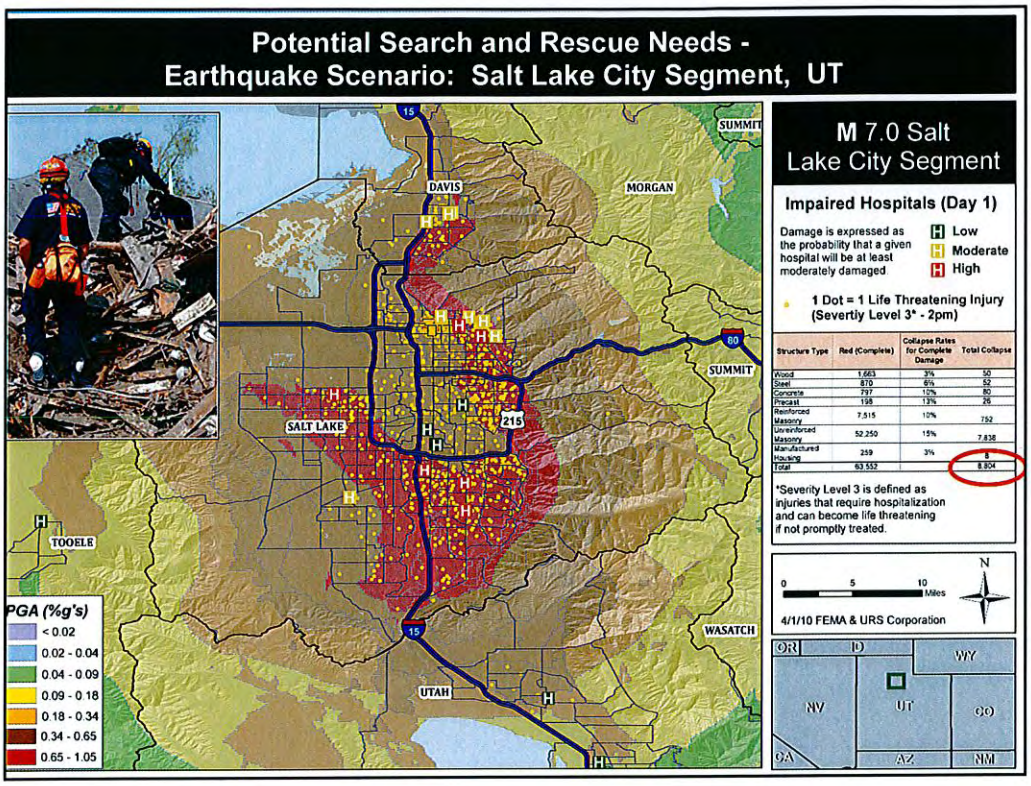
This example include assessments of the numbers of potentially red, yellow and green tagged structures, as well as the potential number of inspectors required to survey the buildings.



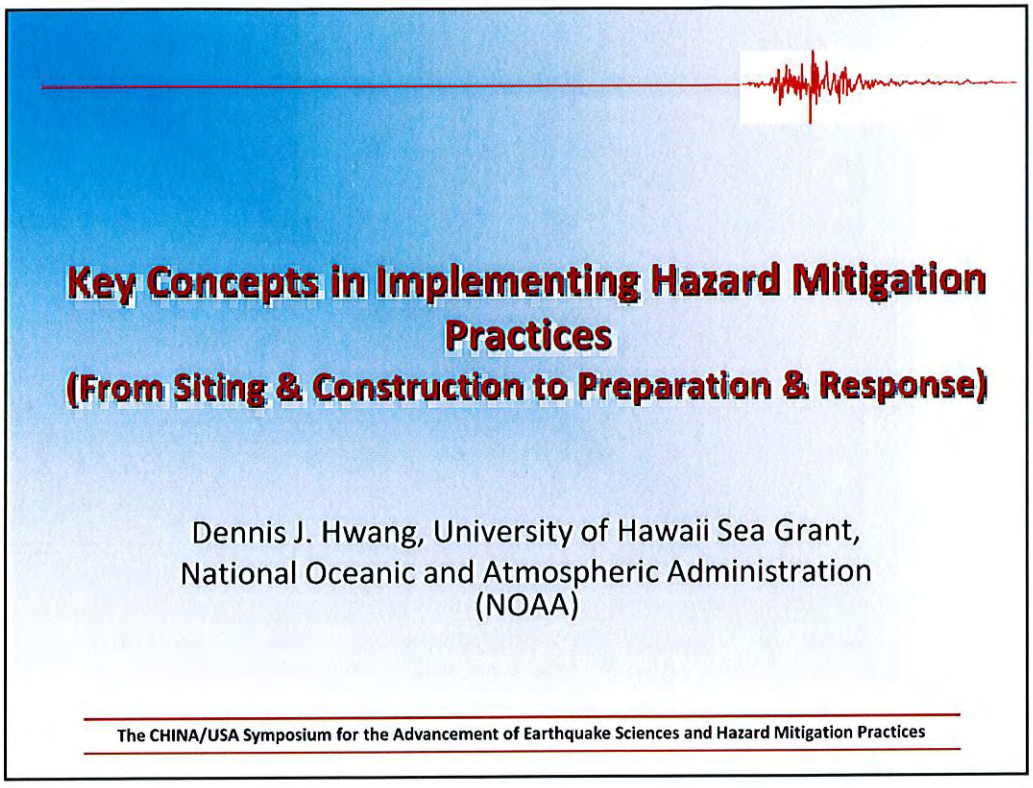
A big factor in logistics in the potable water needs of the affected population. In areas of high ground deformation susceptibility (liquefaction, landslides and faulting) the needs will especially be great and restoration times will be considerably longer.



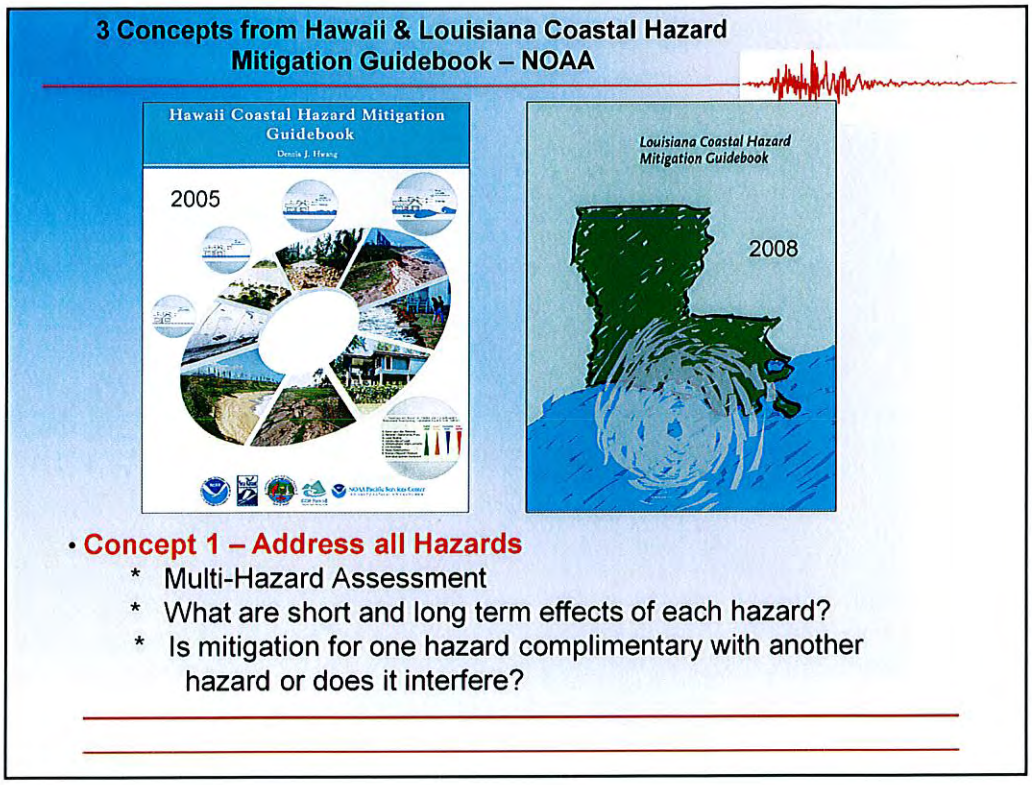
The GIS-based system provides a powerful tool to look at the interrelationships of potential impacts. This example illustrates the transportation problems in terms of highway bridge impacts with the distribution and performance of hospitals. A major vulnerability and mitigation strategy is related to the concentration of our acute care hospitals very near the earthquake source, as well as the inability to move into and out of sections of the City.



Although we estimate only 3 to 15 percent of the completely damaged structures (red-tagged) may collapse, it is these collapses that will drive the search and rescue needs. In addition, HAZUS model building types correlate well to search and rescue team types (Types 1, 2, 3, and 4). For example, our 28 specially trained and equipped Type 1 teams are required at potentially collapsed steel and reinforced concrete structures. As a result we are able to estimate potential numbers of search and rescue teams required and personnel by type.



I would like to quickly summarize the material in my paper in the proceedings.

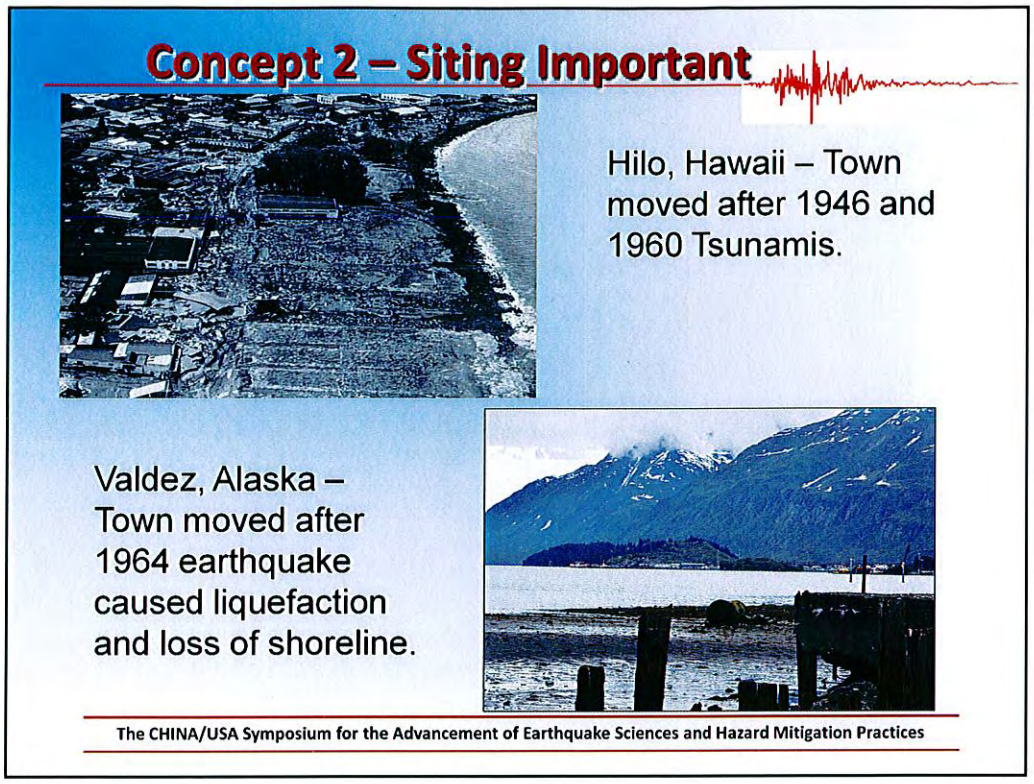


•There are three concepts I would like to cover that were developed in the Hawaii and Louisiana Coastal Hazard Mitigation Guidebooks put out by the National Oceanic & Atmospheric Administration or NOAA

•Concept 1 – Is the Need to address all hazards in an area, usually with a hazard assessment.

•The assessment should address the short and long term effect of each hazard.

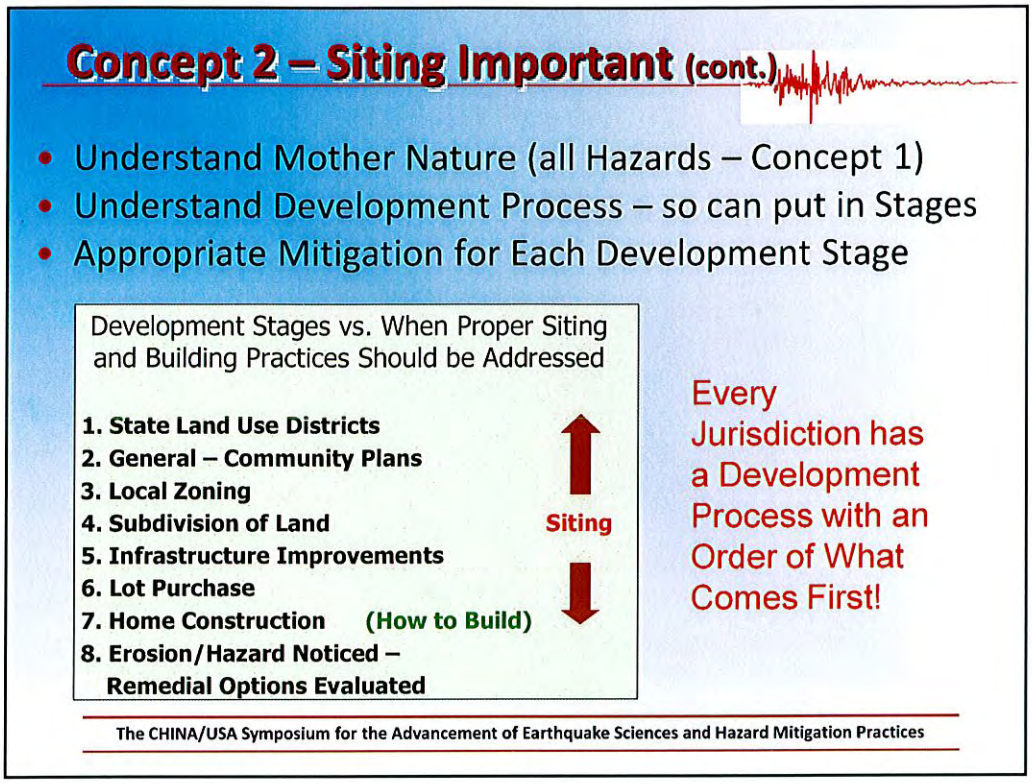
•It is also necessary to determine if the mitigation to reduce risk from one hazard is complimentary or interferes with mitigation for another hazard.



Concept 2 is that Siting can be Important to Reduce Hazard Risk

For Example, In Hilo Hawaii, parts of the town had to be moved after the 1946 and 1960 tsunami

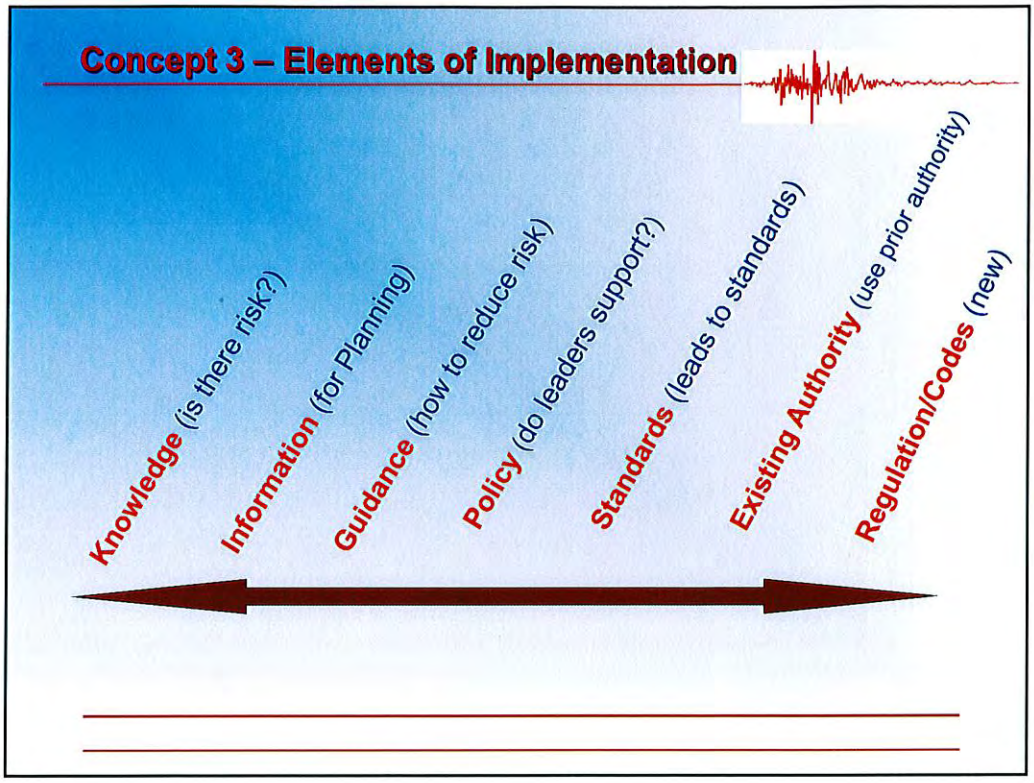
In Valdez, Alaska, the town was moved after the 1964 earthquake caused liquefaction of the soils and loss of the shoreline.



In Siting – it is important to understand Mother Nature (know all hazards – concept 1)

It is also important to know the Development Process so that it can be put in Stages. This is because certain hazard risk reduction measures are appropriate at one stage and not another.

Every Jurisdiction has a Development Process and an Order of What Comes First. Thus this hierarchy can be created.



The Third Concept is to use the various components, or elements of Implementation as arranged in this slide. Let me explain the 7 elements

1) Knowledge – For example, is there a risk of a hazard?

2) Information (or Information for Planning) – For example how frequent is the hazard or how strong?

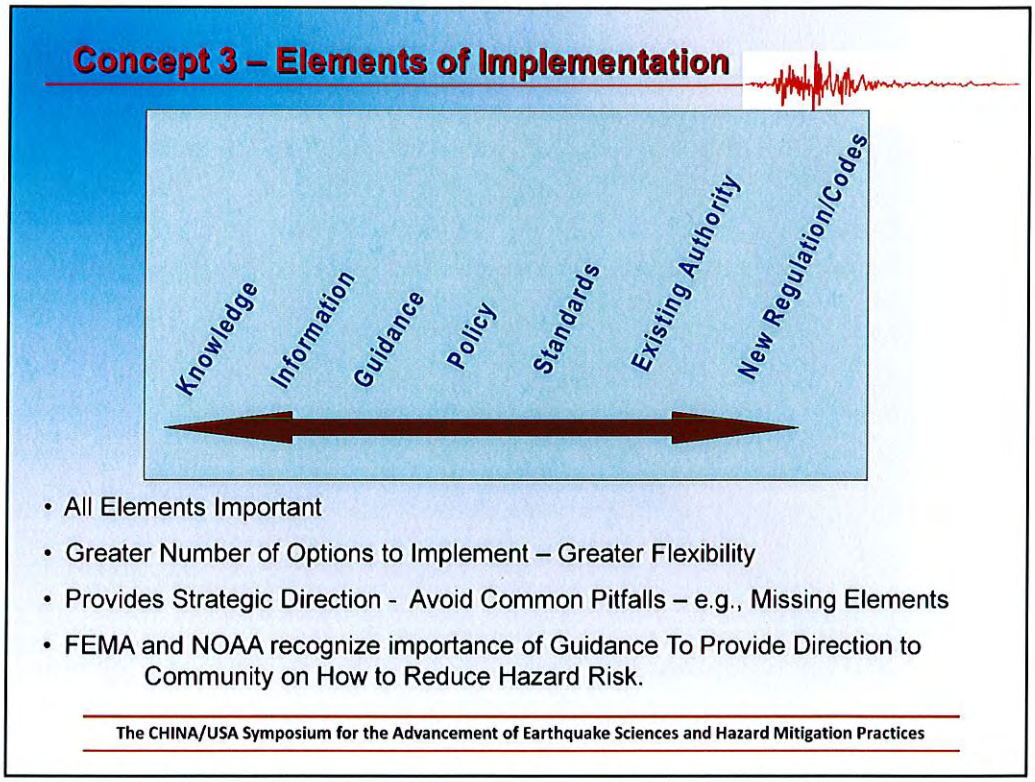
Guidance – (Given the planning information on the Hazard) How do we reduce risk – through building, siting or other measures?

Policy – Do decision makers or leaders support?

Standards are a Measure or Requirement - Policy can take Guidance and convert it to a Standard

Existing Authority – Are current rules – Policy can take Guidance and use it within Existing Rules

Regulation/Codes – New Rules – Policy can take Guidance and convert it to new Rules.

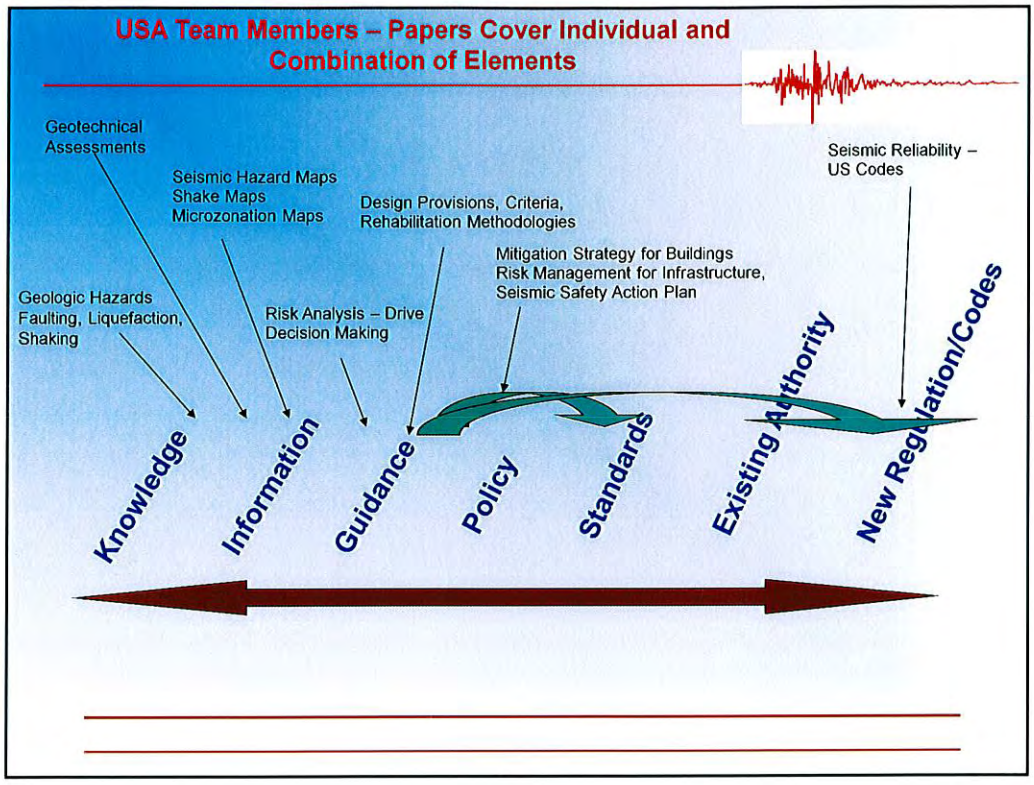


All these elements are important.

If you understand this concept and the arrangement, it will lead to a greater number of options to implement and thus more flexibility.

It will also provide strategic direction and help avoid common pitfalls (such as having missing elements)

Currently FEMA and NOAA recognize the importance of Guidance to Provide Direction to the Community on how to Reduce Hazard Risk.



All Elements are important

You have heard already USA team members speak about different parts of this continuum.

Geologic Hazards – covered by Matt Francis

Geotechnical Assessments by Ken Stokoe

Seismic Hazard and Microzonation Maps – Mark Petersen & Ivan Wong

Risk Analysis – Hazus – Douglas Bausch

Later Groups 2, 3 and 4 will be talking about Guidance, Policy, Standards and Regulations when they talk about design provisions, criteria, rehabilitation methodologies, mitigation strategies, and building codes.

Experience with nees@UTexas Large-Scale Mobile Shakers In Earthquake Engineering Studies

Kenneth H. Stokoe, II[1], F.-Y. Menq[1], S.L. Wood[1], K. Park[1], B.L. Rosenblad[2], B.R. Cox[3]

Abstract

The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) is a US-wide program that is supported by the National Science Foundation. NEES is composed of a network of fifteen testing facilities, called Equipment Sites that spread across the United States. The Equipment Site specializing in mobile, geotechnical, field equipment was developed at the University of Texas at Austin named nees@UTexas. Operational since October 2004, nees@UTexas is a 50% shared-use facility. In the past three years, nees@UTexas has conducted nine shared-used projects and numerous non-shared-use projects. Experience with the shakers is discussed for: (1) deep shear wave velocity profiling in the Mississippi Embayment, (2) in-situ nonlinear shear modulus measurements of soil, (3) field dynamic tests of 1/4-scale bridge bents founded on drilled shafts, and (4) in-situ liquefaction tests in Imperial Valley, CA. Test arrangements and representative results from these projects are also discussed.

Introduction

The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) is a US-wide program that is supported by the U.S. National Science Foundation. NEES is composed of a network of: (1) fifteen advanced testing facilities, called Equipment Sites, (2) an Information Technology infrastructure being developed by NEESit, and (3) a community-based non-profit organization name NEESinc. The 15 equipment sites are link together through the Information Technology infrastructure at NEESit. In addition, NEESit is in the process of providing collaborative tools, a centralized data repository (NEEScental), and earthquake simulation software. NEES Consortium, Inc. (NEESinc) manages NEES as a national, shared-use research facility for the earthquake engineering community.

nees@UTexas is one of the fifteen Equipment Sites. It specializes in mobile, geotechnical, field equipment. In October, 2004, nees@UTexas began operation as a 50% shared-use facility. In the past three years, nees@UTexas has conducted a total of nine shared-use projects and numerous non-shared-used projects. Each of these studies would have been very difficult to perform before nees@UTexas was developed. Shared-use projects are research projects either funded by the National Science Foundation through the NEES program or funded by US public agencies that obtain a shared-use status from NEESinc. Shared-use projects are charged a reduced rate for using the nees@UTexas equipment and are not charged for staff salary. However, shared-use projects are required to share all measured data and results with the public. Data collected in a shared-use project is required to be input into the NEEScental data repository one year after completion of the project.

The shared-use equipment available at nees@UTexas and four example shared-used projects that utilized the nees@UTexas equipment site are discussed in this article. More information about the nees@UTexas equipment site and other NEESR projects can be found at http://nees.utexas.edu/ and https://central.nees.org/.

Overview of nees@UTexas

The nees@UTexas equipment includes: (1) three mobile shakers that have diverse force and frequency capabilities and a tractor-trailer rig to move the two largest shakers to and from the field sites, (2) an instrumentation van that houses state-of-the-art data acquisition systems and a satellite link-up, (3) an instrumentation trailer that provides additional work and storage space in the field, (4) a fuel-supply truck for refueling and field maintenance of the mobile shakers, (5) a collection of field instrumentation that measure

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vibrational motion and pore water pressure, and (6) telepresence capabilities that allow for remote participation in field experiments.

The three mobile shakers are called: (1) T-Rex, (2) Liquidator, and (3) Thumper. Each mobile shaker was designed and built by Industrial Vehicles International, Inc. (IVI), in Tulsa, Oklahoma. All three shakers use vegetable-based hydraulic oil which will not raise environmental concerns if a leak occurs in the field.

T-Rex is capable of generating large dynamic forces in any of three directions (X, Y, or Z directions). A photograph of T-Rex is shown in Figure 1a. The shaking system is housed on an off-road, all-wheel-drive vehicle. The theoretical performance of T-Rex in both the vertical and horizontal modes is shown in Figure 2. As shown in the figure, the force output in the vertical mode is about 267 kN and decreases with frequency below 12 Hz. In the horizontal mode, the maximum force output is about 133 kN and decrease below 5 Hz.

a. High-force, three-axis shaker called T-Rex

b. Low-frequency, two-axis shaker called Liquidator

c. Urban, three-axis shaker called Thumper

Figure 1. Photographs of nees@UTexas shakers

Liquidator is designed to be a lower frequency vibrator and is a one-of-a-kind shaker. A photograph of Liquidator is shown in Figure 1b. The shaking system is specially designed to give a higher force output in the low-frequency range of 0.5 to 4.0 Hz. This makes Liquidator an excellent vibrational source for deep surface wave testing. The theoretical performance of Liquidator in both the vertical and horizontal modes is shown in Figure 2. As shown in the figure, the force output in both modes is about 89 kN and decreases with frequency below 1.3 Hz.

Thumper is a smaller shaker mounted on a standard Ford 650 truck. A photograph of Thumper is shown in Figure 1c. Thumper is ideal for geophysical testing in urban areas because it is highway-legal and has a moderate force output. The theoretical performance of Thumper is shown in Figure 2. As shown in the figure, the maximum force output is about 27 kN over the frequency range of 17 to 225 Hz.

T-Rex and Liquidator must be transported to and from field sites on a tractor-trailer rig. The tractor-trailer rig is part of the nees@UTexas vehicle fleet. It is important to note that the combined weights of one of the large shakers and the tractor-trailer rig are between 48,000 and 51,000 kg. Therefore, the complete system is overweight when moving on the highways and thus requires overweight permits to

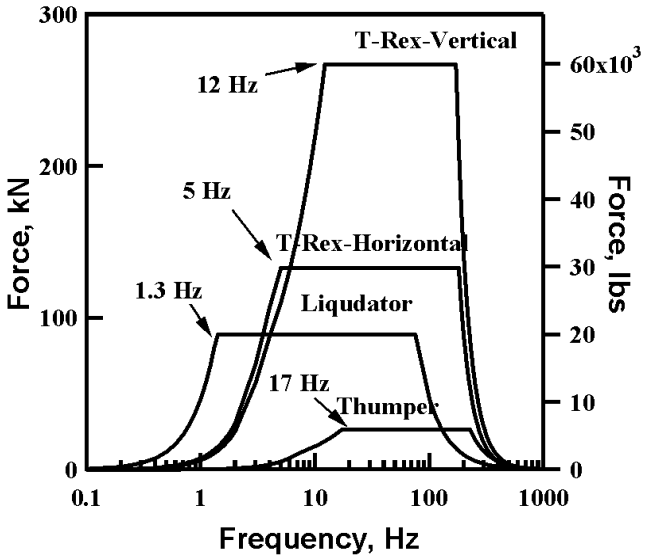

Figure 2. Theoretical force outputs of the three mobile shakers at nees@UTexas (modified from Stokoe et al., 2004)

transport. More information about the shakers can be found in Stokoe et al. 2004.

The instrumentation van is a customized Chevrolet cargo van that includes a diesel generator, an air-conditioned workspace, and a fully-integrated computational network. The fuel-supply truck can carry diesel fuel for T-Rex and Liquidator in the field. It is also designed to carry spare parts and tools for maintenance. The instrumentation trailer is a 2.4 m by 4.8 m cargo trailer. It can be towered by either the instrumentation van or the fuel-supply truck. The interior of the trailer is divided into two parts. The front part of the trailer is air conditioned and is used as work space. The rear part of the trailer is used to carry tools and equipment to the field.

There are three main data acquisition systems at nees@UTexas site. These systems are: (1) a VXI system, (2) Data Physics system, and (3) a Sercel 408XL system. The VXI system includes 64 channels of acquisition at a sampling rate of 50 kS/s and 8 channels of acquisition at a sampling rate of 196 kS/s. The Data Physics system includes 32 channels of acquisition at a sampling rate of 200 kS/s. The Sercel 408XL is designed for the seismic testing and oil exploration industries. It is capable of connection to receivers via digital telemetry cables or via wireless radio links. It can process up to 2000 channels of data. However, only 40 channels are presently available. All three systems can be used in either the instrumentation van or the instrumentation trailer.

The field instrumentation available at nees@UTexas includes 1-Hz and 10-Hz geophones, prototype in-situ liquefaction sensors, and Cone Penetrometer Test (CPT) equipment. The prototype liquefaction sensors were designed and constructed at the University of Texas (Cox 2006). A picture of one liquefaction sensor is shown in Figure 3. The main body of the sensor is a cylindrical, acrylic case with a conical tip. The sensor is compact, measuring 12.7 cm from tip-to-top and 3.8 cm in diameter. Each sensor has a total unit weight of approximately 1.44 g/cm3. It houses a miniature pore water pressure transducer (PPT) and a 3-component, Micro-Electrical Mechanical Systems (MEMS) accelerometer. During tests, the liquefaction sensors are installed at multiple points in the ground to monitor ground motion and pore pressure generation at each point.

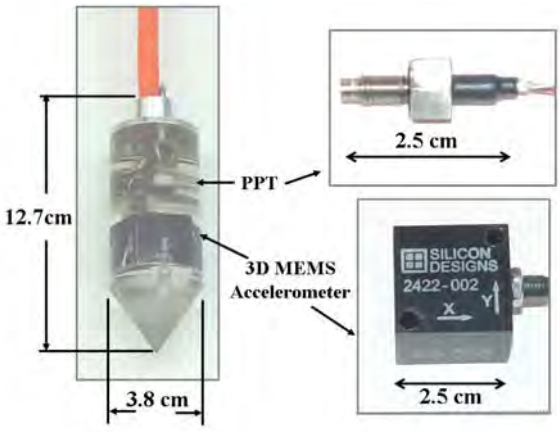

Figure 3. Picture of an in-situ liquefaction sensor (modified Cox, 2006)

Example Studies Using the nees@UTexas Equipment

A total of nine share-use projects have been conducted with nees@UTexas equipment in the past three years. These projects cover a wide spectrum of research topics. Researchers include both geophysical scientists and structural and geotechnical engineers. Because of the space limitation, only four projects are briefly discussed.

Deep Shear Wave Velocity Profiling in the Mississippi Embayment

In this study, Liquidator was used as an active source for surface wave velocity measurements in the Mississippi Embayment region of the central United States (Rosenblad et al. 2007). The region is located on the seismically active New Madrid Seismic Zone (NMSZ) and is vulnerable to large amplifications from earthquake motions. One of the critical input parameters needed for site response analysis is the small-strain shear wave velocity (VS) profile. Soil deposits in this region are hundreds of meters thick, but are poorly characterized at depths below 60 m. The objectives of the study were (1) to study different surface wave measurement techniques and (2) to develop shear wave velocity profiles to depths of 200 to 300 m.

Measurements were performed at five locations in the states of Tennessee and Arkansas. The deep VS profiles presented in Rosenblad et al, 2007 were determined using the Spectral-Analysis-of-Surface-Waves (SASW) method. The SASW method is a non-intrusive seismic method where the dispersive characteristics

of Rayleigh-type surface waves propagating through a layered material are measured and then used to determine the VS profile.

Liquidator was used to excite the requisite low-frequency surface wave energy (down to 0.7 Hz) for deep VS profiling. A 300-m long array of 16, 1-Hz vertical geophones from the nees@UTexas site were used to measure the surface wave motions generated by the source. Wavelengths of 600 m were successfully measured in this study.

The stepped sine function available from the VXI analyzer was used to externally drive Liquidator from 20 Hz down to 0.7 Hz. The analyzer was also used to record the output from the geophones. The integration time and number of averages taken at each frequency were adjusted based on the quality of the measurement as indicated by the coherence value (indicative of signal-to-noise ratio). Figures 4a and 4b show an example of the wrapped phase and coherence values, respectively, measured between receivers located at 300 m and 600 m (the longest spacing) from the source at one site. In this case, the source was stepped through 50 frequency points from 3 Hz down to 0.8 Hz over a period of about 45 minutes. As shown in the figure, even at frequencies below 1 Hz, the coherence values are higher than 0.8.

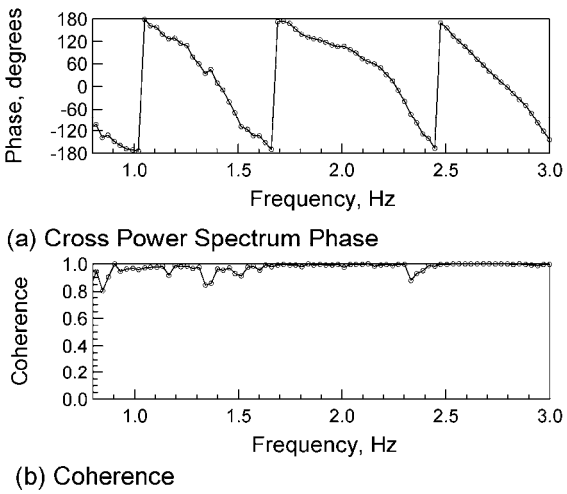

Figure 4. (a) Wrapped phase plot from the cross-power spectrum and (b) coherence function measured with receivers located 300 m and 600 m from the source at one site.

The VS profiles that were determined for the sites are presented in Rosenblad et al. (2007). The median profile and variability generated from the five sites is in general agreement with the reference profile that has been developed for the Mississippi Embayment (Romero & Rix 2001). Disparities between the VS profiles at some sites were shown to be associated with differences in soil lithology.

In-Situ Nonlinear Shear Modulus Measurements in Soil

Generally, the nonlinear behavior of soil is characterized by a reduction in the shear modulus (G) and an increase in the material damping ratio with increasing shearing strain (γ). Evaluation of the nonlinear shear modulus of soil for use in geotechnical engineering often involves field and laboratory tests. In current practice, the shear modulus reduction curve is determined in the laboratory and then combined (scaled) with the in-situ, small-strain shear modulus obtained from field seismic tests. However, with the large nees@UTexas shakers, it is possible to determine shear modulus reduction curves in the field.

Figure 5 illustrates testing arrangements to measure nonlinear compression and shear wave propagation in situ with a footing. An array of three-dimensional (3-D) sensors is embedded below the ground surface. The 3-D sensors are placed in hand-augered boreholes and backfilled with recovered soil. Each sensor consists of three geophones with a natural frequency of 14 Hz. The geophones are glued in acrylic cases using epoxy. Each sensor has the approximate unit weight of the soil. After the sensor array is installed, a concrete footing is constructed. The footing is circular and has a diameter of 0.90 m and thickness of 0.30 m. The footing is reinforced with 1.3-cm diameter rebar. Before pouring the concrete, 3-D geophones are

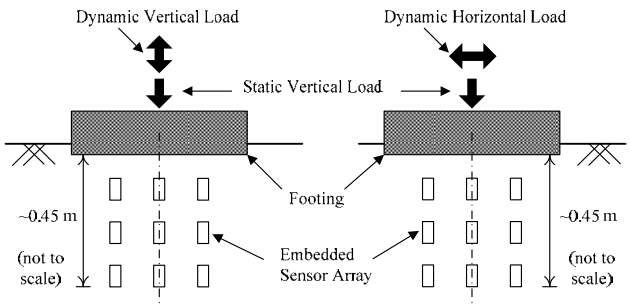

Figure 5. Generalized testing arrangements to measure nonlinear compression and shear wave propagation in situ with a footing (from Stokoe et al. 2006).

attached to the lower rebar which are close to bottom of the footing. These geophones are used to monitor the motion of the footing.

In the nonlinear tests, the dynamic loads are applied with either Thumper or T-Rex. The shakers apply dynamic loads over a wide range, from loads that create only small strains (less than 0.001%) to loads that create significant nonlinear responses (at strains above 0.05%). A load cell is placed between the loading plate and the footing to measure both static and dynamic loads.

An example of the results from an in-situ nonlinear dynamic test is illustrated in Figure 6. In this example, the surface footing was staged loaded to evaluate the G – log γ relationship of a poorly graded sand and silty sand (SP-SM) that was lightly cemented. Measurements of G in the linear range and in the nonlinear range were clearly conducted.

An intact sample of this soil was also tested in the laboratory using a combined resonant column and torsional shear (RCTS) device. The laboratory G – log γ relationship is included in Figure 6. Good agreement exists between the field and laboratory values of G.

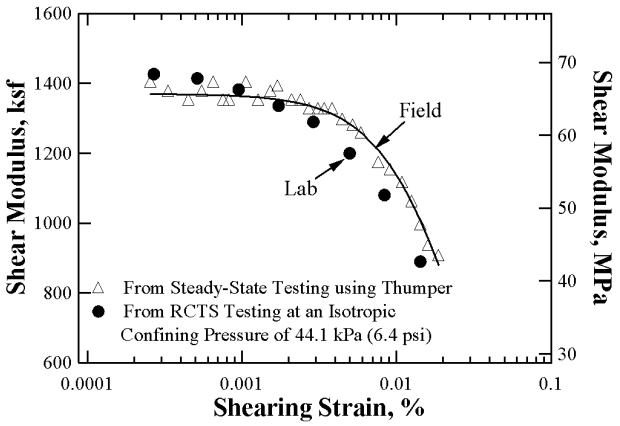

Figure 6. Field measurement of the nonlinear shear modulus of a lightly cemented sand using a horizontally excited surface footing (from Stokoe el al. 2006).

Field Dynamic Tests of 1/4-Scale Bridge Bents Founded on Drilled Shafts

This study is part of a collaborative research project to study soil-foundation-structure interaction (Wood et al. 2004, Agarwal et al. 2006). The prototype structure that was modeled in this investigation is a continuous, reinforced concrete bridge with drilled shaft foundations. This type of structure is common throughout the US. Although the seismic response of the ductile reinforced concrete structural elements is well understood, the extent to which nonlinear behavior of the soil and/or foundation influence the performance of the complete system is not well understood. Due to the size and complexity of the prototype system, it was not possible to test a single physical model and reproduce all key aspects of the system. Four complementary experimental programs, which involved three NEES equipment sites and four non-NEES universities, were developed to investigate the response of critical components.

nees@UTexas was responsible for testing two, ¼-scale, isolated bridge bents on drilled shaft foundations constructed at a field site in Austin, TX. nees@UTexas mobile field shakers have the advantage of studying soil-foundation-structure interaction of the bridge bents in the field at actual settings. The specimens were tested dynamically using three types of loading. Initially, the specimens were stuck with a modal hammer to generate the free vibration response in the linear range. In the second series of tests, T-Rex was used to induce sinusoidal motion in the test specimens by exciting the ground surface in the vertical and two horizontal directions. For the third series of tests, the linear shaker from Thumper was mounted at midspan of the beam (Fig. 7) and used to excite the bent horizontally initially in the linear range and then in the nonlinear range.

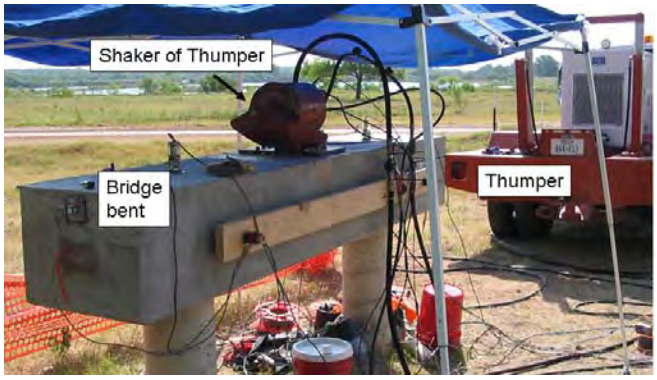

Figure 7. Harmonic excitation of Bent 2 using shaker from Thumper.

When tests were conducted using higher force levels with Thumper, inelastic response was observed. The structure would appear to have achieved resonance at a given excitation frequency. After a number of cycles with increasing response amplitude, the amplitude of the vibrations would decrease suddenly. The amplitude

of the response would then increase when the specimen was excited at the next frequency, only to drop again. This pattern was repeated several times during the stepped sine loading histories at the higher force levels. No cracking of the concrete was observed after the test. The decreasing of the natural frequency resulted from gaps that opened between the edges of the drilled shafts and the surrounding soil during these tests.

At the end of dynamic loading, the wenches mounted in front of both T-Rex and Liquidator were used to cyclically load the bridge bents to failure.

Figure 8 shows one of the bridge bents that was cyclically loaded with both T-Rex and Liquidator. The other bridge bent after cyclically test is also shown in the figure.

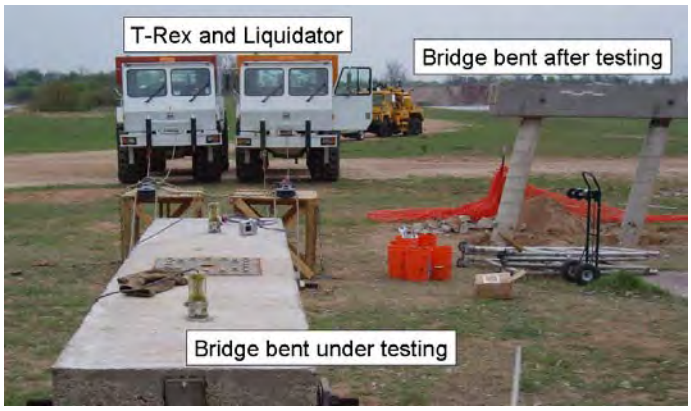

Figure 8. Cyclically load test with T-Rex and Liquidator.

In-Situ Liquefaction Tests in Imperial Valley, CA

This project was directed towards the development and implementation of a new in-situ liquefaction test that can be used to evaluate the coupled response between excess pore water pressure generation and nonlinear shear modulus behavior. The test involves dynamically loading a native soil deposit in a manner similar to an earthquake while simultaneously measuring its response with push-in sensors. During testing, T-Rex is used to generate vertically propagating (downward), horizontally polarized shear waves (Svh waves) of varying amplitudes that propagate through an instrumented portion of a liquefiable soil mass (Fig. 9). Newly-developed, push-in liquefaction sensors (Fig. 3) are installed from the ground surface in a two-dimensional (2D), trapezoidal array within the liquefiable soil layer and are retrievable upon completion of testing.

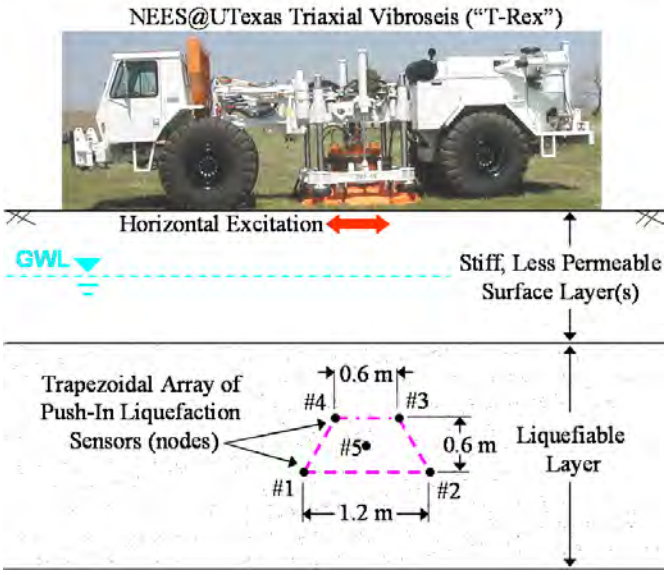

Figure 9. Test arrangement of in-situ liquefaction test.

The validity of the in-situ liquefaction testing equipment, field technique and data analysis procedures have been demonstrated by conducting field experiments at the Wildlife Liquefaction Array (WLA) in Imperial Valley, California. WLA has been intensely studied over the past 25 years and is one of the most researched soil liquefaction sites in the world. It has also recently been designated as a NEES site for the study of soil liquefaction (http://nees.ucsb.edu).

In-situ tests were conducted in a liquefiable soil deposit approximately 3 to 4 m below the ground surface. The tests were successful at measuring: (1) excess pore water pressure generation, and (2) nonlinear shear modulus behavior in the native silty-sand deposit as a function of induced cyclic shear strain and number of loading cycles. An example of the in-situ pore pressure generation curves obtained at WLA is shown in Figure 10. The in-situ pore pressure generation curves compare favorably with laboratory tests (Vucetic & Dobry 1986). Excess pore water pressure in the soil was not generated until shear strains greater than the cyclic threshold shear strain had been induced. Further results and comparisons may be found in Cox (2006).

Conclusions

The mobile shakers and associated equipment acquired by the nees@UTexas equipment sites are unique and tailored to earthquake engineering related research. The shared-use policy makes the equipment available for researchers in the US, and utilizes the equipment site to its full potential. More studies can be expected from future shared-use projects.

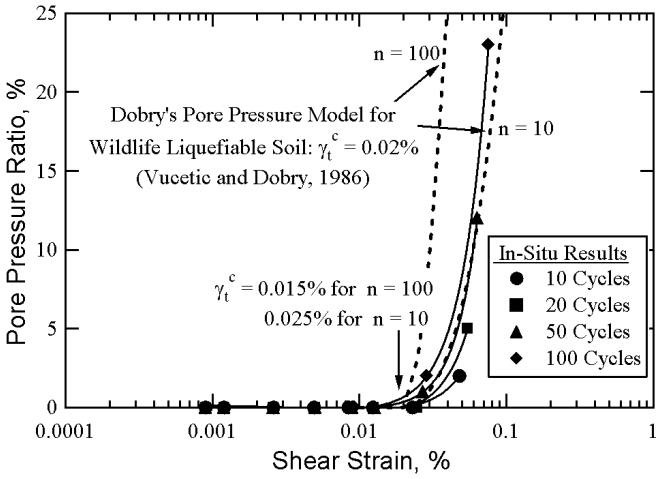

Figure 10. Pore pressure generation curves obtained from in-situ liquefaction tests at the Wildlife Liquefaction Array.

Acknowledgements

Financial support for the development of the nees@UTexas Equipment Site was provided by the NEES under grant CMS-0086605. Financial support for the research projects was provided through the National Science Foundation under grants CMS-0324326, CMS-0421275, and CMS-0530140, and through the U.S. Geological Survey (USGS) under award 01HQR0036. Thanks goes to graduate students and staff at the University of Texas at Austin who assisted in the field and laboratory work, including Puneet Agarwal, Andrew Sheehan, Jung Jae Lee, Seong-Yeol Jeon, Won Kyoung Choi, Mr. Cecil Hoffpauir, Mr. Andrew Valentine, and Mr. Christopher Stanton. Special thanks to the Fitzpatrick family for graciously allowing studies to be conducted on their property near Austin, TX.

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Seismic Hazard Mapping in China and the United States

Mark D. Petersen[1] and Mengtan Gao [2]

Abstract

China and the United States share similar seismotectonic characteristics that lead to significant seismic hazard and risk in highly populated urban areas. During the past few decades several large earthquakes have inflicted billions of U.S. dollars/China Yuan in losses and caused many casualties, injuries, and societal problems within the nearby impacted areas. China and the U.S. have taken important steps in risk mitigation by developing new national seismic hazard maps and tools for rapidly assessing ground shaking and losses following an earthquake. These hazard maps are based on the "best available science" and form the framework of building design codes that when properly applied can mitigate the building collapses that cause most casualties and losses. Rapid assessments of ground shaking and losses can help officials in emergency response following a large, damaging earthquake. The international seismic hazard community should continue to share strong-motion data, hazard and risk methodologies, and collaborate in setting standards for urban hazard models and design guidelines.

Introduction

China and the United States each have extensive regions of high hazard and risk resulting from complex, active tectonic processes. Both countries are dissected by active crustal faults that each contribute to the seismic hazard. Faults in both nations have ruptured in large damaging earthquakes causing billions of U.S. dollars/ China Yuan in structural, building-contents, and business-related losses as well as many casualties and injuries. The 1976 Tangshan (M~7.5), 2008 Wenchuan (M7.9), and 2010 Yushu (M6.9) earthquakes in China and the 1906 San Francisco (M7.8), 1989 Loma Prieta (M6.9), and 1994 Northridge (M6.7) earthquakes in the U.S. were all very destructive and led to strong earthquake shaking and effects. Earthquake ground shaking, fault rupture, landslides, and liquefaction contributed to the overall losses from these earthquakes. Assessing earthquake hazard and risk in China and the U.S. involves: (1) earthquake source models that incorporate up-to-date fault studies, GPS strain rates, and seismicity catalogs, as well as physics-based models that incorporate multi-segment ruptures and fault-to-fault jumps; (2) ground-motion models that are consistent with strong motion data recorded on various soils for subduction zones and crustal sources; (3) design codes that are cost effective and consider reasonable levels of ground shaking; (4) fragility and vulnerability relations that can be used to generate risk and loss estimates for planning; and (5) effective disaster mitigation and response plans and webtools for communication. Future losses can be mitigated by better accounting for potential earthquake effects when designing buildings and infrastructure.

Effective disaster-mitigation planning depends on developing reasonable building codes that will minimize collapse of buildings, bridges, and other infrastructure. Developing and enforcing reliable and cost-effective building codes is, perhaps, the most important way to reduce earthquake losses. Building collapse is one of the largest causes of casualties and losses in earthquakes. Modern building codes have been established in both countries. For China, The National Standards of the People's Republic of China Code for Seismic Design of Buildings was adopted on Jan. 1, 2002 [1]. For the U.S. the International Building Code was updated in 2006 [2] and new seismic provisions will be introduced in the 2012 version. However, as the scientific analyses and engineering techniques improve, these codes need to be constantly updated to improve safety and function in a cost-effective way.

Both China and the U.S. are in the process of updating the hazard assessments that underlie these building codes. Both countries have cooperated in developing new seismic hazard assessments. The China hazard assessment project was initiated in 2007 and will be completed in 2011. This is the fifth national seismic hazard map of China and will include a national standard document on how to apply the hazard maps for building design. China has planned a series of meetings to communicate with engineers and local people on the use of the maps for building design. The U.S. hazard assessment project is ongoing with updates every 6

[1] U. S. Geological Survey (Golden, CO, USA), [2] China Earthquake Administration (Beijing, China)

years; the next version of the hazard maps is expected in 2013. The U.S. also improves hazard maps based on information provided by working groups, regional workshops, and interaction with the broad science and engineering communities. The U.S. and China have sent science experts to each other's country to share hazard methodologies and data. In addition, the U.S. and China scientists have been involved in reviewing the Global Earthquake Model, which displays hazard across the globe. Collaboration on risk mitigation and response efforts can benefit both countries by developing more cost effective building codes and other real-time tools that can save lives, reduce earthquake related losses, and enable critical activities to continue with minimal disruption.

China Earthquake Hazard and Risk Assessments

Seismic hazard models for China have been developed by the China Earthquake Administration (CEA) through a project supported by the Ministry of Science and Technology (MOST). Seismic hazard research has centered on (1) developing methodologies to assess uncertainty in earthquake hazard mapping, (2) improving hazard methodologies for spatial smoothing using instrumental and historical data, (3) delineating boundaries and maximum magnitudes (M 7.5) of active blocks in intraplate regions, (4) building a detailed, active fault database, (5) developing methodologies for assigning recurrence rates from geologic and geodetic strain rates, (6) assessing earthquake magnitudes based on fault length for strike-slip, reverse, and normal faults, (7) assessing earthquake ground shaking using global data for seismically active and inactive regions, and (8) studying the effect of soil condition on ground shaking using a new classification of soil types. For the next seismic hazard update the CEA has compiled new earthquake catalogs, an active fault database, GPS strain-rate data, and other geophysical data needed to characterize the earthquake sources and path effects. They have constructed a new model for potential sources in China using new methods derived from discussions at meetings in Beijing, Harbin, Nanjing, and Lanzhou. In addition, scientists at the CEA have assessed the uncertainties of source parameters. These scientists have made significant changes to the hazard input model. For example, scientists now feel that the maximum magnitude for earthquakes in China is about 20% larger than applied in previous models. These efforts will be important in developing a new China seismic hazard model that can be used in building design criteria.

CEA scientists have also been involved in analyzing the seismic stability of engineering projects. For example, they have participated with local engineers on thousands of seismic hazard evaluation projects for high-rise buildings, long-span bridges, long tunnels, large oil tanks, and dams. In addition, scientists recently completed studies on building collapse caused by earthquakes as well as an assessment of cost requirements for different seismic-design parameters.

U.S. Earthquake Hazard Assessment and Earthquake Response

The U.S. Geological Survey (USGS) updated the seismic maps in 2008 by incorporating new findings on earthquake ground shaking, faults, seismicity, and geodesy [3]. As part of the update a working group developed an earthquake source model for California that was consistent with the historical earthquake rate, allowed multi-segment ruptures, and included new GPS data [4]. Future models must account for multi-segment ruptures and fault-to-fault jumps. Fault-to-fault jumping behaviour was observed in the 1997 M 7.3 Landers earthquake in southern California. One of the biggest challenges in future hazard assessments will be to determine how to use LiDAR imagery in characterizing fault ruptures and GPS strain-rate data in determining recurrence of future earthquakes.

A very important component of hazard calculations is the ground-motion models that quantify the shaking for various earthquakes included in the hazard model. U.S. scientists have made concerted efforts to develop a new generation of models for the national seismic hazard maps. The Next Generation Attenuation (NGA) Project (sponsored by Pacific Engineering Research Center lifelines program) developed new ground-motion prediction relations using data from shallow crustal earthquakes across the globe. The NGA group constructed a ground-motion database and held a series of interactive meetings and workshops to evaluate alternative hypotheses on earthquake ground shaking. They evaluated ground-shaking amplifications due to various site conditions; made consistent evaluations of magnitude, type of faulting, classifications for hanging wall and footwall, and source-to-site distances; estimated ground motions as a function of depth to earthquake ruptures; and accounted for ground-motion amplification caused by sedimentary basins. These ground-motion models

for the active tectonic crustal regions are currently being updated (NGA-West II) for vertical motions and smaller earthquakes and new models for ground shaking are being developed for the craton and extended margin regions (NGA-East). Similar working group efforts are needed to account for ground motions from subduction zone plate-interface and deep earthquakes. Improving these equations will be important for improving future hazard assessments and especially for developing urban hazard maps.

Following a large damaging earthquake, it is important to have accurate, real-time information for developing response strategies. The USGS operates the National Earthquake Information Center, which locates world-wide earthquakes [5]. During the past decade the USGS has developed ShakeMap, a tool to rapidly assesses earthquake ground motions and intensity values to regions surrounding an earthquake [5]. Utilities and other agencies use ShakeCast to automatically retrieve ShakeMap data and set inspection priorities automatically, immediately after an earthquake [5]. Scenario earthquake ground motions can also be calculated to plan for a certain earthquake near an urban area. These ground motions along with soil maps and building and bridge inventories can be input for the Federal Emergency Management Agency Hazard-US (HAZUS) loss estimating methodology to provide estimates of losses and casualties from a particular earthquake scenario for planning purposes. Developing fragility equations for buildings and casualties is an important requirement for assessing losses regionally. One of the biggest challenges in calculating earthquake losses is that inventories of building stock are lacking in many urban regions. The Prompt Assessment of Global Earthquakes for Response (PAGER) [5] rapidly assesses the number of people impacted by an earthquake. This webtool uses population density to estimate inventory and provides earthquake impact estimates to officials that can act on this information in responding to global events. Future collaborative research should focus on developing better fragility, vulnerability, and inventory information.

Conclusions

China and the U.S. face similar risks from earthquakes that can be mitigated through building codes and emergency-response data. Ground shaking, landslide, liquefaction, and fault-rupture hazard are important seismic hazard considerations in both countries. Improved research on physics-based source and ground-motion models that are consistent with scientific observations and understood through computer simulations will improve hazard assessments in both countries. Rapid, real-time assessments of ground shaking and potential losses can assist in emergency response and save lives following an earthquake. China and the U.S. have both been successful in sharing important ground-motion data with the global community. Future collaborations should focus on setting standards for hazard, risk, structural design, inventory and vulnerability analyses, and disaster response models that can be applied in all urban regions.

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Development of Urban Earthquake Hazard Maps in the United States

***Ivan G. Wong*[1]**

Abstract

In the past decade, earthquake ground shaking hazard maps for urban areas in the U.S. have been developed by the U.S. Geological Survey and URS Corporation. These maps illustrate the intensity and variability of ground shaking at a microzonation scale due to the local site response of both soil and rock. The maps are used in a number of ways such as increasing general public awareness of earthquake hazards, urban planning, selecting facility sites, providing a basis for whether site-specific hazard evaluations should be performed, aiding emergency preparedness and response, and loss estimation. Both earthquake scenario and probabilistic maps generally for the building code probabilities of 10% and 2% exceedance in 50 years (return periods of 475 and 2,475 years, respectively) have been developed. Ground motions are generally expressed in terms of peak horizontal acceleration and the building code-specified spectral accelerations at periods of 0.2 and 1.0 second.

Introduction

In the past few decades, tremendous advances have been made in identifying and characterizing seismic sources in the U.S., and in evaluating and quantifying the level of the associated seismic hazards. Many of these advances have resulted from extensive site-specific seismic hazard evaluations performed for critical facilities such as nuclear and other types of power plants, nuclear waste repositories, and dams in addition to research performed by the U.S. Geological Survey (USGS), state geological surveys, and academic institutions. Characterizing ground shaking hazards on a large areal basis has generally been either on a national scale such as the probabilistic National Seismic Hazard Maps produced by the USGS (Frankel *et al.*, 1996; 2002; Petersen *et al.*, 2008) or on a state-wide basis such as the maps produced for a few state departments of transportation (e.g., California, Arizona, and Oregon). However, because of the large-scale nature of these maps, they are usually developed for a single geologic site condition, i.e., rock. Obviously there is also a need to address the site response effects of soils and unconsolidated sediments because of the significant amplification and deamplification that can occur due to these deposits.

In the past decade, ground shaking hazard maps on a microzonation scale have been developed for urban areas, which incorporate the effects of the near-surface geology and in some cases, basin geology and geometry. The need for urban hazard maps is obvious in areas of moderate to high seismic hazard because of the concentration of population. Ground shaking hazard maps have been developed for the San Francisco Bay area, California; Seattle, Washington; and Memphis, Tennessee, urban areas by the USGS. Plans are underway for Salt Lake City, Utah; St. Louis, Missouri; and Portland, Oregon. Since 1997, URS has developed deterministic earthquake scenario and probabilistic microzonation maps for urban areas in the western U.S. including the Portland, Oregon, and the Salt Lake City, Utah, metropolitan areas, the Albuquerque-Belen-Santa Fe urban corridor in New Mexico, and the Salt Lake City-Ogden-Provo urban corridor in Utah.

Urban maps provide a quantitative measure of ground shaking and are of value to the engineering, urban planning, emergency preparedness and response communities, and the general public. A principal objective of these maps is to raise the public awareness of earthquake hazards in a given area. The maps can be used for loss estimation employing, for example, the HAZUS methodology or planning scenarios for emergency response. The intent of the maps is not to replace the USGS National Seismic Hazard Maps, which form the basis for the U.S. building code or site-specific studies particularly for important or critical facilities. Because the maps are for the ground surface, engineers relying solely on a building code-based approach can evaluate the adequacy of their design levels (assuming inclusion of the site factors) by comparing them against the mapped values.

The ground motion parameters illustrated on the hazard maps are parameters of engineering and building code relevance: peak horizontal ground acceleration (PGA) and horizontal spectral accelerations (SA) at periods of 0.2

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and 1.0 sec. The deterministic microzonation maps are for selected earthquake scenarios. The probabilistic maps are generally for return periods of 475 and 2,475 years (10% and 2% exceedance in 50 years, respectively). The most up-to-date information on seismic sources, path effects, and near-surface geology are incorporated into the deterministic and probabilistic seismic hazard analyses. To address the wide range of interpretations and values as well as uncertainties of the input parameters, the latter are performed using a logic tree approach.

Methodology and Input to Hazard Calculations

There are generally six principal tasks that are required to produce urban hazard maps: (1) seismic source characterization; (2) definition and characterization of geologic site response categories; (3) site response analyses and calculation of amplification factors; (4) seismic attenuation characterization; (5) deterministic and/or probabilistic ground motion calculations; and (6) map development. The following is a general description of these tasks although there certainly is variation in how the urban maps are developed.

Seismic Source Characterization

The first step in any assessment of earthquake ground-shaking hazards is a characterization of the seismic sources that will produce ground motions of engineering significance at the site or area of interest. Seismic source characterization is concerned with three fundamental elements: (1) the identification, location, geometry, and rupture process of significant sources of earthquakes; (2) the maximum size distribution of earthquakes for each source; and (3) for probabilistic hazard, the rate at which different size earthquakes occur on each source. Parameters needed in a deterministic analysis include fault location, geometry, orientation, sense of slip, and maximum earthquake magnitude (M_{max}). In probabilistic seismic hazard analyses (PSHA), all these parameters are needed including recurrence model and rate. Uncertainties in the seismic source parameters are generally incorporated into PSHA using a logic tree approach. In this procedure, alternate models and/or the continuous distribution of input parameters are represented on multiple branches of logic trees with discrete characteristics and/or values and assigned weights.

In a PSHA, all seismic sources that can generate significant ground shaking at a site are characterized. That distance is generally a distance of 100 to 200 km in the western U.S. and up to 1,000 km in the central and eastern U.S. (CEUS). The difference in distances is due to the differences in crustal attenuation. Two general types of seismic sources are generally considered in PSHA: active or seismogenic faults and background earthquakes.

Quaternary Faults

All known faults with evidence for repeated Quaternary or late-Quaternary movement are generally included as potential seismic sources. Where the data permit, the structural variations that are potentially significant to hazard analysis are considered and accommodated by including a variety of rupture behavior models and fault geometries in source characterization. Most faults are included as single independent (unsegmented) planar sources, unless the available data suggest otherwise. Zones of faults are modeled as multiple, distributed, parallel fault planes. Some faults show compelling evidence for being segmented, where relatively persistent segment boundaries have apparently confined prehistoric surface ruptures to particular sections of the faults. Faults are assumed to extend the full depth of the seismogenic crust, and so fault dips are averages estimated over the full depth of the seismogenic crust.

A probability of activity is often assigned to each fault source, to assess both the likelihood that it is structurally capable of independently generating earthquakes (seismogenic), and the likelihood that it is still active within the modern stress field. Many factors are considered in assessing these likelihoods, such as: orientation in the modern stress field, fault geometry (length, continuity, depth extent, and dip), relation to other faults, age of youngest movement rates of activity, geomorphic expression, amount of cumulative offset, and any evidence for non-tectonic origin. The probability of activity for faults that do not show definitive evidence for repeated seismogenic Quaternary activity are individually judged based on available data.

M_{max} values are estimated using empirical relationships most notably those of Wells and Coppersmith (1994) based on rupture length and rupture area and also fault displacements per event when such data are available. Uncertainties of $\pm$ 0.2 to 0.3 magnitude units around the preferred M_{max} are included to account for the uncertainties associated with the regression relations used and the input parameters to those relations, insofar as uncertainties in lengths and/or displacements are not explicitly included.

Truncated-exponential, characteristic, and maximum-magnitude (a form of the characteristic model) recurrence models, with weights dependent on the fault length, type of data used to calculate activity rates, and type of rupture model are generally considered in PSHA. Observations of historical seismicity and paleoseismic investigations worldwide suggest that characteristic behavior is more likely for individual faults, whereas seismicity in zones best fits a truncated exponential model. Therefore, except for zones of faults, the characteristic model of Youngs and Coppersmith (1985) and maximum magnitude model of Wesnousky (1986) are favored for fault sources.

Intermediate- (≤ 1.6 Ma) and short-term (≤ 130 ka) slip rate and/or recurrence interval data are often used in characterizing rates of fault activity, but short-term recurrence interval data are favored when available (Wong and Olig 1998). Rates are generally the most important fault parameters in hazard evaluation, but unfortunately most faults in the U.S. lack specific rate data. Compounding this difficulty is that many faults that have been studied show large variations in rates through time and in space. Depending on the available data, a variety of approaches can be used to characterize fault activity rates and their large uncertainties including: statistical analyses (e.g., McCalpin and Nishenko 1996), ergodic analyses that substitute space for time (e.g., McCalpin 1995), and geomorphic analyses and analogue comparisons (e.g., Ruleman 2002; Anderson *et al.* 2005).

Background Seismicity

The hazard from background (floating or random) earthquakes that are not associated with known or mapped faults needs to be incorporated into PSHA. Earthquake recurrence estimates in each study region and M_{max} are required to assess the hazard from background earthquakes. In much of the western U.S., the M_{max} for background earthquakes range from about moment magnitude (**M**) 6½ to 7. In the CEUS, M_{max} is **M** 7.0 or larger. Repeated events larger than these magnitudes probably produce recognizable fault-or fold-related features at the earth's surface (e.g., dePolo 1994). The lower values are used in regions where the seismogenic crust tends to be thinner (< 15 km), i.e., regions characterized by higher than average heat flow. Conversely, higher M_{max} is used in regions with thicker seismogenic crusts such as the forearc of the Cascadia subduction zone and the CEUS.

In addition to the traditional approach of using areal source zones (assuming uniformly distributed seismicity), Gaussian smoothing (Frankel 1995) can be used to address the hazard from background earthquakes in PSHA. In this approach, the historical background seismicity is smoothed to incorporate stationarity.

Geologic Site Response Units and Amplification Factors

In order to quantify the site response of soil and unconsolidated sediments, amplification factors are required. Generic amplification factors have been established and used in the U.S. building code (Borcherdt, 1994). These amplification factors can be used in urban hazard maps. However, a better approach is the use of area- or region-specific amplification factors. To estimate such factors, shear-wave velocity (V_S) profiles, depth to a reference rock datum, and nonlinear dynamic material properties (both shear modulus reduction and damping curves as a function of shear strain) are required to define site response units. Based on these site response units, frequency- and strain-dependent amplification factors can be computed. Site response units are defined based on physical and dynamic properties of the materials and if such data are not available, surface geology. This is probably the key step in developing urban hazard maps and critical to this is the mapping of different site response units. Acquiring V_S data in sufficient amounts to define site response units needs to be performed (Wong and Silva, 2006).

Amplification factors can be computed as a function of site-response unit, ranges in thickness of the unconsolidated sediments, and input rock motion. Based on each average profile, randomized profiles are computed to account for the horizontal and vertical variability in velocities and these are used in the site response analyses. Shear modulus reduction and damping curves are assigned to the various site-response units to account for strain-dependent non-linear soil response.

Equivalent-linear site response analysis is often used to calculate amplification factors for each site response unit. Non-linear approaches can also be used to quantify amplification. One approach used by URS, the point-source stochastic methodology is used to generate rock acceleration response spectra for a earthquake, which are then propagated up through the site response unit profiles (Silva *et al.*, 1997). The earthquake is

placed at several distances to produce a range of input peak accelerations. Thus the amplification factors (the ratios of the response spectra at the top of the profiles to the input spectra) are a function of the reference rock peak acceleration, spectral frequency, and non-linear soil response. Interpolation is used to obtain amplification factors at other reference rock peak accelerations.

Ground Motion Attenuation Characterization

To characterize the attenuation of ground motions, empirical attenuation relationships are used for the western U.S. and due to lack of strong motion data for earthquakes of **M** 5.0 and larger, numerically modeled-based models for the CEUS. Although none of the currently developed urban hazard maps have implemented them, a recent set of empirical models have been developed for tectonically active regions such as the western U.S. These models, called the Next Generation of Attenuation (NGA) models, have been developed through the Pacific Earthquake Engineering Research Center (PEER). Models have been developed by Abrahamson and Silva (2008), Chiou and Youngs (2008), Boore and Atkinson (2008), Campbell and Bozorgnia (2008), and Idriss (2008). New models have also been developed for the CEUS and subduction zones; the latter can be applied to the Cascadia and Alaska subduction zones in the U.S.

To compensate for the lack of region-specific attenuation relationships, stochastic modeling can be used to model earthquakes for ranges of magnitudes, distances, and site conditions. Uncertainties in stress drop, magnitude-dependent focal depths, the crustal attenuation parameters Q_o and η, the near-surface attenuation parameter (kappa), and the V_S profile atop the crustal model are included in the computations of the attenuation relationships through parametric variations. Ranges of magnitude-dependent stress drops appropriate for extensional or compressional regimes are used. The aleatory variabilities in ground motion attenuation is included by using the log-normal distribution about the median values as defined by the standard error associated with each attenuation relationship. Region-specific stochastic attenuation relationships have been developed by Pacific Engineering & Analysis as part of several urban hazard map projects (Wong *et al.*, 2000a, b; 2002a, b; 2004). Although only currently used in one set of urban hazard maps, three-dimensional (3D) numerical modeling of basin effects has also been implemented (Frankel *et al.*, 2007).

Ground Motions Calculations

Scenario ground motions can be calculated using attenuation relationships or numerical modeling. The latter explicitly incorporates the effects of the seismic source (fault geometry and dip, depth of rupture initiation, and sense of slip) and rupture propagation (e.g., directivity), which are particularly important at close distances to the fault.

To calculate the probabilistic ground motions, a Cornell (1968) PSHA using logic trees is used. All known seismic sources that could generate strong ground shaking in the map area are incorporated into the PSHA. Both published empirical and numerically-based attenuation relationships can be used in the analyses to calculate the ground motion values. The mean probabilistic hazard is calculated at selected return periods.

Map Development

The ground shaking maps are often produced using a vector- and raster-based GIS. Ground motions on rock are calculated for the map areas using a grid of points at variable spacings. Each grid point is assigned to a site response category. Surface ground motions are calculated by multiplying the rock ground motions by the appropriate amplification factors. Area- or region-specific amplification factors for each grid point are selected based on the site response unit, depth to rock if known, and the input rock peak acceleration as described above if such information is available. Generic amplification factors (e.g., NEHRP) are used if only the generic site classes are known. Based on grid of computed ground motions, values are interpolated.

USGS Urban Hazard Maps

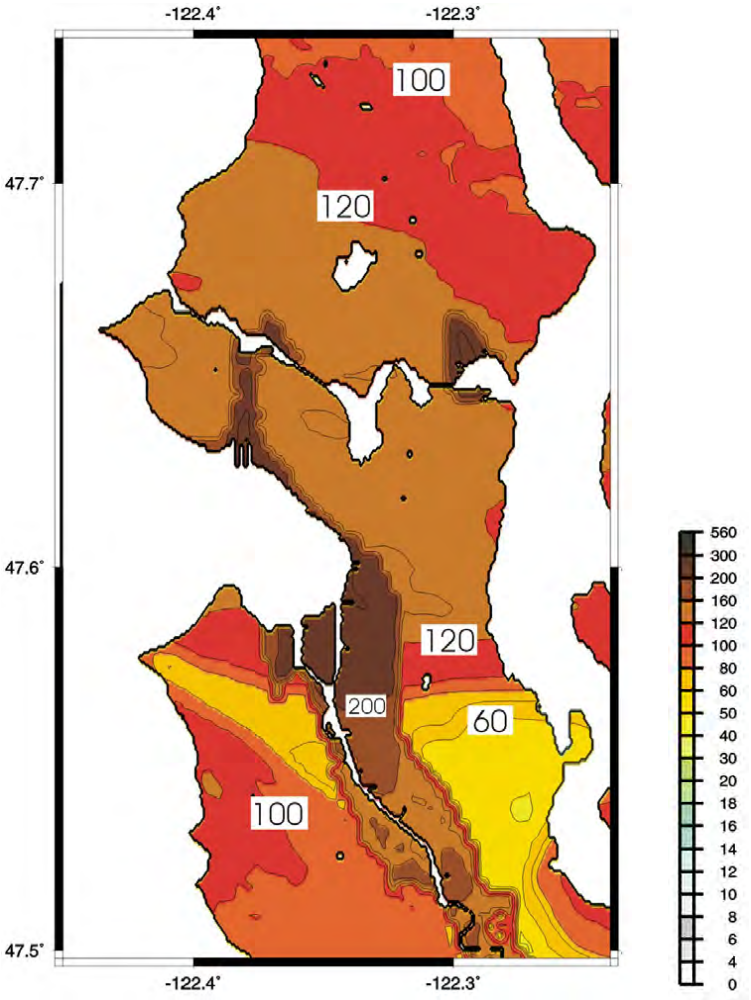
Memphis, Tennessee Metropolitan Area

The Memphis, Shelby County urban maps were the first urban hazard maps developed by the USGS (Cramer *et al.*, 2004). Memphis is located in the vicinity of the New Madrid seismic zone (NMSZ), which produced a

sequence of three large earthquakes, **M** ≥ 7.0 in 1811-1812. These events are the largest earthquakes to strike the CEUS. Both scenario and probabilistic hazard maps have been produced for PGA and 0.2 and 1.0 sec SA. The scenario maps have been developed for **M** 7.7 and **M** 6.2 earthquakes on the southwest arm of seismicity in the NMSZ. Probabilistic maps have been developed for 10%, 5%, and 2% exceedance in 50 years (475, 975, and 2,475 years, respectively). The Memphis area targeted in these maps is characterized by NEHRP site class D (V_S30 [average shear-wave velocity in the top 30 m] of 600 to 1,200 m/sec) (Cramer *et al.*, 2006). Amplification factors were generated using an equivalent-linear site response analysis. The soil profiles used were derived from a 3D geologic model of the Memphis area where the soil is up to 1 km thick (Cramer *et al.*, 2006).

Seattle, Washington Metropolitan Area

Frankel *et al.* (2007) have developed urban hazard maps for Seattle, Washington for 1.0 sec SA (Figure 1). Seattle is located above the Cascadia subduction zone, which has produced **M** 9 megathrust earthquakes about every 500 years (Goldfinger *et al.*, 2010). In addition, intraslab earthquakes such as the 2001 **M** 6.8 Nisqually earthquake have also occurred beneath the Puget Sound. Finally, the region is transversed by several major crustal faults including the Seattle fault, which crosses through the city. The maps are probabilistic in nature and use 3D wave propagation simulations to address effects of the Seattle Basin. The maps also include the nonlinear effects of shallow soft soils and rupture directivity on the Seattle fault, the dominant seismic source in the Seattle area. The maps were developed for exceedance probabilities of 10%, 5%, and 2% in 50 years (475, 975, and 2,475-year return periods, respectively). The 3D model developed for the study was not detailed enough for accurate 3D simulations much below 1 sec.



Source: Frankel *et al.*, 2007

Figure 1. Urban hazard map for Seattle (1 sec SA) for 2% probability of exceedance in 50 years.

These are the first set of probabilistic seismic hazards maps that directly incorporate 3D wave propagation effects. Ground shaking in Seattle are strongly affected by the 3D structure of the underlying Seattle Basin (Frankel *et al.*, 2007). Two major basin effects are the production of basin surface waves by the conversion of incident S-waves at the edge of the basin and focusing of S-waves by the basin edges (Frankel *et al.*, 2007). 3D basin effects are strongly dependent on the azimuth to the earthquake. 3D finite-fault simulations were performed for the Seattle fault, South Whidbey Island fault, the Cascadia subduction zone, and gridded seismicity. Nonlinear site response of fill and young alluvium was incorporated into the hazard maps through a combination of equivalent-linear analyses using the program SHAKE and empirically-based amplification factors.

San Francisco Bay Area, California

Urban scenario hazard maps have been developed for the San Francisco since the mid-1990s (Association of Bay Area Governments [ABAG], 1995). This region situated within the San Andreas fault system is characterized by one of the highest levels of seismic risk in the U.S. Large earthquakes have struck the San Francisco Bay region in 1906 by the Great San Francisco earthquake (**M** 7.9) generated by the San Andreas fault, and in 1868 by a **M** 6.8 event on the Hayward fault. Eleven scenarios hazard maps have been development for earthquakes along the San Andreas, Hayward, San Gregorio, Rodgers Creek, Calaveras, Concord-Green Valley, Maacama, and West Napa faults (ABAG, 1995). Ground shaking is expressed in terms of Modified Mercalli (MM) intensity at the ground surface, hence incorporating site response. The ground motions were calculated using a finite-fault modeling approach, which was calibrated using an intensity attenuation relationship for the 1906 earthquake. The scenario maps were subsequently updated in 1998. They are posted on the website of ABAG and can be used interactively by the general public. Other scenario maps for the San Francisco Bay area have been produced by Boatwright and Bundock (2005) and Silva *et al.* (2006).

URS Urban Hazard Maps

Portland, Oregon Metropolitan Area

The Portland metropolitan area has been the most seismically active region in Oregon in historical times. Recent geophysical studies also indicate the presence of at least three crustal faults beneath the Portland metropolitan area, which could generate damaging crustal earthquakes of **M** 6.5 or larger. Additionally, the area sits over the Cascadia subduction zone where earthquakes **M** 9 in size have occurred in the prehistoric past, as recently as the year 1700. Like Seattle, Portland is located in a basin but one considerably shallower than the Seattle Basin. These are the first quantitative earthquake scenario and probabilistic microzonation maps for ground shaking for the Portland metropolitan area (Wong *et al.* 2000a, 2000b). The maps display color-contoured ground motion values in terms of PGA and horizontal SA at 0.2 and 1.0 sec periods. The maps incorporate the site-response effects of soils, unconsolidated sediments, and shallow rock. The scenario maps are for a **M** 9.0 earthquake along the megathrust of the Cascadia subduction zone and a hypothetical **M** 6.8 event on the Portland Hills fault. The probabilistic maps are for the two return periods of building code relevance, 475 and 2,475 years.

Salt Lake City, Utah Metropolitan Area

The Salt Lake City metropolitan area is one of the most seismically hazardous urban areas in the interior of the western U.S. because of its location within the Intermountain Seismic Belt and its position adjacent to the active Wasatch fault zone. The elapsed time since the last large earthquake on the Salt Lake City segment of the Wasatch fault is approaching the mean recurrence interval based on the short-term paleoseismic record. URS has developed nine microzonation maps showing surficial ground-shaking hazard (Wong *et al.* 2002a, 2002b) (Figure 2). The maps incorporate the site response effects of the unconsolidated sediments that underlie most of the metropolitan area within Salt

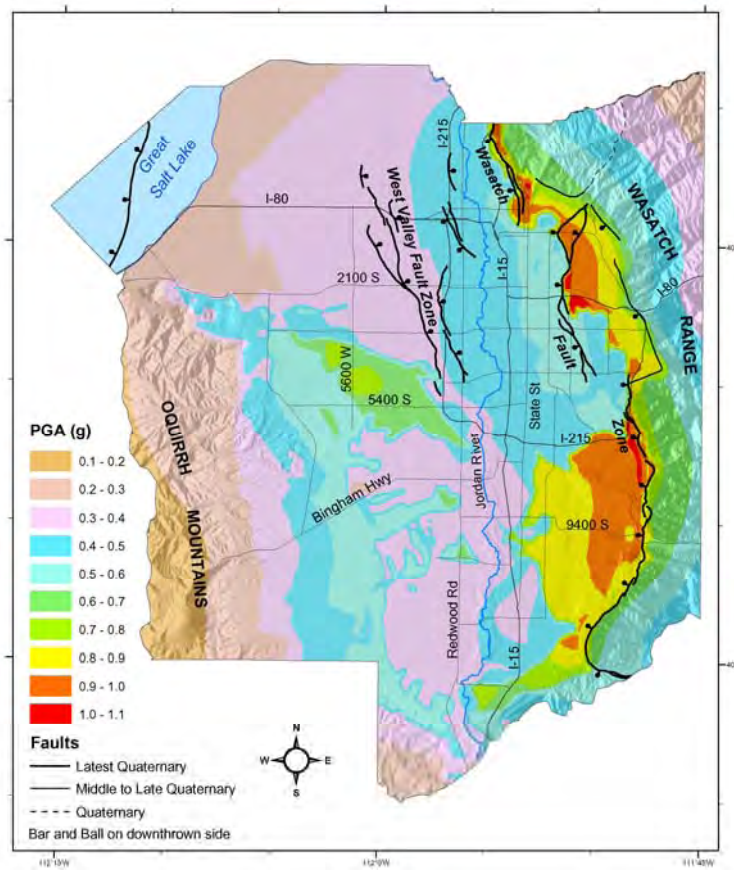


Figure 2. Salt Lake City segment, Wasatch fault M 7.0 earthquake scenario, PGA (g) at the ground surface (Wong *et al.*, 2002a).

Lake Valley. These nine maps, at a scale of 1:75,000, make up three sets, each consisting of three maps that display color-contoured ground motion in terms of PGA and horizontal SA at periods 0.2 and 1.0 sec. One set of maps consists of scenario maps for a **M** 7.0 earthquake on the Salt Lake City segment of the Wasatch fault. The two other sets are probabilistic maps for the two return periods of 475 and 2, 475 years.

Albuquerque-Santa Fe-Belen, New Mexico Urban Corridor

New Mexico's population is concentrated along the corridor that extends from Belen in the south to Española in the north and includes the cities of Albuquerque and Santa Fe. The Rio Grande rift, which encompasses the corridor, is a major tectonically, volcanically, and seismically active continental rift in the western U.S. Although only one large earthquake (**M** ≥ 6) has possibly occurred in the New Mexico portion of the rift since 1849, paleoseismic data indicate that prehistoric surface-faulting earthquakes of **M** 6.5 and greater have occurred on average every 400 years on many faults throughout the Rio Grande rift. URS has developed a series of nine scenario and probabilistic hazard maps that portray the ground shaking that could occur in the Albuquerque-Santa Fe-Belen corridor from future earthquakes in New Mexico (Wong *et al.* 2004). These maps, at a relatively coarse scale of 1:500,000, display color-contoured ground-motion values in terms of PGA and horizontal SA at 0.2 and 1.0 sec periods. The maps depict surficial ground shaking and incorporate the site-response effects at locations underlain by unconsolidated sediments within the Rio Grande rift. The scenario maps are for a **M** 7.0 earthquake rupturing the Sandia-Rincon faults, which are adjacent to and dip west beneath Albuquerque. The probabilistic maps are for return periods of 475 and 2, 475 years.

Salt Lake City-Ogden-Provo, Utah Urban Corridor

As part of a study to characterize the seismic hazards along the populated Wasatch Front extending from Ogden south to Provo, including the Salt Lake City metropolitan area, URS developed three scenario ground shaking hazard microzonation maps (Solomon *et al.* 2004). The scenario maps display the ground motions that would result from a **M** 7.0 earthquake occurring on the Salt Lake City segment of the Wasatch fault. The scenario ground motions were then used in assessments of liquefaction potential and earthquake-induced landsliding for the map area (Solomon *et al.* 2004). The maps incorporate the site response effects of the soils and unconsolidated sediments that exist in the valleys adjacent to the Wasatch fault and in the back valleys in the Wasatch Range. The maps are expressed in terms of PGA and horizontal SA at periods of 0.2 and 1.0 sec. The frequency-dependent pattern of both amplification and deamplification in the map area is clearly a function of the distribution and thickness of the surficial geologic units. Hanging wall effects due to the presence of the Wasatch fault are also evident on the hazard maps but are masked to a large extent by the site response effects.

ShakeMap

ShakeMap is a geographic representation of earthquake ground shaking developed by the USGS (Wald *et al.*, 1999). The maps can be expressed in terms of PGA, peak ground velocity, and instrumental intensity (Modified Mercalli). The strength of ShakeMap is that it provides a regional map of ground motion intensity based on both modeled shaking distribution and actual strong motion recordings at selected sites in real-time. The map also portrays expected ground shaking at other locations where instruments are absent by use of attenuation relationships. ShakeMap incorporates site response effects and currently uses NEHRP amplification factors. ShakeMaps have been produced in real-time for earthquakes of **M** ≥ 3.0 in the seismically active areas of the U.S. almost since its inception.

ShakeMap can be generated at various spatial resolutions by the development of different scale map bases and grids. A selected map base can be converted to a geologic map to portray NEHRP soil classifications. This map is then layered with a grid used in the modeling of ground motion, and each point of the grid is assigned a NEHRP amplification factor. ShakeMap can model the intensity of ground motion produced by a real or scenario earthquake of a given size, location, and depth.

The ShakeMap tool is now being used in the U.S. on a fairly routine basis to produce regional scenario hazard maps. It can be also used in fine-scale urban hazard maps although currently ShakeMap uses NEHRP amplification factors.

Summary

Scenario and probabilistic earthquake hazard maps have been developed for several urban areas in the U.S. The maps are intended to show the intensity and variability of ground shaking within the map areas due largely to shallow and sometimes deep site response effects at a scale useable by a wide variety of users. As exemplified by several recent earthquakes (e.g., 1994 **M** 6.7 Northridge, California), site amplification effects can be significant. A key to developing such maps is the high-resolution definition of site response units based upon geologic and geotechnical information and probably most importantly the acquisition of V_S data. We believe these microzonation maps can be effective tools in earthquake hazard awareness, preparedness, and mitigation.

Acknowledgments

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Geologic Hazards for Siting Considerations

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Introductory Discussion

Seismic hazard mitigation of infrastructure requires identifying hazards (both variety and scale) and implementing correlating protections (i.e. modification to infrastructure) within constraints of functional objectives and feasible siting. Mitigation constraints and opportunities vary significantly depending upon the scale of potential damages and the siting flexibility among three classes of mitigation:

- New developments,
- Existing developments, and
- Disaster recovery.

A logical planning sequence for each class of problem requires using best available hazard and siting data at the earliest possible stage of development. Initial hazard and site screening should always precede detailed studies, which then can be focused upon aspects of greatest uncertainty or consequence. Modifying existing developments poses the greatest constraints to siting mitigations and therefore usually focuses more upon structural mitigations, though no site is exempt from consideration relocation in the face of excessive hazard(s).

Varying uncertainties among hazards requires judgment to consider combinations of hazards and potential interactions for each site. This paper presents an overview of the following siting practices:

1. Current USA approach to geologic hazards input for siting requirements;
2. Current USA practices for evaluating predominant geologic hazards of earthquakes;
3. Recent advances in site hazard screening with desktop level mapping and analysis using abundant digital data and “off the shelf” geographic information system (GIS) web tools.

The third topic is presented with greater emphasis in this paper to advocate initiating multi-hazard risk management practices across local or regional infrastructure portfolios. GIS based interactive screening includes both new mapping and digitized old maps. Digital data can be efficiently combined for “layered” geohazard evaluations and computations giving rapid low cost preliminary risk evaluations over large areas. This provides a badly needed resource to aid developing nations in remote resource-constrained locations of risk across the full range of infrastructure (Harp, 2009).

1.0 Current USA Approach to Geologic Hazards Input for Siting Considerations

The current USA approach to incorporating geologic hazard data into seismic siting considerations is tiered, starting with building code based minimum site assessment provisions and statewide hazard mapping, supplemented by more detailed evaluations in areas of historical failures or for planning or design of more critical sites. These tiered actions are described below.

1.1 Code Based Hazard Mapping

Minimum requirements area to assess potential for seismic induced landslides or liquefaction using simplified methods found in the International Building Code (IBC, 2009) and its adopted structural standard ASCE 7 (ASCE, 2010). Future code provisions are evolving to include more detailed analysis with performance based design (PBD) objectives (FEMA, 2008).

1.2 Screening Level Mapping
Many state agencies produce simplified maps with zonation delineated by historical events or simplified analytic methods to assign susceptibility, mainly for landslides and liquefaction.

1.3 Rapid Reconnaissance
This is a tool becoming popular for timely acquisition of field data to corroborate and enhance digital desktop mapping and analysis. It involves short duration field visits to areas of damage with issues, findings, photographs and measurements then incorporated into hazard maps.

1.4 Site Specific Detailed Hazard Assessments
Areas of known hazards are evaluated in more detail, usually on a voluntary basis supported by project stakeholders to satisfy financial and regulatory risk concerns. It includes subsurface exploration, detailed geologic reconnaissance and mapping, fault trenching, geophysics and detailed analysis and modeling of hazards. Analytical findings are useful for corroborating or back calculating estimated site shaking and associated seismological models and maps.

1.5 Site Specific Detailed Mitigations
Detailed mitigations developed following detailed hazard assessments include quantified risk reduction analysis using site preparations, such as grading and drainage with ground treatments, foundation improvements and structural enhancements. Soil structure interaction modeling is frequently used to optimize mitigation designs and establish conformance to performance based design objectives.

2.0 Predominant Geologic Hazards Evaluated for Earthquakes

(UGS, 1996)

Earthquakes mobilize an abundance of geologic hazards (often concurrent with related flooding and coastal hazards), beyond the basic hazard of strong motion shaking. These consequences inherent with highly variable geologic structures are often exacerbated by siting activities. Primary geologic hazards evaluated for infrastructure development in earthquake prone areas are summarized below.

2.1 Landslides
Earthquake induced landslides pose a small fraction of all landslides and are researched by a relatively small community, though contribute to relatively large losses when they occur in developed areas. Both predictive and forensic stability analysis is predominantly a simplified limit equilibrium approach, though often with sophisticated with site specific constitutive properties of the vulnerable geologic formation (Harp, 2009). Subsurface exploration is often extensive for critical sites, though also subject to access limitations. Design procedures and liability have evolved

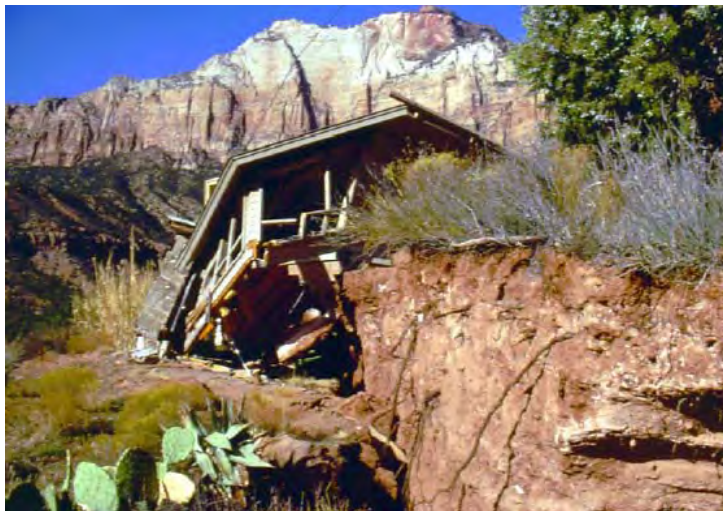


Figure 1. M5.8 1992 Springdale Landslide, Zion Canyon Utah. (UGS, 2001)

during the past two decades from both extensive forensic work on failure case histories and from systematic owner inventory and operational training programs largely within state departments for infrastructure spanning large regions of sloping terrain, such as transportation and pipeline systems (TRB, 2009). National programs include USGS (http://landslides.usgs.gov/) and FEMA (http://www.fema.gov/hazard/landslide) and FWHA (1993). Structural and foundation mitigations are constrained to landslide and rockfalls which are small enough to be manageable or practical, normally failure planes less than 20m deep. More severe cases generally revert to setbacks or alternative siting. Detailed discussion of current seismic landslide hazard mapping tools is provided in Section 3 and in CGS (2008).

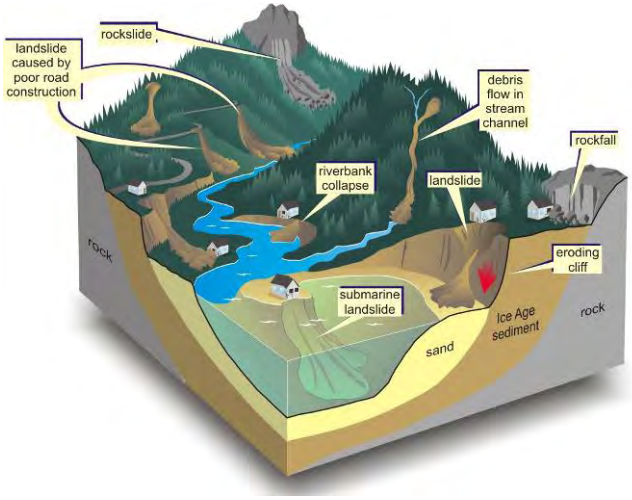


Figure 2. Landslide Forms (TopNews, 2010)

Figure 3. M7.3 1959 Hebgen Lake Landslide, Montana (USGS, 2010)

2.2 Liquefaction & Lateral Spread

Liquefaction hazard evaluation has evolved from a simple screening of susceptibility to a central component of site engineering for seismic design, involving detailed analysis for even simplified methods. The simplified approach describing loss of shear strength for elevated pore pressure set forth by Seed and Idriss remains valid but with numerous augmentations (Idriss et al, 2008).

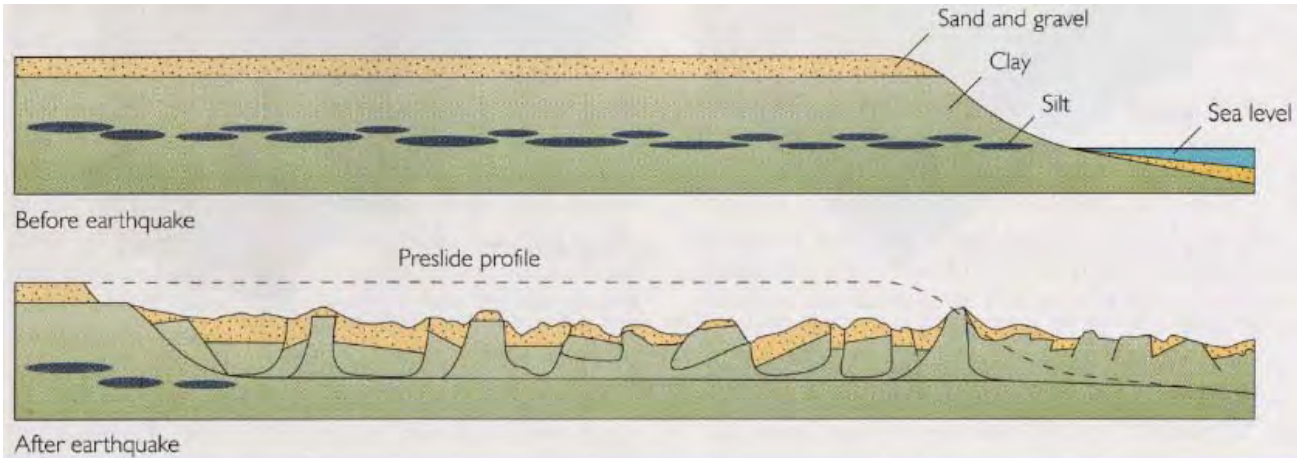
The basic method of susceptibility analysis requires evaluating site specific conditions:

- surface topography (sloping),
- geology (Holocene alluvium),
- soil composition (loose to medium dense granular or “sand like” low plastic materials)
- groundwater (shallow saturated soil conditions)
- level of shaking (liquefaction triggering dependent upon stress ratio and soil density).

The analysis is done for individual borings, CPT soundings or shear wave velocity profiles, and an aggregate profile of combined data is developed to identify susceptible stratigraphy. Where validation of subsurface material gradation and plasticity is available, CPT methods of liquefaction are becoming the preferred norm (Robertson, et al, 2009; Robertson, 2010). Consequences of liquefied zones are calculated in terms of cumulative vertical (Figure 4) and horizontal deformations (Idriss et al, 2008; Zhang et al, 2005), which are also compared with calculated estimates of lateral spread (Youd et al, 2002) in areas of gently sloping terrain (Figure 5). Specialized criteria for evaluating liquefaction in coralline soils has evolving and been validated with ground treatments subject to seismic events over the past 15 years (FEMA, 2008).

Figure 4. M6.9 1983 Loma Prieta EQ Induced Liquefaction, Highway 1, Near Watsonville, CA. (USGS, 2010)

Figure 5. M9.2 1964 Alaska Earthquake, Turnagain Heights Lateral Spread, (USGS, 2010)



Liquefaction mitigations generally follow the basic remediation strategy set forth in Figure 6, (PIANC, 2006). A host of ground treatment technologies are supported by a robust USA specialty contractor marketplace. The degree and methods of treatment vary depending upon:

- **the analytical strategy** (whether to prevent triggering or to allow triggering and design to residual strength (Robertson, 2009b);
- whether liquefied materials exhibit **dilatant** shearing with limited cyclic mobility or **contractive** shearing with uncontrolled flow failure and large strength loss; and
- **infrastructure performance objectives**, which vary by class of infrastructure and materials. Common deformation tolerances are:
    - <0.1m for critical structures (elastic design);
    - 0.2-1.0 m for ductile design of bridges, ports and pipelines (Baum et al 2008); and
    - several meters for deformaable earth structures.

Performance of mitigations is validated by modeling improved regions with limit equilibrium "pseudo static" stress analysis or deformation estimates, with geomechanical modeling of dynamic deformations for more complex problems. Full scale in-situ blast testing of liquefaction simulates earthquake motions, and in conjunction with ground treatment validations is becoming popular for sophisticated projects (Gohl, 2010; Rollins, 2004). Liquefaction design and mitigation guidance is also compiled in port standards and guidelines for a predominance of liquefiable materials in coastal and harbor environments (PARI, 1997; ASCE, 1998; PIANC, 2006; FEMA 2008).

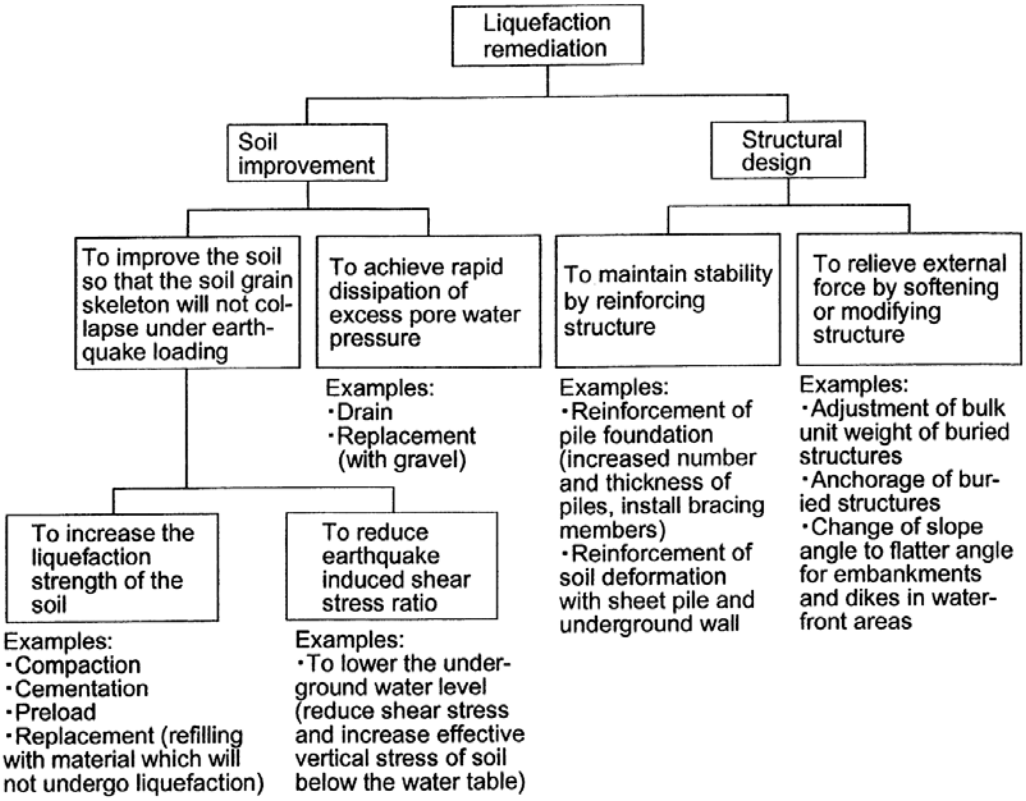


Figure 6. Strategy for Liquefaction Remediation (PIANC, 2006)

2.3 Fault Rupture & Subsidence

Active normal faults can rupture the ground surface during large earthquakes, causing vertical displacements of 1 meter or more. Tectonic subsidence is local subsidence deformation that occurs along faults during surface rupturing earthquakes in the hanging wall, or downthrown side, of normal faults. The ability to determining the extent of subsidence and fault rupture is greatly improved in recent years due to more mature mapping databases, increased detailed trenching activities and augmentations with lidar data in seismic prone areas. Tropical areas with heavy vegetation and developed urban areas remain difficult to delineate surface fault features. Geologic mapping of excavations is a recommended practice for all urban construction. High resolution landside and offshore geophysical profile can provide fault sections sufficiently accurate to estimate rupture magnitude. Accurate fault data in turn is producing more accurate seismic models and correlated area subsidence. Subsidence and fault rupture infrastructure mitigations include building setbacks, ductile joints and large strain connections, often bearing upon deep foundations straddling the fault areas. Detailed mapping of fault rupture hazard zones is available for California (CGS, 2007).

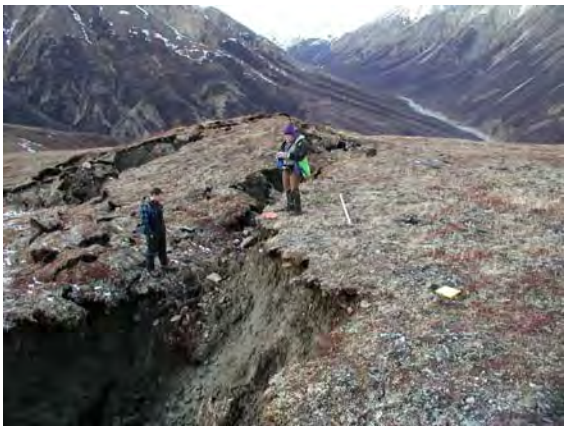


Figure 7. M7.9 2002 Denali EQ, Alaska (USGS, 2010)

Figure 8. Transcanada Pipeline Fault Crossing (USGS, 2010)

2.4 Tsunami & Seiches

Tsunamis are water waves generated by sudden displacement of a large volume of water. The displacement can be created by a coseismic fault rupture, a landslide falling into the water body, a submarine slope failure or slump, a submarine or island volcanic eruption, and extremely rarely, a meteor impact. (Yeh, 2010)

Seiches are standing-wave oscillation of an enclosed or semi-enclosed water body, continuing in pendulum-like-fashion after cessation of the originating force, which is usually considered to be strong winds, tsunami, or barometric pressure changes.

Tsunami and seiche both reflect severe combined seismic hazards (Dean et al, 1984). Simplified screening tools are not available due to complex interaction between surface faulting (rupture and subsidence), bathymetry (plunging landslides and wave propagation), and shoreline topography (wave inundation and runup). Limited estimation of effects can be made by experts using judgment and simplified calculations. Since the 2004 Great Andaman Sumatra Tsunami, extensive detailed field reconnaissance, runup mapping and probabilistic tsunami hazards analysis (PTHA) and runup mapping has been done for the western united states and numerous Pacific and Indian Ocean nations, in pursuit of mitigation efforts for these combined hazard evaluations (Thio, et al, 2006).

Siting elevation plays a major role in determining susceptibility to these severe coastal hazard events which destroy nearly all infrastructure in their path (FEMA, 2009). In the absence of analysis, some locations use flood maps are often used as a general measure of protection, or if available, incorporate detailed runup mapping. This practice has been performed for the State of Hawaii and the Honolulu building code in conjunction with the other mitigations for three decades (FEMA, 2000, 2009). Newer analysis included detailed modeling and guidance for setbacks and green space (Hwang et al, 2005), earthen barriers (dikes, embankments, diversion canals), heavily designed evacuation towers (Figure 9), and reinforced structures and foundations designed to resist impact loads where waves are anticipated to be less than 3-5m (Figure 10), (FEMA, 2008, Yeh, 2006). Other hazards include tsunami induced liquefaction and aggravated drawdown scour (EERI, 2006). Equally critical to hazard mitigation for tsunami are “soft” methods to deploy warning systems, evacuation plans, and educational programs to develop timely and informed evacuation responses (Hwang et al, 2006; NOAA, 2010).

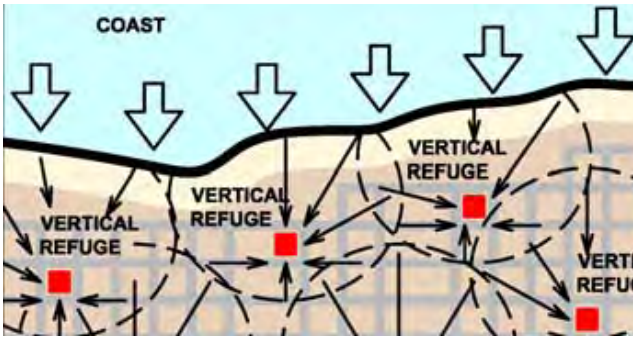


Figure 9. Vertical Evacuation (FEMA, 2008)

Figure 10. Tsunami Inundation. (EERI, 2006)

2.5 Other Geologic Hazards

Section 3 provides discussion of mapping tools to incorporate numerous geologic hazards into a systematic framework for evaluation, including lesser geologic hazards susceptible to possible triggering by seismic activity, each with its own set of geo-materials testing, mapping and mitigation approaches. These may include:

Avalanche	Debris flows	Frost Action
Collapsible Soils	Erosion	Flooding
Corrosive Soils	Expansive Soils	Volcanoes

3.0 Interactive GIS Based Hazard Mapping

An abundance of digital mapping data accumulated over the past decade, from both new maps and digitized old maps, provides source data for new interactive GIS applications and web based access. New "old" data has particularly useful application in geohazard evaluations where combinations of data can provide rapid low cost effective preliminary risk evaluations over large areas, which previously required intensive levels of effort. Desktop digital applications do not replace site specific studies where warranted, but provide effective screening to focus field studies and allow for a reasonable broad view of overall area risk.

Three examples provided in this paper include the following:

- Seismic slope hazard mapping using USGS/FEMA simplified methodologies.
- Multi-hazard analysis of a pipeline alignment, covering over a dozen geologic and climatic hazards in an interactive Google Earth based format.
- GIS based master database using a web based interactive platform to access multiple software platforms across a regional distribution network.

The need for engineering and field judgment is emphasized as it relates to developing simplified GIS shape file calculations and organizing disparate data sources into useful hazard mapping concepts and risk assessments.

These three examples reflect applications with differing levels of detail: from mapping a single hazard, to developing a consistent framework for multiple hazards, and finally managing the operation and maintenance though a web database. Each can be performed independently according to available resources and capital programming needs. The examples are from three independent owners and geographies.

All three infrastructure evaluation examples illustrate the predominant influence of site effects stemming from topography and geology shaping the vulnerability or resistance to abundant natural hazards. Seismic slope hazard mapping is given as an example focusing upon a single hazard requiring interpreting combined datasets on a large scale basis. This example was created in response to earthquake damage, for use in scenario modeling which tends to strongly affect pipelines, normally having little redundancy and high likelihood of traversing troublesome areas. The other examples are system portfolio assessments.

3.1 Seismic Slope Hazard Mapping

Landslide modeling methodologies vary depending upon available data, the size of area to be mapped, potential failure mechanisms, and the authority or organization performing the modeling. Due to large volumes of data generated, most seismic slope models for mapping are based upon simplified limit equilibrium methods. This differs from studies of specific landslides which often incorporate greater levels of details in the material models and geomechanics. It also differs from liquefaction potential mapping, which covers modest (<5 degree) saturate slopes commonly in the coastal area. The example

Figure 11. Hawaii (USGS, 2005)

provided is from the 2006 Kiholo Bay earthquake, where FEMA sponsored a desktop level mapping of the Island of Hawaii, for incorporation into HAZUS loss estimation database used to aid emergency responders in planning and delivering resources during disasters (FEMA, 2009).

Simplified landslide susceptibility mapping usually includes rock or soil constitutive models which incorporate an assigned static factor of safety and a yield acceleration triggering a landslide for a given mapped cluster. Loss estimates are assigned to failed clusters based upon an evaluation of infrastructure within the cluster and estimated degree of damage from estimated displacements. The high level of effort needed to develop local constitutive models throughout a mapped area, and the level of effort to calibrate deformation estimates have slowed the rate of adopting seismic slope risk mapping into HAZUS applications and elsewhere. However the tools have been available for several decades, and have been applied locally to specific areas of interest by a relatively small group of researchers and practitioners (Monroe, 1979; Keefer, 1984). Advances in GIS applications provided an opportunity to efficiently develop a seismic landslide susceptibility application for the entire Big Island (Figure 11).

FEMA HAZUS-MH User Manual (FEMA, 2009) contains a simplified landslide module comparing slope angle to soil strength, consistent with common generalized approaches, based upon a simple three-step modeling methodology developed by the USGS:

Step 1 – characterize landslide susceptibility,

Step 2 – assign probability of landslide,

Step 3 –assign expected permanent ground deformations.

The first step of characterizing landslide susceptibility is based upon three factors:

- Topography, to estimate slope angle,
- Soil/rock geology and type, to estimate shear strength,
- Soil/rock moisture, to estimate its influence on shear strength.

Each of these parameters is assigned a value for a given geospatial coded area (i.e., shapeform or cluster) and combined to calculate and assign a slope risk value ranging from I to X for the cluster, according to equilibrium criteria in Table 1.

The second step of assigning probability of landslide is performed by HAZUS using assigned critical accelerations (i.e., yield acceleration or the pseudo-static horizontal PGA causing a slope stability factor of safety less than 1). Critical accelerations are assigned by HAZUS for a given susceptibility cluster using the relationship by Wilson and Keefer (FEMA, 2009), in Table 2. They are then compared with estimated PGA for a given scenario event or as depicted by ShakeMap, an event mapping module within HAZUS used immediately following an event. The probability of slope instability with this approach is identical to the probability of occurrence of the earthquake producing the yield acceleration (neglecting uncertainty in mapped slope, soil strength, and wetness).

The third step of estimating resulting displacements is also automated by HAZUS. When the event acceleration exceeds the assigned yield acceleration of a given cluster, a permanent ground deformation is assigned based upon a “displacement factor” derived from an assumed number of cycles for a given earthquake magnitude then correlated to the extent of exceedance, represented by the ratio of critical acceleration to induced acceleration (Makdisi and Seed, 1978).

Table 1. HAZUS Landslide Susceptibility of Geologic Groups (FEMA, 2009)

Geologic Group		Slope Angle, degrees					
		0-10	10-15	15-20	20-30	30-40	>40
(a) DRY (groundwater below level of sliding)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c' =300 psf, ϕ' = 35°)	None	None	I	II	IV	VI
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c' =0, ϕ' = 35°)	None	III	IV	V	VI	VII
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c' =0 ϕ' = 20°)	V	VI	VII	IX	IX	IX
(b) WET (groundwater level at ground surface)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone, c' =300 psf, ϕ' = 35°)	None	III	VI	VII	VIII	VIII
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone, c' =0, ϕ' = 35°)	V	VIII	IX	IX	IX	X
C	Argillaceous Rocks (shales, clayey soil, existing landslides, poorly compacted fills, c' =0 ϕ' = 20°)	VII	IX	X	X	X	X

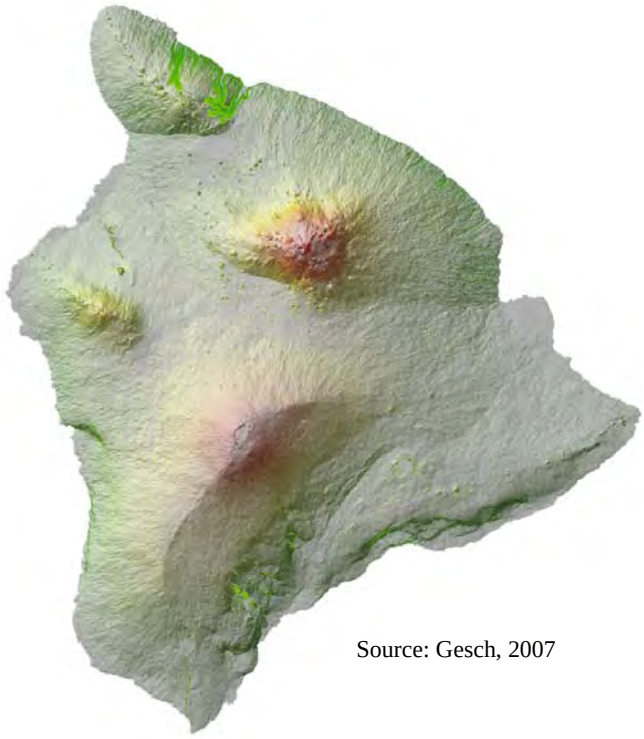
Table 2. HAZUS Critical Accelerations for Susceptibility Categories (FEMA, 2009)

Susceptibility Category	None	I	II	III	IV	V	VI	VII	VIII	IX	X
Critical Accelerations (g)	None	0.60	0.50	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05

Modeling Approach for Hawaii

The recent availability of high resolution topographic data and digital geologic maps allowed use of the HAZUS method for first generation conceptual level mapping to identify major areas of slope stability concerns within HAZUS scenario assessments and then provide guidance on tasks to refine and improve the model in the future. We used geospatial map layers and performed cluster computations, with applied interpretations and available empirical criteria using engineering judgment to enhance computations. The resolution of the mapping varies from layer to layer, based upon source data. The scale of developed 17" x 22" maps is 1:333,732, reproduced as figures in this section at reduced scale.

Topographic Data was compiled using 10 m satellite USGS DEM topographic survey data created for up to 24,000 scale (Gesch, 2007), creating a bare earth slope map of the entire island with shaded slope and elevation contours (Figure 12). The HAZUS slope angle categories were lumped into three assigned categories of low, medium and high hazard



Source: Gesch, 2007

Figure 12. 10m USGS Bare Earth Shaded Relief

susceptibility for slope angles of <20, 20-40 and >40 degrees, respectively. This simplification was necessary to manage the very large dataset in a single island-wide map and allowed easy incorporation of other empirical slope hazard data below, using similar qualitative descriptions.

Figure 13. Geologic Map of the Island of Hawaii

Geologic Data for soil and rock categories was assigned based upon strength and susceptibility to landslide derived from an existing geologic map (USGS 2005) (Figure 13) , and USDA surface soils maps (NRCS, 2004). We assigned adapted geologic group strength correlations to Table 1 categories A, B and C, for unique Hawaii formations, including:

- Strong fresh shallow rock such as pahoehoe and a'a basalts (low hazard, Category A),
- NRCS mapped clayey surficial soils and weathered rock (medium hazard, Category B),
- Weak soft soils such as mapped Pahala ash, historical slide talus, or geologic mapped landslide deposits (high hazard, Category C).

Clusters of common geology were assigned geospatial coding for boundaries of topographic clustering. A combined slope map with assigned geologic units followed low, medium, and high slope hazard grouping.

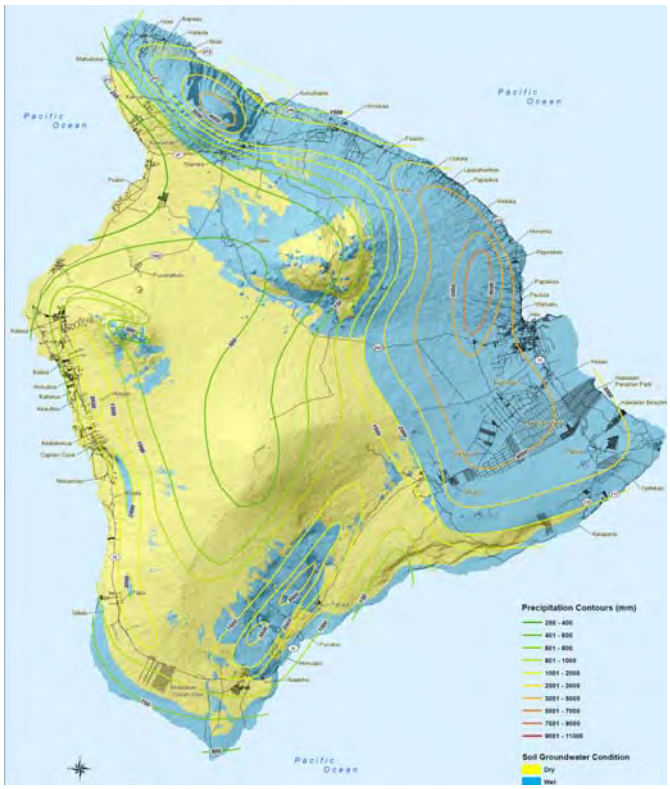


Figure 14. Estimated Soil Moisture Map

Soil moisture assignments for slope hazard mapping (Figure 14) were derived from rainfall mapping contours since regional groundwater and soil moisture data is unavailable island wide. (Giambelluca,1986). Areas with greater than 2000 mm annual precipitation are considered wet soil, corresponding largely to the windward (northeast) side of the island. Coastal areas below elevation 60 m are also considered wet due to potential groundwater seepage from higher elevations, except in the arid Kona coast area.

HAZUS Landslide Combined Susceptibility Processing

ESRI, ArcInfo 9.3.1 software was used to develop the Hawaii HAZUS map (ESRI, 2009)

including the '3D analyst extension', formatted in accordance with HAZUS-MH (FEMA, 2009). To create the final HAZUS compatible geodatabase, we classified original continuous or mapped continuous areas of data into different discrete categories. The slope polygon was overlaid with the various geologic polygons, and the precipitation layer, simplified to specify wet or dry soil conditions was then added. From this combination, the 10 HAZUS risk zones were converted to polygon shape files and mapped to census blocks/tracts for use in HAZUS runs (Figure 15).

HAZUS slope risk trial runs were performed by FEMA from the slope hazard map (Figure 6) and the 2006 event ShakeMap, using automated functions. Computed displacements and distributions appear to be generally reasonable and consistent with approximate regions of damage and contribute to an overall HAZUS loss estimate more consistent with actual values (Figure 16). Future parametric studies, investigation of other scenarios, and evaluations with more detailed mapping input data will also aid more enhanced slope hazard assessment.

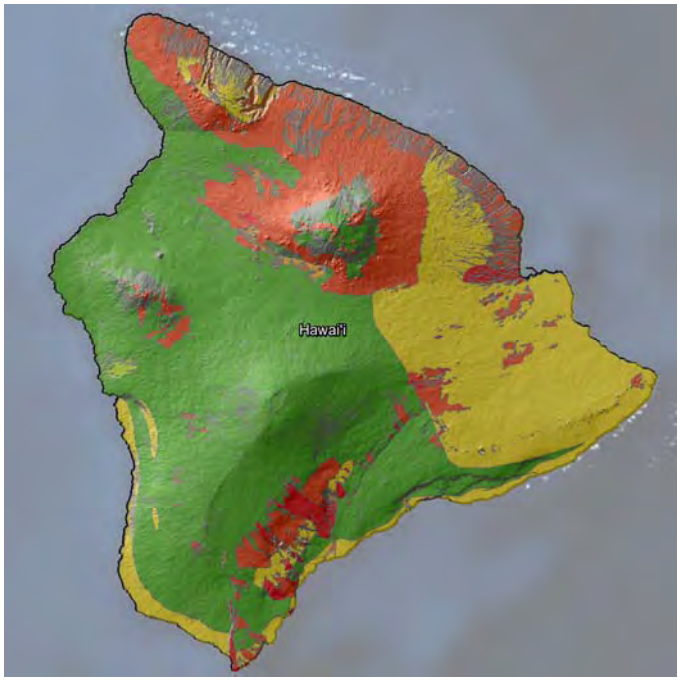


Figure 15. HAZUS Landslide Susceptibility Categories from Hazard Mapping

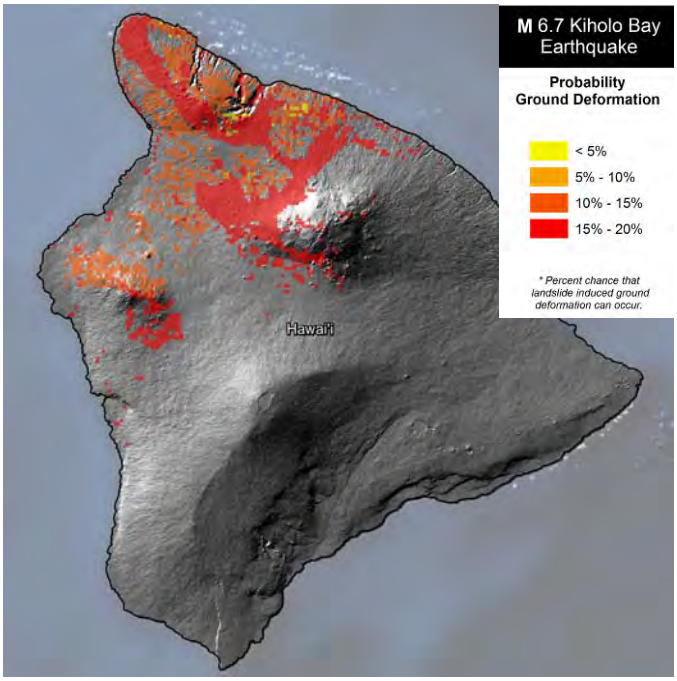


Figure 16. Estimated Probability of Ground Deformation Based on Landslide Susceptibility Mapping and M 6.7 Kiholo Bay Ground Motions From ShakeMap v. 17**.**

3.2 Pipeline Alignment Multi-Hazard Mapping

The second digital mapping example presented is a planning-level geologic and geotechnical hazard analysis for a pipeline in the western USA using readily available information at a desktop level. This study resulted in 22 published maps and 7 interpretive maps covering 13 geologic hazards described in Table 3, and discussed as an abbreviated overview. The purpose of the map is to asses the range of potential hazards and risks along the alignment to prioritize specific locations for more detailed site-specific studies, mitigations or monitoring. In included "rapid-reconnaissance" of the entire alignment to visually inspect key features of interest identified in the mapping. Screenshots of key selected map criteria are provided below in Figures 8-15. Individual or combined hazard maps can be accessed by GIS layers and "flown" in a Google Earth 3-D format to rapidly assess areas of concern, familiarize stakeholders on issues, etc.

Table 3. Description of Hazards for Multi-Hazards Analysis of Pipeline

Hazard	General Description
Problem Soils	
Expansive soils	Expansive soils experience significant volume change in response to wetting and drying. This is caused by clay minerals which trap and release water from their crystal structures. Expansive soils generally contain significant fractions of montmorillonite clay. Expansive soils can cause damage to structures and utilities when localized areas are wetted, creating differential pressures typically ranging from 20-200 pounds per square inch (psi) and several inches of displacement. (Holtz and Kovacs, 1981).
Collapsible soils	Collapsible soils experience a rapid volume reduction when wetted, usually with the original deposition in a loose condition. They usually contain high fractions of sand- and silt-sized particles deposited by wind or water in alluvial fans, or in landslides. Collapsible soils can cause damage to structures and utilities when localized areas are wetted, resulting in differential shear stresses and settlement ranging from several inches to several feet, depending upon the thickness of the deposit.
Soil corrosivity	Soil corrosion to foundations and pipelines occurs by adverse interaction of electrochemical processes. Soil induced corrosion tends to occur in moist soils with low pH and high conductivity. Certain ions, often sulfates and chlorides within either the soil or the pipeline, also encourage corrosion.
Frost heave	Frost heave occurs during cold periods where localized excessive soil moisture forms buried ice lenses causing damaging soil pressures and displacements. Damage can occur both during freezing (expansion) and melting (settlement).
Slopes	
Landslides	Landslides are masses of soil moving down slope in response to gravity (creep), loss of strength (water, weathering, earthquake), or changes in slope (erosion, excavations/grading/retaining walls). Although they may occur catastrophically, most landslides move at rates that are imperceptible to observation without equipment. Landslides are frequently activated and reactivated by reducing soil strengths through seasonal cycles of wetting, adding weight to the top of the landslide, removing material at the toe of the landslide, and/or softening the shear plane.
Rockfall	Rockfall hazards are catastrophic events when portions of steep bedrock slopes fail and tumble down slope in response to weathering, rainfall, seismic events and/or creep. Rockfall debris collisions can destroy or severely damage structures. They tend to occur within fractured formations having adversely oriented, bedding planes, and other discontinuities. Mapping of rockfall hazard areas in included in the mapped landslide regions of this investigation, and is not mapped separately.

Table 3 cont'd. Description of Hazards for Multi-Hazards Analysis of Pipeline

Hazard	General Description
Water	
Erosion potential	Water erosion occurs when moving water entrains soil particles and moves them to a down-gradient location. Erosion can be confined to a channel (streams/rivers), or it can occur on open slopes (sheet erosion).
Flooding	Flooding occurs when excess snowmelt or precipitation exceeds containment capacity within existing drainage channels and reservoirs. It is often associated with erosion.
Debris Flows	Debris flows occur as catastrophic events when flowing water entrains soil to form a fast-moving slurry. Debris flows can cause significant erosion and damage to structures within their paths. They often occur within existing drainage channels and gullies in response to intense precipitation or flooding events that mobilize erodible surficial materials (i.e. landsliding, sheet erosion). Areas recently denuded of vegetation due to wildfire activity are more susceptible to debris-flow activity during intense precipitation events. Debris-flow hazards occur within flood prone regions analyzed in this report and were not evaluated separately.
Seismic	
Fault surface rupture	Seismic surface rupture occurs along an exposed fault trace during large earthquakes. Surface rupture displacements for large faults such as the Wasatch Fault can exceed 10 feet, severely damaging structures spanning the fault.
Ground Shaking	Ground shaking is the acceleration experienced during an earthquake, usually expressed as a percentage of gravity (g). It imposes inertial forces on infrastructure and can trigger landslides, dambreak flooding, liquefaction/lateral spreading and fire following earthquake (FFE) in developed areas with electrical, petroleum, or gas hazards. Liquefaction and lateral spreading are further described below.
Liquefaction/lateral spreading	Liquefaction occurs in saturated sediments when interstitial pore water pressures exceed the forces holding soil particles together. Liquefaction can be triggered during earthquake events. Sandy and silty soils are most susceptible to liquefaction. During liquefaction, the shear strength of the soil becomes severely reduced, and various modes of soil failure may occur. Lateral spreading occurs when soils liquefy and flow down slope, and can occur on slopes as low as 2 percent.
Wildfire	
Wildfires	Wildfire hazards occur in vegetated rural areas or urban-interface areas and are prone to rapid spread by winds. Mountainous areas pose difficult access to fight and control wildfires and tend to have thick deadfall posing a volatile fuel source. The wildfire return interval is the average number of years between fires.

Methodology of Multi-Hazard Mapping

Most natural hazards along a pipeline alignment stem mainly from topography, geology and climate which in turn affect stability, soil behavior, vegetation and climate. The approach for mapping multi-hazards along the pipeline alignment was to develop a common scale digital database, starting with recent high quality aerial photography, topographic, geology and faulting data (USGS 2006) (Figure 17). Properties of the geologic units were compared with soil and rock properties given in USDA soil maps (NRCS, 2009), using mapped values and interpreting conditions where map coverage was limited. Examples given cover problem soils, slope hazards, water hazards and wildfire hazards. Commonly used seismic hazard maps are not shown for brevity .

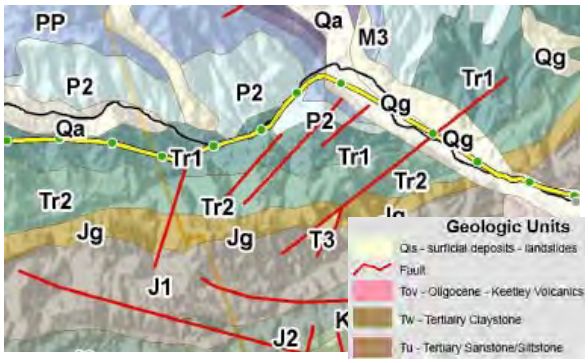


Figure 17. Topography, Geology and Faulting (USGS 2006)

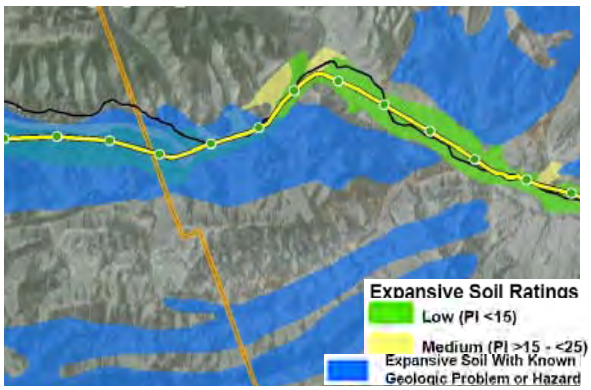


Figure 18. Interpreted Expansive Soils

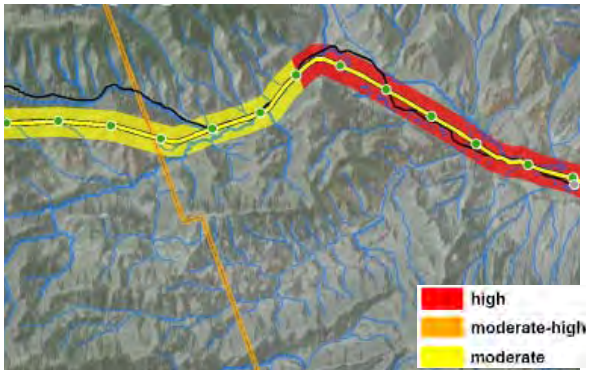


Figure 19. Soil corrosivity (NRCS, 2009)

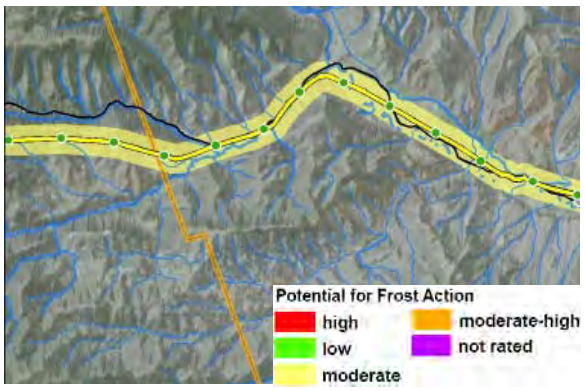


Figure 20. Frost heave (NRCS, 2009)

Problem Soils: ***Expansive soils*** (Figure 18) interpreted and mapped during this study are based upon correlation to NRCS mapped soil plasticity (Holts and Kovaks, 1991), and previous mapped areas of known expansive soils (SGS, 1992).

Corrosive soils (Figure 19) mapped by NRCS provides a soil corrosivity rating based on factors including soil moisture, particle-size distribution, acidity, and electrical conductivity. They express the soil corrosivity qualitatively from “low” to “high.”

Frost action susceptibility (Figure 20) as delineated by NRCS, rates potential for frost action based on soil temperature, texture, density, saturated hydraulic conductivity, content of organic matter, and depth to the water table. NRCS does not consider ground insulation from coverage by vegetation or snow. Moist sandy soils with clay and silt are the most susceptible to frost action (Holtz and Kovacs, 1981).

Slope Hazards: ***Detailed slope mapping*** (Figure 21) developed from digital topo data provides effective initial screening of areas of possible concern. In addition, ***existing landslide maps*** (Figure 22) define areas of known problems (SGS, 2007). These detailed maps include both historical event delineation and material model evaluations similar to the Hawaii example.

Water Hazards: Proximity to drainage channels increases the potential for several of the water hazards examined in this study. Drainage channels of concern include perennial and intermittent streams that flow during all or part of the year as well as ephemeral washes that flow only in response to precipitation events. They also include canals, ponds, irrigation channels, and roadside ditches. Water hazards associated with drainages include:

- Flooding and erosion
- Debris flows
- Streambank erosion at the toe of a slope
- Slope instability from wetting
- Frost heave and corrosion in drainages
- Seismic liquefaction and lateral spreading of saturated sandy soils in drainages

High or moderately high water hazards were mapped by interpreting portions of the alignment within the 100-year flood plain (FEMA 2009, SGS 1988), high erosion areas, high and moderate high frost action areas, and areas deemed to be hazardous based on maps and observations made during the rapid reconnaissance (Figure 23).

Wildfire Hazards (Figure 24): are most pronounced in heavily forested areas. Wildfire activity can damage buried pipelines and increase other geologic hazards including erosion, landsliding, and debris flows. Urban wildfire initiatives provide useful resources for assessing risks and mitigations (Landfire, 2009).

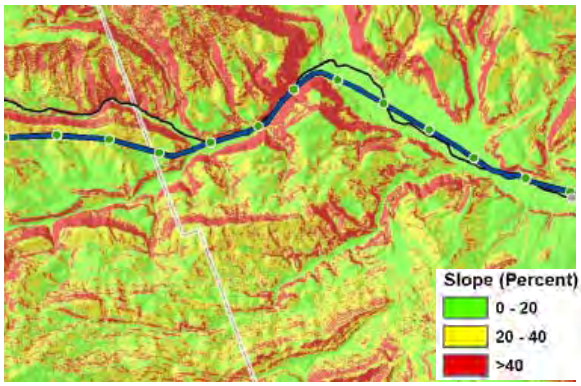


Figure 21. Calculated Slope Map

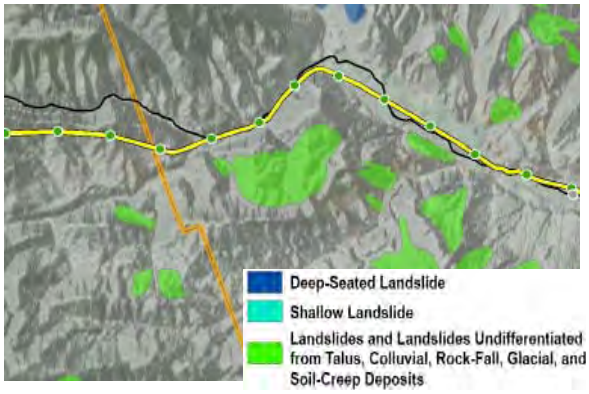


Figure 22. Landslide Map (SGS, 2007)

Figure 23. Interpreted Water Hazards Map

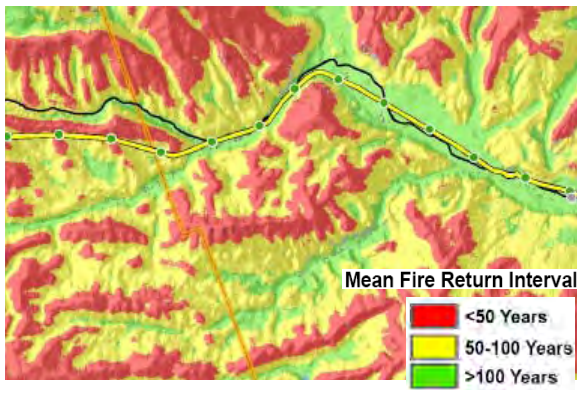


Figure 24. Wildfire Potential (Landfire, 2009)

3.3 GIS Database for Regional Infrastructure Network

A third interactive GIS application for gel example involves two recent GIS applications developed for managing inventory of Utah Department of Transportation (UDOT) infrastructure, including bridges, drainage and flood map features. The first application combines Google imagery with a master database linking various software platforms utilized by the department, including condition assessments, maintenance planning and risk prioritizations (Figure 21). This application combines the functionality of Google Earth with specific department-related data and queries.

The second application, displaying UDOT's critical bridges, was developed using the ESRI Flex framework using ArcGIS Server and Adobe Flash technology. This technology allows for linking project or asset data and geologic hazard data, to a web-based GIS viewer, with an open-source back-end, allowing for full user interface customization. The ESRI Flex web-base viewer has scale dependent aerial photography, infrastructure details, and other spatial features pre-loaded for the entire world, making it an appropriate technology for any organization, anywhere for managing assets and spatial data. Both Google and ESRI Flex applications eliminate the need for client-side GIS software and allow non-technical GIS users access to detailed spatial features, underlying databases, and GIS (querying) functionality.

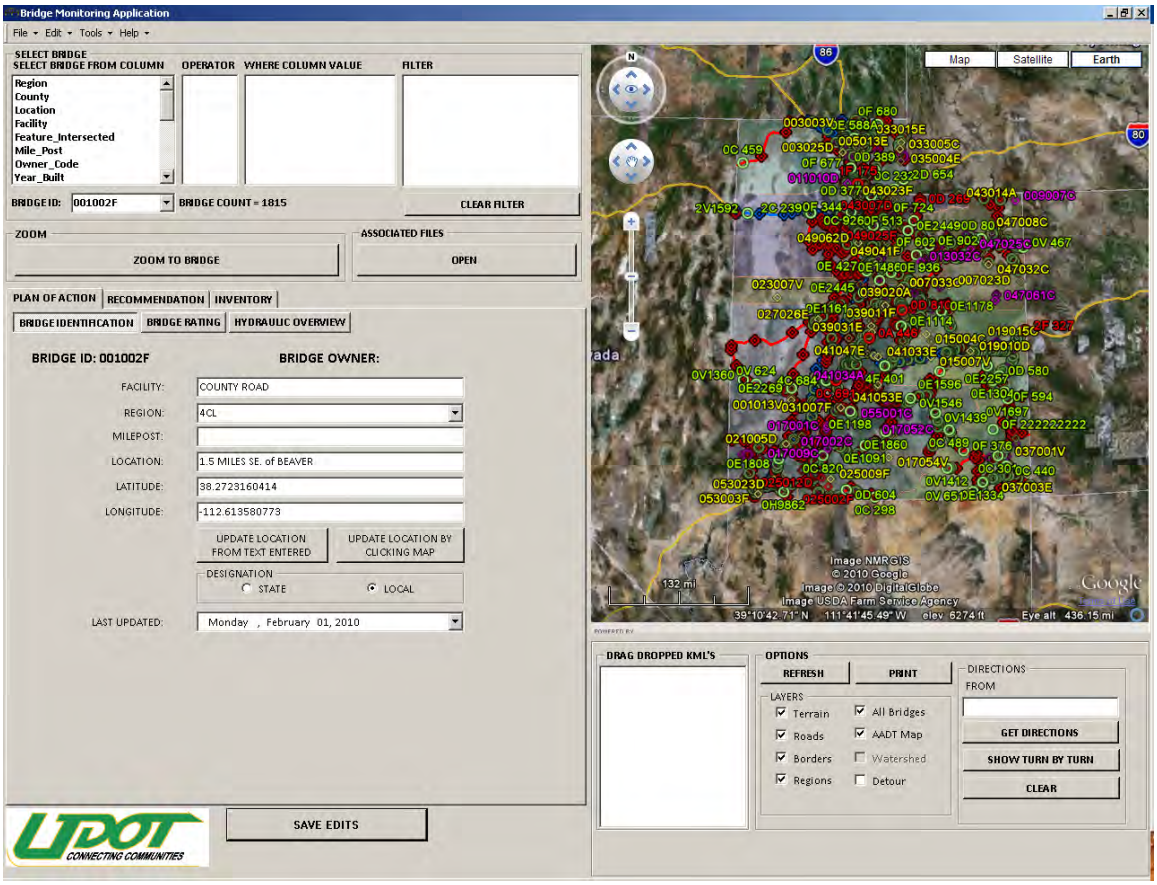


Figure 21. Screenshot of GIS Web Database for Distribution Network O&M

Conclusion

The current USA practices for incorporating geohazard information into siting assessments and earthquake engineering follows a tiered approach using the following:

1. Building code minimum requirements to evaluate liquefaction and landslide hazards on a simplified basis using code based seismic zonation and seismicity inputs.
2. Detailed assessments are required for severe site or important/critical infrastructure.
3. States with high seismicity are implementing detailed geohazard mapping on a broad basis in conjunction with updated seismic mapping and loss estimation modeling such as HAZUS.
4. Evaluation of each individual hazards is subject to significant variability. Accuracy of mapping and risk assessments is dependent upon the quality and extent or coverage of input data.
5. Web based GIS mapping allows for efficient interpretation of a broad array of hazards and aids perspective in applying engineering judgment for siting decisions. Innovations in these applications are increasing the level of detail of data using during the project planning phase and at time are prompting detailed geohazard evaluations also during the planning phase, where warranted. Engineering judgment is needed for practical simplifications and user friendliness.

Examples presented herein give an overview of key seismic siting geological hazards including landslide, liquefaction, fault rupture, and tsunami. Also presented are recent geospatial risk evaluations with interactive mapping of desktop data using off the shelf interactive GIS tools reflecting progressive tiers of detail:

(1) single hazard evaluations,

(2) multi-hazard comparisons and

(3) condition assessments / system inventories.

This kind of mapping provides an initial basis for critical infrastructure/key resources (CI.KR) sector risk assessments required in the National Infrastructure Protection Plan (NIPP) (DHS, 2009). These tools provide a “stopgap” while detailed quantitative risk assessments are being developed or refined, but remain far from complete. The screening level GIS mapping provides perspective in assessing infrastructure systems as a whole, including assessing “triple bottom line” risk (financial, social and environmental stewardship). Siting considerations are also greatly aided by understanding prioritized risks (likelihood) based upon hazards (consequences of failure), with assigned clear lines of responsibility, and collaborative system wide hazard mitigations and monitoring. These are the fundamental USA lessons learned of the past decade, available in more detail as The ASCE Guiding Principles for Critical Infrastructure (ASCE, 2009).

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Earthquake Scenarios and HAZUS Applications in the U.S.

Douglas B. Bausch[1]

Introduction

The Federal Emergency Management Agency (FEMA) developed HAZUS and released the first earthquake loss estimation version in 1997. Since then we have added flood loss and hurricane loss capabilities while continuing to improve the earthquake model. For more than a decade, a broad range of applications have emerged including the development of mitigation strategies, scenario driven catastrophic planning, exercise support, recovery and preparedness planning. This paper will introduce several potentially valuable applications for implementation in China.

HAZUS runs some 247 modules that estimate losses ranging from building damage to social losses including casualties and displaced households. Since HAZUS operates in a powerful GIS platform, we can display a variety of results with critical base layers. These maps and results can effectively communicate risk before the earthquake happens, as well as immediately after the earthquake for response and recovery applications. This paper will highlight some way these results have been applied to help identify vulnerabilities and develop mitigation strategies, as well as potential response and recovery needs. While HAZUS can provide probabilistic results based on 8 different return periods or annualized results, scenario applications have helped support a broad range of emergency management activities. We have coordinated with the U.S. Geological Survey (USGS) on the development of new products that support an extensive library of ShakeMap scenarios, largely based on the USGS National Hazard Map. The Earthquake Scenario Project (ESP), though still under development, is a forward-looking project, estimating earthquake hazard and loss outcomes as they may occur one day. For each scenario event, fundamental input includes i) the magnitude and specified fault mechanism and dimensions, ii) regional Vs30 values for site amplification, and iii) event metadata.

Earthquake Scenario Project (ESP) Plan Overview

A grid of standard ShakeMap ground motion parameters (PGA, PGV, and three spectral response periods) is produced using the well-defined, regionally-specific approach developed by the U.S. Geological Survey (USGS) National Seismic Hazard Mapping Project (NSHMP) (Wald and others, 2009), including recent advances in empirical ground motion predictions (e.g., the NGA relations). The framework also allows for numerical (3D) ground motion computations for specific, detailed scenario analyses. Unlike NSHMP ground motions, for ESP scenarios (Figure 1), local rock and soil site conditions and commensurate shaking amplifications are applied based on detailed Vs30 maps where available or based on topographic slope as a proxy. The scenario event set is comprised primarily by selection from the NSHMP events, though custom events are also allowed based on coordination of the ESP team with regional coordinators, seismic hazard experts, seismic network operators, and response coordinators. The event set will be harmonized with existing and future scenario earthquake events produced regionally or by other researchers. The event list includes approximate 200 earthquakes in California, 100 in Nevada, dozens in each of New Mexico, Utah and Wyoming, and a smaller number in other regions. Systematic output will include all standard ShakeMap products, GIS, KML, and XML files used for visualization, loss estimation, ShakeCast

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(Wald and others, 2008), Prompt Assessment of Global Earthquakes for Response (PAGER), and for other systems. Integration with Hazards U.S. (HAZUS) will be a result of the creation of the HAZUS formatted input as described by Kircher and others (2006). All products will be delivered via the USGS web pages in a user-searchable archive. In addition, we aim to duplicate most of the real-time earthquake event web page functionality (Figure 2) for scenario drills and exercises, including all standard post-earthquake information tools. Hence, for each event, USGS PAGER runs will be produced, providing population exposure at current population levels, and FEMA and its partners will produce HAZUS impact assessments. Anticipated users include FEMA, the loss modeling and insurance communities, emergency responders and mitigation planners (city, county, state, industry, utilities, corporate), the general public and the media. The Earthquake Scenario Project will also take on several pending scientific challenges related to scenario generation, including ways to include fault directivity, numerical ground motions, and ways to produce ground motion uncertainties (in addition to median peak ground motions). A parallel though less comprehensive effort is underway to produce scenarios for targeted regions and events around the globe.

Proof of concept for the USGS scenario process has been done for the Pacific Northwest. A suite of scenarios are online (ShakeMap web pages); this suite was chosen from NSHMP events and by consensus by regional science coordinators, emergency managers and other users. ShakeMaps were generated, including site effects, with the same procedures as the NSHMP computations; output grids were run thru ShakeMap to derive the full suite of ShakeMap output products.

The next step is to automate the NSHMP/ShakeMap generation process, develop web delivery (via scenario “event” pages) and content, and develop event sets for each region with the help of regional coordinators and input from regional users. Scenario data will be stored on the Archive server. Additions and modifications to the products or event page will be managed through Product Distribution Layer (PDL), so the maintenance is in the hands of the product creators. Downstream products will be considered, including full HAZUS-MH loss runs, mapping and summary results, loss computations via PAGER, and risk analyses.

Figure 1: The project homepage will include access via map or through archive database to the library of scenarios, as well as general information on ShakeMap, PAGER and HAZUS.

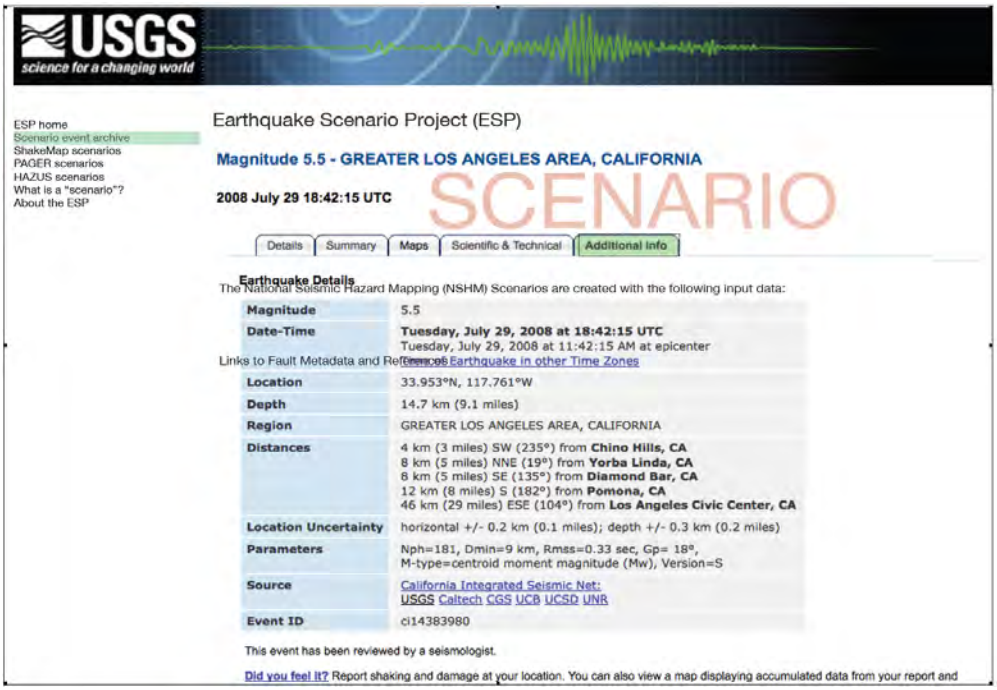

Figure 2: The Scenario Event Web page is nearly identical to a regular event. Metadata includes URL links to Quaternary Fault database and scenario event information. The HAZUS loss estimation information when available will be available under the "Additional Info" tab.

NEHRP ShakeMap/HAZUS Demonstration Pilots

Much of the work completed over the past several years in implementing pilots in Washington and Utah (Figure 3) http://www.nehrpscenario.org/?page_id=504 and more recently Nevada has tested the concept of the Earthquake Scenario Project (ESP) and points to the need for a uniform national system to provide a broad range of potential users a suite or library of credible earthquake scenarios. Frequently, the scenario selection is completed by users that want to test components of their emergency response capabilities without considering whether or not the scenario is credible. The selection of a credible scenario is especially critical for the promotion of mitigation of the vulnerabilities identified. Federal, State and local governments are unlikely to invest in mitigation if the scenarios are not considered reasonable. Deterministic scenarios based largely on the National Hazard Map sources provides a uniform method of selecting scenarios, as well as a more effective communication of the risk to a community from these sources as compared to the probabilistic approach. The ESP will also benefit from the existing ShakeMap/HAZUS interface. Through this interface the suite of ground motion maps needed for HAZUS loss estimations (PGA, PGV, 0.3 sec SA, and 1.0 sec SA) are provided and the suite of ShakeMap products that will be available in a real earthquake are produced so that users can gain valuable experience with the products prior to the event. This is especially critical for the HAZUS loss data which often get misinterpreted in the heat of a real event. Users will have familiarity with the descriptions and units used to describe building damage, social and economic losses.

Standard Operating Procedure for the Creation of Earthquake Scenario Priority Maps using HAZUS and ShakeMap

As a result of the ShakeMap/HAZUS demonstration projects (NEHRP, 2009) completed to date, we developed procedures for producing 12 standardized loss mapping templates we call "Priority Maps". The SOP includes step by step instructions with standardized ArcGIS templates, symbology and

terminology. To ensure interoperability and consistency we also established a standard protocol for the map layout, data symbology and spreadsheet creation (FEMA, 2009).

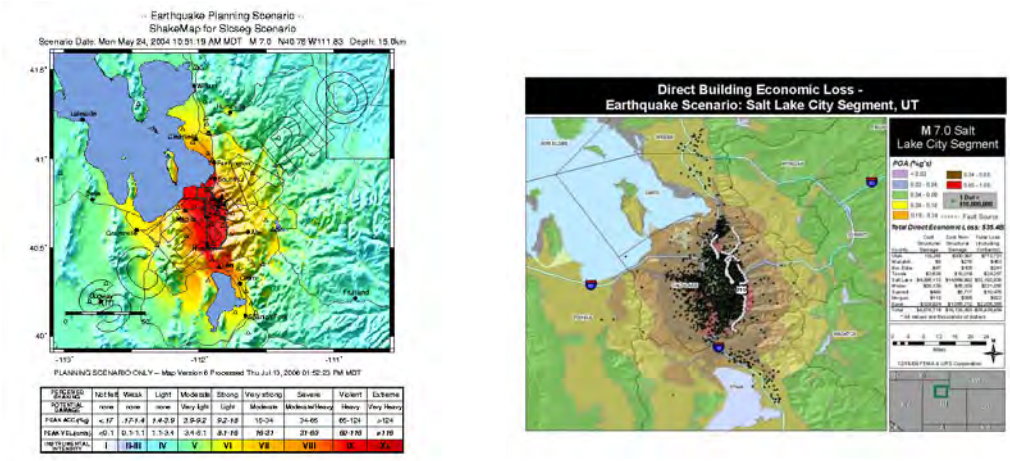

Figure 3: The completion of HAZUS estimates based on the ShakeMap supplied scenarios are displayed on a suite of 12 "priority" maps. The suite was developed over the last several years working with product users and modifying and standardizing the ArcGIS map templates.

The analysis of potential urban search and rescue (USAR) requirements (Figure 4) takes advantage of the correlation between USAR team types and HAZUS building types (Table 1). This particular scenario based on a magnitude 7.0 earthquake on the Wasatch fault underlying Salt Lake City, results in significant damage to the Unreinforced Masonry (URM) building inventory and has been used to support our hazard mitigation strategy for the region. In addition, the scenario identifies personnel significant requirements for USAR team types, especially the Type III teams associated with search and rescue of potentially collapsed URMs.

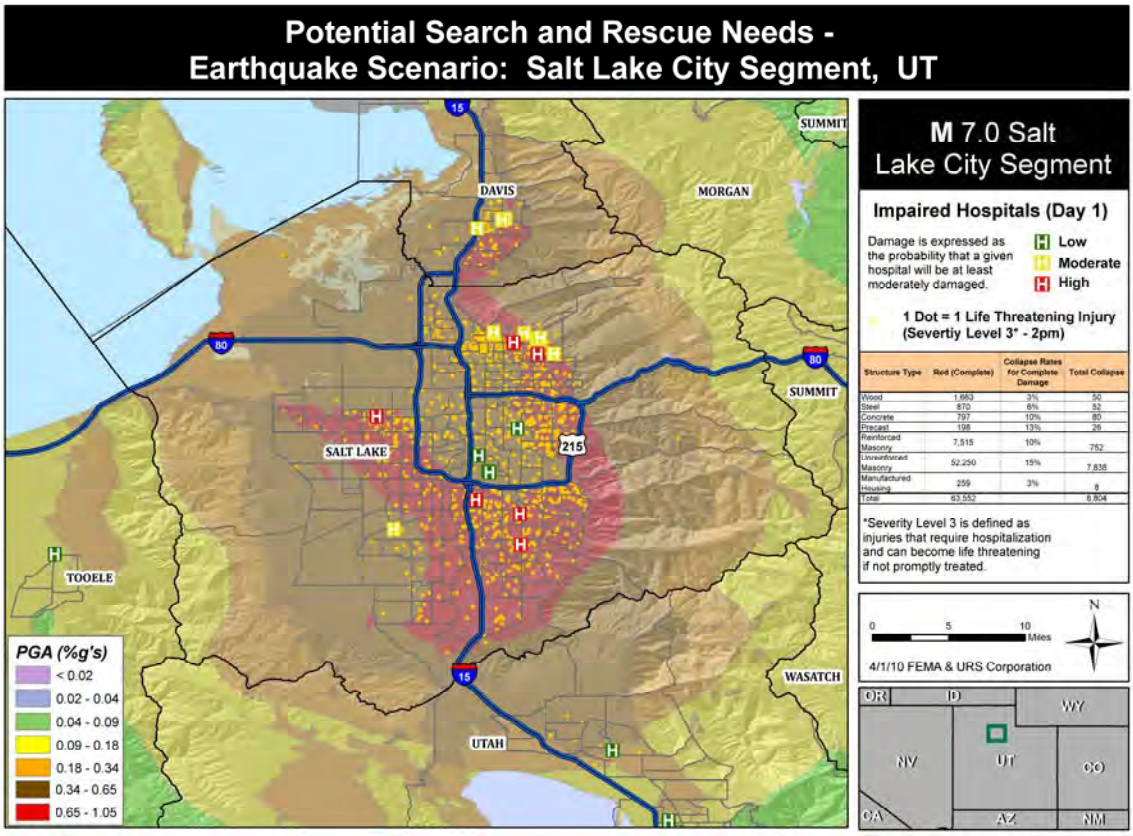

Figure 4: This graphic and associated tables help provide information to plan potential urban search and rescue (USAR) requirements. It also indicates that a single building type (Unreinforced Masonry) drives most of the severe casualties as well as USAR requirements.

URBAN SEARCH & RESCUE GAP ANALYSIS-Mw 7.0 SALT LAKE SEGMENT		
Resource	**Metric**	**Required**
Total number of **US&R Type I Task Forces** required? (Approximately 70 members, trained & equipped for light frame, heavy wall, heavy floor and concrete-steel construction **(heavy reinforced concrete))**.	Number of: Task Forces	**11**
	Trained Personnel	**770**
Total number of **US&R Type II Task Forces** required? (Approximately 32 members, trained & equipped for light frame, heavy wall, heavy floor and concrete-steel construction.)	Number of: Task Forces	**3**
	Trained Personnel	**210**
Total number of **Collapse S&R Type III Teams** required? (Approximately 22 members, trained & equipped for light frame construction.)	Number of: Teams	**261**
	Trained Personnel	**18,270**
Total number of **Collapse S&R Type IV Teams** required? (Approximately 6 members, trained & equipped for light frame construction.)	Number of: Teams	**15**
	Trained Personnel	**1,050**

Table 1: Through using the correlation between USAR team types and HAZUS building types, estimates of the number of teams and personnel required can be made for various scenarios.

The HAZUS methodology includes the integration of hazard susceptibility maps; including liquefaction (Figure 5), landslide, and fault surface rupture hazards, as well as tsunami and dam inundation. The methodology uses the various levels of susceptibility, combined with ground motions to estimate the severity of permanent ground deformation. In areas where these hazards are present, as significant increase in losses may be expected. In addition, highways, airport runways and other surface built infrastructure are only vulnerable to ground deformation and not shaking hazards.

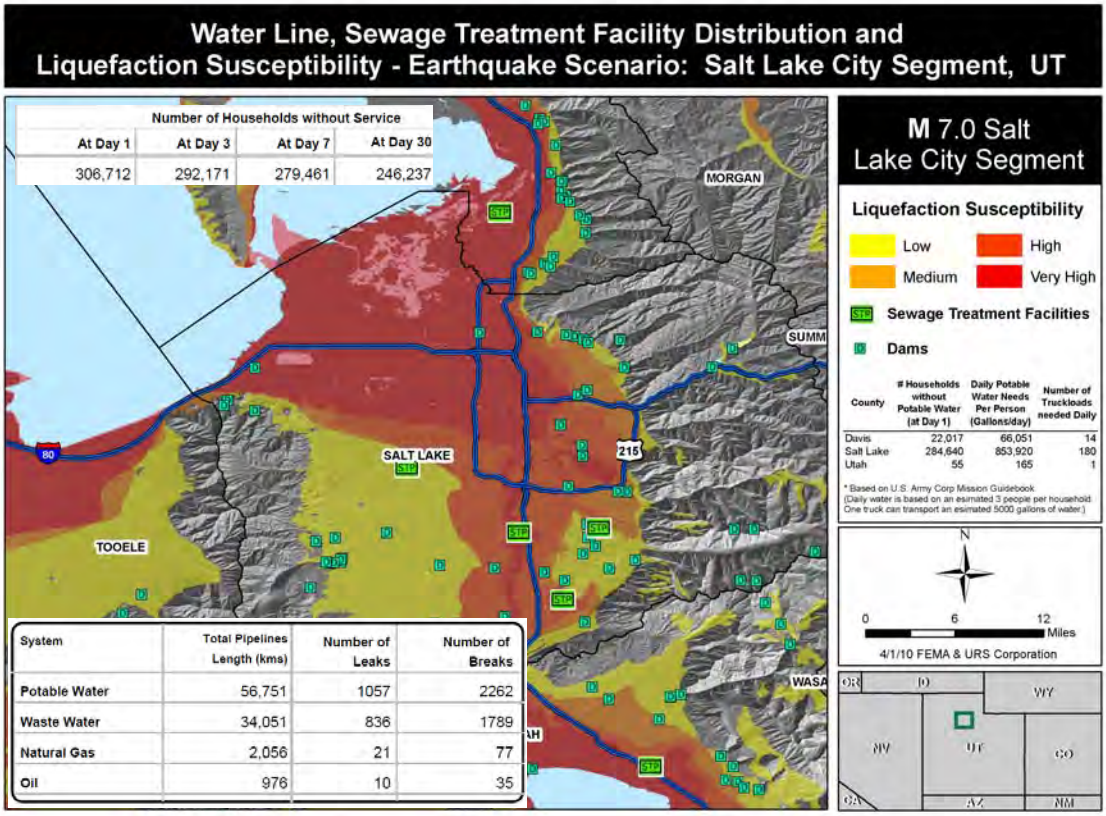

Figure 5: This map helps depict the significant role that ground deformation plays in earthquake related losses. The development of both liquefaction and landslide susceptibility maps are required to develop accurate earthquake loss estimates. Certain types of lifeline infrastructure, such as potable water pipelines are especially vulnerable to ground deformation.

Conclusions

The USGS Earthquake Scenario Project (ESP) is critical in meeting the significant demand for scenarios and associated products. ESP will ensure that scenarios are developed based on authoritative sources and provide consistency with the hazard maps widely used for building codes. By integrating the project with HAZUS activities, we benefit from loss estimation products that help translate the hazard to actual impacts and risk. This includes the potential to identify vulnerabilities and develop mitigation strategies.

Since there may be hundreds of potential scenarios, a critical next step is to automate the process, including the NSHMP/ShakeMap generation process, web delivery (via scenario "event" pages) and content, and full HAZUS-MH loss runs. Pilot testing in Utah and Washington has played a critical role in developing procedures for producing the standardized loss mapping templates intended to support a broad range of emergency management activities.

Development of a Standard Operating Procedure (SOP) ensures interoperability and consistency. The SOP ensures that all scenarios created and analyzed can be interoperable between end-users (FEMA regions, contractors, state and local governments, etc). It also established a standard protocol for the map layout, data symbology and spreadsheet creation. General map templates and spreadsheets are available as part of this project

The next steps require a prioritization of work areas based on work with FEMA and its partners that support ongoing FEMA-State mitigation grant activities, as well as Catastrophic Planning and Exercises. The strategy for developing and disseminating down stream loss products requires further development, as well as automation.

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Key Concepts in Implementing Hazard Mitigation Practices (From Siting & Construction to Preparation & Response)

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Introductory Discussion

One of the greatest challenges for scientists, engineers and other technical professionals is to have their findings, recommendations or studies incorporated into the real world decisions of a community. For those practicing in the area of earthquake science and engineering, the goal of successful implementation is even more vital considering the great risk to life and property for communities without proper design and hazard mitigation protection. In this paper, several concepts developed in the Hawaii Coastal Hazard Mitigation Guidebook (Hwang, 2005), and later for Indonesia after the December, 26, 2004 tsunami (Hwang et al., 2005) and for Louisiana after Hurricane Katrina (Wilkins et al., 2008) are discussed for areas relevant to earthquake mitigation. The concepts are universal and if applied, should lead to greater success with implementation and thus communities that are better protected from natural hazards. These concepts are later discussed in the context of the earthquake in Haiti and many of the works of authors on the USA team.

The three concepts covered in this paper relate to: (i) Multi-Hazard Design, (ii) Utilizing all tools for Hazard Mitigation including Siting, and most importantly (iii) the Key Elements of Implementation.

Concept 1 - Multi-Hazard Design

The trend in the United States and internationally is to consider all hazards in siting and construction design. This multi-hazard approach is done for several reasons. The most obvious is that when a development is properly designed and sited, it is made as safe as possible from all anticipated and known hazards in the area. For example, the Federal Emergency Management Agency's Coastal Construction Manual states:

> "Because most coastal areas of the United States are subject to multiple hazards, the designer must design for all significant hazards in the construction site and determine the vulnerability of the building to those hazards. The risk assessment must account for the short-term and long-term effects of each hazard, including the potential for cumulative effects, and the combination of effects from different hazards. Overlooking a hazard or underestimating the long-term effects can have disastrous consequences for the building and its owner." (FEMA, 2000)

Regarding earthquake and other hazards, the mitigation measures, can either reinforce or hinder each other. An example of complimentary mitigation is a continuous load path connection for a house that ties the roof to the foundation with reinforced connections at all major structural intersections. This can prevent uplift, overturning, sliding, or racking of the house whether the forces are from a wind load from a hurricane or from the shaking of an earthquake. Mitigation that is not complimentary is elevating a structure on piers and columns to protect from flooding or wave inundation. In the United States, it is encouraged to build higher than the design wave and flood forces (100-year events) by providing extra space or height called freeboard (FEMA, 2000). In an earthquake zone, such as in Hawaii or Indonesia, building higher can create a top heavy structure acting as an inverted pendulum with a soft story below. This must be reinforced with bracing (Hwang et al., 2005; Hwang et al., 2007).

Because of the interaction of various mitigation measures, all hazards should be considered and designed for in a development. The organizations in the United States that commonly assess hazards include the United States Geological Survey, the National Oceanic and Atmospheric Administration (National Weather Service, Tsunami Warning Centers), and Universities. On a smaller scale, scientific, engineering and consulting companies are often involved. It is becoming more common in the United States for these companies to be required to do a hazard assessment for certain development projects so that all hazards are considered.

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Concept 2 - Siting as a Tool in Hazard Mitigation

The United States has many examples of towns that were moved due to the damage from unanticipated hazards. This indicates that proper siting or locational characteristics were not considered at the time of development.

The town of Hilo, in Hawaii County, Hawaii, USA was devastated after the April 1, 1946 earthquake in the Aleutian Islands of Alaska generated a tsunami which inundated areas more than 900 meters inland (Figure 1). On May 22, 1960, the Magnitude 9.5 Chile earthquake generated another tsunami inundating areas further inland. Only after the second event, was the decision made to keep the former town site an open space for a park and soccer fields (Figure 2).

Figure 1: Devastation of the Hilo waterfront, Hawaii, USA after a tsunami struck generated by the April 1, 1946 8.6 Mw earthquake in the Aleutian Islands of Alaska (Photo Courtesy of Bishop Museum).

Figure 2: Major portions of the Hilo waterfront today are now open space consisting of parks and soccer fields. The decision to move portions of the town was made after the 1960 tsunami led to loss of life and destroyed many areas rebuilt after the 1946 event.

The old town of Valdez, in Alaska was built on a glacial outwash plain of unconsolidated wet sediments and silt. During the Great Alaskan Earthquake on March 27, 1964 (Magnitude 9.2), the town suffered considerable damage when liquefaction led to a massive underwater landslide causing a section of the city's shoreline to break off and fall into the sea. Due to the unstable soils, the town was moved to higher ground at a more stable site (Figure 3).

Figure 3: The town of Valdez, Alaska, USA today. Remnants of the abandoned old town are in the foreground and the new town, across the bay and on higher ground is in the background.

In the earthquake context, fault rupture, landslides, steep slopes, unstable soils subject to liquefaction, may all require siting considerations (see Francis, 2010). While siting is often politically difficult to do, it does form an important element in the hazard mitigation toolbox. It is also becoming an important consideration throughout the United States.

- In Hawaii, a new coastal shoreline setback law in Kauai County, believed to be the most scientifically based in the country requires consideration of an average annual erosion rate as well as the life expectancy of coastal structures.

- For earthquakes, California developed rules to consider siting before development proceeds. The purpose of the Alquist- Priolo Earthquake Fault Zoning Act ("APEFZA") is to prohibit the location of most structures for human occupancy across the traces of active faults and to thereby mitigate the hazard of fault rupture. The State geologist is to delineate fault zones along known active faults in California. Cities and counties are to withhold development permits until further geologic investigations demonstrate that the sites are not threatened by surface displacement from future faulting.

- In addition to APEFZA, the Seismic Hazard Mapping Act ("SHMA") directs the State Department of Conservation for California to identify areas prone to earthquake hazards of liquefaction, earthquake-induced landslides and amplified ground shaking. Site specific geotechnical investigations must be conducted to identify the hazard and formulate mitigation measures prior to permitting most development projects for human occupancy. Projects include the subdivision of land anticipated for human occupancy, but do not include single family dwellings – unless part of a development of four or more.

To successfully utilize siting as a tool in the hazard mitigation toolbox, it is recommended that the development process be defined in stages. The development process will vary, not only from one community to another within the same state in the U.S, but from one state to the next, and from one country to another. Although there is much variation in the process, certain concepts are universal. First, there is generally a hierarchy of development with certain stages of development occurring first. Second, there are usually some components of planning, zoning, subdivision, infrastructure improvement before construction. It is important to know the development process for several reasons. One being that utilizing siting measures, as well as other hazard mitigation measures, is more suitable for certain stages of development and not others (Figure 4).

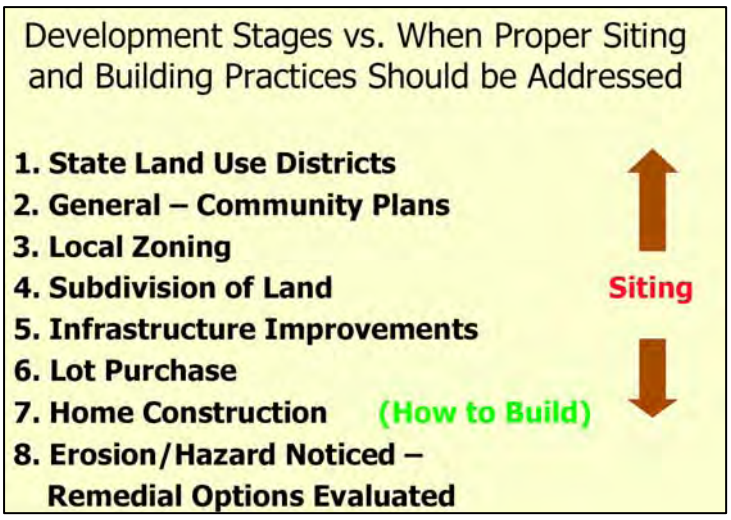

Figure 4: Development process for Hawaii (Hwang, 2005). The process will vary for every community, but in general a hierarchy can always be created for any jurisdiction. Note that siting measures can be addressed at multiple stages of development but are best addressed as early as possible (Stages 1, 2, 3 and 4) in this example. Proper construction – e.g., building codes can be addressed at stage 7.

For any jurisdiction in which there is property ownership, as in most countries, the concepts in Figure 5 apply.

Figure 5: Development Stages versus Market Value, Landowners Investment Expectations and Government Options (Hwang, 2005). With each stage of development, the landowner spends more time and money on the Project, thus increasing its market value, their expectations in the property (related to property rights), while decreasing community input into the project and options for the Government to mitigate risk from hazards.

From Figures 4 and 5, siting considerations should be considered as early as possible in the development process if scientifically based standards are to be implemented. Now applying Concept 1 to Concept 2, the siting mitigation should be considered after a hazard assessment covering all hazards, whether they are erosion, wave inundation, flooding, or earthquake related. In most cases, siting will not be an issue, and proper construction design can address the hazard risk. However, if siting is an issue it should be identified and addressed as soon as possible. Thus for the APEFZA and SHMA in California, consideration should be given in many cases to conducting hazard assessments and geotechnical investigation before the subdivision stage of development, for example before zoning. This concept would apply for the mitigation of all hazards.

Concept 3 – Elements of Government Implementation

A key concept covered in this paper regards the elements of implementation: Knowledge, Information, Guidance, Policy, Standards, Existing Authority and new Regulation (Figure 6). All of these elements are important and they are arranged to form a continuum, which means that for any two elements on the continuum, there is another one in between. Thus while there are seven distinct elements identified, there are many elements in between and there is a gradual transition from one element to the next. If this concept is understood, the hazard mitigation practitioner, or the interested jurisdiction or country will have vastly more options to implement, and thus there will be greater flexibility and a higher chance of successful implementation. Furthermore, many common pitfalls, which will be covered shortly, can be avoided.

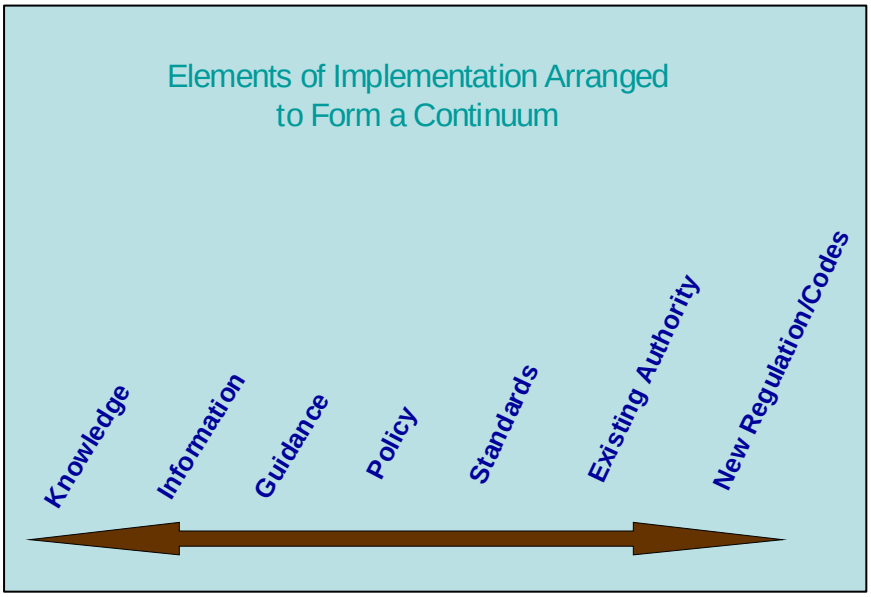

Figure 6: The Elements of Implementation include Knowledge, Information, Guidance, Policy, Standards, Existing Authority and New Regulations or Codes (adapted from Hwang, 2005). These elements apply to any hazard mitigation measure, whether it is siting, construction design, hazard preparedness or emergency response.

Describing these Elements in the context of Hazard Mitigation:

Knowledge: Research or knowledge is needed to answer the basic question – Is there a hazard risk? Many of the most recent disasters around the world occurred because the community did not have this basic knowledge. For example, because the reoccurrence interval was so great, residents in Indonesia were not aware of tsunami risks prior to the December 26, 2004 event and made no effort to move inland when the strong shaking of the ground occurred (Hwang et al., 2005). In Haiti, because the history of earthquakes was relatively sparse, the communities knowledge of earthquakes and thus concern or preparation in terms of adequate building design was negligible, resulting in great loss of life during the January 12, 2010 event (see http://news.stanford.edu/news/2010/march/miranda-quake-compare-033110.html). In the United States, basic knowledge on hazards is likely to come from Research Institutions and Universities, as well as key Government Agencies (such as the United States Geological Survey and NOAA).

Information: Information in this context refers to information for planning. If an area is subject to earthquake risk, how often and how strong?[2] If the area is subject to flooding, how deep and frequent?[3] If the area is subject to erosion, what is the erosion rate and its variability? If the area is subject to subsidence, what is the rate and is it continuous or episodic? All of this information can be used for planning whether it is for the siting of structures or the design of buildings. Many of the papers from fellow USA team members concentrate on efforts to provide planning information in the form of maps (Petersen & Gao, 2010 – Seismic Hazard Mapping in China and the United States – for mapping on a regional bases; Wong, 2010 – Development of Urban Earthquake Hazard Maps in the United States – for mapping on a local level). One paper provides emergency response planning information that it helps the community in their decision making. (see, Bausch, D., 2010 - Earthquake Scenarios and HAZUS Applications in the U.S.)

Guidance: Guidance provides direction to the community on **How to** respond. For example, given there is earthquake risk (Knowledge) with a certain anticipated intensity (Information for Planning), what are the building design characteristics to reduce the risk of collapse? For flooding, **How do** we reduce risk from flooding or wave inundation in our building design? All of this is guidance and without it, the community is lost even with the best planning information available. Commonly it is engineers and architects working with the knowledge and planning information provided by scientists that provide guidance for the community. Many examples of guidance are provided in the USA papers (see, Seismic Rehabilitation Methodologies for Unreinforced Masonry Buildings (Abrams, 2010); Earthquake Risk Management Approaches for Civic and Critical Lifeline Infrastructure:

[2] This is commonly given as a % probability of exceedance of a percentage of gravity over a 50 year period.
[3] In the United States, flooding risk is usually given in terms of the 100-year base flood level.

Applications in Oregon (Wang, 2010); Executive Summary of Symposium Topic Papers: Critical and Important Building Construction (Robertson, 2010); Implementation of Seismic Regulations for Nonstructural Components in Essential and Important Buildings in the United States (Theodoropoulos, 2010).

Policy: Policy is simply the actions and positions of a government or jurisdiction in support of certain issues. Policy combined with guidance can be a powerful tool towards implementation. Policy has the power to take Guidance and turn it into an industry standard, be used within existing authority or form the bases of new regulations and codes. In the United States, there is strong policy backing seismic design criteria so safety design, usually produced by professional engineering associations and committees as guidance are readily converted to industry standards, used within existing authority or converted to new regulations or codes. This may not be the case outside the U.S., or as explained later, with other hazard mitigation issues.

Industry Standards: Are simply standards of practice used within an industry without the benefit of supporting rules or regulations. Guidance and strong policy can easily create an industry standard and this avenue for design maybe the next best option if the political infrastructure in a location is not able to support the development of building codes. Good examples would be a small or developing political jurisdiction, or an area just recovering from a devastating earthquake such as in Haiti. In this situation, guidance provided by engineering professionals, backed by policy of the local government organizations can effectively implement safer practices through developing industry standards that later form the bases of safer building codes in the future as the political system grows in capability.

Existing Authority: Existing regulatory authority is also important in implementation and should be analyzed since there may not be the need for new regulations or codes. Guidance on a hazard mitigation measure combined with policy and existing authority can be just as effective as creating a new regulation and a much faster and more efficient process. If the guidance has already developed into an industry standard, then the amount of government support to use within existing authority should be minimal.

New Regulations/Codes: As a last resort, new regulations or codes can be created to address certain hazard mitigation issues. In the United States, there is a tension between new regulations which have an economic impact but can create certain benefits. With regard to issues of life and safety, these are the most important of factors so there is strong support in terms of new regulations and codes to address earthquake hazards by building design (See Overview of Current USA Seismic Design Provisions for New Construction (Chock, 2010). This may not be the same for other countries, or for other hazard issues related to siting, hazard preparedness, and recovery procedures.

With the Key Elements now defined, it is important to point out the significant advantages of understanding and using the Continuum in Figure 6.

1. **More Flexibility through Greater Number of Options** - For example, scientists and engineers can provide guidance on issues of hazard mitigation. Jurisdictions not able to develop new rules for this guidance, can instead, support it with policy, try to convert it to an industry standard or use it within existing authority. The options are endless when one considers that the elements and subelements can be used in various combinations. Although the political system and disposition of various areas of the United States and in other countries will vary greatly, the jurisdictions will in general be receptive to guidance on how to reduce hazard risk and will take small steps to advance towards implementation.

2. **Provides Short Term and Long Term Goals with a Successful Strategy to Implementation -** Because the elements have been arranged in a continuum, they each provide a mini-goal for the elements before them. For example, research priorities can favor obtaining knowledge that can be later converted to planning information or guidance, versus knowledge that cannot. Similarly, it is hoped that planning information is created in such a way that it can more easily lead to

guidance for the community. That the guidance developed can be supported by policy. That the policy support of the guidance can lead to industry standards, be used within existing authority, or from the basis of new regulations if needed. With these mini-goals recognized, proper steps to realize them can be taken. For example, engineers and consultants may need to work with community officials to develop guidance that is supported by policy.

3. **Help Avoid Pitfalls to Implementation –** Understanding the key elements of implementation will help to avoid pitfalls in implementation. Some of the most common mistakes in the past relate to missing elements. For example:

   i. **Poor understanding of Hazard Risk** (lack of knowledge or planning information). This will require focused applicable research to obtain the knowledge and in some cases collaboration or partnerships to convert knowledge to planning information.

   ii. **Missing Guidance to the Community** - One of the main reasons many scientific efforts in the past have not been utilized is that there is no guidance provided because it was not considered an important part of a project and thus no budget is given to supply it. However, communities are essentially blind without guidance. Thus, there is a trend in the United States with many of agencies dealing with hazards (e.g., FEMA and NOAA) to provide more guidance to the community so that they know how to protect themselves.

   iii. **Failure to consider Policy support** - Sometimes the introduction of new guidance may lead to an attempt to convert to new regulations without having the proper policy support. These jumps may be too large, and it may be politically, socially or economically impossible. In this case, small steps in the right direction are the alternative strategy suggested in the elements of implementation continuum. Using Haiti as an example, if a comprehensive building code considering local building materials, enforcement capability, administrative infrastructure and economic strength is not possible in the short term, then smaller step are suggested. For example, guidance developed by research and engineering professionals, supported by policy of government agencies can help to make them industry or local standards. As the country recovers and gains strength over many years, a building code becomes possible as the long-term solution. These are reasonable, obtainable small goals allowing recovery while proving for long-term resiliency of the area.

Conclusion

To reduce the risk of loss of life and property from hazards, it is important to consider the concepts covered in this paper. The multi-hazard approach is necessary to ensure all hazard risks are considered and that the mitigation for the various hazards are complementary and do not interfere with each other. Secondly, siting is an important tool in planning to reduce hazard risk, and will require designing future developments with nature. Thus it is important to know the nature of hazard risks (multi-hazard assessment) and know the development process (hierarchy of development stages for the particular locality). This will allow implementation of hazard mitigation measures in the most appropriate and efficient manner. Finally, it is important to utilize all elements of implementation (Knowledge, Information, Guidance, Policy, Standards, Existing Authority and New Regulations or Codes) so that there is increased flexibility, with the greatest number of options and opportunities to implement hazard mitigation within the community. This concept applies to all mitigation measures, whether it relates to hazard preparedness, emergency response, building design, siting or other various stages of development. The concept is important for developed countries, developing countries and areas recovering from a natural hazard or disaster.

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Executive Summary of Symposium Topic Papers: Building Codes

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Introductory Discussion

An explicit objective of the USA seismic provisions is establishing a uniform level of risk across the country for similar occupancies, such that life safety protection is achieved with uniform reliability. The U.S. building code has evolved to requirements based on a set of almost fully probabilistic hazard maps. The incorporation of uncertainties in both the characterization of seismic sources and in ground motion models was a key component of the current hazard maps. The development of Seismic Design Categories and Risk Categories in the USA code reflects an increasing risk-conscious philosophy of calibrated design force level and ductility requirements based on site characteristics, building occupancy, and type of structural system and configuration. There is increasing effort towards: validating the level of risk of collapse inherent in the current seismic provisions that utilize a single point hazard level, fostering greater reliability with performance-based seismic engineering in which performance objectives are used as explicit design criteria across a range of seismic hazard levels, and applying performance-based design to seismic rehabilitation of existing buildings. This effort is guided and fostered by the National Earthquake Hazards Reduction Program research and development "roadmap" of focus areas for improved seismic design methodologies. Achievement of the strategic improvements is made through a consenus-building partnership of public agencies, design professionals, academic institutions, and construction and material industries.

Overview of Current USA Seismic Design Provisions for New Construction (Chock, G.)

Current mandatory USA seismic design provisions for building and other structures are given in American Society of Civil Engineers Standard 7, *Minimum Design Loads for Buildings and Other Structures* (ASCE-7). These requirements are enacted through the adoption of the International Building Code (IBC) by federal agencies, state governments, and local jurisdictions. The IBC has become the national model building code for the USA, and it primarily references the ASCE 7 Standard for seismic design requirements. It also makes further seismic amendments to the material specific standards and includes additional geotechnical investigation requirements for seismic site classification, foundation, and construction quality assurance testing and inspection requirements. IBC Chapter 34 also contains seismic requirements for existing buildings undergoing additions, alterations, or repairs. Application to design practice thus requires at a minimum the use of the International Building Code, the ASCE 7 Standard, and the material specific standards (See Table 1). With this series of codes and standards, a comprehensive range of seismic design requirements exist for all structural systems and major nonstructural components, essentially applicable throughout the country. Other provisions for non-building structures and prescriptive codes and standards for one- and two-family dwellings are not examined in this paper.

Comparison of USA and China Seismic Design Procedures (Yu, G., Chock, G., and Luo, C.)

There are many aspects of the Chinese Code for Seismic Design of Buildings that have evolved rapidly since the Tangshan Earthquake in 1976, continuing up to the post-Wenchuan Earthquake 2008 revisions to the Code for Seismic Design of Buildings of GB 50011-2001 (MHURDC, 2001) and the Standard for Classification of Seismic Protection of Building Construction of GB 50223-2008 (MHURDC, 2008). In the United States, since the first seismic provisions were included in the appendix of the 1927 Uniform Building Code, the practice of seismic design and construction has gone through substantial changes after nearly one century of development. This paper presents a comparison of the current seismic design procedures in the United States and China.

The comparison is made based on the current version of seismic design codes in both countries. In the U.S., the 2006 International Building Code (IBC) is the currently adopted building code for most states while some states have adopted the 2009 International Building Code (ICC, 2009). The IBC references American Society

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of Civil Engineering Standard 7, Minimum Design Loads for Building and Other Structures (ASCE, 2005) and material-specific codes as seismic design provisions with some amendments or modifications. Unlike the IBC that references other standards as seismic provisions, The Chinese Code for Seismic Design of Buildings is a self-contained document that includes almost all seismic design requirements for building structures. The current seismic code in China is the Code for Seismic Design of Buildings GB 50011-2001. However, the new seismic code GB 50011-2010 (MHURDC, 2010) will be effective on December 1, 2010. This paper will compare the Chinese seismic code GB 50011-2010 and the seismic provisions of the 2009 IBC (ASCE 7-05). The seismic design practices in the United States and China are compared by focusing on issues such as (1) design ground motion; (2) classification of building structures; (3) soil/site classification; (4) design response spectrum; (5) base shear calculation; (5) analysis procedures; (6) drift control and deflection; (7) detailing requirements; and (8) general seismic design procedures.

Target Seismic Reliability Against Collapse in USA Codes and Assessment of Variations in Expected Performance (Harris, J.)

The design limit state of resistance to seismic effects is unlike any of the other loads considered in the ASCE 7 Standard. Due to the high demand exerted by earthquakes, the earthquake limit state is based on inelastic system performance rather than member limit state performance, with energy dissipation throughout many cycles of inelastic strain necessary for adequate performance. In order to provide a prescriptive linear elastic procedure for the design of buildings, the code regulates configuration, height, materials, detailing, and strength and stiffness of each system. Seismic design parameters representing the inelastic and deformation performance of such systems are specified as system response coefficients (R, C_d , and Ω_0). These system response coefficients then govern the magnitude of seismic design loads and deformation. With 88 types of earthquake resisting systems classified in the ASCE 7 standard, the ability of these systems to achieve the intended performance objective has been the subject of recent study.

The FEMA P695 investigation by the Applied Technology Council, *Quantification of Building Seismic Performance Factors* (June 2009) explored nonlinear analysis techniques by which the inelastic response characteristics and reliability against collapse of structures designed to current system-specific seismic requirements could be quantified and compared to the intended reliabilities of the ASCE 7 Standard. This technique is applicable generally to explicitly evaluate the ability of structural systems to meet seismic collapse prevention reliability objectives. This investigation verified that the seismic performance of structures must be evaluated in terms of the inelastic behavior of the entire seismic-force-resisting system, and not solely by the behavior of its individual components. This methodology provides a rational basis for establishing systemic seismic performance-based factors of seismic-force-resisting systems proposed for inclusion in model building codes, and a means of re-evaluation of existing systems in model building codes. Issues of non-uniform risk have been identified that indicate the need for revisions to the assignment of system seismic response factors in the USA seismic design code. Further work on achieving more uniform risk performance is presently underway at the National Institute of Standards and Technology.

Risk Category I & II	
Total or partial structural collapse	10% conditioned on Maximum Considered Earthquake (MCE) of approximately 2,500 MRI
Failure that could result in endangerment of individual lives	25% conditioned on MCE
Risk Category III	
Total or partial structural collapse	6% conditioned on MCE
Failure that could result in endangerment of individual lives	15% conditioned on MCE
Risk Category IV	
Total or partial structural collapse	3% conditioned on MCE
Failure that could result in endangerment of individual lives	10% conditioned on MCE

Table 1 Estimated Conditional Probabilities of Failure for USA Seismic Designs for an Extreme Event of 2,500 year Mean Recurrence Interval

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Preparation of USA Seismic Design Maps and Associated Web Application (Luco, N.)

In April of 2008, the United States Geological Survey (USGS) completed its latest update of the National Seismic Hazard Maps. This update was timed for use in developing new seismic design maps for USA model building codes. In collaboration with the USGS, the Building Seismic Safety Council (BSSC), with funding from the Federal Emergency Management Agency (FEMA), updated the methodologies used to derive seismic design maps from underlying hazard maps. Based on both the 2008 USGS National Seismic Hazard Maps and the new BSSC methodologies, the USGS has prepared seismic design maps for the 2009 NEHRP Provisions, the 2010 ASCE 7 Standard, the 2012 International Building Code, and the 2012 International Residential Code. In addition to the probabilistic uniform-hazard National Seismic Hazard Maps, this preparation included computation of (i) deterministic ground motion values and (ii) risk coefficients which transform uniform-hazard values into "uniform-risk" ground motions for use in design that explicitly targets a specified level of risk, in this case 1% probability of collapse in 50 years. This paper provides an overview of these computations and explains the USGS implementation of the new BSSC methodologies for deriving seismic design maps from hazard maps. In addition, it describes an associated web application developed by the USGS for obtaining values from the new seismic design maps in a user-friendly and accurate manner. These products include (i) a webpage for obtaining summary and detailed reports on seismic design values for a user-specified address or set of coordinates that is displayed in Google Maps, (ii) downloadable poster-sized color maps of seismic design values for a specified site class that can be used to visually verify the results of the aforementioned webpage, and (iii) Google Earth/Maps files for these and some of the other seismic design maps prepared by the USGS.

Figure 1: USGS Web Tool for Seismic Ground Motion Maps [compatible with USA Building Code Seismic Provisions]

USA Seismic Rehabilitation Methodologies for Unreinforced Masonry Buildings (Abrams, D.)

Over the last two decades, substantial development of national engineering guidelines for seismic rehabilitation of buildings has occurred in the United States through financial support and oversight by the Federal Emergency Management Agency (FEMA). This development started with the Applied Technology Council (ATC-33 project) that culminated in publication of recommended provisions (FEMA 273/274),

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which introduced the first national consensus approach to performance-based seismic design in the United States. Unlike prior seismic codes for new construction or methods for assessment of existing buildings, this document approached the issue of seismic rehabilitation through a displacement-based approach. Four analysis methods were prescribed ranging from a linear static analysis to a nonlinear dynamic analysis as well as nonlinear static and linear dynamic analyses. By estimating deformation capacity of individual structural elements, seismic structural systems comprising mixed components of structural steel, reinforced concrete, masonry or timber could be assessed and rehabilitated to meet specific performance objectives. Thus, this effort was a pioneering attempt to reach a new frontier for structural design of masonry buildings. This initial resource document was then further refined in the form of a prestandard (FEMA 356/357) and subsequently as a consenus-based standard (ASCE 41). This paper will provide an overview of these rehabilitation methodologies.

One unique aspect of using a displacement-based approach for seismic rehabilitation is that schemes for improving seismic performance do not necessarily need to increase structural strength, but rather such schemes should increase displacement ductility capacity. This distinction is particularly significant for relatively stiff structures such as unreinforced masonry buildings, which can attract large lateral accelerations and inertial forces, but then crack and become more accommodating to seismic input as structural walls or piers rock and slide. Whereas a stress-based approach would deem these systems to be weak in resisting earthquake motions, a displacement-based analysis may reveal that they can perform with adequate capacity. If properly detailed for ductility, unreinforced masonry buildings can be shown to resist moderate or even high intensities with an acceptable level of damage, or conversely, they can be rehabilitated in such ways to enhance their deformation or displacement capacities.

Common practices for seismic rehabilitation of masonry buildings will be outlined. Their relative effectiveness for resisting seismic actions will be evaluated and contrasted in terms of force-based or displacement-based methodologies. Such comparisons will be made on the bases of experimental studies where unreinforced brick masonry piers were rehabilitated with various schemes including: (a) parging with ferro-cement surface layers, (b) applying a reinforced concrete layer, (c) drilling cores and reinforcing them with grout and conventional reinforcement or placement of prestressing tendons within the cores, and (d) application of fiber reinforced polymer strips. These examples will include comparisons of both strength and deformation capacities as a result of the rehabilitation scheme.

Conclusion

It is hoped that through mutual discussion of developing technologies, improved methods of seismic design and seismic rehabilitation will be developed that will ultimately result in better performing building construction in China and the United States, by which economic loss, injuries and deaths will be diminished in future earthquakes.

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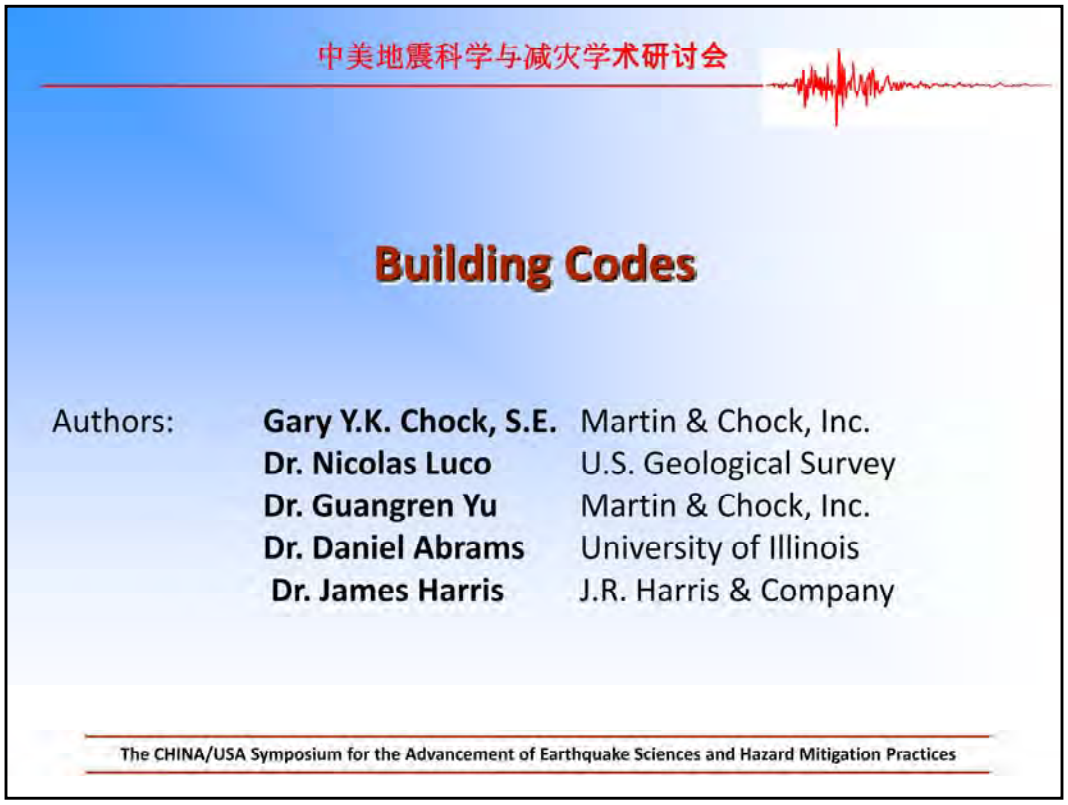


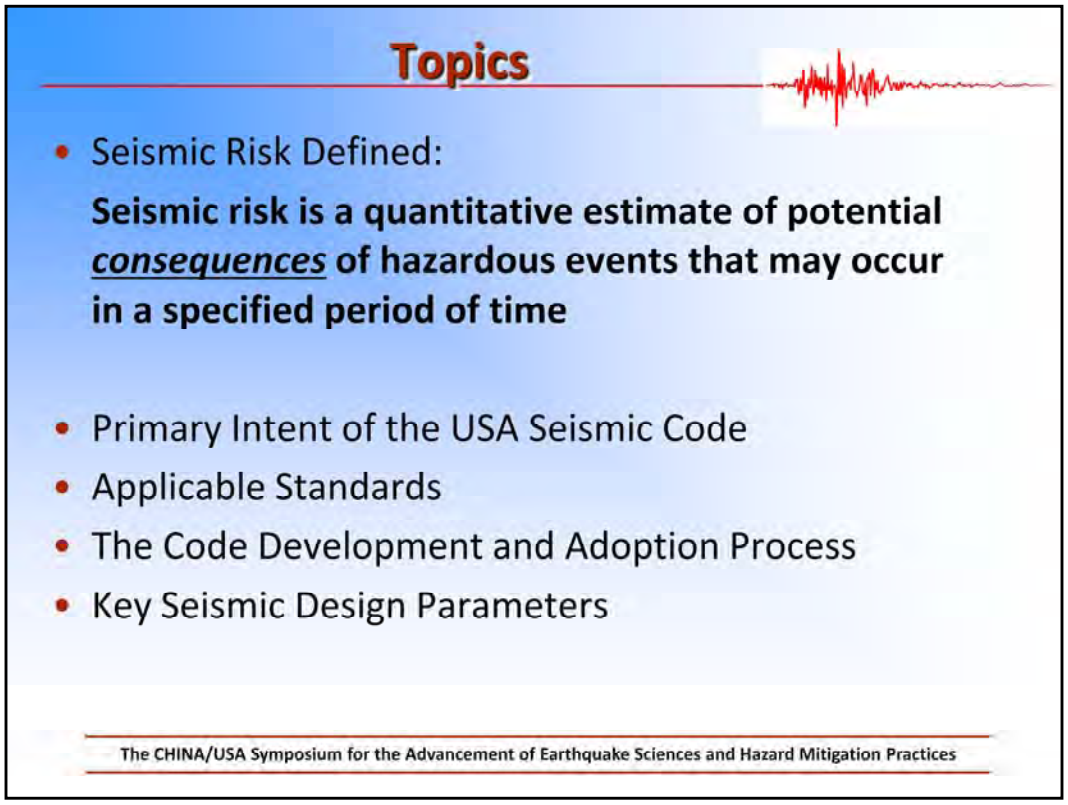
I am Gary Chock [卓日光], Structural Engineer, President of Martin & Chock, Inc. [马丁和卓氏结构工程顾问公司], (with a Master of Science from Stanford University,) and the USA Building Code session leader.

Joining us today are:

- Dr. Nicolas Luco is a research structural engineer representing the United States Geological Survey, where he leads its Seismic Design Maps Task of the National Seismic Hazard Mapping Project.
- Dr. Guangren Yu [俞广仁] is a Structural Engineer and research specialist with Martin & Chock, Inc. (He also has a Master of Science from Tongji University.)
- Dr. Daniel Abrams is a faculty member in structural engineering at the University of Illinois. He specializes in earthquake resistant masonry construction. He is currently involved in research into new seismic systems for masonry construction.
- *Dr. James Harris was unable to attend due to a concurrent work engagement in the USA. I will be presenting his briefing on reliability analysis of building seismic performance.*

- The emphasis of these papers and presentations is the reliability and risk-based objectives of current USA seismic design standards and practices. We invite you to read our detailed papers in the Proceedings on the topics discussed today.

Let us begin with this summary briefing: **Overview of Current USA Seismic Design Provisions for New Construction**.



First, for clarity, in these talks we utilize the following definition of seismic risk:

> Seismic risk is a quantitative estimate of potential *consequences* of hazardous events that may occur in a specified period of time.

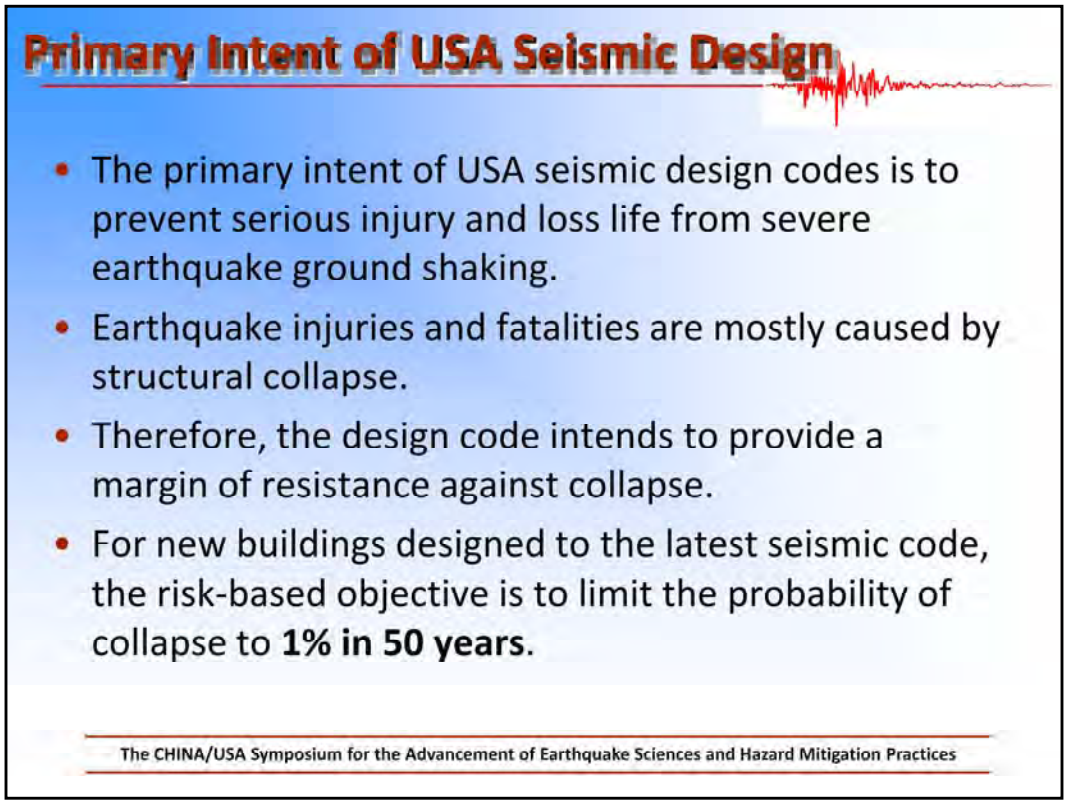
With that, I will discuss:

•Primary Intent of the USA seismic design code: the objective for a margin against collapse

• Applicable Standards: design standards referenced by the building code

• The Code Development and Adoption Process: how the USA seismic design requirements are developed

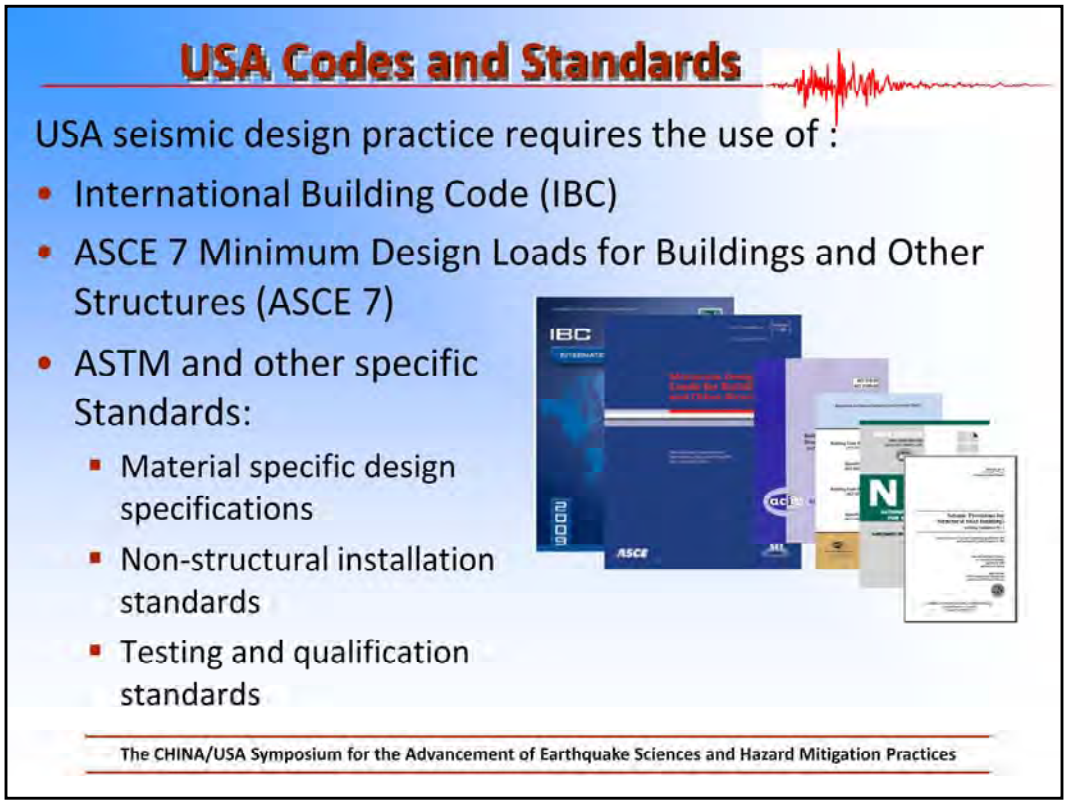
• Key Seismic Design Parameters: some of more important USA design factors



The primary intent of USA seismic design codes is to prevent serious injury and loss life from severe earthquake ground shaking. History shows that earthquake injuries and fatalities are mostly caused by structural collapse. Therefore, the code intends to provide a margin of resistance against collapse.

For new buildings designed to the latest USA seismic code, the objective is to limit the probability of collapse to **1% in 50 years**.

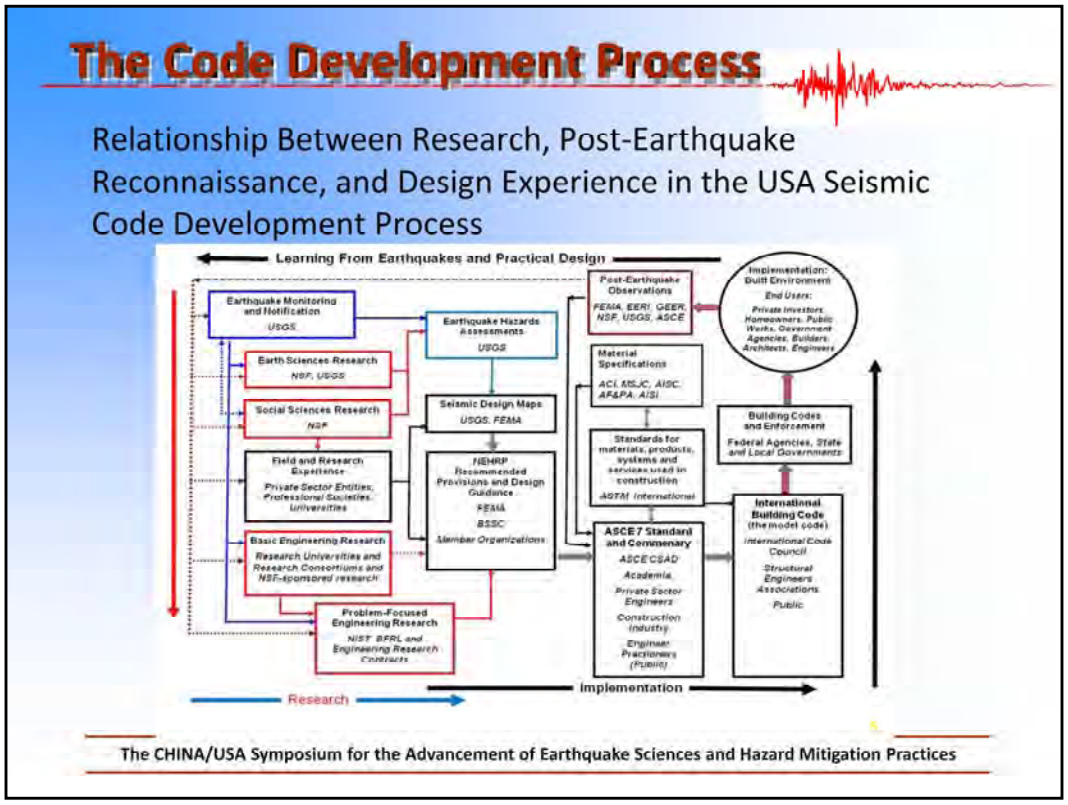
We shall see in this session that this is a risk-based design approach.



In the United States, the national model building code is the International Building Code (IBC), promulgated by the International Code Council.

The IBC references seismic design provisions for building and other structures that are given in American Society of Civil Engineers Standard 7, Minimum Design Loads for Buildings and Other Structures (ASCE-7). The ASCE 7 Standard Minimum Design Loads for Buildings and Other Structures becomes part of an enacted law through adoption of the building code.

The IBC and ASCE 7 reference detailed requirements for material specifications, methodologies, and procedures given in the ASTM International set of standards and other consensus-based standards. My paper includes an itemized list of the applicable seismic standards.



Improvements in the seismic design code is achieved through a continual process involving public agencies, academic institutions, private industry structural engineering experts, and construction and material industry associations.

These entities are involved in the principal undertakings of

- research & development,
- codes and standards, and
- learning from design experience and earthquake reconnaissance.

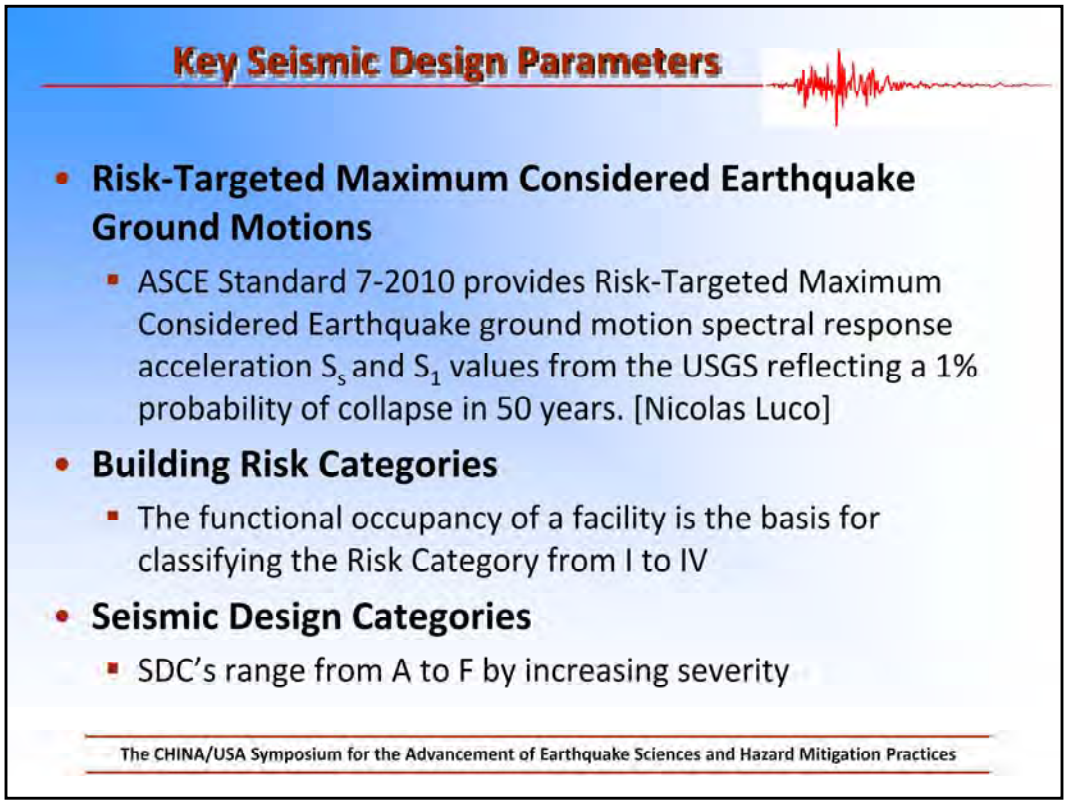
Research and development work on earthquake science and engineering is mostly conducted under the National Earthquake Hazards Reduction Program (NEHRP). In addition, the material standards association and contractor organizations sponsor research and development.

The ASCE Codes and Standards Activities Division is responsible for developing the final design standards under rules for consensus-based standards. Decision-making ASCE committees are composed of 1/3 academic, 1/3 professional engineers with relevant expertise, and 1/3 technical representatives from industry and material associations.

The International Building Code is updated every 3 years through an open process where code change proposals from any party must be considered in the decision-making by building official members nationwide.

Learning from design experience and earthquake reconnaissance is the key of ultimate validation, which is why the National Science Foundation, ASCE, and others place high importance on post-earthquake inspections. Lessons learned from earthquakes may foster new research or may be immediately implemented in the code.

Much more detail on the code development process in included in the paper.



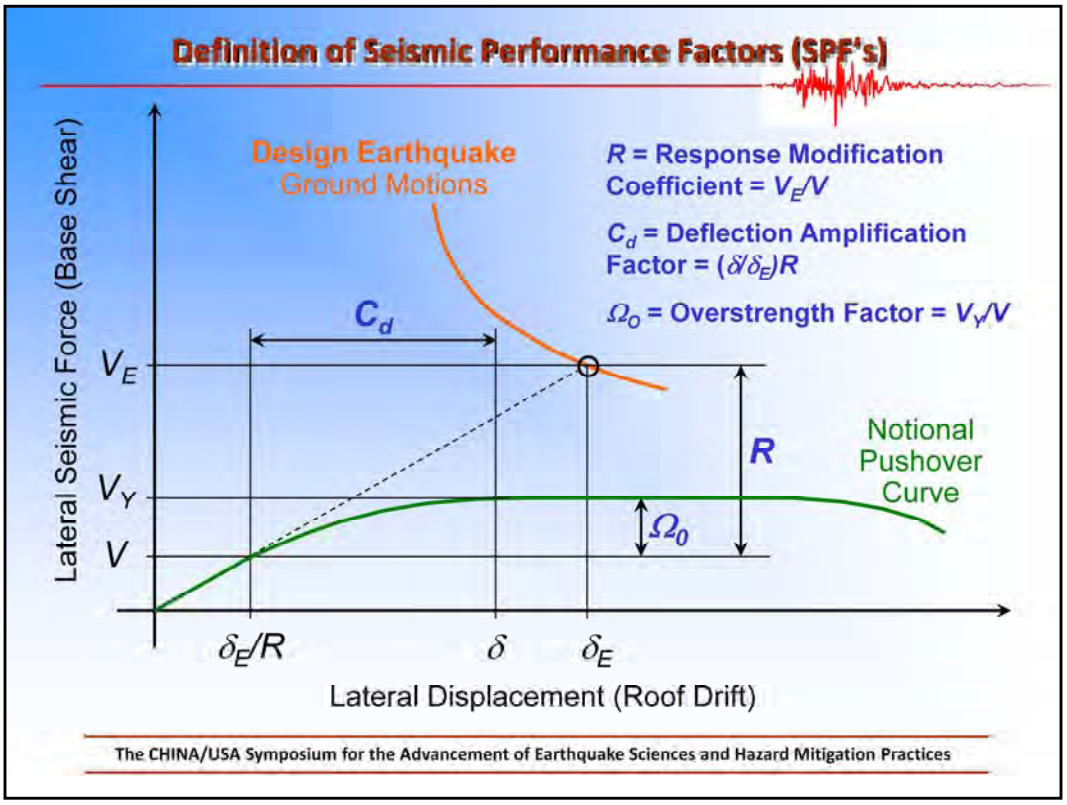
•The key seismic design parameters of the USA seismic code are the following:

• **Risk-Targeted Maximum Considered Earthquake Ground Motions -** The presentation by Nicolas Luco that follows later will describe the procedure for calculating Risk Coefficients for each region of the country in order to produce *Risk-Targeted* Maps of seismic ground motion.

• **Building Risk Categories -** The functional occupancy of a facility is the basis for classifying the Risk Category of a building. The Risk Category then determines the Importance Factor and most importantly affects the building's Seismic Design Category.

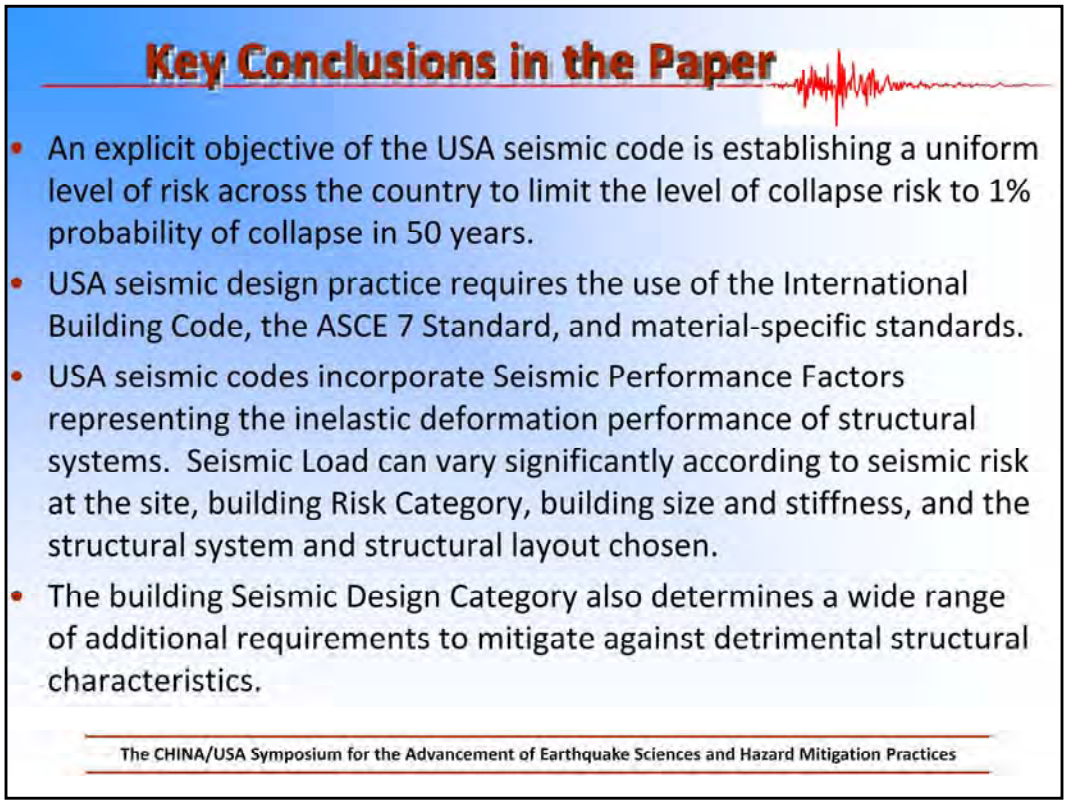
• **Seismic Design Categories -** Seismic Design Categories (SDC) are based on the spectral response accelerations of the site and the building Risk Category.

•Based on Seismic Design Category, the code includes additional checks to mitigate structural characteristics detrimental to ductile nonlinear response. This includes prohibitions against less ductile structural systems and height limitations, seismic detailing, nonstuctural component design requirements, and testing and inspections.



Seismic Performance Factors for Structural Systems

Seismic design parameters (R, C_d , and Ω_0) represent the inelastic and deformation performance of each type of structural system.



Key Aspects of the USA Seismic Code:

•An explicit objective of the USA seismic code is establishing a uniform level of risk across the country to limit the level of collapse risk to 1% probability of collapse in 50 years.

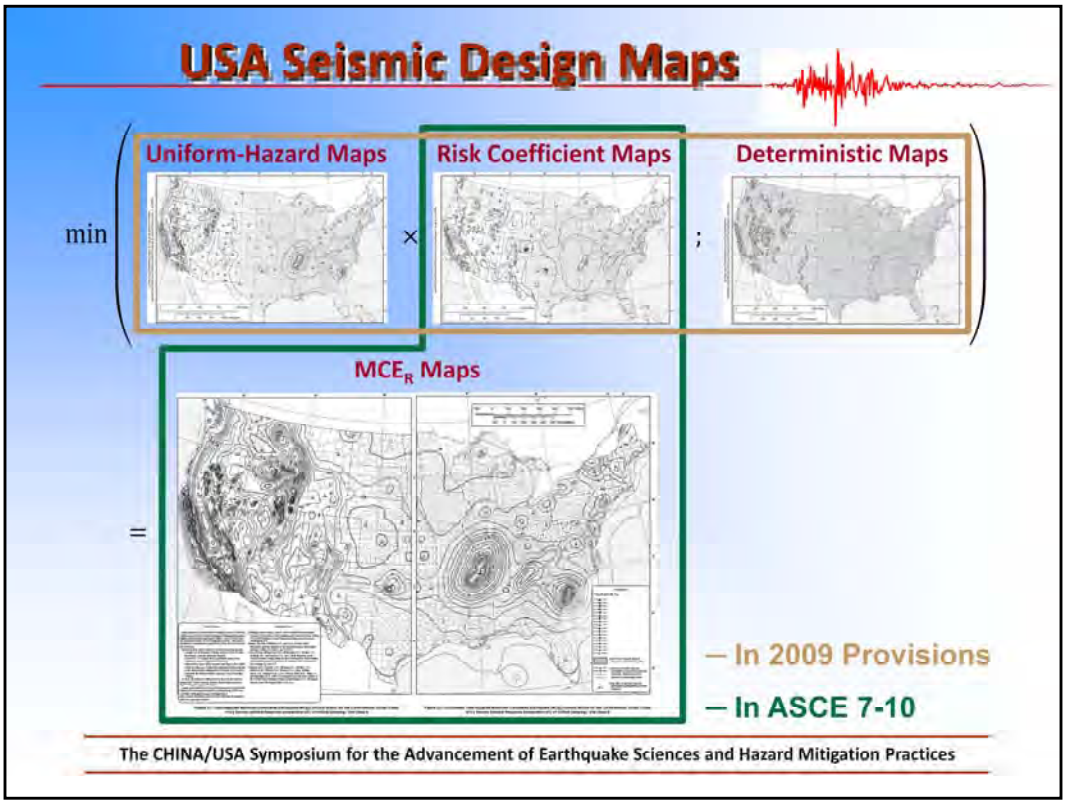
•USA seismic design practice requires the use of the International Building Code, the ASCE 7 Standard, and material-specific standards.

•USA seismic codes incorporate Seismic Performance Factors representing the inelastic deformation performance of structural systems. Seismic Load can vary significantly according to seismic risk at the site, building Risk Category, building size and stiffness, and the structural system and structural layout chosen.

•The building Seismic Design Category also determines a wide range of additional requirements to mitigate against detrimental structural characteristics.

•Dr. Luco will now present information on the latest method of seismic risk mapping.

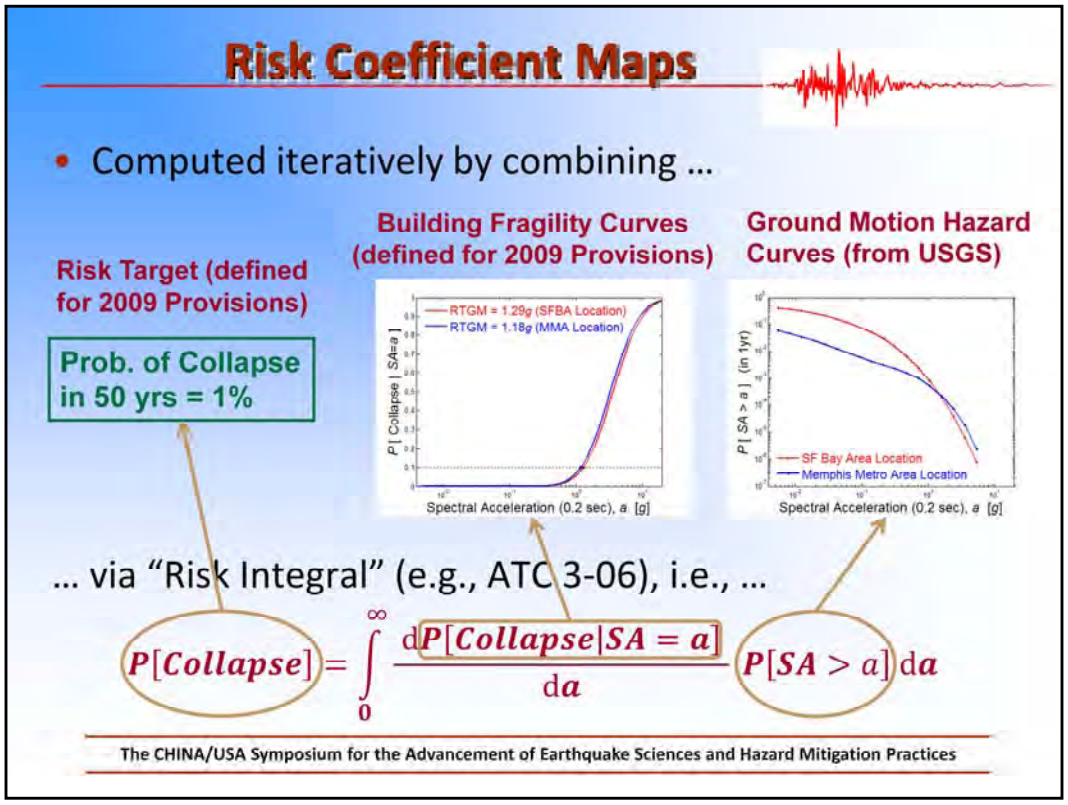
Ni hao, I am Nicolas Luco, Nico for short, and I am a research structural engineer with the US Geological Survey (USGS). I serve as leader of the Seismic Design Maps Task of the USGS National Seismic Hazard Mapping Project, and also as co-Project Chief of the USGS Engineering Risk Assessment Project. My very brief presentation will focus on preparation of new USA seismic design maps and an associated web application.



The new seismic design maps in the ASCE 7-10 Standard that was introduced earlier by Mr. Chock were originally developed for the 2009 NEHRP Recommended Seismic Provisions for New Buildings and Other Structures (FEMA Publication 750).

This slide illustrates all 3 components of the new MCE_R ground motion maps, namely underlying (1) uniform-hazard ground motion maps, (2) risk coefficient maps, and (3) deterministic ground motion maps. The 3 component maps are in the 2009 Provisions, whereas the composite MCE_R Maps are in ASCE 7-10 (and the 2012 IBC). The risk coefficient maps are also in ASCE 7-10 for use in development of site-specific ground motions.

I only have time to talk about the preparation of the risk coefficient maps which underlie the Risk-Targeted Maximum Considered Earthquake (MCE_R) Ground Motion maps in ASCE 7-10 and the 2012 International Building Code.



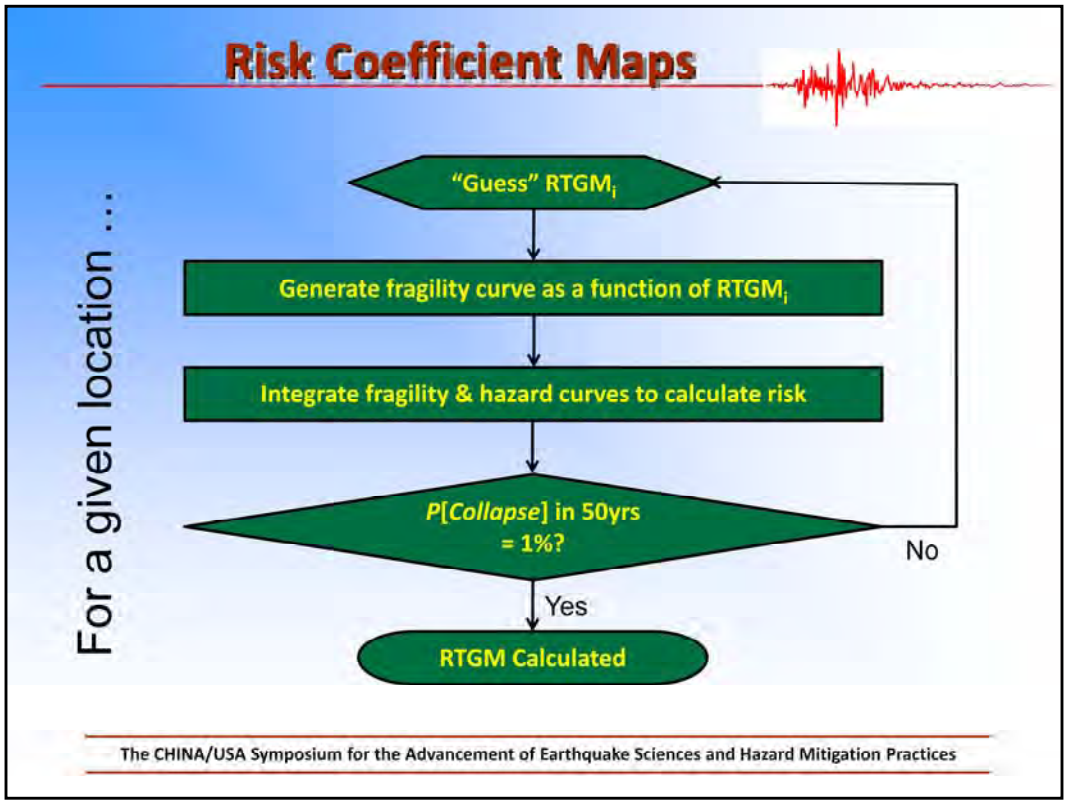
The values on the risk coefficient maps are computed iteratively by combining ground motion hazard curves from the USGS, building fragility curves defined by the committees that developed the 2009 Provisions, and a risk target also defined by those committees. As mentioned earlier by Mr. Chock, the risk target defined by the 2009 Provisions committees is a 1% probability of collapse in 50 years, the assumed life of a building.

•The location-specific ground motion hazard curves provide annual probabilities of exceeding different ground motion intensities, in terms of spectral acceleration at 0.2 seconds (shown here) and 1.0 seconds.

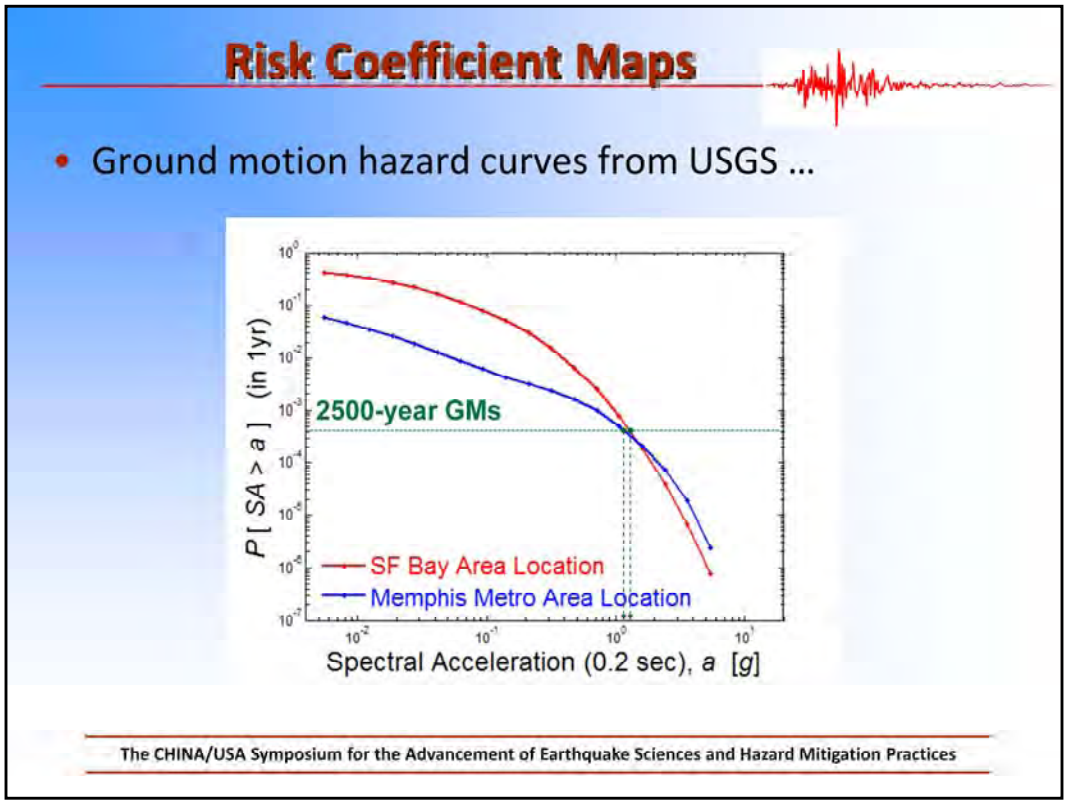
•The building fragility curves provide probabilities of collapse for the different ground motion intensities. It is important to note that a building's fragility curve depends on the ground motion intensity the building was designed to resist, which is referred to here as the Risk-Targeted Ground Motion (RTGM).

The hazard curves, fragility curves, and risk target are combined via the so-called risk integral. The risk integral says that annual risk of collapse is equal to the integration, over all possible ground motion intensities, of the product of the derivative of a fragility curve and a hazard curve.

Since the fragility curves defined for the 2009 Provisions depend on the ground motion intensity a building is to be designed to resist (the RTGM), the risk integral can be used to back-calculate the RTGM value at each location that results in the target risk, as explained further by the next slide. The RTGM values are related to the risk coefficients in a way that will be explained by a later slide.



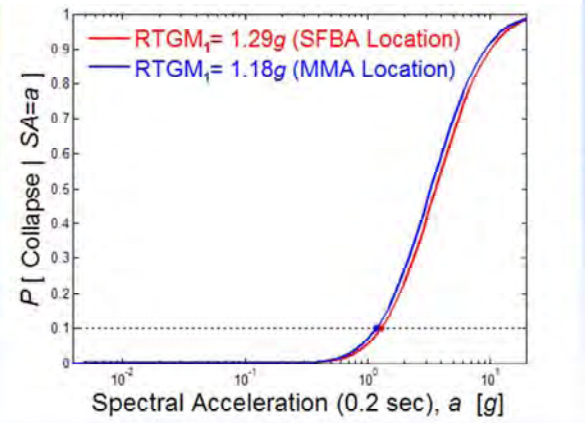
This flowchart illustrates how a Risk-Targeted Ground Motion (RTGM) is computed for a given location on the risk coefficient maps. The computation starts with an educated guess of the RTGM value. The building fragility curve that corresponds to this RTGM is then generated. Then the fragility curve in combined with a ground motion hazard curve for the location, via the risk integral, to calculate the risk of collapse. If the risk is equal to 1% probability of collapse in 50 years, the RTGM has been calculated. If not, a new guess of the RTGM is made and the process is repeated. The next few slides demonstrate this with an example.



This slide shows example ground motion hazard curves from the USGS. Recall that hazard curves provide annual probabilities of exceeding different ground motion intensities. The red hazard curve is for a San Francisco Bay Area location, and the blue curve is for a Memphis Metropolitan Area location. As shown in green, conventional 2500-year uniform-hazard ground motions are interpolated from such hazard curves. It is important to note that whereas the 2500-year ground motions for the two locations are very similar, the shapes of the two hazard curves are quite different. The risk coefficients for the two locations will quantitatively capture this difference.

Risk Coefficient Maps

- Building fragility curves assuming, for the 1st iteration, that RTGMs = 2500-year GMs …



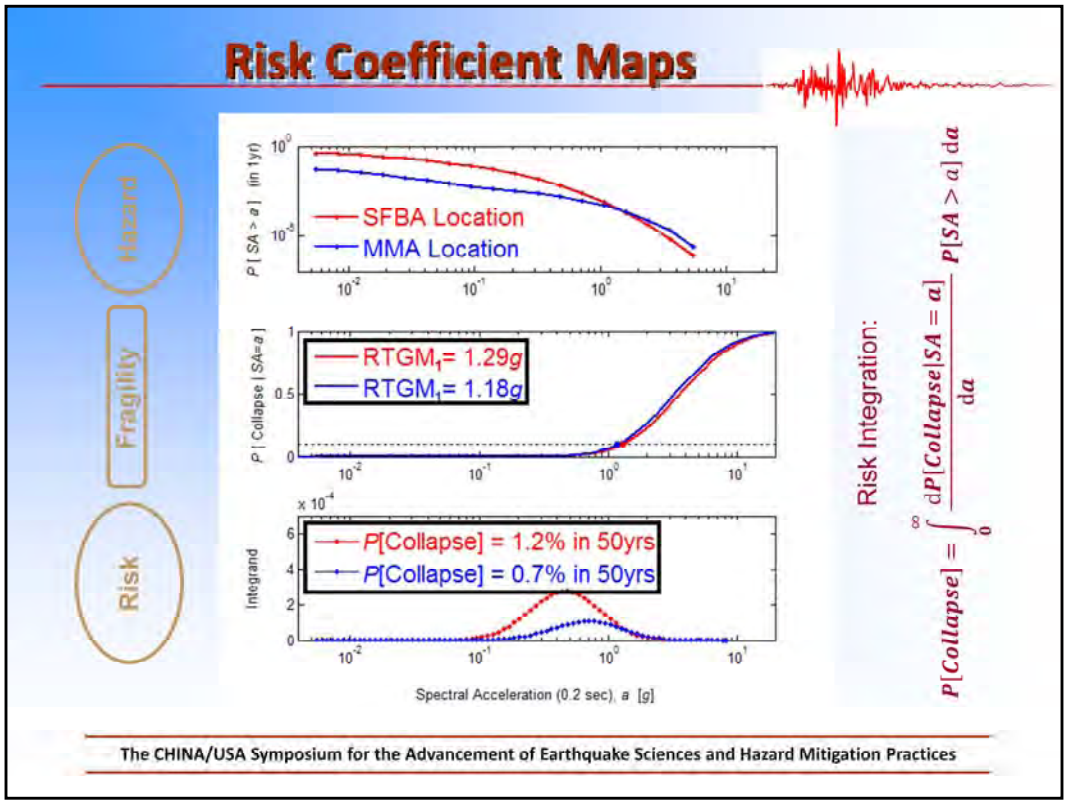
Building fragility curve equation:

$$P[Collapse|SA = a] = \Phi\left[\frac{\ln a - (\ln RTGM + 1.28 \times 0.8)}{0.8}\right]$$

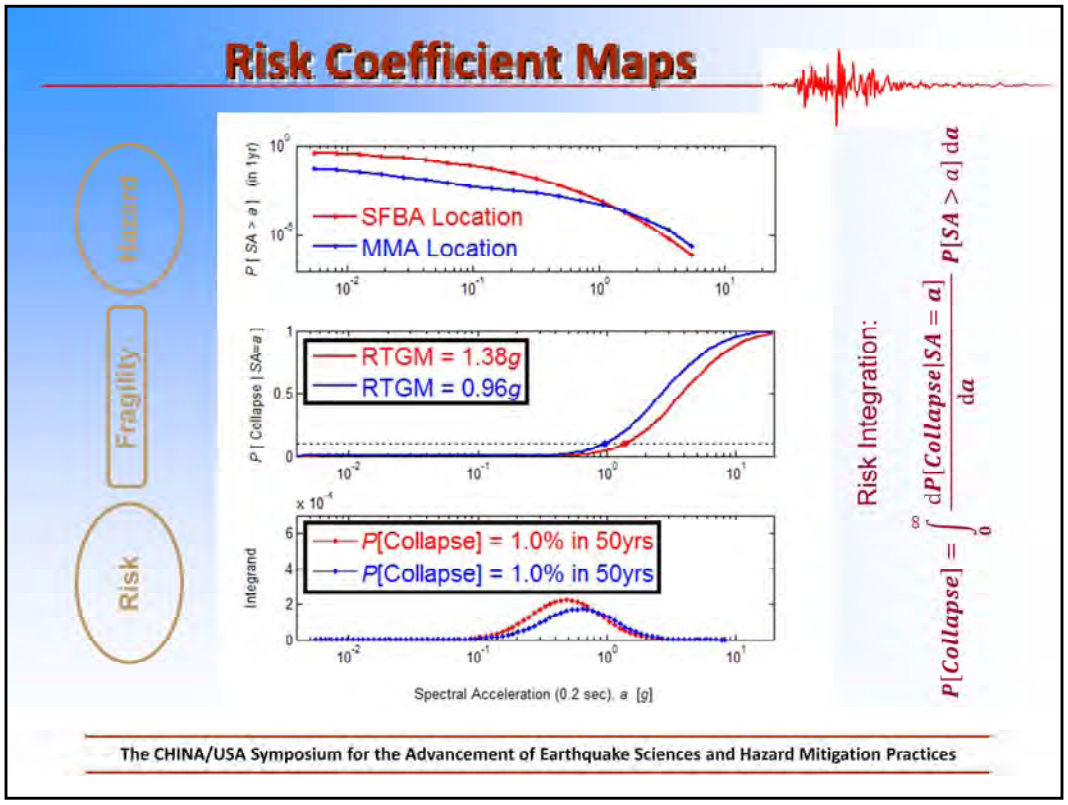
where

$\Phi[\cdot] \equiv$ **Normal/Gaussian CDF**

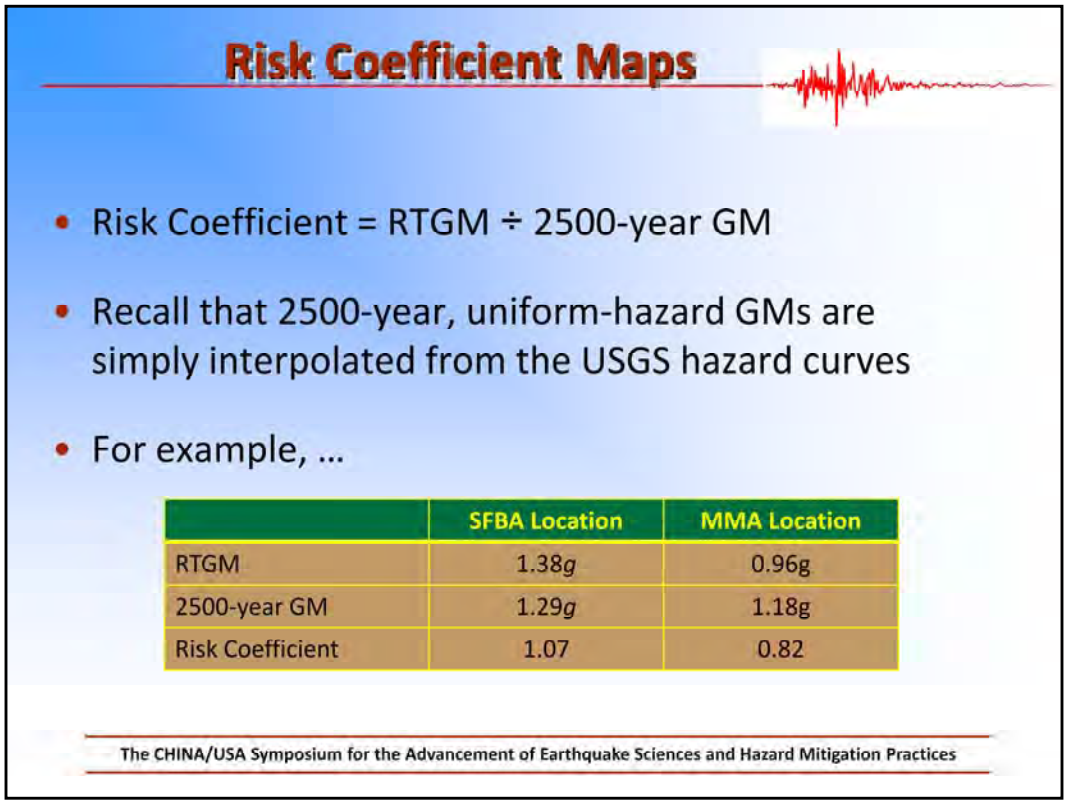
Assuming for the first iteration of the example risk coefficient computation that the RTGM is equal to the 2500-year ground motions from the previous slide, this slide shows the corresponding building fragility curves for the San Francisco (SFBA) and Memphis (MMA) locations, and the equation that defines them. Recall that the fragility curves provide probabilities of collapse for different ground motion intensities. Note that the two fragility curves are very similar, because the 2500-year ground motions assumed for this first iteration are very similar.



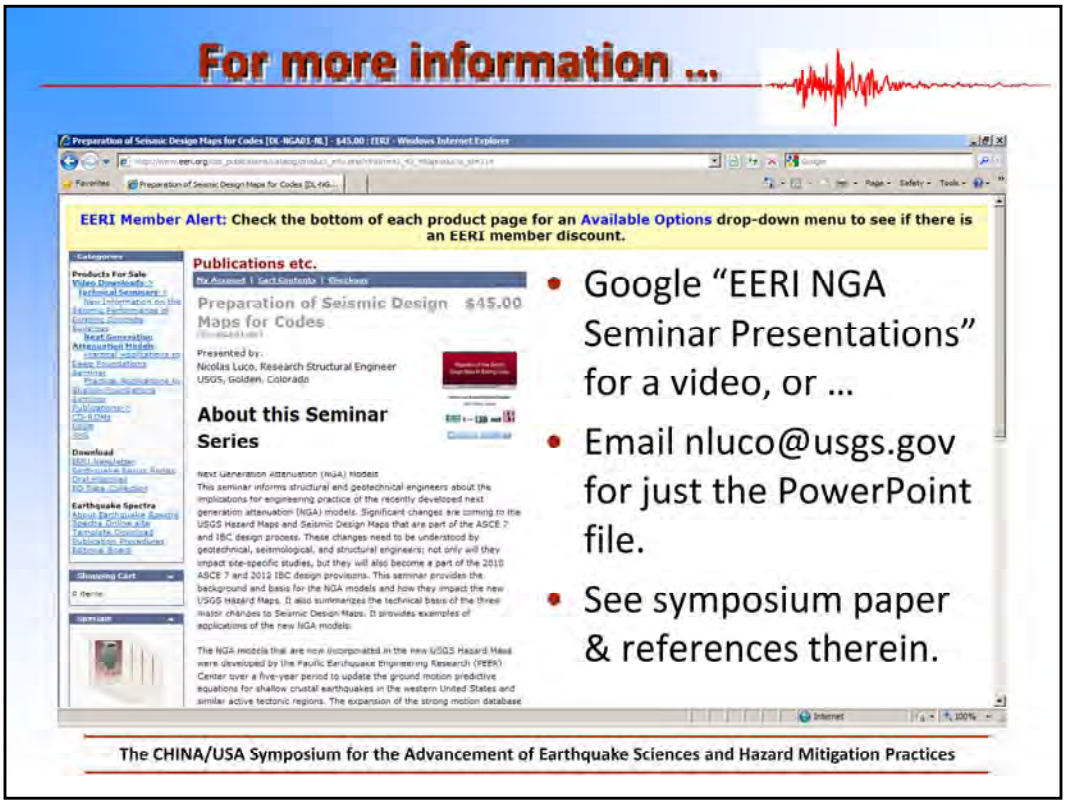
Given the example ground motion hazard curves and building fragility curves shown in the previous two slides, this slide illustrates their combination via the risk integral. The top panel shows the hazard curves for the two locations, the middle panel shows the fragility curves that correspond to the first-iteration RTGM values for the two locations, and the bottom panel shows the results of combining these hazard and fragility curves via the risk integration. In summary, if the RTGM values were 1.29g in San Francisco and 1.18g in Memphis, the respective collapse risks would be 1.2% and 0.7% in 50 years, not 1.0%. By iteration, the RTGM values will be adjusted to result in a collapse risk of 1.0% in 50 years at both locations.



In this iteration, the RTGM values have been increased to 1.38g for San Francisco and decreased to 0.96g for Memphis, in an attempt to achieve a collapse risk of 1.0% in 50 years. Finally, it is found that if the RTGM values are 1.38g for San Francisco and 0.96g for Memphis, the resulting collapse risk is 1.0% in 50 years at both locations. These are the Risk-Targeted Ground Motion values that lead to risk coefficients for the two locations, as explained in the next slide.



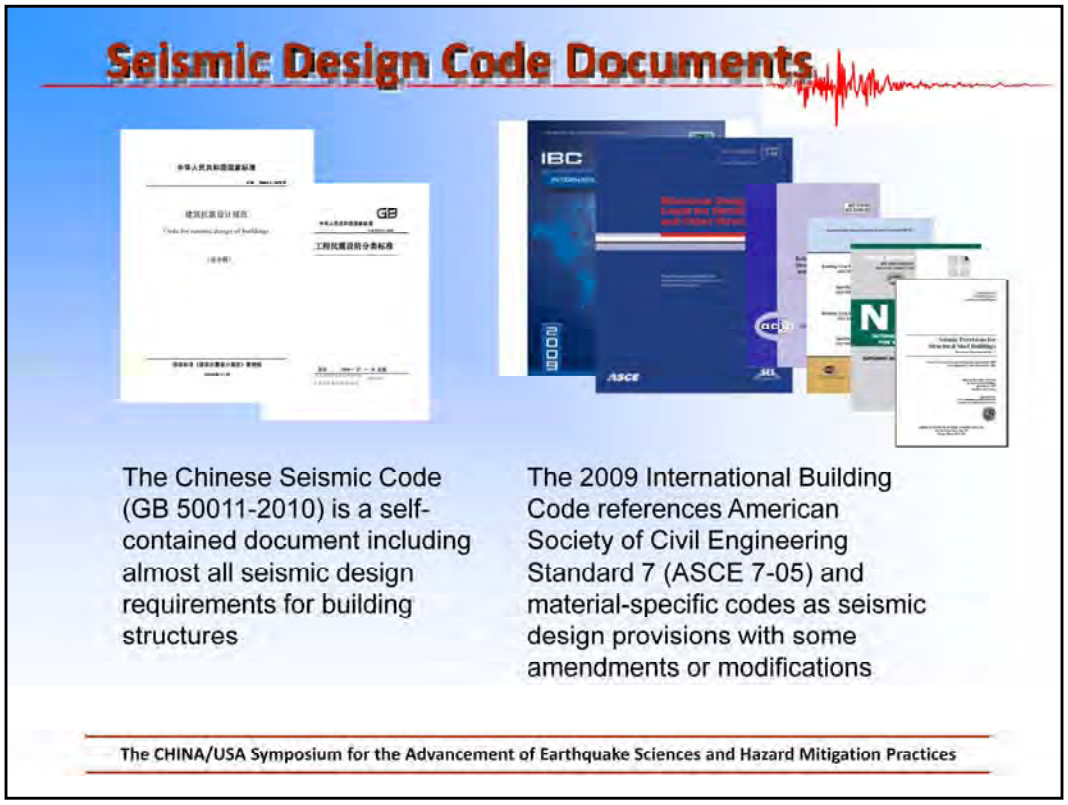
The risk coefficient maps that underlie the MCE_R ground motion maps in ASCE 7-10 and the 2012 International Building Code represent ratios of RTGM values like those just computed for San Francisco and Memphis divided by corresponding 2500-year, uniform-hazard ground motions. For the San Francisco (SFBA) and Memphis (MMA) locations in the example, the resulting risk coefficients are 1.07 for San Francisco and 0.82 for Memphis. These risk coefficients indicate that at the San Francisco location the ground motion for designing buildings should be larger (by a factor of 1.07) than the conventional 2500-year ground motion, in order to achieve the 1%-in-50-year target collapse risk. Conversely, the design ground motions at the Memphis location can be smaller (by a factor of 0.82).



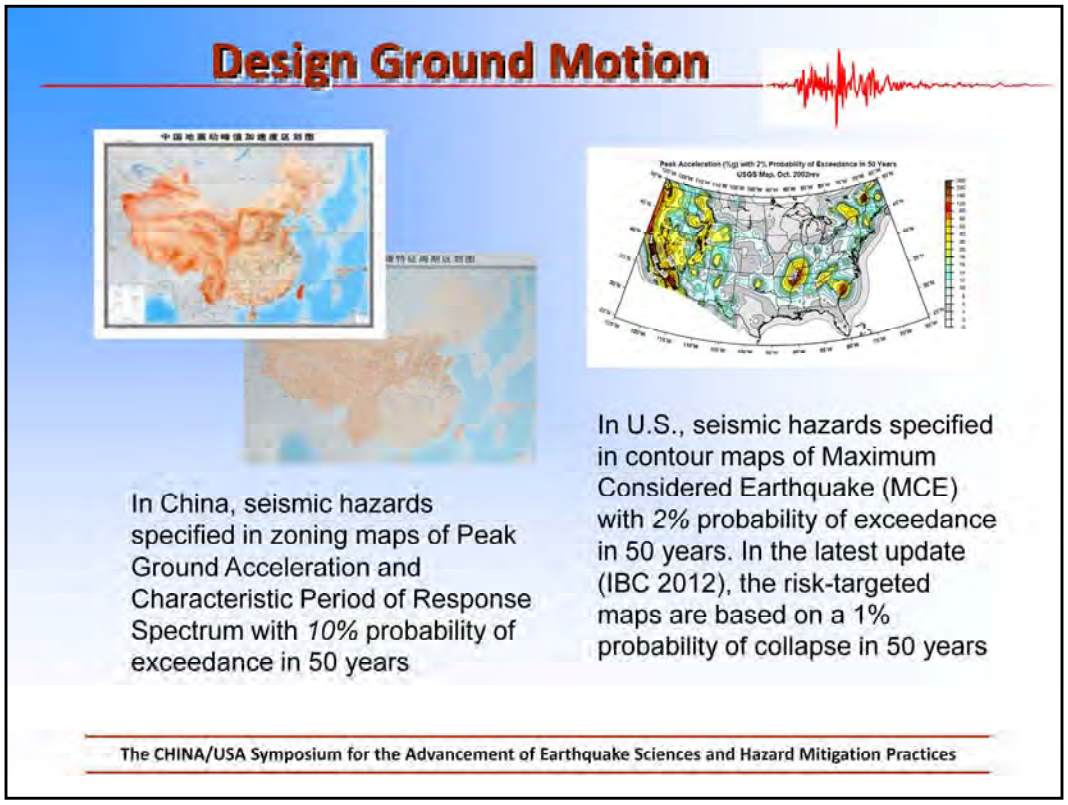
For a longer presentation on the preparation of the new USA seismic design maps, please Google "EERI NGA Seminar Presentations" for a video or email me (nluco@usgs.gov) for just the PowerPoint file. For even more details, please see my symposium paper and the references therein.

Before concluding, allow me to quickly mention that the USGS has also prepared an associated web application that allows engineers to obtain values from the new seismic design maps for a specified address or latitude and longitude. The URL of the application and a screenshot are shown here.

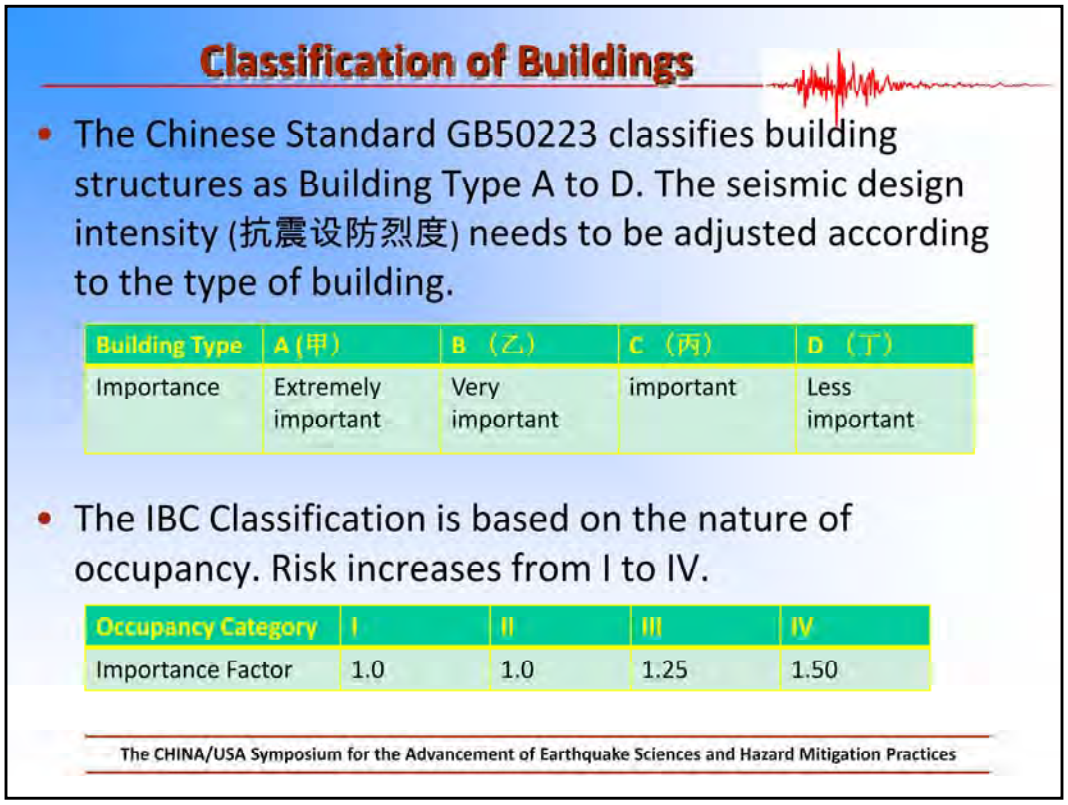
I am going to compare the U.S. and China seismic design provisions. The comparison will be based on the 2010 Chinese Seismic Code and the 2009 International Building Code. I will focus on the differences though there are a lot of similarities. I will also present comparative designs that highlight some significant differences between the two countries' seismic design practices.



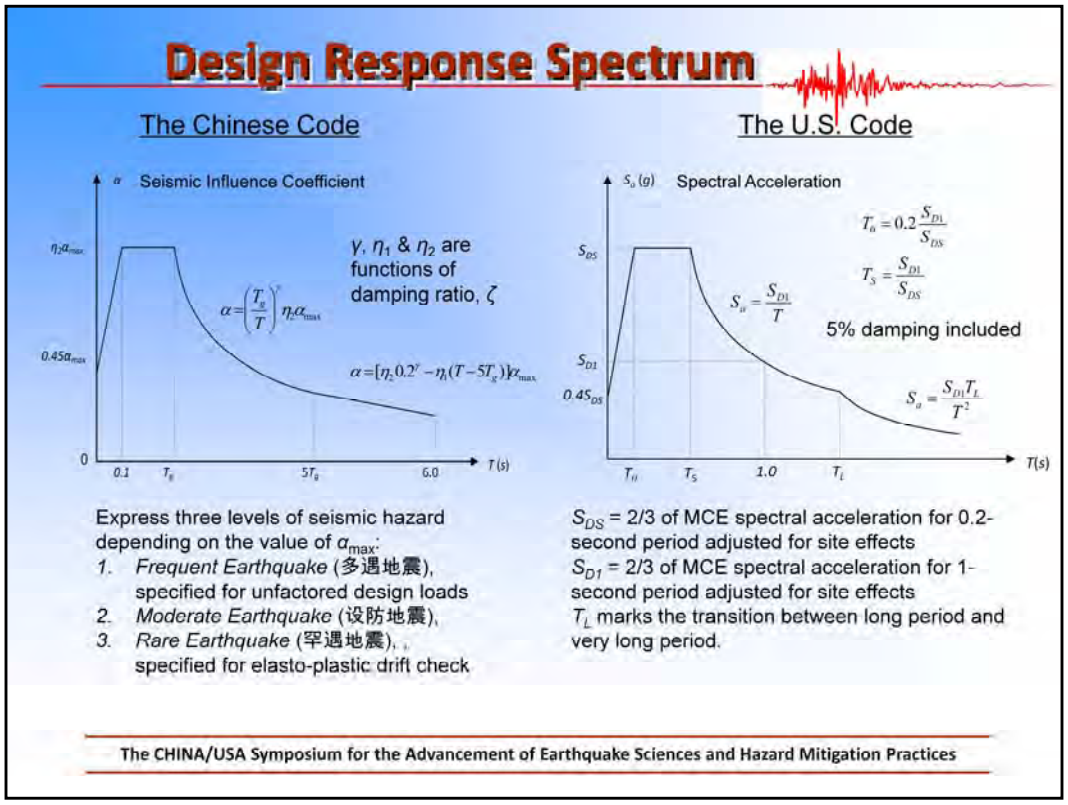
The Chinese Seismic Code is a self-contained document including almost all seismic requirements for building structures. In the U.S., the 2009 IBC references ASCE 7-05 and material-specific codes as seismic design provisions with some amendments or modifications. ASCE 7-05 specifies minimum design loads including seismic loading.



In China, seismic hazards are specified in zoning maps of Peak Ground Acceleration and Characteristic Period of Response Spectrum with *10%* probability of exceedance in 50 years. Instead of directly using the peak ground acceleration (PGA) map, the PGA is used to select the Seismic Intensity which is then used for design purposes.
In U.S., seismic hazards are specified in contour maps of Maximum Considered Earthquake with *2%* probability of exceedance in 50 years. In the latest update (IBC 2012), the risk-targeted maps are based on a 1% probability of collapse in 50 years, which was discussed by Nico Luco.

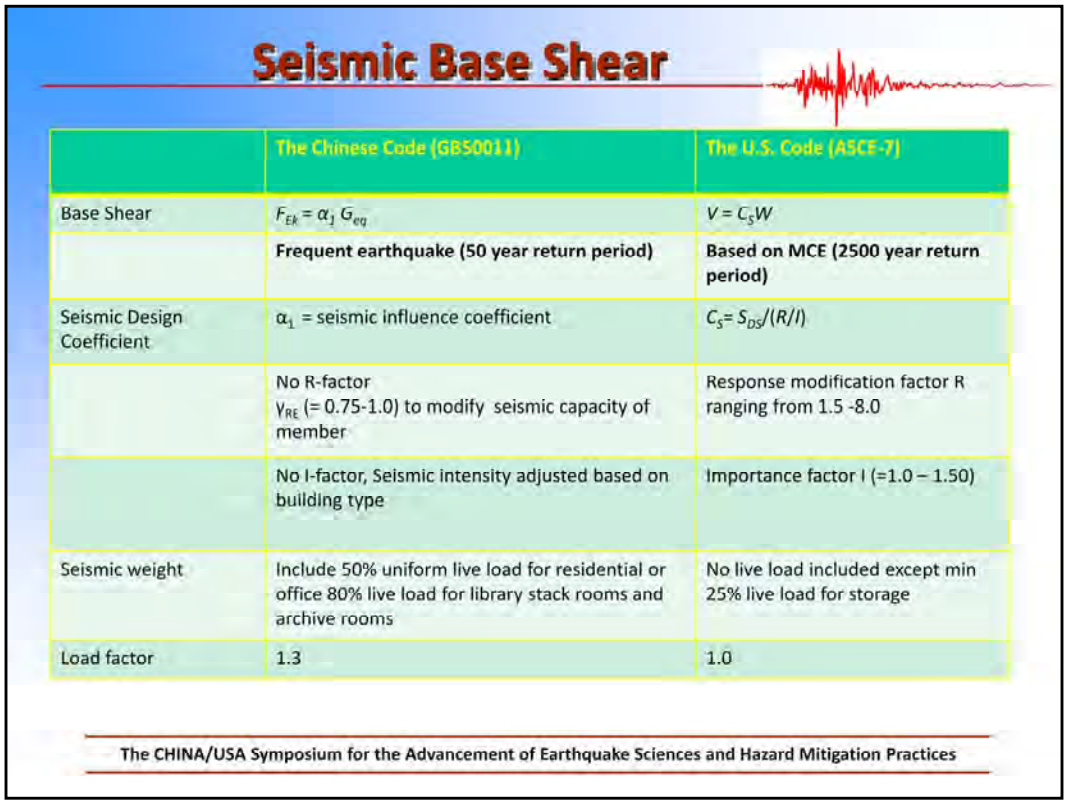


The Chinese Standard for Classification of Seismic Protection of Building Construction GB 50223-2008 classifies building structures as Building Type A to D. Type A is most important and Type D is less important. There is no importance factor in Chinese code. Instead, the seismic design intensity should be adjusted according to the type of building.
The U.S. code classifies buildings and other structures as Occupancy Category from I to IV on the nature of occupancy. Risk increases from Type I to Type IV, and load is increased by the Importance Factor.



The Chinese seismic code specifies the seismic influence coefficient curve which is comparable to a response spectrum. The curve expresses three levels of seismic hazard, frequent earthquake, moderate earthquake and rare earthquake depending on the value of α_{max}. The frequent earthquake spectrum is used for design.

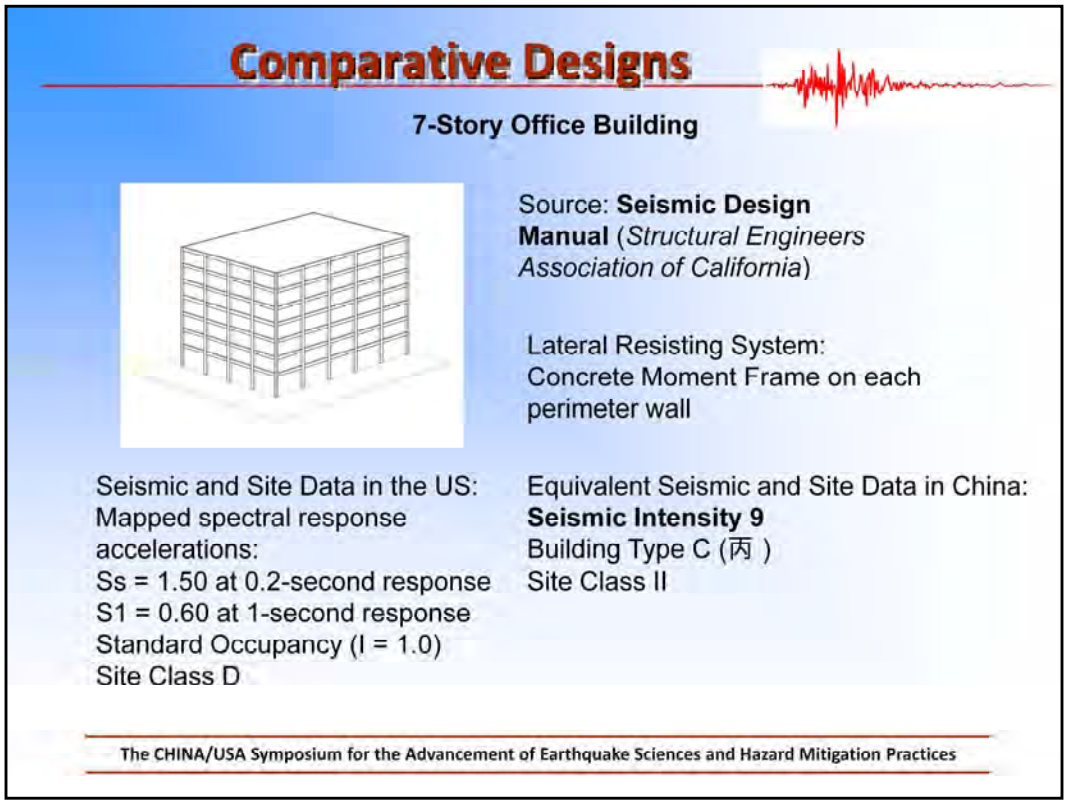
The design response spectrum specified by the IBC is based on the mapped Maximum Considered Earthquake.



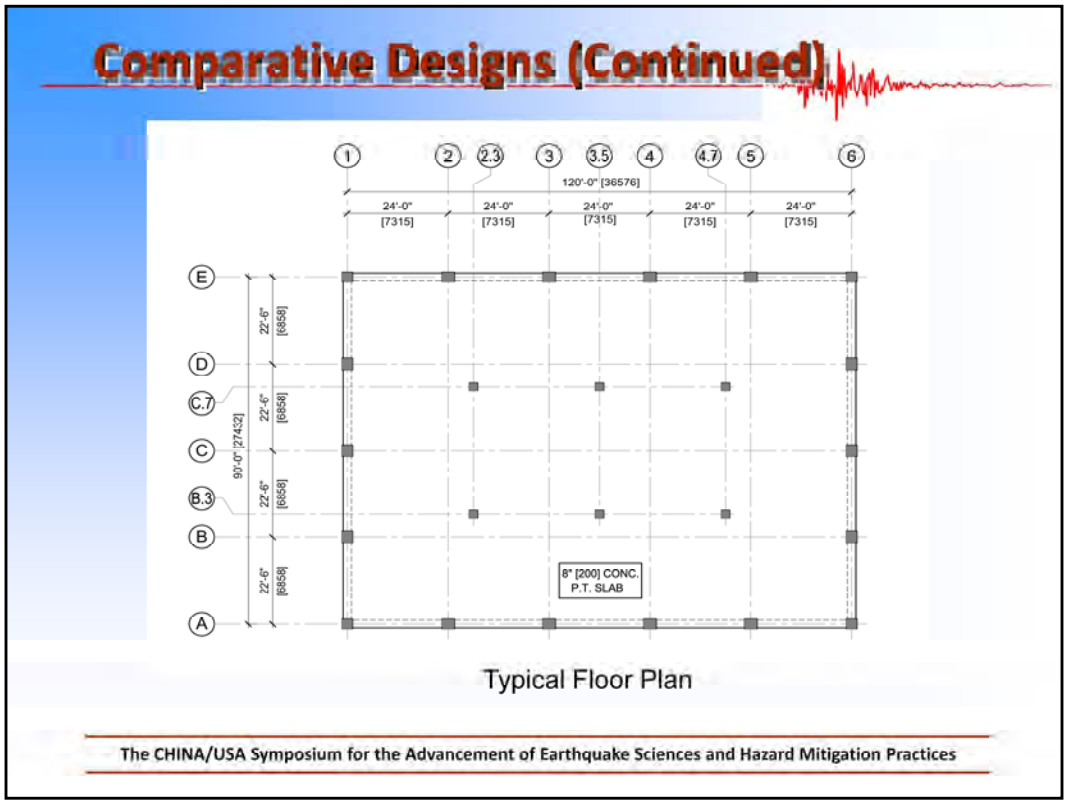
To calculate seismic base shear, both Chinese code and ASCE 7 multiply seismic weight by a factor and use a similar equation. However, there are some essential differences determining the two factors.

There are no R-factor in Chinese code. The R factor in the U.S. code accounts for the inherent ductility and damping of seismic lateral systems. It ranges from 1.5 to 8.0.

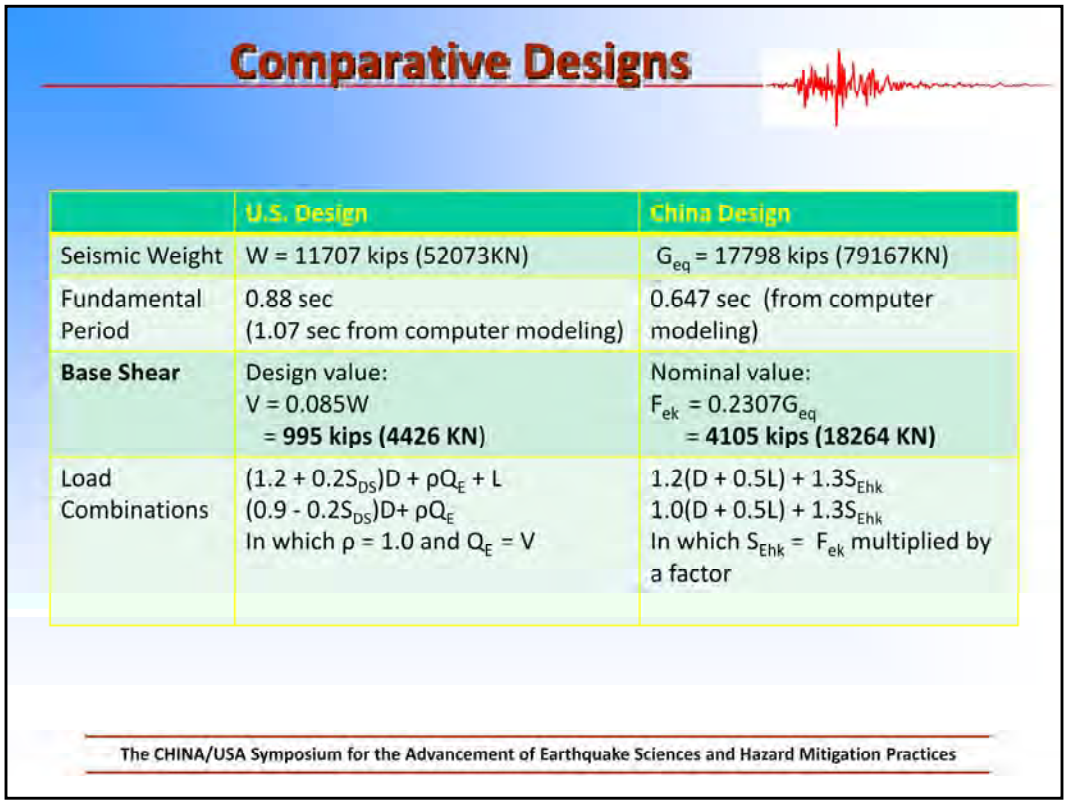
The Chinese seismic code requires that besides dead loads, seismic weight have to include 50% uniform live load for residential or office and 80% live load for library stack rooms and archive rooms. In ASCE 7, no live load is required to be included in seismic weight except min 25% live load for storage occupancies.



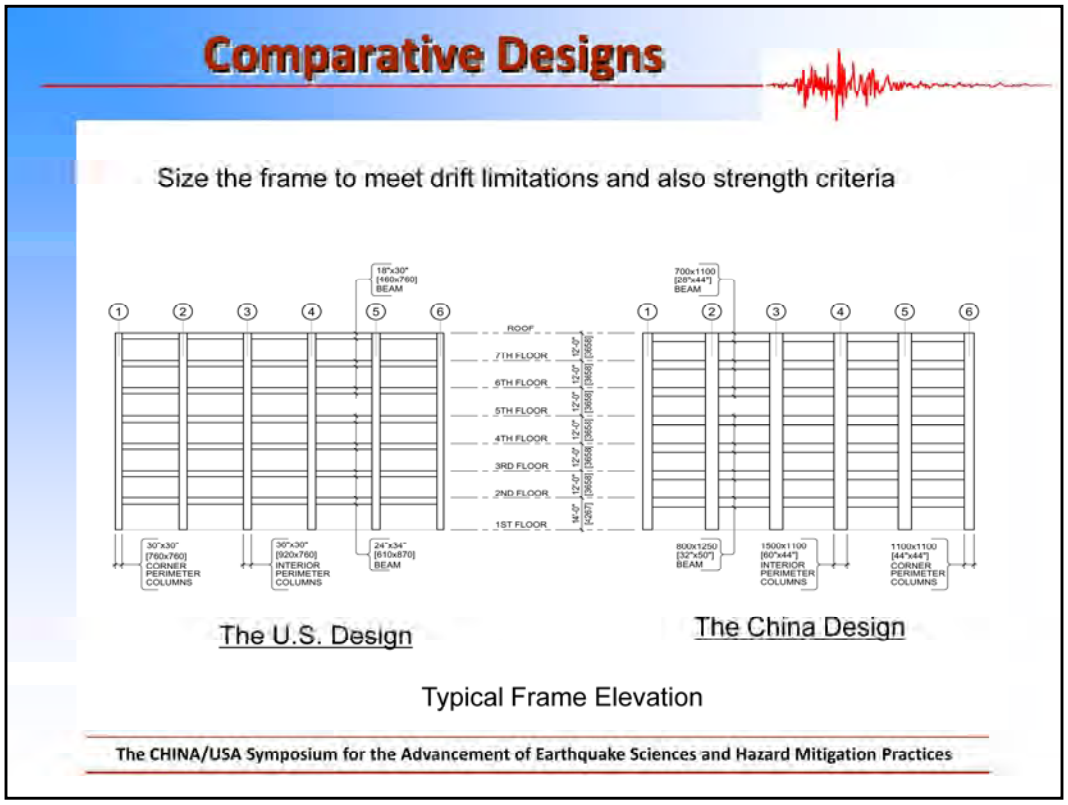
At last, I will present a design example using the IBC and the Chinese seismic code. The example is a 7-story office building selected from the Seismic Design Manual published by the Structural Engineers Association of California. Mapped 0.2-second and 1-second spectral response accelerations are 1.50 and 0.60, respectively and Site Class D are used for the design based on the U.S. code. Equivalently, Seismic Intensity 9 and Site Class II are used in the Chinese design.



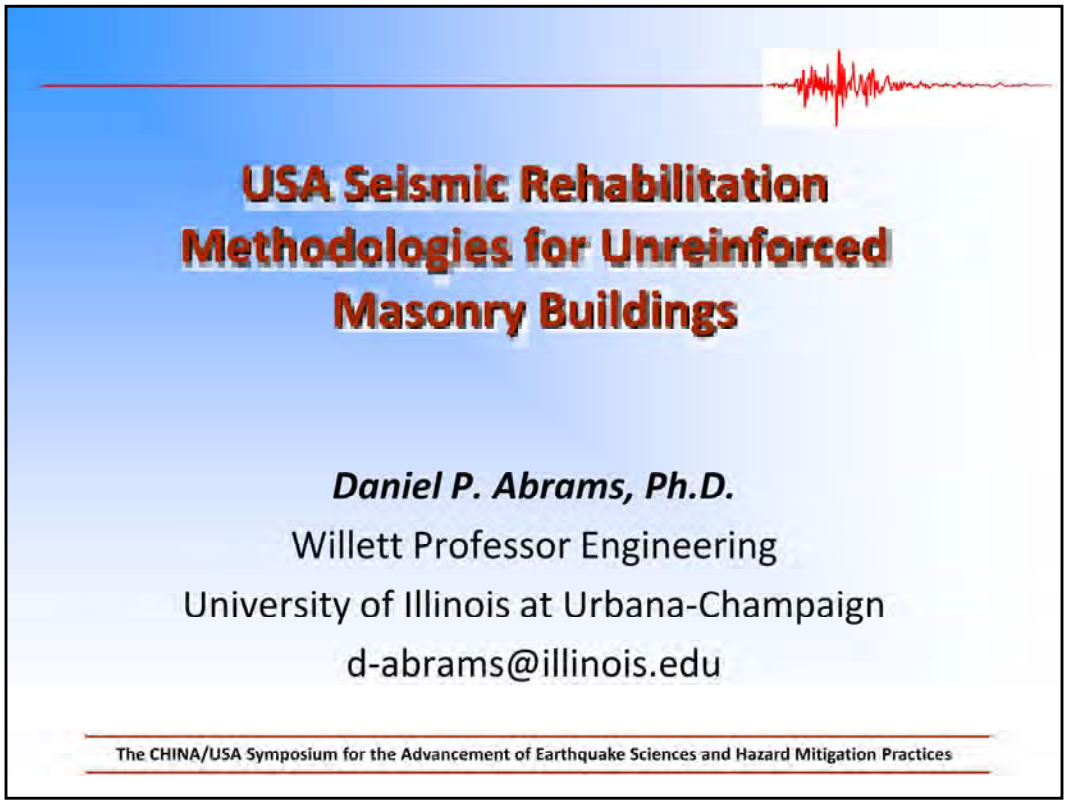
This is typical floor plan. The building has seven stories and has a reinforced concrete moment frame on each perimeter wall. The floor system consists of post-tensioned slabs and girders.



Base shear from the Chinese design is about 3 times greater than that from the U. S. design, and the Chinese lateral deflection limits are lower.

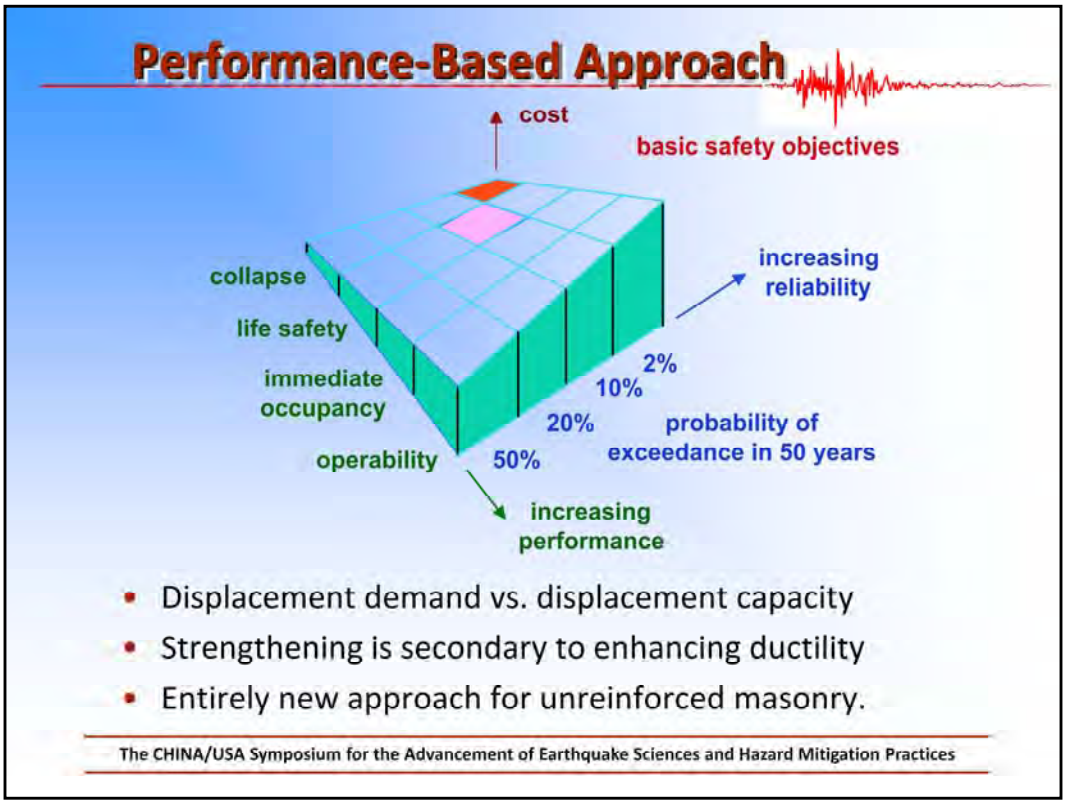


For both U.S. design and Chinese design, the moment frames were sized to meet drift limitations and also strength criteria. It turns out that based on the Chinese seismic code, a stiffer and stronger frame has to be selected.

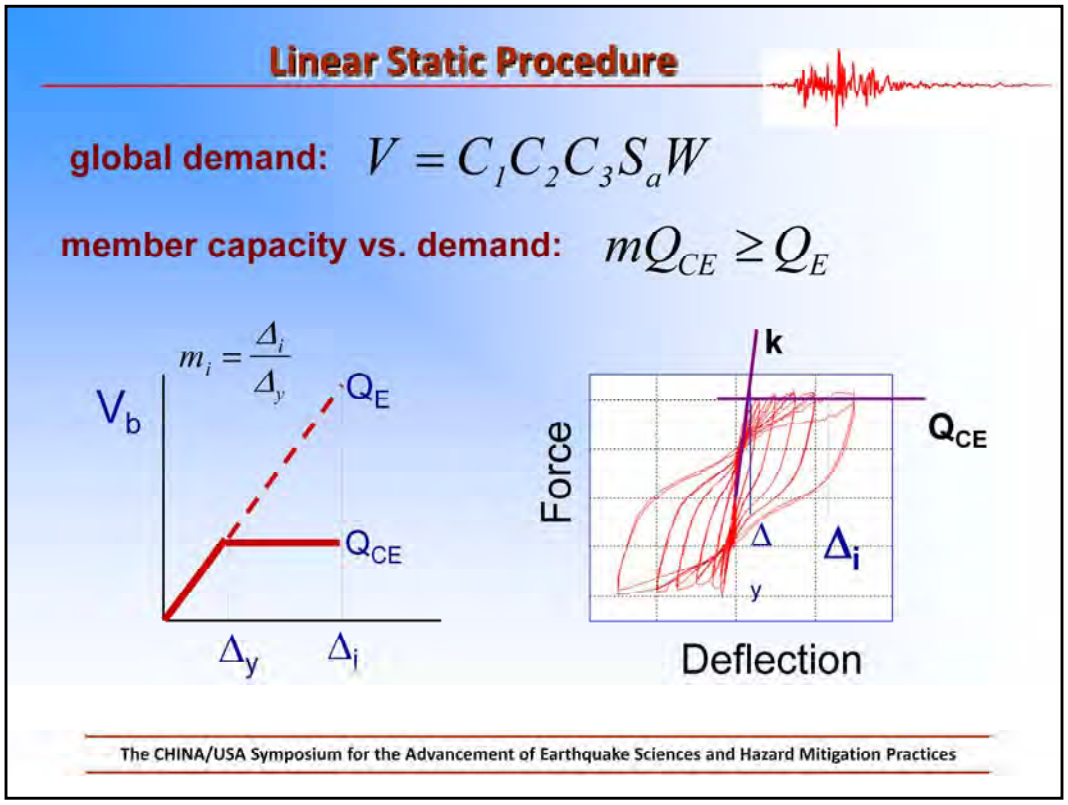


Greetings from the great prairie of Illinois. I am pleased to address you today on advancements in seismic rehabilitation of buildings in the United States, particularly newly issued national guidelines based on performance-based concepts.

The Federal Emergency Management Agency (FEMA) of the United States is very much concerned with mitigation of earthquake losses through rehabilitation of buildings. In 1993, FEMA initiated a project with the Applied Technology Council (ATC) which produced the first set of performance-based guidelines for seismic rehabilitation (FEMA 273). This was followed in 2000 with the publication of a Prestandard document (FEMA 356). The American Society of Civil Engineers (ASCE) published a standard in 2006 (ASCE 41) based on this earlier development which is now the most recent consensus document for seismic rehabilitation of existing buildings.



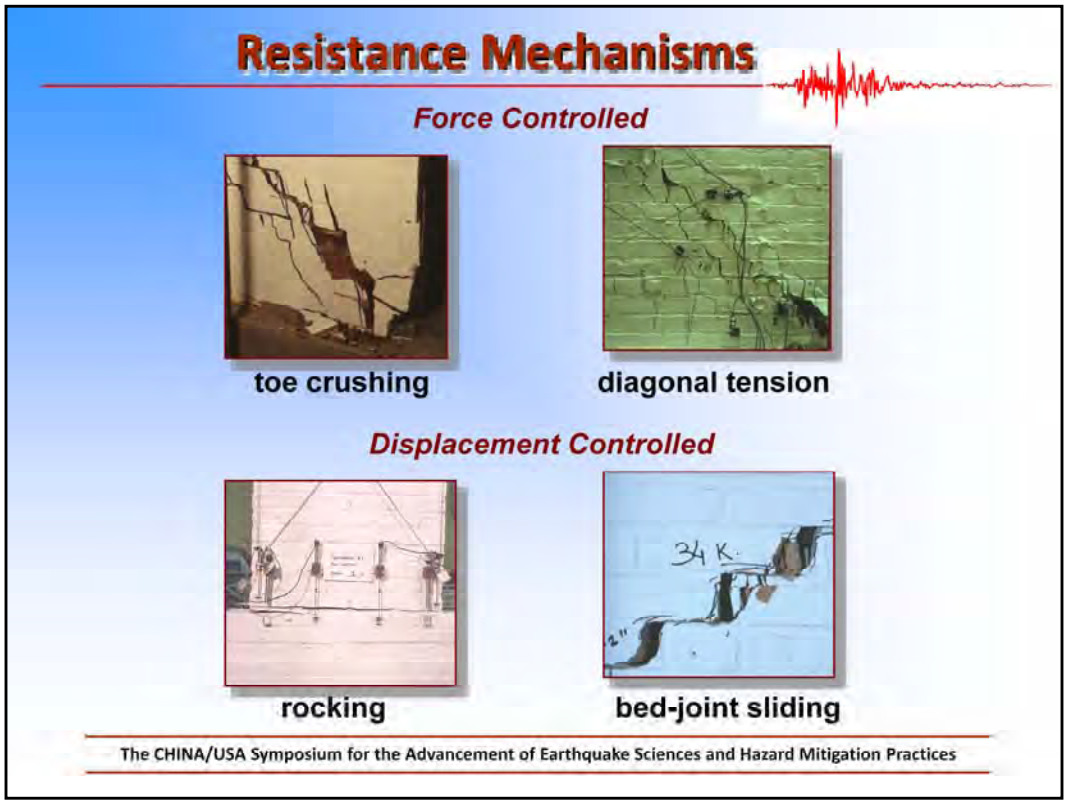
The basic premise of performance-based rehabilitation is that a building can be modified to result in various levels of performance for various earthquake intensities. Rehabilitation is not mandated based on life-safety concerns as is done with other building codes, but rather a building owner can select the levels of performance (continued operation, immediate occupancy, life safety or collapse prevention) they so desire and can afford. Thus essential facilities can be rehabilitated to remain operable for even large earthquakes whereas more common construction (residential, office, etc.) can be selectively rehabilitated to incur more damage for large earthquakes while suffering little damage for more frequent earthquakes. This approach permits risk reduction to be done in a much more systematic manner than in the past.



ASCE 41 prescribes four basic methods for estimating seismic displacements of a building. These include static as well as dynamic analyses, and modeling the system either as a linearly or nonlinearly behaving oscillator.

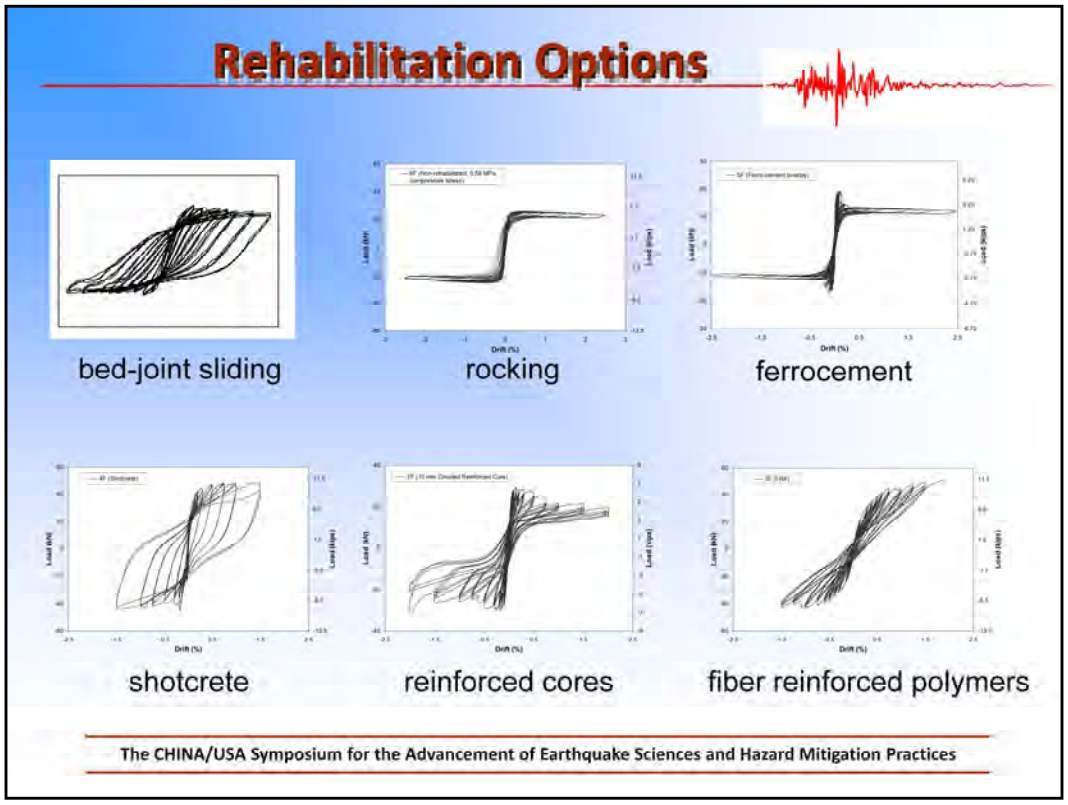
The simplest method is the linear static procedure depicted here. Demand forces are estimated based on spectral accelerations read from national hazard maps and other coefficients depending on period of vibration, damage, stability and damping. Demand displacements for individual members are then determined by applying these global demand forces to a structural system using a linear model. Member displacement capacities are compared with these demands assuming that nonlinear and linear behaving members reach the same displacements. As a result, force capacities are multiplied by a ductility factor, m, to compare with demand forces.

Thus, the deformation capacity of an individual beam, column or wall is of primary importance and is explicitly considered.



Unreinforced masonry walls or piers have traditionally been considered as brittle elements, however, research has shown that two behavior modes can posses substantial displacement capacity. Rocking and bed-joint sliding can result in nonlinear displacements many times that at first cracking. Thus, the "m" factor for these displacement controlled actions can exceed 3 or 4. This is contrasted with actions that are force-controlled such as toe crushing or diagonal tension where brittle failures occur when cracks are developed.

It is best to develop a rehabilitation scheme that will promote displacement-based actions and demote force-based actions. For example, gravity stress on a pier should be decreased so that the pier will rock rather than crush at the toe. Or, weaker mortars and stronger masonry units are preferable so that bricks will slide along mortar joints and thus develop frictional resistance at large displacements. Adding strength without increasing deformation capacity is not an effective way to mitigate damage.

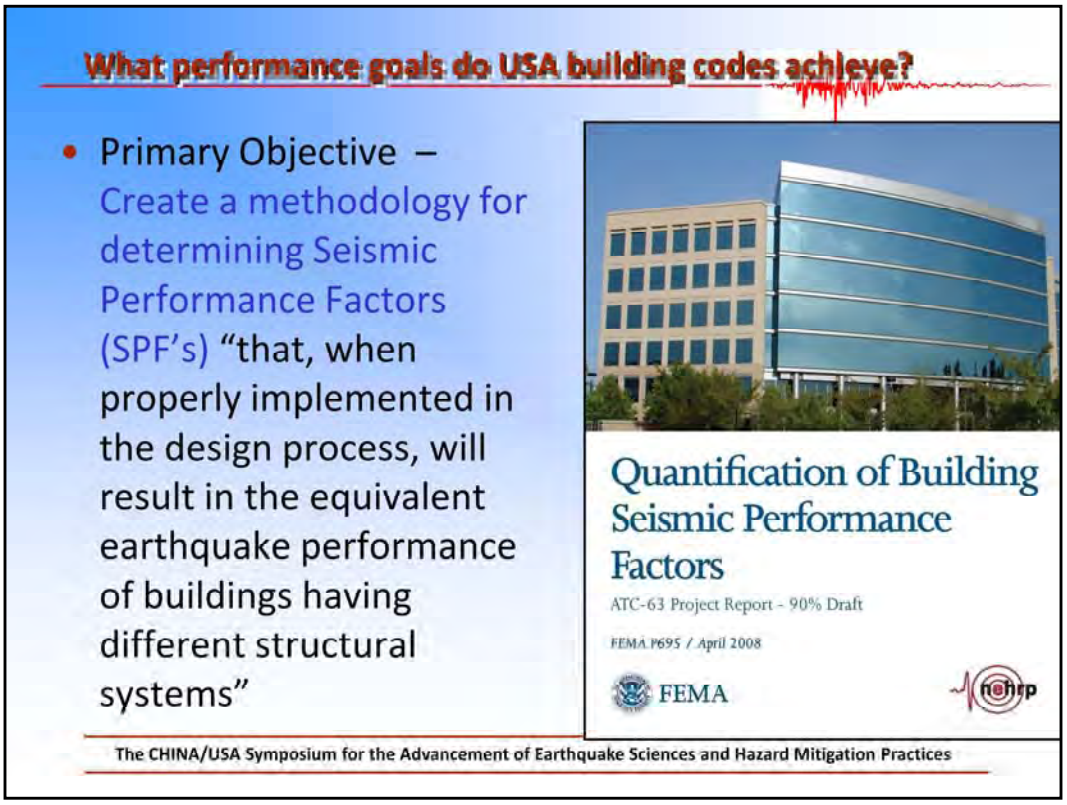


Testing of unreinforced brick masonry piers has been done at the University of Illinois to assess the relative effectiveness of various rehabilitation options. Measured force-deflection relations are shown in this slide for piers that were strengthened with: (a) a ferrocement plaster overlay, (b) sprayed on concrete over reinforcing bars, (c) vertical reinforcement grouted within cores that were drilled through the height of a pier and (d) fiber reinforced polymer (FRP) strips that were adhered to the surface of a brick pier. Resulting behavior of piers strengthened with each of these methods was not necessarily improved over the basic rocking or sliding behavior seen with non-rehabilitated piers. Displacement capacity was usually better without rehabilitation.

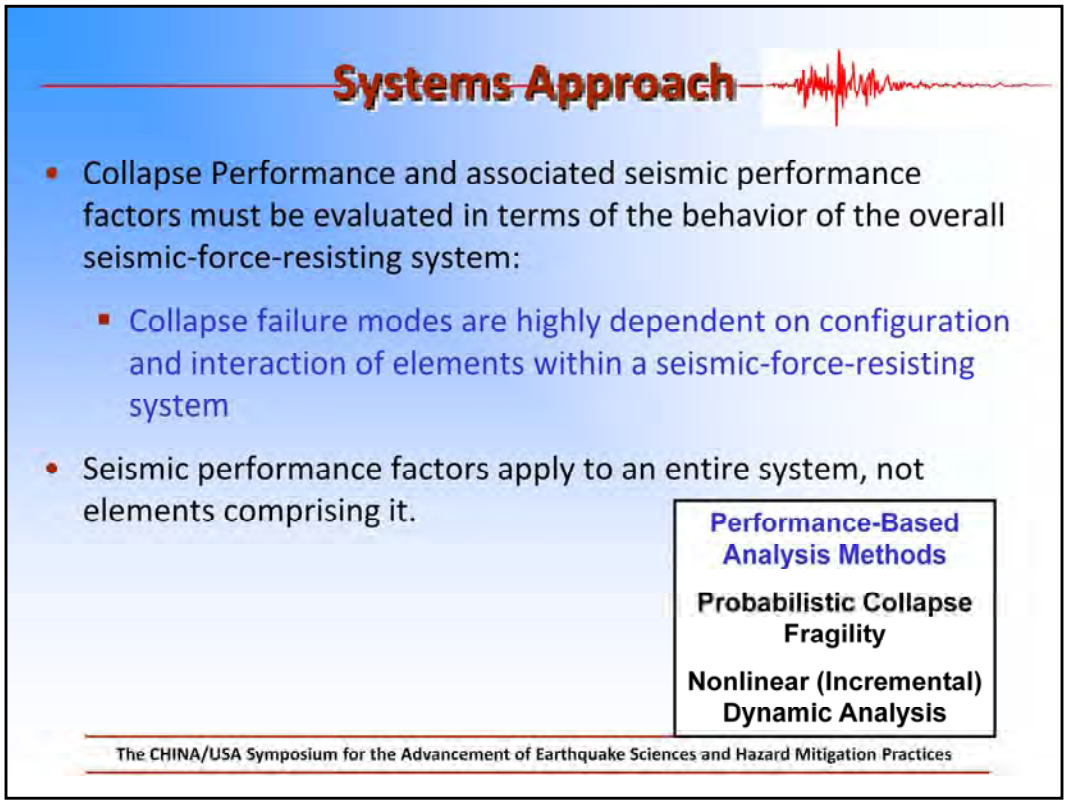
More research is needed to identify displacement capacity for unreinforced masonry walls or piers and to evaluate seismic response of masonry structural systems rehabilitated with these new concepts. Sharing of these engineering aspects between the USA and PRC can yield significant advancements in the mitigation of earthquake hazards in both countries.

Thank you for your attention. I look forward to discussing these ideas with you and to possible collaboration in the future.

I will now give a summary of a technique developed to determine the seismic reliability of various types of structural systems. This presentation is on behalf of Jim Harris and Charlie Kircher. Those who wish to have details should read the paper by Jim Harris, and you may contact Project Technical Director Charles Kircher at CAkircher@aol.com.

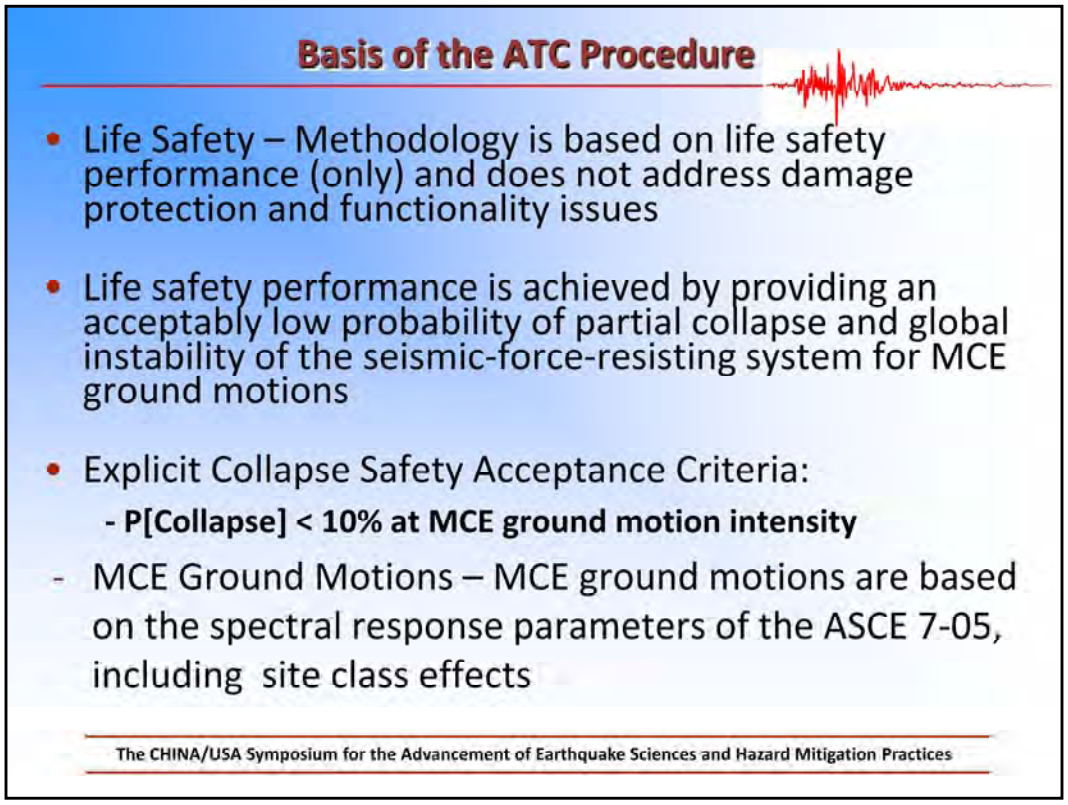


The primary objective of this technique is to quantitatively evaluate the seismic performance reliabilities of structural systems, so that the specified design Seismic Performance Factors could be calibrated to provide an uniform target reliability.



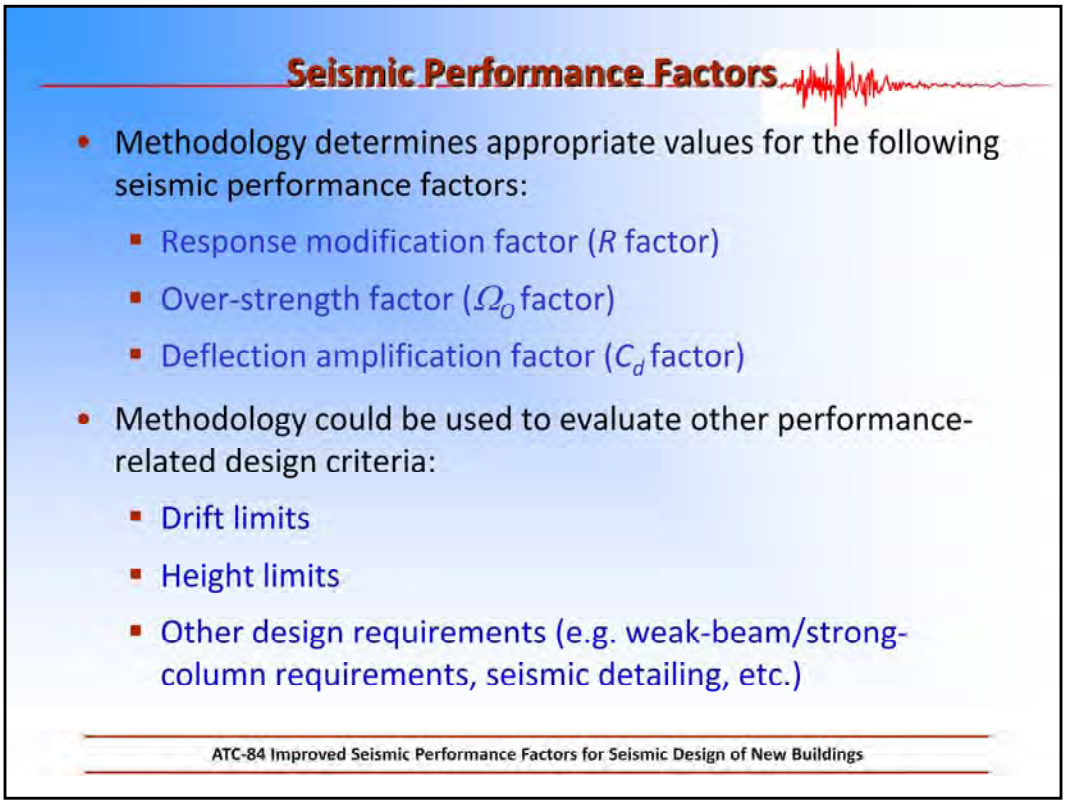
Due to the high demand exerted by earthquakes, the earthquake limit state is based on inelastic system performance rather than member limit state performance, with energy dissipation throughout many cycles of inelastic strain necessary for adequate performance.

A series of archetype models of the structural system are developed, which reflect the range of configurations and seismic behavioral aspects of the system. This requires defining an idealized model that reflects salient design features that affect the collapse response of the structural system.

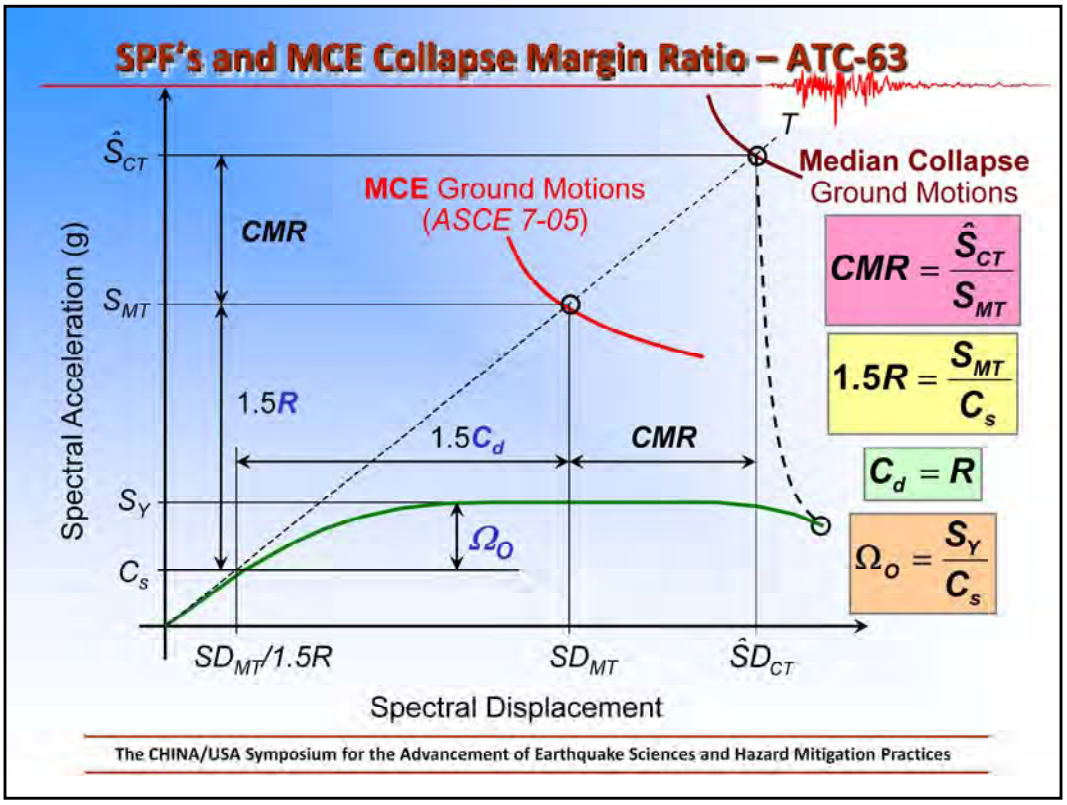


In general, collapse of a structure would lead to very different numbers of fatalities, depending on the structural system type, the number of building occupants, etc. However, life safety risk is both difficult to calculate accurately, due to uncertainty in casualty rates given collapse, and even greater uncertainty in assessing the effects of falling hazards in the absence of collapse.

Rather than attempting to provide uniform protection of “life safety”, the Methodology provides approximate uniform protection against collapse of the structural system during the Maximum Considered Earthquake. The criteria is **P[Collapse] < 10%** ***at the MCE ground motion intensity***.



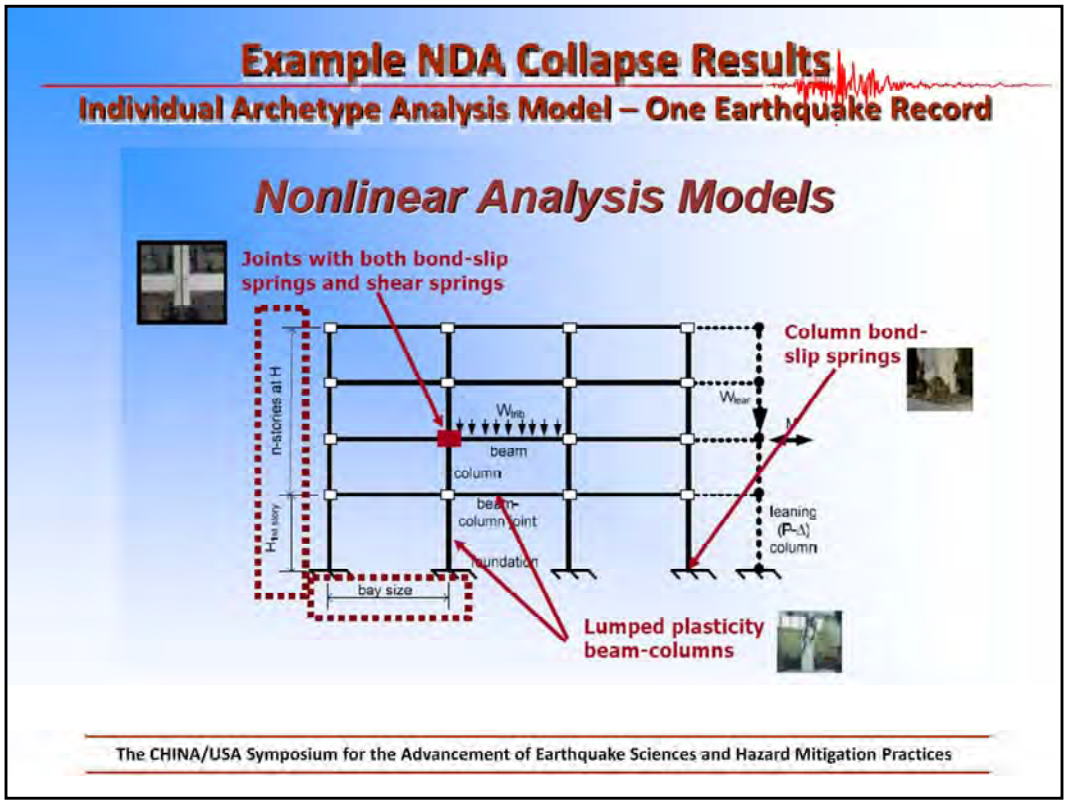
The Methodology determines the response modification coefficient **(*R factor)*** and evaluates system over-strength (Ω factor) using nonlinear models of seismic force-resisting system "archetypes." *The* Methodology could be used to evaluate other performance-related design criteria as well.



System Seismic Performance Factors (SPF's) include the response modification coefficient (*R factor), the system over-strength factor (Ω_O factor) and the deflection amplification factor (C_d factor), values of which are given in ASCE 7 for seismic force-resisting systems.*

As illustrated in the figure, the R factor is the ratio of the forces that would be developed for design earthquake ground motions if the structure remained entirely linearly elastic to those forces prescribed for design.

The collapse margin ratio, *CMR,* is defined as the ratio of the median spectral acceleration (of collapse level ground motions to the spectral acceleration of MCE ground motions at the fundamental period of the seismic force-resisting system.



For each archetypical model, nonlinear static (pushover) analysis is initially performed to establish the Ω factor, based on the ratio of normalized strength, S^{max}, to the seismic response coefficient, C^s, used for archetype design.

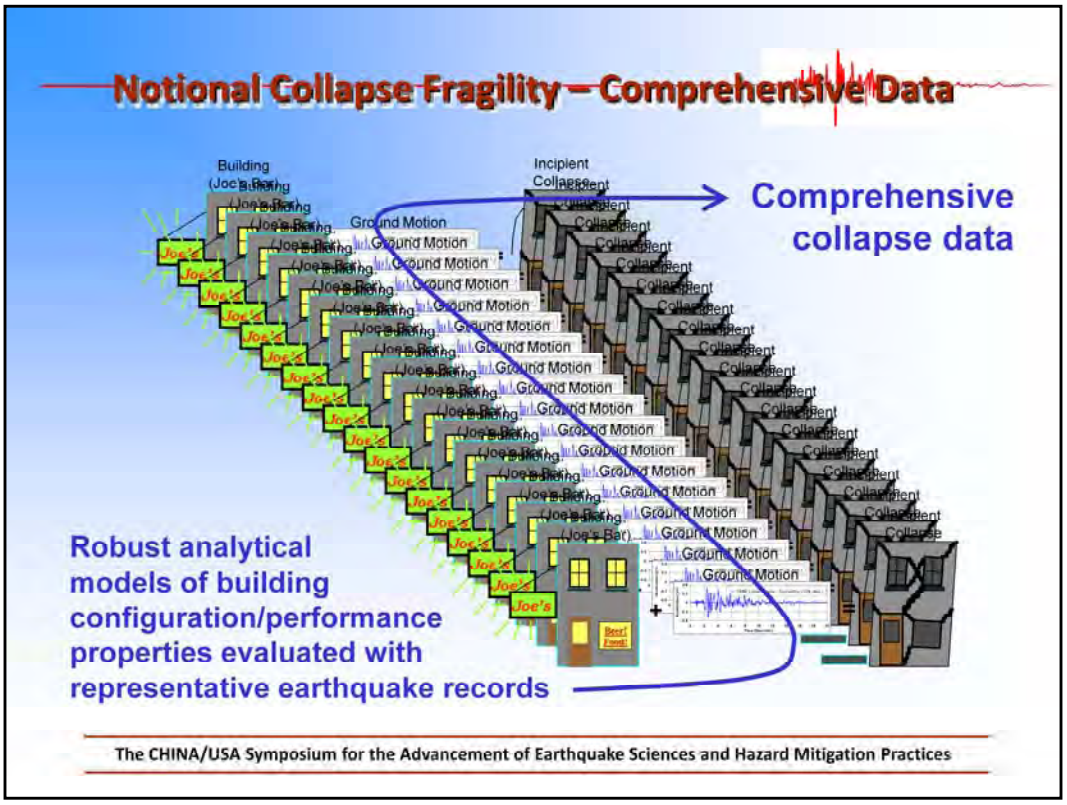
The collapse assessment is done using nonlinear time history analysis, a key aspect of which are

models that capture strength and stiffness degradation at large deformations. Collapse modes can

generally be distinguished between sidesway and vertical collapse.

Sidesway collapse occurs when the lateral strength and stiffness become insufficient to resist destabilizing P-Δ effects, resulting in large interstory drifts.

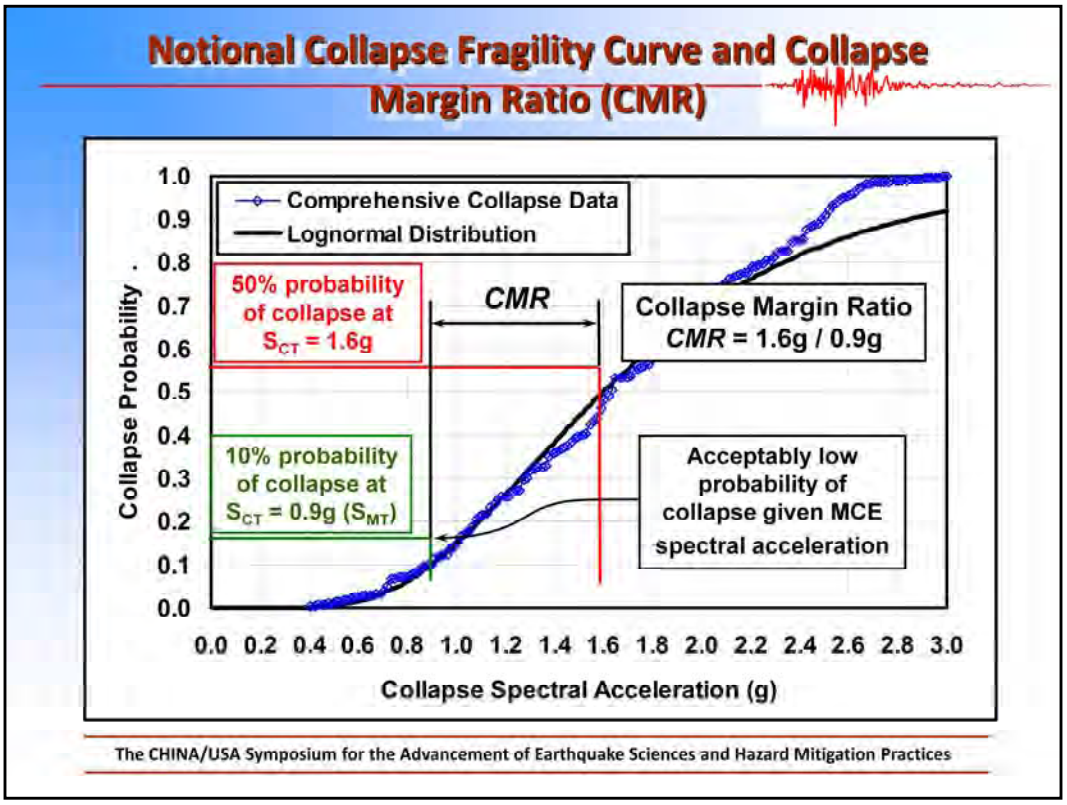
Vertical collapse can arise due to loss in vertical load carrying capacity of one or more components in the structure, such as punching failure at a slab-column joint or loss in axial capacity of a column.



The Methodology requires nonlinear analysis of a sufficient number of archetype models (with different design, heights, etc.) to broadly represent the system of interest.

In the limit, if we could evaluate all possible variations of each type of seismic force-resisting system for all possible earthquake records, then we would have a large set of collapse data that could be plotted to represent the collapse "fragility" curve of the system. Therefore, we use incremental dynamic analysis to evaluate nonlinear models of the system of interest for a large set existing earthquake records. Incremental Dynamic Analysis (IDA) is a technique to systematically process the effects of increasing earthquake ground motion intensity on structural response up to collapse.

Nonlinear dynamic analysis then establishes the collapse margin ratio using a suite for ground motion records scaled incrementally until median collapse is determined (50% of the records induce collapse of the archetypical model).



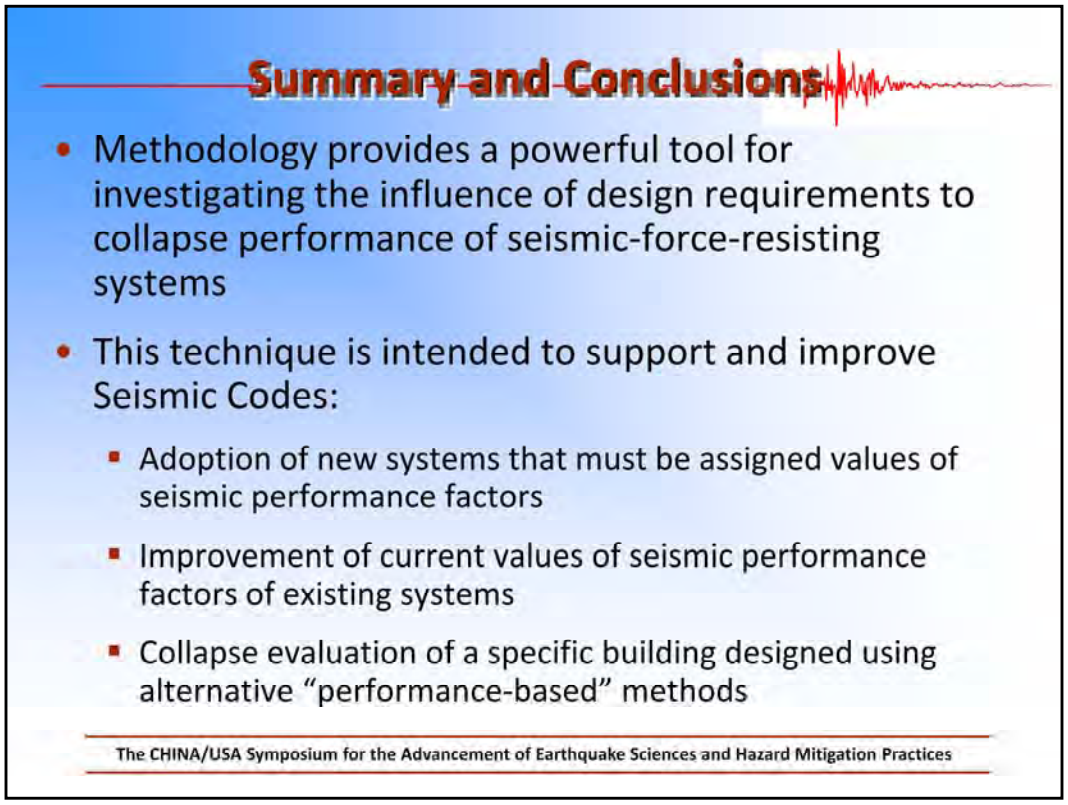
Using collapse data obtained from dynamic analysis results, a collapse fragility is defined through a cumulative distribution function, which relates the ground motion intensity to the

probability of collapse.

The collapse margin ratio (CMR), is the fundamental concept underlying the methodology. It essentially

measures the factor of safety (margin) against collapse. The sufficient "margin' is a CMR (Collapse Margin Ratio) = [Median value (at 50% probability of collapse)]/[MCE value (at 10% probability)] that is large enough such that the probability of collapse given (the very rare) MCE ground motions is not more than 10%, on average.

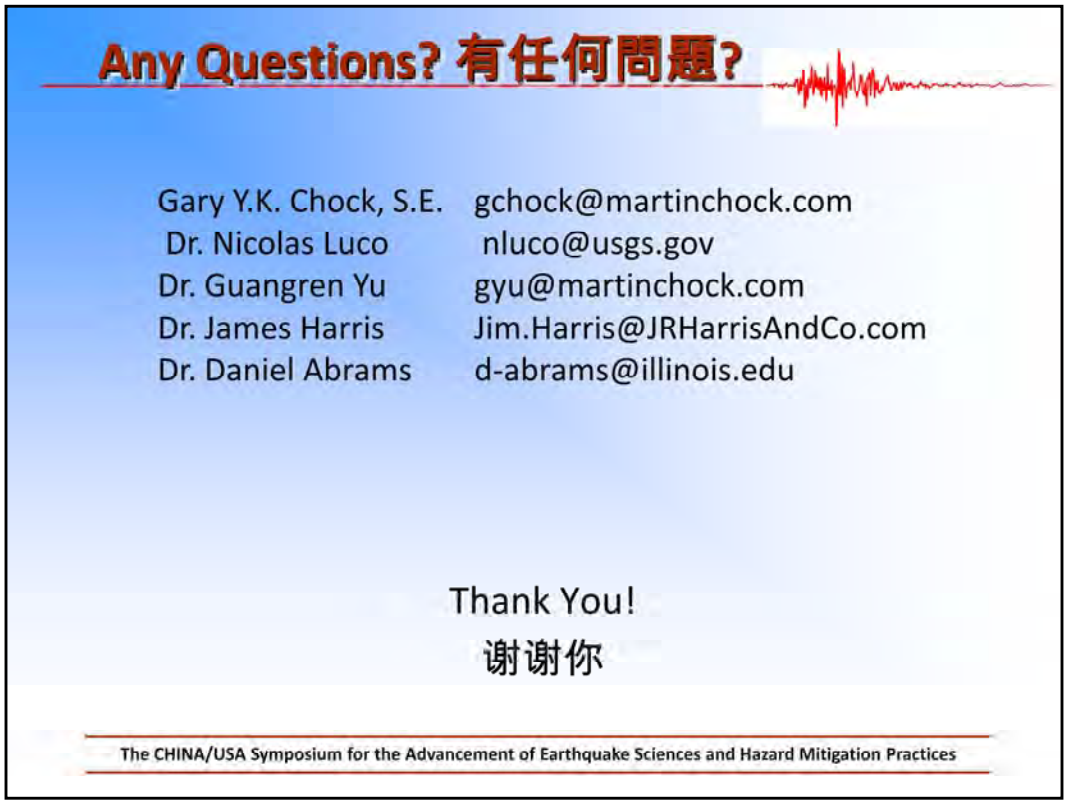
The calculated value of the collapse margin ratio is compared with acceptable values of the collapse margin ratio that reflect collapse uncertainty. If the calculated collapse margin is large enough to meet life-safety objectives, then the trial value of R factor used for design of the archetype is acceptable. If not, a new (lower) trial value of the R factor must be re-evaluated by the Methodology.



The Methodology is recommended for use with model building codes and resource documents to set minimum acceptable design criteria for standard code-approved seismic-force-resisting systems. The Methodology provides approximate uniform protection against collapse of the structural system.

It also provides a basis for evaluation of current code-approved systems for their ability to achieve intended seismic performance objectives.

It is possible that results of future work based on this Methodology could be used to modify or eliminate those systems or requirements that cannot reliably meet these objectives.



Thank you for your attention. Please let us answer any questions that you may have now.

We invite you to read our detailed papers in the Proceedings on the topics discussed today. If you have questions later after reading the papers, please contact us by email.

Overview of Current USA Seismic Design Provisions for New Construction

***Gary Y.K. Chock, S.E.*[1]**

Introductory Discussion

An explicit objective of the USA seismic provisions is establishing a uniform level of risk across the country for similar occupancies, such that life safety protection is achieved with uniform reliability. This effort is guided and fostered by the National Earthquake Hazards Reduction Program (NEHRP) research "roadmap" of focus areas for developing improved seismic design methodologies. Achievement of the strategic improvements is made through a consensus-building process involving public agencies, structural engineers, academic institutions, and construction and material industry associations. The Building Seismic Safety Council of the National Institute of Building Sciences evaluates state-of-the-art research and develops this into Recommended Seismic Provisions for New Buildings and Other Structures.

Current mandatory USA seismic design provisions for building and other structures are given in American Society of Civil Engineers Standard 7, Minimum Design Loads for Buildings and Other Structures (ASCE-7). These requirements are enacted through the adoption of the International Building Code (IBC) by federal agencies, state governments, and local jurisdictions. The IBC has become the national model building code for the USA, and it primarily references the ASCE 7 Standard for seismic design requirements.

Primary Intent

The primary intent of USA seismic design codes is to prevent serious injury and loss life from severe earthquake ground shaking. Since earthquake injuries and fatalities are mostly caused by structural collapse, the code intends to provide a margin of resistance against collapse sufficient to also achieve building performance that will maintain a life safety level of protection. For critical facilities with continuity of operations requirements or with the potential of large scale loss of life or hazardous material storage, seismic provisions are upgraded when triggered by their Risk Category designation, to avoid loss of function during severe earthquakes.

The severity of earthquake initially considered is the Maximum Considered Earthquake ground motion for the building site, associated with an estimated hazard level of 2 percent chance of exceedance in a 50-year period, i.e., a 2,500-year mean recurrence interval event. Consideration of (i) deterministic ground motion values in certain higher seismic regions such as California near active faults where the deterministic limits of the local seismic source govern and (ii) risk coefficients that account for variability in the shape of the regional ground motion hazard curves, leads to a transformation of the uniform-hazard values into "uniform-risk" ground motions that explicitly target a specified level of collapse risk: a 1% probability of collapse in 50 years.

Falling nonstructural components also cause casualties during earthquakes, and the predominant economic value of a building is invested in its nonstructural components and contents, so the code includes provisions for the bracing and anchorage of items such as ceiling systems, lighting, piping, mechanical and electrical equipment, and cladding.

USA Code Development

Research and development work on earthquake science and engineering is mostly conducted under the National Earthquake Hazards Reduction Program (NEHRP), which involves the Federal Emergency Management Agency (FEMA), National Institute of Standards and Technology (NIST), United States Geological Survey (USGS), the National Science Foundation (NSF) - Directorates for Geosciences and for Engineering, and the Building Seismic Safety Council (BSSC) of the National Institute of Building Sciences (NIBS). NEHRP's overarching goal is implement hazard mitigation measures to ultimately reduce losses

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from earthquakes. It does this through the research and development of improved technology that can ultimately be utilized in building codes and standards. BSSC plays a technical role in master planning, evaluating, coordinating, and transferring state-of-the-art research information into design guidance that is expected to be relevant to future updates of the ASCE 7 seismic provisions. Although NIBS is funded by Congress, BSSC is not an agency of the USA federal government and is primarily comprised of volunteer organizations with expertise in earthquake engineering. Sponsored by FEMA, one of BSSC's major contributions is the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures. The current version of these provisions is the 2009 edition.

In addition to public sector-sponsored research, the material standards association and contractor organizations sponsor much research and development on focus areas of seismic-force-resisting system performance. These organizations have sponsored research and testing initiatives to develop and validate design methodologies for innovative types of seismic-force-resisting systems. In order for new structural systems to become listed in the NEHRP provisions as a permitted type of system, research documentation must be submitted to BSSC. This research has become essential for industry associations because new types of lateral-force-resisting systems are not approvable by building officials unless they appear in the permitted list of seismic-force-resisting systems in the ASCE 7 Standard, which is based in large part on the NEHRP provisions.

Examples include recent work on hybrid precast wall systems and composite shear walls for seismic regions. The American Institute of Steel Construction Committee on Research has sponsored work into steel braced frames, steel eccentric braced frames, steel moment-resisting frame connections, and new "reserve capacity" design methodologies for moderate seismic regions. The Masonry Society Council for Masonry Research has been promoting work on masonry shear wall behavior, performance-based masonry design, vertically post-tensioned masonry shear wall systems, and the cyclic behavior of hybrid masonry infill wall frame systems. The American Iron and Steel Institute's Steel Framing Alliance has sponsored work on cold-formed steel frame shear walls with a variety of sheathing materials and bracing techniques.

The ASCE Codes and Standards Activities Division is responsible for developing the final design standards under rules and procedures for consensus-based standards accredited by the American National Standards Institute. Only when developed in accordance with definitive rules of procedure and consensus does a standard obtain the necessary stature for regulatory use in building codes. The essence of consensus decision making is the recognition that all members of a standards committee with balanced representation of stakeholders are equal in their standing. As a result, the committee arrives at decisions that reflect the input from all the members, not just the majority. It is important to be clear that it arrives at a unity of opinion rather than a unanimous opinion, and that all comments are resolved and documented. The standards committee must also consider and address proposals from the public, typically at this stage of code development from other engineers or material industry representatives.

The technical work of developing and maintaining the ASCE standards for design methodologies is accomplished through committees that are typically comprised of 1/3 academic, 1/3 professional engineers with relevant expertise, and 1/3 technical representatives from industry and material associations who are usually also engineers. Consensus on an item requires that 2/3rd's of Committee must return ballots on any item, and that 75% of the submitted ballots must vote to affirm. The ASCE CSAD has a seismic subcommittee of more than 50 members that prepares technical provisions for consideration by the ASCE 7 main committee of about 50 members. Each operates under accredited consensus rules. The ASCE 7 Standard Minimum Design Loads for Buildings and Other Structures becomes an enacted law through adoption of a building code that references it. The current version of the Standard is the 2010 edition. It will be updated every 5 years.

In the United States, the national model building code is the International Building Code, promulgated by the International Code Council, a nonprofit corporation that develops and maintains a set of national model building codes for federal, state, and local jurisdiction government use in the administration of building regulations. The IBC contains administrative provisions and language that makes them enforceable by building officials, and the IBC incorporates consensus standards by reference to a great degree. It also makes

further seismic amendments to the material specific standards and includes additional geotechnical investigation requirements for seismic site classification, foundation, and construction quality assurance testing and inspection requirements. IBC Chapter 34 also contains seismic requirements for existing buildings undergoing additions, alterations, or repairs.

The current version of the IBC is the 2009 edition. The International Building Code is updated every 3 years through an open process where code change proposals from any party must be considered in the decision-making. The ICC Structural Committee makes initial evaluations about technical proposals in a public code development hearing. The results of the code development hearing affects the discussion/voting process utilized for each proposal in the final action hearing and balloting by ICC members. The public may also make formal comments on the results of the code development hearing. The ICC voting members that make final approval or disapproval are comprised of governmental building officials nation-wide with numbers based on the population of the jurisdiction. As building codes and design standards evolve, material specifications, methodologies, and procedures given in the ASTM International set of standards are updated or created to remain consistent with advancing technology. Figure 1 provides an overall diagram of the USA seismic code development process.

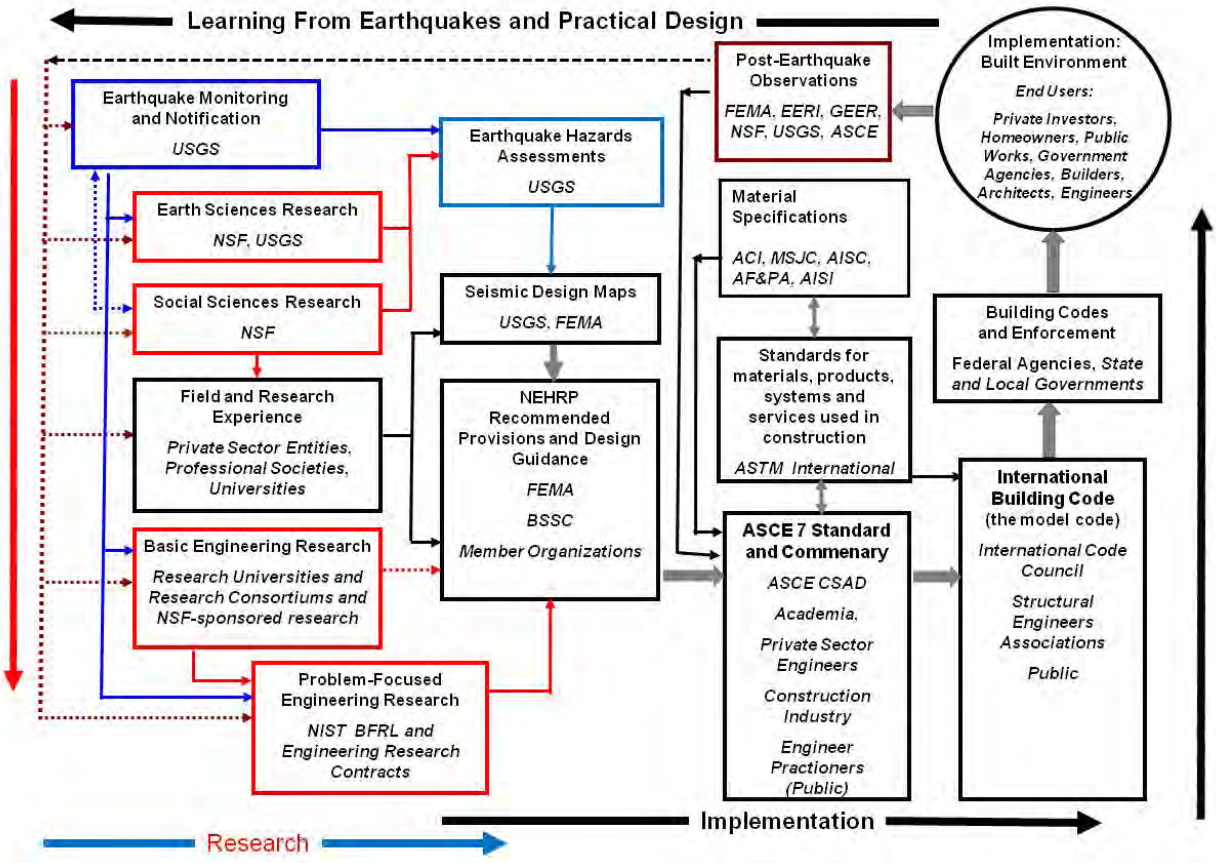

Figure 1 The Relationship Between Research, Post-Earthquake Reconnaissance, and the USA Seismic Code Development Process

Application to USA seismic design practice thus requires at a minimum the use of the International Building Code, the ASCE 7 Standard, and the material specific standards (See Table 1). With this series of codes and standards, a comprehensive range of seismic design requirements exist for all structural systems and major nonstructural components, essentially applicable throughout the country. Other specialized seismic provisions such as non-building structures, prescriptive codes and standards for one- and two-family dwellings, and the seismic evaluation and rehabilitation of existing buildings are not examined in this paper.

Seismic Design Requirement	Standard
Seismic Loads, including regional seismicity, site characteristics, building occupancy, structural system, and nonstructural components	ASCE 7-2010 Minimum Design Loads for Buildings and Other Structures
Aluminum	ADM1-05 Aluminum Design Manual:
Concrete	American Concrete Institute, ACI 318-08 Building Code Requirements for Structural Concrete
Masonry	Masonry Standards Joint Committee, ACI 530-08/ASCE 5-08/TMS 402-08 Building Code Requirements for Masonry Structures
Structural Steel	American Institute of Steel Construction, AISC 341-05 Seismic Provisions for Structural Steel Buildings, including Supplement No. 1 (2006). American Welding Society, AWS D1.1 Structural Welding Code (2008)
Light-Gage Cold-Formed Steel	American Iron and Steel Institute, AISI S213-07 North American Standard for Cold-formed Steel Framing—Lateral Design.
Cold-Formed Steel Special Bolted Moment Frames	AISI S110-07 Standard for Seismic Design of Cold-Formed Steel Structural Systems--Special Bolted Moment Frames, including Supplement No. 1 (2009)
Wood	American Forest & Paper Association, AF&PA SDPWS-2008 - Special Design Provisions for Wind and Seismic Standard with Commentary
Bracing and Anchorage of Nonstructural Components	ASCE-7-2010, Chapter 13 Seismic Design for Nonstructural Components National Fire Protection Association NFPA 13,-2007, Standard for the Installation of Sprinkler Systems ASTM International ASTM E 580-09, Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions American Society of Mechanical Engineers ASME A17.1-05, Safety Code for Elevators and Escalators ASME B31E Standard for the Seismic Design and Retrofit of Above-Ground Piping Systems ASME Boiler and Pressure Vessel Code Sheet Metal and Air Conditioning Contractors National Association, ANSI/SMACNA 001-008, Seismic Restraint Manual: Guidelines for Mechanical Systems International Code Council Evaluation Service, ICC-ES AC156 (2007), Seismic Qualification by Shake Table Testing of Nonstructural Components and Systems

Table 1 USA Structural Seismic Standards Referenced by the International Building Code

General Outline of the Typical USA Seismic Design Procedure and Related Requirements

The seismic design procedure most utilized for normal occupancy buildings is described by the following steps:

1. Determine the USGS mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) spectral response accelerations at 0.2 second and 1 second fundamental period, S_S and S_1 for the building location.
2. Determine whether the seismic hazard is at a negligible amount (principally just in the northern states of the USA Midwest and certain areas in Florida and Texas) such that nominal loads and connectivity are sufficient.
3. Determine the Site Classification based on characteristics of the upper 100 ft. of site soil profile based on a geotechnical investigation of the site, and select tabulated Site Coefficients F_a and F_v .
4. Calculate the Site Class-adjusted spectral response accelerations for the building site, , S_{MS} and S_{M1}

   $S_{MS} = F_a S_S$ $S_{M1} = F_v S_1$
5. Calculate the design spectral response accelerations for the life safety level of protection, S_{DS} and S_{D1}.

   $S_{DS} = (2/3) S_{MS}$ $S_{D1} = (2/3) S_{M1}$
6. Construct the Design Response Spectrum for the site, using parameters S_{DS} , S_{D1}, and long-period transition point T_L.selected from a map.
7. Determine the building's Risk Category from a table of occupancies and the resulting Importance Factor, I_e for earthquake effects.
8. Based on the Risk Category and design spectral response accelerations, determine the building's Seismic Design Category, SDC from tables.
9. Select the seismic-force-resisting system from those permitted for the Seismic Design Category.
10. Determine the configuration of the seismic-force –resisting system for the building.
11. Check structural characteristics for irregularities and other detrimental factors in accordance with the Seismic Design Category.
12. Select the analysis procedure based on the Seismic Design Category and structural characteristics.
13. Calculate the building's approximate lower-bound fundamental period of vibration, T .
14. If designing by the equivalent lateral force procedure, use the site Design Response Spectrum, system's Response Modification Factor, R, and building lower-bound fundamental period, T, to calculate the Seismic Response Coefficient, C_s .
15. Calculate the building Effective Seismic Weight, W .
16. Multiply the Seismic Response Coefficient by the building Effective Seismic Weight to determine the Seismic Base Shear Base Shear, $V = C_s W$.
17. Distribute the Seismic Base Shear vertically based on the building's fundamental period and parametric mode shape.
18. Apply Seismic Load Effects Q_E with other factors and apply additional load effect cases relating to checks of the configured system's structural characteristics for additional detrimental features.
19. Perform structural analysis, taking into account prescriptive checks for irregularities, torsional moment, drift, and the effect of drift on structural and nonstructural components not included in the seismic-force resisting system.
20. Check building story drifts, Δ , against the allowable building drift Δ_a for the seismic-force-resisting system and building Risk Category.
21. Incorporate foundation seismic design requirements indicated in the geotechnical investigation.
22. Proceed with structural component limit state designs following the material specific seismic detailing requirements.
23. Determine seismic certification requirements of mechanical and electrical equipment and check anchorage of nonstructural components.

24. Determine structural inspection and testing requirements for the construction quality assurance program.
25. Submit construction documents to the jurisdiction having authority.
26. Perform structural observation for compliance with complete construction documents.
27. Review structural material test results and inspection reports.

Discussion of Key Seismic Design Parameters

The design limit state of resistance to seismic effects is unlike any of the other loads considered in the ASCE 7 Standard (ASCE 7 Commentary). Due to the high demand exerted by earthquakes, the earthquake limit state is based on inelastic system performance rather than member limit state performance, with energy dissipation throughout many cycles of inelastic strain necessary for adequate performance in high seismic regions. In other words, structures typically designed using linear elastic methods respond in the nonlinear range during actual design earthquake events.

Risk-Targeted Maximum Considered Earthquake Ground Motions, Site Classes, and Design Spectral Response Accelerations S_{DS} and S_{D1}

The USA encompasses regions with different geologic settings and seismic sources, and the slope of the hazard curves can vary greatly. An explicit objective of the USA seismic provisions is establishing a uniform level of risk across the country for similar occupancies, such that life safety protection is achieved with uniform reliability. It was realized that the uniform risk criteria for seismic design against structural collapse needed to be established on the basis of a long return period, essentially capturing the asymptote of the hazard curve. Otherwise, it was concluded that inadequate protection would occur during severe earthquakes in the regions of low to moderate seismicity. (See Figure 2). Setting the Maximum Considered Earthquake (MCE) average return period at approximately 2,500 years was intended to capture the risk from large infrequent earthquakes in the low to moderate seismic regions of the U.S. However, due to the variability of the slope of the hazard curves, the probability of collapse of a building would vary by region when the complete range of earthquake events is considered. Therefore, after incorporating further analysis to take into account the effect of the slope of the hazard curve on collapse probabilities, the latest seismic design maps in ASCE Standard 7-2010 provide Risk-Targeted Maximum Considered Earthquake ground motion spectral response acceleration S_s and S_1 values from the USGS reflecting a 1% probability of collapse in 50 years (See Figure 3.)

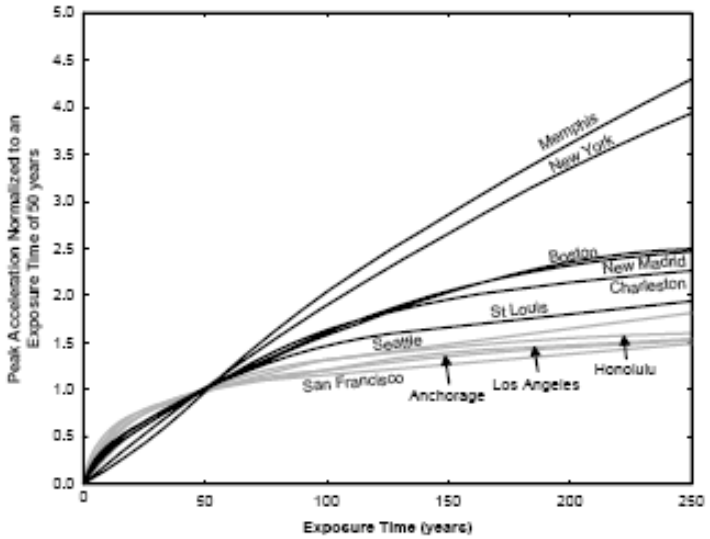

Figure 2 Ground Motion Hazard Curve Shapes - Normalized to a 50-year Building Economic Lifespan Exposure Duration

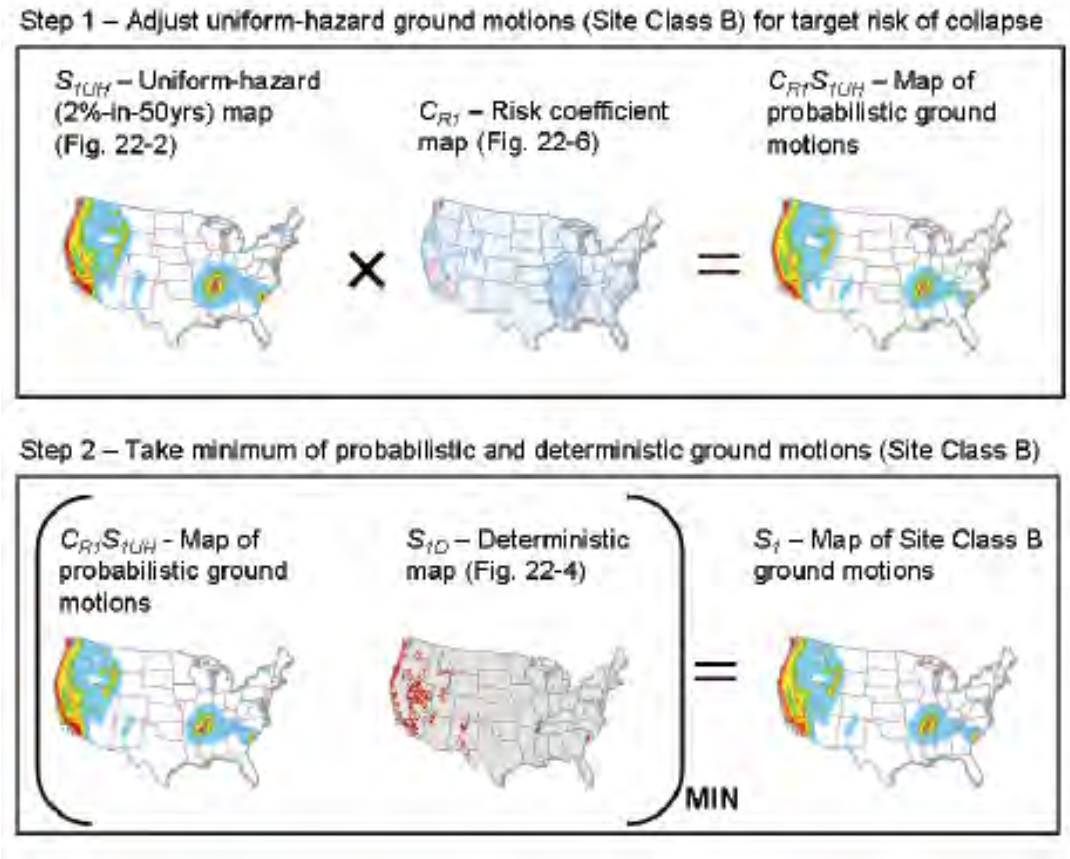

Figure 3
Simplified Illustration of Processing of a Uniform Hazard Map to a Uniform Risk Map (FEMA P750, 2009)

These MCE_R spectral response acceleration are further adjusted by tabulated Site Coefficients F_a and F_v to take into account the site soil properties in accordance with the Site Class (ranging from A to F by increasing softness) that represents the amplification of the ground motion caused by the softness of the upper 100-ft. of the site soil profile relative to a reference Site Class B rock profile. ASCE 7 prescribes procedures on how to determine the Site Class using soil boring-derived parameters such as standard blow counts, undrained shear strength, or most preferably, testing of shear wave velocity within the upper 100 ft. of the soil profile. Site Class D is the default classification where site specific soil properties or geologic conditions are insufficiently known. With the application of Site Coefficients F_a and F_v , the spectral response accelerations for the building site, , S_{MS} and S_{M1} , are determined. The Site Class is a very influential determinant of the level of seismic design required, since the values of F_a and F_v range from 0.8 to over well over 2.

Site-adjusted short period spectral acceleration at 0.2 second	$S_{MS} = F_a S_s$
Site-adjusted long period spectral accelerations at 1.0 second	$S_{M1} = Fv S_1$

The performance objective of collapse prevention at this intensity of ground motion is notionally converted to a life safety performance objective by a reduction factor of 2/3. *"Design ground motions are based on a lower bound estimate of the margin against collapse inherent in structures designed to the seismic provisions in the standard. This lower bound was judged, based on experience, to correspond to a factor of about 1.5 in ground motion. Consequently, the design earthquake ground motion was selected at a ground shaking level that is 1/1.5 (or 2/3) of the MCE_R ground motion."* (FEMA P-750). Because of the differences in regional hazard curves, there is not a single-value of return period associated with the design ground motion after application of this conversion factor. A special case exists for essential facilities, in which the Importance Factor I value of 1.5 cancels out this conversion so that such a facility is designed for a life safety performance objective at the MCE_R ground motion.

Application of the 2/3 conversion to the life safety performance level to the MCE_R spectral accelerations results in the design spectral accelerations S_{DS} and $S_{D1,}$ at the short (0.2 second)and long (1.0 second) periods. With these values, the Design Response Spectrum versus fundamental structural period can be drawn for the site based on these S_D parametric values, along with T_L, the period on the design response spectrum separating the constant-velocity and constant-displacement segments. T_L was estimated for the earthquake magnitude range that contributed most to the total seismic hazard at the 2,500 year mean recurrence interval. Thus, the Design Response Spectrum is relevant to the practical range of structures designed under these provisions, including very tall buildings. (See Figure 4.)

Design spectral acceleration at 0.2 second $S_{DS} = 2/3 S_{MS}$
Design spectral acceleration at 1.0 second $S_{D1} = 2/3 S_{M1}$

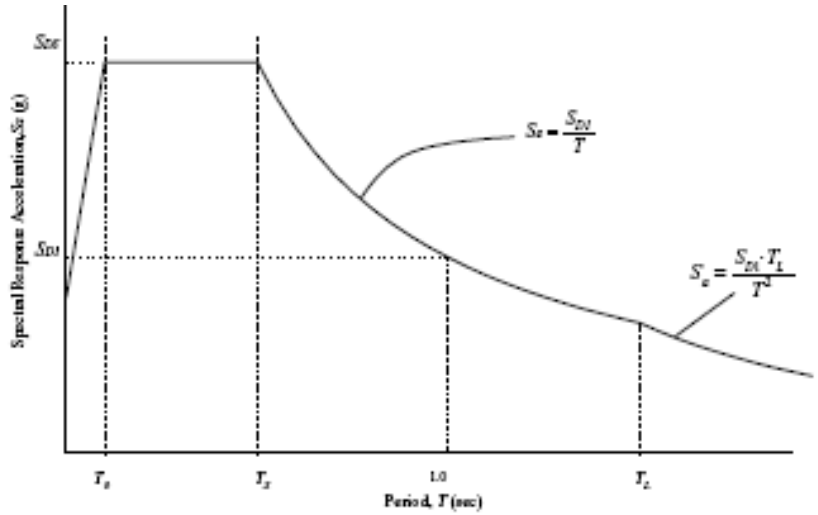

Figure 4
Construction of the Design Response Spectrum for the Site from Parameters S_{DS} , S_{D1} ,and T_L (ASCE 7)

Building Risk Categories

The functional occupancy of a facility is the basis for classifying the Risk Category of a building, as paraphrased in Table 2. The Risk Category then determines the Importance Factor and affects the building's Seismic Design Category. The International Building Code provides more explicit listings of building types within each Risk Category in accordance with the generic descriptions of the ASCE 7 Standard.

Occupancy	Risk Category	Importance Factor
Buildings with a low risk to human life in the event of failure	I	1.0
All buildings except those in Risk Categories I, III, or IV	II	1.0
Buildings with: Substantial risk to human life in the event of failure Substantial economic impact and/or mass disruption of civilian life in the event of failure Hazardous materials exceeding threshold quantities	III	1.25
Buildings that have Essential facilities Highly toxic materials exceeding threshold quantities Buildings required to maintain functionality similar to essential facilities	IV	1.5

Table 2 Building Risk Categories and Importance Factors (from ASCE 7-2010)

Seismic Design Categories

Seismic Design Categories (SDC) in the USA seismic code reflect a risk-conscious philosophy of calibrated system configuration and ductility requirements. Seismic Design Categories are based o the spectral response accelerations of the site S_{DS} and S_{D1} and the building Risk Category. The SDC's range from A to F by increasing severity, and they are used to trigger prescriptive requirements deemed necessary to achieve sufficiently ductile performance for the ground shaking intensity of a site. Seismic Design Category B is the initial point at which Modified Mercalli Intensity VI is experienced at the MCE_R ground motion, and this is the level at which seismic design and detailing becomes required. The SDC D design level for normal occupancies was set roughly at the threshold of Modified Mercalli Intensity(MMI) VIII at the MCE_R ground motion and about 50% of the maximum design force level used in building codes prior to the International Building Code. The Seismic Design Category (SDC) D is the point at which higher ductility and configuration restrictions are required.

The SDC is determined by comparing the site class adjusted design spectral accelerations at the short and long periods against tabulated reference values. The SDC's are assigned one category higher for buildings that are in the highest Risk Category IV, e.g., essential facilities that have emergency response function that should have continuity of operations after an earthquake, or the failure of which could pose unusual hazard to public safety. There are two special cases. SDC E is assigned to Risk Category I, II, or III structures where S_1, the Risk-Targeted Maximum Considered Earthquake (MCE_R) spectral response acceleration at 1 second, exceeds 0.75g. SDC F is assigned to Risk Category IV structures where S_1, the Risk-Targeted Maximum Considered Earthquake (MCE_R) spectral response acceleration at 1 second, exceeds 0.75g.

The code includes additional checks to mitigate structural characteristics detrimental to ductile nonlinear response. The Seismic Design Category determines the application of the following rules:

- Scope of geotechnical investigation
- Permitted structural systems and their height
- Limitations/restrictions and additional requirements for horizontal and vertical irregularities
- Redundancy of the seismic-force-resisting system configuration
- Common wall and column elements of intersecting systems
- Analysis procedure selection
- Amplification of torsional moment
- Application of overstrength factors to floor and roof diaphragms
- Design for equivalent nonlinear deformation compatibility of structural components not explicitly included in the seismic-force-resisting system
- Foundation design detailing
- Applicability of nonstructural component design requirements
- Additional material and system specific seismic requirements
- The International Building Code also mandates tests and inspections of structural systems and nonstructural components of buildings that are SDC C and higher.. These requirements shall be itemized on the building construction documents
- The International Building Code also mandates structural observation of construction by the structural engineer for Seismic Design Category D and higher, if the building is Risk Category III and IV, taller than 75 feet (22.86 m), or a Risk Category I or II structures of more than two stories tall *and* SDC E.
- For Seismic Design Category E and F structures, there are further prohibitions against site location proximity to known faults, and limitations on structural systems, system configuration and height, and prohibitions against highly torsional horizontal irregularity and weak and soft-story vertical irregularities.

Seismic Performance Factors

In order to provide a prescriptive linear elastic procedure for the design of buildings, the code regulates configuration, height, materials, detailing, and strength and stiffness of each system. Seismic design parameters representing the inelastic and deformation performance of such systems are specified as system

response coefficients (R, C_d , and Ω_0). These system response coefficients then govern the magnitude of seismic design loads and deformation for 88 classifications of structural systems (See Figure 5). In general, the seismic shear for a building with effective weight W is inversely proportional to R, as shown in the following equations for constructing the Design Response *Coefficient* Spectrum:

Seismic Base Shear is given by $V = C_s W$

where the seismic response coefficient $C_S = S_{DS}/(R/I)$

but need not exceed: $C_S = S_{D1}/T(R/I)$ for $T \le T_L$;

$C_S = S_{D1}T_L/T^2(R/I)$ for $T > T_L$;

but C_s shall not be less than: 0.01, and nor shall it C_s be less than $C_S = 0.5S_{D1}/(R/I)$ where $S_1 \ge 0.6g$

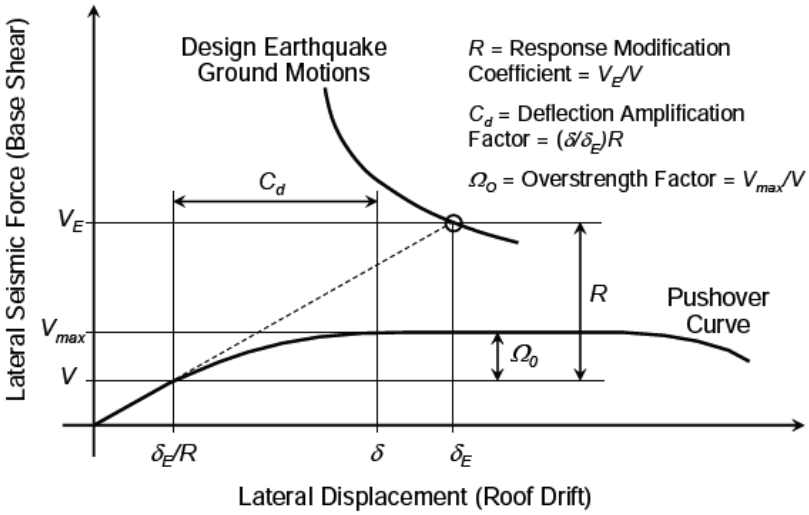

Figure 5 Illustration of Seismic Performance Factors (R, C_d, and Ω_0) and their role in establishing the required lateral seismic design force [diagram is not to scale]. (ATC/FEMA P695, 2009)

V_E represents the force level that would be developed in the seismic-force-resisting system, if it remained entirely linearly elastic for the design earthquake ground motion. The term V_{max} represents the *anticipated* maximum strength of the fully-yielded system if determined by a pushover analysis, and the term V is the seismic base shear for the equivalent linear static method, i.e., the elastic design, assuming that the system can provide the *anticipated* amount of nonlinear ductility. V is the horizontal seismic load applied to the structure with a load factor of 1.0.

The value of R is the ratio of V_E/V. Each type of structural system has been assigned a Response Modification Coefficient R that operates as a reduction factor to convert the assumed nonlinear response demand to a level appropriate for linear elastic analysis of that system. The Ω_0 factor is the *anticipated* ratio of the maximum strength of the fully-yielded system to the design base shear. Overstrength Factor Ω_0 is used to amplify design loads for individual components detrimentally affected by nonductile response mechanisms.

Building Drift and Floor Accelerations

C_d is the anticipated ratio of the actual inelastic lateral drift of the system to the elastic drift calculated using the prescribed design lateral force for that system. Deflection Amplification Factor C_d is used to scale the calculated drift of the elastic model back up to the inelastic design drift reflecting the actual force-deformation performance regime. This approximate inelastic drift of the structure is then used for the purposes of checking overall drift limitations for damage limitation, stability for P-Δ effects, building separations, and the design detailing of nonstructural drift-sensitive components such as cladding, glazing, and partitions.

Maximum deflections at each level are calculated per $\delta_x = C_d \delta_{xe} / I_e$

Where δ_{xe} are the elastic deflections calculated using the vertically distributed design seismic shear V, and including translational and any torsional displacements. The values of estimated maximum inelastic story drift Δ (the differential deflection of the top δ_x and bottom δ_{x-1} for a story) are checked against prescriptive limits Δ_a for the system and building Risk Category. Allowable interstory drift movement is more restricted for the higher Risk Category buildings in order to reduce nonstructural drift sensitive damage.

Acceleration-sensitive nonstructural components include ceiling systems, mechanical and electrical equipment, piping and ducts, and elevator systems. Each type of nonstructural component is assigned an Importance Factor I_p of 1.0 or 1.5 based on it criticality to life safety (and/or continued functionality in the case of essential facilities). Architectural, mechanical, and electrical components are also assigned a_p Component Amplification Factors based on the rigidity or flexibility the component and its attachment and a R_p Component Response Modification Factors based on the strength and deformability of the component. Floor accelerations are parametrically estimated on the basis of height within the building. Seismic forces on nonstructural components are then determined by:

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left(R_p / I_p\right)}\left(1 + 2\frac{z}{h}\right)$$

This equation represents the floor acceleration (estimated based on the component location within the height of the building) multiplied by its amplification factor and weight, divided by its effective component inelastic response modification. Anchors to concrete and masonry structures must comply with special seismic qualifications.

The performance of mechanical and electrical components depends not only on their attachment to the structure but the toughness of the component itself. For Seismic Design Category C and higher, manufacturers must satisfy the component general design requirements by "seismic qualification" in accordance with a national standard such as ICC-ES AC 156. Per the IBC:

> *Certification shall be based on an actual test on a shake table, by three-dimensional shock tests, by an analytical method using dynamic characteristics and forces, by the use of experience data (i.e., historical data demonstrating acceptable seismic performance) or by more rigorous analysis providing for equivalent safety.*

Recent and Ongoing Research

While defined in concept, actual values of R, C_d, and Ω_0 for structural systems classified in the code have not all been analytically derived but many are largely based on historical precedence, or by judgment of the expected performance of one system compared to one with previously established factors. Much attention is given to earthquake reconnaissance of systems in actual earthquakes to acquire empirical performance data on structural systems, as exemplified by the Earthquake Engineering Research Institute's Learning from Earthquakes program. Analytical research by the Applied Technology Council and the Consortium of Universities for Research in Earthquake Engineering has been sponsored by FEMA and NIST to determine whether the desired system reliabilities against collapse can be verified by nonlinear analysis of designs based on the presently used seismic performance factors. There is also recent research into the fragility of nonstructural components and testing protocols for determining the seismic performance of these components.

Accordingly, while further research proceeds, the rigorous application of the SDC-dependent design rules plays a critical role in mandating proper system configuration and seismic details of construction, to enable the seismic-force-resisting systems to be reasonably capable of sustaining the amount of nonlinear deformation response associated with the system's Response Modification Coefficient. The material-specific standards, developed by industry association testing and evaluated by code developing organizations, play a critical role in replicating to the greatest degree practical the limitations of the archetypical configurations, proportions, details, and material specifications used in research and validation testing of the seismic-force-resisting system. ASCE 7 provides a compilation of these Material-Specific Seismic Design and Detailing Requirements as they are applied using industry consensus design standards.

Site-Specific and Advanced Design Techniques for New Construction

This paper has described the seismic design provisions most commonly applicable to building structures. ASCE 7 also includes special procedures for Site-Specific Ground Motion Procedures, Soil-Structure Interaction, Modal Response Spectrum Analysis, Seismic Response (Time) History Procedures, Seismically Isolated Structures, Structures with Damping Systems, and Nonbuilding Structures.

Conclusions

An explicit objective of the USA seismic code is establishing a uniform level of risk across the country for similar occupancies, such that life safety protection is achieved with uniform reliability. This effort is guided and fostered by the National Earthquake Hazards Reduction Program (NEHRP) research "roadmap" of focus areas for developing improved seismic design methodologies. Achievement of the strategic improvements is made through a consensus-building process involving public agencies, structural engineers, academic institutions, and construction and material industry associations.

Since earthquake injuries and fatalities are mostly caused by structural collapse, the code intends to provide a margin of resistance to achieve a specified level of collapse risk, namely a 1% probability of collapse in 50 years. The latest seismic design maps in ASCE Standard 7-10 provide Risk-Targeted Maximum Considered Earthquake ground motion spectral response accelerations.

Current mandatory USA seismic design provisions for building and other structures are given in American Society of Civil Engineers Standard 7, Minimum Design Loads for Buildings and Other Structures (ASCE-7). These requirements are enacted through the adoption of the International Building Code (IBC) by federal agencies, state governments, and local jurisdictions. The IBC has become the national model building code for the USA, and it primarily references the ASCE 7 Standard for seismic design requirements. Application to USA seismic design practice thus requires at a minimum the use of the International Building Code, the ASCE 7 Standard, and material-specific standards. The ASCE 7 Standard, the NEHRP Recommended Provisions, and the commentaries to the material-specific standards provide information on the current state of knowledge. Those references should be consulted by those desiring to understand the basis for the technical requirements of the USA seismic code.

Due to the high demand exerted by earthquakes, the earthquake limit state is based on inelastic system performance rather than member limit state performance, with energy dissipation throughout many cycles of inelastic strain necessary for adequate performance in high seismic regions. In other words, structures typically designed using linear elastic methods are responding in the nonlinear range during actual design earthquake events. USA seismic codes incorporate Seismic Performance Factors intended to represent the inelastic deformation performance of each system that is permitted by the code. Seismic Base Shear can vary significantly according to seismic risk at the site, building Risk Category, building size and stiffness, and the structural system and structural layout chosen.

Seismic drift is evaluated at the anticipated nonlinear response range and is subject to limiting maximum allowable levels based on the building system and Risk Category. Nonstructural components that are acceleration-sensitive must be seismically qualified and anchored to resist a seismic force applied to the component.

The building Seismic Design Category determines a wide range of additional requirements to mitigate against structural characteristics detrimental to ductile nonlinear response. The rigorous application of the Seismic Design Category design rules plays a critical role in mandating proper system configuration and seismic details of construction, to enable the seismic-force-resisting systems to be capable of sustaining the amount of nonlinear deformation response associated with the system's Response Modification Coefficient. The material-specific standards play a critical role in replicating to the greatest degree practical the limitations of the archetypical configurations, proportions, details, and material specifications used in research and validation testing of the seismic-force-resisting system.

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Comparison of USA and China Seismic Design Procedures

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Introduction

There are many aspects of the Chinese Code for Seismic Design of Buildings that have evolved rapidly since the Tangshan Earthquake in 1976, continuing up to the post-Wenchuan Earthquake 2008 revisions to the Code for Seismic Design of Buildings of GB 50011-2001 (MHURDC, 2001) and the Standard for Classification of Seismic Protection of Building Construction of GB 50223-2008 (MHURDC, 2008). In the United States, since the first seismic provisions were included in the appendix of the *1927* Uniform Building Code, the practice of seismic design and construction has gone through substantial changes after nearly one century of development. This paper presents a comparison of the current seismic design procedures in the United States and China.

The comparison is made based on the current version of seismic design codes in both countries. In the U.S., the 2006 International Building Code (IBC) is the currently adopted building code for most states while some states have adopted the 2009 International Building Code (ICC, 2009). The IBC references American Society of Civil Engineering Standard 7, *Minimum Design Loads for Building and Other Structures* (ASCE, 2005) and material-specific codes as seismic design provisions with some amendments or modifications. Unlike the IBC that references other standards as seismic provisions, The Chinese Code for Seismic Design of Buildings is a self-contained document that includes almost all seismic design requirements for building structures. The current seismic code in China is the Code for Seismic Design of Buildings GB 50011-2001. However, the new seismic code GB 50011-2010 (MHURDC, 2010) will be effective on December 1, 2010. This paper will compare the Chinese seismic code GB 50011-2010 and the seismic provisions of the 2009 IBC (ASCE 7-05).

The seismic design practices in the United States and China are compared by focusing on issues such as (1) design ground motion; (2) classification of building structures; (3) soil/site classification; (4) design response spectrum; (5) base shear calculation; (5) analysis procedures; (6) drift control and deflection; (7) detailing requirements; and (8) general seismic design procedures. Tables and diagrams are presented to illustrate the differences and similarities of methodologies utilized by the two countries in dealing with these common issues. The reader should refer to the paper by Chock (Chock, 2010) for more details of USA seismic code.

Objectives of Seismic Design Codes

The primary objective of any seismic design code is to protect life and minimize economic loss. However, by looking into how the objective is presented in the code, one could get some insight of the intent of the seismic code and better understand some of its specific provisions

The ASCE 7-05 that is referenced by the 2009 IBC uses FEMA-450, i.e., the 2003 edition of the NEHRP Recommended Seismic Provisions as the technical basis for seismic design requirements. The NEHRP provisions (BSSC, 2004) clearly states the purposes as: 1) to minimize the earthquake-related risk to life for all buildings; and 2) to improve the capability of essential facilities and structures containing substantial quantities of hazardous materials to function during and after earthquakes. The specified design earthquake ground motion levels may result in damage, both structural and nonstructural. For most structures, damage from the design earthquake ground motion would be repairable but at a cost that might be not economically desirable. For essential facilities, it is expected that the damage from the design earthquake ground motion

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would not be so severe to prevent continued occupancy and function of the facilities. For the ground motions greater than design levels, the intent is that there be a low likelihood of structural collapse. Whether or not these goals are achieved largely depends on a number of factors, including the structural framing type, configuration, materials and as-built construction details.

From the objectives of the U.S. seismic design code, the design and construction requirements are a function of seismic risks rather than seismic hazard. In the code, Seismic Design Categories (SDC) are related to seismic risk, since its classification includes consideration of seismic hazard (the seismicity and soil type of the site) and the nature of the building occupancy.

The Chinese Code for Seismic Design of Buildings GB 50011-2001 sets the basic seismic design objectives as: 1) There should be no damage for a structure during frequent earthquakes or no repair is required for the structure to continue its service after a frequent earthquake; 2) Minor damage (in other words, the structure should be able to continue its service with or without repair) during a moderate earthquake; 3)No collapse or severe (life-threatening) damage during a rare earthquake.

The new code GB 50011-2010 also requires that when performance-based design is performed, specific or higher goals may be set for the buildings with some specific requirements regarding functions. A three-level or two-phase design is to be performed to achieve these stated goals. The first two objectives are met by the first phase design which includes two-level designing: 1) Designing the structure by combining load effects of the frequent earthquake with other loading effects to assure the structure has elastic response under a frequent earthquake event; 2) Detailing the structure and its components to meet ductility requirement inherent in the second goal. To meet the goal of no collapse or severe damage during a rare earthquake, the second phase design needs to be performed. While the second phase design is not required for a majority of structures, some structures still are required to be checked for nonlinear story drift criteria (Table 16).

Design Ground Motion

Depending on the occupancy and use of a building and the risk to public safety inherent in its failure, the ASCE 7 seismic provisions are intended to provide for a uniform margin against collapse at the design ground motion. In order to accomplish this, ground motion hazards are defined in terms of Maximum Considered Earthquake (MCE) ground motions. For most regions of the U.S., the MCE is defined with a uniform probability of exceedance of 2 percent in 50 years (return period of about 2500 years). In regions of high seismicity, such as coastal California (where the seismic hazard is typically controlled by characteristic large-magnitude events occurring on a limited number of well-defined fault systems), the MCE is calculated by multiplying the median estimate of ground motion resulting from the characteristic event by 1.5. The MCE is mapped in terms of the spectral acceleration at short period (0.2 second), Ss and at 1 second, S_1, for Class B sites, which are firm rock sites. For sites other than Site B, two coefficients, F_a and F_v are used to modify the *Ss* and S_1 values. The MCE spectral response accelerations adjusted for Site Class effects are designated S_{MS} ($=F_aS_S$) and S_{M1}($=F_vS_1$), respectively, for short-period and 1-second-period response. The design ground motion was selected at a ground shaking level that is 2/3 of the MCE ground motion. Accordingly, two additional parameters, S_{DS} ($= 2/3S_{MS}$) and S_{D1} ($=2/3S_{M1}$), are used to define the acceleration spectrum for the design level event (see Chock, 2010).

In the Chinese seismic code, the expected performance of a structure is conceptually defined at three levels of seismic hazard: frequent earthquake, moderate earthquake and rare earthquake. Table 1 gives probabilistic definitions of the three levels of seismic hazard. Seismic hazards in China are defined for the “moderate earthquake” at a uniform 10 percent probability of exceedance in 50 years. The seismic hazards, in terms of Seismic Peak Ground Acceleration and Characteristic Period of Response Spectrum (T_g) are specified in Seismic Ground Motion Parameter Zoning Maps of China GB 18306-2001 (CEA, 2001). This standard includes two maps. The first map is the zoning map of peak ground acceleration with 10 percent probability of exceedance in 50 years with a seven-level grading system used, i.e., < 0.05*g*, 0.05*g*, 0.1*g*, 0.15*g*, 0.20*g*, 0.30*g*, and ≥0.40*g*. The other map is the Characteristic Period (T_g) zoning map which has three zones or three Seismic Groups in which the first group is defined as T_g = 0.35s, the second group as T_g = 0.40s, and the third group as T_g = 0.45s all based on Site Class II (medium firm). The Characteristic Period (T_g) has to be adjusted based on the site class (Table 5).

Instead of the peak ground acceleration map, Seismic Intensity is used for design purposes, and it is

determined by the peak ground acceleration as shown in Table 2. The Seismic Intensity level is to be modified based on building types (Table 3)and site classes (Table 4). The Appendix of the Chinese Seismic Design Code GB50011-2010 also provides a Tabulation of Seismic Intensity, PGA and Seismic Group for all administrative districts (county or above).

Table 1 Quantified Definition of the Three-Level Hazards

Level of seismic hazard	Quantified definition of the hazard	
	Probability of exceedance during 50 years	Return period (years)
Frequent earthquake	63%	50
Moderate earthquake	10%	475
Rare earthquake	2% - 3%	1640 - 2475

Table 2 Seismic Intensity Designation and Peak Ground Acceleration (Return period =475yrs)

Peak Ground Acceleration (g)	≤ 0.05	0.10	0.15	0.20	0.30	≥ 0.40
Seismic Intensity	6	7		8		9

Table 3 Modification of Seismic Intensity According to Structure Type

Building Type[1, 2]	Basic Seismic Intensity	Adjusted Seismic Intensity
A	6 – 8	+1
	9	>9
B	6 – 8	+1
	9	>9
C	6 - 9	No change
D	6 - 9	No change or reduce

[1]No change for small buildings with sound structural system.
[2]See Table 7 for definition of Building Types.

Table 4 Modification of Seismic Intensity According to Site Class

Site Class	Intensity modification
I	Type A and B buildings: Intensity unchanged Type C buildings: Intensity allowed to be lowered one degree but not less than 6
II	Intensity unchanged
III or IV	7 with PGA = 0.15 increased to 8 with PGA = 0.20 8 with PGA = 0.30 increased to 9 with PGA = 0.40

Table 5 Characteristic Period of Response Spectrum T_g (second)

Seismic Group[1]	Site Class				
	I_0 (Very firm)	I_1 (Firm)	II (Medium firm)	III (Medium soft)	IV (Soft weak)
Group 1	0.20	0.25	*0.35*	0.45	0.65
Group 2	0.25	0.30	*0.40*	0.55	0.75
Group 3	0.30	0.35	*0.45*	0.65	0.90

[1]Seismic Group is defined based on the Characteristic Period T_g on Site Class II, given by the Characteristic Period zoning map.

Classification of buildings

The IBC classifies buildings and other structures as Occupancy Category from I to IV based on the nature of occupancy (Table 6). Importance factors used in the calculation of wind loads, snow loads and seismic load

effects are assigned to each structure based on its Occupancy Category. Generally the value of importance factor increases with the importance of the facility. Occupancy Categories I and II have a seismic importance factor of 1.0. The seismic importance factors for Occupancy Category III and IV are 1.25 and 1.50, respectively. Structures assigned a greater seismic occupancy must be designed for larger seismic forces. As a result, these structures are expected to experience lower ductility demands than structures with lower occupancy importance factors and, thus sustain less damage. Occupancy Categories are also a basis for determining Seismic Design Categories, which are keys for establishing the detailed seismic design requirements for any structure.

The Chinese Standard for Classification of Seismic Protection of Building Constructions GB 50223-2008 (MHURDC, 2008) classifies building structures as Building Type A to D with Type A as most important and Type D as less important (Table 7). There is no occupancy importance factor in Chinese code. Instead, the seismic design intensity should be adjusted according to the type of building structure (Table 3).

Table 6 The IBC Classification of Buildings and Other Structures

Occupancy Category	Nature of Occupancy
I	Representing a low hazard to human life in the event of failure
II	Except those listed in other categories
III	Represent a substantial hazard to human life in the event of failure
IV	Designed as essential facilities

Table 7 Chinese Standard for Classification of Seismic Protection of Building Constructions

Building Type	Description
A (Extremely important)	Special facilities related to national security or causing secondary disasters in the event of failure.
B (Very important)	Facilities designed to be functional during and after earthquake or building representing a substantial hazard to human life.
C (Important)	Those not listed in other types.
D (Less important)	Representing a low hazard to human life or causing no secondary hazard.

Soil or Site Classification

The 2009 IBC classifies each site as one of six site classes from A to F based on one of three soil properties measured over the top 100 feet. The three properties are soil shear wave velocity, standard penetration resistance and soil undrained shear strength. Site Class A is hard rock which is typically found in the eastern United States. Site Class B is softer rock typical of the western parts of the country. Site Class C, D or E indicates progressively softer soils. Site Class F indicates soil so poor that site-specific evaluation is needed to determine appropriate site coefficients.

The 2010 Chinese seismic code first classifies a site as Favorable, Common, Unfavorable and Hazardous (Table 8). Some restrictions apply at unfavorable or hazardous sites as shown in Table 8. The code also classifies a site as one of four classes from I to IV depending on the equivalent shear wave velocity and the effective soil depth which is generally measured from ground surface to the soil layer with shear wave velocity greater than 500m/s (Table 9).

Table 8 Site Classification of Chinese Seismic Code (I)

Site Classification (I)	Definition	Restrictions
Favorable	Rock or stiff soil	
Common	Except those listed in other categories	
Unfavorable	Soft soil, liquefiable soil and other unfavorable conditions	Be avoided for all constructions except appropriate measures being taken
Hazardous	Areas with hazards of landslide, avalanche, subsidence, ground fissure or debris flow	Prohibited for Building Types A and B. Not suggested for Building Type C

Table 9 Site Classification of Chinese Seismic Code (II)

Equivalent shear wave velocity (m/s)	Site Class				
	I_0	I_1	II	III	IV
$v_{se} > 800$	0				
$800 \geq v_{se} > 500$		0			
$500 \geq v_{se} > 250$		< 5m	≥ 5m		
$250 \geq v_{se} > 140$		< 3m	3 – 50m	>50m	
$v_{se} \leq 140$		< 3m	3 – 15m	>15 – 80m	>80m

Design Response Spectrum

Figure 1 illustrates the design response spectrum specified by the 2009 IBC. The point T_S ($T_S = S_{D1}/S_{DS}$) corresponds to the period which divides the short-period range from the long-period range. The point T_0 equals 20% of the value of T_S. T_L is long-period transition period which marks the transition between long period and very long period. Relatively few structures have such a long period to fall into this range. The T_L maps are also included in the code.

The Chinese seismic code specifies the seismic influence coefficient curve (α) which is comparable to a response spectrum (Figure 2). In fact, the curve expresses two levels of seismic hazard, the frequent earthquake or rare earthquake depending on the value of α_{max} (maximum seismic influence coefficient). Table 10 gives the values of α_{max} for three-level seismic hazards. Design forces are based on the α_{max} for the frequent earthquake multiplied by a load factor. Characteristic Period of Response Spectrum (Table 5), T_g, is the period where the transition to long-period range occurs. $T = 5T_g$ is the point corresponding to the period which divides the nonlinear relationship (between α and T) and linear relationship. The parameters, γ, η_1, η_2, in Figure 1 are determined by Eqs 1-3, respectively.

$$\gamma = 0.9 + \frac{0.05 - \zeta}{0.3 + 6\zeta} \qquad \textbf{Eq. 1}$$

$$\eta_1 = 0.02 + \frac{0.05 - \zeta}{4 + 32\zeta} \qquad \textbf{Eq. 2}$$

$$\eta_2 = 1 + \frac{0.05 - \zeta}{0.08 + 1.6\zeta} \qquad \textbf{Eq. 3}$$

where ζ is the damping ratio and $\eta_2 \geq 0.55$.

Table 10 Maximum Horizontal Seismic Influence Coefficient (α_{max})

Seismic Intensity	6	7		8		9
PGA Zone	< 0.10g	0.10g	0.15g	0.20g	0.30g	≥ 0.40g
Frequent earthquake[1] (specified for unfactored design loads)	**0.04**	**0.08**	**0.12**	**0.16**	**0.24**	**0.32**
Moderate earthquake[2]	0.12	0.22	0.32	0.42	0.60	0.80
Rare earthquake[3] (elasto-plastic drift check)	0.28	0.50	0.72	0.90	1.20	1.40

[1, 2, 3] See Table 1 for definitions of "Frequent earthquake", "Moderate earthquake" and "Rare earthquake".

Based on Table 10, hazard curves, i.e., peak ground acceleration (normalized to hazard with a return period of 50 years) as a function of return period, are plotted as shown in Figure 3. The figure shows that as return period is lengthens, the hazard range deviation gets larger. For the moderate earthquake with a return period of 475 years, normalized PGA of Seismic Intensity 6 is about 3 times that of frequent earthquake, and normalized PGA of Seismic Intensity 9 is about 2.5 times that of frequent earthquake. However, for a rare

earthquake with a return period of around 2000 years, normalized PGA of Seismic Intensity 6 is about 7 times that of frequent earthquake, and normalized PGA of Seismic Intensity 9 is only about 4.4 times that of frequent earthquake. For areas designated with low or moderate seismicity, designs based on hazards of shorter return period could have inadequate protection if a severe earthquake occurs (Chock, 2010).

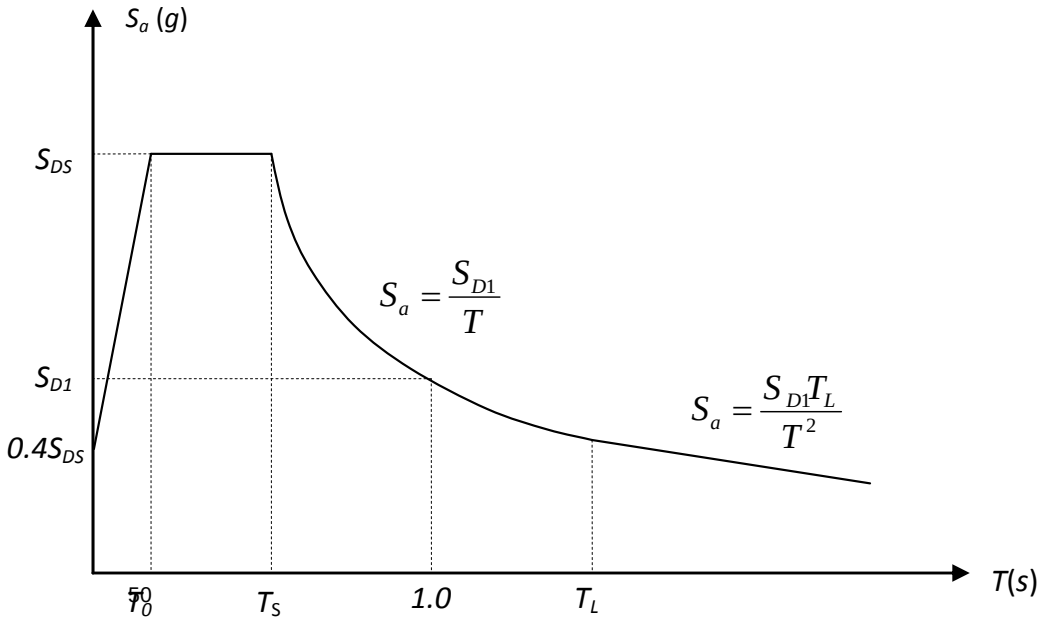

Figure 1 USA Design Response Spectrum, S_a

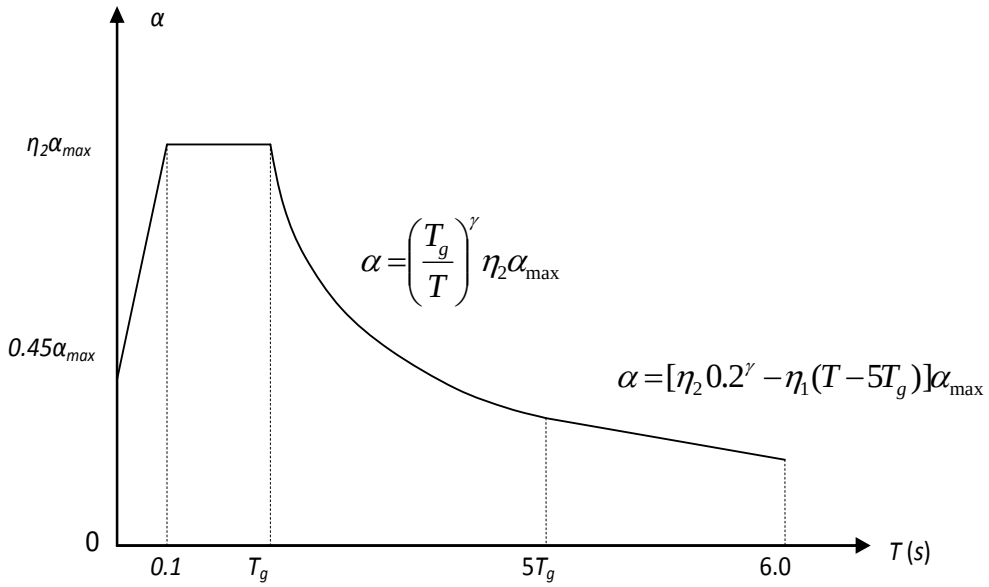

Figure 2 China Seismic Influence Coefficient, α

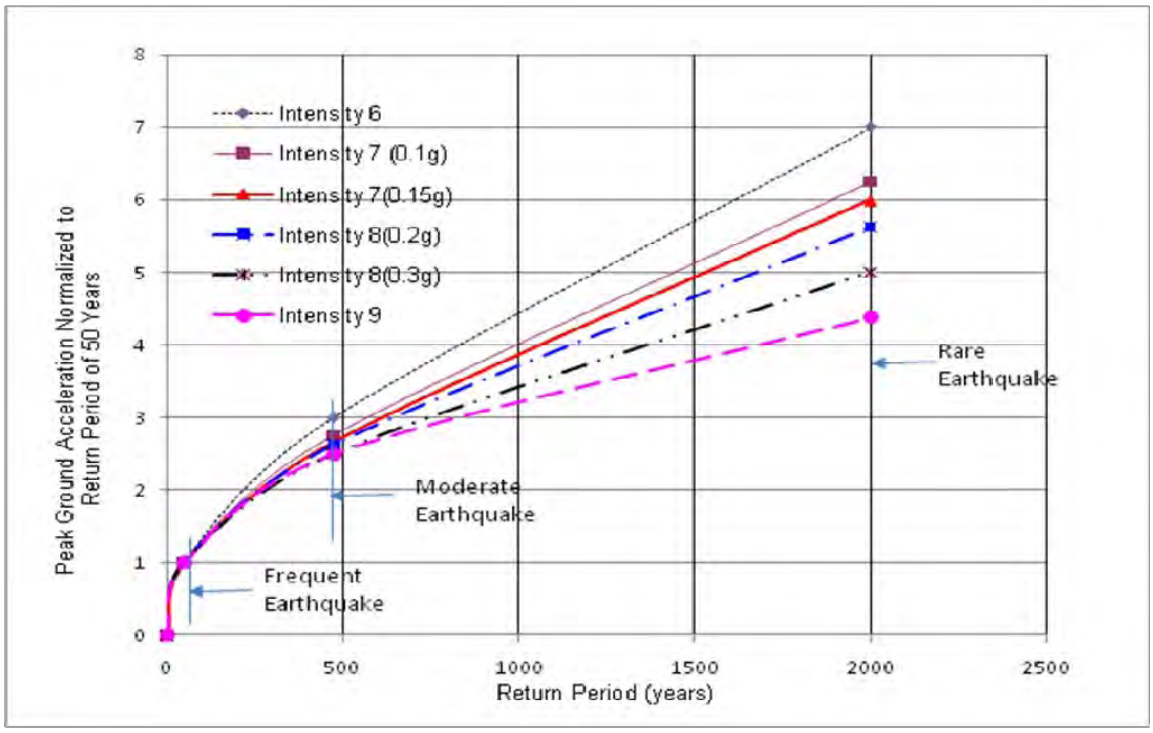

Figure 3 China Ground Motion Hazard Curve Shapes – Normalized to a 50-Year Return Period

Seismic Base Shear

For the equivalent lateral force procedure, both ASCE-7 and GB 50011multipy seismic weight by a factor and use a similar equation to calculate base shear (Table 11). However, there are some essential differences determining the two factors (C_S and α).

The base shear in ASCE – 7 is determined based on the design ground motion which is about two-thirds of the soil-modified maximum considered ground motion. In contrast, two levels of seismic load effects under frequent earthquake and rare earthquake are given in GB 50011. The prescribed design load procedure utilizes the frequent earthquake.

ASCE – 7 uses the response modification factor, R, to account for the inherent ductility and damping of seismic lateral resisting systems. Basically the R-factor decreases the design base shear for those systems with good earthquake performance. For example, the R-factor for a special concrete moment frame system is 8 and a ordinary concrete moment frame (with much less stringent detailing and other requirements) has a R-factor of 3.5. Seismic load effects for the special moment may have less than half of the ordinary moment frame. The R-factor ranges from 1.5 to 8.

No response modification factor (R) appears in the GB 50011 base shear equation. As stated earlier, a lateral system and its components are required to meet the code required detailing so that only minor damage would occur during a moderate earthquake. Adjustment factors (γ_{RE}) ranging between 0.75 and 1.0 are used to modify seismic capacity of structural components based on type of material and type of structural components (generally seismic capacity is increased by dividing the nominal capacity by this γ_{RE} factor).

In ASCE – 7 seismic importance factor (I) increases the base shear for an Occupancy Category III or IV structure with a factor of 1.25 or 1.5, respectively. The Chinese code does not explicitly include such an importance factor and the issue is addressed by adjusting seismic fortification intensity according to the building type (Table 3).

The Chinese Seismic Code requires that besides dead loads, seismic weight have to include 50% uniform live load for residential or office buildings and 80% uniform live load for library stack rooms or archive rooms. In

ASCE -7 no live load is required to be included in seismic weight except a minimum of 25% of floor live load for storage area plus partition weight assuming partitions can be rearranged.

The seismic load effect (E) has a load factor of 1.0 when combining factored loads using strength design according to ASCE – 7 or the IBC. The Chinese seismic code assigns a load factor of 1.30 to the horizontal seismic load effect (S_{Ehk}) when combining the load effect of the frequent earthquake (50-year return period) with other loads to perform strength design.

Table 11 compares base shear equations between ASCE 7-05 and GB 50011-2010.

Table 11 Base Shear Calculations

Subject	The U. S. code (ASCE – 7)	The Chinese code (GB 50011)
Base shear	$V = C_S W$	$F_{Ek} = \alpha_1 G_{eq}$
Seismic design coefficient	$C_S = S_{DS}/(R/I)$	α_1 seismic influence coefficient determined by Figure 2
Upper limit	$C_S \le S_{D1}/(T)(R/I)$ for $T \le T_L$ $C_S \le S_{D1}\, T_L /(T^2)(R/I)$ for $T \ge T_L$	Governed by Figure 2
Lower limit	$C_S \ge 0.01$ $C_S \ge 0.5S_1/(R/I)$ for $S_1 \ge 0.6g$	Governed by Figure 2
Seismic weight	W	G_{eq}

By applying the base shear equations for identical buildings of standard occupancy on similar firm rock sites with identical seismic hazard, a comparison of factored seismic design force can be made in high seismic regions. Expressing the factored seismic base shear as the reduced value of a 2000-2500 year earthquake ground motion, Chinese concrete shear wall and moment frame buildings are designed for a base shear that is reduced by a factor of 3.9 to 4.5 from the rare earthquake level. USA special concrete shear wall and moment frame buildings are designed for a base shear that is reduced by a factor of 7.5 to 12 from the MCE level. In other words, Chinese seismic design loads are about 2 times greater than those used in the USA.

Structural Analysis Procedure

Approaches to analyze a structure subject to seismic load effects includes static methods (linear or nonlinear) and dynamic methods (response spectrum analysis or time history analysis).The more complex the building is and the greater the seismic hazard, the more rigorous analysis needs to be performed. Table 12 summarizes the requirements of ASCE - 7 and GB 50011 when selecting the structural analysis procedure. The analysis procedure required by ASCE – 7 is based on seismic design category and building configuration. GB 50011 requires that the analysis procedure be selected based on dynamic properties, building height, regularity and seismic hazard.

Table 12 Permitted Analytic Procedures

Analysis procedure	ASCE 7-05	GB 50011-2010
Equivalent static approach	1. All structures assigned to Seismic Design Category B or C 2. Structures assigned to Seismic Design Category D, E or F with the following characteristics: a) All structures of light-frame construction; or b) Regular structures with $T<3.5T_s$ or c) Irregular structures with $T<3.5T_s$ and not having torsional irregularities and not having vertical stiffness, weight or geometric irregulaties. 3. Structures assigned to Seismic Design Category A need only to be analyzed by applying lateral force equal to 1% of dead load (at each floor) to each level.	Structures with a linear first mode shape or structures not higher than 40m and with dominant shear deflection and vertically uniformly distributed stiffness

Analysis procedure	ASCE 7-05	GB 50011-2010
Modal response spectrum analysis	All structures	Structures not permitted for equivalent static procedure
Time history analysis		Extremely irregular structures, Type A structures or those high-rise structures listed in Table 13.

Table 13 Time History Analysis Should be Selected for the Following High-Rise Buildings in China

Intensity or Site class	Building height limit (m)
Intensity 8 and Site Class I or II Intensity 7	>100
Intensity 8 and Site Class III or IV	>80
Intensity 9	>60

Drift and Deflection

The design story drift (Δ) shall be computed as the difference of the deflections at the top and bottom of the story under consideration. ASCE – 7 uses Eq. 4 to calculate the deflection of Level *x*.

$$\delta_x = \frac{C_d \delta_{xe}}{I} \qquad \textbf{Eq. 4}$$

where

C_d = the deflection amplification factor depending on type of seismic lateral resisting system;
δ_{xe} = the deflection determined by an elastic analysis using design seismic load effect; and
I = the importance factor.

Table 14 Allowable Story Drift, Δ_a (ASCE – 7)

Structure	Occupancy Category		
	I or II	III	IV
Structures, other than masonry shear wall structures, 4 stories or less with interior walls, partitions, ceilings and exterior wall that have been designed to accommodate the story drift	$0.025h_{sx}$*	$0.020h_{sx}$	$0.015h_{sx}$
Masonry cantilever shear wall structures	$0.010h_{sx}$	$0.010h_{sx}$	$0.010h_{sx}$
Other cantilever shear wall structures	$0.007h_{sx}$	$0.007h_{sx}$	$0.007h_{sx}$
All other structures	$0.020h_{sx}$	$0.015h_{sx}$	$0.010h_{sx}$

* h_{sx} = the story height below Level *x*

The Chinese seismic code GB 50011 requires that the elastic story drift (Δu_e) is determined using seismic load effects of the frequent earthquake level with load factor of 1.0. Δu_e should not be greater than the allowable story drift in Table 15.

The Chinese code also requires that some structures have to be checked for elasto-plastic story drift criteria under seismic load effects of the rare earthquake event (Table 16). Nonlinear static or nonlinear time history analysis has to be performed to compute the elasto-plastic drift except that a simplified method may be used for concrete moment frames or concrete columns in a single story industrial building with no stiffness irregularity and not higher than 12-stories. Using the simplified method, the elasto-plastic story drift may be calculated from the following equations:

$$\Delta u_p = \eta_p \Delta u_e \qquad \textbf{Eq. 5}$$

$$\textbf{or } \Delta u_p = \mu \Delta u_y = \frac{\eta_p}{\xi_y} \Delta u_y \qquad \textbf{Eq. 6}$$

where
Δu_p = elasto-plastic story drift
Δu_e = elastic story drift under rare earthquake event
η_p = Amplification factor.

The elasto-plastic story drift, Δu_p, should not be greater than the allowable elasto-plastic story drift as shown in Table 17.

Table 15 Allowable Elastic Story Drift (GB 50011)

Structure	Allowable story drift ($\theta_e h$)
Concrete moment frame	0.00182h
Concrete moment frame –shear wall interactive system Concrete shear wall with flat plate floor Moment frame with a tube core	0.00125h
Concrete shear wall or tube within a tube	0.001h
Moment frame supporting discontinuous walls	0.001h
Mid-rise or high-rise steel structure	0.0033h

Table 16 Structures Required or Suggested to Check for Elasto-Plastic Story Drift

Required	Suggested
1.Tall single-story concrete bent frame with Seismic Intensity 9 or Seismic Intensity 8 with site class III or IV. 2. Concrete moment frame with story yielding ratio less than 0.5 and with Intensity 7 , 8 or 9 3. Steel structures higher than 150m 4. All Building Type A structures; and Building Type B: concrete or steel structures 5. Seismically isolated structures or structures with damping systems.	1. High-rise steel structures with height of less than 150m 2. Masonry structures with concrete moment frame supporting structures above 3. Shear wall structure with flat plate floor 4. Building Type B: concrete or Steel structures with Intensity 8 or Intensity 7 with site class III or IV 5. Structures listed in Table 13 and with vertical irregularity, i.e., beams, slabs or trusses supporting discontinuous walls or frames above.

Table 17 Allowable Elasto-Plastic Story Drift (GB 50011)

Structure	Allowable story drift ($\theta_p h$)
Single story concrete bent frame column	0.0333h
Concrete moment frame	0.02h
Ground-level Moment frame or shear wall supporting masonry structure above	0.01h
Concrete moment frame –shear wall interactive system; Concrete shear wall with flat plate floor; Moment frame with a tube core	0.01h
Concrete shear wall or tube within a tube	0.0083h
Mid-rise or high-rise steel structure	0.02h

Detailing Requirements

The 2009 IBC references and modifies material specific codes for detailing requirements (e.g., seismic design requirements for concrete structures are contained in Chapter 21 of ACI 318-08 *Building Code Requirements for Structural Concrete*). The Chinese seismic code GB 500111-2010 includes seismic design requirements for structures of concrete, steel, masonry/brick, wood or other materials. It is beyond possibility for this paper to compare all seismic provisions about detailing requirements between the two countries. Since reinforced concrete is the most common structural material in building construction in China, the comparisons presented herein focuses on reinforced concrete structures especially moment frames.

ACI 318-08 recognizes ordinary moment frames, intermediate moment frames, special moment frames (including precast concrete), intermediate structural walls and special structural walls (including precast concrete). The detailing requirements are related to type of structural framing and Seismic Design Category. The level of required detailing (the degree of required toughness) increases for structures progressing from ordinary through intermediate to special categories. Special moment frames must be used for buildings assigned to Seismic Design Categories D, E or F. Intermediate moment frames are not permitted for buildings assigned to Seismic Design Categories D, E or F. Ordinary moment frames are not permitted for buildings assigned to Seismic Design Categories C, D, E or F.

The Chinese seismic code requires that reinforced concrete structures be classified as Categories from I to IV based on seismic intensity, type of structural system and building height. The level of the detailing requirements decreases from I to IV. Table 18 shows seismic classifications for moment frames and shear walls. The height limits on buildings are set out in the Chinese seismic code and dependent on the structural material, the structural system and Seismic Intensity. Table 19 shows the maximum allowable height for reinforced concrete structures. For the buildings exceeding specified height limits, it is required that the design be subject to expert panel review and/or the jurisdiction's approval.

To provide a concrete moment frame column with some ductility, the Chinese Seismic Code limits the ratio between the axial design force and concrete compressive strength ($P_u/A_g f_c'$) based on the Seismic Category of the concrete moment frame (see Table 20). The ratio of area of longitudinal reinforcement to gross area should not be less than the ratios shown in Table 21. Transverse reinforcement as shown in Table 22 shall be provided over a length l_0 from each end of the column. Length l_0 should not be less than the largest of (a), (b), and (c):

(a) The depth of the column;
(b) One-sixth of the clear span of the column (one-third of the clear span for the columns at ground level); and
(c) 500mm.

Table 18 Seismic Classification of Reinforced Concrete Moment Frames and Shear Walls

Structure		Intensity									
		6		7			8			9	
Moment frame	Height (m)	≤24	>24	≤24		>24	≤24		>24	≤24	
	Seismic category	IV	III	III		II	II		I	I	
Shear wall	Height (m)	≤80	>80	≤24	24~80	>80	≤24	24~80	>80	≤24	24~60
	Seismic category	IV	III	IV	III	II	III	II	I	II	I

Table 19 Maximum Allowable Heights of Cast-in-Place Reinforced Concrete Structures[1] (m)

Structural system	Seismic Intensity				
	6	7	8 (0.2g)	8(0.3g)	9
Moment frames	60	50	40	35	24
Moment frame – shear wall system	130	120	100	80	50
Shear walls	140	120	100	80	60
Systems with discontinuous shear walls supported by moment frames	120	100	80	50	Not permitted
Moment frames with a tube core	150	130	100	90	70
Tube within a tube	180	150	120	100	80
Shear walls with flat plate floor	80	70	55	40	Not permitted

[1]The limits should be reduced for structures on the site classified as Site Class IV.

Table 20 Allowable Ratio Between the Axial Design Force and Concrete Compressive Strength ($P_u/A_g f_c'$)

Structural system	Seismic Category			
	I	II	III	IV
Columns of Concrete moment frame	0.65	0.75	0.85	0.90

Table 21 The Minimum Ratio of Area of Column Longitudinal Reinforcement to Column Gross Area[1, 2]

Type	Seismic Category			
Column	I	II	III	IV
Middle/Boundary columns	1.0%	0.8%	0.7%	0.65%
Corner columns or columns supporting discontinuous elements	1.2%	1.0%	0.9%	0.8%

[1]The minimum ratio should be increased by 0.1% for high-rise buildings on the site classified as Class IV.
[2]The minimum ratio should be increased by 0.2% for moment frame columns.

Table 22 Maximum Spacing and Minimum Diameter of Transverse Reinforcement for Column Confinement Areas

Seismic Category	Maximum spacing of ties (mm) (whichever is smaller)	Minimum diameter of ties (mm)
I	6*d*, 100	10
II	8*d*, 100	8
III	8*d*, 150 (100 at footing)	8
IV	8*d*, 150 (100 at footing)	6 (8 at footing)

Typical Seismic Design Procedures

This section is summarized in Table 23.

Table 23 Comparison of Seismic Design Procedures

Typical seismic design steps in the U.S.	Typical seismic design steps in China
1.Determine Maximum Considered Earthquake (MCE) spectral response accelerations, Ss (02 second) and S_1 (1 second) from USGS map	1. Determine Basic Seismic Fortification Intensity and Seismic Group.
2. Determine if the structure is exempt from seismic requirements.	2. Determine if the structure is exempt from seismic requirements.
3. Determine Occupancy/Risk Category (I – IV) and Seismic Use Group.	3a. Determine building seismic classification (A – D); 3b.Adjust Basic Seismic Fortification Intensity based on building type.
4. Determine the site/soil class (A – F). Select the site coefficients F_a and F_v based on site class and mapped spectral response accelerations.	4a. Classify the site as Favorable, Unfavorable or hazardous; 4c. Determine the site/soil class (I – IV).
5. Calculate site class-adjusted spectral response accelerations, $S_{MS} = F_a S_S$ $S_{M1} = F_v S_1$	5a. Determine characteristic period, T_g based seismic group and site class; 5b. Determine maximum seismic influence coefficient, α_{max}, for frequent earthquake and rare earthquake.
6. Calculate the design spectral response accelerations, $S_{DS} = (2/3) S_{MS}$ $S_{D1} = (2/3) S_{M1}$	
7. Determine the building's seismic design category (A – F) based on Seismic Use Group and design spectral response accelerations.	6. Select the seismic force resisting system
8. Select the seismic force resisting system.	
9. Determine Response Modification Coefficient, R, System Overstrength Factor, Ω_0, and Deflection Amplification Factor, C_d based on selected seismic force resisting system.	
10. Calculate the structure's approximate fundamental period, T.	7. Calculate the structure's approximate fundamental period, *T*.
11. Select analysis procedure based on Seismic Design Category and structural characteristics (e.g., any irregularities, period, building height).	8. Select analysis procedure based on dynamic properties, building height, regularity and seismic intensity.
12. Calculate seismic response coefficient $C_s = S_{DS}/(R/I)$ and seismic base shear, $V = C_s W$, where I = the seismic importance factor and W = the effective seismic weight.	9a. Construct seismic influence coefficient (α) curve as a function of fundamental period (*T*), Based on the parameters of characteristic period, T_g, maximum seismic influence coefficient, α_{max}, and damping ratio, ζ. 9b. Determine seismic influence coefficient (α) from the constructed curves ($T \sim \alpha$) for frequent earthquake and rare earthquake.
13. Obtain seismic load effects for all members of lateral system using the analysis procedure selected at step 11.	10. Obtain seismic load effects for all members of lateral system using the analysis procedure selected at step 6.
14. Perform combinations of seismic load effect with other load effects taking into account system overstrength when specifically required.	11. Perform combinations of seismic load effect of frequent earthquake event with other load effects.
15. Check building story drift, Δ, against the allowable building drift Δa.	12a. Check elastic story drift Δu_e (under frequent earthquake load effect) against the allowable elastic story drift $\theta_e h$. 12b. If required, check for elasto-plastic story drift criteria under rare earthquake load effect.

Typical seismic design steps in the U.S.	Typical seismic design steps in China
16. Design structural member following material specific seismic detailing requirements.	13. Design structural member following material specific seismic detailing requirements.
17. Determine structural inspection and testing requirements.	
18. Submit construction documents to the jurisdiction having authority.	14. Prepare design documents and submit to the authority for review.
19. Perform structural observation and review structural material test results and inspection reports.	15. Perform structural inspection and review structural material test results.

Concluding Remarks

While seismic design codes for all countries share similar objectives, the seismic code for each country had its own path of development. For common issues, different methodologies and approaches may be adopted along the way. Seismic codes are always in the process of evolution. The comparison of the seismic design codes of the U. S. and China illustrates the differences and similarities of methodologies, in order to facilitate the exchange of seismic design practice and experience.

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Target Seismic Reliability Against Collapse in USA Codes and Assessment of Variations in Expected Performance

***James Robert Harris, P.E., Ph.D.*[1]**

Introduction

The intellectual basis for standards for structural engineering design to resist the effects of earthquakes is in the midst of a significant evolution in the United States. Improvements in our understanding of the nature of strong ground shaking and our ability to predict the behavior of structures subjected to such motions is making possible quantitative validation of target reliabilities. In the past the question "how safe is safe enough?" had to be answered on the basis of empirical correlations between seismic intensity and structural performance, with a healthy dose of engineering judgment. Now the tools of reliability analysis are being applied to assist the judgments and place the provisions for seismic design on a basis similar to those for resistance to gravity and wind loadings. This paper will summarize aspects of the recently completed project "Quantification of Building Seismic Performance Factors," published as FEMA P695 (FEMA 2009) and known as the ATC 63 project, and how that project has affected the primary standard for seismic-resistant design, *Minimum Design Loads for Buildings and Other Structures*, published as standard ASCE/SEI 7-2010 (ASCE 2010).

The design limit state of resistance to seismic effects is unlike any of the other loads considered in the ASCE 7 Standard. Due to the high demand exerted by earthquakes, the earthquake limit state is based on inelastic system performance rather than member limit state performance. Energy dissipation through many cycles of inelastic strain is necessary for safe performance. The overwhelming majority of building design is based upon a linear elastic analysis of response. In order to provide a method to use linear elastic procedures, seismic design coefficients are specified to adjust the computed elastic response to predict the nonlinear response. The coefficients are illustrated in Figure 1.

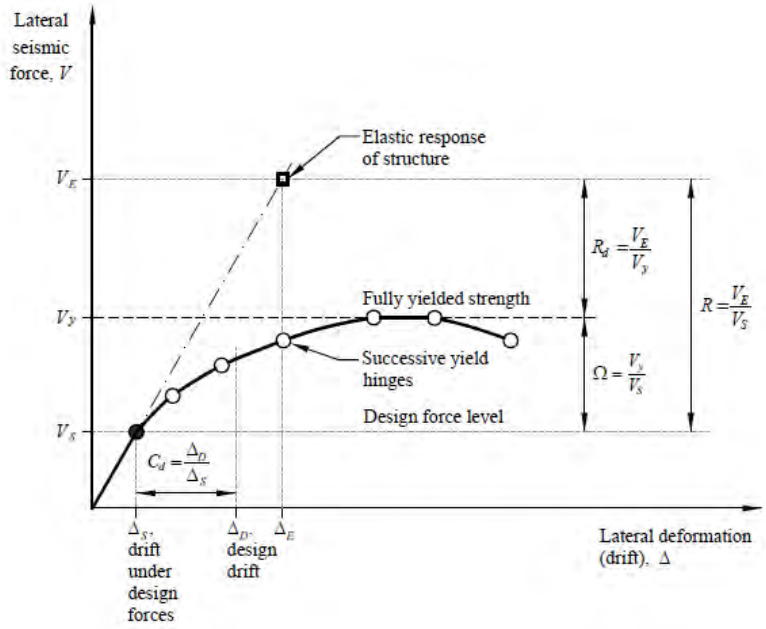

Figure 1 Graphic definition of seismic design factors (FEMA P750)

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The coefficients include:

- ***R***, the "response modification factor" to reduce the inertial forces to a design yield level,
- C_d, the "deflection amplification factor" to amplify the displacements from the level corresponding to the reduced forces to those anticipated in the nonlinear response, and
- Ω_0, "the system overstrength factor" to amplify the design force to an approximation of the maximum force resisted in the system.

The equations that define these coefficients are shown in figure 1. These system response coefficients govern the requirements for strength and stiffness of the seismic force-resisting system, which means they significantly affect the economy of construction and therefore are of considerable interest. They, together with the specified ground motions and the details to deliver the desired energy dissipation control the reliability of structures designed in accord with current seismic codes in the USA. Note that the figure defines Ω, not Ω_0. The former is the ratio for a specific system; the latter is the value specified for design purposes to protect against fragile limits states within the system. The specified value is intended to be on the high, or conservative, side of the average.

Background

Guidelines for seismic resistant design first appeared in the USA in the mid 1920's, and the first mandatory codes were introduced in California following the 1933 Long Beach Earthquake. These early codes were simple by today's standards, requiring the strength to resist a static lateral force based upon a percentage of the weight of the building. Design provisions of the era were based upon allowable stress design, and the force levels were set based upon empirical evaluation of success and failure in contemporary earthquakes. In the 1950's the level of design force and the distribution of forces along the height of multistory structures began to recognize the results of early studies of the dynamic response to ground shaking. At about this time a concept requiring different levels of force for different types of structural systems was introduced, and shortly thereafter the first concepts of detailing reinforced concrete for ductility began to appear. Only four types of structural systems were recognized, and they did not depend on the material of construction, only the configuration of the elements.

In the 1970's the explicit recognition of ductility in response was developed in the ATC-3 project (ATC 1978), along with the concept of probabilistic mapping of seismic ground shaking hazards. It took another 20 years for these issues to be fully implemented in building codes. The seismic hazard maps were based upon a probability of 10% that the ground motion would be exceeded in a 50 year reference period, which is a nominal 500 year mean return interval.

In the 1990's the seismic hazard mapping was strongly revised. The probability of the ground motion was changed to a 2% chance in 50 years, or a nominal 2500 mean return interval. The acceleration parameters on these maps were named the "maximum considered earthquake ground motions", or the MCE. In conjunction with this change, the design limit state was changed from "substantial yield" to "collapse prevention". This change in design limit state was incorporated very coarsely; the MCE motion parameters include a reduction factor of 2/3, which equivalent to multiplying all the ***R*** factors by a factor of 1.5.

Specification of the R factor originally distinguished about 20 different structural systems, and that has now grown to nearly 90 systems. Many of these newly defined systems have very little or no history of performance in actual earthquakes. Wity the number and variety of seismic force-resisting systems proliferating, the need for a systematic methodology to validate the seismic design parameters became pressing, which led FEMA to sponsor the ATC 63 project.

Overview of FEMA P695 Methodology

The FEMA P695 Methodology has been developed to provide a rational basis for establishing the seismic performance factors, especially the ***R*** factor.[2] It is based upon the life safety objective of the NEHRP[3] Recommended Provisions (FEMA 2004 and FEMA 2009). It does not consider the higher performance desired for essential or high risk facilities. Life safety risk depends on many factors, including number of occupants, variation in occupancy over time, casualty rates. The Methodology adopts structural collapse as a single metric for life safety, thus systems designed with parameters validated by the Methodology will provide an approximate uniform protection against collapse of the structural system. Failure of individual components that do not lead to global or significant local collapse do not constitute collapse, and components that are not structural are not considered.

Figure 2 adapts the explanation of figure 1 for the purpose of this Methodology. The seismic performance parameters are defined in terms of equations, which in all cases are dimensionless ratios of force, acceleration or displacement. However, in the figure, graphical license is taken in two ways. First, seismic performance factors are depicted as incremental differences between two related parameters, rather than as ratios of the parameters. Second, as a consequence of being depicted as incremental differences, seismic performance factors are shown on plots with units, when, in fact, they are dimensionless.

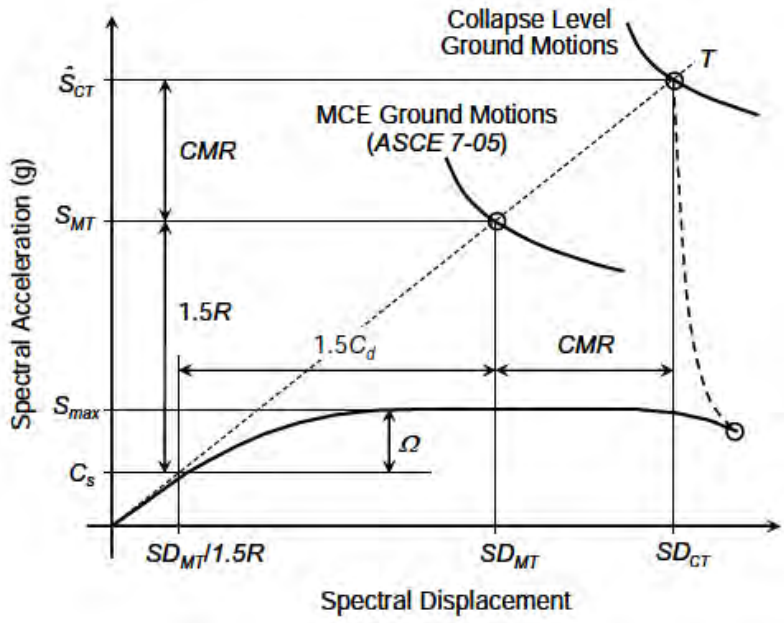

Figure 2: Seismic Response Parameters (After FEMA P695)

Figure 2 is plotted in spectral coordinates (spectral acceleration and spectral displacement) rather than pushover force and displacement, but the concepts are the same, given the assumption that all the effective seismic mass of the structures participates in the fundamental mode at period T, which defines the slope of the dashed line.. $\boldsymbol{S_{MT}}$ is the acceleration corresponding to the MCE ground motion, which is 1.5 times the "design" earthquake represented in figure 1. In the Methodology $\boldsymbol{C_d}$ is set equal to ***R***, which is consistent with a long standing idealization attributed to Nathan Newmark (Newmark 1982). For systems in which the actual damping at large motions is substantially different than 5% of critical damping, this idealization is not precise, because the mapped spectral response motions are developed for 5% of critical damping.

[2] The report is available in electronic format (pdf) at http://www.fema.gov/library/irlSearchFemaNumber.do Acknowledgement is given to FEMA, ATC, and the leadership of the ATC 63 project team, specifically Charles Kircher and Jon A. Heintz, that most of the following material is abstracted from that report.
[3] NEHRP is the National Earthquake Hazard Reduction Program.

Figure 2 includes a line for "Collapse Level Ground Motions", and the point at which the linear response intersects that line defines S_{CT}, the spectral acceleration corresponding to collapse of the system. The median of the values found in response to a defined set of ground motions is shown on the figure as $\hat{S}_{CT}$, and the ratio of that acceleration to S_{MT} defines the Collapse Margin Ratio, or ***CMR***. After accounting for uncertainty from various sources, the ***CMR*** is the criterion by which the collapse safety level is determined in the Methodology.

General Framework

The Methodology consists of a framework for establishing seismic performance factors (SPFs) that involves the development of detailed system design information and probabilistic assessment of collapse risk. It utilizes nonlinear analysis techniques, and explicitly considers uncertainties in ground motion, modeling, design, and test data. The technical approach is a combination of traditional code concepts, advanced nonlinear dynamic analyses, and risk-based assessment techniques.

Reliable analysis requires valid ground motions and representative nonlinear models of the seismic force-resisting system. Development of representative models requires both detailed design information and comprehensive nonlinear test data on structural components and assemblies that make up the system of interest. A summary of the key elements of the Methodology includes:

- Ground motions for response analysis
- System design and detailing requirements
- Test data to form the basis for analytical modeling
- Methods of response analysis
- Peer review of all aspects

The Methodology includes fully defined characterizations of ground motion and methods of analysis that are generically applicable to all seismic force-resisting systems. Design information and test data will be different for each system, and may not yet exist for new systems. The Methodology includes requirements for defining the type of design information and test data that are needed for developing representative analytical models of the seismic force-resisting system of interest.

Rather than establishing minimum requirements for design information and test data, the use of better quality information is encouraged by rewarding systems that have "done their homework." Systems that are based on well defined design requirements and comprehensive test data will have inherently less uncertainty in their seismic performance. Such systems will need a lower margin against collapse to achieve an equivalent level of safety, as compared to systems with less robust data.

Due to the complexity of nonlinear dynamic analysis, the difficulty in modeling inelastic behavior, and the need to verify the adequacy and quality of design information and test data, the Methodology requires independent peer review of the entire process.

Description of Process

The steps comprising the Methodology are shown in Figure 3. These steps outline a process for developing system design information with enough detail and specificity to identify the permissible range of application for the proposed system, adequately simulate nonlinear response, and reliably assess the collapse risk over the proposed range of applications. Each step is linked to a corresponding chapter in FEMA P695, and described in the sections that follow.

Develop System Concept

The process begins with the development of a well-defined concept for the seismic-force-resisting system, including type of construction materials, system configuration, inelastic dissipation mechanisms, and intended range of application. The amount of documentation necessary to describe the system and characterize system

components will vary, depending on the novelty and uniqueness of the proposed system relative to other well-established structural systems.

Obtain Required Information

Required information includes detailed design requirements and results from material, component, and system testing. Design requirements include the rules that engineers will use to proportion and detail structural components of the system, and limits in the application of the system. Test results include information on component material properties, force-deformation behavior, and nonlinear response.

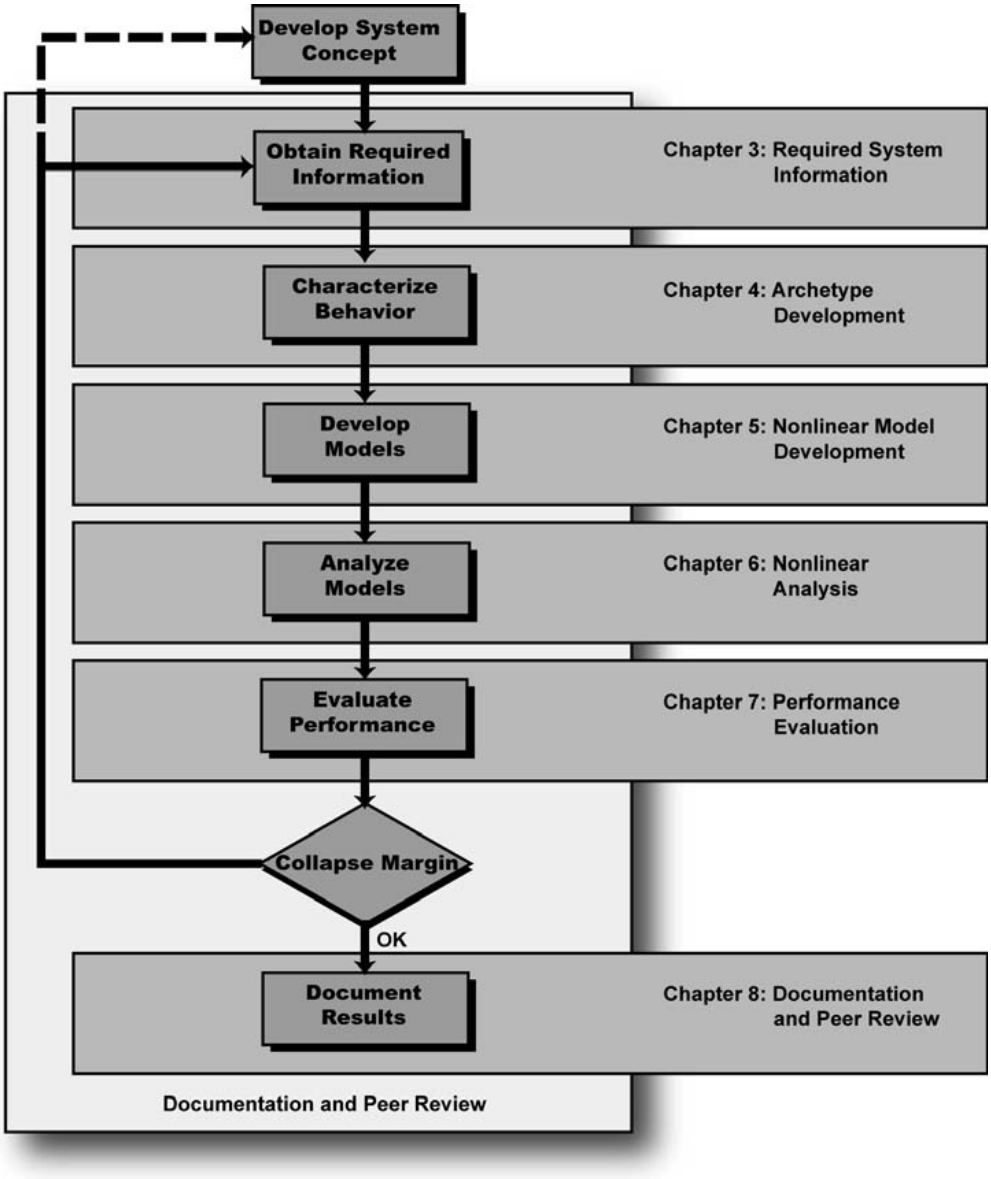

Figure 3 Overview of Process (Chapter citations are to FEMA P695)

Comprehensive design provisions are developed within the context of the seismic provisions of ASCE/SEI 7-05 (ASCE 2006) and other applicable standards. The provisions should address all significant aspects of the design and detailing of the seismic force-resisting system and its components. Important exceptions and deviations from established building code requirements should be clearly stipulated. Design provisions should address criteria for determining minimum strength and ensuring inelastic deformation capacity through a combination of system design requirements, component design and detailing requirements, and project-specific testing requirements. Design provisions should also specify the seismic performance factors (R , Ω_0, C_d) and other criteria (e.g., drift limits, height limits, and seismic usage restrictions) that are proposed as part of the design basis for the new system.

Test data are necessary for characterizing the strength, stiffness and ductility of the materials, members, and connections of the proposed system. Test data are also necessary for establishing properties of the nonlinear analysis models used to assess collapse risk. Test data and other substantiating evidence should be acquired as the basis of the design provisions and for calibrating analysis models. Design requirements should be documented with supporting evidence to ensure sufficient strength, stiffness and ductility of the proposed system, across the intended range of application of the system.

Characterize Behavior

System behavior is characterized through the use of structural system archetypes. The concept of an archetype is described in Chapter 4 of FEMA P695. Establishment of archetypes begins with identifying the range of features and behavioral characteristic that describe the bounds of the proposed seismic force-resisting system.

Archetypes provide a systematic means for characterizing permissible configurations and other significant features of the proposed system. Like building code provisions, archetypical systems are intended to represent typical applications of a seismic force-resisting system, recognizing that it is practically impossible to envision or attempt to quantify performance of all possible applications. They should, however, reflect the degree of irregularity permitted within standard building code provisions.

The challenge in defining and assessing structural system archetypes is in narrowing the range of parameters and attributes to the fewest and simplest possible, while still being reasonably representative of the variations that would be permitted in actual structures. In addition to ground motion intensity (Seismic Design Category), the following characteristics are considered in defining structural system archetypes:

- building height;
- fundamental period;
- structural framing configurations;
- framing bay sizes or wall lengths;
- magnitude of gravity loads; and
- member and connection design and detailing requirements.

Structural system archetypes are assembled into bins called performance groups, which reflect major divisions, or changes in behavior, within the archetype design space. The collapse safety of the proposed system is then evaluated for each performance group.

In the collapse assessment process, only framing components that are specifically designated as part of the seismic-force-resisting system are included in the archetypes. While it is recognized that other portions of the building (e.g., components of the gravity system or certain nonstructural components) can significantly affect collapse behavior, such components, which are not controlled by seismic force-resisting system design requirements, cannot be relied upon for reducing collapse risk.

Develop Analytical Models

Structural system archetypes provide the basis for preparing a finite number of trial designs and developing a corresponding number of idealized nonlinear models that sufficiently represent the range of intended applications for a proposed system. Index archetype models are developed to provide the most basic (generic) idealization of an archetypical configuration, while still capturing significant behavioral modes and key design features of the proposed seismic force-resisting system.

Designs consider the range of seismic criteria for each applicable Seismic Design Category, variations in gravity loads, and other distinguishing features including alternative geometric configurations, varying heights, and different tributary areas that impact seismic design or system performance. To the extent possible, nonlinear models include explicit simulation of all significant deterioration mechanisms that could lead to structural collapse.

Recognizing that it is not always possible (or practical) to simulate all possible collapse modes, the Methodology includes provisions for assessing the effects of behaviors that are not explicitly simulated in the model, but could trigger collapse. Nonlinear models must account for the seismic mass that is stabilized by the seismic-force-resisting system, including the destabilizing P-delta effects associated with the seismic mass. In most cases, elements are idealized with phenomenological models to simulate complicated component behavior. In some cases, however, two-dimensional or three-dimensional continuum finite element models may be required to properly characterize behavior. Models are calibrated using material, component,

or assembly test data and other substantiating evidence to verify their ability to simulate expected nonlinear behavior.

Analyze Models

Collapse assessment is performed using both nonlinear static (pushover) and nonlinear dynamic (response history) analysis procedures. Nonlinear static analyses are used to help validate the behavior of nonlinear models and to provide statistical data on system overstrength and ductility capacity.

Nonlinear dynamic analyses are used to assess median collapse capacities and collapse margin ratios. Nonlinear response is evaluated for a set of pre-defined ground motions that are used for collapse assessment of all systems. Two sets of ground motion records are provided for nonlinear dynamic analysis. One set includes 22 ground motion record pairs from sites located greater than or equal to 10 km from fault rupture, referred to as the "Far-Field" record set. The other set includes 28 pairs of ground motions recorded at sites less than 10 km from fault rupture, referred to as the "Near-Field" record set. While both Far-Field and Near-Field record sets are provided, only the Far-Field record set is required for collapse assessment. This is done for reasons of practicality, and in recognition of the fact that there are many unresolved issues concerning the characterization of near-fault hazard and ground motion effects. The Near-Field record set is provided as supplemental information to examine issues that could arise due to near-fault directivity effects, if needed.

The record sets include records from all large-magnitude events in the Pacific Earthquake Engineering Research Center (PEER) Next-Generation Attenuation (NGA) database (PEER, 2006). Records were selected to meet a number of sometimes conflicting objectives. To avoid event bias, no more than two of the strongest records have been taken from any one earthquake, yet the record sets have a sufficient number of motions to permit statistical evaluation of record-to-record (RTR) variability and collapse fragility. Strong ground motions were not distinguished based on either site condition or source mechanism. The Far-Field and Near-Field record sets are provided in Appendix A of the FEMA P695 report, along with background information on their selection.

For collapse evaluation, ground motions are systematically scaled to increasing earthquake intensities until median collapse is established. Median collapse is the ground motion intensity in which half of the records in the set cause collapse of an index archetype model. This process is similar to, but distinct from the concept of incremental dynamic analysis (IDA), as proposed by Vamvatsikos and Cornell (2002).

Figure 4 shows an example of IDA results for a single structure subjected to a suite of ground motions of varying intensities. In this illustration, sidesway collapse is the governing mechanism, and collapse prediction is based on lateral dynamic instability, or excessive lateral displacements. Using collapse data obtained from IDA results, a collapse fragility can be defined through a cumulative distribution function (CDF), which relates the ground motion intensity to the probability of collapse (Ibarra et al., 2002). Figure 5 shows an example of a cumulative distribution plot obtained by fitting a lognormal distribution to the collapse data from Figure 4.

While the IDA concept is useful for illustrating the collapse assessment procedure, the Methodology only requires calculation of the median collapse point, which can be calculated with fewer nonlinear analyses than would otherwise be required to calculate the full IDA curve.

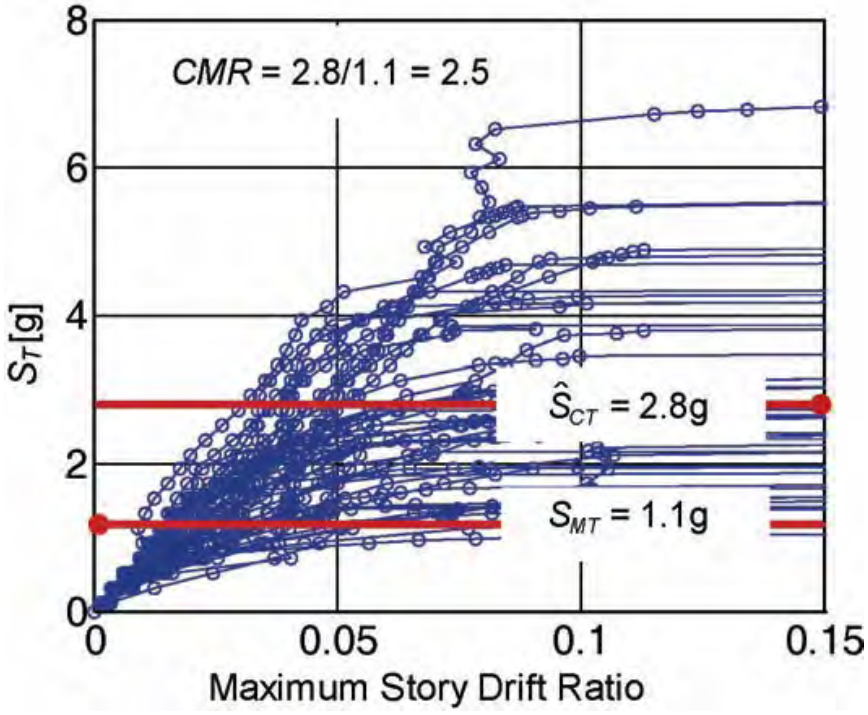

Figure 4: Incremental dynamic analysis response plot of spectral acceleration versus maximum story drift for one particular archetype for which the MCE spectral acceleration is 1.1g

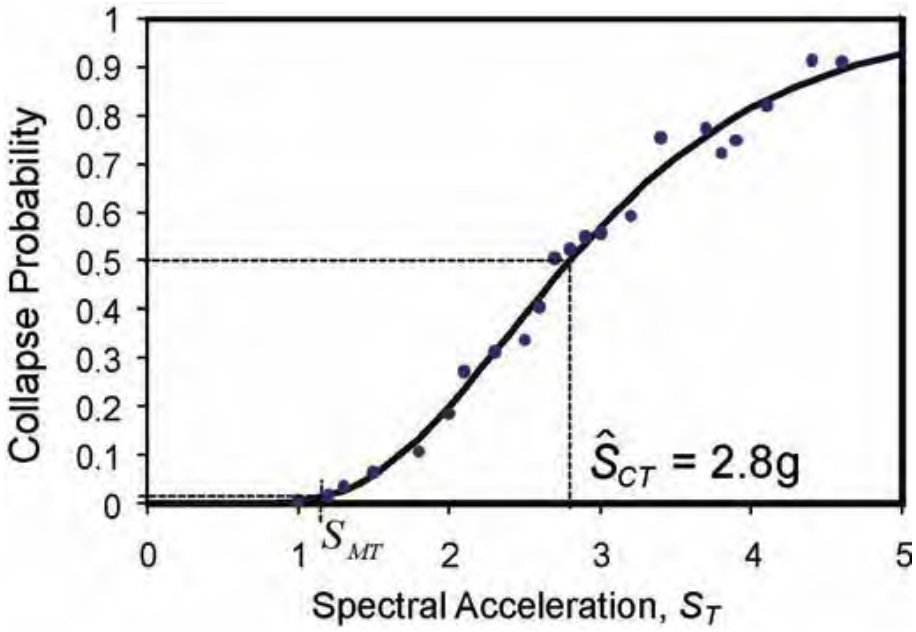

Figure 5: Collapse fragility curve, or cumulative distribution function for one archetype

Evaluate Performance

The performance evaluation process utilizes results from nonlinear static analyses to determine an appropriate value of the system overstrength factor, Ω_o, and results from nonlinear dynamic analyses to evaluate the acceptability of a trial value of the response modification coefficient, ***R***. The deflection amplification factor, C_d, is derived from an acceptable value of ***R***, with consideration of the effective damping of the system of interest.

The trial value of the response modification coefficient, ***R***, is evaluated in terms of the acceptability of a calculated collapse margin ratio, which is the ratio of the ground motion intensity that causes median collapse, to the Maximum Considered Earthquake (MCE) ground motion intensity defined by the building code. Acceptability is measured by comparing the collapse margin ratio, after some adjustment, to acceptable values that depend on the quality of information used to define the system, total system uncertainty, and established limits on acceptable probabilities of collapse.

To account for unique characteristics of extreme ground motions that lead to building collapse, the collapse margin ratio is converted to an adjusted collapse margin ratio. The adjustment is based on the shape of the spectrum of rare ground motions, and is a function of the structure ductility and period of vibration. Systems with larger ductility and longer periods benefit by larger adjustments. The background and development of this adjustment to account for the effects of spectral shape are provided in an Appendix of FEMA P695.

Acceptable values of the collapse margin ratio are defined in terms of an acceptably low probability of collapse for MCE ground motions, considering uncertainty in collapse fragility. Systems that have more robust design requirements, more comprehensive test data, and more detailed nonlinear analysis models, have less collapse uncertainty, and can achieve the same level of life safety with smaller collapse margin ratios. The following sources of uncertainty are explicitly considered:

- record-to-record uncertainty;
- design requirements-related uncertainty;
- test data-related uncertainty; and
- modeling uncertainty.

The probability of collapse due to MCE ground motions applied to a population of archetypes is limited to 10%, on average. Each performance group is required to meet this average limit, recognizing that some individual archetypes could have collapse probabilities that exceed this value. The probability of collapse for individual archetypes is limited to 20%, or twice the average value, to evaluate acceptability of potential "outliers" within a performance group. It should be noted that these limits were selected based on judgment. Within the performance evaluation process, these values can be adjusted to reflect different values of acceptable probabilities of collapse that are deemed appropriate by governing jurisdictions or other authorities employing this Methodology to establish seismic design requirements for a proposed system.

If the adjusted collapse margin ratio is large enough to result in an acceptably small probability of collapse at the MCE, then the trial value of ***R*** is acceptable. If not, the system must be redefined by adjusting the design requirements, re-characterizing behavior, or redesigning with new trial values, and then re-evaluated using the Methodology. In some cases, inadequate performance could require extensive revisions to the overall system concept.

Document Results

The results of system development efforts must be thoroughly documented for review and approval by an independent peer review panel, review and approval by an authority having jurisdiction, and eventual use in design and construction. Documentation is required at each step of the process. It should describe seismic design rules, range of applicability of the system, testing protocols and results, rationale for the selection of structural system archetypes, results of analytical investigations, evaluation of quality of information, quantification of uncertainties, results of performance evaluations, and proposed seismic performance factors.

Documentation should be of sufficient detail and clarity to allow an unfamiliar structural engineer to properly implement the design, and an unfamiliar reviewer to evaluate compliance with the design requirements.

Documentation should also provide sufficient information to allow peer reviewers, code authorities, or material standard organizations to assess the viability of the proposed system and the reasonableness of the proposed seismic performance factors.

Peer Review

Peer review by an independent team of experts is a requirement of the Methodology, and should be an integral part of the process at each step. Implementation of the Methodology involves much uncertainty, judgment and potential for variation. Deciding on an appropriate level of detail to adequately characterize performance of a proposed system should be performed in collaboration with a peer review panel, on an ongoing basis, during developmental efforts.

The peer review panel is responsible for reviewing and commenting on the approach taken by the system development team, including the extent of the experimental program, testing procedures, design requirements, development of structural system archetypes, analytical approaches, extent of the nonlinear analysis investigation, and the final selection of the proposed seismic performance factors. Members of the peer review panel must be qualified to critically evaluate the development of the proposed system including testing, design, and analysis, and sufficiently independent from the system development team to provide an unbiased assessment of the developmental process.

The peer review panel, and their involvement, should be established early to clarify expectations for the collapse assessment. The peer review team is expected to exercise considerable judgment in evaluating all aspects of the process, from definition of the proposed system, to establishment of design criteria, scope of testing, and extent of analysis deemed necessary to adequately evaluate collapse safety. Details on the required peer review process, and guidance on the selection of peer review panel members, are provided in FEMA P695.

Quantified Performance Objectives in ASCE/SEI 7-2010

The Applied Technology Council has been working on another project with funding from FEMA that is very pertinent to the subject of structural reliability and earthquakes: the ATC 58 project to develop Next Generation Performance-based Seismic Design Guidelines. The purpose of the project is to develop a series of resource documents that define procedures that can be used to reliably and economically design new buildings or upgrade existing buildings to attain desired performance goals, and to assist stakeholders in selecting appropriate design performance goals for individual buildings. The project includes the establishment of a methodology for predicting the earthquake performance of buildings characterized in terms of probable life loss, repair costs and time out of service resulting from earthquake effects, expressed in a variety of formats useful to different stakeholders and decision makers. The ultimate goals of performance-based design are the development of practical design criteria that give the building owner and regulator the ability to select a building's desired performance capability as well as to optimize the performance of code-designed buildings, relative to society’s needs. While the project is funded under seismic programs, the intent is that the technologies developed in this program will be directly relevant and applicable to other extreme events, such as blast, fire and tornadic winds.

Reliability-based load combinations for strength limit state design were introduced in the 1982 edition of the standard Minimum Design Loads for Building and Other Structures (then developed by a committee operating under a secretariat at the National Bureau of Standards and issued as standard ANSI A58.1 (ANSI 1982)). The load factors were coordinated with resistance factors specified in standards for design of structural materials. To a great extent the level of reliability was calibrated to successful experience with selected common designs. The nominal computed reliability corresponded (very approximately) to 0.15% chance of failure in a 50 year reference period for structural members in structures of ordinary occupancy where the limit state gave some warning of collapse and the extent of failure would be limited. This is a considerably

lower risk than the basis developed in FEMA P695. The 10% chance of collapse given occurrence of the MCE ground motion is approximately a 1% chance of collapse in a 50 year reference period.

It should be recalled that these probabilities are computed from predictive models. Engineering judgment indicates that real failure rates are actually lower, probably because there are unrecognized conservative assumptions in the analytical models used to develop the probabilistic computations. In the case of earthquakes it may be that the actual risk of collapse varies across the spectrum of hazard level.

The ATC projects are indicative of a trend in the highest level practice of structural engineering towards performance-based procedures to design important and expensive projects. This trend has influenced a change in the ASCE/SEI 7 Standard. The 2010 edition includes a section permitting design by performance-based procedures that is more extensive than traditional "alternate means and materials" clauses in most model building standards. The commentary gives quantitative guidance for validating a performance-based design in terms of acceptable probabilities of failure that are consistent with the load combinations for gravity loads and wind. It then gives a second set of acceptable probabilities for load combinations that include earthquake effects, which are consistent with the FEMA P695 Methodology and extrapolated for other than ordinary buildings. Table 1 summarizes these probabilities of failure.

Load Combination	Limit State	Risk Category			
		I	II	III	IV
Dead, Live, Wind, Snow, Rain, Atmospheric Ice, Flood:	Failure with warning and of limited extent	$P_F = 1.25x10^{-4}$ $\beta = 2.5$	$P_F = 3.0x10^{-5}$ $\beta = 3.0$	$P_F = 1.25x10^{-5}$ $\beta = 3.25$	$P_F = 5.0x10^{-6}$ $\beta = 3.5$
P_F = annual probability of failure	Failure without warning or of wide spread extent	$P_F = 3.0x10^{-5}$ $\beta = 3.0$	$P_F = 5.0x10^{-5}$ $\beta = 3.5$	$P_F = 2.0x10^{-6}$ $\beta = 3.75$	$P_F = 7.0x10^{-7}$ $\beta = 4.0$
β = reliability index for 50 year exposure	Failure without warning and of wide spread extent	$P_F = 5.0x10^{-6}$ $\beta = 3.5$	$P_F = 7.0x10^{-7}$ $\beta = 4.0$	$P_F = 2.5x10^{-7}$ $\beta = 4.25$	$P_F = 1.0x10^{-7}$ $\beta = 4.5$
Earthquake, probability of failure given the occurrence of MCE ground motions	Total or partial collapse	10% (approx $2.0x10^{-4}$ annual)		6%	3%
	Failure that could result in danger to individual lives	25%		15%	10%

Table 1 Probabilities of Failure from ASCE/SEI 7-2010 Commentary on Performance- Based Design

A brief examination will show that there is a significant difference between the accepted reliability depending on whether earthquake is part of the hazard or not. Given the power of strong earthquakes, it would be unrealistic to expect equality. This means that there is an assumed risk with construction in seismically active areas. It would also be unrealistic to expect that targets for reliability will be static; refinements and perhaps significant changes could occur in the future, particularly if more economical methods are developed to construct more reliable structures.

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Preparation of New USA Seismic Design Maps and Associated Web Application

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Abstract

In April of 2008, the United States Geological Survey (USGS) completed its latest update of the National Seismic Hazard Maps. This update was timed for use in developing new seismic design maps for USA model building codes. In collaboration with the USGS, the Building Seismic Safety Council (BSSC), with funding from the Federal Emergency Management Agency (FEMA), updated the methodologies used to derive seismic design maps from underlying hazard maps. Based on both the 2008 USGS National Seismic Hazard Maps and the new BSSC methodologies, the USGS has prepared seismic design maps for the *2009 NEHRP Provisions*, the *2010 ASCE 7 Standard*, the *2012 International Building Code*, and the *2012 International Residential Code*. In addition to the probabilistic uniform-hazard National Seismic Hazard Maps, this preparation included computation of (i) deterministic ground motion values and (ii) risk coefficients which transform uniform-hazard values into "uniform-risk" ground motions for use in design that explicitly targets a specified level of risk, in this case 1% probability of collapse in 50 years. This paper provides an overview of these computations and explains the USGS implementation of the new BSSC methodologies for deriving seismic design maps from hazard maps. In addition, it describes an associated web application developed by the USGS for obtaining values from the new seismic design maps in a user-friendly and accurate manner.

Background & Introduction

The 2008 update of the USGS National Seismic Hazard Maps incorporates new seismic, geologic, and geodetic information on earthquake rates and associated ground shaking (Petersen et al., 2008). The 2008 maps supersede versions released in 1996 and 2002. Updating the maps involved interactions with hundreds of scientists and engineers at regional and topical workshops. The USGS also solicited advice from working groups, expert panels, State geological surveys, Federal agencies, and hazard experts from industry and academia. The most significant changes to the 2008 maps fall into two categories: 1) changes to earthquake source and occurrence rate models and 2) changes to models of ground shaking caused by earthquakes, both based on new published studies. For example, the Working Group on California Earthquake Probabilities revised the California earthquake rate model, and the Pacific Earthquake Engineering Research Center developed new "Next Generation Attenuation" (NGA) crustal ground-motion models. The new 2008 maps represent the best available science as determined by the USGS from the extensive information-gathering and review process, including three expert panels assembled to provide advice. The maps are used for insurance-related earthquake risk modeling in addition to building code and other applications. Changes will be made in future versions of the maps as new information on earthquake sources and resulting ground motion is gathered and processed.

While updating the National Seismic Hazard Maps, the USGS collaborated with the Building Seismic Safety Council (BSSC) funded by the Federal Emergency Management Agency (FEMA) to prepare updated and new seismic design maps for the *2009 NEHRP Recommended Seismic Provisions for New Buildings and Other Structures*. The end results were so-called Risk-Targeted Maximum Considered Earthquake (MCE_R) ground motions and new Peak Ground Acceleration (PGA) maps.[1] The former were proposed by the BSSC Seismic Design Procedures Reassessment Group, also known as Project '07 (Kircher, Luco & Whittaker, 2010), and the latter were developed by the BSSC Mapping, Foundations and Geotechnical Subcommittee. With respect

[1] The USGS also prepared smaller versions of the long-period transition period (T_L) maps previously prepared for the *2005 ASCE 7 Standard*. The T_L maps are not described in this paper, because they are not "new," but the reader can find a detailed description of them in (Crouse et al, 2006).

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to previous editions of the *NEHRP Provisions*, the MCE_R ground motions incorporate three main technical changes to the methodology for deriving seismic design maps from underlying seismic hazard maps, namely 1) use of risk-targeted probabilistic ground motions, 2) use of maximum-direction ground motions, and 3) use of 84th-percentile deterministic ground motions. Reasons for each of these three changes are explained in the *2009 NERHP Provisions (Part I)* commentary on the changes relative to the *2005 ASCE 7 Standard*. This paper focuses on the impacts of the three technical changes on the preparation of the seismic design maps.

As the *2009 NEHRP Provisions* update concluded, the USGS also collaborated with the American Society of Civil Engineers (ASCE) Seismic Subcommittee to prepare updated and new seismic design maps for the *2010 Minimum Design Loads for Buildings and Other Structures, Standard ASCE/SEI 7-10*. Concurrently, the USGS collaborated with the FEMA-funded BSSC Code Resource Support Committee to prepare updated seismic design maps for the *2012 International Building Code* and *2012 International Residential Code*. The various seismic design maps prepared for each of these four reference documents and model building codes are enumerated in the first four sections below. In subsequent sections of the paper, each type of map is described in more detail. The last section before the summary describes the web application developed by the USGS for obtaining values from the new seismic design maps.

Maps for the *2009 NEHRP Provisions*

Rather than merely updating the Maximum Considered Earthquake ground motion maps in previous editions of the *NEHRP Provisions* using the 2008 USGS National Seismic Hazard Maps but the same methodology for deriving seismic design maps, for the *2009 NEHRP Provisions* BSSC decided to update the maps using both the 2008 hazard maps and the new SDPRG-proposed methodology mentioned in the preceding section. The BSSC also decided to add transparency to the derivation of the seismic design maps. As a result, the USGS prepared the following three new sets of maps for the *2009 NEHRP Provisions*: 1) Maps of uniform-hazard (2% in 50-year) ground motions, 2) maps of the risk coefficients for converting 2% in 50-year uniform-hazard ground motions to 1% in 50-year risk-targeted probabilistic ground motions, and 3) maps of deterministic ground motions. Each of these three set of maps is described in later sections of the paper. Values from these three sets of maps are combined according the formulas of Section 11.4.3 of the *2009 NEHRP Provisions* to develop so-called Risk-targeted Maximum Considered Earthquake (MCE_R) ground motions. The use of these MCE_R ground motions in developing a design spectrum remains the same as in previous editions of the *NEHRP Provisions* (e.g., see Chock, 2010 in the proceedings of this symposium). As will be reiterated in the sections below, the MCE_R ground motion values developed in the *2009 NEHRP Provisions* are identical to those mapped in the *2010 ASCE 7 Standard* and the *2012 International Building Code*.

In addition to the maps of uniform-hazard ground motions, risk coefficients, and deterministic ground motions, for the *2009 NEHRP Provisions* the USGS prepared a fourth set of maps of peak ground acceleration (PGA) values for evaluation of the potential for liquefaction and soil strength loss according to Section 11.8.3. It is important to note that these PGA maps are not used in developing design spectra, because they are derived from underlying hazard maps in a different manner than are the MCE_R ground motions, as explained further later in the paper. The PGA maps can be found in the *2010 ASCE 7 Standard*, but under a different name.

Maps for the *2010 ASCE 7 Standard*

As updates to the Maximum Considered Earthquake ground motion maps in previous editions of the *ASCE 7 Standard*, the USGS prepared maps of the new Risk-Targeted[2] Maximum Considered Earthquake (MCE_R) ground motions mentioned in the preceding sections. As alluded to there and explained further in a section below, the MCE_R ground motion maps are combinations of the maps of uniform-hazard ground motions, risk coefficients, and deterministic ground motions prepared for the *2009 NEHRP Provisions*.

[2] The pre-errata version of the *2010 ASCE 7 Standard* mistakenly used the terminology "risk-adjusted" instead of "risk-targeted." The latter is consistent with the *2009 NEHRP Provisions* and (Luce et al, 2007).

In addition to the MCE_R ground motion maps, the new PGA maps prepared for the *2009 NEHRP Provisions* have also been incorporated into the *2010 ASCE 7 Standard*, but under a different name for reasons explained later in the paper.

Lastly, the risk coefficient maps prepared for the *2009 NEHRP Provisions* have also been included in the *2010 ASCE 7 Standard*. These maps are already implicit in the MCE_R ground motion maps prepared for the *2010 ASCE 7 Standard*, but they are required for development of site-specific ground motions by Section 21.2.1 (Method 1).

Maps for the *2012 International Building Code (IBC)*

As updates to the Maximum Considered Earthquake ground motion maps in previous editions of the *IBC*, for the *2012 IBC* the USGS has provided the same MCE_R ground motion maps that were prepared for the *2010 ASCE 7 Standard*. As mentioned in the preceding section, these MCE_R ground motion maps present values that are identical to the MCE_R ground motions derived (but not mapped) in the *2009 NEHRP Provisions*.

Maps for the *2012 International Residential Code (IRC)*

As an update of the seismic design category (SDC) maps in previous editions of the *IRC*, for the *2012 IRC* the USGS has prepared new maps of SDC's that are derived from the new MCE_R ground motion maps and the SDC definitions in the *2012 IBC* (and the *ASCE 7 Standard*). Since they are derived from the new MCE_R ground motion maps, the new SDC maps are based on the 2008 USGS National Seismic Hazard Maps and incorporate the risk-targeted, maximum-direction, and 84th-percentile improvements mentioned above in the background and introduction section. The new SDC maps also incorporate a slight change to the SDC D/E definition, as explained in the SDC section below.

Uniform-Hazard Ground Motion Maps (for *2009 NEHRP Provisions*)

The uniform-hazard ground motion maps in the *2009 NEHRP Provisions* provide short-period (0.2-second) and 1-second spectral response accelerations for 5% of critical damping, denoted S_{SUH} and S_{1UH}, that each have a 2% probability of being exceeded in 50 years. These maps are for NEHRP Site Class B, the reference site class. The reason for specifying 2%-in-50-years, short- and 1-second spectral response accelerations and NEHRP Site Class B is that previous editions of the *NEHRP Provisions* (and of the *ASCE 7 Standard* and *IBC*) used such ground motions for the probabilistic portions of their Maximum Considered Earthquake ground motions maps. The rationale for selecting such ground motions is explained in the *1997 NEHRP Provisions Commentary*.

Unlike in previous editions of the *NEHRP Provisions*, the values on the uniform-hazard ground motion maps (and deterministic ground motion maps described later in this paper) represent the maximum direction of horizontal spectral response acceleration. Thus, while the uniform-hazard ground motion maps are based on corresponding 2008 USGS National Seismic Hazard Maps, they are different because overall the values on the USGS maps represent geometric means of two horizontal components of ground motion. The BSSC provided factors for approximately converting from "geomean" to "maximum direction" ground motion based on research by Huang et al. (2008) and others. The factors are 1.1 and 1.3 for the spectral response accelerations at 0.2 seconds and 1 second, respectively. As mentioned in the introduction, justification for the use of maximum-direction ground motions is provided in the *2009 NEHRP Provisions (Part I)* commentary.

Risk Coefficient Maps (for *2009 NEHRP Provisions* & *2010 ASCE 7 Standard*)

The risk coefficient maps in the *2009 NEHRP Provisions* and the *2010 ASCE 7 Standard* provide multipliers, C_{RS} and C_{R1}, that are applied to short-period (0.2-second) and 1-second uniform-hazard spectral response accelerations like those described in the previous section. The products are risk-targeted probabilistic ground motions that underlie MCE_R ground motions. In the *2009 NEHRP Provisions*, the risk coefficient maps are used in both the "general" ground motion procedures of Chapter 11 (Equations 11.4-1 and 11.4-2) and the

site-specific procedures of Chapter 21 (Section 21.2.1.1 Method 1). In the *2010 ASCE 7 Standard*, the risk coefficient maps are only needed for the site-specific procedures, since they are implicit in the MCE_R ground motion maps therein.

The mapped risk coefficients are the ratios of risk-targeted probabilistic ground motions derived from the 2008 USGS National Seismic Hazard Maps to the corresponding uniform-hazard ground motions described in the previous section. As very briefly explained in Method 2 (Section 21.2.1.2) of the site-specific procedures of the *2009 NEHRP Provisions* and the *2010 ASCE 7 Standard*, a risk-targeted probabilistic ground motion is computed via iterative integration of a seismic hazard curve with a specified building collapse fragility that is a function of the risk-targeted probabilistic ground motion itself. In each iteration for a candidate risk-targeted probabilistic ground motion, the integration results in an annual frequency of building collapse, which is translated into a probability of collapse within a 50-year period. Two such iterations are illustrated in Figure 1. The iteration is carried out until the candidate ground motion results in a 1% probability of collapse in 50 years. Please see (Luco et al., 2007) for more information on the development of risk-targeted probabilistic ground motions and resultant risk coefficients.

Deterministic Ground Motion Maps (for *2009 NEHRP Provisions*)

The deterministic ground motion maps in the *2009 NEHRP Provisions* provide short-period (0.2-second) and 1-second spectral response accelerations for 5% of critical damping, denoted S_{SD} and S_{1D}, that parallel the uniform-hazard ground motion maps described two sections above. Like them, the deterministic ground motions maps are for NEHRP Site Class B and the maximum direction of spectral response acceleration. As described in the paragraphs below, the mapped deterministic values represent the greater of 84th-percentile ground motions and "water level" values

As specified in the site-specific procedure (Section 21.2.2) of the *2009 NEHRP Provisions* (and the *2010 ASCE 7 Standard*), each deterministic ground motion is calculated as an 84th-percentile spectral response acceleration for a characteristic earthquake on a known active fault within the region. The specific characteristic earthquake is the one that generates the largest 84th-percentile spectral response acceleration at the given location. In computing the deterministic ground motions for the *2009 NEHRP Provisions*, it is worthwhile to note that the USGS applied a simplification specified by the BSSC. The 84th-percentile spectral response accelerations were approximated as 180% of median values. This approximation corresponds to a logarithmic ground motion standard deviation of approximately 0.6, as demonstrated in the *2009 NEHRP Provisions (Part I)* commentary. Furthermore, the aforementioned BSSC factors for approximately converting from "geomean" to "maximum direction" ground motion were applied, as they were for the uniform-hazard ground motion maps. The computation of deterministic ground motions is further described in the *2009 NEHRP Provisions (Part 2)* commentary for the *2005 ASCE 7 Standard*.

As also specified in the site-specific procedure of the *2009 NEHRP Provisions* (and the *2010 ASCE 7 Standard*), the deterministic spectral response accelerations for Site Class B shall not be taken as lower than 1.5g for the short (0.2-second) period and 0.6g for the 1-second period; hence, the values on the deterministic ground motion maps are no lower than these values.

MCE_R Ground Motion Maps (for *2010 ASCE 7 Standard* & *2012 IBC*)

For the *2010 ASCE 7 Standard*, ASCE decided to directly provide maps of the Risk-Targeted (see footnote 2 on page 3) Maximum Considered Earthquake (MCE_R) ground motions that result from combining the uniform-hazard ground motion, risk coefficient, and deterministic ground motion values mapped in the *2009 NEHRP Provisions* (via its Equations 11.4.1 through 11.4.4). The same MCE_R ground motion maps will be included in the *2012 IBC*. They provide the short-period (0.2-second) and 1-second spectral response accelerations that are denoted S_S and S_1. Like the uniform-hazard and deterministic ground motion maps they combine, the MCE_R ground motion maps are for the maximum direction of spectral response acceleration, 5% of critical damping, and NEHRP Site Class B.

Recall that the maps of uniform-hazard ground motions and risk coefficients are combined in order to arrive at risk-targeted probabilistic ground motions that, when used for design, are expected to result in buildings with a 1% chance of collapse over their approximate lifetimes, i.e., 50 years. The reason the MCE_R ground motions are the minimum of the resulting probabilistic and parallel deterministic spectral response accelerations, like the Maximum Considered Earthquake ground motions are in earlier editions of the *ASCE 7 Standard* and *IBC*, are explained in the *1997 NEHRP Provisions Commentary*. In brief, the deterministic ground motions provide a reasonable and practical upper-bound to design ground motions, although their use implies a somewhat higher level of collapse risk than the 1% probability of collapse in 50 years associated with purely probabilistic risk-targeted ground motions. In general, deterministic ground motions govern only at sites near active sources in regions of high seismicity (e.g., coastal California).

Seismic Design Category Maps (for *2012 IRC*)

The seismic design category (SDC) maps prepared by the USGS for the *2012 IRC* are derived from the short-period MCE_R ground motion (S_S) maps described in the preceding section, using the SDC definitions in the *2012 IBC* and the *2010 ASCE 7 Standard*. Please see the symposium paper by Chock ("Overview of Current USA Seismic Design Provisions for New Construction") for a description of SDC's. Whereas the S_S maps are for NEHRP Site Class B, the SDC maps are for NEHRP Site Class D (the default site class) and Risk Categories I-III. SDC maps for other site classes and risk categories, both in poster and Google Earth/Maps form, are also being prepared by the USGS for users who would like to visually verify their calculations or the values returned by the USGS "DesignMaps" web application described in the section after the next.

Besides being derived from the new MCE_R ground motions, the SDC maps for the *2012 IRC* are different from earlier versions in that the division between Seismic Design Categories D2 and E has been changed from 118% g to 125% g. The 125% g contour, which is more consistent with the SDC definition in the *IBC*, would have been used in earlier maps but the mapping technology then available for drawing the SDC maps did not permit this to be done.

PGA Maps (for *2009 NEHRP Provisions* & *2010 ASCE 7 Standard*)

The "MCE Geometric Mean PGA" maps in the *2009 NEHRP Provisions* and the identical but renamed "Maximum Considered Earthquake Geometric Mean (MCE_G) PGA" maps in the *2010 ASCE 7 Standard* provide values of peak ground acceleration for Site Class B. As emphasized by the MCE_G abbreviation, these PGA values represent the geometric mean of two horizontal component of ground motion, not the maximum direction represented by the MCE_R (and uniform-hazard and deterministic) ground motion maps described above. Corresponding risk coefficients are not included in the development of the PGA maps.

Despite representing geometric mean ground motions, the PGA maps are different from the 2008 USGS National Seismic Hazard Maps upon which they are based. This is because they represent the lesser of uniform-hazard (2% in 50-year) probabilistic and corresponding deterministic PGA values. Like the values on the deterministic ground motion maps described above, the deterministic PGA values are calculated as the greater of 180% of median ground motions (as an approximation of 84th-percentile ground motions) and a water level, of 0.5g in this case. Such details of the basis of the PGA maps are available in the site-specific procedures (Chapter 21) of the *2010 ASCE 7 Standard*; the *2009 NEHRP Provisions* do not contain a site-specific procedure for PGA values.

USGS "DesignMaps" Web Application

In order to accurately obtain values from the seismic design maps described above, the USGS has developed a new web application that generates summary and detailed reports for a user-specified address or set of coordinates: http://earthquake.usgs.gov/designmaps/usapp/. As illustrated in Figure 2, the web application displays the user-specified location on a Google Map so it can be visually checked. The application then

spatially interpolates the gridded data sets that underlie the seismic design maps, and goes as far as calculating a design spectrum for the site. Multiple sites can be batch processed.

As of June of 2010, the "US Seismic DesignMaps Web Application" outputs earthquake ground motion parameters from the *2009 NEHRP Provisions* and the *2010 ASCE 7 Standard*. The *2012 IBC* and *IRC* will be added in the near future, followed by previous editions of all four building code reference documents. Until then, users seeking the previous editions are directed to the predecessor of the new application, namely the USGS Java Ground Motion Parameter Calculator (http://earthquake.usgs.gov/designmaps/javacalc.php).

In addition to a site location, the application requires the user to input a soil classification (e.g., Site Class C for "very dense and soft rock"). The soil classification for the location is a required input because it is not available from the USGS. A simpler but worldwide counterpart to this US application that provides S_S and S_1 values for NEHRP Site Class B is also being developed by the USGS through derivations from numerous existing sources of hazard information.

Summary

Based on its 2008 update of the National Seismic Hazard Maps, but with additional computations, the USGS prepared updated and new seismic design maps for the *2009 NERHP Provisions*, the *2010 ASCE 7 Standard*, the *2012 International Building Code (IBC)*, and the *2012 International Residential Code (IRC)*. More specifically, the USGS prepared maps of uniform-hazard ground motions, risk coefficients, and deterministic ground motions for the *2009 NEHRP Provisions*, Risk-Targeted Maximum Considered Earthquake (MCE_R) ground motion maps for the *2010 ASCE 7 Standard* and the *2012 IBC* that combine the three sets of maps in the *2009 NEHRP Provisions*, Seismic Design Category (SDC) maps for the *2012 IRC* that are derived from the MCE_R ground motion maps, and maps of peak ground acceleration (PGA) values for the *2009 NEHRP Provisions* and *2010 ASCE 7 Standard*. The freely-available *2009 NEHRP Provisions* CD provides electronic copies of all of these seismic design maps, as shown in Figure 2. In order to accurately obtain values from these maps for a user-specified site, the USGS has also developed the US Seismic "DesignMaps" Web Application shown in Figure 1.

The new maps of uniform-hazard ground motions, risk coefficients, and deterministic ground motions add transparency to the development of the MCE_R ground motion maps, which themselves represent a major redefinition of the ground motions that buildings are designed to resist. Unlike previous editions of the *NEHRP Provisions*, *ASCE 7 Standard*, *IBC* and *IRC*, the new MCE_R ground motion maps mean that the latest editions explicitly target a tolerable risk of building collapse over its lifetime, namely a 1% probability of collapse in 50 years. The updated SDC maps for the *2012 IRC* are more consistent with the SDC definitions in the *IBC*, and the new PGA maps provide an alternative to the rough $S_S/2.5$ approximation of PGA values previously used for liquefaction and soil strength loss evaluations. Lastly, the new USGS "DesignMaps" web application represents an improvement of the USGS Java Ground Motion Parameter Calculator.

Acknowledgements

The author of this paper is merely the leader of the Seismic Design Maps Task of the USGS National Seismic Hazard Mapping Project. Other USGS employees who very directly contributed to the preparation of the new USA seismic design maps and the associated web application include K. Rukstales, E. Martinez, M.D. Petersen, S. Harmsen, G. Smoczyk, and S. McGowan. Special thanks to C.A. Kircher and C.B. Crouse of the BSSC and ASCE committees with which the USGS collaborated.

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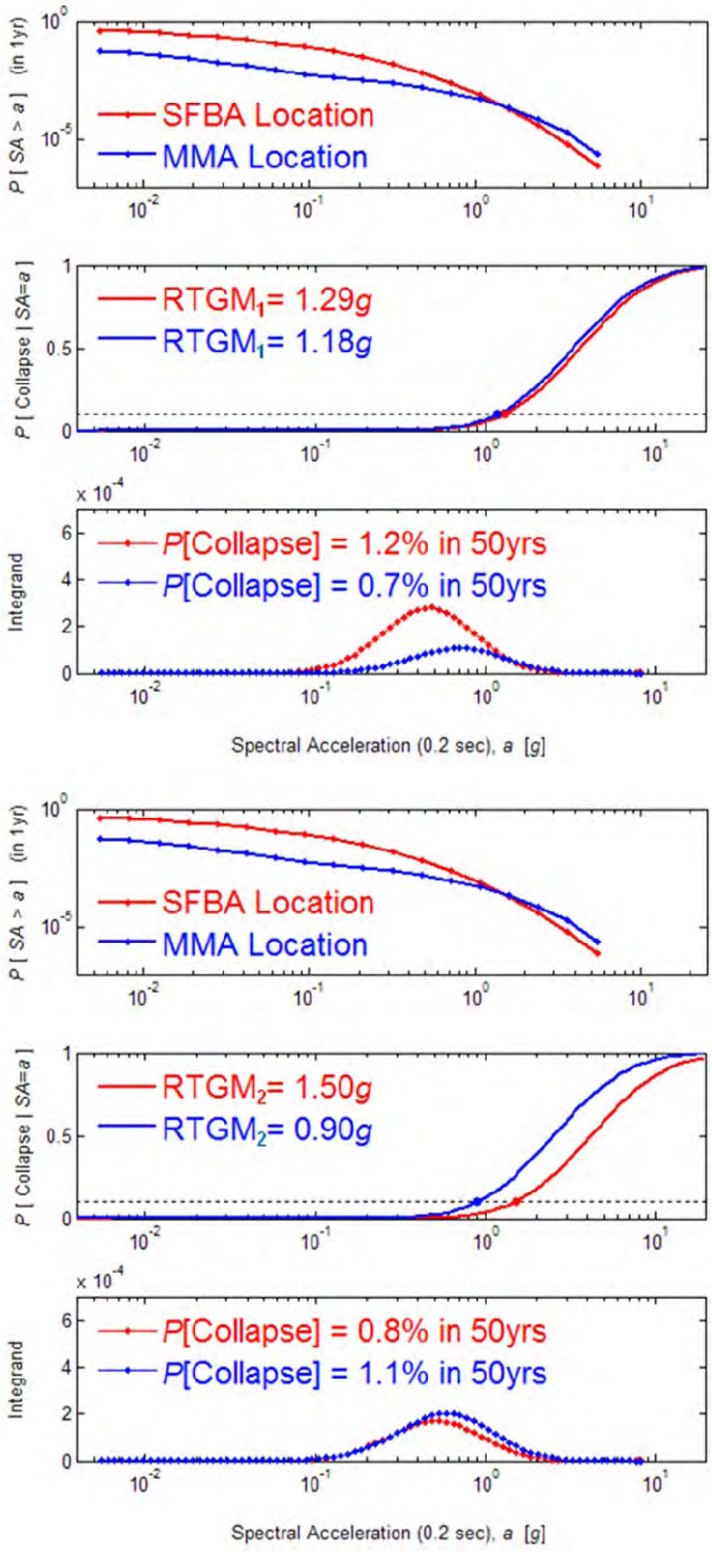


Figure 1: Illustrations of two iterations of the computation of probabilistic risk-targeted ground motions (RTGM) values for a San Francisco Bay Area (SFBA) and a Memphis Metropolitan Area (MMA) location. The top panel for each iteration shows the ground motion hazard curves for the two locations, the middle panel shows the building collapse fragility curves that correspond to the candidate RTGM values, and the third panel shows the 50-year collapse probabilities that result from convolution of the hazard and fragility curves. Iteration is continued until the candidate RTGM results in 1% probability of collapse in 50 years.

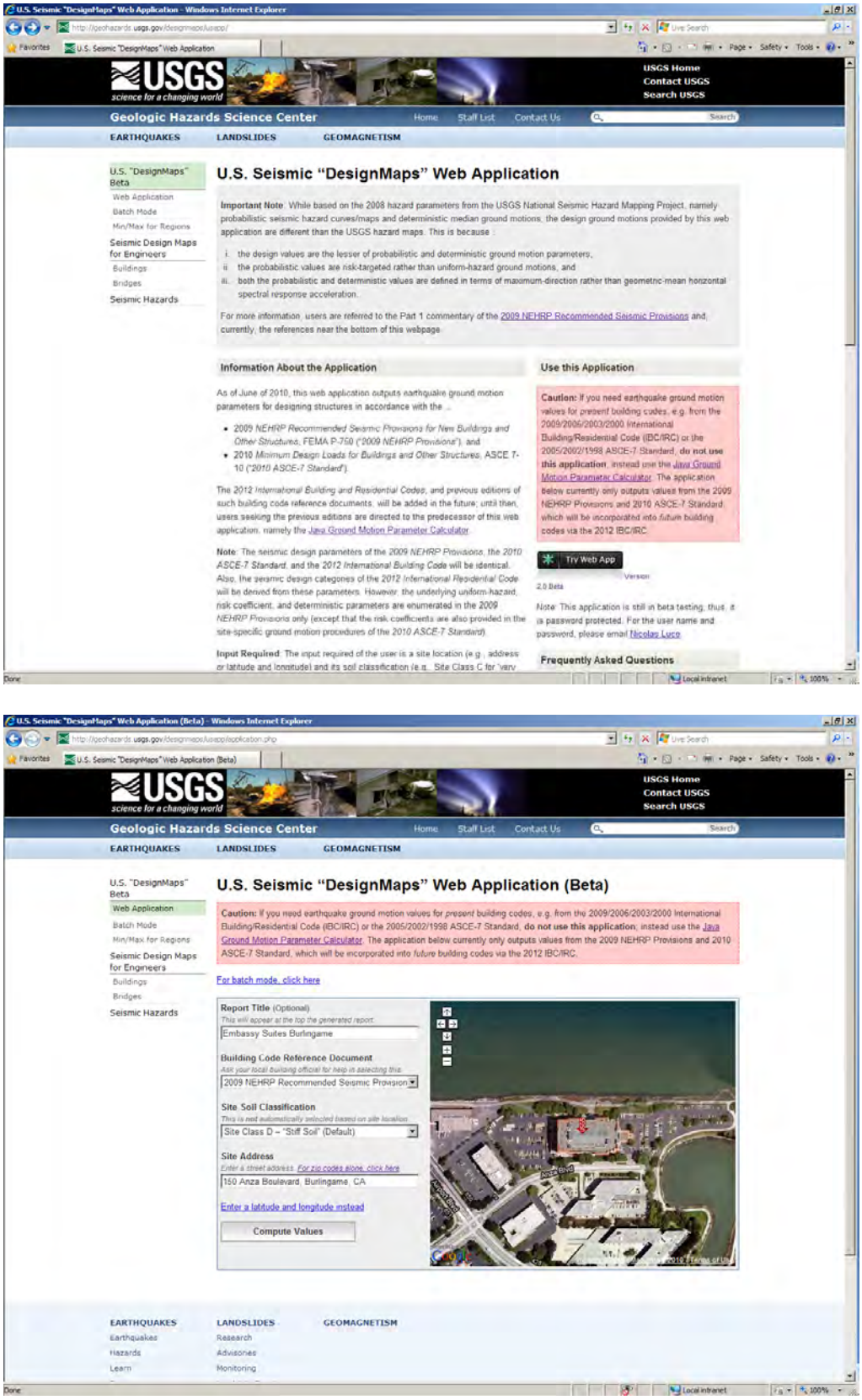
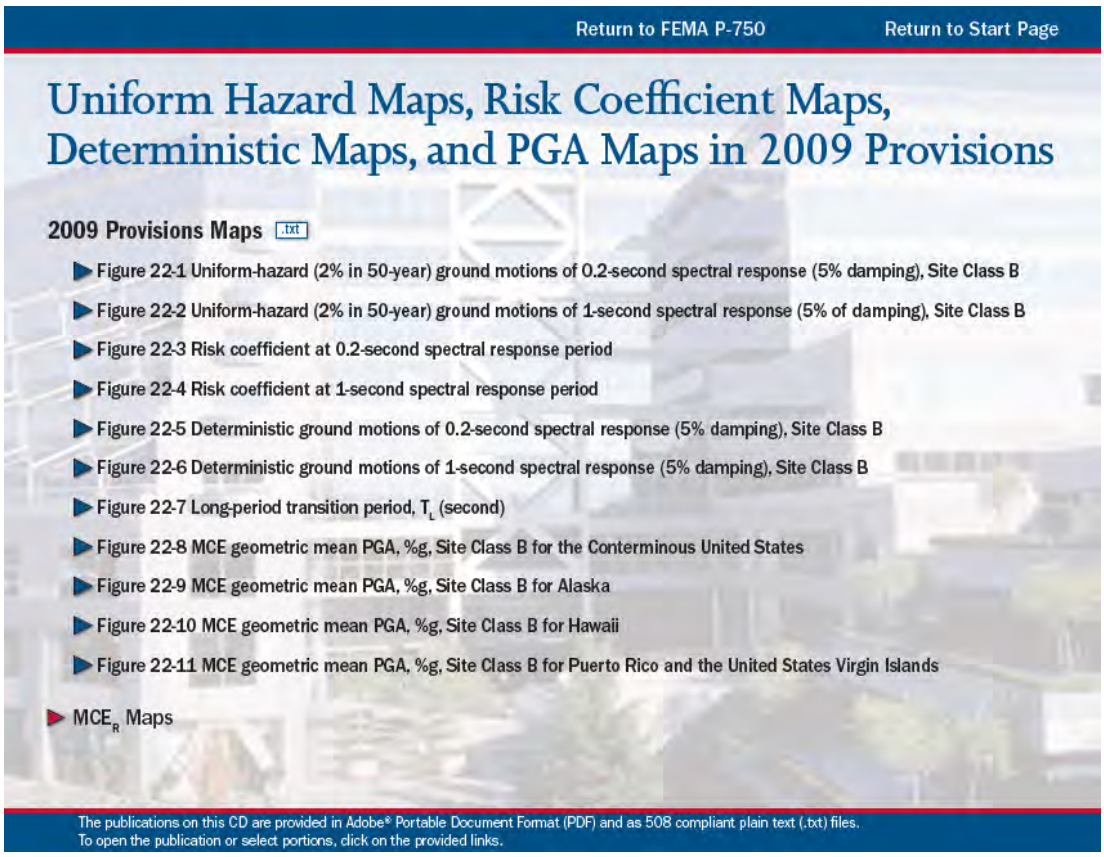


Figure 2: Screenshots of the new USGS "DesignMaps" web application (http://earthquake.usgs.gov/designmaps/usapp/). It is important to note that for the time being this application only provides values from the new seismic design maps described in this paper. For values from previous editions of such maps, please see the USGS Java Ground Motion Parameter Calculator (http://earthquake.usgs.gov/designmaps/javacalc.php).



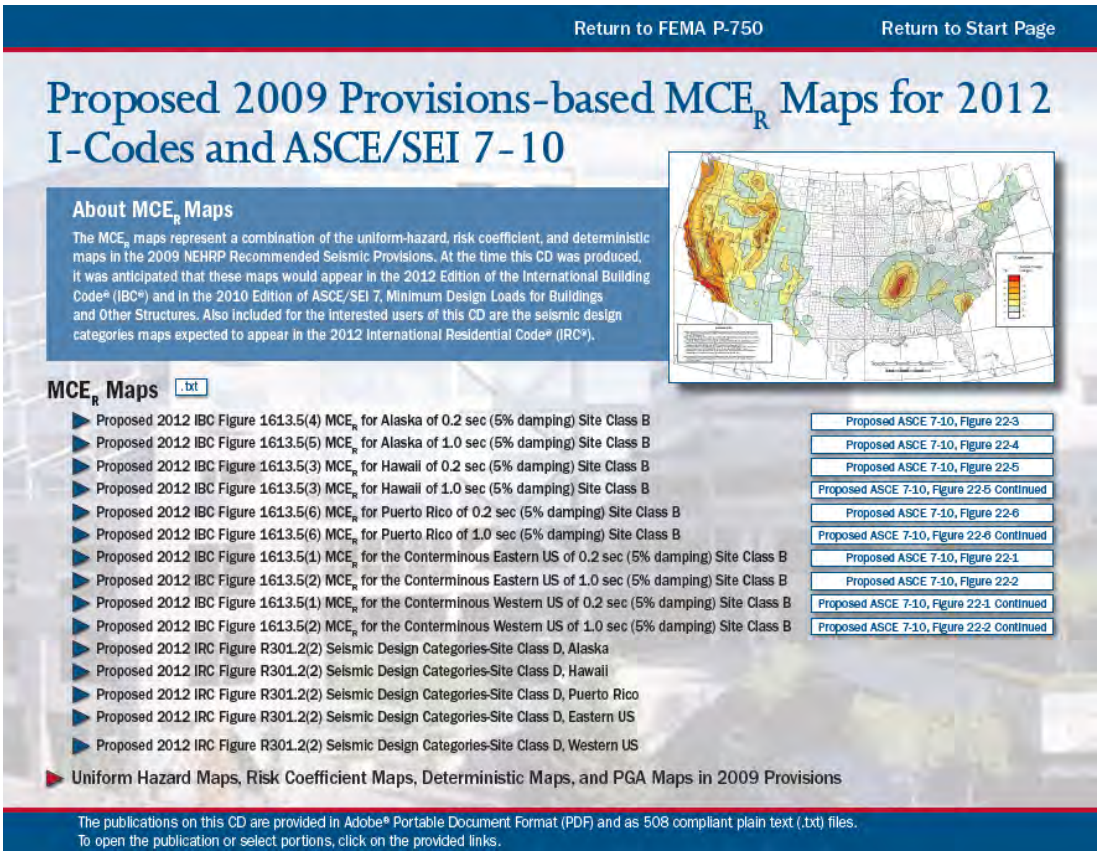


Figure 3: Screenshots from the *2009 NEHRP Provisions* CD that serve as a list of most of the new seismic design maps prepared by the USGS.

USA Seismic Rehabilitation Methodologies for Unreinforced Masonry Buildings

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Introductory Discussion

Unreinforced masonry buildings comprise the urban core of nearly every American city or town. They were constructed as early as the mid-nineteenth century for residential, office, or commercial occupancies and continued as the primary construction type through the first third of the twentieth century. Because of substantial damage to this construction form with the 1933 Long Beach earthquake in California, other types of more ductile construction such as reinforced concrete or structural steel were used. None-the-less, many of these buildings exist today throughout the United States though they are considered as hazardous in regions of moderate or high seismicity. Some municipalities, particularly in California, have retrofit ordinances that require building owners to strengthen their buildings either with prescriptive requirements such as bracing parapets and bolting floors and roofs to walls, or more elaborate methods based on structural engineering calculations and design. Such buildings continue to be the culprit for significant damage and loss resulting from nearly every earthquake. This is true not only in America, but across the globe, including China where masonry construction represents a large fraction of the building stock. Though masonry construction methods and materials may vary from country to country, commonalities in seismic damage are prevalent and philosophies regarding seismic rehabilitation can be similar. Thus, international collaboration can yield more than the sum of the parts by increasing seismic safety across political borders. For this reason, this paper is intended to stimulate symposium participants to conceive how performance-based seismic rehabilitation methods can be adapted to indigenous construction types of their respective countries.

Over the last two decades, substantial development of national engineering guidelines for seismic rehabilitation of buildings has occurred in the United States through financial support and oversight by the Federal Emergency Management Agency (FEMA). This development started with the Applied Technology Council (ATC-33 project) that culminated in publication of recommended provisions (FEMA 273/274), which introduced the first national consensus approach to performance-based seismic design in the United States. Unlike prior seismic codes for new construction or methods for assessment of existing buildings, this document approached the issue of seismic rehabilitation through a displacement-based approach. Four analysis methods were prescribed ranging from a linear static analysis to a nonlinear dynamic analysis as well as nonlinear static and linear dynamic analyses. By estimating deformation capacity of individual structural elements, seismic structural systems comprising mixed components of structural steel, reinforced concrete, masonry or timber could be assessed and rehabilitated to meet specific performance objectives. Thus, this effort was a pioneering attempt to reach a new frontier for structural design of masonry buildings. This initial resource document was then further refined in the form of a prestandard (FEMA 356/357) and subsequently as a consenus-based standard (ASCE 41). This paper will provide an overview of these rehabilitation methodologies.

Performance-Based Earthquake Engineering and Displacement-Based Rehabilitation

Performance-based seismic engineering is much different than a conventional force-based strength design or even more so than an allowable stress design, which is still used for masonry design in America. Not only are life safety concerns addressed, but also other performance limits including continued operation, immediate occupancy and collapse prevention are considered. Building owners can select how much damage or loss they wish to incur for various earthquake intensities. With a performance-based approach, owners can invest in rehabilitation to whatever level of risk they wish to assume for earthquakes of expected intensities.

From an engineering perspective, the essential difference between a performance-based and traditional approach is that displacement demands are explicitly calculated and compared with displacement capacities for specific limit states. With such a design methodology, schemes for improving seismic performance do not

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necessarily need to increase structural strength, but rather increase displacement capacity. This distinction is particularly significant for relatively stiff structures such as unreinforced masonry buildings, which can attract large lateral accelerations and inertial forces, but then crack and become more accommodating to seismic input as structural walls or piers rock and slide. Whereas a stress-based approach would deem these systems to be weak in resisting earthquake motions, a displacement-based analysis may reveal that they can perform with adequate capacity. If properly detailed for ductility, unreinforced masonry buildings can be shown to resist moderate or even high intensities with an acceptable level of damage, or conversely, they can be rehabilitated in such ways to enhance their deformation or displacement capacities.

To fit a PBE framework, dynamic response of a building system must be depicted within acceptable ranges of precision. This entails modeling of the ground motions as well as the strength and stiffness of the structural system. Moreover, acceptable levels of damage must be defined to set performance limits. Both of these conditions is challenging for unreinforced masonry, which is a complex continuum of bricks and mortar that is highly prone to cracking. Another complexity is that a masonry building system is not clearly depicted in terms of discrete structural elements. It has elements that are considered to participate with the lateral-force resisting system as well as those that are considered not to participate. Whereas such modeling assumptions fit well with a strength design approach where non-participating elements may be neglected, it does not necessarily fit as well with a performance-based approach since the damage to non-participating elements will limit performance of the overall system. For example, extensive damage or collapse of a partition wall (non-participating) may cause occupants to evacuate the building and thus limit immediate occupancy. In such case response and damage of these non-participating elements needs to be included in the assessment.

Analysis Procedures to Estimate Demand Forces and Displacements

The common analytical method for structural design of buildings is a linear, static procedure. This is acknowledged as appropriate even though members of the structural system will deform inelastically when the system is subjected to dynamic loads. A linear static procedure (LSP) is also accepted as appropriate to assess performance of a rehabilitated structure. However, since displacements rather than forces are the critical parameter in defining performance, a LSP yields displacement properties even though force terms are used. This is done assuming that displacements are the same for linear and nonlinear behaving systems which results in the force capacity being multiplied by an "*m*" factor or ductility factor yielding a displacement type capacity which is then compared with the seismic demand elastic force according to the following equation:

$$mQ_{CE} \geq Q_E \qquad [1]$$

where m is a ductility-like factor that varies with the displacement capacity of the element at a specific limit state; Q_{CE} is the expected strength of the element; and Q_E is the elastic force demand on the element resulting from application of an equivalent base shear.

With the LSP, earthquake loads are determined from spectral accelerations, S_a, as given on USGS hazards maps of the United States. Map values are given for short period oscillators as well as those with a period of 1.0 second, and are adjusted with respect to soil type and damping. Equivalent base shears are determined from these spectral values by multiplying by the weight of the structure, and coefficients to account for the range of natural periods, the framing type, and P-delta effects. The equivalent base shear is then applied as a static lateral load to a building system. Element demand forces, Q_E, (moments, shears, and axial forces) are then determined using conventional static analysis. These demand forces are then compared with the force capacities using Equation 1.

More sophisticated analytical procedures than the linear static one can be used though they may not necessarily be more precise for a URM building. These include a nonlinear static analysis, or more commonly termed a "pushover" analysis; a linear dynamic procedure using conventional modal analysis and response spectra; and a nonlinear dynamic procedure using time-step integration methods with specific depictions of the earthquake time records and hysteresis properties of the elements. Because of the difficulties in modeling structural properties of an URM building and defining scenario earthquake records, linear static procedures will yield results with equivalent or better precision and are felt to be appropriate.

USA Seismic Rehabilitation Methodologies for Unreinforced Masonry Buildings

Displacement Capacities for Unreinforced Masonry Construction

Because performance limit states are expressed in terms of displacements rather than forces, displacement capacity is of primary interest. Thus, if a masonry pier or shear wall can possess good displacement capacity either in its plain or rehabilitated form, then the system will be judged to have good seismic performance. This concept is orthogonal to conventional structural design practice where forces or stresses are compared with allowable values or lower bounds in strength. An element may be weak in strength but have appreciable displacement capacity, and thus be considered to be a good performer.

Four limiting mechanisms are considered for unreinforced masonry piers or shear walls: (a) toe crushing, (b) diagonal tension, (c) rocking and (d) bed-joint sliding. The first two mechanisms are considered to be force based since they are limited by stress (either toe compressive stress or diagonal tension or shear stress). The last two mechanisms are considered to be displacement based since elements can displace well beyond the displacement at initial cracking. A pier or wall can rock after cracking in flexural tension. Lateral displacement at the top of such pier or wall will be directly attributable to this rocking and occur without a significant decrease in force capacity (which is directly related to the gravity force that remains constant). Such behavior is illustrated in the hysteretic relations shown in Figure 3, which were obtained from the experimental research described below. Similarly a pier or wall that develops a bed-joint crack (either stair-stepped along many head and bed joints, or along a single bed joint) will continue to slide, as the frictional force remains constant. Hysteretic relations for a masonry wall prone to sliding are given in Figure 4. The force-deflection relation for rocking or sliding is elasto-plastic with substantial displacement capacity. Upon unloading, the rocking pier will follow an elastic path back to the origin of the force-deflection curve indicating little energy dissipation, but also little damage. The sliding pier will have a much fuller hysteresis curve upon unloading as friction is resisted in the reversed loading direction, and thus dissipate more energy. However, each mechanism can be considered as limited by the displacement and not the force applied. As a result the "*m*" factors for each can be quite high making the comparison of capacity and demand according to Equation 1 much more favorable than what would result with conventional force-based design.

Rehabilitation Techniques for Unreinforced Masonry Piers

Common practices for seismic rehabilitation of masonry buildings used in America have originated largely as strengthening procedures. Now, their capacity to resist displacements and thus enhance seismic performance is of question. Research has been done at the University of Illinois at Urbana-Champaign in this regard. The testing rig shown in Figure 1 was used. Lateral displacements were imposed at the top of masonry piers while vertical compressive stress was maintained at a constant amount. A control specimen consisted of a plain masonry pier with no rehabilitation. This pier rocked about its base after forming a bed-joint crack along its base (Figure 2). As demonstrated with the force-deflection curve presented in Figure 3 behavior is essentially nonlinear, but elastic, since the deflection and the force return to zero at nearly the same time. In this mode, a member can possess considerable nonlinear deformation capacity though the hysteretic energy dissipation is low. In accordance with the NEHRP *Guidelines*, the *m* factor for this type of action is quite large, exceeding ten in some cases. Recognizing that the capacity as given in Equation 1 is multiplied by this *m* factor for comparison with the demand force, implies that rocking is a highly desirable mode. A masonry member performing with this behavior should *not* be rehabilitated to increase its strength at the cost of decreasing its deformation capacity. Furthermore, masonry members acting in other than a rocking mode could be altered in such a way as to promote rocking. For example, the height of window openings may be enlarged so that the aspect ratios of adjacent piers will be increased. Or conversely, gravity axial compressive forces resisted by such piers should be reduced to prevent toe crushing and allow a pier to rock instead.

USA Seismic Rehabilitation Methodologies for Unreinforced Masonry Buildings

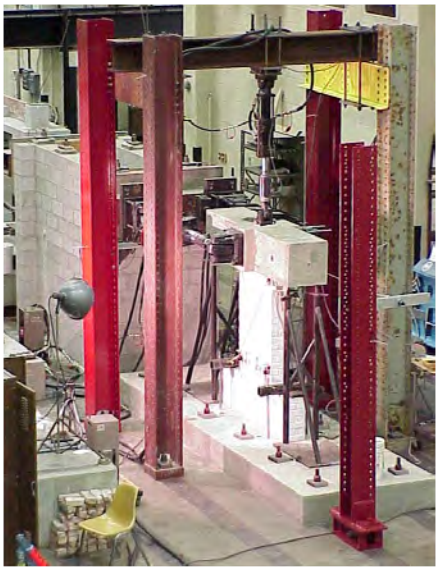

Figure 1: Test of Brick Piers

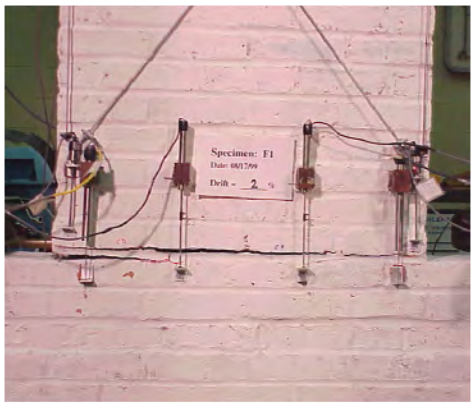

Figure 2: Rocking of Masonry Pier

One common practice of masonry seismic rehabilitation is to strengthen. Typical strengthening methods include: (a) application of a thin coating of ferrocement, (b) casting shotcrete over reinforcement, or (c) infilling door or window openings with new masonry. Each of these methods can increase strength though deformation capacity may be sacrificed. Measured force-deflection behavior of a pier strengthened with a ferrocement surface coating is presented in Figure 5. For this case, a thin (25mm) coating of cement plaster was parged over a mesh of steel hardware cloth (widely available at local stores). A slight increase in strength is noted, but once the wire reinforcement fractures, behavior reverts to that of a rocking pier. Thus, this retrofit method does not have appreciable benefits for increasing the capacity term on the left side of Equation 1.

Applying shotcrete over a grid of reinforcing bars results in similar behavior as that for a reinforced concrete wall (Figure 6). Inelastic behavior is robust with a significant increase in both strength and deformation capacity. Large crack widths in the masonry and shotcrete along the wall base, resulting from yield of vertical reinforcement limit performance of the element. This is a highly appropriate rehabilitation method in terms of increasing capacity per Equation 1, though expensive and intrusive.

Infilling door or window openings with new masonry will indeed increase the cross-sectional area of a wall and apparently the shear strength according to formulas given in current building codes. However, damage observed after earthquakes, has shown that cracking often occurs in or near to the infilled opening, limiting deformation capacity. This is a result of incompatible moduli or inadequate shear transfer between old and new masonries.

Reinforced cores are another option for strengthening unreinforced masonry walls. A vertical core is drilled through the height of a wall and then filled with a grout to bond a conventional reinforcing bar, thus effectively causing the wall to behave as a reinforced masonry component. This method is advantageous for increasing lateral strength and deformation capacity provided that sufficient anchorage of reinforcement to the grout, and of the grout to the masonry, is provided. This retrofit procedure results in a force-deflection relation similar to that for reinforced masonry. The curve in Figure 7 is for a pier strengthened with vertical reinforcement. Behavior was influenced by inadequate anchorage at the base of the test pier. This procedure is unobtrusive since the coring and grouting procedure can be done externally from the roof of a building, however, the coring process can be expensive.

One other method for increasing deformation capacity is post-tensioning of piers. This method, in effect, increases the vertical compressive stress and thus promotes rocking. Piers are core drilled with the same procedure as used for reinforced cores. Unbonded tendons are draped into cores and anchored at their base with grout. Tendons are then tensioned by pulling them at the top of a wall. This procedure results in a nonlinear, but elastic type of response similar to the rocking response shown in Figure 3.

USA Seismic Rehabilitation Methodologies for Unreinforced Masonry Buildings

The opposite of infilling openings with new masonry as discussed in the previous section, is to enlarge the openings to increase the deformation capacity of the adjoining piers. This was discussed previously as a method for promoting rocking behavior by increasing the height-to-width aspect ratio of a pier. In such case, nonlinear deformation capacity will increase more than the lateral strength of a wall or pier will reduce. As a result, the left-hand side of Equation 1, expressing capacity, will increase despite the fact that material is being removed.

Behavior mechanisms for piers or beams of a masonry shear wall perforated with openings can be altered by adhering fiber-reinforced polymer (FRP) strips to the surface of a masonry wall. Several configurations of strips are possible to provide strengthening to resist excessive tensile or shear stresses that would otherwise limit strength. Behavior of piers strengthened with vertical strips to increase flexural strength is shown in Figure 8. The strength was increased as much as five times over a counterpart part pier that was not rehabilitated and susceptible to rocking. Due to delamination of the FRP at the peak strength, nonlinear deformation capacity of the rehabilitated pier was limited. As a single element, strengthening of a pier in this manner would not necessarily be of benefit in terms of increasing capacity as defined with the left-hand side of Equation 1. However, selective strengthening of critical piers or beams with this procedure may have merit for redirecting undesirable nonlinear mechanisms.

Concluding Remarks

Effective seismic rehabilitation of unreinforced masonry buildings is indeed a current challenge to both researchers and engineers alike. Sophistication in structural analyses methods for this traditional form of construction can result in minimal amounts of necessary rehabilitation to meet a specific performance objective, thus leading to a practical, economical, aesthetic and safe solution. However, more knowledge of nonlinear force-deflection behavior of various components is needed as well as additional quantification of this behavior when a component is rehabilitated. In this regard, experimental testing of components is encouraged even on a building-specific basis to avoid expensive rehabilitation solutions.

Engineers will need to adopt a new perspective on an old problem. Seismic retrofit of unreinforced masonry buildings need not be prescriptive, or simply based on life-safety concerns as in the past. Engineers can tune these systems to respond to desired displacements and performance limits in postulated earthquakes. Displacement-based approaches incorporating nonlinear analyses will invariably lead to simpler designs, but this will necessitate a new way of thinking that unreinforced masonry can respond in a ductile manner.

Rehabilitation need not be limited to strengthening of individual components. Rather, deformation capacity can be enhanced in critical components. In some cases, strength can be traded for ductility to enhance overall performance.

Undesirable interventions should be avoided at all costs. Structural components that are governed by displacement-controlled mechanisms such as rocking or bed-joint sliding should not be rehabilitated to alter their behavior to a force-controlled mechanism. Contrarily, desirable interventions should be strived for where force-controlled components are rehabilitated to respond in displacement-controlled modes.

Interventions should be kept to a minimum. The concept of selective rehabilitation should be followed in prescribing which components of a structural system should be enhanced with respect to strength and/or deformation capacity. Due consideration of the effect of component behavior on global response or performance should be made.

Seismic rehabilitation to meet specific performance objectives is a choice, not a mandate. Engineers need to understand performance-based concepts and educate building owners with regard to the amount of damage they are willing to tolerate for various intensities of earthquakes.

It is hoped that through mutual discussion of developing technologies, improved methods of seismic design and seismic rehabilitation will be developed that will ultimately result in better performing building

construction in China and the United States, by which economic loss, injuries and deaths will be diminished in future earthquakes.

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USA Seismic Rehabilitation Methodologies for Unreinforced Masonry Buildings

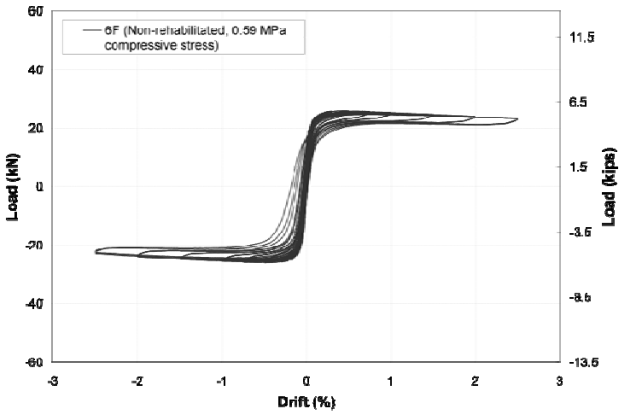

Figure 3: Behavior of Rocking Pier

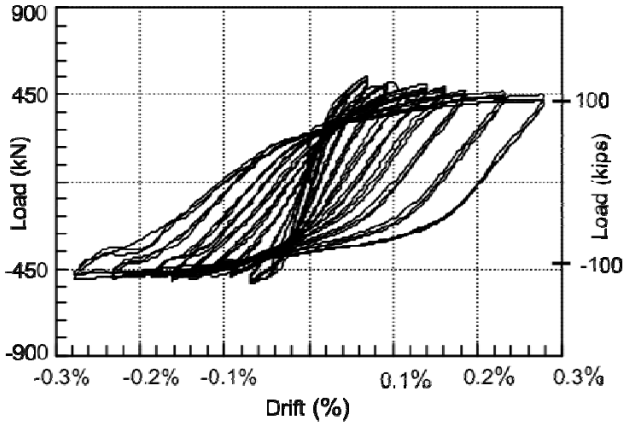

Figure 4: Behavior of Sliding Pier

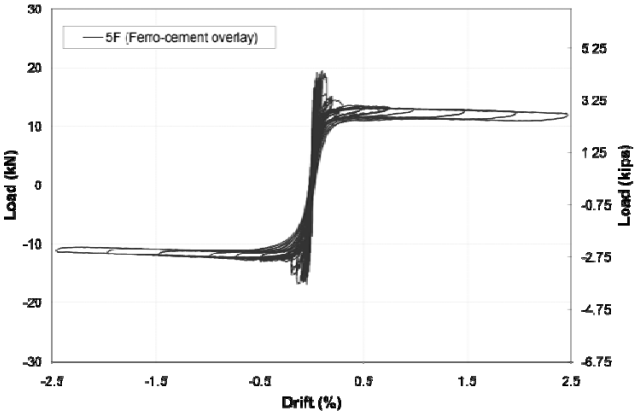

Figure 5: Behavior with Ferrocement

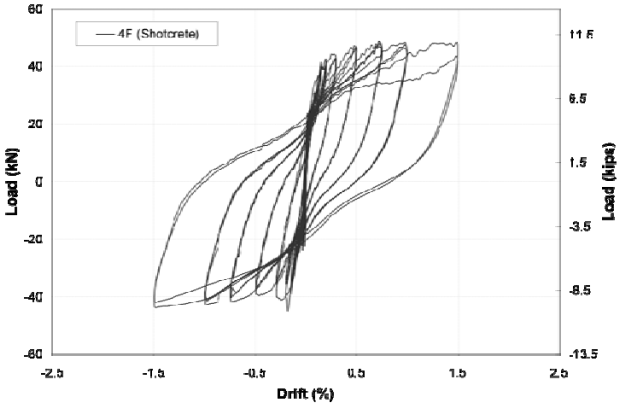

Figure 6: Behavior with Shotcrete

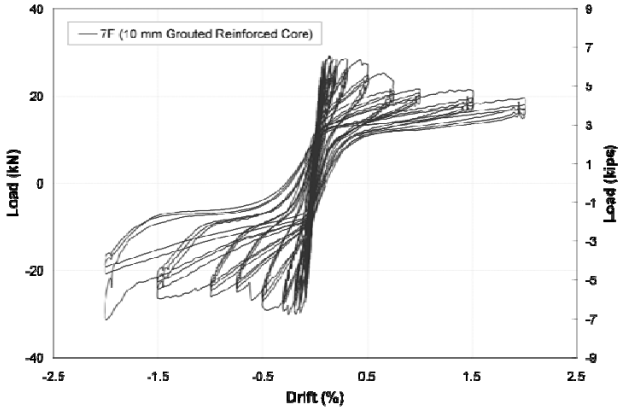

Figure 7: Behavior with Reinforced Cores

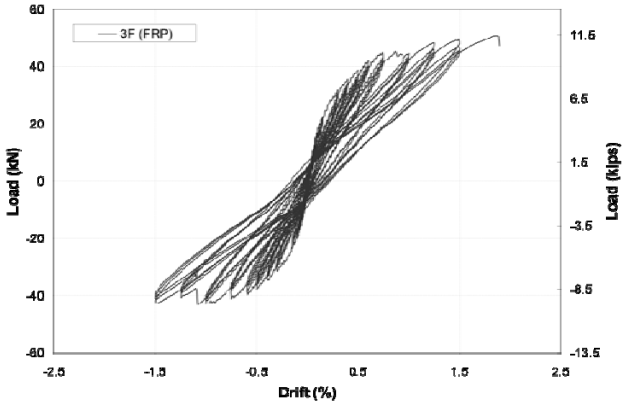

Figure 8: Behavior with FRP Strips

Executive Summary of Symposium Topic Papers: Hazard Mitigation of Critical and Important Building Construction

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University of Hawaii at Manoa, Honolulu, Hawaii

Introductory Discussion

It is essential that critical facilities such as hospitals, fire and police stations, and emergency response centers remain undamaged and operational throughout a design level earthquake. The safety and well-being of the affected community are directly affected by the performance of critical and important buildings during an earthquake event. Damage as minor as water leaks, ceiling collapse, power failure, or as profound as partial structural collapse or severe residual lateral drift, can render an essential facility unusable. It has therefore failed to serve its purpose, and the facility designers have failed to satisfy the immediate life-safety needs of the community.
The papers summarized here address various aspects of the design and construction of critical and important buildings to meet the design seismic demands while remaining operational. Although no design can be guaranteed to perform exactly as intended, every effort needs to be made to ensure superior performance of critical facilities during future seismic events.

Current Technologies and Future Research Trends for Seismic Hazard Mitigation of Critical and Important Building Construction (Robertson, I.N.)

It is essential that critical facilities such as hospitals, fire and police stations, and emergency response centers remain undamaged and operational throughout a design level earthquake. Seismic hazard mitigation measures are employed most readily during design and construction of new buildings, but can also be applied as retrofits for existing buildings. Current USA building codes based on the IBC 2009 require superior design and construction measures for new critical and important buildings, particularly hospitals, emergency response centers and police and fire department first responders. These facilities must be designed to remain fully operational during and after a design level seismic event. Although traditional seismic construction utilizing special shear walls or moment resisting frames are still often used for these structures, the trend in recent years has been to include some form of seismic mitigation measure such as base isolators, dampers or structural control, either passive, active or semi-active. Existing critical and important buildings that lack the necessary seismic performance to remain operational immediately after a seismic event can be retrofitted using similar seismic mitigation devices.
This paper gives an overview of current technology, including; base isolation in the form of lead-core rubber bearings and friction pendulum systems; visco-elastic and fluid viscous dampers; buckling restrained braces; passive tuned mass dampers; active control systems; and semi-active control devices. Future research trends for seismic hazard mitigation of critical and important buildings are presented, focusing on; multi-modal base isolation; advanced damper systems; replaceable ductile fuses; and self-centering rocking systems.

Building-Specific Loss Estimation for Performance Based Design (Miranda, E.)

The goal of performance-based seismic design (PBSD) is to design facilities that satisfy the performance expectations of their owners. Implicit in PBSD when applied to buildings is the need and ability to predict the performance of the structure, its non-structural components and contents for a wide range of possible earthquake ground motion intensities. Recent research conducted at the Pacific Earthquake Engineering Research (PEER) Center aims at describing the seismic performance of structures quantitatively by continuous variables rather than discrete performance levels such as those used in FEMA 356 document. The three continuous variables studied by PEER include: economic (e.g. dollar) losses, downtime and fatalities.

This paper is focused on economic loss estimation and presents an approach for describing the seismic performance of buildings as a continuum and in terms of economic losses. Two alternative measures of economic losses are described and discussed. In the proposed approach the total loss in a building due to physical damage is treated as a random variable and it is computed as the sum of the losses in individual structural and nonstructural components. Economic losses are computed using a fully probabilistic approach

Executive Summary of Symposium Topic Papers: Hazard Mitigation of Critical and Important Building Construction

that permits the explicit incorporation of uncertainties in the seismic hazard at the site, in the response of the structure, on the fragility of individual structural and nonstructural components, and on the costs associated with the repairs or replacement of individual building components. Physical damage is estimated by combining structural response parameters such as interstory drift ratio or peak floor acceleration with component fragility functions. Unlike previous work, the proposed methodology explicitly accounts for economic losses resulting from the possibility of having to demolish the building after a seismic event. The probability of demolition is computed as a function of peak residual lateral deformations experienced in the building. Results from an existing non-ductile seven story reinforced concrete building and from two ductile reinforced concrete moment resisting frame buildings design according to current seismic provisions and assumed to be located in Los Angeles, California are presented to illustrate the proposed loss estimation methodology.

Site-Specific Ground Motion Criteria for Performance Based Design for Critical Facilities (Singh, J.P.)

The American Society of Civil Engineers (ASCE) publication ASCE 7-10, Minimum Design Loads on Structures (ASCE 7-10) has introduced changes to the seismic design provisions for structures for their implementation in model codes such as the International Building Code. For Site Specific Ground Motions, the changes in ASCE 7-10 include (1) incorporation of the most recent Ground Motion Prediction Equations (GMPE) for ground motion mapping, (2) a move to a maximum direction of ground motion and, (3) a "risk-targeted" design response spectrum and (4) changes to the site-specific seismic hazard analysis. The implications of these changes to design practice will be tested once the International Building Code (IBC) adopts the standard in its 2012 edition, and the California Building Code (CBC) adopts the standard in its 2013 edition. As of January 2009, the maximum rotated ground motion has been specified in California for so-called critical facilities: schools, hospitals, and other state-owned structures subject to review by either the Division of the State Architect (DSA) or the Office of Statewide Health Planning and Development (OSHPD). This paper briefly describes (1) ground motion mapping efforts, (2) proposed adjustments to the uniform-hazard portion of the seismic maps that result in uniform estimated collapse probability and (3) explains the concepts of maximum direction and maximum rotation. The purpose of this paper is to make seismologists, geotechnical and structural engineers conversant with changes in ground motion maps and ground motion directions for their proper development and use in the structural analysis. Because the terms maximum direction and maximum rotated have been used interchangeably, the goal of this paper is to define the different terminologies of ground motions such as geometric mean, SRSS, direction of maximum response, maximum direction, and maximum rotated for the users.

Collapse Hazard and Design Process of Essential Buildings with Dampers (Miyamoto, K.)

The combination of steel moment frame structures and fluid viscous dampers (SMRF-FVD) has been shown to produce essential structures that have significant damping and perform well in seismic regions. This approach is economically competitive when compared to typical code design. The viscous damper and driver brace are typically modeled as dashpot and spring elements, respectively, in series. Once a damper reaches its limit states, this simple modeling is no longer applicable. Reaching the displacement limit (bottoming out) results in the damper being transformed to a steel brace of large stiffness, whereas, reaching the force limit implies fracture or buckling and thus rendering the damper ineffective. To address the damper limit states and assess such effect on the building performance, an advanced mathematical model of viscous dampers that includes its limit states was developed. The accuracy of the analytical formulation was verified by correlation to laboratory tests. This model was then used in the modeling of buildings ranging from 1 to 10 stories with SMRF-FVD. Incremental dynamic analysis using 44 sets of PEER NGA records were conducted to compute the probability of the models reaching a failure state at the MCE intensity. Analysis showed that the SMRF-FVD had low probability of collapse at the MCE level and superior performance compared to conventional code design.

Executive Summary of Symposium Topic Papers: Hazard Mitigation of Critical and Important Building Construction

Implementation of Seismic Regulations for Nonstructural Components in Essential and Important Buildings in the United States (Theodoropoulos, C.)

Higher than expected nonstructural damage in moderate level earthquakes, such as Northridge (1994) and Nisqually (2001), has drawn attention to the need to regulate the design and construction of nonstructural elements. Post earthquake field observations recorded by reconnaissance teams from the Earthquake Engineering Research Institute (EERI) and other professional organizations provide important information about earthquake damage to nonstructural systems and components commonly used in the United States. Although essential and important facilities are regulated to meet more stringent seismic design and construction standards, there are cases in which the continued operation of critical or important facilities has been interrupted by nonstructural damage or secondary effects such as water leakage from damaged pipes. Reconnaissance reports also show that the extent of nonstructural damage can be significant and that there are ongoing problems with the implementation and enforcement of seismic design regulations for nonstructural elements.

In the United States, building codes include mandatory provisions for the reduction of nonstructural earthquake damage to provide life-safety levels of protection for the general building stock and increased nonstructural performance in essential facilities such as hospitals, fire and police stations, schools, and buildings with hazardous contents. Requirements for higher performance levels in essential facilities can also provide guidance for the voluntary protection of non-structural elements which preserve important cultural and economic resources. As more attention is being paid to the development of codes that reduce nonstructural damage in earthquakes, and the development of design procedures that achieve specified levels of nonstructural performance, designers and other stakeholders are calling for improved implementation of seismic regulations within an integrated approach to building design and construction. This paper presents best practices for the implementation of seismic provisions of nonstructural elements which are emerging from government agencies, building industries, universities and professional entities conducting research, as well as design and construction professionals.

Conclusion

These papers address various aspects of the design and construction of critical and important buildings to meet the design seismic demands while remaining operational. It is hoped that discussion of the topics raised in these papers will lead to consensus of the need for superior seismic performance of critical and important buildings. By sharing current research and design practices in China and the United States, it is hoped that common interests can be identified and pursued in future collaboration between parties involved in these discussions.

Subject Matter Papers

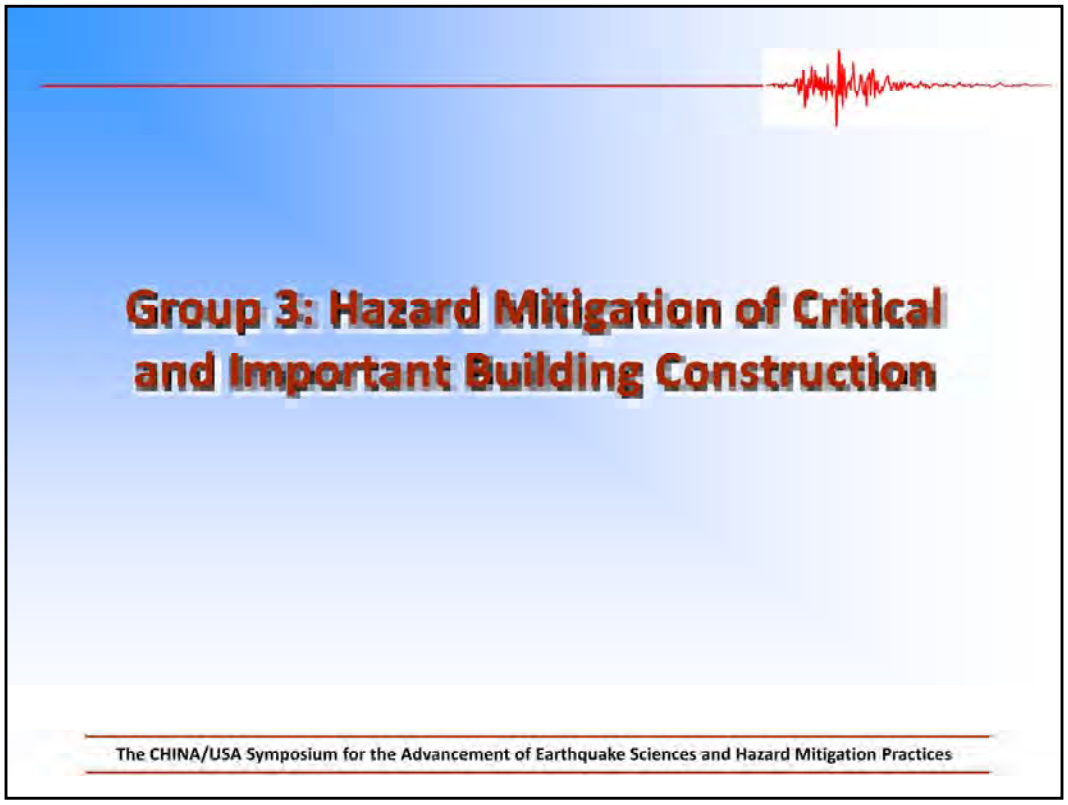
Robertson, I.N. (2010), University of Hawaii at Manoa, *Current Technologies and Future Research Trends for Seismic Hazard Mitigation of Critical and Important Building Construction*, China/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices, Beijing, China.

Miranda, M. (2010), Stanford University, *Building-Specific Loss Estimation for Performance Based Design*, China/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices, Beijing, China.

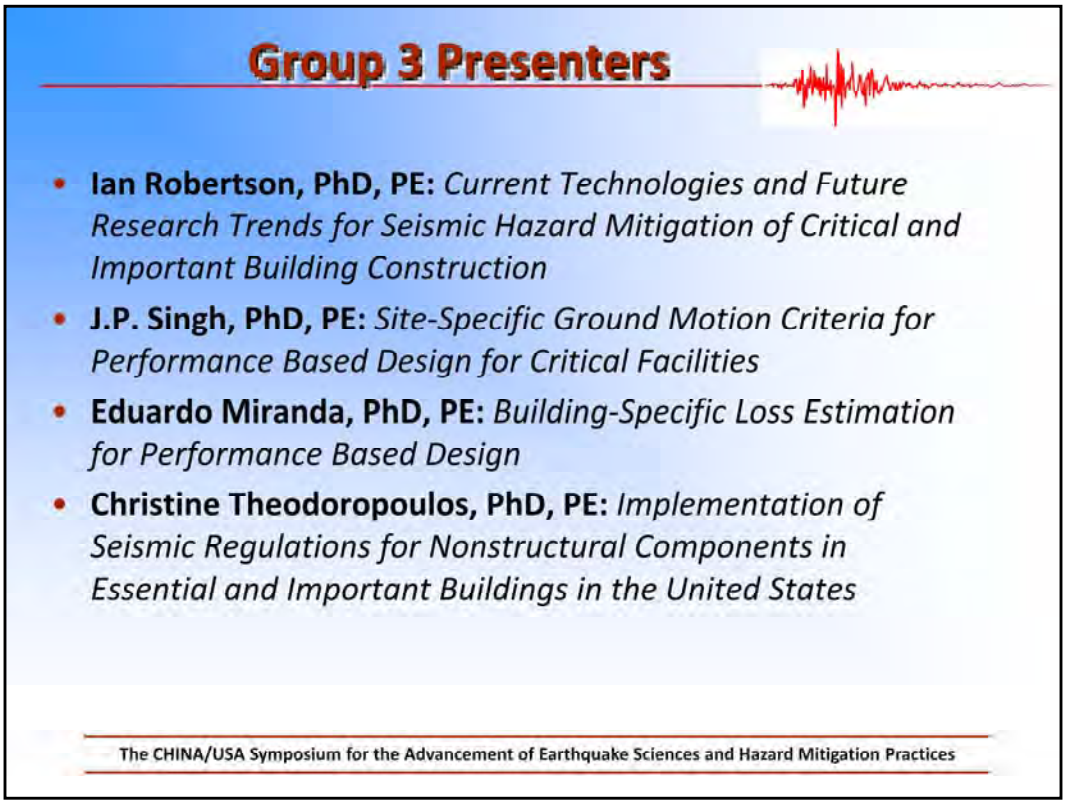
Singh, J.P., Walker, M., Golesorkhi, R., and Hachem, M. (2010), *Site-Specific Ground Motion Criteria for Performance Based Design for Critical Facilities*, China/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices, Beijing, China.

Miyamoto, H.K., Gilani, A.S.J., and Wada, A. (2010), Miyamoto International and Tokyo Institute of Technology, *Collapse Hazard and Design Process of Essential Buildings with Dampers*, China/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices, Beijing, China.

Theodoropoulos, C. (2010), *Implementation of Seismic Regulations for Nonstructural Components in Essential and Important Buildings in the United States*, China/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices, Beijing, China.



Good afternoon. My name is Ian Robertson and I am a structural engineering professor at the University of Hawaii. I will introduce the Group 3 participants and our topics. This session will focus on the mitigation of seismic damage to critical and important buildings.



In group 3 we have five speakers and five related topics.

I am the first speaker. I am a professor of structural engineering at the University of Hawaii specializing in disaster mitigation.

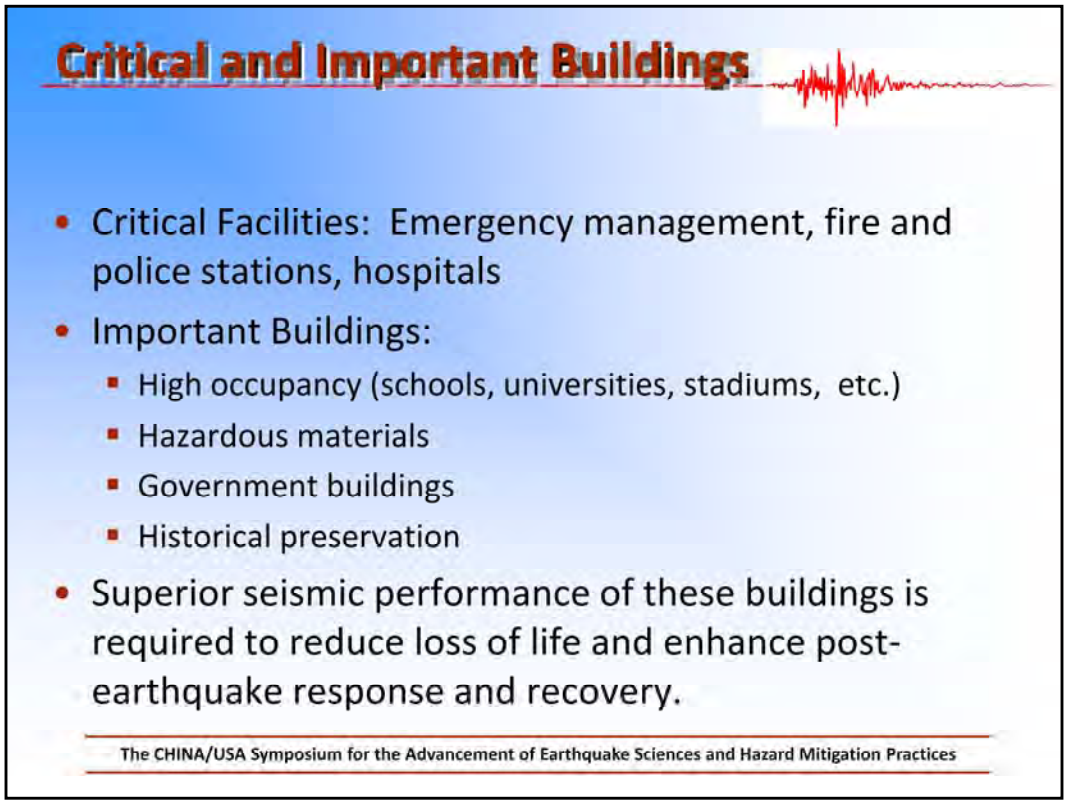
Our second speaker is Dr. Eduardo Miranda, an associate professor in structural engineering at Stanford University. He is also an investigator for PEER, the Pacific Earthquake Engineering Research Center where he conducts research on Performance Based Seismic Design.

The third speaker is Dr. J. P. Singh, an international leader in earthquake engineering and seismology. As CEO of J.P. Singh & Associates, Dr. Singh has been involved in numerous seismic engineering projects, including post-earthquake investigations of major earthquakes around the world.

The fourth speaker is Dr. Kit Miyamoto, CEO of Miyamoto International and Global Risk Miyamoto. Dr. Miyamoto works on major disaster risk reduction and response projects, including the recent devastating earthquake in Haiti.

The final speaker is Dr. Christine Theodoropoulos, head of the Department of Architecture at the University of Oregon. Dr. Theodoropoulos has served as a consultant for various earthquake related projects, including developing earthquake hazard models and disaster preparedness plans for the State of Oregon.

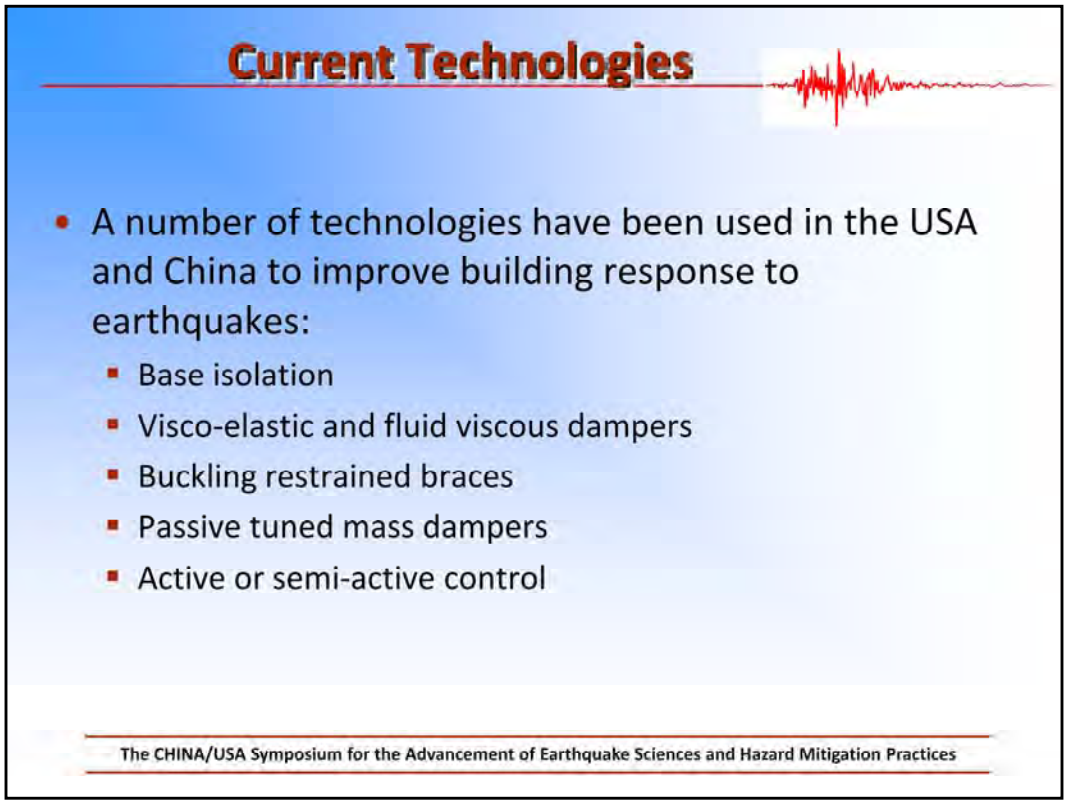
Over the next few minutes I will review some of the current technologies used to mitigate damage in critical and important building construction, and introduce some future research trends.



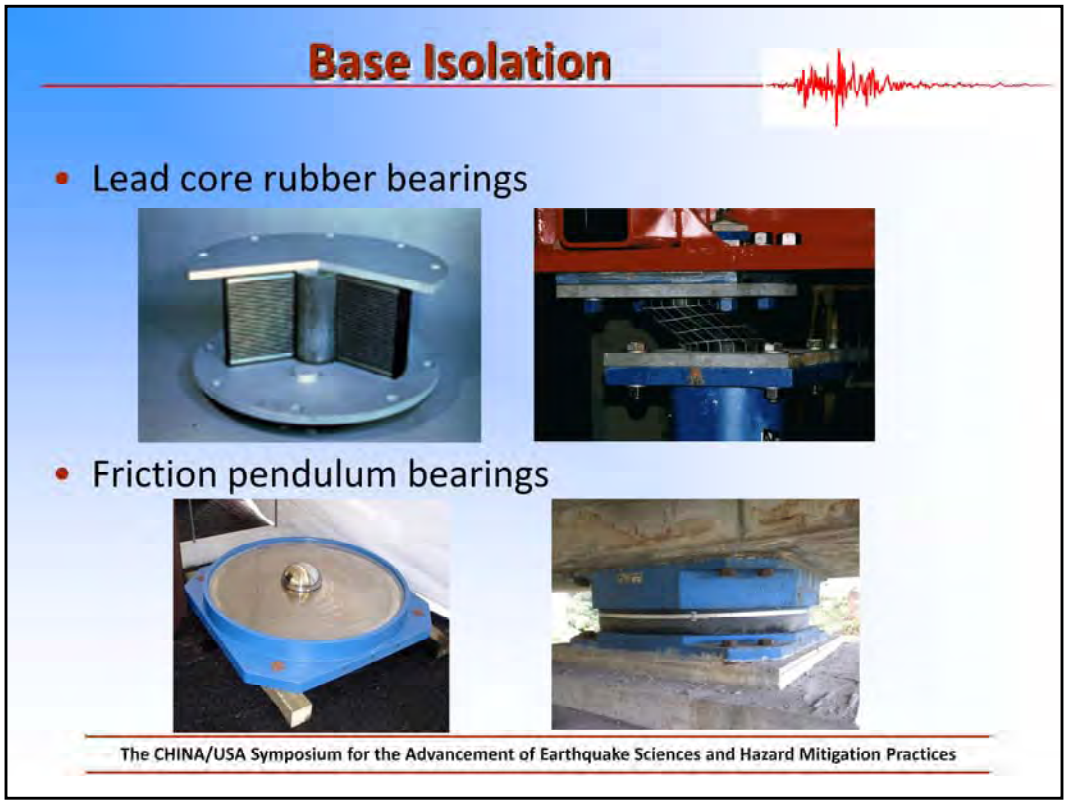
Critical buildings include emergency management control centers, immediate responders such as fire and police stations, and hospitals and clinics. It is essential that these buildings remain relatively undamaged during an earthquake so that they are immediately available after the event for response and recovery.

Important buildings include those with high occupancy, such as schools, universities, sports arenas, and similar buildings. Buildings used to manufacture or store hazardous materials must be able to survive the earthquake without harmful spills. In addition, government buildings and those with historical significance must be protected from severe damage or collapse.

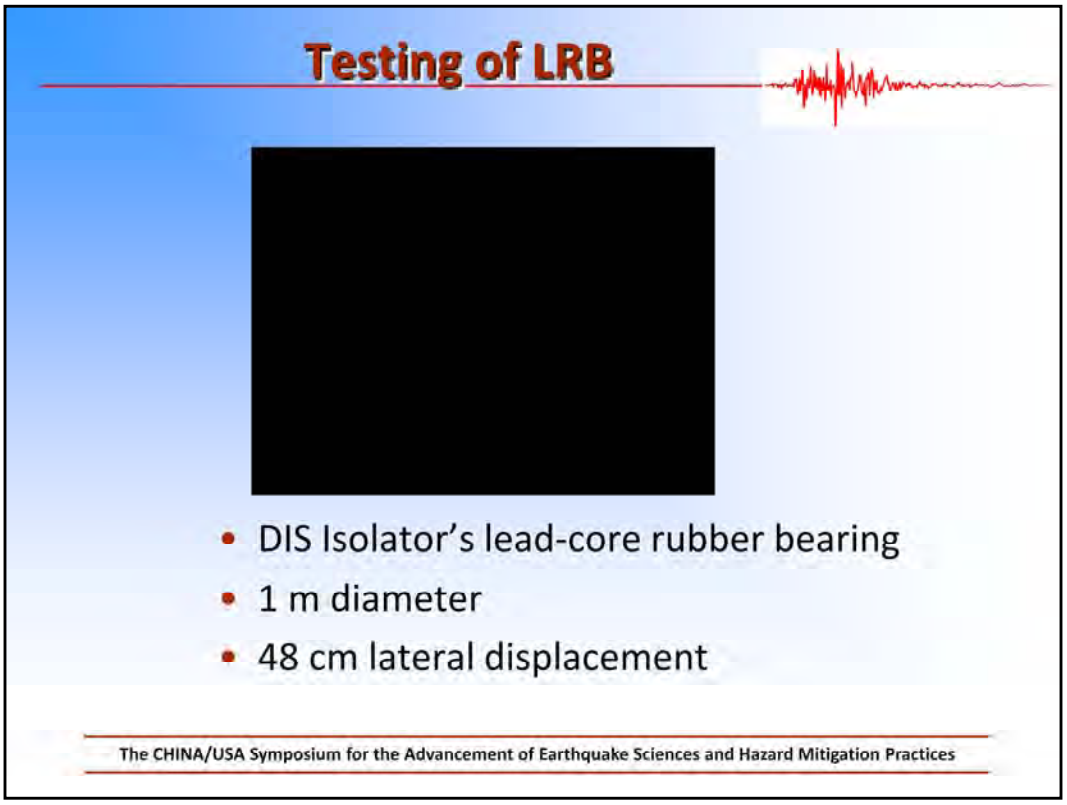
Superior seismic performance of these buildings is required to reduce loss of life and enhance post-earthquake response and recovery.



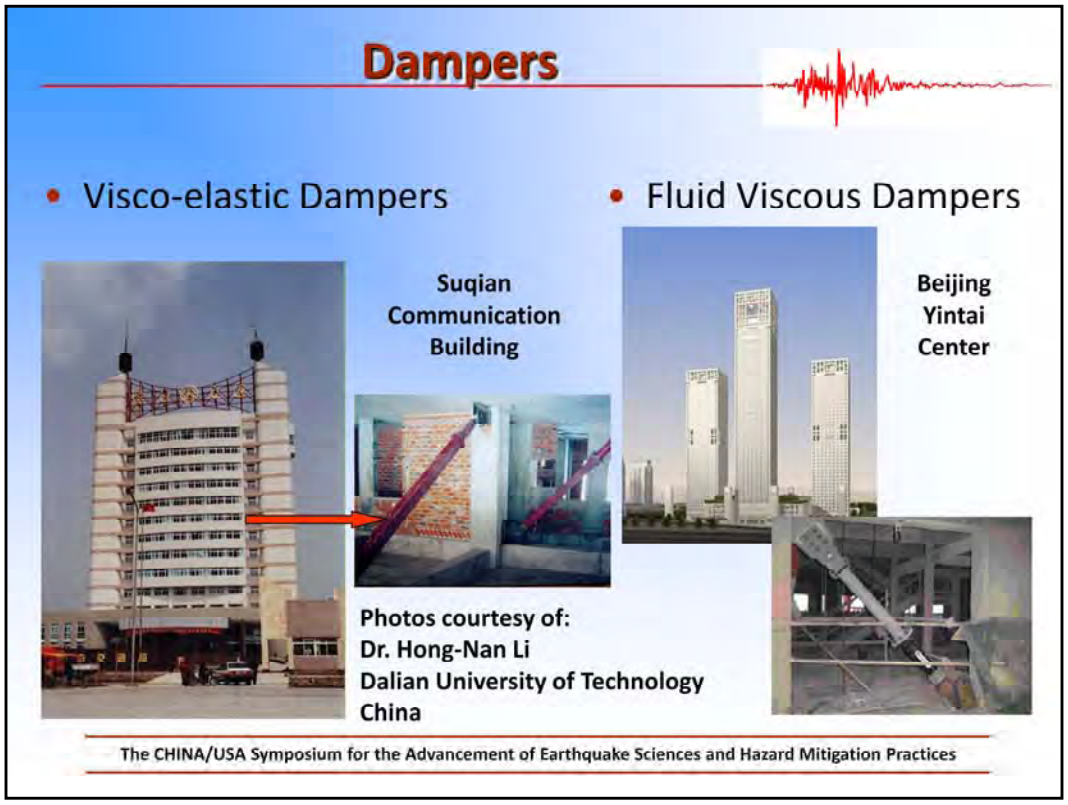
A number of technologies have been used extensively in the US and China over the past few years to improve building response to earthquakes. These include base isolation, dampers, buckling restrained braces, passive, active and semi-active control. I will give brief examples of some of these technologies.



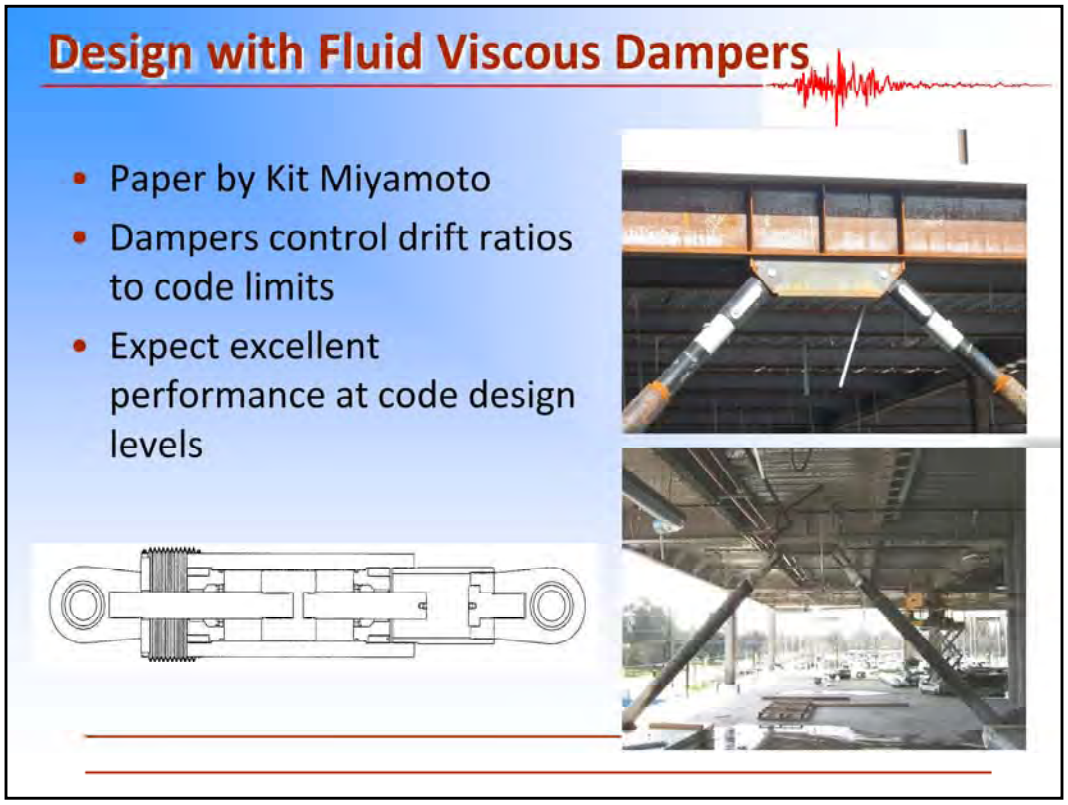
Primary forms of base isolation include lead-core rubber bearings and friction pendulum bearings. Both systems can support extremely high vertical loads while enabling large lateral displacements.



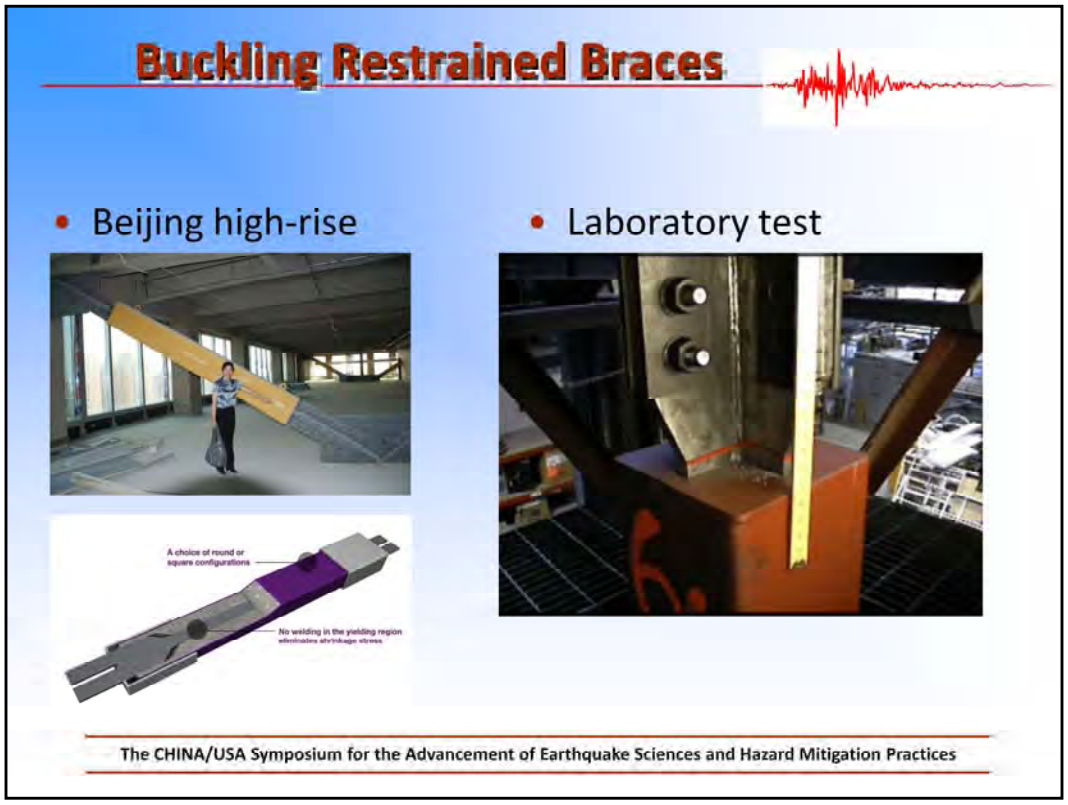
This video shows testing of a 1 meter diameter lead-core rubber bearing. I don't have a total number of base isolation applications in the US, but I heard recently from Prof. Hong-Nan Li of Dalian University of Technology that more than 1000 buildings and bridges in China utilize base isolation.



Visco-elastic and fluid viscous dampers have also been installed in numerous buildings and other structures both in China and the US. By absorbing energy and controlling lateral displacements, dampers can reduce the structural and non-structural damage in critical buildings.

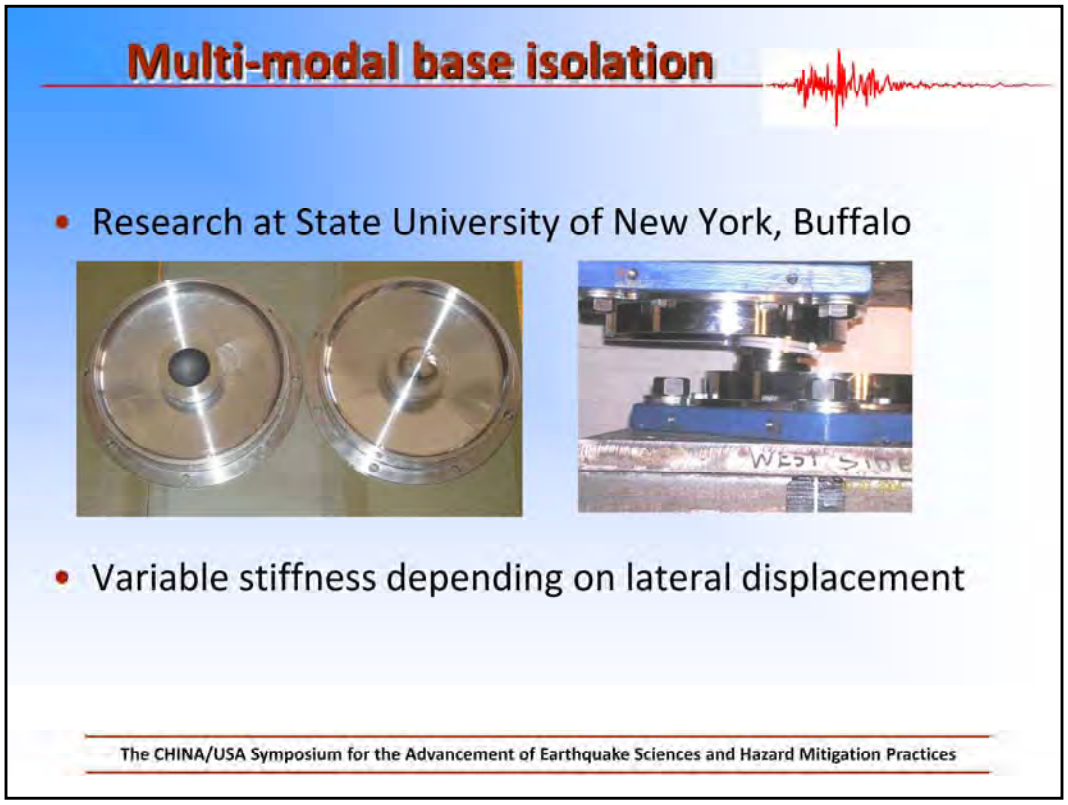


One of the papers in the Symposium Proceedings focuses on structural design with fluid viscous dampers. Unfortunately the author, Kit Miyamoto, was called at the last minute to assist with earthquake recovery efforts in Haiti, so was not able to join us to present his paper. As you will see from his paper, the main conclusions are that dampers are an excellent tool to keep drift levels within code limits.

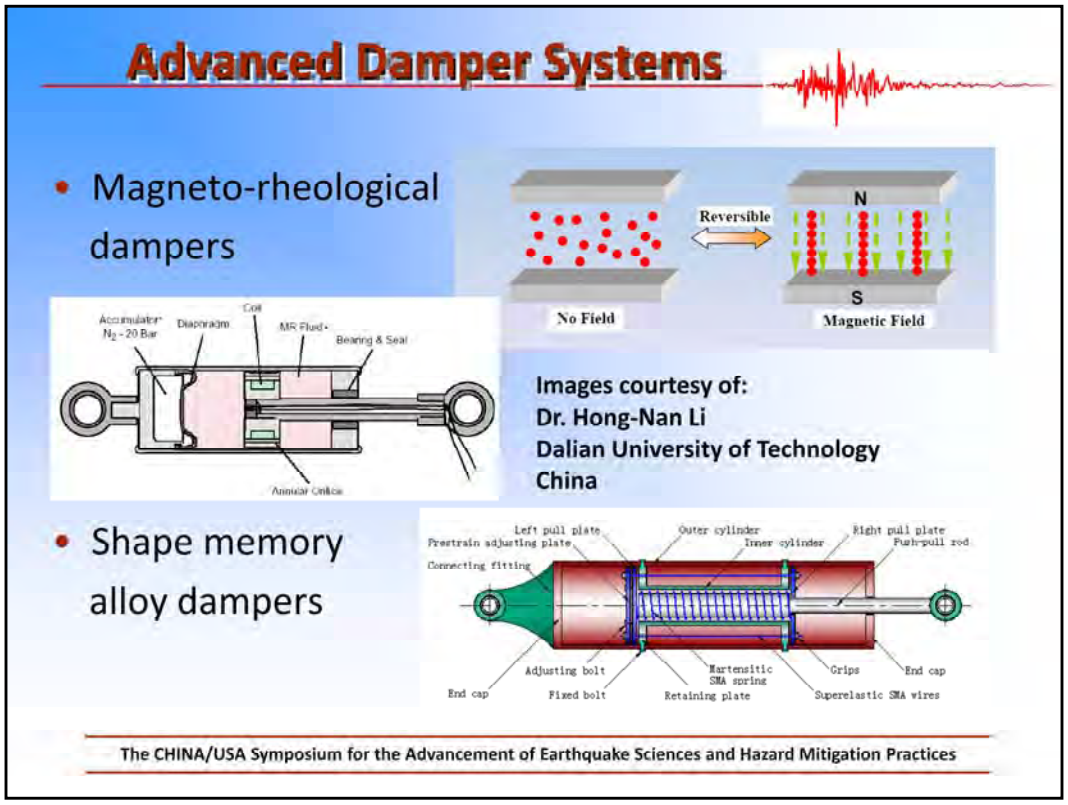


Buckling restrained braces consist of a ductile brace member surrounded by a grout-filled sleeve to prevent buckling under compression. The braces absorb a large amount of energy during yielding cycles, while controlling lateral drift levels.

New technologies under development in the United States and China include multi-modal base isolation, advanced damper systems, replaceable ductile fuses and self-centering rocking systems.

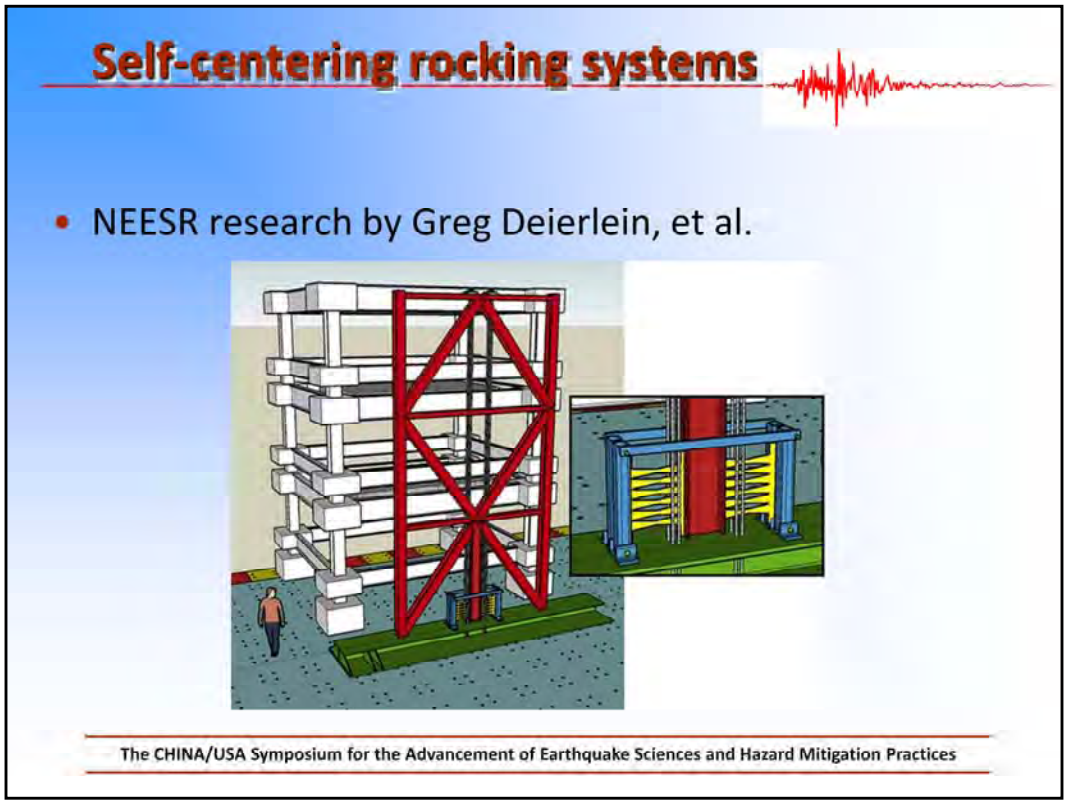


Researchers at the State University of New York, Buffalo, have developed a multi-modal base isolator that adjusts the level of stiffness based on the lateral displacement. These systems provide lower stiffness during moderate ground-shaking, thereby reducing damage to non-structural elements. As the ground-shaking increases, the base isolator stiffness increases to prevent excessive lateral displacements, thus limiting the size of the isolator and the separation joints required around the structure.



Magneto-rheological dampers allow active control of the properties of the damper to adapt to the demands during an earthquake. If active control is lost due to power failure, they behave as passive fluid viscous dampers.

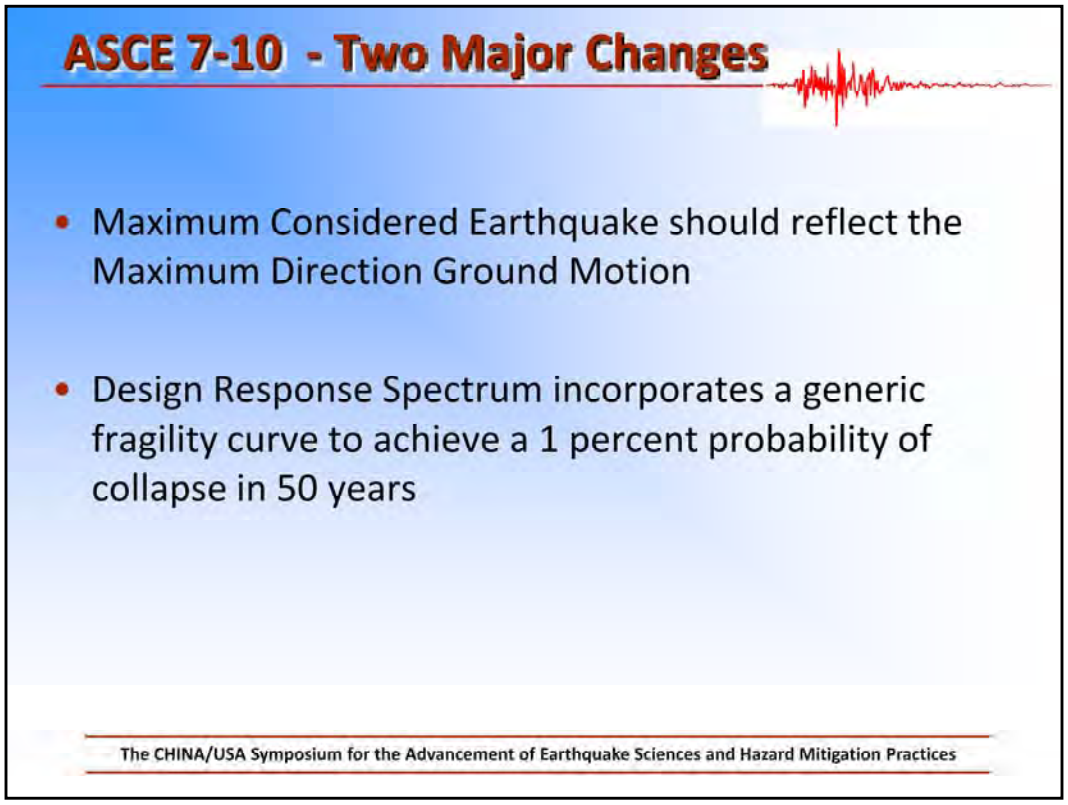
Shape memory alloy dampers rely on spring elements that absorb energy during the earthquake, but can be restored to their original configuration through thermal adjustments.



Researchers working on an NSF-funded NEESR project are developing self-centering rocking systems that utilize replaceable ductile fuses for energy absorption and high-strength prestressed tendons to control lateral displacement and restore the building to plumb after shaking ends.

As these and other new technologies are developed, their implementation in real life structures still presents numerous hurdles. Nevertheless, there are clearly a large number of established technologies that can be implemented to improve the seismic performance of critical and important buildings.

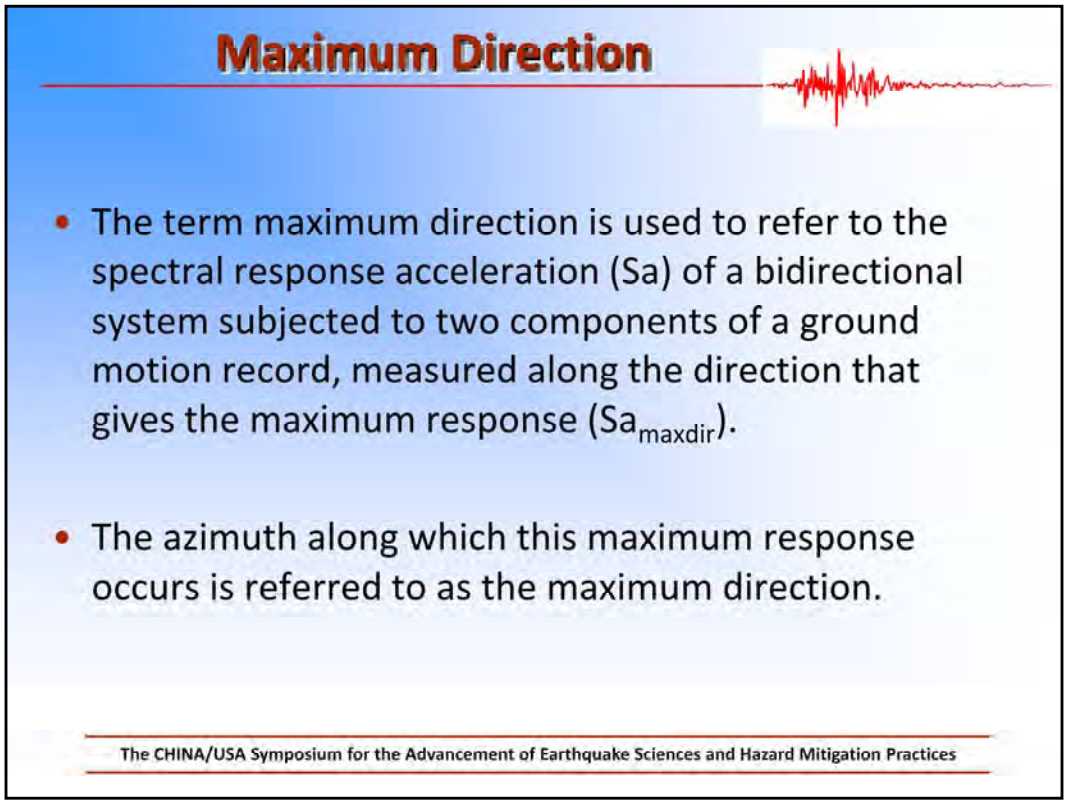
Our next speaker is Dr. J.P. Singh of J.P. Singh and Associates who will address site-specific ground motion criteria for performance based design for critical facilities.



ASCE 7-10 has proposed two major changes as they relate to the site specific ground motions criteria for performance based design of critical facilities.

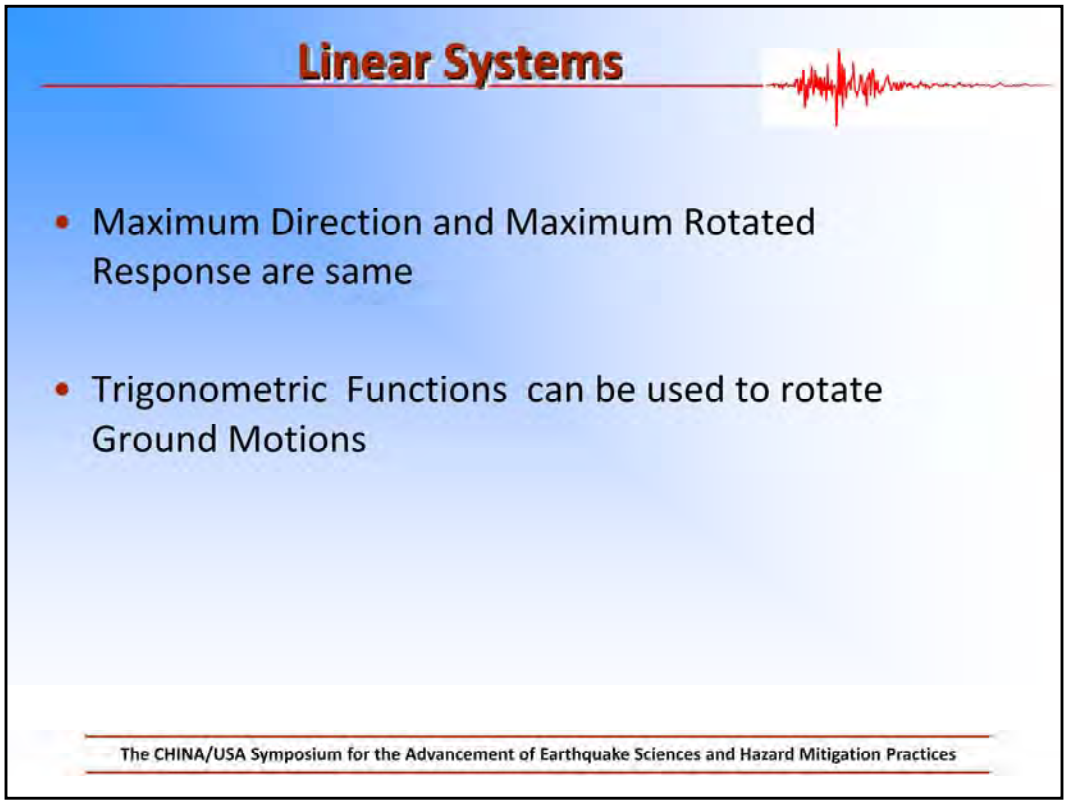
They are:

1.Maximum Considered Earthquake should reflect the Maximum Direction of Ground Motion
2.Design Response Spectrum incorporates a generic fragility curve to achieve a 1 percent probability of collapse in 50 years



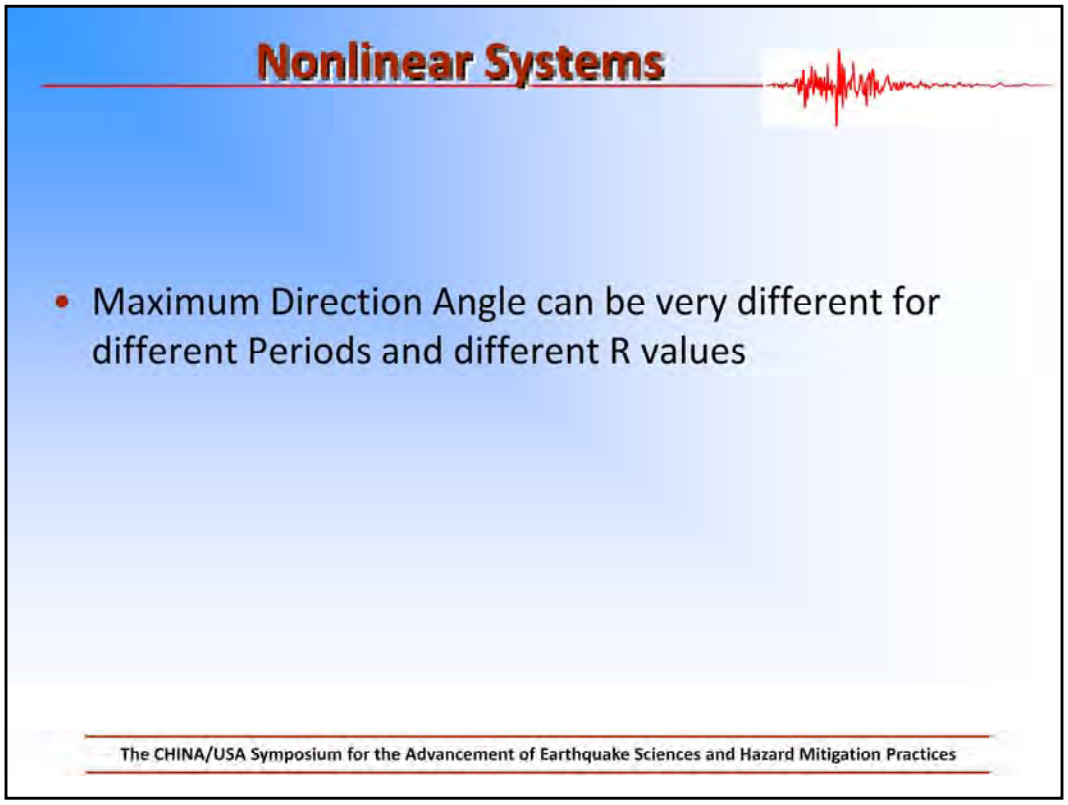
The term maximum direction is used to refer to the spectral response acceleration of a bidirectional system subjected to two components of a ground motion record, measured along the direction that gives the maximum response.

The azimuth along which this maximum response occurs is referred to as the maximum direction.

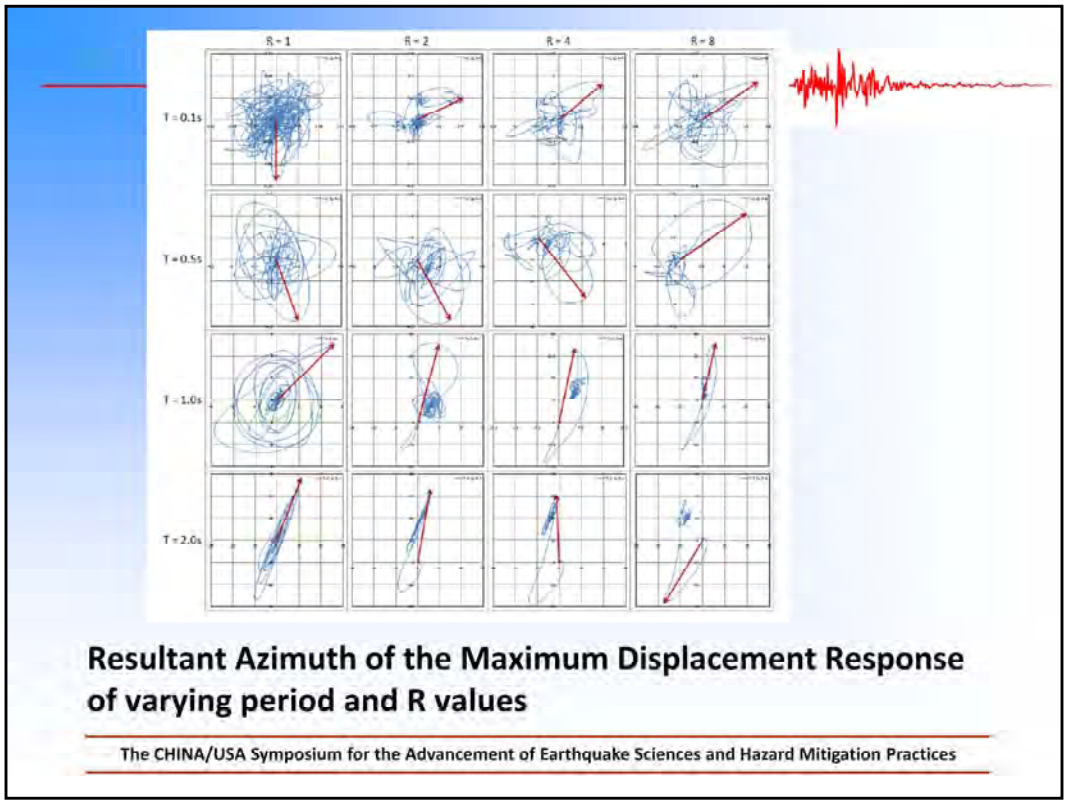


For Linear Systems Maximum Direction and Maximum Rotated Response are same.

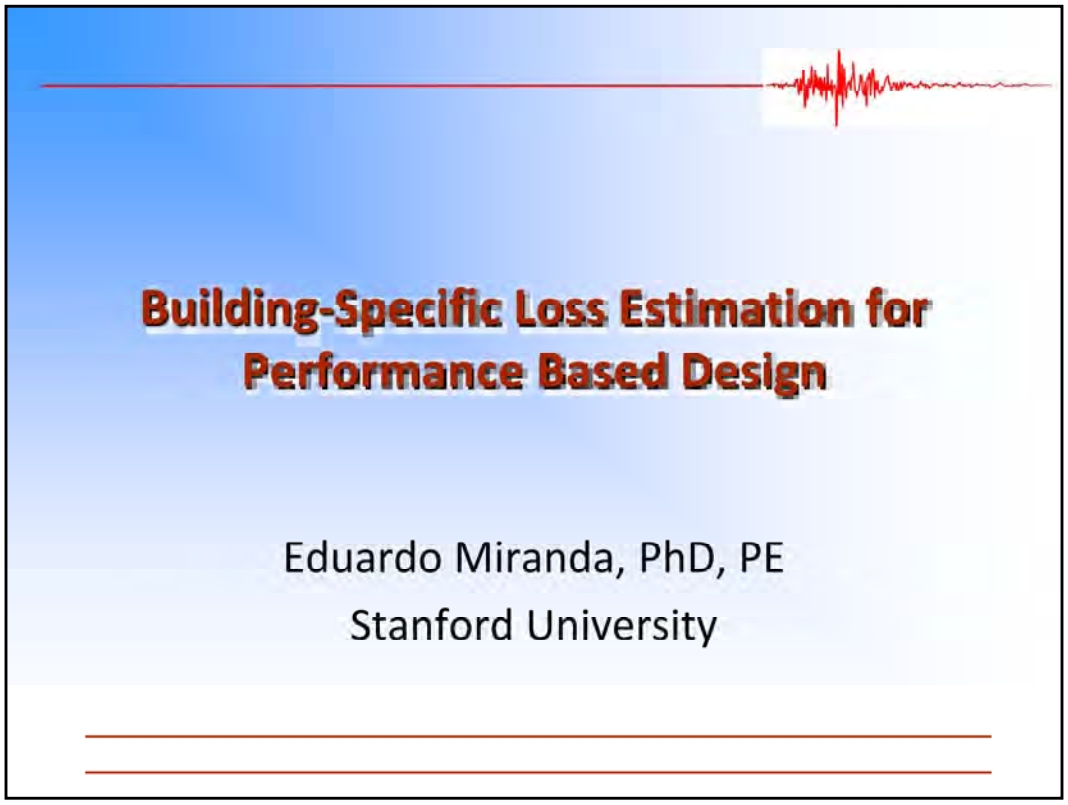
Simple Trigonometric Functions can be used to rotate Ground Motions



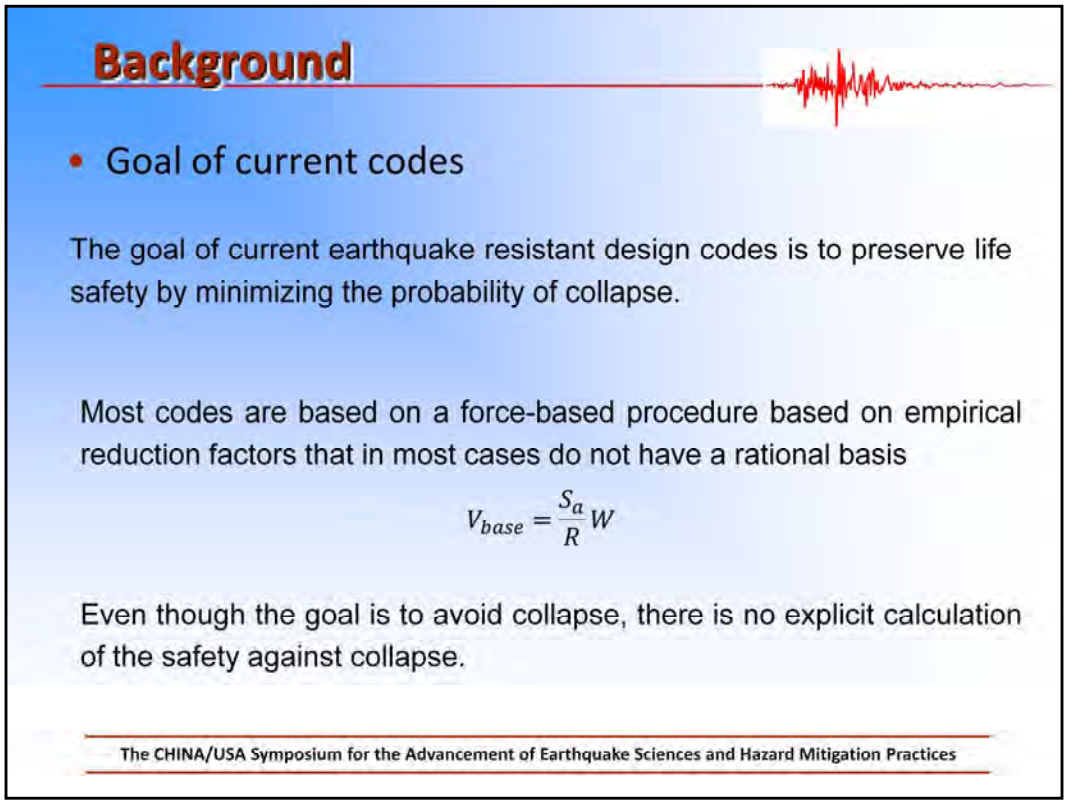
For nonlinear systems Maximum Direction Angle can be very different for different Periods and different R values



Four periods (0.1, 0.5, 1 and 2 seconds) of the two degrees of freedom were considered.
The effect of inelastic behavior was investigated by varying R=Fy/Felastic, over values of 1, 2, 4, and 8.
The plot shows the maximum direction angle is very sensitive to both the period of vibration as well as the yield strength of the system.
This means that there is not one angle to which the record can be rotated that will yield the maximum direction spectrum.
Thus, the maximum response spectrum does not represent a realistic ground motion, and is instead an envelope of the maximum response spectral accelerations of the record at all possible rotation angles and periods.



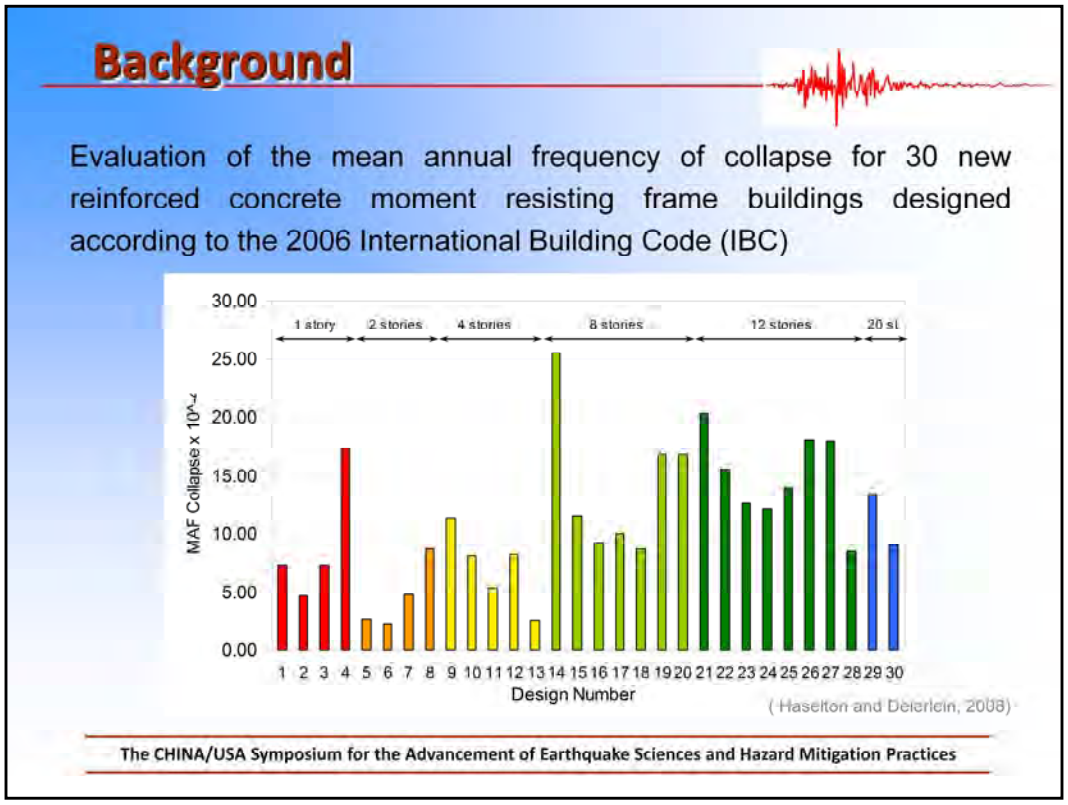
Our next speaker will be Dr. Eduardo Miranda of Stanford University presenting building specific loss estimation for performance based design.



The goal of current seismic codes is to preserve life safety by minimizing the probability of collapse.

Most codes are based on overly simplified procedures in which, for example, the structure is designed to resist lateral forces that are a small fraction of those required to maintain the structure elastic. These lateral forces are often based on reduction factors that do not have a rational basis.

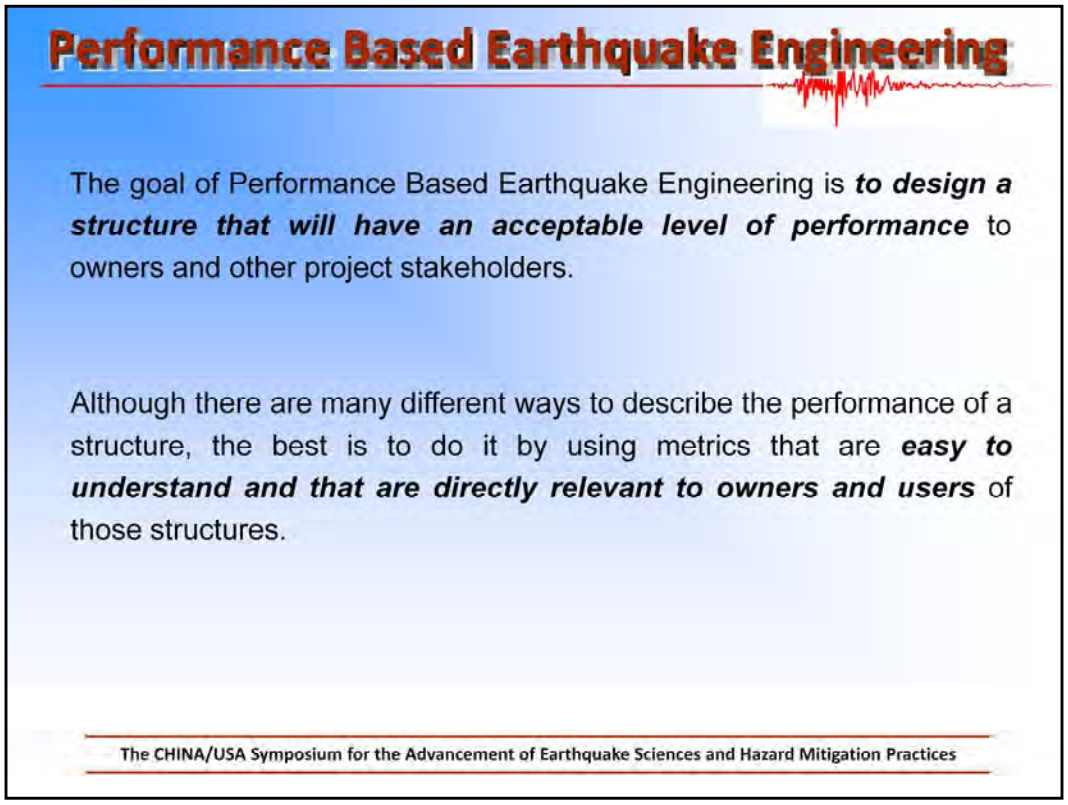
Even though the goal is to avoid collapse, there is no explicit assessment of the safety against collapse.



The result of using this overly simplified prescriptive set of rules is that it may not yield a sufficiently small probability against collapse, nor a similar level of risk for structures designed with the codes.

This slide presents the results of a recent study conducted by Prof. Deierlein in which the annual probability of collapse was evaluated for 30 new reinforced concrete moment resisting buildings designed according to the 2006 International Building Code (IBC) and the latest version of the American Concrete Institute (ACI) recommendations.

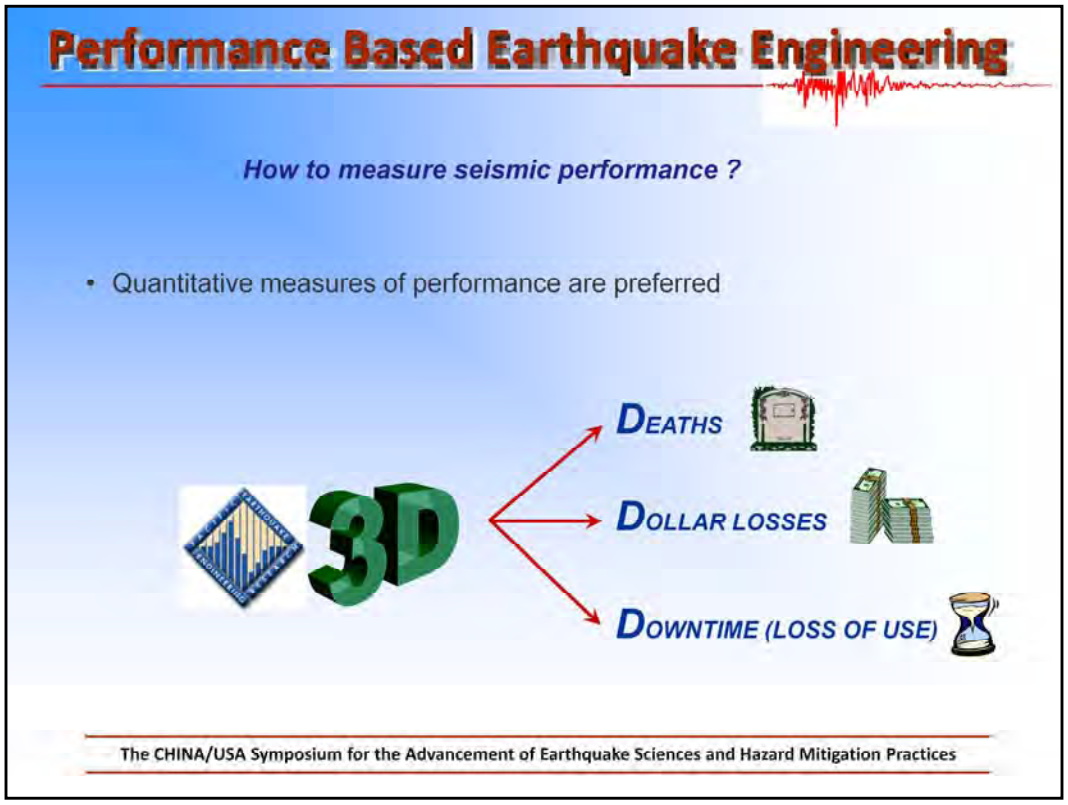
As shown in this slide, the study revealed that even buildings designed with the same code, with the same structural system and for the same location had differences in collapse risk up to ten times larger for some structures with respect to others.



In recent years there has been a lot of research in the United States to develop an alternative (improved) way of designing structures by using what is referred to as a PERFORMANCE-BASED DESIGN.

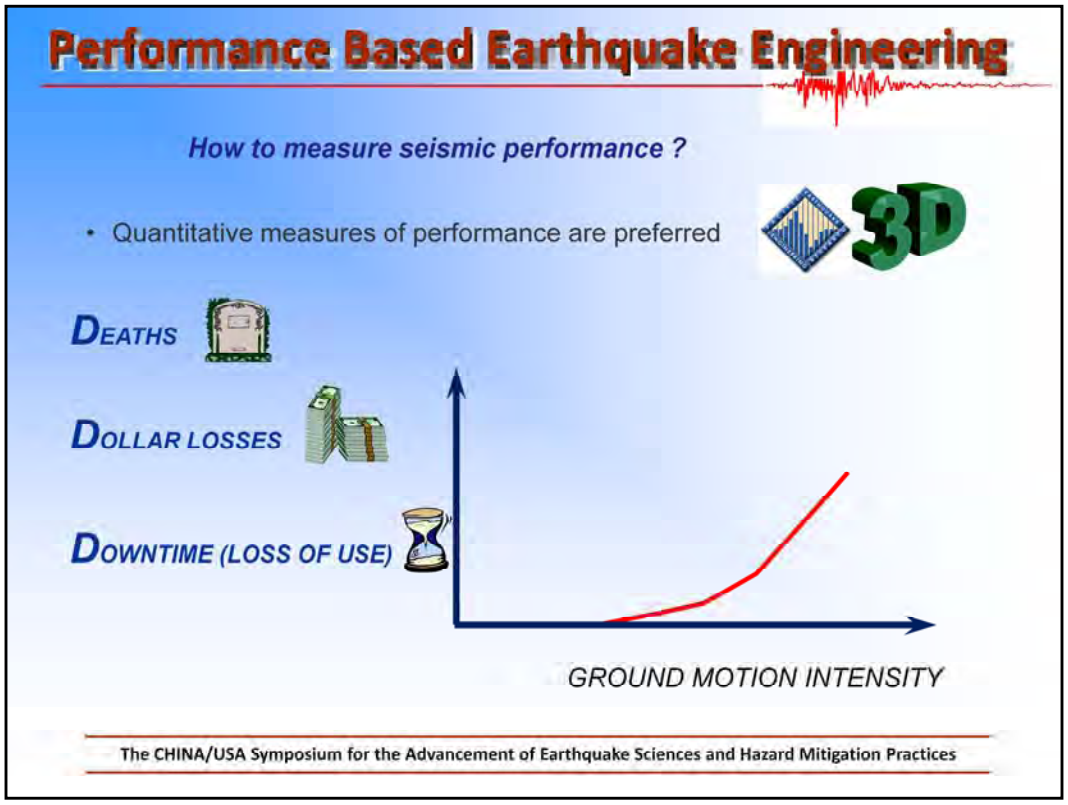
The goal of Performance Based Earthquake Engineering is ***to design a structure that will have an acceptable level of performance*** to owners and other project stakeholders.

Although there are many different ways to describe the performance of a structure, the best is to do it by using metrics that are ***easy to understand and that are directly relevant to owners and users*** of those structures.

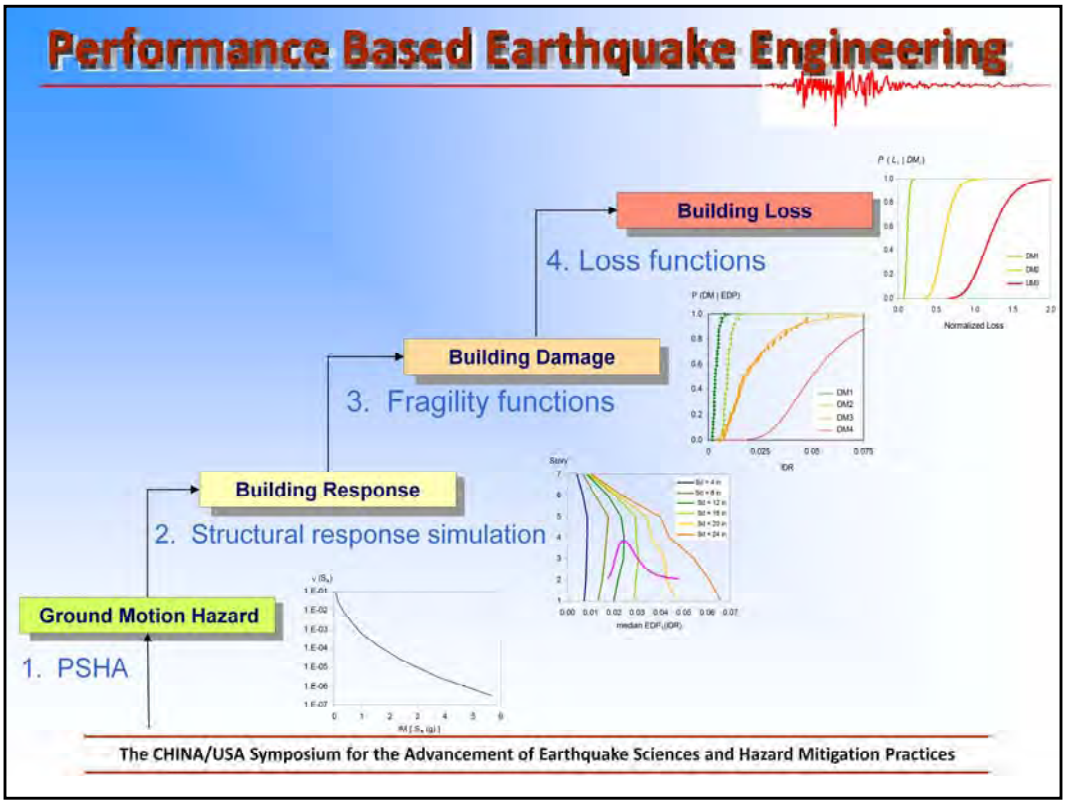


In the approach developed by the Pacific Earthquake Engineering Research (PEER) Center, seismic performance is described by quantitative measures of performance that are directly relevant to owners and users of the facilities.

These measures of performance are referred to as “decision variables” and are the so-called 3Ds: Deaths, Dollars and Downtime



In the approach developed by the Pacific Earthquake Engineering Research (PEER) Center, these quantitative measures of performance are evaluated for a continuum of increasing levels of ground motion intensity using a fully probabilisitic approach. Therefore the design is not aimed at a “design event” but rather to a continuum of possible ground motion intensities that can occur at the site.



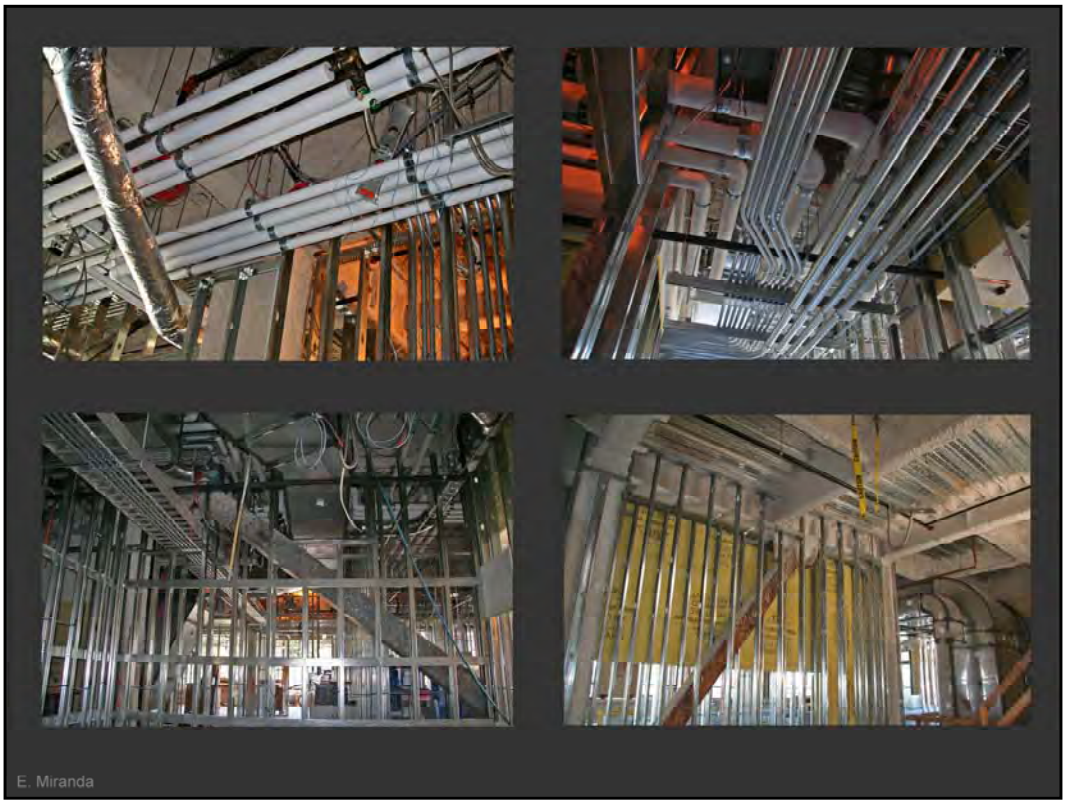
The probabilistic performance assessment consists of four separate analyses:

1.A seismic hazard analysis to determine the probability of exceedance of different levels of ground motion intensity

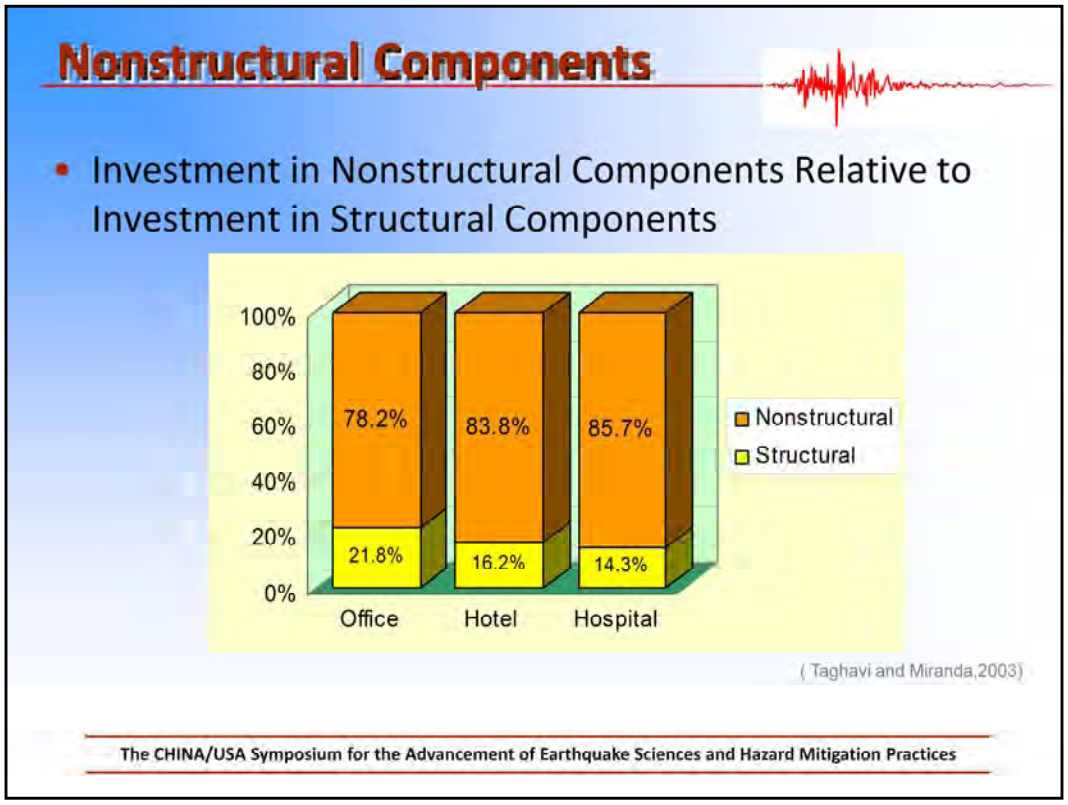
2.A structural response simulation to determine the response of the structure at increasing levels of ground motion intensity

3.A damage analysis to determine the level of damage at increasing levels of structural response

4.A loss analysis to determine the economic loss, downtime or deaths as a consequence of increasing levels of damage



When estimating the seismic performance of a building it is very important to take into account not only the structural components but also the nonstructural components



This is because nonstructural components in many buildings represent 75% to 85% of the economic investment. Damage to these components is of utmost importance when determining economic losses and downtime. Sometimes the failure of these components can also result in injuries to the occupants or even casualties.

Our final speaker is Professor Christine Theodoropoulos of the University of Oregon who will address the implementation of seismic regulations for non-structural components in essential and important buildings in the United States.

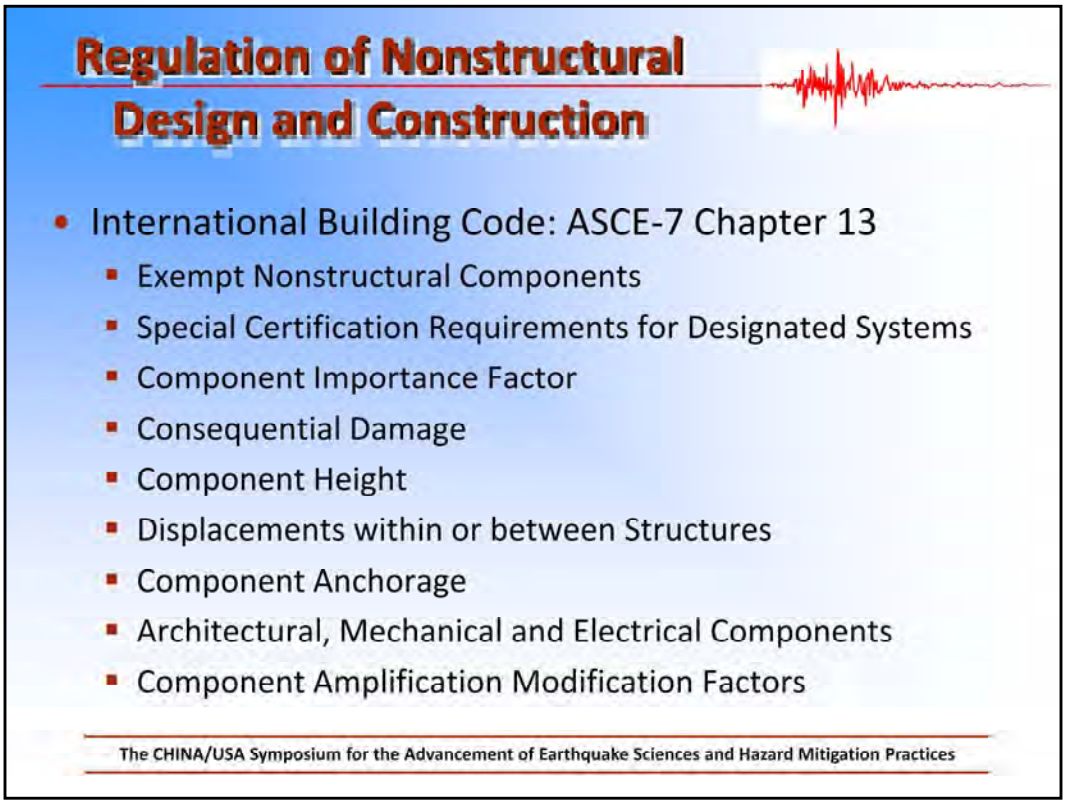
Thank you to our hosts for your kind hospitality. I am delighted to be here and pleased to convey greetings from the American Institute of Architects. For the next few minutes I will give an overview of U.S. seismic regulations of nonstructural elements and discuss several implementation challenges and best practices.

Higher than expected nonstructural damage in moderate level earthquakes has drawn attention to the need to regulate nonstructural design and construction for essential and important facilities.

In this recent example, a school constructed in the 1960s experienced significant damage to the ceilings of classrooms. The failure of seismically fragile nonstructural systems within the space between a roof or floor structure and a suspended ceiling is a common occurrence in earthquakes in the United States. The light gage metal grid supporting acoustical ceiling tiles interspersed with heavier fluorescent lighting fixtures were connected to the structure with wires which did not provide adequate strength, lateral resistance or prevent damaging collisions between components.

Plaster ceiling soffits overhanging exterior walkways fell in a progressive fashion when the failure of improperly attached wire hangers transferred excessive forces throughout the support system. Fallen soffits blocked classroom exit doors and sheared off exterior door knobs. Sometime ago, to prevent breakage, the school's glass windows were replaced with Lexan, a polycarbonate. If students had been inside the blocked classrooms, they would have been unable to exit through blocked doors or break out of the Lexan windows. The failure of the soffits caused the failure of the emergency egress system. Fortunately the school was unoccupied at the time of the earthquake.

This example illustrates the complex interactions of nonstructural systems and why nonstructural design and construction requires regulatory oversight that thoroughly reviews all components and connections and considers the consequential damage that can occur when the failure of one weak link has widespread impacts on safety and performance.



Nonstructural design requirements are specified in the American Society of Civil Engineering Standard 7, *Minimum Design Loads for Building and Other Structures*. It presents minimum design criteria for nonstructural components permanently attached to building structures. These provisions include both force and displacement controlled design considerations and address position retention for components that pose safety hazards as well as post-earthquake operation of critical equipment.

The standard defines low risk, exempt components; and for essential and important buildings it specifies:

•certification requirements for equipment;

•importance factors for design seismic forces;

•the need to prevent failure of an essential component caused by the failure of a nonessential component;

•amplification of seismic forces over the building height;

•effects of structural displacement on nonstructural components;

•component anchorages;

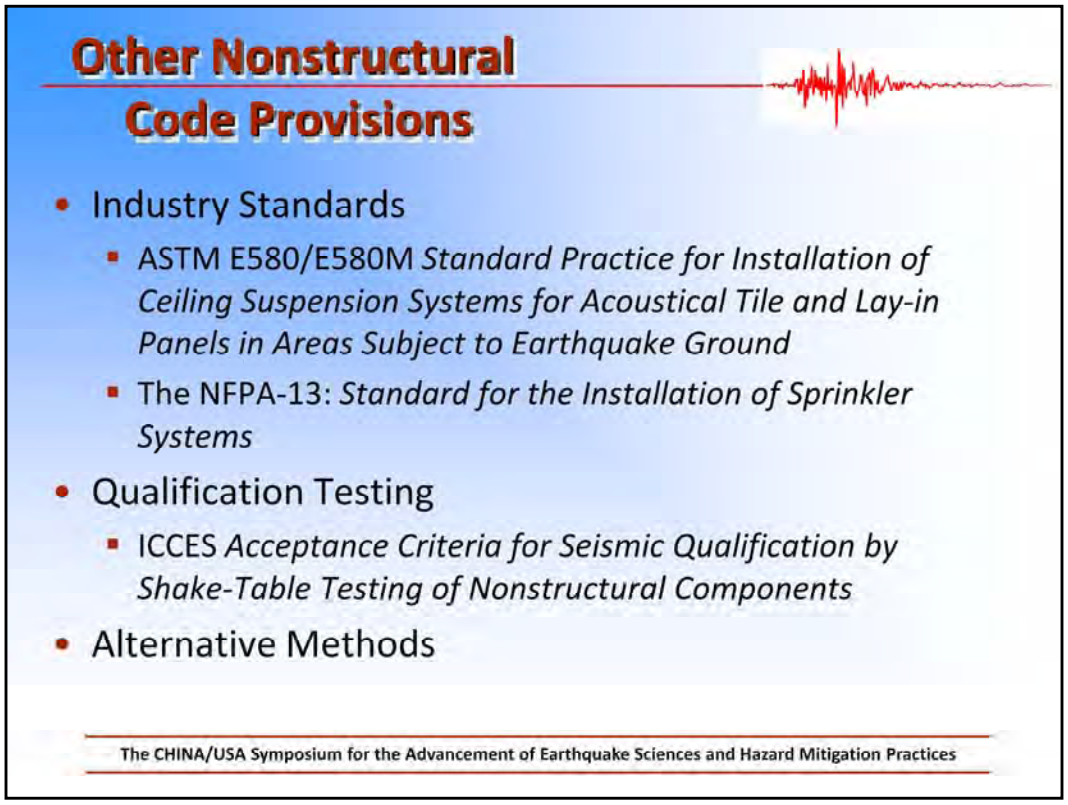
•requirements for common nonstructural components; and

•Component Amplification Modification Factors which provide guidelines for 56 common nonstructural component types.

Component Amplification Modification Factors

Nonstructural Component	a_p	R_p	a_p/R_p
Connecting system fasteners for exterior nonstructural walls	1.25	1.0	1.25
Cantilever interior nonstructural walls (not braced to the structural frame)	2.5	2.5	1.0
Ceilings	1.0	2.5	0.40
Air distribution boxes constructed of sheet metal framing	2.5	6.0	0.42
Piping in accordance with ASME B31, in-line components, welded joints	2.5	12	0.21

These representative examples show how the combined effect of component amplification and response factors ($\mathbf{a_p/R_p}$) adjust lateral design forces according to component type.

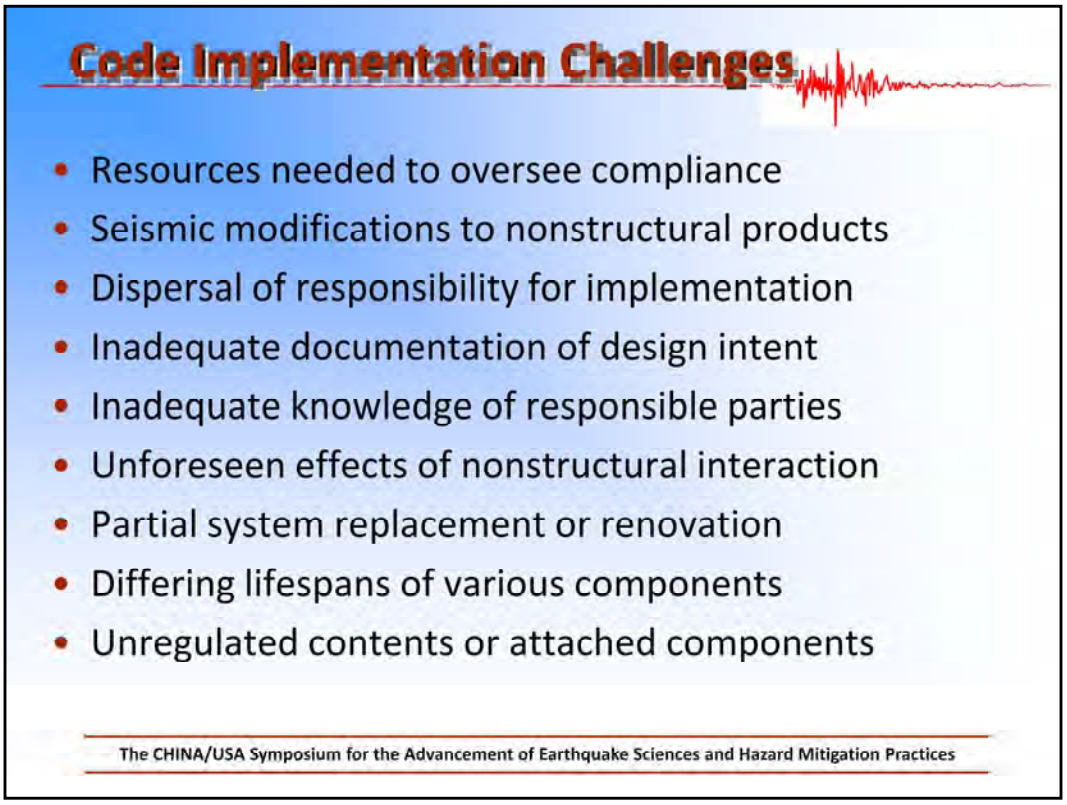


Other types of nonstructural code provisions reference industry standards, and qualifications testing.

For example, the ASTM International (American Society for Testing and Materials)*Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* is a prescriptive set of installation methods for suspended ceilings that can be applied in lieu of designing separate lateral restraint systems;

The International Code Council Evaluation Service's *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components* is referenced for use in the seismic certification of essential equipment that must be operational after an earthquake.

Other types of experience data or analytical methods are also admissible in lieu of code provisions if building officials approve the substitution. Regulations are not intended to hinder the development of new products, or innovative approaches to nonstructural seismic design.



Although the development of nonstructural codes have progressed in recent years, the U.S. seismic design community faces code implementation challenges.

They include:

•Substantial resources and effort needed to oversee compliance for the large quantity and variety of nonstructural components.

•Building products developed to be affordable in zones of low seismicity and then modified for higher seismic demand introduce more chances for errors or complications.

•Responsibility for implementation is dispersed among many individuals who have different roles in the building process.

•Inadequate documentation of design and construction information for components provided by contractors.

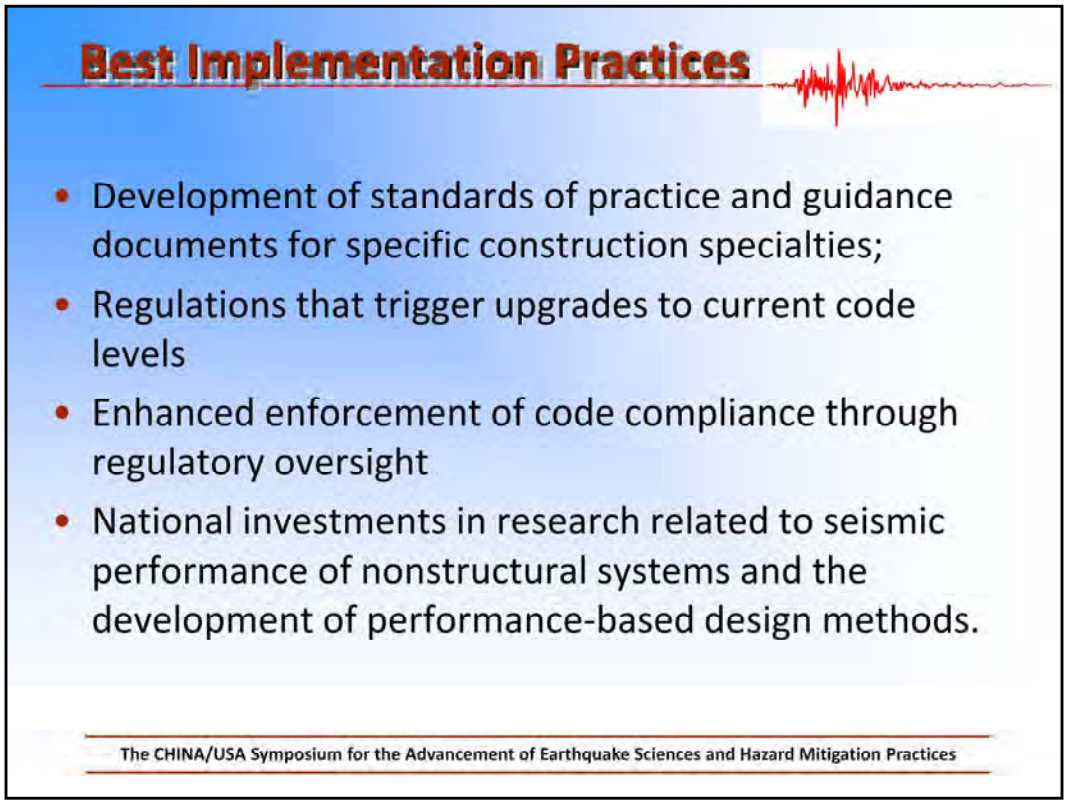
•Inadequate knowledge of responsible parties including designers, contractors and inspectors.

•Unforeseen effects of the interaction between nonstructural components

•Tenant improvements may only include partial replacements or renovations of nonstructural systems.

•Differing lifespans of various nonstructural components can, over time, contribute to performance problems because of compatibility conflicts and remnants from obsolete systems.

•Furnishings, equipment and other unregulated contents provided by building users



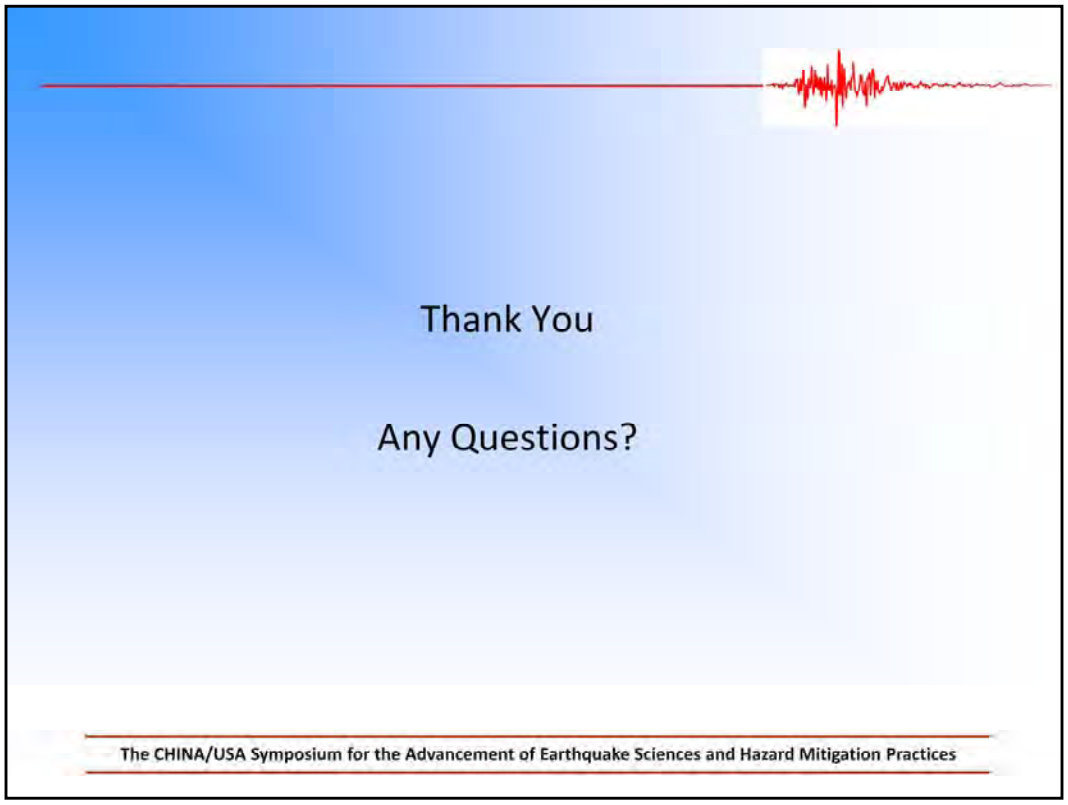
Best nonstructural implementation practices in the United States include:

Industry wide standards of practice that guide the work of contractors responsible for the selection and installation of nonstructural components have integrated code requirements thereby improving implementation reliability

Regulations that trigger upgrades to current code levels is improving the performance of existing essential and important buildings. The State of California now requires all acute care hospitals become compliant with the nonstructural seismic safety provisions of the California Hospital Code by the year 2030.

Enhanced enforcement of code compliance through special regulatory oversight. by the California Seismic Safety Commission has improved school building performance.

National investments in research related to seismic performance of nonstructural systems funded by the Federal Emergency Management Agency and the National Science Foundation is producing new knowledge about nonstructural performance that will be used to inform future codes. Other research on energy efficient and ecologically responsible building technologies is generating new types of non-structural systems and components that will have seismic design implications.



Thank you for your attention. We would be happy to answer any questions.

Current Technologies and Future Research Trends for Seismic Hazard Mitigation of Critical and Important Building Construction

***Ian N. Robertson, Ph.D., S.E.*[1]**

Introduction

The San Fernando earthquake on February 9, 1971, was a wake-up call to many in the engineering community in the US and particularly in California. The magnitude 6.6 earthquake resulted in the complete collapse of many buildings and bridges, and widespread damage to other structures. In particular, partial collapse of the newly constructed Los Angeles County - Olive View Medical Center resulted in 4 deaths and a total loss of the building exactly one month after its opening ceremony (Figure 1). The nearby Veterans Administration Hospital also suffered severe structural and nonstructural damage resulting in 49 deaths. As medical facilities at the center of a disaster, these hospitals were desperately needed, but were clearly not able to serve the community. It is essential that critical facilities such as hospitals, fire and police stations, and emergency response centers remain undamaged and operational throughout a design level earthquake.

Figure 1: First floor collapse of two story building (left) and severe damage to columns of six story building (right) at the Olive View Medical Center after the 1971 San Fernando earthquake.

The Olive View Medical Center was rebuilt in 1976 with a conservative design including reinforced concrete and steel shear walls providing a very high lateral load resisting capability. This new facility experienced design level peak accelerations (0.82g ground floor and 2.31g roof level) during the January 17, 1994 magnitude 6.8 Northridge earthquake, suffering only limited structural and nonstructural damage (Celebi, 1997).

Seismic hazard mitigation measures are employed most readily during design and construction of new buildings. Current USA building codes based on the IBC 2009 (ICC, 2009) require superior design and construction measures for critical and important buildings, particularly hospitals, emergency response centers and police and fire department first responders (Chock, 2010). These facilities must be designed to remain fully operational during and after a design level seismic event. Although traditional seismic construction utilizing special shear walls or moment resisting frames are still often used for these structures, the trend in recent years has been to include some form of seismic mitigation measure such as base isolators, dampers or structural control, either passive, active or semi-active. Existing critical and important buildings that lack the necessary seismic performance to remain operational immediately after a seismic event can be retrofitted using similar seismic mitigation devices.

This paper gives an overview of current technology and future research trends for seismic hazard mitigation of critical and important buildings.

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Current Technologies and Future Research Trends for Seismic Hazard Mitigation of Critical and Important Building Construction

Ian N. Robertson

Current Technologies

Base Isolation

Base isolation is one of the most successful structural control technologies currently available for reduction of seismic response of buildings and other structures. Base isolation systems generally function by shifting the natural period of the structure so as to reduce the structural response, and breaking the load transmission path from foundation to superstructure.

Research on the development of natural rubber bearings for isolating buildings from earthquakes began in 1976 at the Earthquake Engineering Research Center (EERC) of the University of California at Berkeley. These bearings have developed into laminated rubber and steel plate bearings with lead core known as lead-core rubber bearings (LRB) (Figure 2). Capable of supporting large vertical loads while undergoing large lateral deformations, these bearings have become a popular seismic isolation system for numerous retrofit and new construction projects throughout the world.

Friction pendulum systems (FPS) consist of a spherical sliding interface that provides a restoring stiffness, with friction between the sliding interfaces to dissipate energy and limit relative motion during small loading events (Figure 3). Friction pendulum bearings provide greater strength and stability than the rubber bearings. They are not affected by aging or temperature and can be designed for very large lateral displacements while maintaining a relatively low profile. They have become a popular base isolation option for large axial load applications such as low to mid-rise buildings and long-span bridges. With increased production, the cost of these bearings has declined, making them economically attractive for use in critical and important buildings. Often the reduction in cost of foundation and building structure due to the reduction in seismic forces can offset the cost of the base isolators.

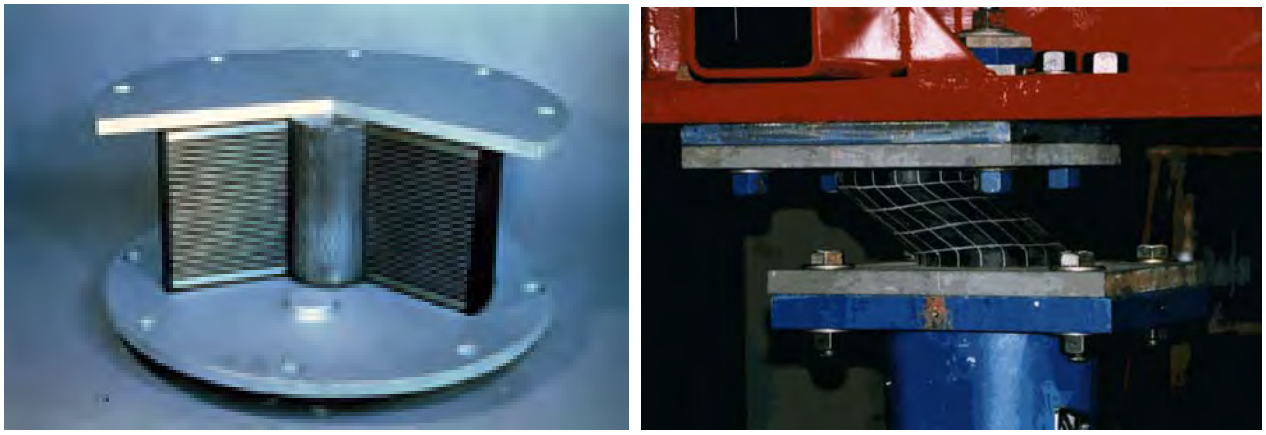

Figure 2: Lead Core Rubber Bearings; cutaway view (left) and laboratory test (right)

Figure 3: Friction Pendulum Bearings; open (left) and installed in the Kealakaha Bridge, Hawaii (right)

A recent example of base isolation performance was the excellent response of two hospitals in Chile during the February 27, 2010, magnitude 8.8 Maule earthquake. Both the Santiago Military Hospital, and the *San Carlos Clinica Catolica* utilize LRB isolators for some of their buildings (Holmes, 2010). Figure 4 shows a model of the Santiago Military Hospital where the main building was base isolated while the adjacent curved tower was not. The base isolated building had minor damage at isolation joints, but no structural or nonstructural damage inside the building. In contrast, the non-isolated curved tower had substantial nonstructural damage requiring two weeks for cleanup and repair. Similar good performance of base isolation was noted at the San Carlos Catholic Clinic also in Santiago, Chile (Holmes, 2010).

Figure 4: Santiago Military Hospital base isolation success story (Holmes, 2010)

Visco-elastic and Fluid Viscous Dampers

Conventionally designed structural frame systems develop significant inelastic deformations under strong earthquakes. This inelastic hysteretic behavior results in stiffness and strength degradation, increased interstory drifts, structural member damage and residual drift. Passive seismic protection systems in the form of supplemental damping devices are an effective approach for reducing response and limiting damage by shifting the inelastic energy dissipation from the framing system to the dampers. Both visco-elastic and fluid viscous dampers are commercially available and have been used on numerous retrofit and new construction projects for seismic hazard mitigation.

Dampers are often used in conjunction with other seismic mitigation measures. Base isolation systems combined with dampers are often more suitable for relatively flexible buildings than base isolation alone. Miyamoto et al (2010) present the benefits of steel moment frame structures combined with fluid viscous dampers (SMRF-FVD). Research at MCEER, SUNY Buffalo, helped to develop a toggle brace structural damper configuration installed in the Yerba-Buena Tower in San Francisco (Figure 5).

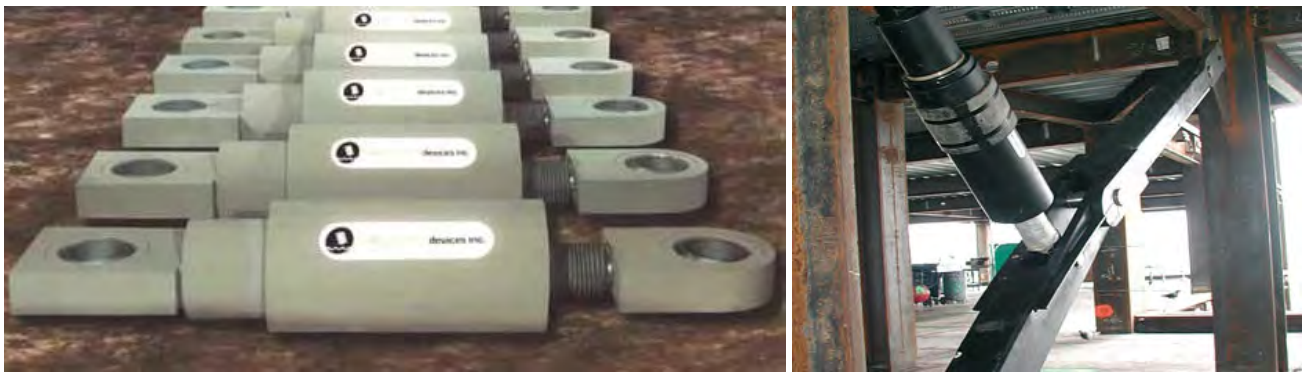

Figure 5: Fluid viscous dampers (left) and installed in Yerba-Buena Tower toggle brace (right)

Buckling Restrained Braces

A buckling restrained brace (BRB) consists of two major components; a steel core which resists axial stresses, and the outer concrete filled steel casing which resists buckling stresses (Figure 6). The casing restrains the steel core from buckling when the brace is subjected to compression, thereby developing similar brace response in both tension and compression. Braced frames constructed with BRBs exhibit full, balanced hysteresis loops with compression yielding similar to tension yielding behavior (Hussain et al, 2005). BRB frame systems are currently used as primary lateral force resisting elements both in new construction and seismic retrofit projects. Careful analysis and brace sizing can result in a considerable increase in damping without a significant decrease in building period. The robust nature of these systems makes BRB frames good candidates for a variety of applications in high seismic regions (Hussain et al, 2005). A typical application of BRB using the UnBonded Brace (UBB) product in a high-rise building in Beijing is shown in Figure 6.

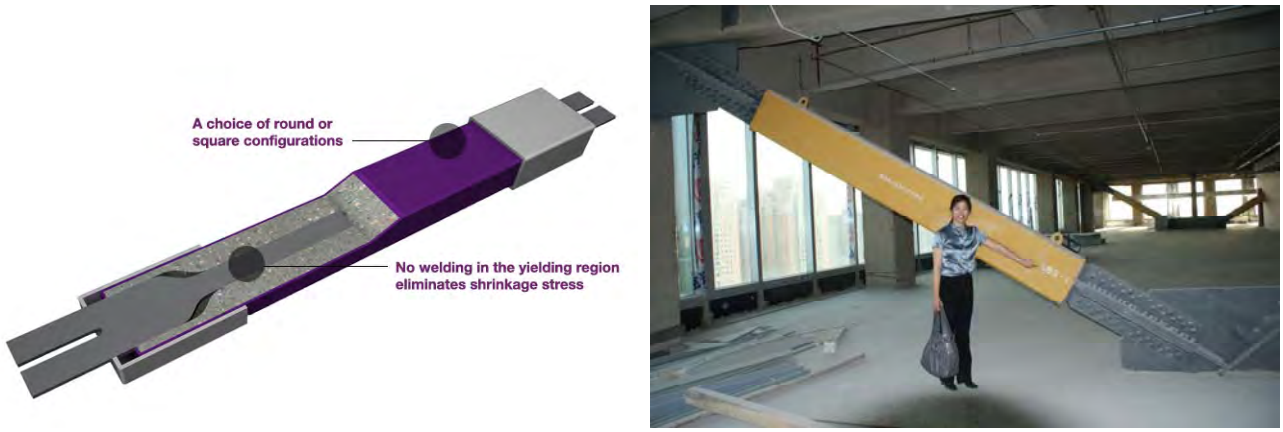

Figure 6: Schematic of Buckled Restrained Brace (Star Seismic) and typical installation in Beijing high-rise

Passive tuned mass dampers

The concept of a tuned mass damper (TMD) originated in the early 1900s for use in vibration control of mechanical engineering systems. More recently, they have been employed in numerous buildings for control of wind-induced structural response in the elastic range. The tuned mass may be a solid body or liquid in a sloshing tank or U-tube. Figure 7 shows the pendulum mass damper installed at the top of Taipei 101 tower within a public observation area.

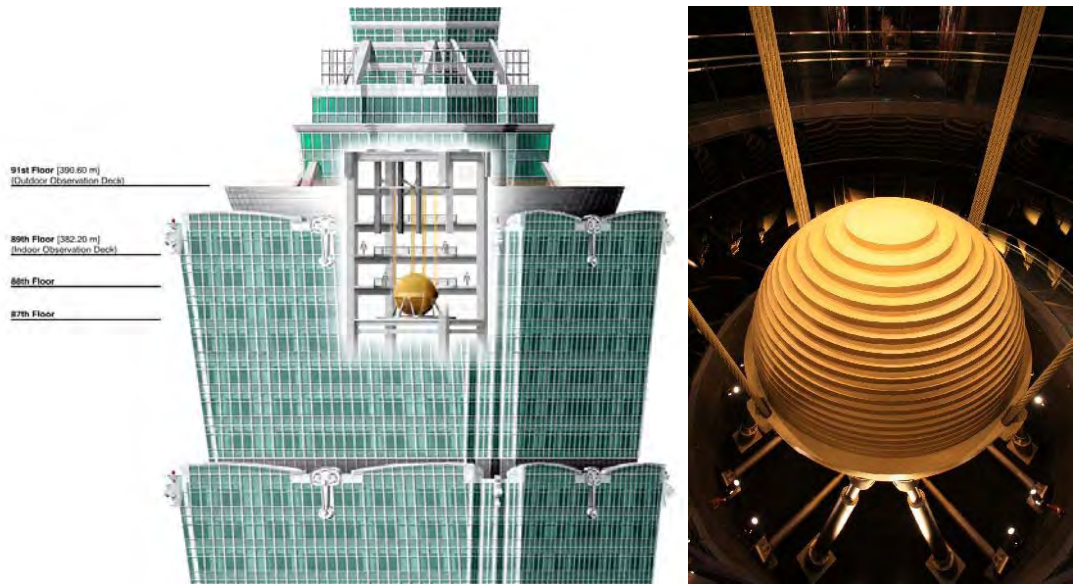

Figure 7: Passive tuned mass damper in Taipei 101 tower

As a passive control system, TMDs do not require an external power source, and are therefore reliable even when power is lost to the building due to earthquake damage elsewhere on the power grid. However, a passive control system has limited ability because it cannot adapt to structural changes or varying input motions. To overcome these shortcomings, active or semi-active control systems can be employed.

Active control

An active control system is one in which an external source powers control actuators that apply forces to the structure in a prescribed manner. These forces can be used to both add and dissipate energy in the structure. In an active feedback control system, sensors located on the structure provide input for the control algorithm, which then determines the appropriate response from the control actuators. Rapid sensor-control feedback is required to ensure that the system responds rapidly enough to counteract the adverse effects of the wind loading or ground shaking. Considerable research has focused on development of appropriate control algorithms. However, while active control systems have been installed in numerous buildings for control of wind-induced vibration, only a limited number of systems have been installed in critical or important buildings for seismic response control. Widespread implementation of this technology for control of seismic response is hampered by the concern that loss of power to the control system will render the building unsafe during an earthquake event.

Semi-active control

Because of the concern over power loss and the need for routine maintenance to ensure proper performance of active systems, semi-active control systems have also been developed. These systems combine the features of active and passive control to reduce the response of structures to dynamic loading. Semi-active control devices can also be viewed as controllable passive devices. With loss of power, the device reverts to a passive system, still capable of providing life-safety performance for the building. Magneto-rheological dampers are an example of semi-active structural control currently undergoing extensive research and development.

Future Research Trends

Multi-modal base isolation

In an effort to improve the performance of friction pendulum isolators, researchers at SUNY Buffalo demonstrated the superior performance of double concave friction pendulum bearings compared with conventional friction pendulum bearings (Figure 8) (Constantinou, 2004). Researchers at UC Berkeley are developing a new multi-stage isolation bearing, capable of progressively exhibiting different hysteretic properties at different stages of response (Morgan and Mahin, 2008). These properties can then be targeted to achieve specific performance goals for a range of ground motion intensities and structural dynamic characteristics. A newly-developed triple pendulum isolator incorporates four concave surfaces and three independent pendulum mechanisms. Pendulum stages can be set to address specific response criteria for moderate, severe and very severe seismic events.

Figure 8: Friction Pendulum Double Concave Bearing tested at SUNY, Buffalo (Constantinou, 2004)

Advanced damper systems

Recent investigations have shown that a combination of adaptive stiffness and damping (ASD) devices can provide substantial response modification, particularly during near-fault pulse-type earthquakes (Nagarajaiah et al, 2009). ASD devices offer structural response modification by optimally varying the restoring forces (stiffness) linked to the frequencies of vibration and dissipative forces (damping) that govern the behavior of a structural dynamic system. Development of new ASD devices is being performed at the NEES equipment site at the University of New York, Buffalo, to shift the energy dissipation and associated stiffness variations from the structural system to the ASD devices to reduce damage in frames, eliminate residual interstory drift, and provide self-centering capability (Nagarajaiah, 2008).

One popular form of ASD is magneto-rheological fluid dampers which allow for active control of the properties of the fluid in the damper, thereby enabling response modification to match the demand. A magnetic field is used to alter the orientation of magnetic particles in the damper fluid to facilitate this change in properties. Large-scale testing is being performed at the NEES equipment site at Lehigh University to understand better the performance of structures containing advanced damping systems (Sause, 2009). These tests are expected to result in design procedures for application of damper systems for performance-based design of structures, as well as validation of such damping technologies for civil engineering applications (Dyke, 2010).

Replaceable ductile fuses

A relatively simple technique to limit damage in critical and important buildings and other structures is the use of replaceable ductile fuses. The intent of ductile fuses is to concentrate all of the seismic damage and energy absorption at specific locations in the structure, while limiting the demand on the rest of the structural elements. The damaged fuse elements can then be removed and replaced after the seismic event, restoring the structure to its original condition. Figure 9 shows a laboratory test specimen of a ductile fuse in a tension brace (Prion and Timler, 2010). These fuses are being developed for use in HSS seismic bracing systems in low-rise buildings. Figure 10 shows a fuse connector being developed for use in Hybrid Masonry Seismic Systems that combine ductile masonry infill shear walls and structural steel frames for low to mid-rise construction (Robertson, 2010).

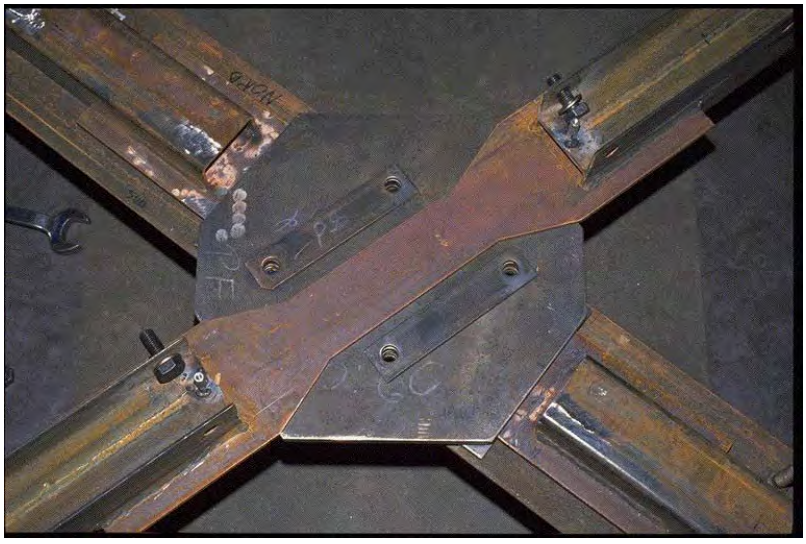

Figure 9: Experimental fuse in tension brace (Prion and Timler, 2010)

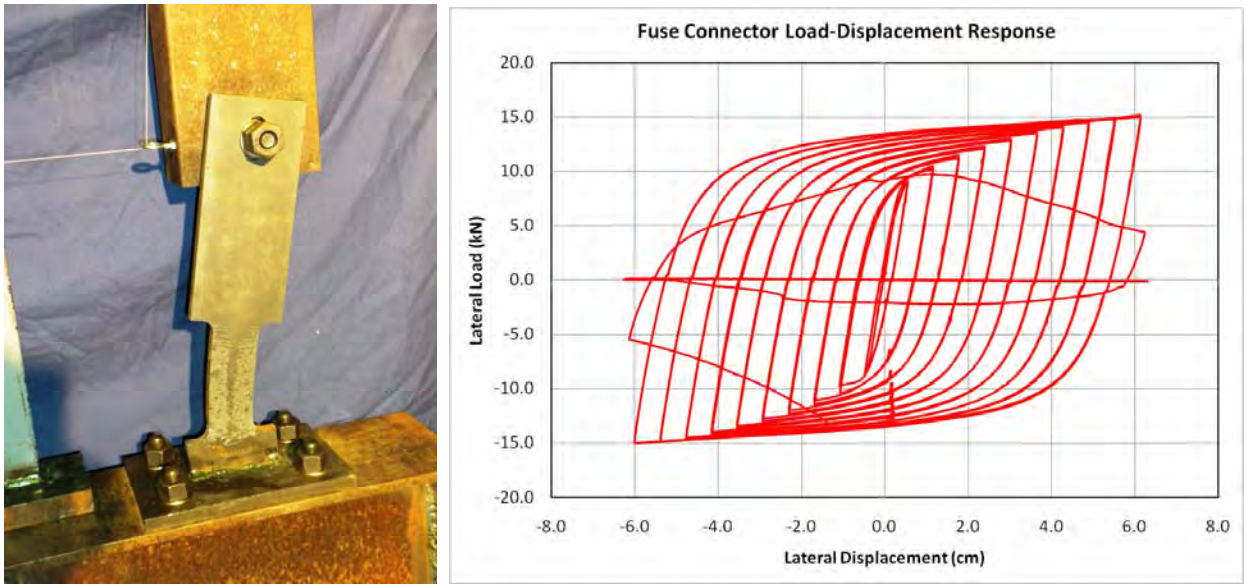

Figure 10: Fuse connector being developed for Hybrid Masonry Seismic Structural System (Robertson, 2010)

Self-centering rocking systems

Recent research has investigated rocking shear walls using nonlinear soil-foundation-structure interaction as a mechanism for reducing demands on the structure. Concern over permanent displacement of these systems has lead to the concept of self-centering rocking shear wall systems. In 2009, researchers from the US and Japan conducted a large-scale shaking table test of an innovative steel braced frame that resists strong ground shaking through controlled rocking. This system relies on prestressed steel tendons and replaceable ductile fuses to facilitate frame rocking but ensuring self-centering after ground shaking ceases (Figure 11). By maintaining integrity of the main structure, this system limits structural damage and residual drift, thereby minimizing disruption following a major earthquake (Deierlein, et al, 2009)

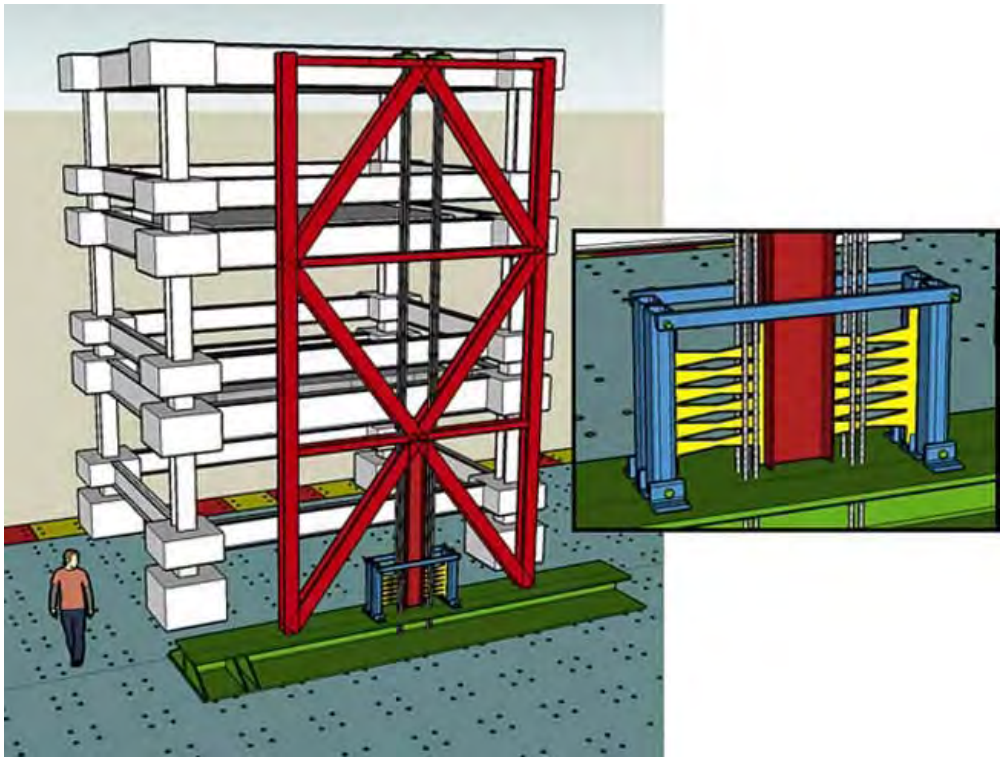

Figure 11: Schematic diagram of the rocking frame set up for shake-table testing (Deierlein, et al, 2010)

Conclusion

Critical and important buildings such as hospitals, emergency response centers, fire and police stations, should be designed for superior performance during strong ground shaking. These facilities are required to be operational immediately after the earthquake, and so must be designed to survive the ground shaking with no structural and very limited non-structural damage. A number of mature and emerging technologies are now available for designers to incorporate into critical and important buildings to reduce seismic damage and limit downtime after a major earthquake. This paper provides a brief overview of these technologies. It is hoped that structural engineers will investigate the use of these technologies in future design and construction of critical buildings, and consider them for retrofit of existing buildings.

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Site Specific Ground Motion Criteria for Performance-Based Design for Critical Facilities

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Abstract

This paper describes the changes in ASCE 7-10 as they relate to Site Specific Ground Motion Criteria for Performance Based Design for Critical Facilities. Two major changes stipulated in ASCE 7-10 are: (1) the maximum considered earthquake should reflect the maximum direction ground motion and (2) the standard and code specify that the design response spectrum incorporate a generic fragility curve to achieve a 1 percent probability of collapse in 50 years. This paper briefly describes (1) ground motion mapping efforts, (2) adjustments to the uniform-hazard portion of the seismic maps that result in uniform estimated collapse probability and (3) explains the concepts of maximum direction and maximum rotation. This paper's goal also is to simplify some terminology related to ground motion mapping and its use in design such as geometric mean, SRSS, direction of maximum response, maximum direction, and maximum rotated.

Introduction

The American Society of Civil Engineers (ASCE) publication ASCE 7-10, Minimum Design Loads on Structures (ASCE 7-10) has introduced changes to the seismic design provisions for structures for their implementation in model codes such as the International Building Code. For Site Specific Ground Motions, the changes in ASCE 7-10 include (1) incorporation of the most recent Ground Motion Prediction Equations (GMPE) for ground motion mapping, (2) a move to a maximum direction of ground motion and, (3) a "risk-targeted" design response spectrum and (4) changes to the site-specific seismic hazard analysis.

The implications of these changes to design practice will be tested with the use of International Building Code (IBC) 2012 edition, and the California Building Code (CBC) when adopted in its 2013 edition. As of January 2009, the maximum rotated ground motion has been specified in California for so-called critical facilities: schools, hospitals, and other state-owned structures subject to review by either the Division of the State Architect (DSA) or the Office of Statewide Health Planning and Development (OSHPD). This paper briefly describes (1) ground motion mapping efforts, (2) proposed adjustments to the uniform-hazard portion of the seismic maps that result in uniform estimated collapse probability and (3) explains the concepts of maximum direction and maximum rotation. The purpose of this paper is to make seismologists, geotechnical and structural engineers conversant with changes in ground motion maps and ground motion directions for their proper development and use in the structural analysis.

Because the terms maximum direction and maximum rotated have been used interchangeably, the goal of this paper is to define the different terminologies of ground motions such as geometric mean, SRSS, direction of maximum response, maximum direction, and maximum rotated for the users.

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Ground Motion Mapping Efforts

In 2008, the USGS released a new set of ground motion contour maps. These new maps were developed using the GMPEs called NGA (Next Generation Attenuation Relationships) developed by PEER (Earthquake Spectra, February 2008). NGA incorporates recent data for large magnitude earthquakes as well as thousands of additional ground motion records. The PEER ground motion database also includes measured site shear wave velocity measurements, $Vs_{30,}$ for many sites.

The 2002 and previous versions of the seismic maps were developed using the 1997 GMPE relationships for B/C boundary (termed site class B) for "rock" maps. The GMPE relationships used to develop rock maps in actuality were representative of site class C. The 2008 "rock" ground motion maps were developed using NGA GMPE relationships for an appropriate value of Vs_{30} of 760 m/s for site class B. As a result, the 0.2 second and 1.0 second values of 2008 maps are typically lower than those published in 2002. Furthermore, the deterministic cap was also defined as the 84^{th} percentile spectral level.

The 2008 USGS hazard maps have been incorporated into the SPDG 2009 NEHRP Provisions with some modifications, and adopted into the ASCE 7-10 Standard. Differences in parameters, S_S and S_1, among ASCE 7-10 and ASCE 7-05 mapped values are attributed to the following:

1. Earthquake ground motion recording data base doubled for NGA GMPEs.

2. Vs_{30} of 760 m/s used to represent Site Class B.

3. Lower geomean levels of shaking were considered to provide lower confidence against collapse. 2009 NEHRP maps were developed to represent ground motion design values in the direction of maximum response.

4. Deterministic cap as 84th percentile spectral level.

5. The mapped parameters incorporate a risk targeting factor to begin incorporating concepts of performance based design into ground motions.

Geometric Mean

Prior to NGA, GMPEs were typically developed using the geometric mean (GM) of the response spectra of two orthogonal, recorded components of motion (Boore et al. 2006). The GM in equation form is shown below:

$$GM = \sqrt{X \cdot Y} \qquad \text{Equation 1}$$

Because the geometric mean can vary with rotation of the record, a measure called GMRotD50 was proposed by Boore et.al, 2006. The GMRotD50 measure of ground motion is the average geomean of two components of motion over all possible rotations at a particular period. The resulting measure is rotation-independent and has the advantage of capturing the 50th percentile motion over all rotations by definition. However, the rotation angle corresponding to GMRotD50 is different at different periods (period dependent), so a different measure, GMRotI50, was also proposed, which uses a single rotation at all periods. The downside is that the GMRotI50 will not be exactly the 50 percentile at each period, but the angle of rotation is chosen such that the error is minimized over the period range. GMRotI50 was used in development of the NGA GMPEs.

Square-Root of the Sum of the Squares

The square-root of the sum of the square (SRSS) is another measure that is commonly used to incorporate the bidirectional aspect of a ground motion.

$$SRSS = \sqrt{X^2 + Y^2}$$ Equation 2

Like the GM, the SRSS is also rotation dependent, and will vary with the azimuth rotation of the ground motion pair. There are no attenuation relationships developed for the SRSS of spectral acceleration. However, the SRSS is used by ASCE 7 as the criteria for scaling pairs of ground motion records for bidirectional dynamic analysis.

Maximum Direction

Chapter 21 of ASCE 7-10 defines design response spectrum as follows:

> **Probabilistic Ground Motions.** The probabilistic spectral response accelerations shall be taken as the spectral response accelerations *in the direction of maximum horizontal response* represented by a 5 percent damped acceleration response spectrum *that is expected to achieve a 1 percent probability of collapse* within a 50-yr. period. [emphasis added]

The term maximum direction is used to refer to the spectral response acceleration (Sa) of a bidirectional system subjected to two components of a ground motion record, measured along the direction that gives the maximum response (**Sa_{maxdir}**). The azimuth along which this maximum response occurs is referred to as the maximum direction.

The ground shaking at a site is represented by three components of recorded ground motion, two orthogonal horizontal components and one vertical. For maximum direction definition, we will focus on the two horizontal components of motion. Two orthogonal horizontal component recordings represent the directions of the recording instrument orientations. Figure 1 displays two orthogonal horizontal ground motion recordings from instruments oriented in N00W and N90W directions recorded during September 19, 1985, magnitude 8.1 Mexico Earthquake.

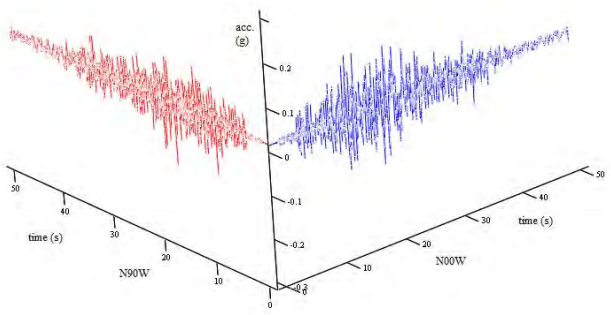

Figure 1 - Recorded acceleration time histories - N00W and N90W Components

A response spectrum is computed by solving the equation of motion for the maximum response of a single degree of freedom (SDOF) or two degree of freedom (TDOF) simple damped oscillator. The maximum response is computed as a function of the frequency (or period) of the oscillator and a critical damping ratio (Figure 2). The period plotted on the horizontal axes is representative of the fundamental period of vibration of the structure.

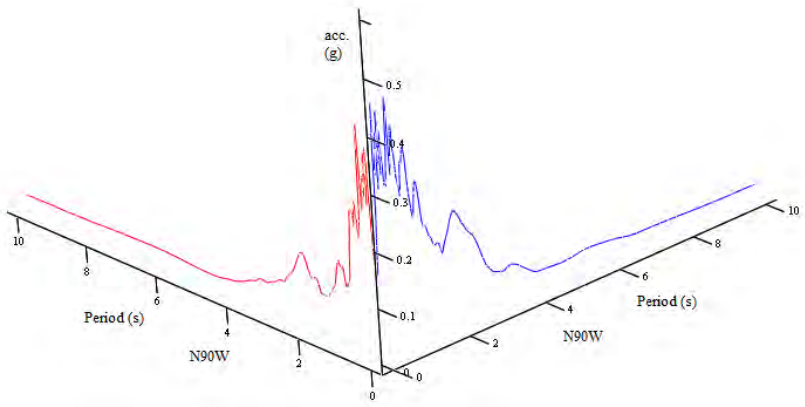

Figure 2 - Acceleration response spectra - N00W and N90W Components

Maximum Rotated

The two horizontal recorded (call them X and Y) components of the acceleration time history can be displayed for any angle, θ, with respect to the original orientation using simple trigonometric transformation. The relationship between the recorded motion, X-Y, and the calculated motion, X'-Y', is taken from the simple trigonometric relationship, shown in Equation 2.

$$\begin{bmatrix} X' \\ Y' \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix} \qquad \text{Equation 3}$$

Calculating X' and Y' by Equation 3 is the graphical equivalent of rotating the azimuth of the recording instruments counter-clockwise (or rotating the ground motions clockwise).

Using the relationship shown in Equation 3, the ground shaking at a site can be reproduced along any orientation. In Figure 3 below, the components from Figure 1 have been plotted rotated 30 degrees counterclockwise using Equation 3 and a θ of 30 degrees.

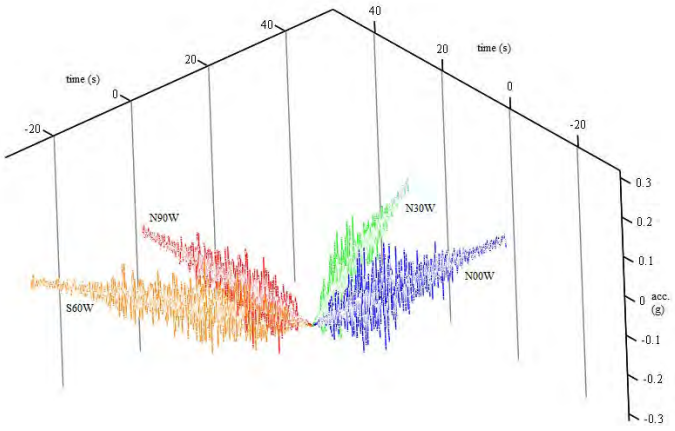

Figure 3 - N00W and N90W components and components rotated 30 degrees counterclockwise

Response spectra for the recorded and rotated directions are shown in Figure 4.

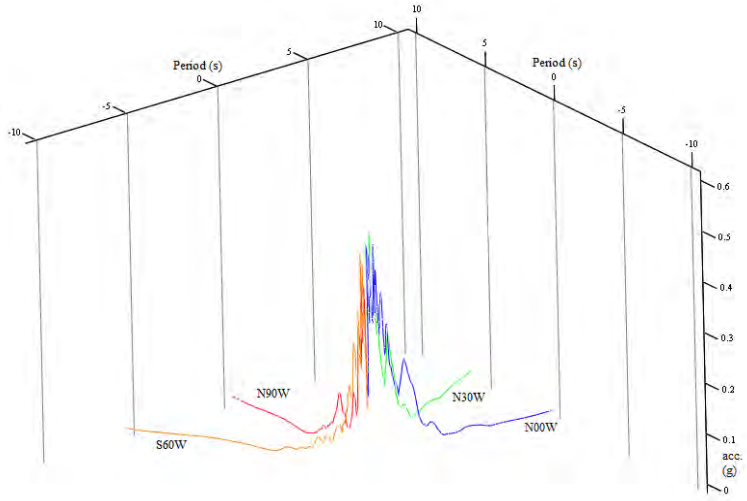

Figure 4 – Response Spectra for N00W and N90W components and components rotated 30 degrees counterclockwise

Each time history recording will have an angle of rotation that yields spectral response maximum for a given period called "maximum rotated spectral response (Sa_{maxrot})". Maximum rotated ground motion spectra can then be developed by plotting the maximum responses together with the angles of rotation that produces the maximum response at different periods of vibration.

Maximum Direction

For any two orthogonal components of horizontal ground motion there will be a direction along which maximum response results at any given period of vibration. The angle of maximum response for a spectral period can be found by plotting the response of a two-degree-of-freedom (TDOF) oscillator. This approach is a departure from the traditional response spectrum obtained from maximum response of a SDOF oscillator.

Figure 5 shows how two recorded, X-Y, components of motion are used used to excite a TDOF oscillator. The azimuth of the maximum response of the TDOF oscillator is the maximum direction for that period. If the recorded motion is rotated so that a component lies along the angle of the maximum response indicated by the dashed arrow in the plots in Figure 5, that rotated ground motion will result in a spectral response of a SDOF oscillator at that period equal to Sa_{maxdir}, which will also be equal to Sa_{maxrot} (by definition of Sa_{maxrot}).

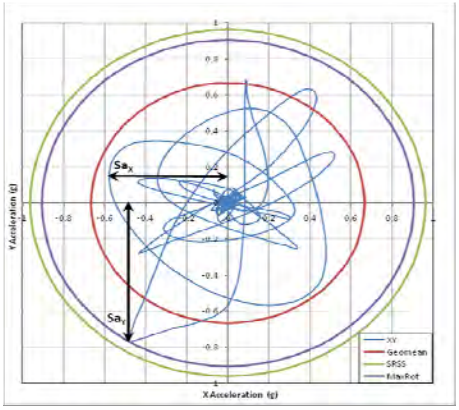

Figure 5 - Acceleration response orbit (T=1s, R=1) for 1994 Northridge Sylmar, Olive View FF records

For linear systems, it can be shown that the Sa_{maxdir} and Sa_{maxrot} are the same. Assume that Sa_{maxdir} occurs along an angle θ. Consider the ground motion accelerations recorded along the principal directions are $g_X(t)$ and $g_Y(t)$, and the resulting oscillator responses along each direction X and Y for a given period T, $r_X(t)$ =

response($g_X(t)$) and $r_Y(t)$ = response($g_Y(t)$), which together define the bidirectional response of a TDOF oscillator. The ground motion response along angle θ is the projection of the resulting bidirectional response over the direction of interest, at each time step. This is given by:

$$r\theta_{projected}(t) = r_X(t) * \cos\theta + r_Y(t) * \sin\theta \quad \text{Equation 4}$$

Note that Equation 4 is the one-dimensional rotation function of Equation 2. The ground motion input along angle θ can also be computed from the responses to the two principal directions as follows:

$$g\theta_{rotated}(t) = g_X(t) * \cos\theta + g_Y(t) * \sin\theta \quad \text{Equation 5}$$

Since the response is linear, superposition can be used to show that:

$$r\theta_{rotated1D}(t) = response(g\theta_{rotated}(t)) \quad \text{Equation 6}$$
$$= response(g_X(t) * \cos\theta + g_Y(t) * \sin\theta) \quad \text{Equation 7}$$
$$= response(g_X(t)) * \cos\theta + response(g_Y(t)) * \sin\theta \quad \text{Equation 8}$$
$$= r_X(t) * \cos\theta + r_Y(t) * \sin\theta \quad \text{Equation 9}$$
$$= r\theta_{projected}(t) \quad \text{Equation 10}$$

It follows that both $r\theta_{rotated1D}$ and $r\theta_{projected}$ will be maximized along the same angle θ_{max}, and $Sa_{maxrot} = Sa_{maxdir}$.

Note that the trigonometric transformation should be performed on the time history before calculating the spectral value. Transforming the orthogonal spectral responses does not yield the correct rotated spectrum, because the peak spectral responses in the two orthogonal directions do not necessarily occur at the same time.

Maximum Direction Variation with Period and Nonlinearity

Maximum direction response and maximum rotated response are the same for a linear system. This means that the response of a TDOF oscillator along a certain direction is the same as the response of a SDOF oscillator under a unidirectional ground motion rotated to the same direction. This also means that it is only required to compute the dynamic oscillator response along the two principal directions, and the response along any other direction can be computed using the trigonometric transformation of Equation 3 or Equation 4. The maximum response and maximum direction are unique to each ground motion record. Different ground motion records will have maximum response along different directions, even at the same site. Except for near-field conditions (say, within 3 to 5 km of a fault), the maximum direction angle can be considered to be random, with equal probability of occurrence along any direction (Huang et al. 2008).

Moreover, the maximum direction angle can be very different for different periods and strengths (R Value) as shown by the arrows in Figure 6, which represents the response of TDOF systems under a pair of ground motion records. Four periods of the TDOF were considered (0.1s, 0.5s, 1s and 2s). The effect of inelastic behavior was also investigated by varying the strength, which was accomplished by varying R=Fy/Felastic, over values of 1, 2, 4, and 8. The plot shows the maximum direction angle is very sensitive to both the period of vibration as well as the yield strength of the system. This means that there is not one angle to which the record can be rotated that will yield the maximum direction spectrum. Thus, the maximum response spectrum does not represent a realistic ground motion, and is instead an envelope of the maximum response spectral accelerations of the record at all possible rotation angles and periods.

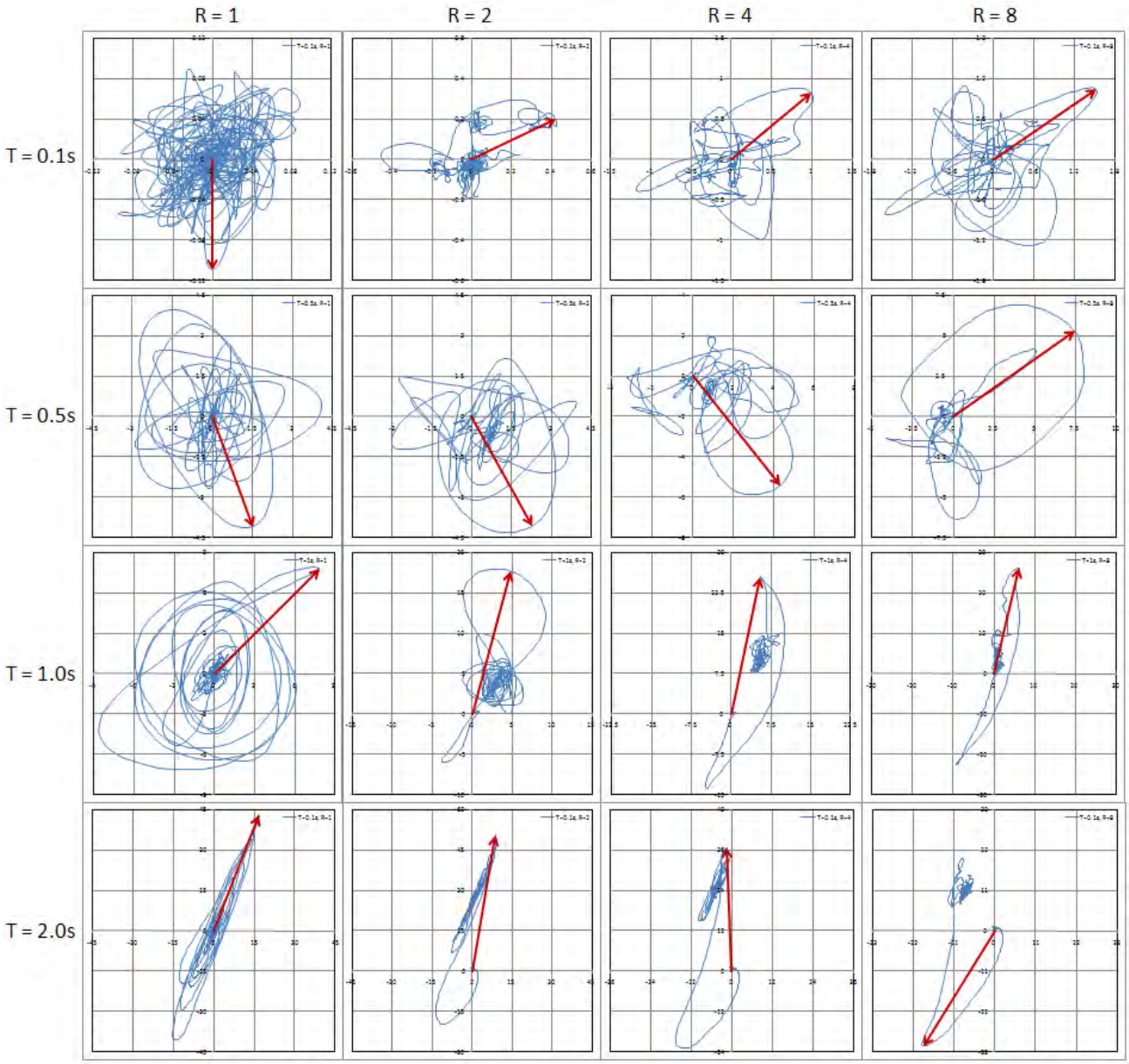

Figure 6 - Resultant azimuth of the maximum displacement response of TDOF systems of varying period and strength excited by the SAC project LA33/34 ground motion pair. Note the directionality variation.

In order to make a general assessment of the effect of yielding on maximum direction, 10 records at random were selected from the SAC ground motion database (records LA01 through LA20) for analysis. For each record, the acceleration and displacement responses were calculated for 50 periods ranging from 0.1s to 2.0s. The resulting principal directions were averaged over all periods. The procedure was repeated for R values of 1, 2, 4, 6 and 8.

The maximum spectral response and maximum direction angle of that response are shown in Figures 7 and 8, respectively, for one of the records for R=1 (elastic response) and R=4 (nonlinear). Figure 8 also shows the circular average of the maximum direction angle averaged over periods 0.1s – 2s.

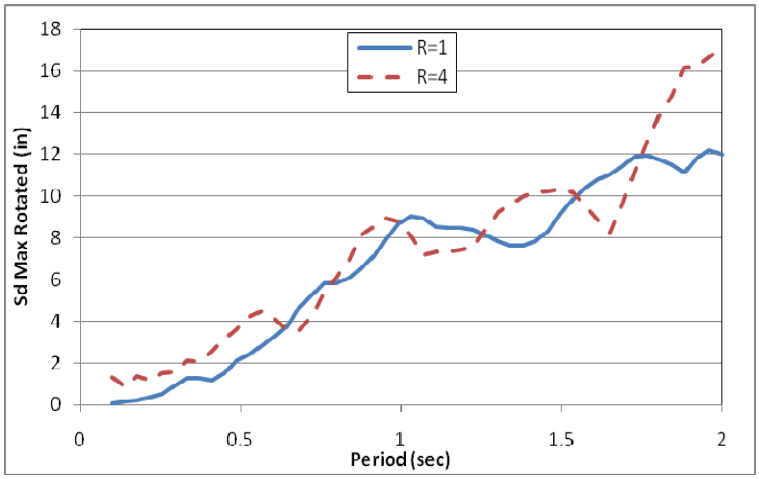

Figure 7 - Spectral displacement Sd vs period for R=1 and R=4, for records LA07/08

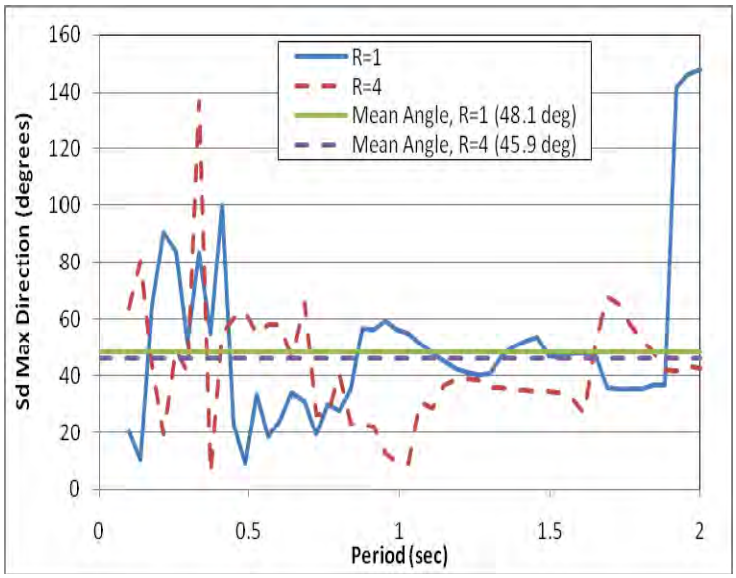

Figure 8 -Maximum direction of Sd vs Period for R=1 and R=4, for records LA07/08.

The above process is repeated for all values of R (1, 2, 4, 6 and 8), and for the 10 different ground motion records. The obtained mean maximum direction angles (10*5 = 50 values) are then plotted in Figure 9, in which the x-axis represents the maximum direction angle for Sa under linear response. Note that the Sa and Sd maximum direction angles appear to be perfectly correlated (linear relationship) for R=1 (linear-elastic), while Sd angle values are less correlated to the linear case for higher values of R (nonlinear). Figure 10 shows the computed correlation coefficient as function of R. A correlation coefficient of 1.0 indicates that the variables are perfectly correlated. These results are another indication that the maximum direction angle will vary with nonlinear response, in addition to being a function of period.

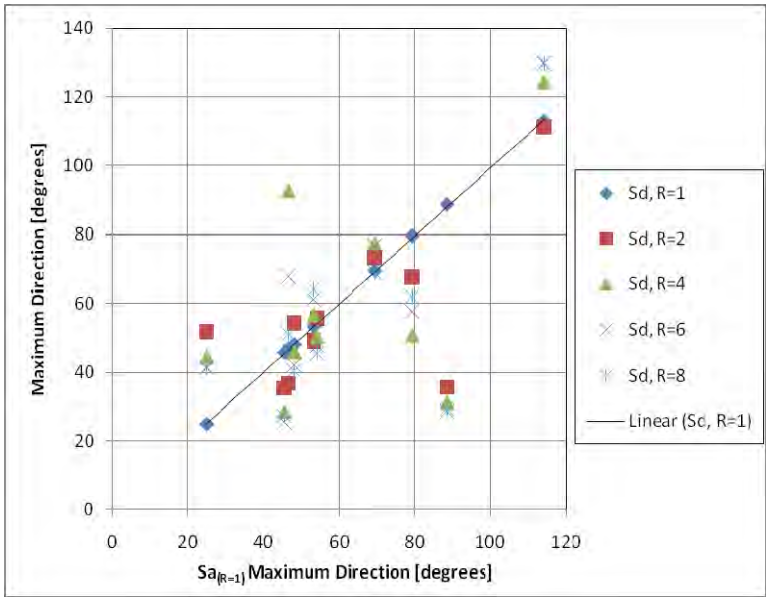

Figure 9 - Maximum direction (averaged over T=0.1s-2s) for 10 records at different R values.

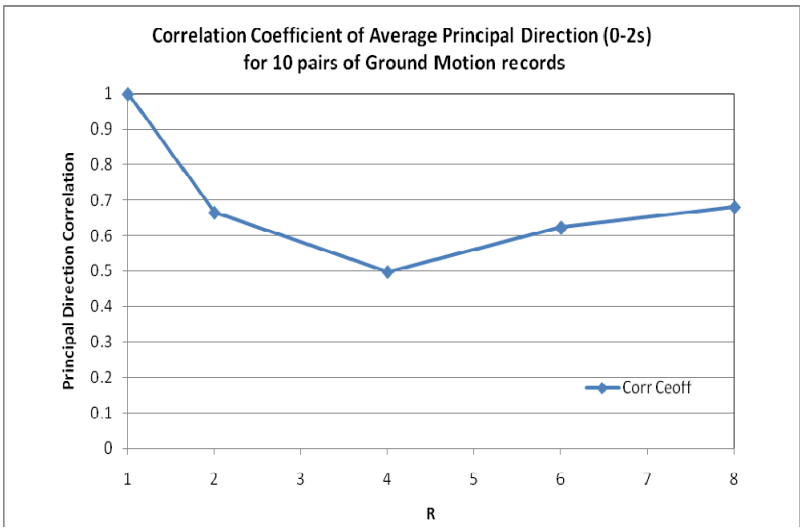

Figure 10: Correlation of principal direction between elastic response (R=1) and other values of R.

The USGS used the average of three NGA relationships to develop ground motion contour maps, an update of the maps included in ASCE 7-05 Chapter 22. As shown in the plots above, Sa_{maxdir} and the maximum direction angle can vary with the period and strength (R Value) of the structure (oscillator). Ratios of Sa_{maxdir} to GMRotI50 vary between 1.2 and 1.35 (Campbell and Bozorgnia 2007). The variability of the Sa_{maxdir} is highlighted in the commentary for the proposal to incorporate new ground motion design in ASCE 7-10, dated May 18, 2009. The maps presented in Chapter 22 of ASCE 7-10 were developed by using factors to convert GMRotI50 to Sa_{maxdir}. The Building Seismic Safety Council of FEMA adopted factors of 1.1 and 1.3 for 0.2-second and 1.0-second, respectively, to develop Chapter 22 maps (NEHRP Provisions 2009).

Risk Targeted Maps

The risk-targeted parameter contour maps presented in ASCE 7-10 are based on the Update of the National Seismic Hazard Maps (USGS 2008). The Seismic Hazard Maps are generated for a combination of the geomean 2 percent probability of exceedance in 50 years in seismically inactive areas and a deterministic median level ground shaking in high-seismicity areas. To represent the maximum direction ground motion, the parameters of the short- and long-period ground motions have been modified by factors of 1.1 and 1.3, respectively (as discussed above). Additional factors for risk targeting were applied to the maximum direction ground motion.

Under the assumption that the capacity against collapse of structures designed for these "uniform hazard" ground motions is equal to, without uncertainty, the corresponding mapped value at that location of the structure , the probability of it collapse is also uniform. Luco et al. indicate that the probability of collapse is not a specific threshold at the MCE, and is more uncertain (Luco et al. 2007). Variability in the regional hazard curves and structure-to-structure variability in response results in lack of uniform reliability. To correct for this, the risk factors incorporate a generic structural fragility curve to define a probability of collapse that is calculated across the probabilistic range of hazard curves that vary by region of the country. The risk factors are then adjusted in order to create uniform reliability across the country. The fragility curve itself is related to the MCE ground motion at that period – for the fragility factor maps presented in ASCE 7-10, the period used was either 0.2 seconds or 1.0 seconds. The MCE_R Ground Motion Parameters presented in ASCE 7-10 Chapter 22 are the 2008 USGS Seismic Hazard Map value multiplied by the maximum direction factor (1.1 or 1.3) and by the risk targeting factor from the risk contour maps.

Conclusions

The use of dynamic analysis of structures has been spreading with developments in computing power, structural analysis tools, and performance-based design. The intent of this paper is to highlight the changes in ASCE 7-10 that will impact the development and processing of the information by seismologists, geotechnical and structural engineers. Major changes relate to the use of NGA GMPE for consistent soil classification for Ground Motion Mapping. This has resulted in a decrease in the mapped values at 0.2 and 1.0 second for the reason that the old maps which were mapped for Soil Type B (rock) were in fact mapped for Soil Type C. Because of the lower level of confidence against collapse with the use of geomean level mapped values, the 2009 NEHRP maps were developed to represent ground motion design values in the direction of maximum response. Whether ground motion is the geomean or the maximum direction, it could make up to 30 percent difference in the design load on the structure.

Because the terms maximum direction and maximum rotated have been used interchangeably, terminologies of ground motions such as geometric mean, SRSS, direction of maximum response, maximum direction, and maximum rotated have been defined for the users. Finally, the concept of risk targeted maps is introduced.

It is the authors' intent to jumpstart the conversations between the geosciences and engineering professionals to start understanding the changes in ground motion input to be used in performance based design of structures.

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Building-Specific Loss Estimation for Performance Based Design

***Eduardo Miranda, Ph.D.*[1]**

Abstract

An approach for describing the seismic performance of buildings as a continuum and in terms of economic losses is presented. Two alternative measures of economic losses are described and discussed. In the proposed approach the total loss in a building due to physical damage is treated as a random variable and it is computed as the sum of the losses in individual structural and non-structural components. Economic losses are computed using a fully probabilistic approach that permits the explicit incorporation of uncertainties in the seismic hazard at the site, in the response of the structure, on the fragility of individual structural and non-structural components, and on the costs associated with the repairs or replacement of individual building components. Physical damage is estimated by combining structural response parameters such as interstory drift ratio or peak floor acceleration with component fragility functions. Unlike previous work, the proposed methodology explicitly accounts for economic losses resulting from the possibility of having to demolish the building after a seismic event. The probability of demolition is computed as a function of peak residual lateral deformations experienced in the building. Results from an existing non-ductile seven story reinforced concrete building and from two ductile reinforced concrete moment resisting frame buildings design according to current seismic provisions and assumed to be located in Los Angeles, California are presented to illustrate the proposed loss estimation methodology.

Introduction

The goal of performance-based seismic design (PBSD) is to design facilities that satisfy the performance expectations of their owners. Implicit in PBSD when applied to buildings is the need and ability to predict the performance of the structure, its non-structural components and contents for a wide range of possible earthquake ground motion intensities.

Recent research conducted at the Pacific Earthquake Engineering Research (PEER) Center aims at describing the seismic performance of structures quantitatively by continuous variables rather than discrete performance levels such as those used in FEMA 356 document. The three continuous variables studied by PEER include: economic (e.g. dollar) losses, downtime and fatalities. The present work is focused on economic loss estimation.

There are many studies on seismic loss estimation. However, most previous studies have been aimed at estimating losses on a regional basis for a large number of facilities (e.g. ATC-13, HAZUS, etc.) as opposed to a more accurate estimation of economic losses in individual facilities. For a comprehensive literature review on different loss estimation approaches, the reader is referred to FEMA 249 (1994).

The objective of this work is to summarize research conducted by the author aimed at quantifying the seismic performance in specific buildings in terms of economic losses. In the proposed approach the total loss in a building due to physical damage is treated as a random variable and it is computed as the sum of the losses in individual structural and non-structural components. Economic losses are computed using a fully probabilistic approach that permits the explicit incorporation of uncertainties in the seismic hazard at the site, in the structural response, on the fragility of individual structural and non-structural components, and on the costs associated with the repairs or replacement of individual building components. Physical damage is estimated by combining structural response parameters such as interstory drift ratio or peak floor acceleration with component fragility functions. The proposed approach is illustrated by applying it to a non-ductile seven-story reinforced concrete building.

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Measures of Economic Loss

There are many possible measures of economic losses that can be used to describe seismic performance. Only two measures of economic loss are discussed here. For a more complete discussion of alternative economic losses the reader is referred to Miranda and Aslani (2003) and Krawinkler and Miranda (2004). The first economic loss measure is the expected annual loss, which corresponds to the economic loss that, on average, occurs every year in the building. The expected annual loss provides quantitative information to assist stakeholders in making risk management decisions. In particular, owners, lending institutions, insurers, and other stakeholders can use expected annual losses to compare, for example, annual revenues versus expected annual losses. Similarly, they can compare annual earthquake insurance premiums to annual expected losses, etc.

The second measure of economic loss discussed here is the probability of having an economic loss equal or greater than a certain amount, which provides information of the probability of experiencing an economic loss larger than a certain amount (e.g., the probability of loosing more than one million dollars due to earthquake damage in the building). This second measure of economic loss also provides economic losses associated with particular probabilities of being exceeded (e.g., the total dollar loss that has 1% probability of being exceeded in 50 years).

The expected annual loss in a building $E[L_T]$ over a time period t can be computed as (Rosenblueth 1976, Wen et al. 2001)

$$E\left[L_T\right]=\int_0^t\int_0^\infty e^{-\lambda\tau}E\left[L_T\,|\,IM\right]\left|d\,\nu(IM)\right|d\tau \tag{1}$$

where $e^{-\lambda\tau}$ is the discounted factor of the loss over time t, λ is the discount rate per year, $E\,[\,L_T\,|\,IM\,]$ is the expected loss in the building corresponding to a ground motion intensity, IM, $\nu(IM)$ is the mean annual rate of exceeding a ground motion intensity IM. In (1) the time period t can correspond to the design life of the structure, the remaining life of an existing structure or another reference time period. For purposes of setting design actions in building codes or for setting insurance premiums long t are usually assumed (Rosenblueth, 1976) and the effect of the finite life span of the facility becomes negligible.

Since collapse (C) and non-collapse (NC) are mutually exclusive damage states, the expected loss in a building conditioned on ground motion intensity IM, can be computed using the total probability theorem as follows

$$E\left[L_T\,|\,IM\right]=E\left[L_T\,|\,NC,IM\right]\cdot\left[1-P(C\,|\,IM)\right]+E\left[L_T\,|\,C\right]\cdot P(C\,|\,IM) \tag{2}$$

where $E[L_T\,|\,NC,IM]$ is the expected loss in the building provided that collapse does not occur for ground motions with an intensity level $IM=im$, $E[L_T\,|\,C]$ is expected loss in the building when collapse occurs in the building and $P(C|IM)$ is the probability that the structure will collapse conditioned on ground motion intensity.

The expected total loss in the building provided that collapse does not occur at a ground motion intensity $IM=im$, $E[L_T\,|\,NC,IM]$, is computed as the sum of the losses in individual components of the building as

$$E\left[L_T\,|\,NC,IM\right]=E\left[\sum_{i=1}^{N}\left(a_i\cdot L_i\,|\,NC,IM\right)\right]=\sum_{i=1}^{N}a_i\cdot E\left[L_i|NC,IM\right] \tag{3}$$

where $E[L_i|NC,IM]$ is the expected normalized loss in the ith component given that global collapse has not occurred at the intensity level im, a_i is the replacement cost of component i and L_i is the normalized loss in the ith component defined as the cost of repair or replacement in the component normalized by a_i. Details on the computation of $E[L_T\,|\,NC,IM]$ and $E[L_T\,|\,IM]$ are given in Aslani and Miranda (2004b).

The mean annual frequency of exceedance of a certain level of economic loss l_T is computed as

$$\nu\left[L_T>l_T\right]=\int_0^\infty P\left[L_T>l_T\,|\,IM\right]\cdot\left|\frac{\mathrm{d}\,\nu(IM)}{\mathrm{d}IM}\right|dIM \tag{4}$$

where $P[L_T>l_T\,|\,IM]$, is the probability of exceeding a certain level of loss for a given IM. For values smaller than 0.01 the mean annual frequency of exceedance of a loss l_T is approximately equal to the mean annual probability of exceedance.

In Eq. (4), $P(L_T > l_T \mid IM)$ can be assumed lognormally distributed (Aslani and Miranda 2004b). On the basis of this assumption only the first two moments of the probability distribution are required to evaluate this conditional probability. The first moment, the expected value, is given by equation (2) while the variance of the loss, is computed as follows

$$\sigma^2_{(L_T>l_T|IM)} = \sigma^2_{(L_T|NC,IM)} \cdot \left[1 - P(C \mid IM)\right] + \sigma^2_{(L_T|C)} \cdot P(C \mid IM)$$
$$+ \left\{E[L_T \mid NC, IM] - E[L_T \mid IM]\right\}^2 \cdot \left[1 - P(C \mid IM)\right] + \left\{E[L_T \mid C] - E[L_T \mid IM]\right\}^2 \cdot P(C \mid IM) \quad (5)$$

where $\sigma^2_{(L_T|C)}$ is the variance of the total loss in the building given that collapse has occurred and $\sigma^2_{(L_T|NC,IM)}$ is the variance of the total loss in the building given that collapse has not occurred at intensity level *im* which can be computed as a function of the dispersion in the losses of individual components as follows

$$\sigma^2_{[L_T|NC,IM]} = \sum_{i=1}^{N}\sum_{j=1}^{N} a_i \cdot a_j \cdot \rho_{L_i,L_j|NC,IM} \cdot \sigma_{L_i|NC,IM}\sigma_{L_j|NC,IM} \quad (6)$$

where $\sigma_{L_i|NC,IM}$ is the dispersion of the loss in the *i*th component when collapse has not occurred at intensity level *im*, and $\rho_{L_i,L_j|NC,IM}$ is the correlation coefficient between the losses in the *i*th and *j*th components conditioned on *IM* when collapse has not occurred.

The correlation between the losses in two individual components conditioned on the ground motion intensity level, $\rho_{L_i,L_j|NC,IM}$, can be computed as

$$\rho_{L_i,L_j|NC,IM} = \frac{\sigma_{L_iL_j|NC,IM}}{\sigma_{L_i|NC,IM}\sigma_{L_j|NC,IM}} \quad (7)$$

where $\sigma_{L_iL_j|NC,IM}$ is the covariance of the loss between the *i*th and *j*th components conditioned on *IM* , when collapse has not occurred. As will be explained later, this correlation is a function of three correlations: (1) the correlation of the engineering demand parameters *EDP* (i.e., response parameters) that have an influence on the components; (2) the correlation of the damages in the components conditioned on the *EDP*; and (3) the correlation between the repair/replacement costs of the components associated with a given damage state. The proposed approach not only takes into account the correlation between losses in individual components but also the variation of this correlation with changes in the ground motion intensity level.

Structural Response Estimation

In the proposed approach the mean annual frequency of exceedance of the *intensity measure, IM*, (i.e. the seismic hazard curve) is from a conventional probabilistic seismic hazard analysis. For the United States this information is readily available at closely spaced grid points, which permit obtaining seismic hazard curves for any zip code or any geographical coordinates in the country.

The selection of the parameter to be used to characterize the ground motion intensity for the structure (i.e. the intensity measure IM) depends on a number of aspects such as the fundamental period of vibration of the structure, the response parameters of interest, location of interest within the structure, level of nonlinearity, etc.

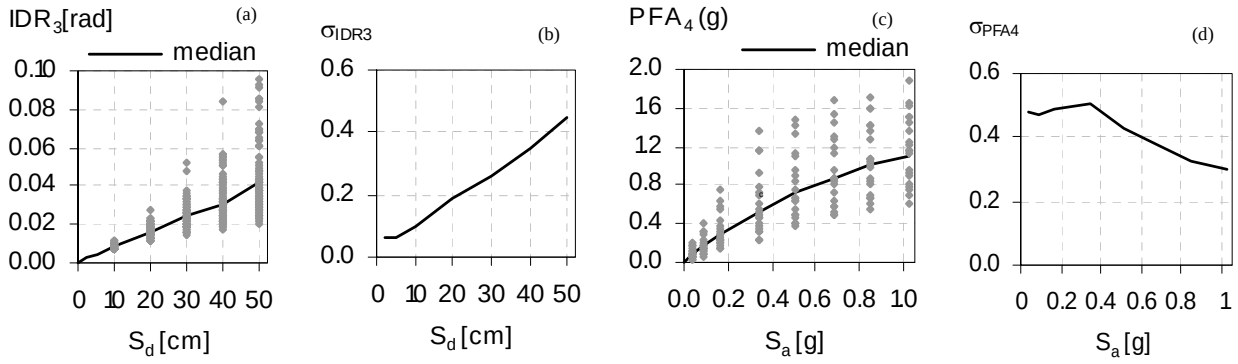

Figure 1: Variations of the probability parameters of *EDP*s with changes in the elastic displacement spectral ordinate, S_d: (a) median of IDR1 (b) dispersion of IDR1 (c) median PFA_{roof} (d) dispersion of PFA_{roof}

In this study the use three different parameters as *IM*'s was investigated. The first one is the elastic displacement spectral ordinate of a single-degree-of-freedom, *SDOF*, system evaluated at the fundamental period of vibration of the building, $S_d(T_1)$. The second *IM*, is the maximum displacement $\Delta_i(T_1)$ of a bilinear *SDOF* system with the same period and strength as that of the building. The third parameter that was studied as *IM* is the peak ground acceleration (*PGA*).

The probability that a structural response parameter, referred in PEER as *engineering demand parameter*s (*EDP*), exceeds a certain value conditioned on a given ground motion intensity P(*EDP*|*IM*) is obtained by using the results of non-linear response history analyses (Miranda and Aslani 2003). Ground motions are scaled, such that all have the same intensity measure and the analysis is repeated for increasing levels of intensity. Figure 1 shows the variations of the median and dispersion of the interstory drift ratio at the first story, IDR_1, and of the peak floor acceleration at roof level, PFA_{roof} of a non-ductile seven-story reinforced concrete building. The figure shows changes in central tendency and dispersion of these two response parameters for five increasing levels of elastic displacement intensity S_d. For each intensity level 80 nonlinear response history analyses were performed. Gray dots in the figure represent results for individual ground motions. It can be seen that considerable variability exists in the response of the structure from one record to another. In general, the response will increase as the ground motion intensity increases; however, the trend is not necessarily linear. Several simplified approaches assume the dispersion to remain constant with changes in ground motion intensity. As shown in the figure for the case of drift in the first floor, the level of dispersion exhibits a sharp increase with the increasing *IM*. However, dispersion will not always increase. For example, dispersion in upper stories was observed to decrease with increasing *IM*. Figures 1c and 1d presents similar results but for the peak floor acceleration at the roof, PFA_{roof}. In this case, the acceleration demand increases with increasing S_d, but the demand tends to saturate with increasing level of nonlinearity. It can be seen that dispersion sharply decreases with increasing level of ground motion intensity. It is noteworthy that the variations of the dispersion of the *EDP* with changes in *IM* shown here are very large both for IDR_1 and PFA_{roof}.

Figure 2a presents the variations of the median and dispersion of IDR_1 with changes in *IM*, when using inelastic spectral ordinates $\Delta_i(T_1)$ as the intensity measure. Comparison of figures 1 and 2 shows that using $\Delta_i(T_1)$, as the intensity measure leads to lower levels of dispersion for IDR_1, particularly at higher level of intensity. Figure 2b shows the variations of peak floor acceleration demands at the roof when *PGA* is used to characterize the ground motion intensity. Comparing figure 1 and 2 shows that using *PGA* as the intensity measure leads to lower levels of dispersion than those computed when $S_d(T_1)$ is used as *IM*. This agrees well with previous observations, which indicate that when a significant portion of the exposed value is sensitive to floor accelerations (e.g. in museums, clean rooms, laboratories, etc.) acceleration-based intensity measures lead to smaller dispersions in response and hence a smaller number of ground motions may be used (Taghavi and Miranda 2003b).

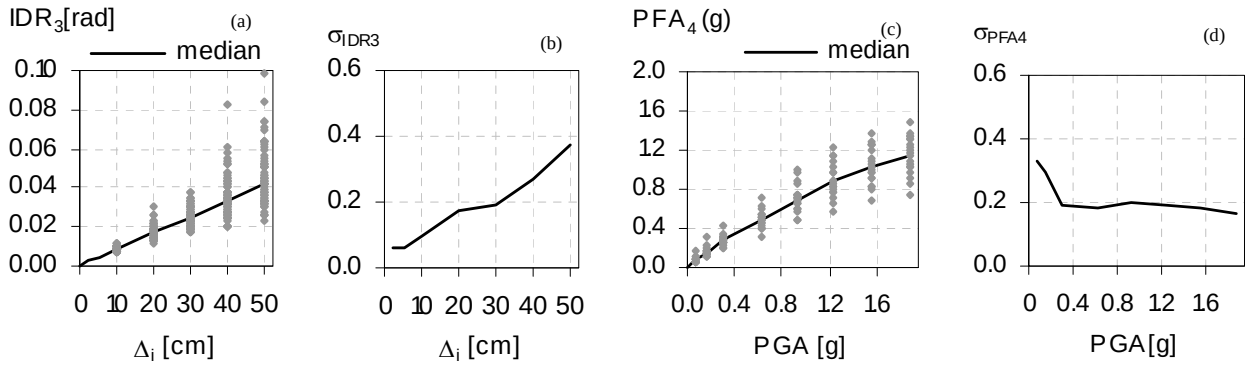

Figure 2: (a) Variations of median and dispersion of IDR_1 with changes in the inelastic spectral ordinate, Δ_i; (b) Variations of median and dispersion of PFA_{roof} with changes in PGA.

Damage Estimation

Once the response of the structure has been computed, an estimation of the damage in individual components can be obtained through the use of fragility functions. Fragility functions are curves that permit the estimation of the probability that a structural or non-structural component will be in a certain damage state when it is subjected to a certain level of *EDP*.

For each component, damage states, referred in PEER as *damage measures DM*, associated with different repair actions were identified. Fragility functions for each damage state were then developed using the results of experimental results available in the literature. Many studies have concluded that the structural response parameter that is best correlated with structural damage is the interstory drift ratio, *IDR*. Therefore, this parameter was used to develop fragility functions of structural components. Analysis of the results of various damage states indicates that fragility functions can be assumed to have a lognormal distribution. Therefore, only two parameters, namely the median and logarithmic standard deviation of the *EDP*, are required to define the fragility function corresponding to a certain damage state.

Figure 3a, shows an example of fragility function for the first damage state of a reinforced concrete column in the building. It is observed that the *EDP*, which in this case corresponds to the interstory drift ratio, associated to certain damage states of structural components exhibits a very large scatter. In order to reduce the uncertainty in damage estimation for these damage states *fragility surfaces* were developed (Aslani and Miranda 2004a). In a fragility surface the mean and standard deviation of *EDP* corresponding to a damage state are evaluated as a function of a new parameter, α, which allows the incorporation of additional information. The parameter α can incorporate information on the element (e.g., geometry, detailing, etc.), its loading and or a combination of the two. The probability of exceeding the damage state is then estimated as a function of the level of *EDP* in the component but also as a function of the parameter α. Figures 3b and 3c present examples of the fragility surfaces developed to estimate the probability of experiencing a shear failure and or the loss of vertical load carrying capacity in non-ductile reinforced concrete columns. For more details on the fragility curves and fragility surfaces of structural components the reader is referred to Aslani and Miranda 2004a.

Consistent with parameters used in FEMA 356, fragility functions for non-structural components were developed as a function of either *IDR* or *PFA*. Non-structural components were assumed to be sensitive to only one of these parameters. Figure 4a presents an example of fragility functions developed for gypsum board partitions as a function of the level of the *IDR* imposed to the partition. Figure 4b presents an example of fragility functions developed for suspended ceilings as a function of the level of the *PFA* in the component. More details on the fragility of non-structural components are presented in Taghavi and Miranda (2003a).

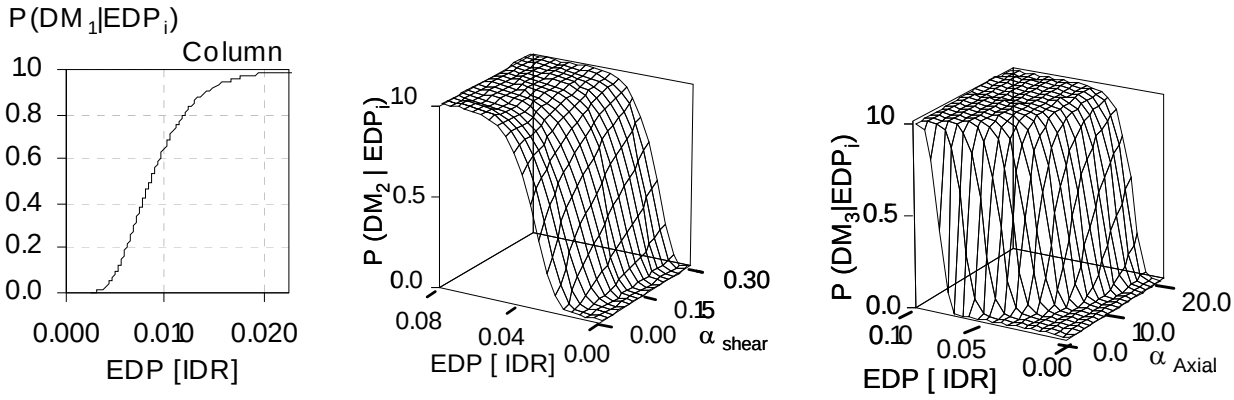

Figure 3: Fragility assessment of non-ductile reinforced concrete columns.

Estimation of the Probability of Collapse

As shown in Eqs (2) and (5) both the expected value of the losses and the dispersion of the losses for a given ground motion intensity requires an estimate of the probability of collapse. Two different approaches were used to estimate the probability of collapse. In one approach collapse was produced by the occurrence of lateral displacements that lead to a dynamic instability in the structure. In the second approach it was assumed that the structure could collapse even if the lateral displacements were not very large but enough to cause damage states that could trigger the loss of vertical carrying capacity in structural members. The second type of collapse triggering mechanism is particularly important in the case of non-ductile structures. In order to get an estimate of the probability of collapse due to the loss of vertical carrying capacity of structural components it was assumed that if a loss of vertical carrying capacity occurred in either a column of a slab column connection, such failure would trigger a progressive collapse of the structure. As shown in Aslani and Miranda (2004b), with this assumption the probability of collapse due loss of vertical carrying capacity (LVCC), $P(C_{LVCC}|IM)$, is equal to the largest probability of any individual structural element that can loose its vertical carrying capacity

$$P\left(C_{LVCC} \mid IM\right) = \max_{\forall i}\left[P\left(LVCC_i \mid IM\right)\right] \tag{8}$$

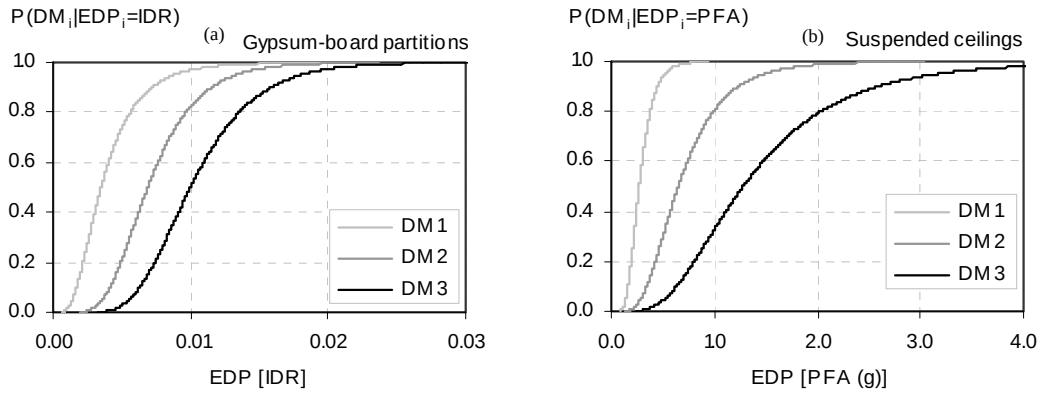

Figure 4: Fragility functions of drift-sensitive and acceleration-sensitive non-structural components at different damage measures; (a) Gypsum-board partitions, (b) Suspended ceilings

where $P\left(LVCC_i \mid IM\right)$ is the probability of losing the vertical carrying capacity in the *i*th component conditioned on *IM* and is computed as

$$P(LVCC_i|IM)=\int_0^{\infty} P(LVCC_i|EDP_i)\cdot\left|dP(EDP_i|IM)\right| \quad (9)$$

where $P(LVCC_i|EDP_i)$ is the probability of the *i*th component losing its vertical carrying capacity given that it is subjected to a deformation level equal to *edp*. $P(LVCC_i|EDP_i)$ is computed from fragility surfaces, developed for *LVCC* damage states on the basis of experimental studies on structural components. $dP(EDP_i|IM)$ is the probability density function of EDP_i conditioned on *IM*, which can be estimated from a probabilistic response analysis. Figure 5, presents a graphical presentation of the steps to estimate $P(C_{LVCC}|IM)$, using Eqs. (8) and (9).

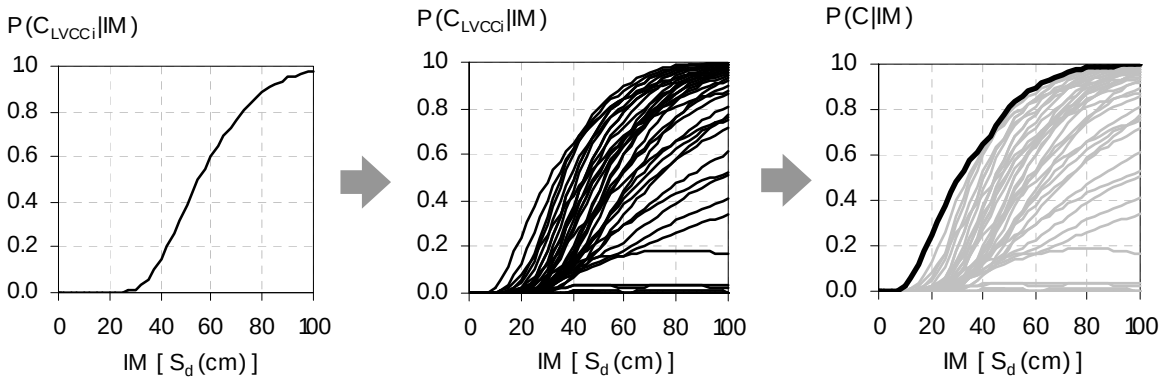

Figure 5: Different steps of estimation of the probability of collapse of the system conditioned on *IM*

Repair or Replacement Costs Estimation

For each component loss functions are developed to estimate the cost of repair or cost to replace each component. Loss functions are functions that provide information on the probability of exceeding a certain level of repair or replacement cost given that the component is in the damage measure, *DM*. Examples of these functions are given in Aslani and Miranda (2004a).

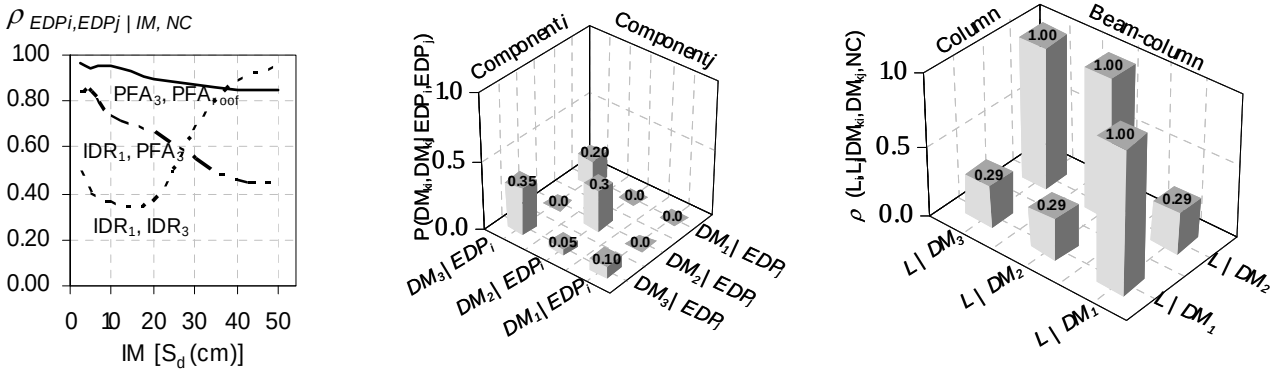

Figure 6: Variations of the required parameters to estimate the correlation of losses in individual components.

Modeling Correlation Between Losses in Individual Components

Estimation of the correlation between losses in individual components requires information on the correlation at three different levels; *EDP* | *IM* level, *DM* | *EDP* level and *DV* | *DM* level. The correlation at the response level, *EDP* | *IM* is estimated based on the results from nonlinear response history analyses. The correlation at the damage level, *DM* | *EDP*, is mathematically modeled by categorizing components into certain groups in

terms of their damageability and estimating the joint probability of two components being at different damage states conditioned on the level of deformation each of them is subjected to. The correlation at the repair cost level, $DV \mid DM$, is estimated from the information on the correlation between different tasks required to repair the component.

Figure 6 presents examples of each of the correlation at each of the above three level. Figure 6a shows how the correlation between different types of *EDP* varies as the ground motion intensity increase. Shown in Figure 6b is an example of the joint probability distribution of two components being at different damage states. Figure 6c shows the correlation between repair costs for a column and a beam-column connection.

Building loss estimation

Figure 7a presents the variations of the expected loss at different levels of intensity, $E[L_T|IM]$, estimated for the case study building. It can be seen that for this building losses rapidly increase at small levels of ground motion intensity. Figure 7b presents the variations of the dispersion of the loss of the building with increasing level of ground motion intensity for two cases: when losses in individual components are assumed to be correlated and when they are assumed non-correlated. It can be seen that correlation has significant effects on the uncertainty of the loss. For example, at S_d=20 cm assuming that the losses are uncorrelated leads to an underestimation of 25% of the dispersion of the loss.

The loss curve for the case study building is shown in Figure 7c where it can be seen that losses smaller than $1,000,000 have relatively high mean annual frequencies of exceedance.

Loss Disaggregation

Similarly to seismic hazard disaggregation (McGuire, 1995) building losses can also be disaggregated. In particular, it is interesting to investigate the ground motion intensities that most contribute to expected annual losses in a building. Figure 8 provides three examples of loss disaggregation. Figure 8a presents the contribution of collapse and non-collapse expected loss to the total loss at different levels of intensity. It can be seen in the figure that at small levels of intensity, (S_d<25cm), the contribution of non-collapse losses dominates the expected losses. Figure 8b provides similar information for the contribution of structural and non-structural losses to the total loss. It can be send that losses are primarily produced by damage to non-structural components.

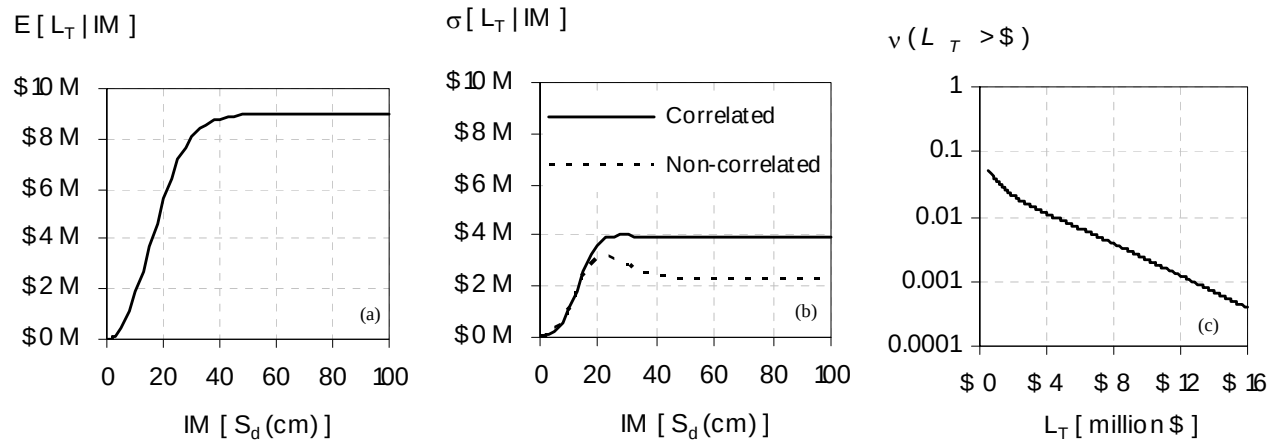

Figure 7: (a) Expected loss at different levels of intensity, (b) dispersion of loss at different levels of intensity, (c) building loss curve

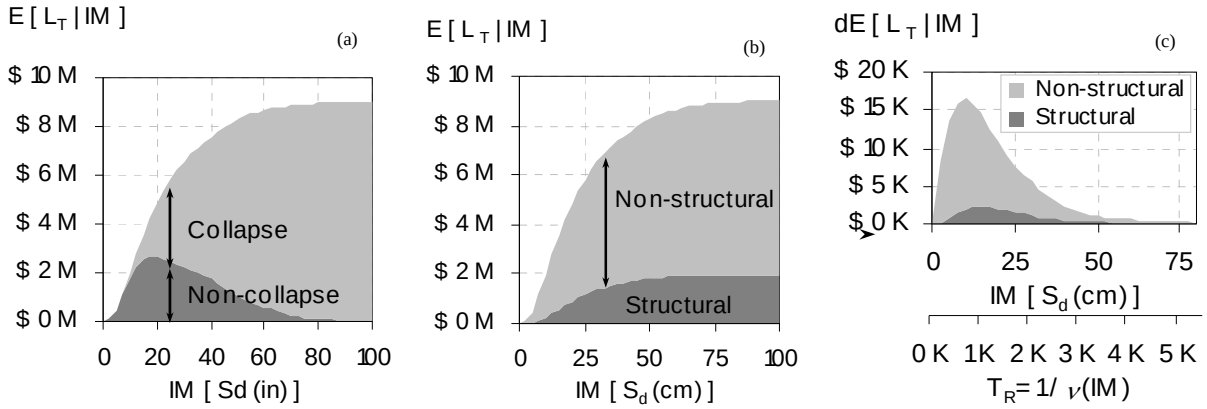

Figure 8: Loss deaggregation results; (a) contribution of collapse and non-collapse losses to the total loss at different levels of intensity, (b) contribution of structural and non-structural losses to the total loss at different levels of intensity, (c) deaggregation of the expected annual loss.

Figure 8c presents loss deaggregation results for the expected annual loss. It can be seen that for the case study building the earthquakes with S_d smaller than 50 cm, (return periods, T_R of less than 3500 years), contribute 96% to the expected annual loss, 81% of which comes from non-structural components and only 15% corresponds to structural components.

Role of Residual Deformations

Residual deformations although often ignored, they are of utmost importance in defining the seismic performance of a structure. In particular, the amplitude of residual deformations is critical in determining the technical and economical feasibility of repairing damaged structures. For example, many damaged reinforced concrete buildings in Mexico City had to be demolished after the 1985 Michoacan, Mexico earthquake because of the technical difficulties to straighten and repair buildings with large lateral residual drifts (Rosenblueth and Meli, 1986). Similarly, many reinforced concrete bridge piers were demolished in the city of Kobe in Japan after the 1995 Hyogo-Ken-Nambu, Japan earthquake due to the technical difficulties and elevated costs that would be required to straighten and repair piers with large permanent lateral deformations (Kawashima 2000).

Figure 9: Examples of buildings with residual displacements that lead to their demolition (Photos courtesy of NISEE, UC Berkeley).

Recent analytical and experimental studies (Mahin and Bertero 1981, MacRae and Kawashima 1997, Pampanin et al. 2002, Ruiz-Garcia and Miranda 2005) have shown that the structures subjected to large

inelastic deformations have a very high probability of experiencing residual deformations (see figure 1). This suggests that ductile lateral force resisting systems which are designed and detailed to be able to sustain large lateral displacements without collapse, unless they have a self-centering capability, are especially susceptible of experiencing residual deformations when subjected to intense seismic ground motions. Large residual displacement can thus lead to a total loss of stakeholders' investment on the building despite having avoided collapse.

In Eq. (2) $E[L \mid NC, IM]$ is an increasing function that describes the increment in losses with increasing ground motion intensity but it fails to recognize that the building may have to be demolished and therefore lead to a total loss even if it has survived the earthquake without collapse. In the enhanced approach the expected value of the loss in the building conditioned on the ground motion intensity is computed as

$$E\left[L_T \mid IM\right] = L_R + L_D + L_C \tag{10}$$

where L_R are the contributions to the total expected loss from losses associated with cases in which collapse does not occur (non-collapse, *NC*) and damage in the building is repaired, *R*, (i.e., $NC \cap R$); L_D are the contributions to the total expected loss from losses associated with cases in which collapse does not occur (non-collapse, *NC*) but the building subsequently demolished, (i.e., $NC \cap D$); and L_C are the contributions to the total expected loss from losses associated with cases in which building collapse (*C*) occurs.

In (10) the loss contribution due to damage repairs is computed as

$$L_R = E\left[L \mid NC \cap R, IM\right] \cdot P\left(NC \cap R \mid IM\right) \tag{11}$$

where $E[L \mid NC \cap R, IM]$ is the expected value of the loss in the building given that the building does not collapses and the damage is repaired knowing that it has been subjected to earthquakes with a ground motion intensity $IM=im$. $P(NC \cap R \mid IM)$ which is the probability that the building will not collapse and that it will be repaired given that it has been subjected to earthquakes with a ground motion intensity $IM=im$. Similarly, the loss contribution due to building demolition is computed with

$$L_D = E\left[L \mid NC \cap D\right] \cdot P\left(NC \cap D \mid IM\right) \tag{12}$$

where $E[L \mid NC \cap D]$ is the expected loss in the building when there is no collapse but the building is demolished and $P(NC \cap D \mid IM)$ is the probability that the building will not collapse but that it will have to be demolished given that it has been subjected to earthquakes with a ground motion intensity $IM=im$. Finally, the collapse contribution is computed as

$$L_C = E\left[L \mid C\right] \cdot P\left(C \mid IM\right) \tag{13}$$

where $E[L \mid C]$ is the expected value of the loss in the building when collapse occurs and $P(C \mid IM)$ is the probability that the structure will collapse under a ground motion with a level of intensity, *im*. Comparing equations (2) and (10) it is then clear that previous building-specific loss estimation investigations (Miranda et al. 2004; Aslani and Miranda, 2004; Haselton et al., 2005) neglected the intermediate term Eq (10) and given that, in general, this term is larger than zero, a systematic underestimation in losses was produced.

The probability that the building will not collapse and that it will be repaired given that it has been subjected to earthquakes with a ground motion with a level of intensity, *im* is given by

$$P\left(NC \cap R \mid IM\right) = P\left(R \mid NC, IM\right) \cdot P\left(NC \mid IM\right) \tag{14}$$

Similarly, the probability that the structure will not collapse but that will need to be demolished when subjected to an earthquake ground motion with intensity level $IM=im$ is computed as

$$P(NC \cap D \mid IM) = P(D \mid NC, IM) \cdot P(NC \mid IM) \tag{15}$$

where $P(D \mid NC, IM)$ is the probability that the structure will be demolished given that it has not collapsed when subjected to an earthquake ground motion with intensity level $IM=im$ and $P(NC|IM)$ is the probability of no collapse when the building is subjected to an earthquake ground motion with intensity level $IM=im$.

Since repair and demolition events conditioned on non collapse are mutually exclusive events (i.e., if the structure survives the earthquake without collapse you either demolish it or not) then

$$P(R \mid NC, IM) = 1 - P(NR \mid NC, IM) \tag{16}$$

Similarly, collapse and non-collapse are also mutually exclusive events (i.e., the structure will either collapse or not collapse during an earthquake) then

$$P(NC \mid IM) = 1 - P(C \mid IM) \tag{17}$$

Substituting (16) and (17) into (15) we obtain

$$P(NC \cap D \mid IM) = P(D \mid NC, IM) - P(D \mid NC, IM) \cdot P(C \mid IM) \tag{18}$$

Estimating the probability that the structure will need to be demolished given that it has not collapsed is particularly challenging because of the many factors that may be involved in arriving to such decision. In the proposed methodology we estimate such probability as a function of residual lateral deformations. Experience after the 1985 Mexican earthquake, the 1995 Hyogo-ken-Nambu (Kobe) earthquake and other earthquakes indicates that permanent (residual) lateral deformation was the primary factor driving the decision to demolish buildings and other structures even when damage was with relatively small. In the proposed enhanced approach the probability of having to demolish a building that has not collapsed given that it has been subjected to an earthquake ground motion with intensity *IM=im* is computed as a function of the peak residual interstory drift ratio as follows:

$$P(D \mid NC, IM) = \int_0^\infty P(D \mid RIDR) dP(RIDR \mid NC, IM) \tag{19}$$

where $P(D|RIDR)$ is the probability of having to demolish the structure conditioned on the peak residual interstory drift in the building (maximum from all stories in the building) and $P(RIDR|NC,IM)$ is the probability of experiencing a certain level of residual interstory drift ratio in the building given that it has not collapsed and that it has been subjected to a ground motion with intensity *IM=im*. Eq. (19) considers that there is not a single residual interstory drift that triggers demolition, but rather that there is variability in the decision to demolish a building for a given level of residual interstory drift. This probability may be interpreted as the percentage of engineers that would recommend demolition of the building for a given of residual interstory drift. Based on limited information and on engineering judgment $P(D|RIDR)$ is assumed to be lognormally distributed

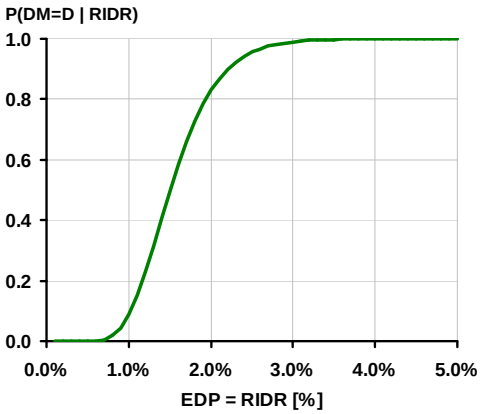

Figure 10: Probability of having to demolish a building that has not collapsed as a function of the peak residual interstory drift in the building.

with a median of 0.015 and a logarithmic standard deviation of 0.3. The resulting cumulative probability distribution is shown in figure 10. As shown in this figure, residual drifts that would lead to demolition range from about 0.7% to 3%. In particular, buildings with a residual interstory drift ratio of 1% would have approximately a 10% probability of having to be demolished and buildings experiencing residual interstory drift ratios larger than 3% would practically be certain that they would have to be demolished.

Illustrative Examples

In order to illustrate the use of the proposed enhanced loss estimation methodology was used to evaluate economic losses in two reinforced concrete frame buildings whose seismic response was previously studied by other investigators (Haselton and Deierlein, 2007). The first building is a 4-story building with ductile detailing, and the second one a 12-story building also with ductile detailing. Both structures were assumed to be located at a site in Los Angeles, CA, south of the city's downtown area, and is representative of a typical urban California site with high levels of seismicity. The two buildings were designed by Haselton and Deierlein (2007) according to the 2003 International Building Code and related ACI and ASCE provisions (ACI 2002, ASCE 2002, ICC, 2003). For detailed information on the designs and modeling parameters of these structures the reader is referred to Haselton and Deierlein (2007).

The buildings were modeled in OpenSees (PEER, 2006) using a two-dimensional, three-bay model of the lateral resisting system and a leaning (P-Δ) column. Beams and columns were modeled with concentrated hinge (lumped plasticity) elements and employ a material model developed by Ibarra et al. (2005). The nonlinear simulation models of the reinforced concrete frames were analyzed by Haselton and Dierlein using the incremental dynamic analysis technique by analyzing each model using a large set of ground motions scaled at increasing levels of ground motion intensity. Subsequently economic losses were computed using the story-based approach suggested by the authors (Ramirez and Miranda, 2009). In each case economic losses were computed considering without considering the intermediate term in Eq (10) and considering this intermediate term in order to evaluate its influence in economic losses. The influence of this term was evaluated for each building by comparing expected losses at increasing levels of ground motion intensity, by comparing expected annual losses and by comparing the probability of exceedance of large economic losses.

Figure 11 compares the expected economic losses with and without considering losses due to the possibility of having to demolish in the two buildings for three different levels of seismic hazard. For each building, the first pair of results corresponds to expected losses for a service level earthquake with a 50% probability of occurrence in 50 years. The middle pair of bars corresponds to the expected economic losses at the Design Basis Earthquake (DBE) defined as the intensity with a 10% of occurrence in 50 years and the third pair corresponds to the losses due to seismic event that has a probability of exceedance of 2% in 50 years (often referred to as the Maximum Credible Earthquake, MCE). The values of the seismic ground motion intensity that correspond to all three hazard levels are indicated at the bottom of the figure. Expected values are normalized by the replacement cost of the structure.

For each hazard level, the left bar corresponds to losses that do not considering losses due demolition and the right bar corresponds to the losses that consider losses due to demolition. It can be seen that at the service-level earthquake, the effect of losses due to building demolition does not have an influence on the overall normalized loss for the four-story building and a relatively small influence for the 12-story building. On the other hand, for the four-story building the normalized economic losses increase from 31% to 42% at the DBE and from 48% to 73% at the MCE corresponding to increments in expected losses of 35% and 52% and the DBE and MCE levels, respectively. The relative increase is the difference between the two values of expected loss, with and without considering losses due to demolition, divided by the expected loss with considering losses due to demolition, multiplied by 100. This means that losses due to demolition have a large influence in the overall loss estimate, and that neglecting these losses can lead to significant underestimations in economic losses.

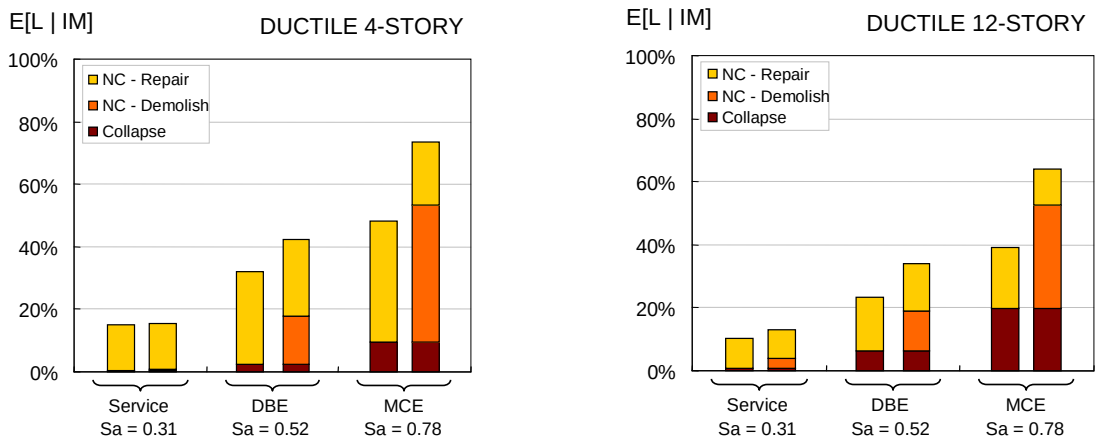

Figure 11. Comparison of expected losses in the 4 and 12-story buildings computed without the inclusion of the possibility of demolition and including the possibility of demolition.

To gain further understanding of the influence of the possibility of having to demolish a building after an earthquake even though it has not collapse loss results at these levels were disaggregated following the approach proposed by Aslani and Miranda, (2005). In figure 11 each bar in the figure is divided up into collapse losses, non-collapse (NC) losses due to building demolition and non-collapse losses due to repair costs. The proportions of each bar are equal to how much each type of loss contributes to the overall loss. As shown in this figure, demolition losses have the largest contributions to the overall loss at the MCE. At this intensity level, losses conditioned on non-collapse due to demolition dominate the expected loss. In particular, the losses due to demolition are significantly larger than those of collapse even though both lead to total loss of the initial investment. This is because at the MCE, the probability of demolition is much higher (45%) than the probability of collapse (8%), that is, at this level of ground motion intensity the structure is more likely to experience large residual deformations that will lead to demolition, than collapsing. Similar results were computed for the 12-story building.

Conclusions

A methodology is proposed to estimate the seismic performance of buildings in terms of economic losses. The methodology explicitly incorporates the uncertainties corresponding to the seismic hazard, to the response of the structure, to the damage incurred in different components and to the repair or replacement cost of damaged components. Generic procedures are proposed to improve the estimation of various sources of uncertainty that contribute to the loss estimation methodology. Specifically, the concept of fragility surfaces is introduced which leads to smaller dispersions while estimating damage and provides a powerful tool to estimate the conditional probability of system collapse. Furthermore, the effects of correlation between losses in individual components are explicitly considered. It is concluded that the correlation between losses at the component-level can significantly increase the dispersion in the losses in the building.

As part of the study, the use different of different parameters as ground motion intensity measures was investigated. It is concluded that for drift-sensitive components, using inelastic spectral displacement ordinates leads to lower dispersion of building response than those computed using elastic spectral ordinates. For acceleration-sensitive components, it was observed that peak ground acceleration, *PGA*, provides smaller levels of dispersion of peak floor accelerations compared to those computed using elastic spectral ordinates as intensity measure.

Finally, the results from the loss estimation methodology were disaggregated in order to determine the contribution of different ground motion levels and different components on losses in the building. Examples on disaggregation were presented to identify the contribution of structural and non-structural components to expected losses and contributions of collapse and non-collapse to expected annual losses.

The Pacific Earthquake Engineering Research (PEER) Center methodology for seismic performance assessment has been further extended to explicitly account for the possibility of having to demolish a building that did not collapse during an earthquake. In the proposed framework the probability of having to demolish the building given that it has not collapsed is computed as a function of the peak residual interstory drift in the building conditioned on the ground motion intensity. The latter is computed by conducting and incremental dynamic analysis in which peak residual interstory drifts are computed at increasing levels of ground motion intensity. By doing so, the record-to-record variability of residual drift demands is explicitly taken into account.

Results indicate that neglecting the probability of demolition due to excessive residual lateral deformations as typically done presently leads to significant underestimations of economic losses. Underestimations are typically larger in ductile buildings than in non-ductile buildings. This is because ductile structures are very effective in reducing the probability of collapse when subjected to intense ground motions, but they have a significant probability of having to be demolished due to residual drifts. Meanwhile, when non-ductile structures are subjected to intense ground motions they typically have a relatively large probability of collapse and the probability of surviving the earthquake with large permanent deformations that will lead to demolition is much smaller.

The proposed framework provides an ideal tool to assess the tradeoffs and benefits of various design alternatives. In particular it provides a framework to properly account for the economical benefits of incorporating self-centering technologies with significantly reduce or even eliminate residual drifts.

Acknowledgements

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Collapse Hazard and Design Process of Essential Buildings with Dampers

Kit Miyamoto[1], Amir S.J. Gilani[2], and Akira Wada[3]

Introductory Discussion

The combination of steel moment frame structures and fluid viscous dampers (SMRF-FVD) has been shown to produce essential structures that have significant damping and perform well in seismic regions. This approach is economically competitive when compared to typical code design. The viscous damper and driver brace are typically modeled as dashpot and spring elements, respectively, in series. Once a damper reaches its limit states, this simple modeling is no longer applicable. Reaching the displacement limit (bottoming out) results in the damper being transformed to a steel brace of large stiffness, whereas, reaching the force limit implies fracture or buckling and thus rendering the damper ineffective. To address the damper limit states and assess such effect on the building performance, an advanced mathematical model of viscous dampers that includes its limit states was developed. The accuracy of the analytical formulation was verified by correlation to laboratory tests. This model was then used in the modeling of buildings ranging from 1 to 10 stories with SMRF-FVD. Incremental dynamic analysis using 44 sets of PEER NGA records were conducted to compute the probability of the models reaching a failure state at the MCE intensity. Analysis showed that the SMRF-FVD had low probability of collapse at the MCE level and superior performance compared to conventional code design.

Introduction

Fluid viscous dampers (FVDs) originally developed as shock absorbers for the defense and aerospace industries have been used extensively for seismic applications in recent years. During seismic events, the devices become active and the seismic input energy is used to heat the fluid and is dissipated. FVDs possess stable and dependable properties for design earthquakes. Figure 1 depicts the application of dampers to a new essential building in California (Miyamoto and Gilani, 2008). To date, no comprehensive study has been undertaken to investigate the limit state of viscous dampers and to characterize the effect on the building once a damper limit state is reached. This paper presents some results from a comprehensive research currently underway to address this issue. Since dampers are ideal for drift control in steel moment resisting frame buildings, the investigation is focused on such application.

Modeling of Viscous Dampers

Component of Viscous Dampers

Typical viscous dampers consist of a cylinder filled with an incompressible silicone fluid and a stainless steel piston. The damper is activated by the flow of silicone fluid between chambers at opposite ends of the unit, through small orifices. Figure 2 shows the damper cross section. In most applications, the dampers are modeled as simple model of Figure 3. The viscous damper itself is modeled as a dashpot in series with the elastic driver brace member. Such model is adequate for most design applications, but is not sufficiently refined for collapse evaluation. In particular, force and displacement limit states are unaccounted.

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Figure 1. SMRF-FVD

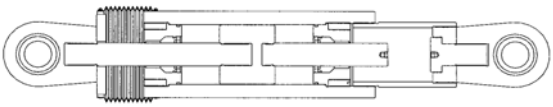


Figure 2. FVD cross section

Damper Limit States

The FVD limit states are governed by the stroke and force. The stroke limit state is reached once the dampers bottoms out, this occurs when the piston motion reaches its available stroke and, the damper transitions from a viscous damper to a steel brace with the stiffness equal to that of the cylinder wall. The force limit states in compression and tension are governed by the buckling capacity of the driver brace and the tensile capacity of the piston rod, respectively.

Advanced Model for Viscous Dampers

Figure 4 presents the advanced model for viscous dampers. This model is developed to incorporate the limit states and consists of five components:

- The driver (KD), attaches the damper to the SMRF is modeled as a nonlinear spring.
- The piston rod (KP) and undercut is modeled as a nonlinear spring. In tension, the undercut section of the piston can yield and fracture.
- Dashpot (C and α) is used to model the viscous component.
- Gap element and linear springs (Kc) are used to model the limit state when the piston retraction equals the stroke. The elastic stiffness depends on the cylinder properties.
- Hook elements and linear springs (Kc) are used to model the limit state when the piston extension reaches the damper stroke (umax). The stiffness is the same the gap element.

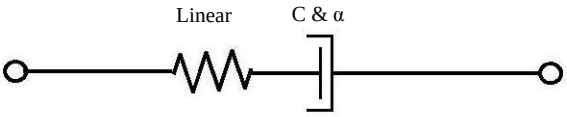


Figure 3. Simple model

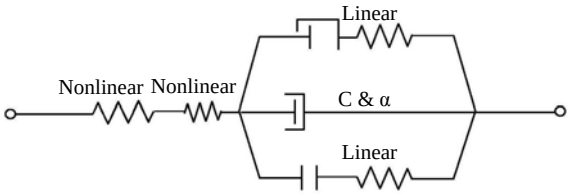


Figure 4. Advance model

Response of The Advance Model

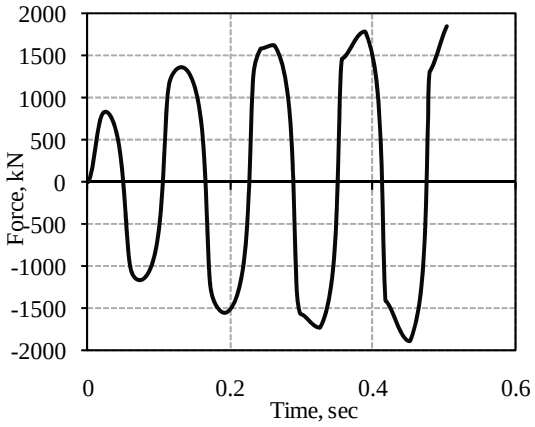
To illustrate the response of the advance model and illustrate its capability to capture the damper limit states, analytical simulations were conducted. The damper was modeled in program OpenSees (PEER 2009a) using the refined model. All analysis was conducted using a sinusoidal displacement loading function. The damper used was a 700-kN unit with a constitutive relation (force in kN and velocity in mm/sec) of Eq. 1.

$$F = 88\,\mathrm{sgn}(v)|v|^{0.3} \quad (1)$$

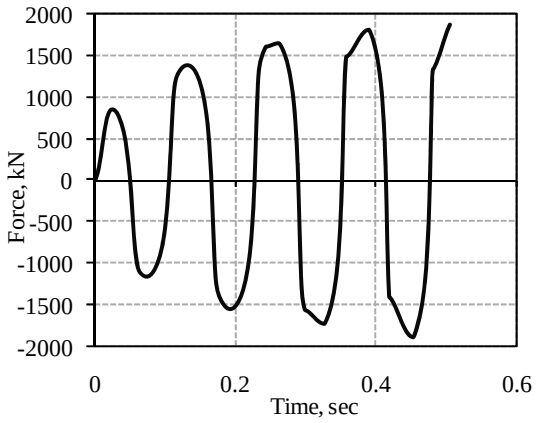
Force Limit State of Piston Fracture

This simulation was conducted to investigate the damper response for the limit state of piston-undercut fracture. The stroke was artificially set to be large enough to ensure that the damper did not bottom. The

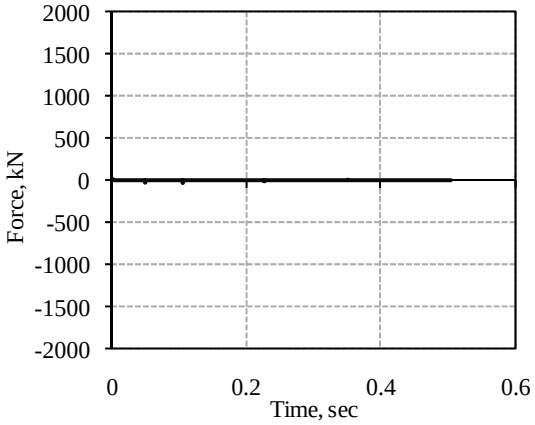
response is shown in Figure 5. Note that the force transmitted by the cylinder walls was zero since the damper had not bottomed out. Once the piston undercut reaches its tensile capacity, the damper element is automatically removed from the simulation and the forces drop to zero.



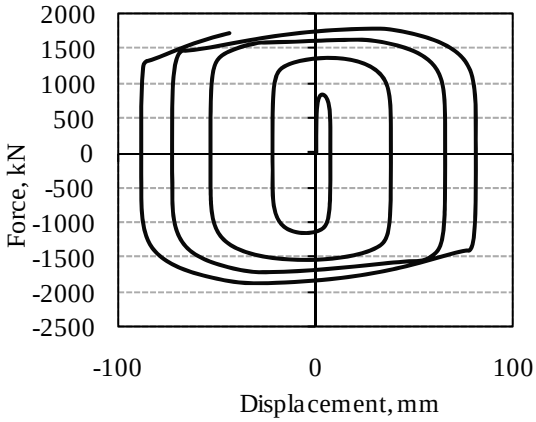
a. Damper



b. Viscous element



c. Cylinder walls

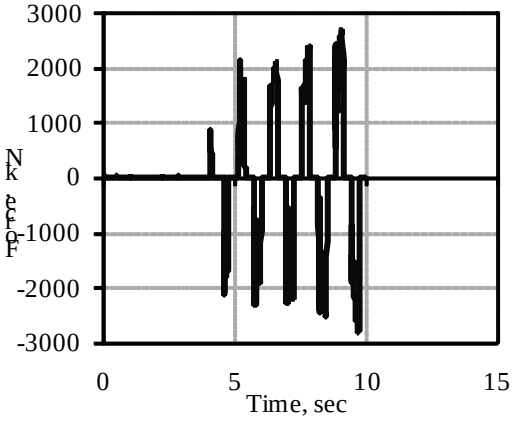


d. Damper hysteresis

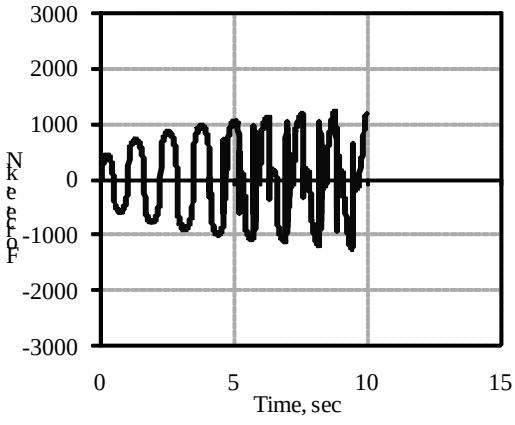
Figure 5. Response when undercut fractures

Stroke Limit State

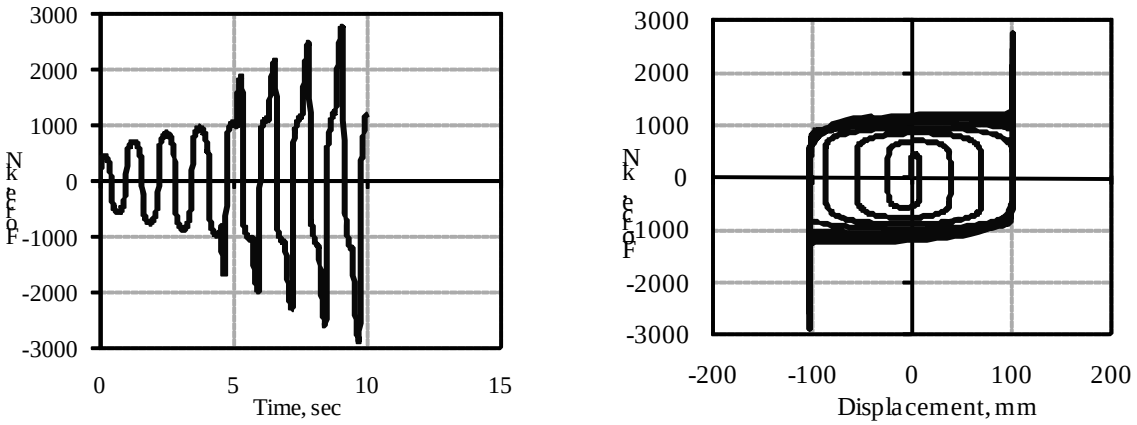
This simulation was conducted to investigate the damper response for the limit state when the stroke limit in extension and retraction are reached. The undercut tensile and driver brace compressive capacity were artificially set to be large enough for these members to remain elastic. The response is shown in Figure 6. Note that the force transmitted by the cylinder walls is non-zero, once the stoke limit was reached.



a. Damper



b. Viscous element

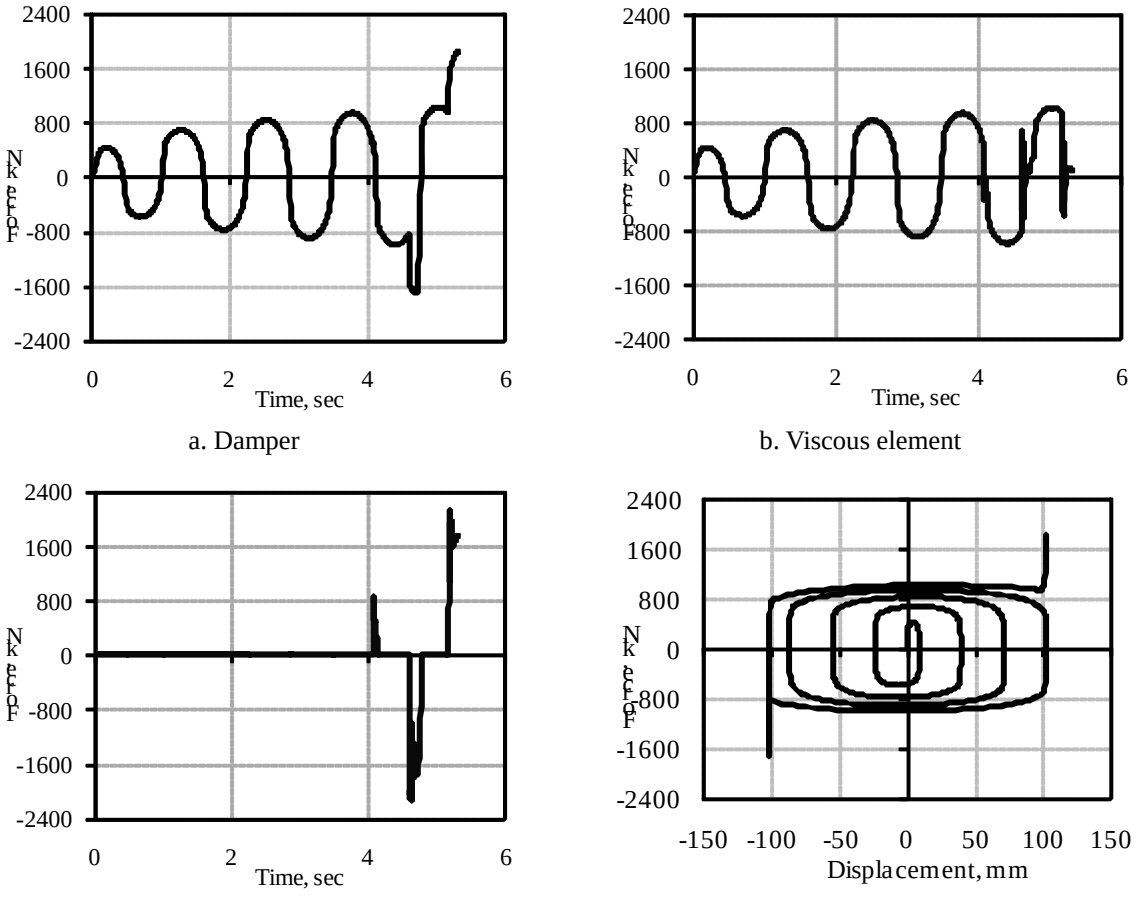


c. Cylinder walls d. Damper hysteresis

Figure 6. Response when damper bottoms out

Displacement and Force Limit States

This simulation was conducted to investigate the damper response for the limit state of piston fracture following the bottoming out of the damper at full extension. The response is shown in Figure 7. At 4.5 sec, the piston extension reaches the stroke limit, and the damper bottoms out. At this point, velocity was zero and thus the force in the viscous element dropped to zero. The damper now acted as an elastic brace. The undercut yielded but does not fracture. Loading is then reversed. This resulted in the disengagement of cylinder walls, and re-loading of the viscous component. At 5.3 sec, piston bottomed out again. The damper again became an elastic brace. Loading is increased further resulting in fracture of undercut. The entire damper was now ineffective and removed.



a. Damper b. Viscous element

c. Cylinder walls d. Damper hysteresis

Figure 7. Response for compound case

Correlation with Experimental Data

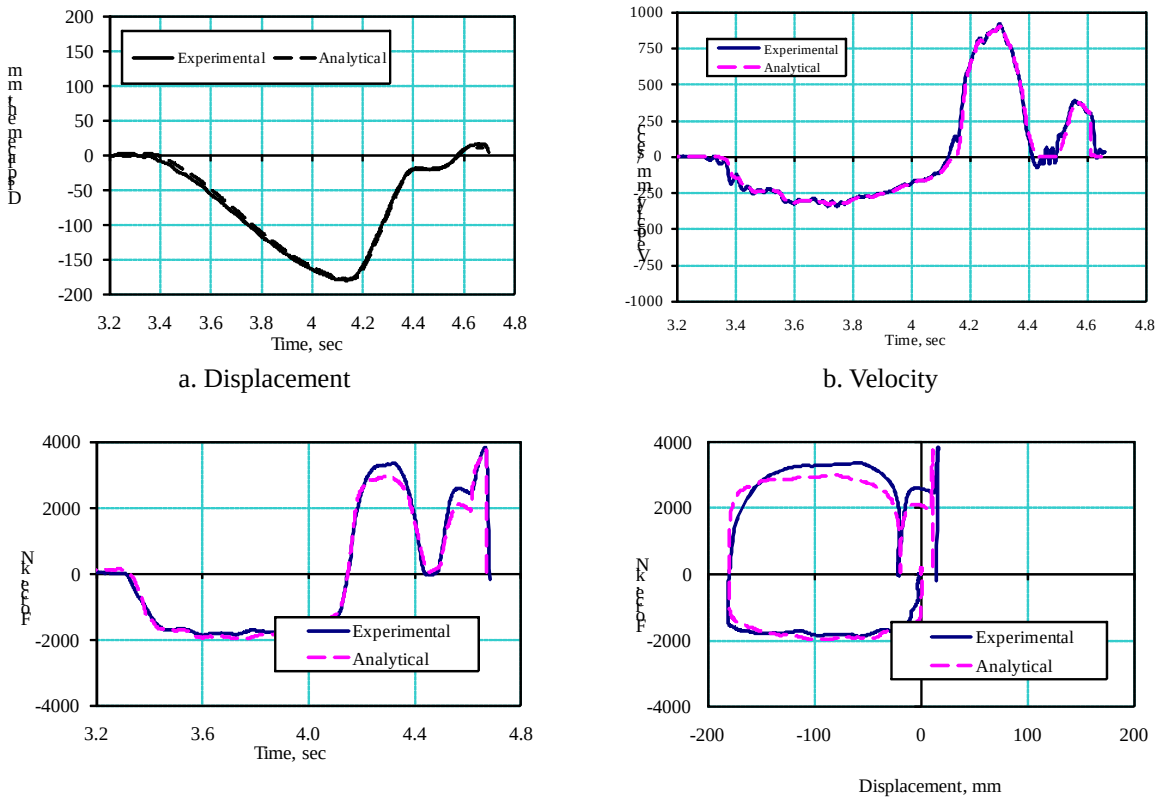
Experimental data from a damper (Taylor, 2009) was used to assess the accuracy of the advance model. This damper had a nominal capacity of 2000 kN, a stroke of 140 mm, and constitutive relation of Eq 2.

$$F = 3.5\,\mathrm{sgn}(v)\left|v\right|^{0.5} \qquad (2)$$

The damper was placed in the test rig and subject to a displacement loading history. The unit was placed with its piston extended to within 10 mm of the stroke limit prior to start of the displacement cycles. The experimental displacement, velocity, and force responses are presented as solid lines in Figure 8a through Figure 8c, respectively. The displacement, velocity, and force limit states are identified in these figures respectively.

- At 4.30 sec, the unit was pulled in tension at 910 mm/sec and stopped just before it bottomed. This large velocity was close to 300% of its nominal design. This resulted in the forces developed in the damper that exceeded the nominal value computed from the constitutive relation.
- At 4.61 sec, the damper bottomed out in tension, resulting in sharp increase in the measured force. This was followed by tensile yielding. The displacement response after this point was nearly flat with a slight increase due to yielding.
- Finally at 4.68 sec, fracture occurs and the damper load drops to zero. After this time, no force can be transferred by the damper.

The dashed lines in these figures represent the results obtain from simulation using the refined damper element. Good correlation is obtained between the experimental data and analytical simulations. The analytical model was able to capture the bottoming of the damper and tensile fracture correctly. Figure 8d presents the force-displacement hysteresis and the dissipated energy in the damper. The analytical model captures the experimental responses closely.



a. Displacement b. Velocity

c. Force d. Damper hysteresis

Figure 8. Experimental and analytical results

Analysis Procedure

The input histories used in analysis were based on the two components of the 22 far-filed (measured 10 km or more from fault rupture) NGA PEER (2009b) records. These 44 records have been identified by FEMA P695 (FEMA 2009) for collapse evaluation analysis. The selected 22 records correspond to a relatively large sample of strong recorded motions that are consistent with the code (ASCE/SEI 7) (ASCE 2005) and are structure-type and site-hazard independent. Figure 9 presents the acceleration response spectra for these records. The design MCE spectrum is shown as the thick solid line in the figure. For analysis, the 44 records were first normalized and then scaled. Normalization of the records was done to remove the record-to-record variation in intensity. For collapse analysis, the normalized records were then scaled upward or downward to obtain data points for the nonlinear incremental dynamic analysis (IDA) simulations (Vamvatsikos and Cornell, 2004). Program OpenSees was used to conduct the nonlinear analyses. Pertinent model properties are:

- Analytical models were two-dimensional
- Beam and column elements, were represented as one dimensional frame elements. The members were prismatic and linear.
- Material nonlinearity was represented by concentrated plastic hinges represented by RBS hinges placed at the center of the reduced section and by column P-M hinges.
- The damper element was represented by the advance model.

Application to Steel Buildings

Introduction

To illustrate the concepts described in this chapter, design and analysis of a single story structure with viscous damping was conducted. The one-story frame was square in plan and measures 27 m on each side. It is 4 m tall. The structure had one interior SMRF on the perimeter on each side. One of the 9x4 m frames was selected for design and analysis. Figure 10 presents the plan drawing for the structure. This design was representative of a typical office building built in Los Angeles California with the following conditions: Seismic Design Category D, S_S=1.5g and S_1 = 0.6g. The frame was designed using the code provisions and special requirements for SMRFs. For this structure, the fundamental period (T1) was 0.42 sec. The ASCE/SEI 7 maximum period used to compute base shear (Tmax) was 0.31 second and was used for evaluation. Various frame and damper configurations were investigated; Table 1 presents the properties of the archetypes.

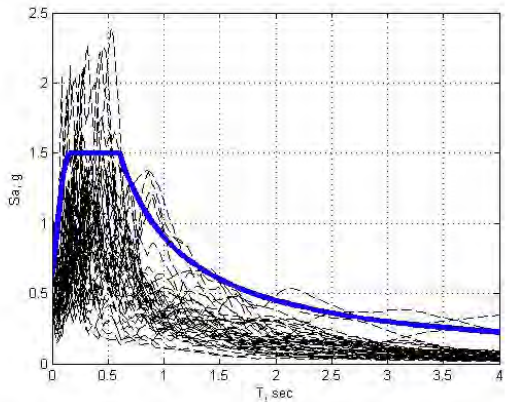


Figure 9. Response spectra of records

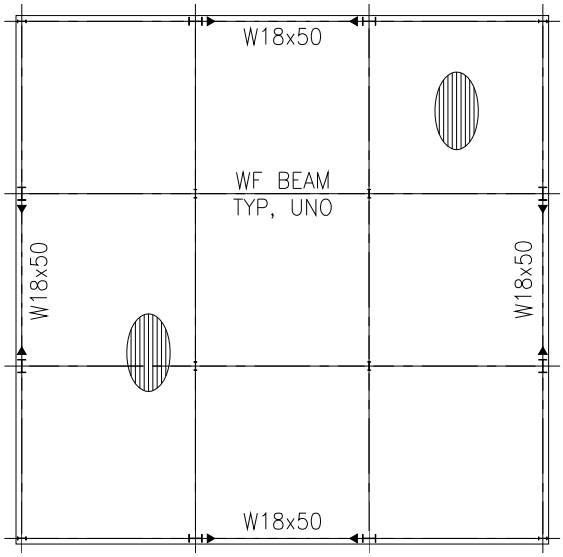


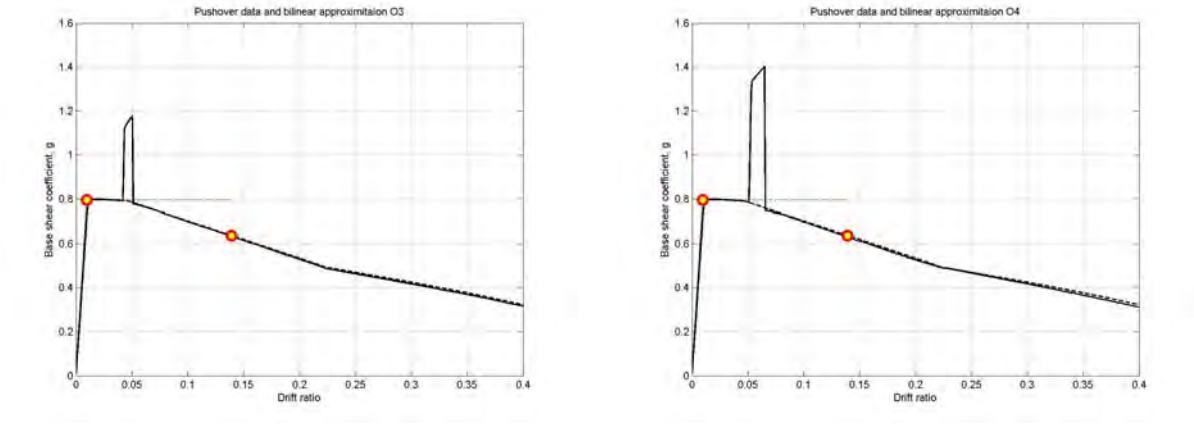
Figure 10. One story archetype

Archetype	Stories	Column base	Story Drift Ratio, %	Damper FS
O1	1	Pinned	2.5%	1.0
O2	1	Pinned	1.0%	1.3
O3	1	Fixed	2.5%	1.0
O4	1	Fixed	1.0%	1.3

Table 1. Archetypes

Pushover Results

Figure 11 presents the pushover curve for the archetypes O3 and O4. The solid and dashed lines correspond to the archetypes and bare frame models, respectively. As long as the damper did not bottom out, the plots are identical. Once the damper bottomed out, there was significant increase in stiffness and strength since a stiff brace (cylinder wall) was now added to the system. After the damper failed, the damped pushover curve reverts to the undamped case. The dotted line corresponds to a bilinear approximation used to compute the yield and ultimate drifts and the corresponding ductility (μc). Using the building period and ductility, the spectral shape factor (SSF) is the computed. Note that O4 had a larger damper factor of safety and thus a larger increase in overall strength once the damper bottoms out.

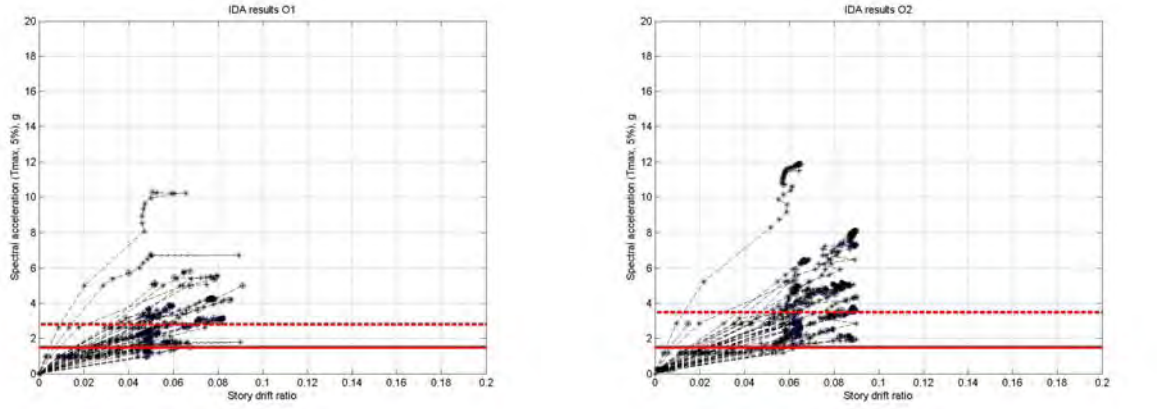


a. O3 b. O4

Figure 11. Static pushover curves

IDA Results

Figure 12 presents the IDA plots for the O1and O2. The solid and dashed red lines correspond to the MCE (SMT) and the median collapse capacity (SCT), respectively. Note that the addition of small damper factor of safety significantly increased collapse margin. The collapse margin ratio (CMR) is defined as the ratio of SCT and SMT. The adjusted collapse margin ratio (ACMR) is then computed as the product of SSF and CMR. FEMA P695 specifies a minimum ACMR of 1.59 for acceptable performance. As shown in Table 2, all archetypes have significantly larger collapse margins and therefore pass easily.



a. O1 b. O2

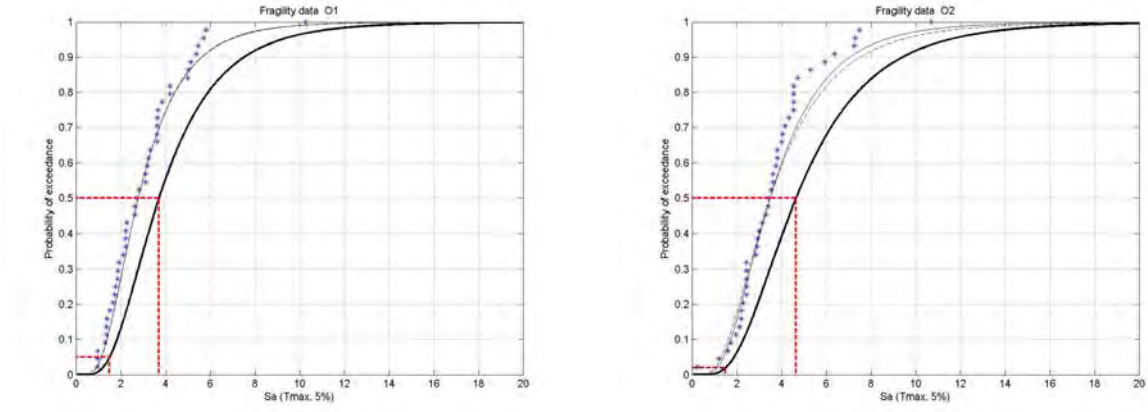
Figure 12. IDA plots

Archetype	SCT	SMT	CMR	SSF	ACMR	P/F
O1	2.79	1.50	1.86	1.34	2.49	Pass
O2	3.49	1.50	2.33	1.34	3.12	Pass
O3	5.27	1.50	3.51	1.34	4.71	Pass
O4	6.12	1.50	4.08	1.34	5.47	Pass

Table 2. Collapse Margins For Archetypes

Collapse fragility Data

Figure 13 presents the fragility plots for O1 and O2. The 44 collapse data are statistically organized (data points in the figures) and a lognormal curve was fitted to the data (dashed lines in the figures). The plot was then rotated to correspond to a total uncertainty of 0.55 (solid line) per FEMA P695. Finally the curve was shifted to account for the effect of the SSF (dark solid lines in the figures). The probability of collapse at MCE intensity was then computed using the fragility curves as listed in Table 3. Note that the probability of collapse at MCE level was reduced by a factor of approximately 2.5 when an additional damper factor of safety of 30% is included in design. Such small increase is cost efficient and provides significant additional protection to the structure.



a. O1 b. O2

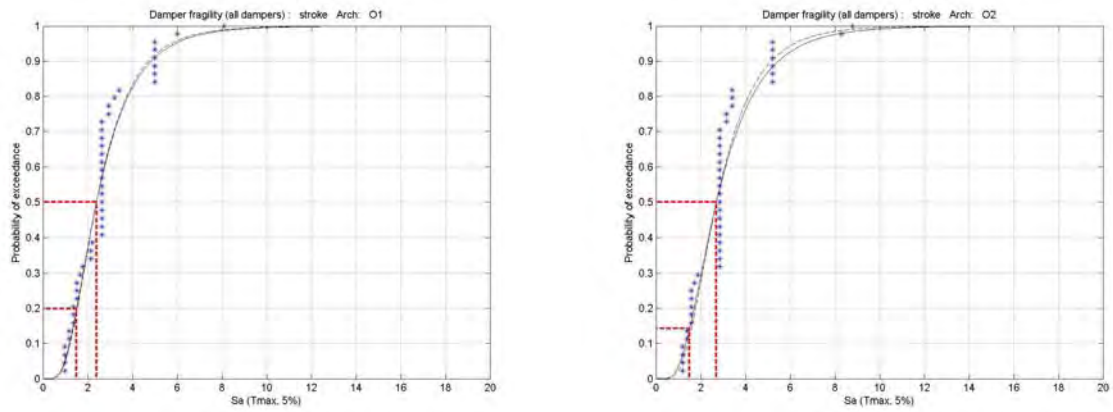
Figure 13. Fragility plots

Archetype	MCE Probability of collapse %
O1	4.9
O2	2.0
O3	2.5
O4	1.0

Table 3. Collapse probability for archetypes at MCE

Damper Responses

Figure 14 and Figure 15 presents the fragility plots for the damper stroke and force, respectively. For each response quantity and archetype, the 44 data points for the damper reaching its stroke or force limit states were statistically organized (data points in the figures) and a lognormal curve is filled to the data (dashed lines in the figures). The plot was then rotated to correspond to a total uncertainty of 0.55 per FEMA P695 (solid line). The probability of the damper reaching its limit state at the MCE intensity can then be computed from the fragility plots. At MCE intensity, the probability of collapse can then be computed using the fragility curves as listed in Figure 14. Note that the probability of damper reaching a limit state is significantly reduced when a damper factor of safety of 30% is included in design. Such small increase is cost efficient and provides significant additional protection to the dampers.

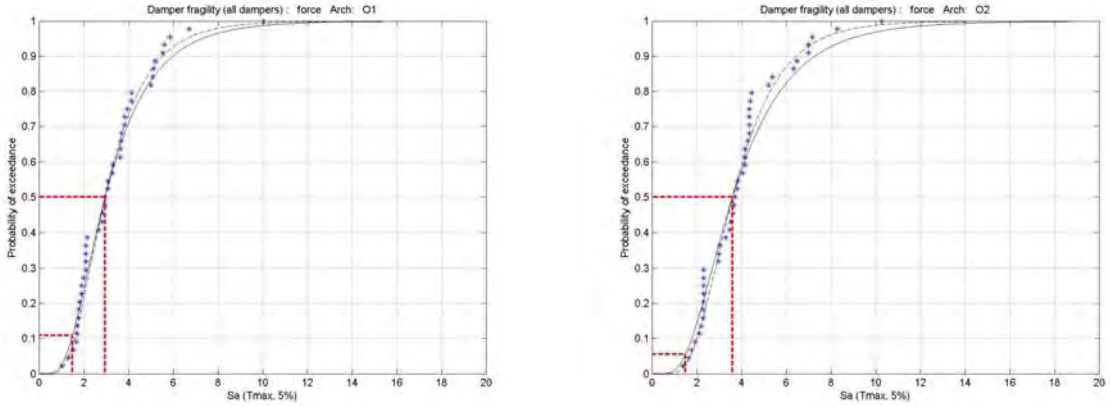


a. O1 b. O2

Figure 14. Damper stroke fragility

Archetype	Median Sa intensity to reach limit		Probability of reaching limit state at MCE	
	Stroke	Force	Stroke	Force
O1	2.39	2.95	20%	11%
O2	2.71	3.60	14%	6%
O3	3.83	5.89	6%	0.6%
O4	3.84	6.11	4%	0.5%

Table 4. Damper Fragility Data



a. O1 b. O2

Figure 15. Damper force fragility

Ongoing Research

The ongoing research at the Tokyo Institute of Technology by the authors is intended to expand the knowledge base for steel SMRF buildings with dampers. The research closely follows the guidelines and procedures established by FEMA P695.

Fifteen archetypes (from one to thirty story buildings) are currently under consideration. The geometry and distribution of dampers for the models are summarized in Table 5. The selected building models are regular in plan and elevation with a dominant first mode response. The period of tall buildings is limited to approximately 5 sec to ensure sufficient energy is present in the input histories.

Archetype	Stories	Column base	Story Drift Ratio, %	Damper FS
O1	1	Pinned	2.5%	1.0
O2	1	Pinned	1.0%	1.3
O3	1	Fixed	2.5%	1.0
O4	1	Fixed	1.0%	1.3

A1	2	Pinned	2.5%	1.0
A2	2	Pinned	1.0%	1.3
A3	2	Fixed	2.5%	1.0
A4	2	Fixed	1.0%	1.3
B1	5	Fixed	2.0%	1.0
B2	5	Fixed	1.0%	1.3
C1	10	Fixed	2.0%	1.0
C2	10	Fixed	1.0%	1.3
D1	20	Fixed	2.0%	1.0
D2	20	Fixed	1.0%	1.3
E1	30	Fixed	1.0%	1.0

Table 5. Archetypes

Conclusions

New steel buildings were designed with Special Moment Resisting Frames were used to provide strength; dampers were used to control story drifts. Demand on both structural and nonstructural components is reduced compared to conventional design.

- Current research using Incremental Dynamic Analysis and limit states of dampers is currently underway. The outcome of this study will provide a more realistic assessment of the performance of moment frames with dampers.
- All the archetypes had significant margin against collapse and thus had satisfactory performance. When an additional damper factor of safety is included in design, additional protection for the structures and dampers is provided.
- As one of the research deliverables, pertinent information will be provided for the designers to assist in seismic design using this viscous dampers

Acknowledgements

This work was supported in large part by Taylor Devices, Inc and Armour Steel. Mr. Christopher Ariyaratana, formerly of University of Illinois was responsible for conducting the analysis. The technical assistance of Mr. Doug Taylor and Mr. John Metzger of Taylor Devices is acknowledged. Professor Curt Haselton of the California State University, Chico provided guidance for this study.

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Implementation of Seismic Regulations for Nonstructural Components in Essential and Important Buildings in the United States

***Christine Theodoropoulos, AIA, P.E.*[1]**

Introduction

In the United States, building codes include mandatory provisions for the reduction of nonstructural earthquake damage to provide life-safety levels of protection for the general building stock and increased nonstructural performance in essential facilities such as hospitals, fire and police stations, schools, and buildings with hazardous contents. Requirements for higher performance levels in essential facilities can also provide guidance for the voluntary protection of non-structural elements which preserve important cultural and economic resources. As more attention is being paid to the development of codes that reduce nonstructural damage in earthquakes, and the development of design procedures that achieve specified levels of nonstructural performance, designers and other stakeholders are calling for improved implementation of seismic regulations within an integrated approach to building design and construction. Best practices for the implementation of seismic provisions of nonstructural elements are emerging from government agencies, building industries, universities and professional entities conducting research, as well as design and construction professionals.

Nonstructural Damage in U.S. Earthquakes

Higher than expected nonstructural damage in moderate level earthquakes, such as Northridge (1994) and Nisqually (2001), has drawn attention to the need to regulate the design and construction of nonstructural elements. Post earthquake field observations recorded by reconnaissance teams from the Earthquake Engineering Research Institute (EERI) and other professional organizations provide important information about earthquake damage to nonstructural systems and components commonly used in the United States. Although essential and important facilities are regulated to meet more stringent seismic design and construction standards, there are cases in which the continued operation of critical or important facilities has been interrupted by nonstructural damage or secondary effects such as water leakage from damaged pipes. Reconnaissance reports also show that the extent of nonstructural damage can be significant and that there are ongoing problems with the implementation and enforcement of seismic design regulations for nonstructural elements. (ATC, 2008) (Filiatrault, 2001)

In a recent example, the Jefferson Elementary School, constructed in the 1960s in Calexico, California, at a time when nonstructural systems were less stringently regulated, experienced significant damage to the ceilings of classrooms and exterior covered walkways during the 2010 Sierra El Mayor Earthquake. The combined failure of seismically fragile nonstructural systems within the sandwich of space between a roof or floor structure and a suspended ceiling is a common occurrence in earthquakes in the United States.

Damage to Jefferson School Classrooms, Sierra El Mayor Earthquake, 2010. Photos: Gary L. McGavin

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In the photos above, the light gage metal grid supporting acoustical ceiling tiles interspersed with heavier fluorescent lighting fixtures and other systems components are connected to the structure with wires which did not provide adequate strength, lateral resistance or prevent damaging collisions between components.

Approximately 110 square meters of plaster ceiling soffits overhanging exterior walkways fell in a progressive fashion when the failure of improperly attached wire hangers transferred excessive forces throughout the support system. Gary L. McGavin, AIA, Commissioner for the California Seismic Safety Commission, compared the support of the Jefferson School walkways with other, similarly constructed, walkways that survived the earthquake and found evidence suggesting that the failed soffit attachments were deficiently constructed and may have not complied with the original design intent. The fallen soffits blocked classroom exit doors, sheared off exterior door knobs and a hose bib. The Jefferson School has fixed windows, constructed of Lexan, a polycarbonate resin thermoplastic which is a common replacement for glass to prevent breakage. If students had been inside the blocked classrooms, they would have been unable to exit through doors or break out of windows. The failure of the soffits caused the failure of the emergency egress system. Fortunately the school was unoccupied at the time of the earthquake. (EERI, 2010) This example illustrates the complex interactions of nonstructural systems and why nonstructural design and construction requires regulatory oversight that thoroughly reviews all components and connections and considers the consequential damage that can occur when the failure of one weak link has widespread impacts on safety and performance.

Damage to Jefferson School Walkways, Sierra El Mayor Earthquake, 2010. Photos: Gary L. McGavin

Post-earthquake field data is collected by professional volunteers within days after earthquakes. Debris removal and other emergency response or recovery activities can quickly eliminate evidence of nonstructural damage. Reconnaissance teams usually record the most severe, visible examples but they do not have resources or time to collect evidence that describes patterns of damage for particular types of nonstructural systems distributed over an entire building stock. Other information sources pertaining to regional earthquake losses, such as insurance claims, do not include information needed to draw conclusions about statistical relationships between nonstructural damage and deaths, injuries, direct loss of construction value or loss of functionality. Earthquake specialists are calling for more systematic gathering of perishable earthquake experience data in order to generate nonstructural damage statistics. The Applied Technology Council recommends the development of a standardized data collection framework, a national web-based repository for new data, and a pilot project to collect nonstructural damage data for a single public building use type. (ATC, 2008)

The Regulation of Nonstructural Seismic Design and Construction

In the United States, jurisdictions at state and local levels develop building codes using a process that adopts a model building code with revisions that address local building concerns. Buildings owned by the federal government are regulated by federal agencies using the same or similar models. Historically, nonstructural provisions related to seismic safety were added to local and model codes in the aftermath of damaging earthquakes and tended to follow developments in provisions for structural systems.(FEMA, 2006) Over time, codes governing the most earthquake prone areas of the country were incorporated into a single national

model code, the IBC (*International Building Code*) which provides requirements for all building types, including essential and important facilities. (ICC, 2009) Single and two-family houses are regulated by the IRC (*International Residential Code*). The IBC is a comprehensive code which references standards produced by professional and industry associations concerned with various aspects of nonstructural performance. Because the IBC is an assembly of standards developed by different organizations, nonstructural seismic provisions are dispersed among various documents. In some cases referenced standards are the sole source of code requirements, in others their purpose is to provide more detailed protocols to meet code requirements, or approved alternates to the general provisions of the code. Some of the key documents are discussed below.

ASCE-7 Chapter 13

Nonstructural design requirements are specified in the same national standard—the American Society of Civil Engineering Standard 7, *Minimum Design Loads for Building and Other Structures* (ASCE-7) that is used to regulate the design and construction of structural systems. (ASCE, 2010) Chapter 13, *Seismic Design Requirements for Nonstructural Components*, presents minimum design criteria for nonstructural components permanently attached to building structures. These provisions include both force and displacement controlled design considerations and address position retention for components that pose safety hazards as well as post-earthquake operation of critical equipment. Nonstructural seismic provisions specified in this document include:

Exempt Nonstructural Components: To simplify the nonstructural design process, the code defines exempt components based on Seismic Design Category (a factor combining risks related to site response and building occupancy) and component importance. Non-essential service system components with low weight and flexible attachments to system piping or ductwork are generally exempt from seismic design provisions.

Special Certification Requirements for Designated Systems: Mechanical or electrical equipment supporting essential functions that must remain operational after an earthquake are required to be certified using approved shake table testing or experience data allowed by the authority with jurisdiction over buildings. Components with hazardous substances also require special certification. Special certifications are required to be reviewed and accepted by a registered design professional.

Component Importance Factor: An increase factor of 1.5 is applied to seismic design forces for components that are necessary for the continued function of essential facilities as well as components in any building that are required to protect life safety such as fire sprinkler systems or elements that pose risks to stairways required for egress.

Consequential Damage: Component interactions must be considered to prevent failure of an essential component caused by the failure of a nonessential component.

Component Height: The height of the component at the point of attachment to the structure is incorporated into the equivalent lateral force formula to reflect the amplification of seismic forces over the building height.

Component Amplification Modification Factors: The 2010 version of the IBC includes listed amplification(a_p) and modification factors(R_p) for 56 common types of nonstructural components. Amplification factors range from 1.0 for most rigid and rigidly attached members to 2.5 for most flexible or flexibly attached members. Component response modification factors range from 1 to 12. The table below presents representative examples showing the combined effect of these two factors (a_p/R_p) to illustrate the range of adjustment to lateral design forces based on component type.

Nonstructural Component	a_p	R_p	a_p/R_p
Connecting system fasteners for exterior nonstructural walls	1.25	1.0	1.25
Cantilever interior nonstructural walls (not braced to the structural frame)	2.5	2.5	1.0
Ceilings	1.0	2.5	0.40
Air distribution boxes constructed of sheet metal framing	2.5	6.0	0.42
Piping in accordance with ASME B31, in-line components, welded joints	2.5	12	0.21

Acceleration and Modification Factors for Nonstructural Components (ASCE-7, 2010)

Displacements within Structures or between Structures: This requires consideration of the effects of structural displacement on attached nonstructural components. Design displacements are increased by Seismic Importance Factor (SIF) associated with the IBC defined Risk Category of the building. For essential facilities and facilities containing levels of hazardous substances that pose a threat to the public, the SIF is 1.5.

Nonstructural Component Anchorage: Because the variety of anchorages used for nonstructural systems presents different types of seismic performance issues, these provisions include specific requirements for common anchorage types and reference several industry-specific standards.

Architectural Components: Provisions for architectural components identify specific requirements for several common architectural systems including: suspended ceilings, access floors and partitions, as well as glass in curtain walls, storefronts and partitions.

Mechanical and Electrical Components: Provisions for these service systems identify requirements for equipment support, piping and ductwork systems as well as elevators.

Industry Standards

In addition to defining the general requirements for force and displacement-controlled nonstructural design, the IBC and the ASCE-7 reference industry standards that regulate common nonstructural construction assemblies and materials using design requirements and testing protocols. These standards are produced by industry organizations with varying missions and scopes of influence. Examples include:

American National Standards Institute and the American Society of Heating, Refrigerating and Air-Conditioning Engineers
The ANSI/ASHRAE 171 *Method of Testing Seismic Restraint Devices for HVAC&R Equipment* provides equipment manufacturers with static-test procedures for determining the shear and tensile strength of seismic restraints for heating, ventilation, air-conditioning and refrigeration equipment. (ANSI/ASHRAE, 2008)

ASTM International (American Society for Testing and Materials)
ASTM E580/E580M *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* is a prescriptive set of installation methods for suspended ceilings that can be applied in lieu of designing separate lateral restraint systems. It provides separate standard practices for locations with light to moderate earthquake potential (Seismic Design Category C) and for locations with severe earthquake potential (Seismic Design Categories D, E & F). In order to provide a single source containing all requirements for this common type of ceiling assembly, ASTM E580 integrates requirements from the IBC, ASCE-7 as well as guidelines published by CISCA, the Ceilings and Interior Systems Construction Association. (ASTM, 2010)

American Concrete Institute
The ACI 318 *Building Code Requirements for Reinforced Concrete* specifies requirements for anchorage to concrete, and ACI 355.2 *Qualification of Post-Installed Mechanical Anchors in Concrete*, prescribes testing programs and evaluation requirements for post-installed mechanical anchors used in concrete under the design provisions of ACI 318. (ACI, 2008) (ACI, 2007)

National Fire Protection Association
The NFPA-13: *Standard for the Installation of Sprinkler Systems* includes a chapter on hanging, bracing and restraint of system piping with a section on the protection of piping against earthquake damage. The standard provides prescriptive design procedures that can be used to determine the connection, bracing and restraint requirements for typical sprinkler system configurations. (NFPA, 2010)

Qualification Testing and Alternative Methods for Code Compliance

The IBC references the International Code Council Evaluation Service's *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components* (ICC-ES AC 156), for use in the seismic certification of essential equipment that must be operational after an earthquake. (ICC-ES, 2004) Even where

qualification testing is not required, tests using procedures referenced by codes, or otherwise approved by building officials, can be presented as evidence of the seismic resistance of nonstructural components. Testing serves as an alternative to code-stipulated analysis methods. Other types of experience data or analytical methods that substitute more accurate, performance-based design approaches are also admissible in lieu of code provisions if building officials approve the substitution. Seismic design regulations for nonstructural components are intended to provide acceptable levels of performance using consistent approaches to design and construction. They are not intended to hinder the development of new products, or innovative approaches to nonstructural seismic design. Codes and Standards typically include a statement about the acceptability of alternatives. The International Building Code states:

> *The provisions of this code are not intended to prevent the installation of any materials or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.* (ICC, 2009)

Code Implementation Challenges

As requirements governing the design and construction of nonstructural elements become more stringent, there is an increasing need to resolve code implementation challenges posed by nonstructural systems. (ATC, 2008) (ATC, 2003) These challenges include:

1) **Resources needed to oversee compliance for the large quantity and variety of nonstructural components**
   The quantity and diversity of nonstructural elements that can impact the earthquake resilience of communities pose significant regulatory challenges. For most buildings, over 70% of the construction value resides in nonstructural elements. HAZUS, the national loss estimation software used by government agencies, estimates that 77% of the construction value of grade schools and 83% of the construction value of hospitals is non-structural. (Reitherman, 2009) Consistent interpretation and enforcement of codes is especially resource intensive because of the complexity of nonstructural elements which are designed, manufactured, specified and installed by separate industries, professions and trades. The effort required to ensure full compliance of all aspects of nonstructural work may not be feasible given the resources available to local building departments and building project teams.

2) **Adaptation of nonstructural elements originally developed without attention to earthquake effects**
   Most nonstructural elements commonly used in buildings were originally developed without particular attention to earthquake resistance. As expectations for nonstructural earthquake performance increase, components and systems are modified to meet code requirements. National and international markets for building products serve regions with varying levels of earthquake risk and use similar modification approaches to adapt products for use in areas of high seismic risk. Off-the-shelf and standardized nonstructural building products can also be value engineered to minimize unnecessary costs by developing products for the minimum expected load conditions and then "retrofitting" them for earthquake prone regions. The adaptation of nonstructural components typically involves adding lateral bracing, upgrading anchorage hardware, introducing flexible connections, etc. This additive design process used to increase seismic performance means that seismic resistance may not be integrated into nonstructural products in an optimal way. It introduces complexity in specifications, and field installations, with more chances for errors or complications.

3) **Dispersal of responsibility for implementation among many individuals who have different roles in the building process**
   Parties responsible for seismic protection of a building include private or public owners and their insurance or lending institutions, design professionals, general contractors who manage the construction of the whole building, subcontractors who provide particular nonstructural systems,

producers of nonstructural materials and components, plan reviewers, and construction inspectors. Without interdisciplinary coordination that involves communications with all of these parties, there can be uneven attention to nonstructural regulations or unintended conflicts that cause compliance or performance problems.

4) **Inadequate documentation of design and construction information**
Construction documents include drawings which describe the architectural and engineering elements specifically designed for the building project. Many of the nonstructural components that make up a building are designed by manufacturers and provided by contractors according to standard practice and are either not represented or only schematically represented in architectural drawings. Written specifications outline requirements for these nonstructural elements by referencing industry standards but frequently leave decisions about product selection and details of installation to the subcontractor providing the system. Building inspectors rely on construction documents to verify seismic design compliance, and are hindered in performing their inspection duties if important nonstructural components are inadequately documented. The lack of inclusion of nonstructural elements in design drawings also makes it difficult for design teams to identify potential conflicts between systems that can impact seismic performance.

5) **Inadequate knowledge of responsible parties including designers, contractors and inspectors**
Structural engineers who practice in earthquake prone regions invest significant amounts of time learning about seismic design and keeping up to date on seismic design regulations. However their primary interest and responsibility is the design of the structural system. Typically the architect is responsible for nonstructural design and code compliance. When designing important or essential buildings architects usually delegate some aspects of nonstructural compliance to structural or mechanical engineers. This transfer of responsibility to engineers is often triggered by code requirements or a building official's request for engineering approval or calculations. Most nonstructural components and contents are designed, constructed and inspected by individuals who are less familiar with seismic design requirements.

6) **Unforeseen effects of the interaction between nonstructural components during earthquakes**
When multiple nonstructural systems are designed independently and constructed by specialized contractors who negotiate clearances between components in the field, unintended interactions between systems can occur. Although the code requires consideration of consequential damage, the coordination of numerous systems is difficult to implement. Interaction effects are a common problem for suspended ceiling construction in commercial and institutional buildings throughout the United States. Sprinkler systems, lighting fixtures, ductwork and other service components are installed in the limited space between the suspended ceiling and the floor slab. The ceiling and all of the systems it conceals require structural support and lateral bracing that are positioned by the installing contractors. Differential movement between these systems and collisions between assemblies caused sprinkler rupture and subsequent loss of function in several health care facilities during the Northridge earthquake. (Reitherman, 1995)

7) **Partial nonstructural system replacement or renovation**
Nonstructural elements are often renewed as the needs of owners or tenants change. Each renewal can potentially improve seismic performance by retrofitting or replacing nonstructural systems to meet the most recent code requirements. But comprehensive nonstructural seismic upgrades can be costly and disruptive to building operations. Therefore nonstructural remodeling is often restricted to portions of an existing building or to individual components of a nonstructural system. Although building codes have provisions that trigger mandatory upgrades to seismically deficient structural systems in buildings that are substantially renovated, codes do not normally require seismic upgrades for non-structural systems, when parts of those systems are renewed. When nonstructural seismic upgrades are voluntary and paid for by tenants making short term investments, cost becomes a limiting factor.

8) **Differing lifespans of various nonstructural components**
In the United States the average lifespan of buildings is generally assumed to be about forty years; the

normal lifespan of hospitals is between forty and fifty years and school buildings have an average lifespan of about fifty years. Structural systems tend to remain unchanged until a building is demolished. Building enclosure systems are typically renovated every 20 years and building service systems (heating, cooling, electrical, communications, elevators, etc.) become obsolete in 7 to 15 years. Interior renovations alter space plans every 5 to 7 years and the contents provided by building occupants change even more frequently. (Brand, 1994) The makes the cumulative capital investment in nonstructural elements significantly higher than the initial construction investment. Although this investment in new systems is significant, compatibility problems can occur when new nonstructural systems are introduced independently. Components from obsolete systems are sometimes left in place rather than removed increasing the risk for unintended interactions.

9) **Unregulated contents or attached components provided by building occupants**.
Furnishings, equipment and other unregulated contents provided by building users make up a significant additional non-structural investment, particularly in facilities with high-value equipment, such as hospitals where contents can be valued at 80% or more of the construction value of the building. Occupants are responsible for the nonstructural performance of the elements they introduce, yet most building owners and users have limited knowledge about the risks posed from building contents or access to the expertise needed to develop and implement a nonstructural contents protection plan. State and local government agencies promulgate guidance documents that assist owners and property managers with the assessment of nonstructural seismic risk and prescriptive suggestions for securing nonstructural elements and contents. The Federal Emergency Management Agency (FEMA) recently revised the manual, *Reducing the Risks of Nonstructural Earthquake Damage: a Practical Guide,* a comprehensive reference for non-specialists. (FEMA, 2010) Of particular interest are nonstructural guidelines for schools published by several state and local governments. The *Nonstructural Protection Guide,* prepared to accompany the State of Washington Office of the Superintendent of Public Instruction (OSPI) School Facilities Manual (Noson, Perbix, 2000), is a good example that addresses implementation strategies and offers prescriptive methods for nonstructural protections, but without a mandate for compliance, voluntary or unfunded facilities guidelines are implemented unevenly without consistent attention to highest priority nonstructural hazards.

Best Implementation Practices

Clearly the implementation of nonstructural codes poses many challenges that need attention from design and construction professionals, building officials and other stakeholders concerned with seismic performance of essential facilities. Significant improvements in implementation practice have been achieved by:

i) **Development of standards of practice and guidance documents for specific construction specialties;**
The reliability of seismic code implementation increases when code requirements are integrated into industry wide standards of practice that guide the work of contractors responsible for the selection and installation of nonstructural components. The *Guidelines for Seismic Restraint for Direct-hung Suspended Ceiling Assemblies* have contributed toward furthering compliance of suspended ceilings. (CISCA, 2004). These guidelines are prepared by the Seismic Committee of the Ceilings and Interior Systems Construction Association (CISCA) to include the minimum design loads and lateral design requirements required for Seismic Design Categories D, E, and F as specified by ACSE-7. ASHRAE produces a similar industry standard to guide the design and installation of seismic restraints for HVAC equipment and NFPA 13 is a comprehensive document that addresses all aspects of code compliance for sprinkler systems, including seismic provisions.

ii) **Regulations that trigger upgrades to current code levels**
During the 1994 Northridge earthquake, California hospitals built after the passage of the Alfred E. Alquist Hospital Seismic Safety Act of 1983 sustained little structural damage but nonstructural damage to architectural components and power and water systems prevented several hospitals from being operational and required evacuation of patients from acute care facilities. In response, the California legislature passed Senate Bill 1953 which amended and furthered the Alquist Act to

mandate that all acute care hospitals become compliant with the seismic safety provisions of the California Hospital Code by the year 2030. This included all nonstructural code requirements. An interim provision required seismic bracing of all nonstructural equipment and as well as mechanical, electrical and plumbing components in critical care areas to be completed by 2008.(CHSPD, 2008) This stringent and comprehensive seismic upgrade regulation is a model for attaining nonstructural compliance in essential facilities.

iii) Enhanced enforcement of code compliance through regulatory oversight

More than 230 school buildings were destroyed or severely damaged in the 1933 Long Beach Earthquake. To address school building performance, the State of California established the Field Act, which required earthquake-resistant design and construction for all public schools. Since its inception the Field Act has regulated the construction of billions of dollars of public school building investments. Under the Field Act, the Division of the State Architect establishes and implements a separate design standard for schools that supersedes local building codes. In a recent assessment of Field Act outcomes, the California Seismic Safety Commission concluded that stringent design requirements combined with enhanced plan review, field inspection and testing substantially improved school building performance. Compliance is achieved through establishing higher level qualification standards for professions responsible for school design and inspection, more detailed review of design documents including review of all changes to plans, and requirements for ongoing construction inspection and field observation by the design team. Professional responsibility and elimination of conflicts of interest are carefully monitored. Architects, engineers, inspectors, and contractors must file reports, under penalty of perjury, that verify that actual construction complies with approved plans. Over time, nonstructural standards applied by the Field Act have been adopted into general practice. Another benefit of Field Act-constructed buildings is that public school facilities can also serve as temporary emergency shelters and as places to assist communities in recovery. Although the Field Act has been highly successful in achieving compliance with nonstructural seismic design regulations, time delays and inconsistencies in implementation due to administrative complexity is an ongoing concern. (CSSC, 2007)

iv) National investments in research related to seismic performance of nonstructural systems and the development of performance-based design methods.

Until recently, industry sponsored most of the U.S. research related to nonstructural seismic performance for the purpose of developing new or improved products and addressing industry interests related to the performance of specific types of nonstructural components and systems. As the performance of structural systems advances, there is increased interest in mitigating the hazards and losses posed by nonstructural components and systems. In 2001, The Federal Emergency Management Agency (FEMA) engaged the Applied Technology Council (ATC) to undertake a multi-year project to develop seismic design procedures and guidelines that will inform the future regulation of structural and nonstructural design. The project, known as ATC- 58, *Development of Next-Generation Performance-Based Seismic Design Guidelines for New and Existing Building* (FEMA, 2006b), draws from state-of-the-art nonstructural practice and research to create nonstructural performance products which define procedures that can be used to reliably and economically design new buildings or upgrade existing buildings to attain specified performance goals that extend beyond the life safety focus of current codes to include control of property losses or continued functionality for essential and important facilities. The ATC defines performance-based design as, *"a systematic methodology for assessing the performance capability of a building, system or component. It can be used to verify the equivalent performance of alternatives, deliver standard performance at a reduced cost, or confirm higher performance needed for critical facilities."* (ATC, 2009) To date several reports and technical papers produced by the ATC 58 project address nonstructural design methods.

The scope of research needed to inform the ATC 58 project is extensive and engages numerous constituencies. Currently, there is a multi-university effort underway to investigate the seismic performance of ceiling-piping-partition nonstructural systems. This research involves full scale testing to understand the interacting performance of multiple systems. Test results are being used to develop analytical models; establish system and subsystem fragility functions; and develop visualization tools that will assist designers and educators. The project is sponsored by the Network for Earthquake

Engineering Simulation (NEES) research program of the National Science Foundation. (NEES, 2010) As architects and engineers seek to produce a new generation of buildings that are energy efficient and ecologically responsible, extensive changes are being made to nonstructural systems that are likely to impact future seismic performance. Current research and design innovation related to green building introduces new nonstructural systems and components and challenges conventional building practices. For example, the nonstructural components of high performing building enclosures are characterized by double envelopes, externally mounted shading or reflecting devices and sentient facades that automatically respond to environmental change. Technology for sentient and responsive nonstructural systems is a developing research area, with interesting implications for seismic design. Another increasingly common practice is the night ventilation of the thermal mass in concrete floor slabs to maintain comfortable indoor temperature. This is a design strategy that renders air conditioning systems unnecessary, uses plenum spaces in lieu of ductwork, and eliminates the suspended ceilings which obstruct the contact between the concrete slab and the space it cools. The introduction of other passive ventilation strategies further reduces the quantity of nonstructural components associated with air handling. In the future, it is conceivable that these innovations in environmental controls systems will replace conventional ceiling assemblies with less seismically fragile designs.

Conclusion

As architects and engineers pursue integrated design approaches that promote increased collaboration among owners, design teams, construction materials and component producers, builders and regulators, there is greater attention to nonstructural performance through the implementation of nonstructural standards and guidelines promulgated by government entities as well as industry and professional associations. Although best practices in nonstructural regulation have resulted in significant improvements in nonstructural performance in the United States, the seismic design community is actively pursuing ways to further reduce the many challenges associated with the implementation of nonstructural regulations. This work is particularly important to improve consistency in meeting performance requirements for essential and important buildings.

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Executive Summary: Pre-Disaster Planning, Mitigation and Emergency Response

L. Thomas Tobin

Five papers are presented on Pre-Disaster Planning, Mitigation and Emergency Response regarding aspects of earthquake risk reduction activities carried out in the United States.

Risk Reduction and Management Responsibilities in the United States (Tobin, L.T.)

This paper describes the division of responsibilities between federal, state and local governments in the United States. Sharing risk reduction experience and knowledge between Chinese and American professionals requires communications involving language and culture, and a mutual understanding of the governmental context regarding who does what, who is responsible (or shares responsibility), and how measures are implemented. The states have responsibility for public health, safety and welfare, not the federal government. The federal programs emphasize funding research, providing intellectual and political leadership, advocating mitigation measures, and providing incentives to state and local governments for dealing with the earthquake hazard.

Emergency Preparedness and Planning in the USA National Incident Management System and the Primary Role of Local and State Governments (Eisner, R.)

This paper describes the organization and structure of the Emergency Management System in the United States is result of tradition, culture and the functional and constitutional relationship between the federal (national) government and the states. The reservation of emergency management responsibilities to local and state governments has historically resulted in fifty differing organization structures and procedures at the state level, and thousands of structures at the local (municipal and county) levels in the United States. The emergency management system in the United States has changed significantly in the past three decades with the introduction and evolution of the Incident Command System, the Standardized Emergency Management System and the National Incident Management System. These structures will evolve in response to lessons learned from disasters, the influence of the American culture, traditions, growth of professionalism and standard in the field and adaptation to new technology.

Earthquake Risk Management Approaches for Civic and Critical Lifeline Infrastructure: Applications in Oregon (Wang, Y.)

This paper recommends a risk management approach to effectively prepare for earthquake disasters by improving resiliency of civic and critical lifeline infrastructure. Lessons learned from past earthquakes, applications of earthquake risk management for civic infrastructure (e.g., schools, fire stations, police stations, and hospitals), and critical lifeline infrastructure are discussed. Recommended steps to improve community resiliency and the reliability of critical lifeline infrastructure services after major disasters are: 1) characterize the potential disaster, 2) conduct risk assessment, including the probability of the hazard, the vulnerability of the exposed elements, and the consequence of the damage, 3) determine potential interdependencies and cascading impacts, 4) establish mitigation plan with stakeholders that includes timelines and prioritized actions, and 5) initiate mitigation program with stable funding mechanisms to ensure timely progress.

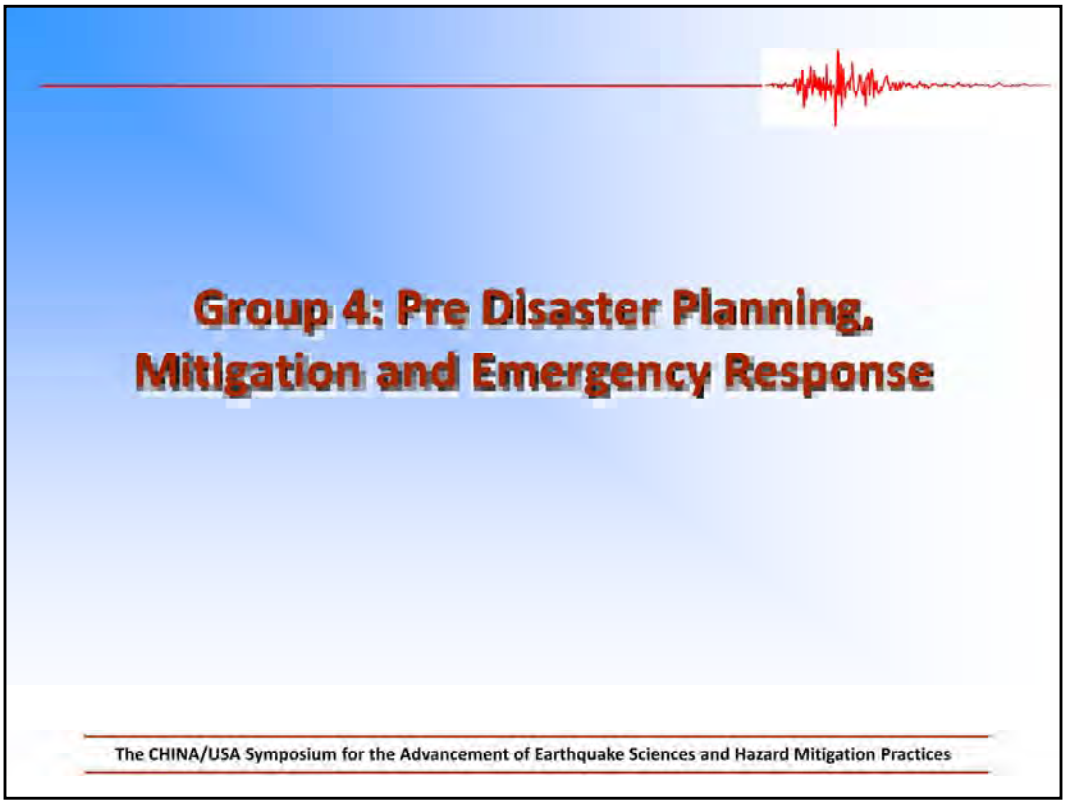
The Role and Importance of an Independent Multi-Disciplinary Technical Society, with Examples of the Benefits to the Earthquake Professions (Greene, M.)

This paper describes the Earthquake Engineering Research Institute (EERI), which was founded in 1948 as an independent multidisciplinary national society of engineers, geoscientists, building officials and architects with the intention to establish a research institution. Over the years EERI evolved into an active professional association that addresses the objective of reducing earthquake risk by (1) advancing the science and practice of earthquake engineering, (2) improving understanding of the impact of earthquakes on the physical, social, economic, political, and cultural environment, and (3) advocating comprehensive and realistic measures for

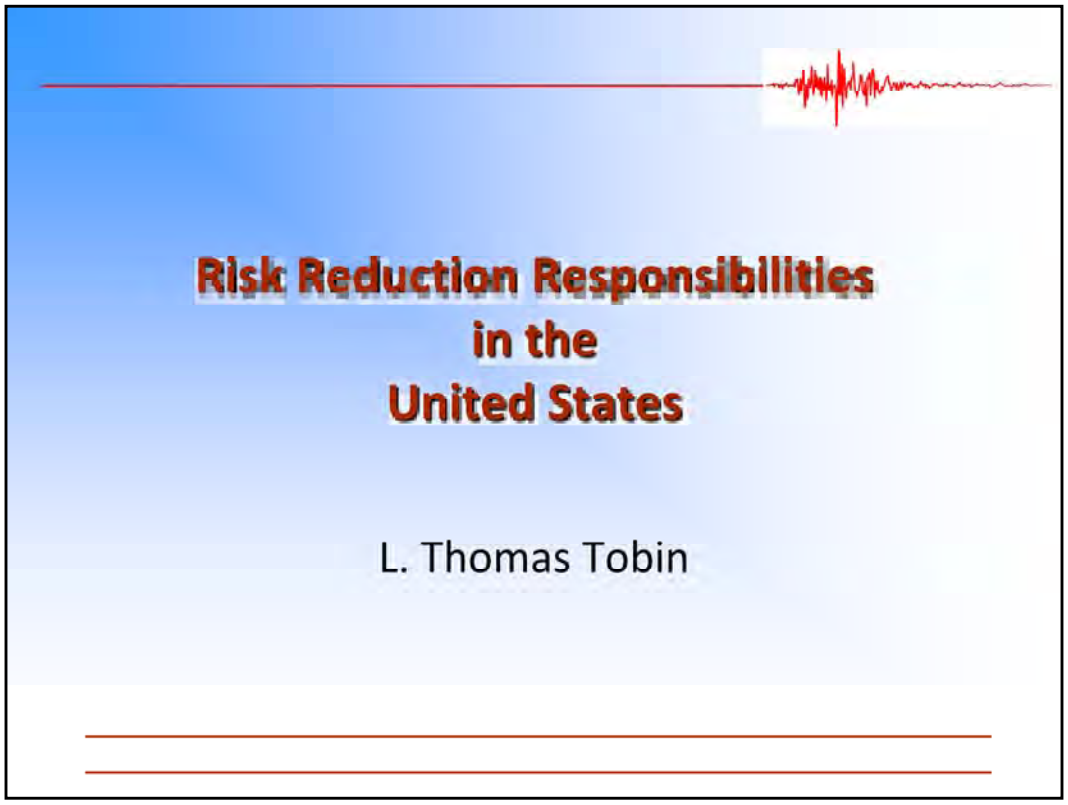
reducing the harmful effects of earthquakes. Today, with approximately 2,300 members, EERI takes on tasks that reflect its unique multidisciplinary membership, fostering communication among different disciplines and bridging the gap between new knowledge, design, practice, and risk reduction policies. This paper highlights many of the unique and effective ways EERI engages in education, research and public policy to further its mission and support its membership.

Community Action Plan for Seismic Safety (CAPSS) Project (Tobin, L.T.)

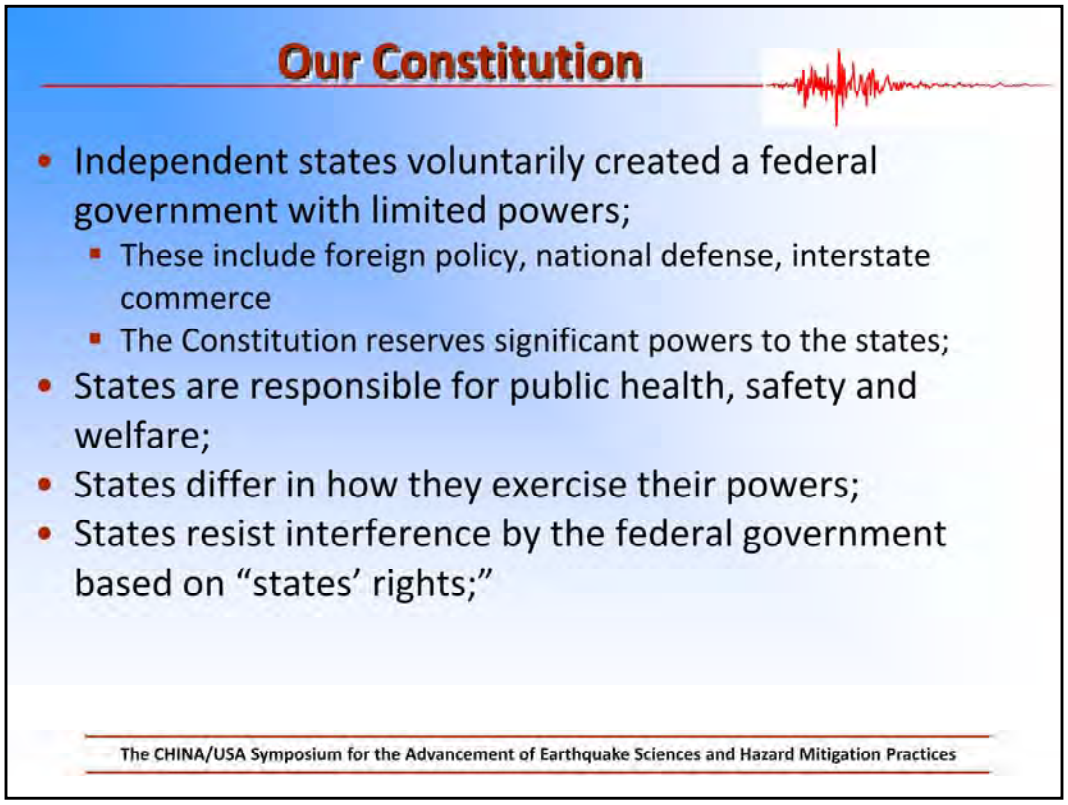
This paper describes the Community Action Plan for Seismic Safety (CAPSS) is a project for the City and County of San Francisco, Department of Building Inspection. CAPSS will recommend an action plan to reduce earthquake risks in existing private buildings and develop repair and rebuilding guidelines that would expedite recovery after an earthquake. An action plan will be drafted, discussed and adopted during the fall of 2010. This plan might consist of implementing actions, and setting priorities and an implementation schedule for categories of buildings. A possible program could take 40 years and emphasize the use of market forces. It would give priority to multi unit residential uses, neighborhood serving retail businesses and private schools. The strategy would encourage retrofitting through information and incentives, triggered evaluations and disclosure of earthquake vulnerable buildings, but ultimately might require retrofitting.



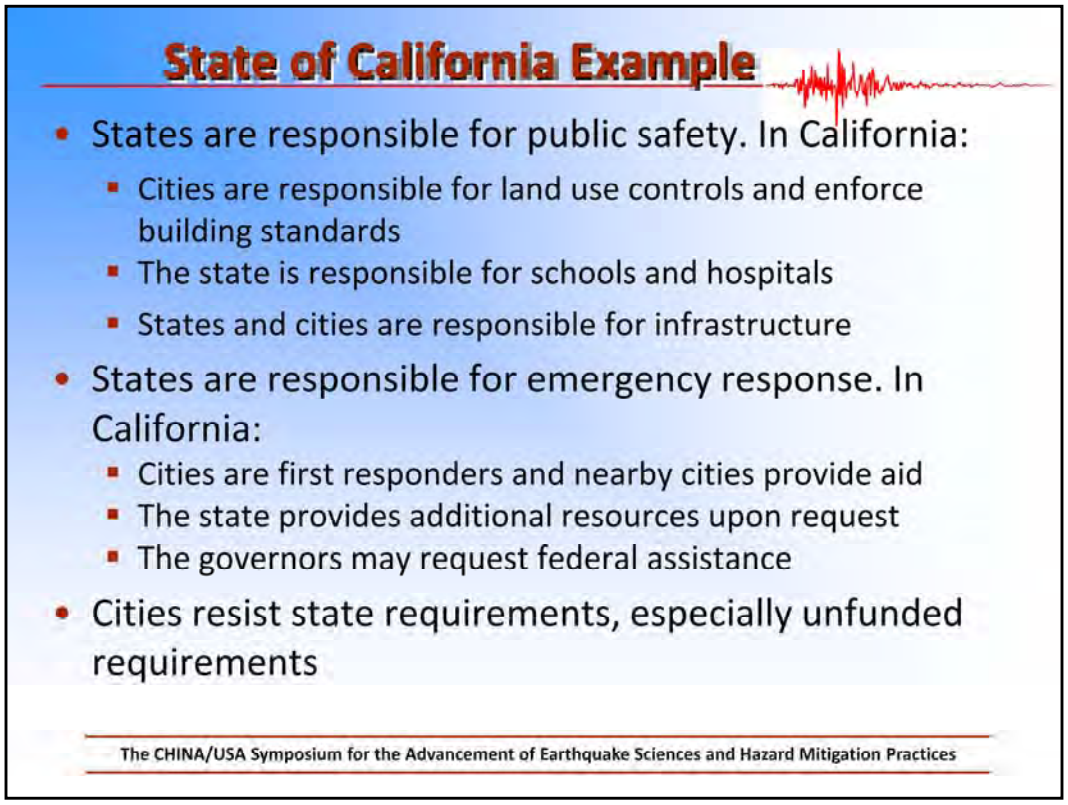
I will introduce the Group 4 participants and our topics. We will discuss pre disaster planning, mitigation and emergency response in the United States.



To begin, I want to spend a few minutes to describe the government structure in the United States to give you some context as to why our earthquake programs differ from state to state. Without this context our presentations could be confusing.



Our arrangements for sharing government authority are rooted in our history. The US Constitution assigned limited powers to the federal government and reserved certain powers for the states. These laws laws that assign responsibility for building safety and emergency response to the states. The states, however, exercise these powers differently, but guard them carefully. The argument between the federal government and states is often referred to as states rights.

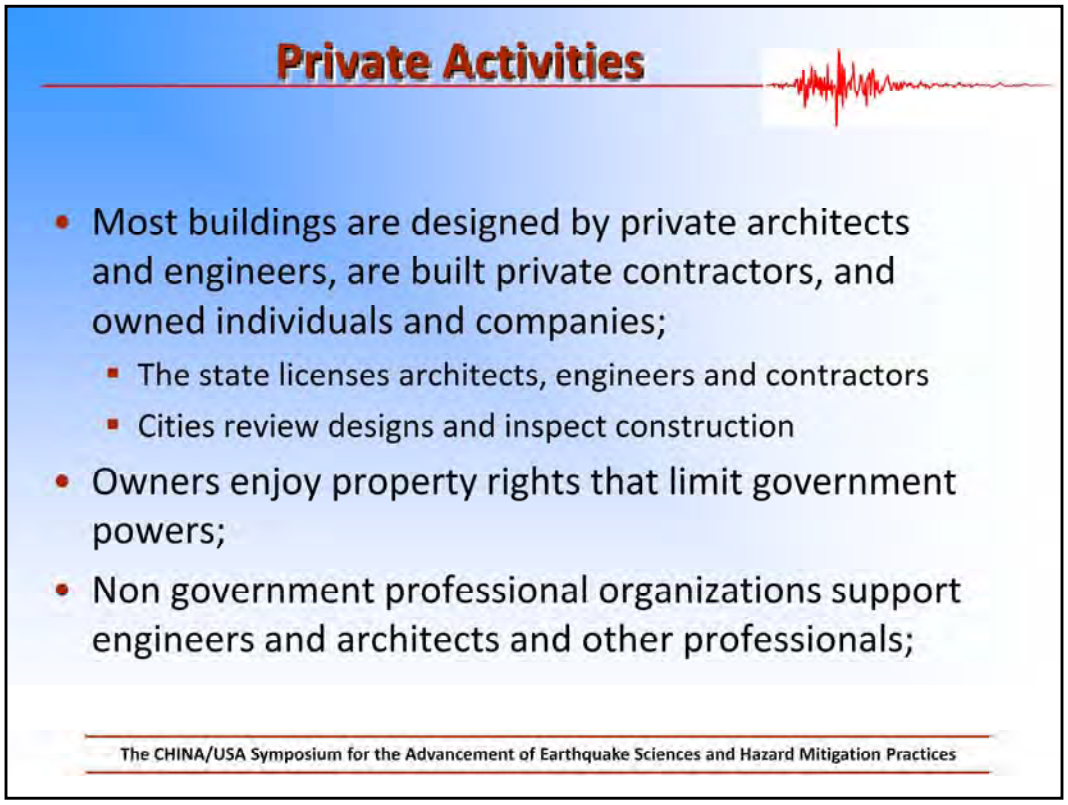


States are responsible for public safety, health and welfare. They share this power with lower level state governments such as cities, counties and special districts.

In California the state requires adoption and enforcement of the state-adopted building code. However, the state retains building official responsibilities for hospitals and public schools.

Cities are the first responders during emergencies, but the state and nearby cities may provide assistance. The federal government gets involved only if the emergency is large enough and the governor makes a request.

Cities resist state-imposed requirements, especially those that are unfunded. We call this "home rule."

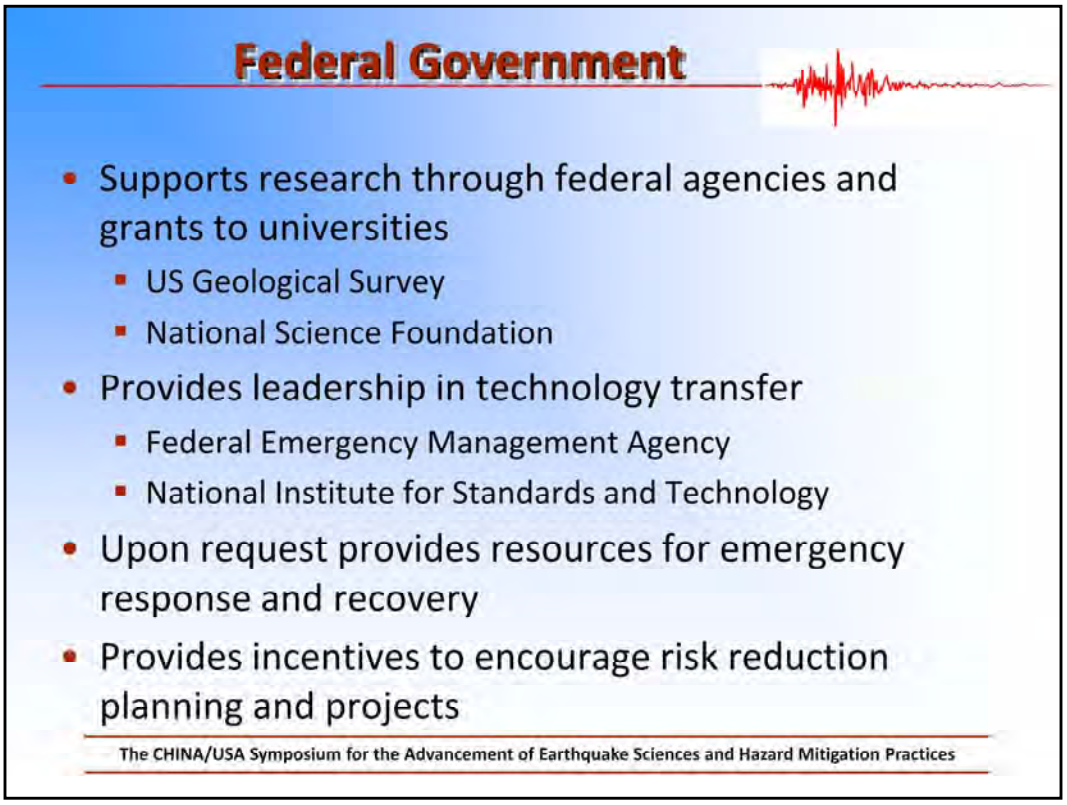


Most buildings in the United states are privately owned. They are built on private property by owners who hire private engineers, architects and building contractors. It seems almost every building is unique.

Owners also have rights guaranteed by our federal and state constitutions. There are limits on the controls the government can exercise over private property, but building codes are clearly enforced.

In California owners must get permission from the city regarding the use and size of the proposed building, and to have the engineer's plans reviewed and approved for conformity with the code. Good design by qualified professionals, independent plan review and construction inspection by the cities is our basic strategy to build earthquake-resistant buildings.

Professional engineers, architects, geologists and other professionals are personally responsible for maintaining their competence and learning new concepts. Non governmental professional organizations are essential to developing new information and transferring technology.



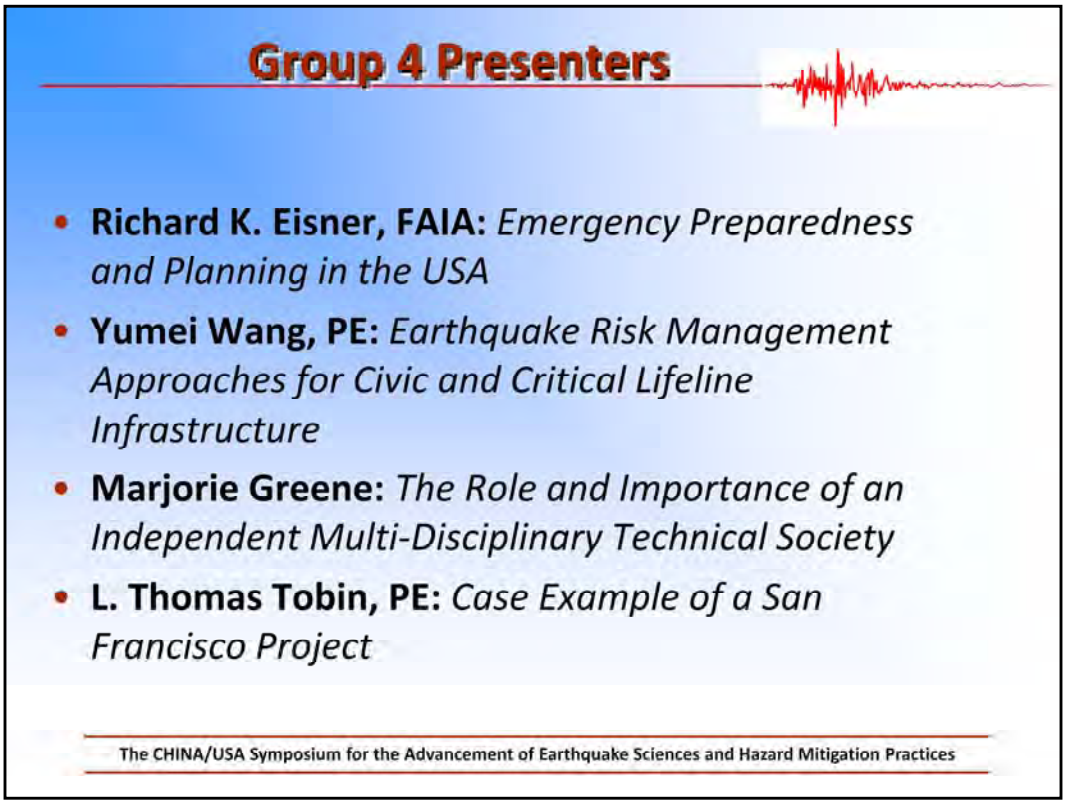
The federal government still has important powers and contributes significantly to earthquake safety.

Federal support for research for the sciences and engineering, especially university-based research, has advanced our idea and empowered professionals who practice privately, and states that develop and enforce relevant public policies.

The government also uses incentives to encourage states to develop emergency response and hazard mitigation plans that are similar in their content. Coordination and working together are important concepts between states and with the federal government.

The federal government also encourages hazard mitigation through matching grant programs.

The federal government also helps fund disaster recovery through grants to help states and cities repair infrastructure and government-owned buildings and though housing assistance to those displaced. Disaster recover can be a long and difficult process involving the federal, state and city governments and the private sector.

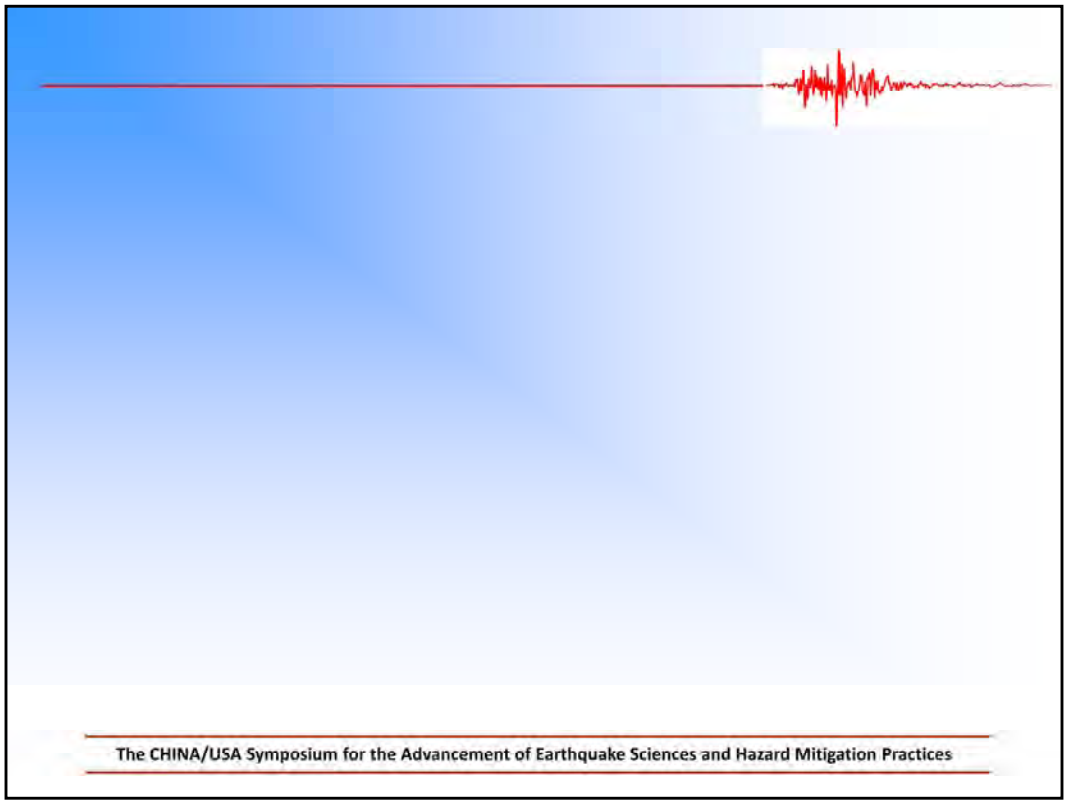


In group 4 we have four speakers and four related topics. Our speakers are Mr. Richard Eisner, an architect and former California state emergency response professional. Currently he is a visiting professor at Kyoto University in Kyoto, Japan.

The second speaker is Ms. Yumei Wang, a geotechnical engineer with the Division of Geology and Mineral Industries who also has experience working for a US senator in our Congress.

The third speaker is Ms. Marjorie Greene, a urban planner and manager of special projects for the Earthquake Engineering Research Institute, a non government professional organization.

I will be the fourth speaker. I am a civil engineer and a consultant to government agencies on earthquake public policy.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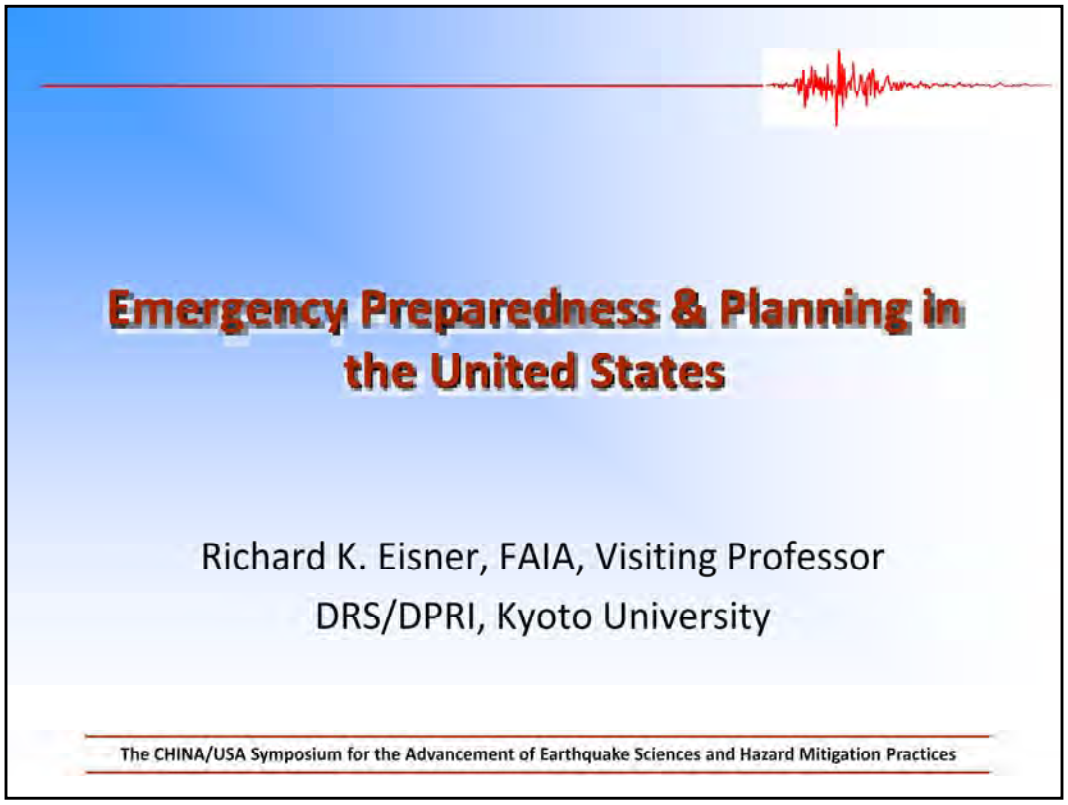
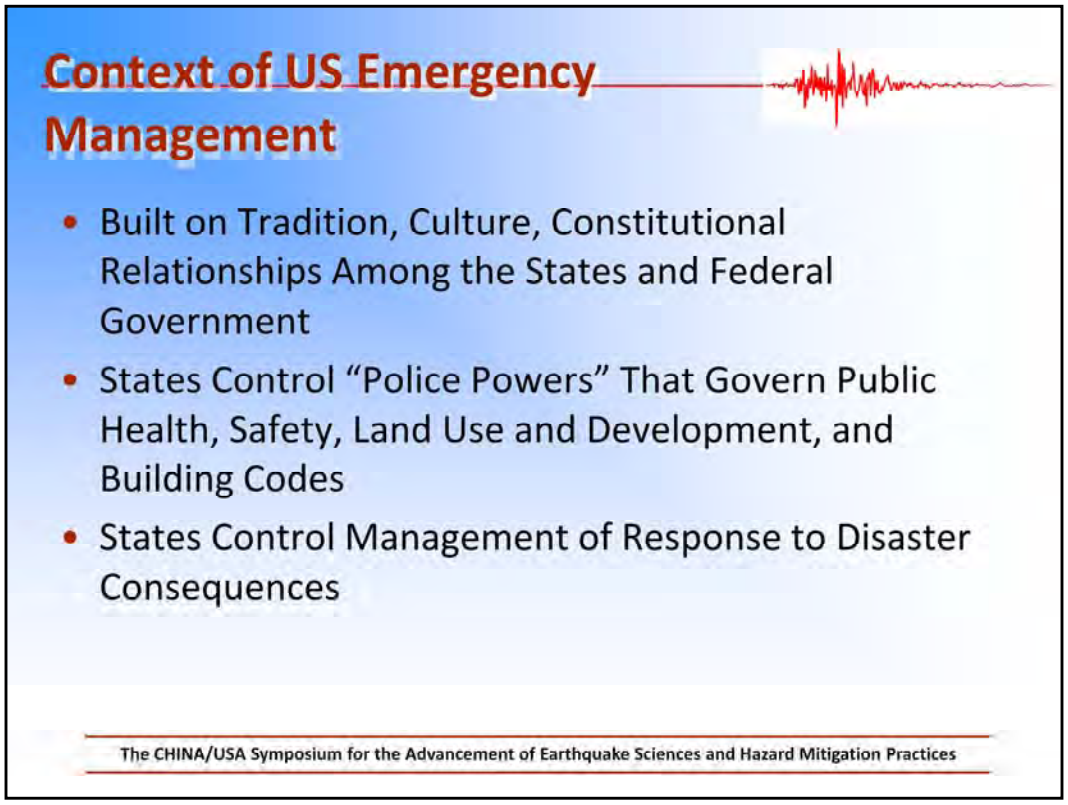

Emergency Preparedness & Planning in the United States
Richard K. Eisner, FAIA, Visiting Professor
DRS/DPRI, Kyoto University
The CHINA/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices



Emergency management in the United States is a product of tradition, American culture and values, Constitutional prescribed responsibilities of the national government and those responsibilities delegated to states and local governments.

The responsibility for the "Police Powers" that include public health, safety and welfare, including land use and development, and enforcement of building standards and codes is left to the states and local governments. This has resulted in a great variation in building practices and development across the 50 states.

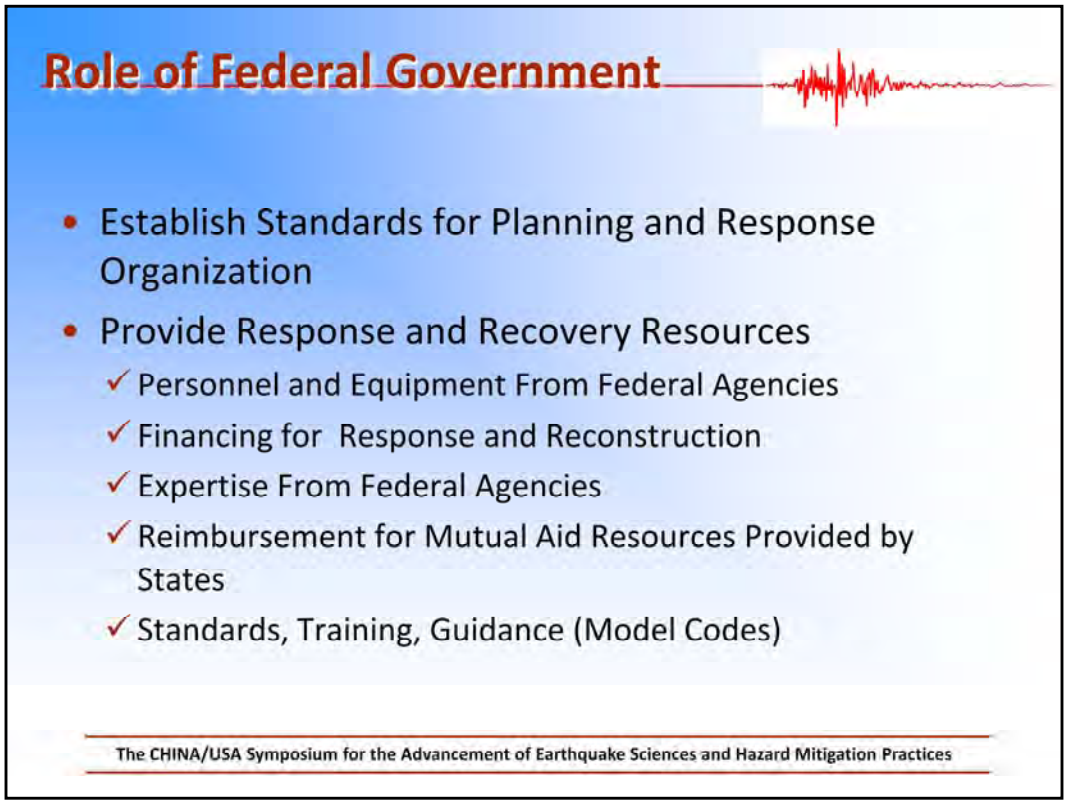
In addition, states and local governments are responsible for managing emergency response to disasters.

Police, fire and health services are the responsbility of local governments. Local governments are the first responders to disasters and are responsible for managing resources brought in from other jurisdictions. Local governments are always in-charge. They are responsible for mitigating hazards as well as for determining policy for response and recovery from disasters that is consistent with local community values, tradition and culture.

Adjacent jurisdictions, States and the Federal Government are expected to provide “mutual aid” to the impacted community, but the responsibility for management of contributed resources remains with the impacted community.

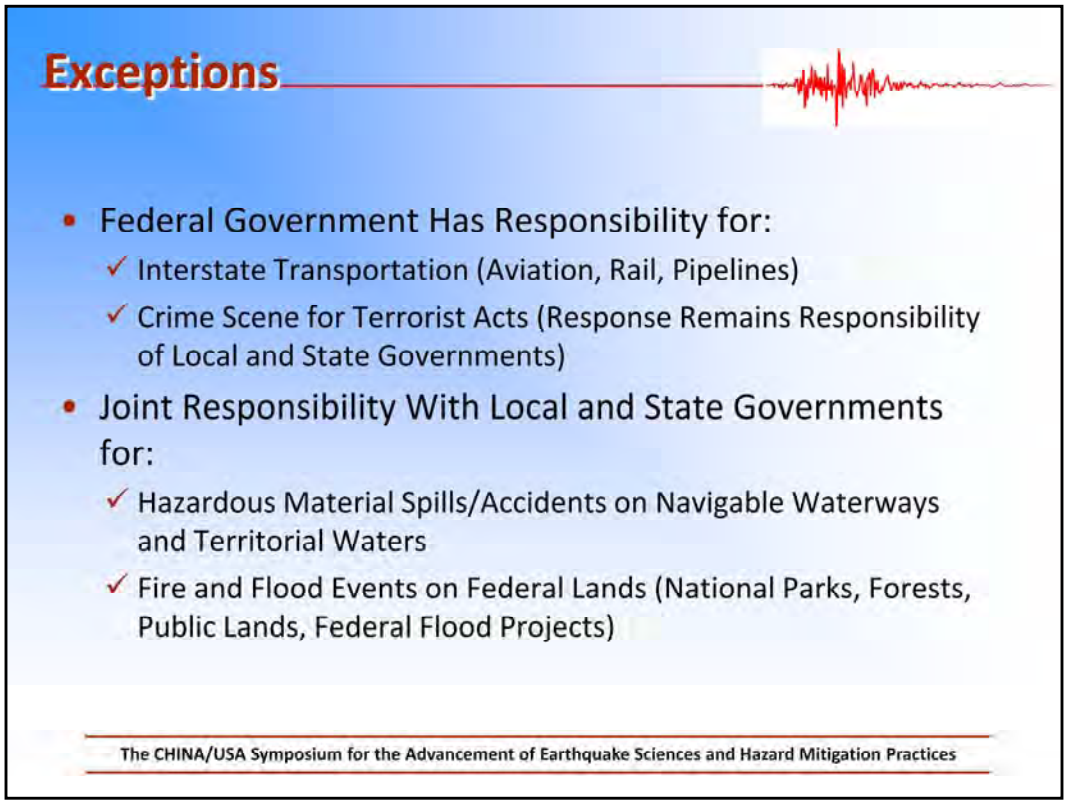
Local governments remaini-charge throughout the response and recovery period of a disaster, and are responsible for determining priorities for action and post disaster development policy.

Local governments are also responsible for integrating diverse non-government and community- and faith-based organizations into response and recovery operations.



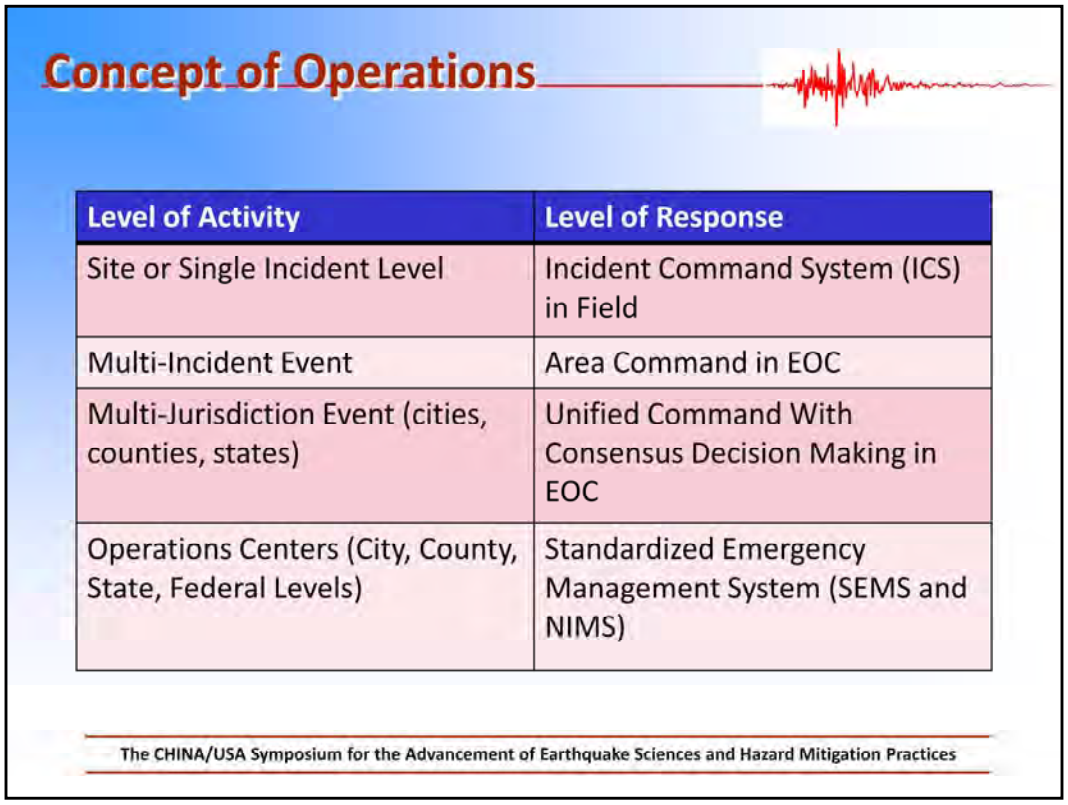
The Federal governments role is to establish Standardized Framework for response that enables coordination and collaboration among local, state and federal agencies.

The Federal Government also provides a range of resources to states and local governments before, during and after disasters that include: coordinating the delivery of personnel and equipment from Federal agencies to local jurisdictions; providing financial assistance to cover the costs of response and reconstruction; provide technical expertise from science and research agencies to assist local decision making; reimburse local governments for the "mutual aid" provided to the impacted jurisdiction; and to develop and provide Standards, Training and Guidance to local governments This includes the development of hazard and risk assessments, emergency management training, and model building codes.



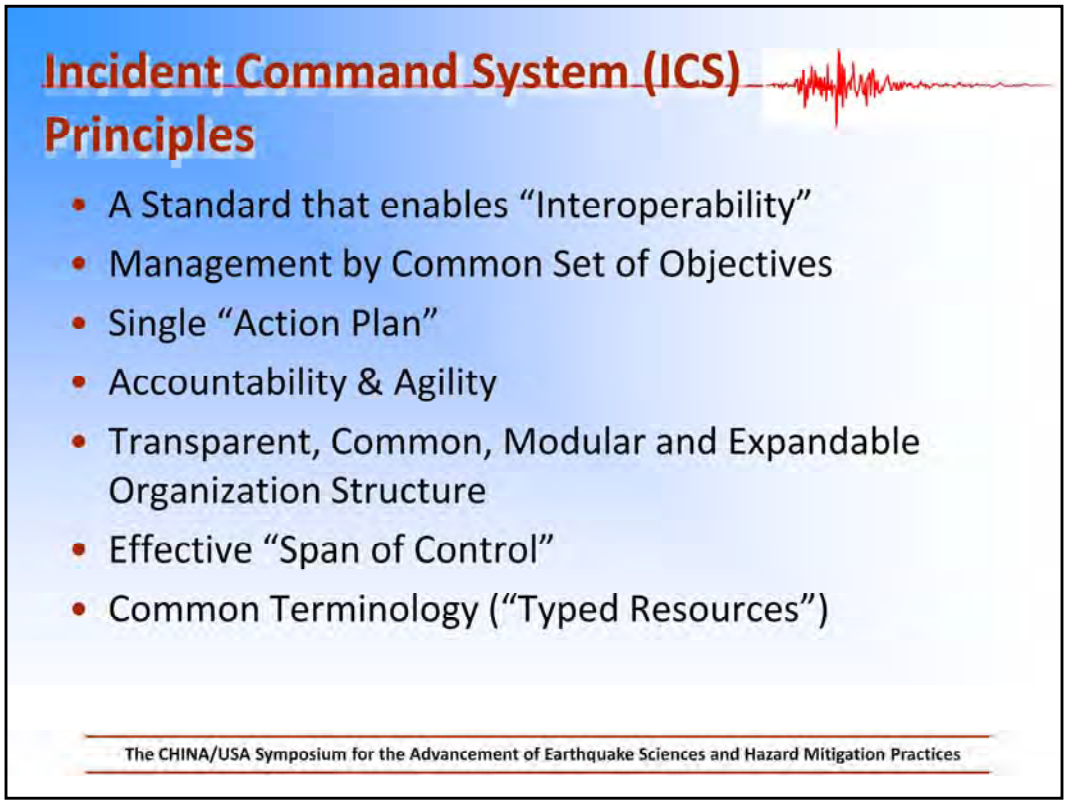
There are some areas where the Federal Government retains responsibilities in disaster management. These areas include disasters that result from interstate transportation, aviation, rail or pipeline accidents where the Federal government has regulatory jurisdiction; and for the "crime scene" of acts of terrorism. In these cases, the local governments remain responsible for response, care and shelter of victims and recovery, but the Federal government is responsible for prevention and criminal investigation.

Federal government and states share responsibility for disasters that occur on navigable inland waterways or coastal territorial waters; or where disaster events occur across federal, state, local and private land boundaries.



The basic organizational structure of response organizations in the United States is based on the Incident Command System (ICS) and systems that evolved from ICS. For small single incidents (both scale and complexity), local governments will use the Incident Command System with management occurring at the scene. When a number of incidents result from an disaster event, such as an earthquake or fire, local, state and federal responders will establish a "Area Command" which will serve as an intermediate level of command for a geographic area. The primary role of the Area Command is to allocate resources among Incident level managers. When an event, such as a flood, oil spill or hazardous materials event encompasses multiple local governments or includes local, state and federal jurisdictions, responders will establish a "Unified Command" to establish, by consensus, overall strategies and priorities for resources.

There is a slight variation in structure for disaster response event management that occurs within an Emergency Operations Center. In EOCs, the structure is primarily responsible for acquisition and allocation of resources. This system is referred to as the Standardized Emergency Management System (SEMS) or by the Federal standard description, the National Incident Management System (NIMS)



ICS is a common system that enables interoperability. Personnel from one city will recognize the organizational structure of another city.

ICS requires establishing a single set of common objectives for all agencies participating in disaster response

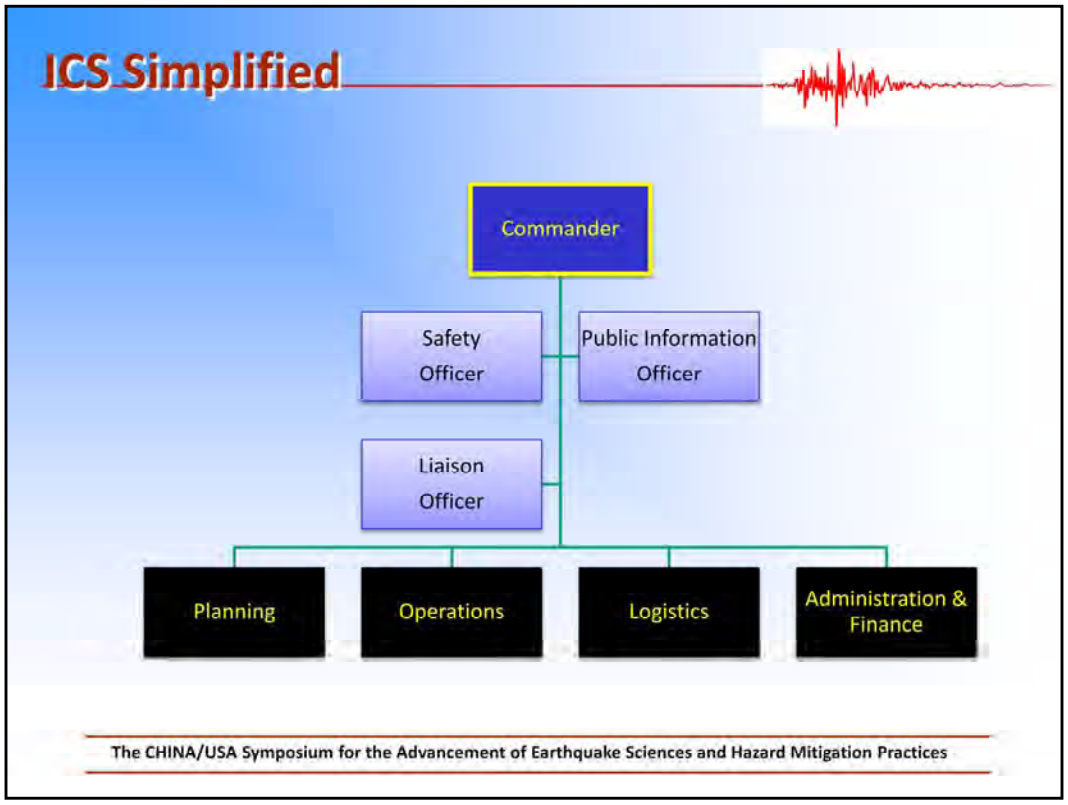
ICS requires the formulation of an "Action Plan" that identifies the common objectives, assigns responsibility to achieve those objectives and sets priorities for allocation of available resources

ICS is a flexible system that provides for accountability of participants

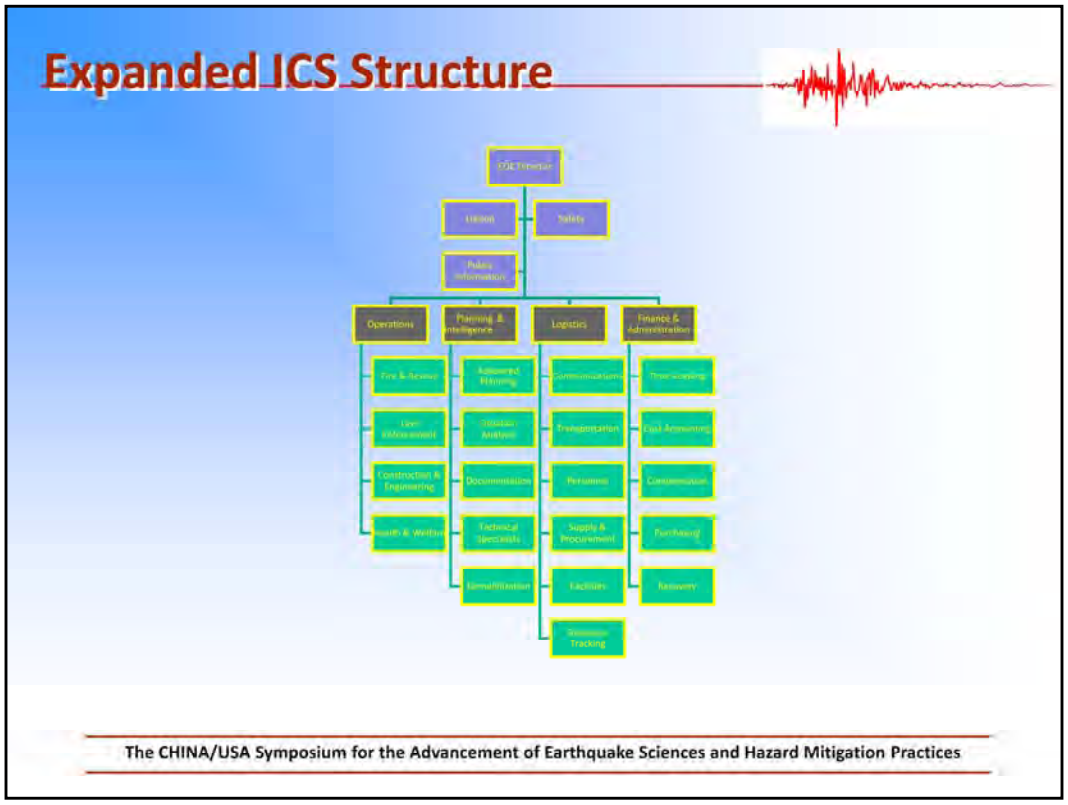
The structure of ICS is modular, allowing it expand or contract as needed to respond to a disaster event. It is a transparent organizational structure and management system. For small events, all the responsibilities of ICS can be fulfilled by one person, or, if needed, expanded as necessary to fit the needs of the disaster response

ICS is governed by a concept of limiting management span of control to between 5 and 7 subordinates or divisions

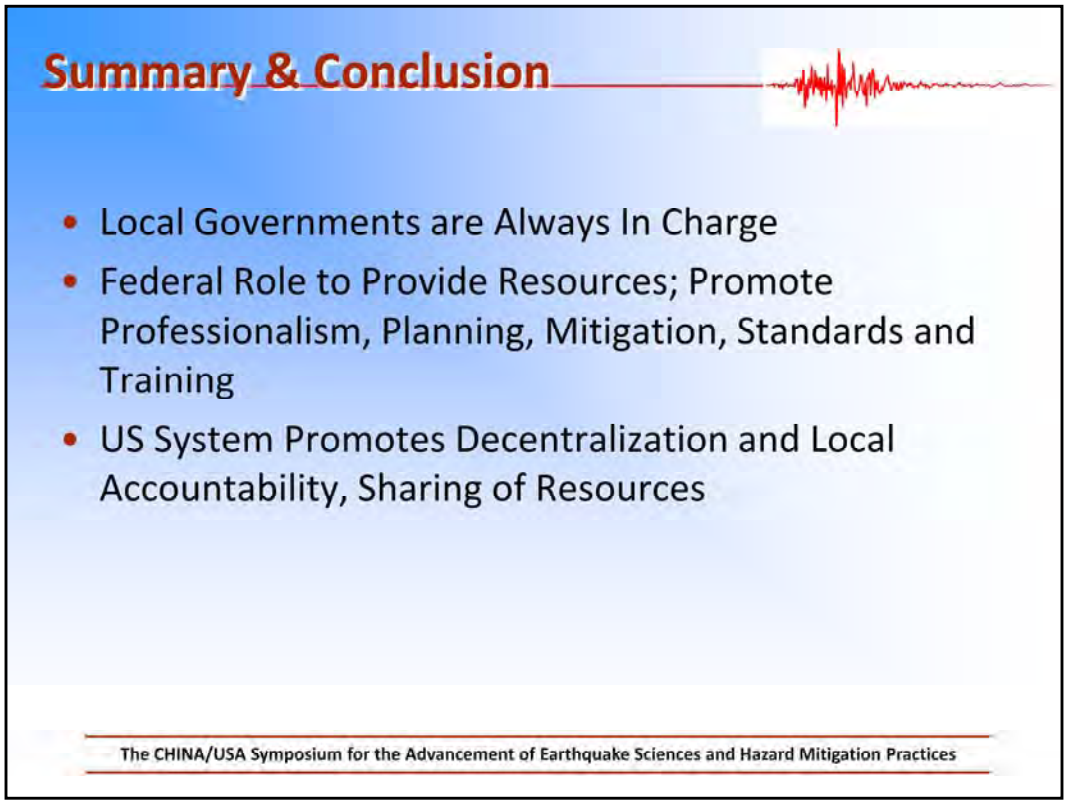
ICS provides for use of common terminology to define positions, functions and resources.



This graphic describes the ICS organizational structure. There is a Management function, Command staff function, and 4 General Staff functions. For simple events all the functions can be performed by one person. For complex, large or sustained response, the structure can expand to meet the need. The Safety Officer plays a unique role -- to determine when an operation would endanger personnel and should not be performed

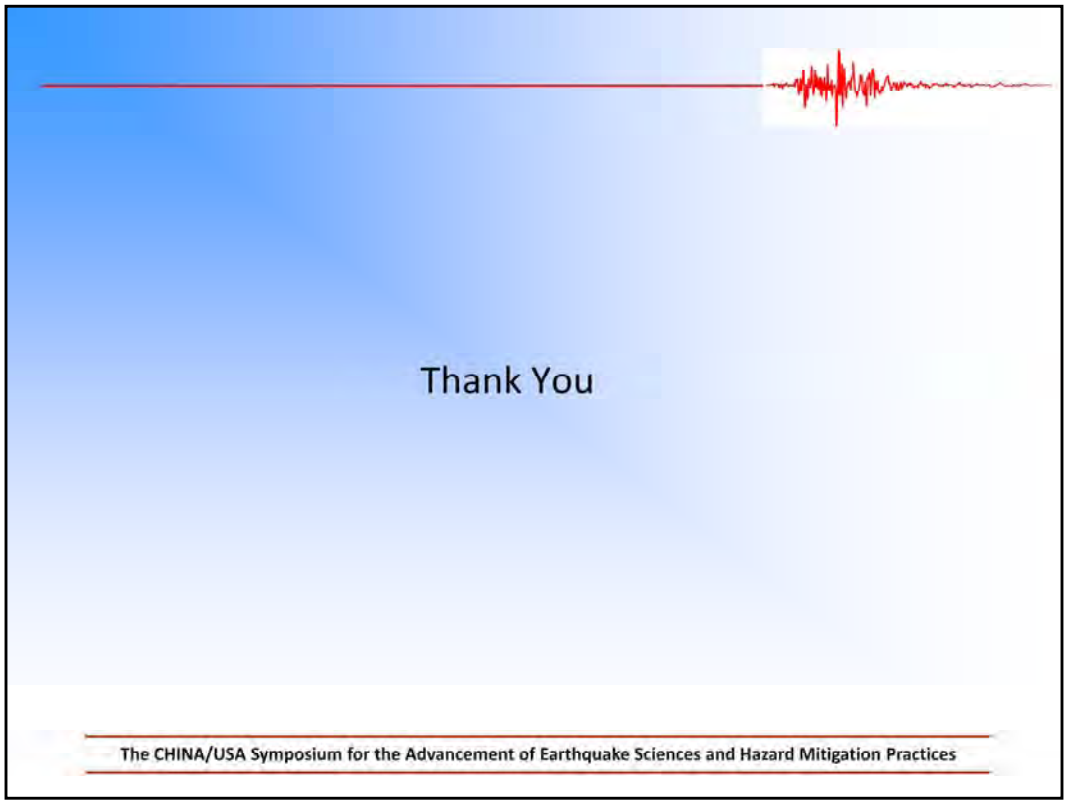


Each of the four Sections can be expanded with additional Branches, each Branch can expand with additional Units to Adapt the structure to the complexity and needs of the disaster event



In the US Emergency Management System, the following attributes of define the system:

- Local Governments are always in-charge
- The Federal (National) role is to provide resources, promote professionalism, planning, mitigation, standards and provide training
- The US System is structured on decentralized decision making, local government accountability and sharing of resources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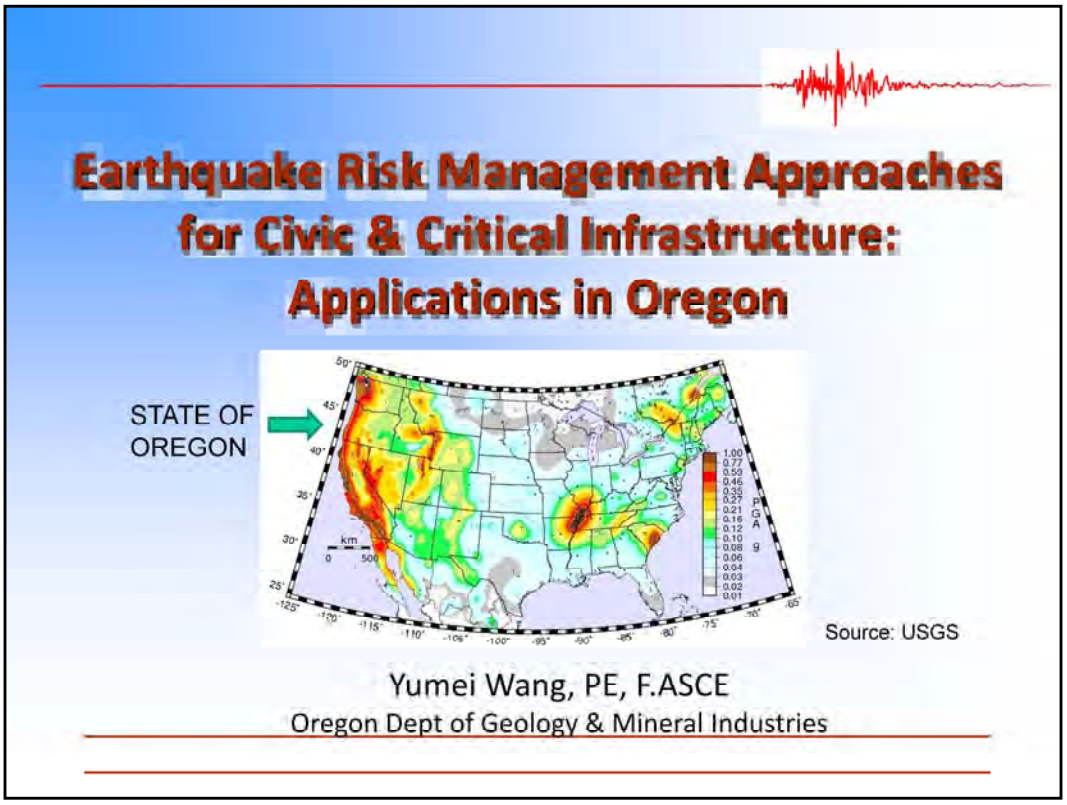


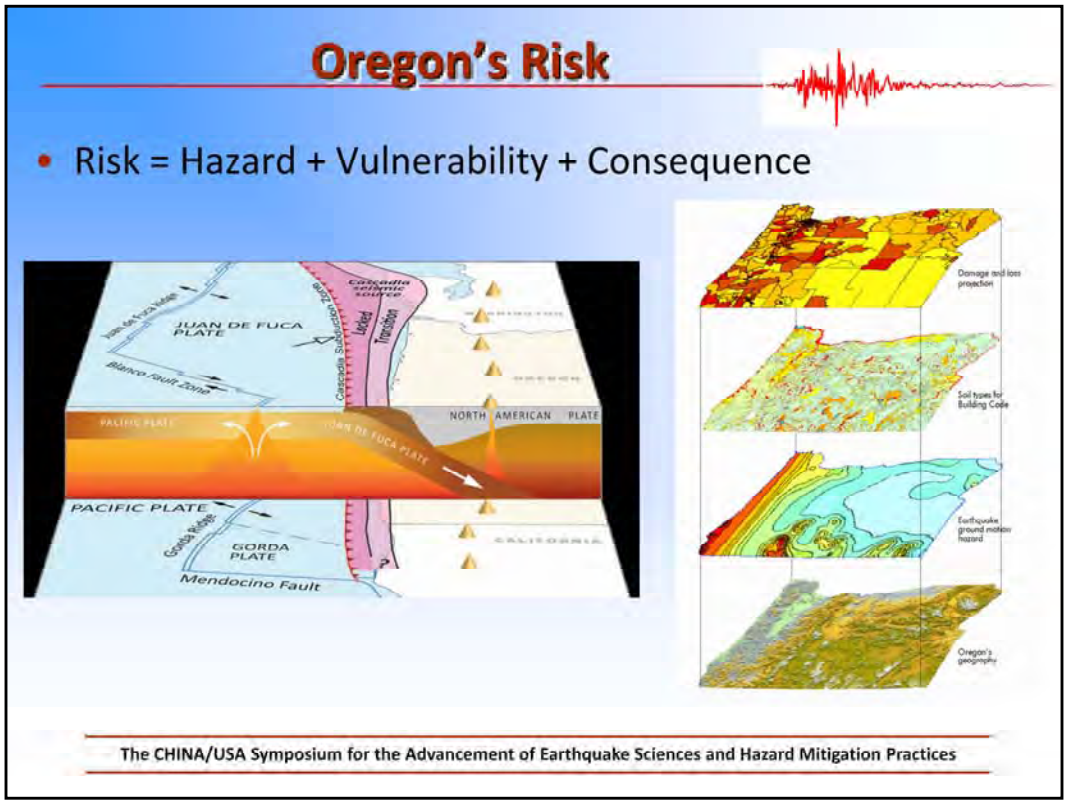
Geotechnical Engineer with State of Oregon, Dept of Geology

Oregon is situated between the states of California and Washington

My area of expertise is geologic hazards, specifically on risk identification and risk management, and public policy

My responsibility is public safety and welfare with an emphasis on Cascadia earthquakes and tsunamis

This presentation will introduce you to Oregon's top priorities, which are improving civic infrastructure and critical infrastructure



Oregon is subject to a large magnitude earthquake on the Cascadia subduction zone fault. The fault is 1000 km long, can produce a magnitude 9 earthquake and near-field tsunami. The fault is shown in pink on the left.

Oregon's is preparing for the next Cascadia earthquake and tsunami using a risk-based approach. Risk is a combination of the probability of the hazard, the vulnerability of the exposed infrastructure and environment, and the consequence of the incurred damage.

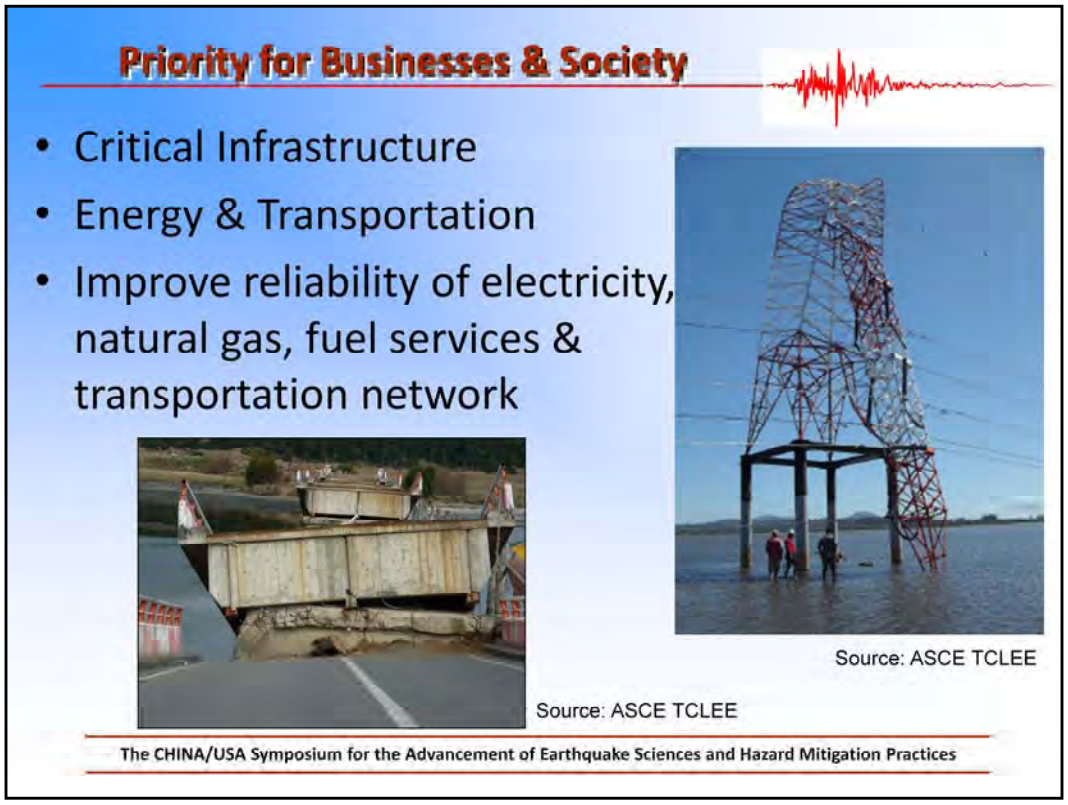
In 1998, Oregon conducted a damage and loss assessment using HAZUS, a GIS-based modeling program developed by the Federal Emergency Management Agency (FEMA) . A summary diagram is shown on the right with the landform (as the bottom layer), probabilistic earthquake ground motions developed by the U.S. Geological Survey, soils that reduce or amplify shaking levels, and the damage and loss results by census tracts.

These results have been used as a basis to prepare for future Cascadia earthquakes and tsunamis.

The earthquake safety commission of Oregon is an 18 member policy group that advises the Oregon Governor and Legislature, and I am a member. We accept that everything that is vulnerable cannot be fixed because of the high costs.

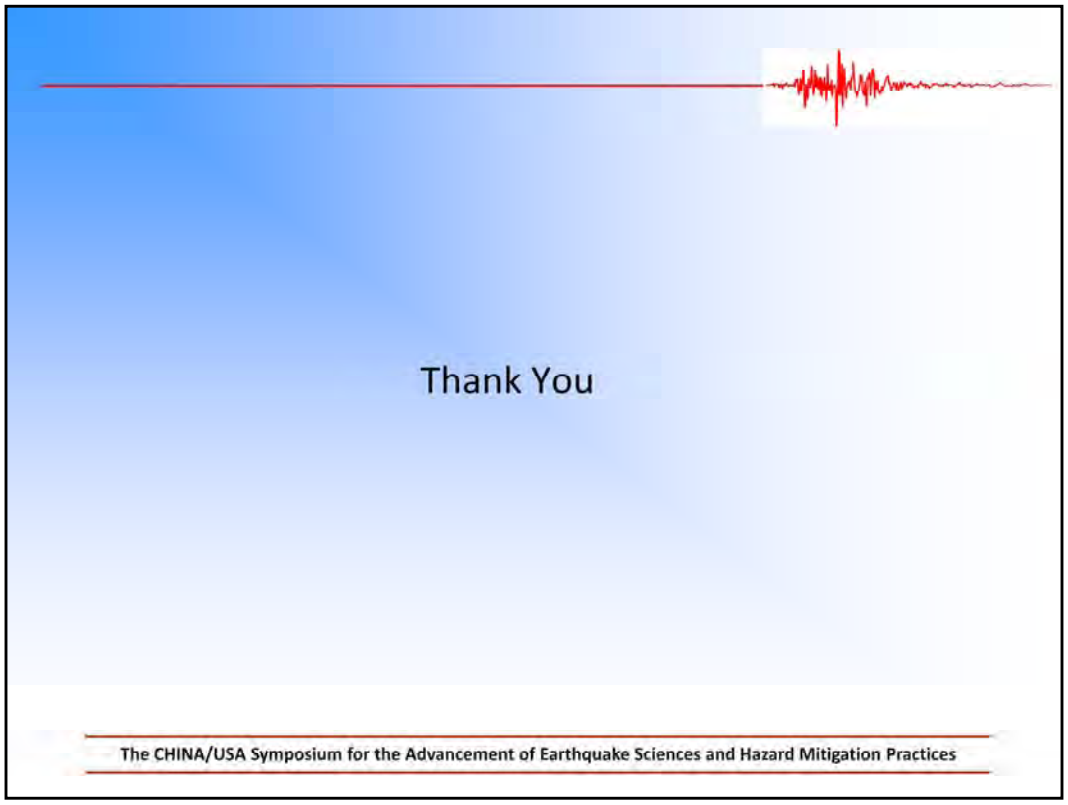
This commission determined it's top priority to be protecting people in communities. Public schools were determined to a top priority because school children should be safe while attending school. Emergency facilities were determined to be a top priority because everyone relies on them during a disaster. Emergency facilities include fire stations, police stations, and hospitals.

After a 10 year effort, in 2009, Oregon established a grant program to provide up to $1.5 million per facility to conduct seismic strengthening.. Oregon laws require all emergency facilities to be seismically safe by 2022 and all high occupancy public schools, community college and university buildings to be seismically safe by 2032.



The earthquake safety commission of Oregon is also concerned about protecting the economy and our high standard of living. Our economy relies on the energy sector, which includes electricity, natural gas, and liquid fuels. Our economy also relies on a multi-modal transportation network, including highways, rail, air, and marine traffic.

Oregon has new efforts to increase the reliability of energy and transportation services. The Oregon government is working to determine emergency transportation routes that can withstand strong earthquake shaking. The Oregon government is collaborating with privately owned companies to determine the vulnerability of the energy sector, and put in place long term mitigation programs to reduce the initial impact from a Cascadia earthquake, and quicken the restoration time after the earthquake. These actions will improve the response and recovery of the next Cascadia earthquake and tsunami.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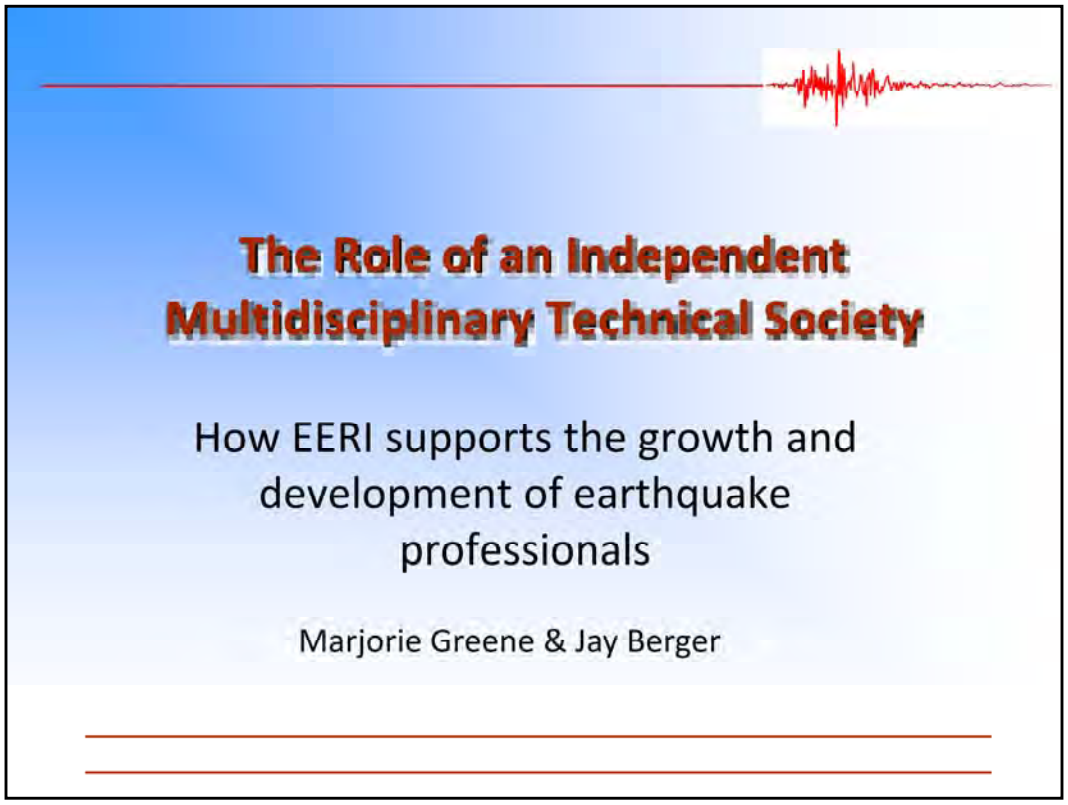
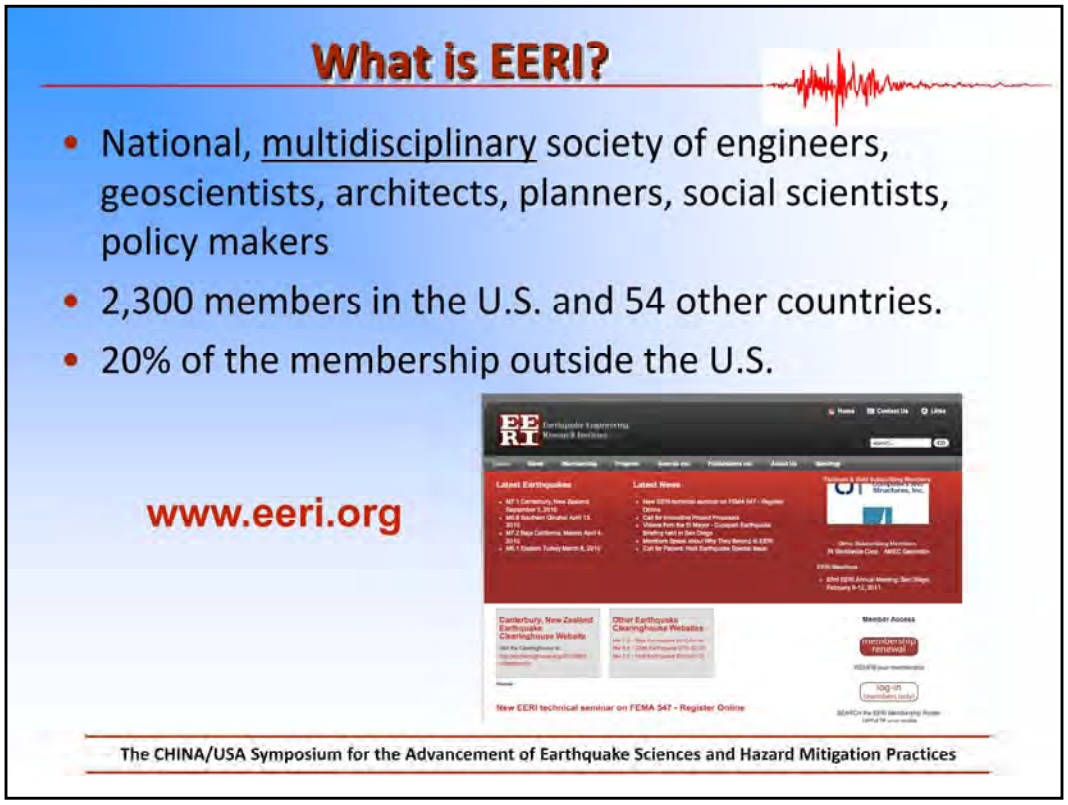
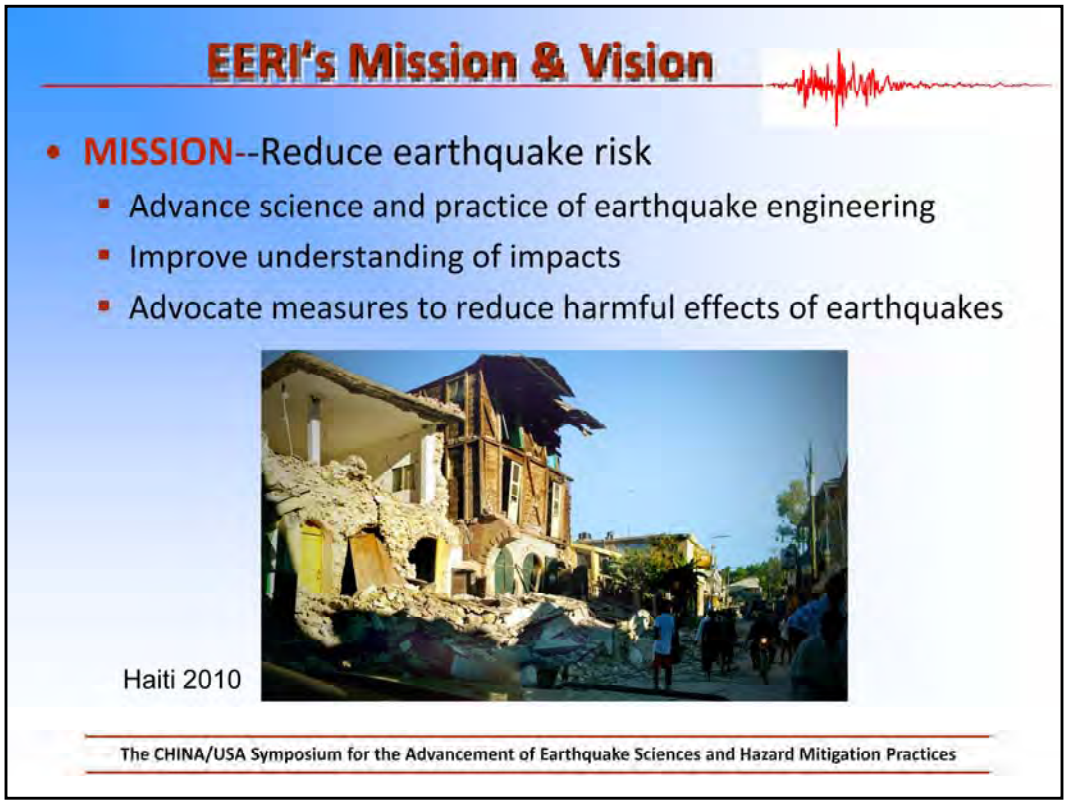


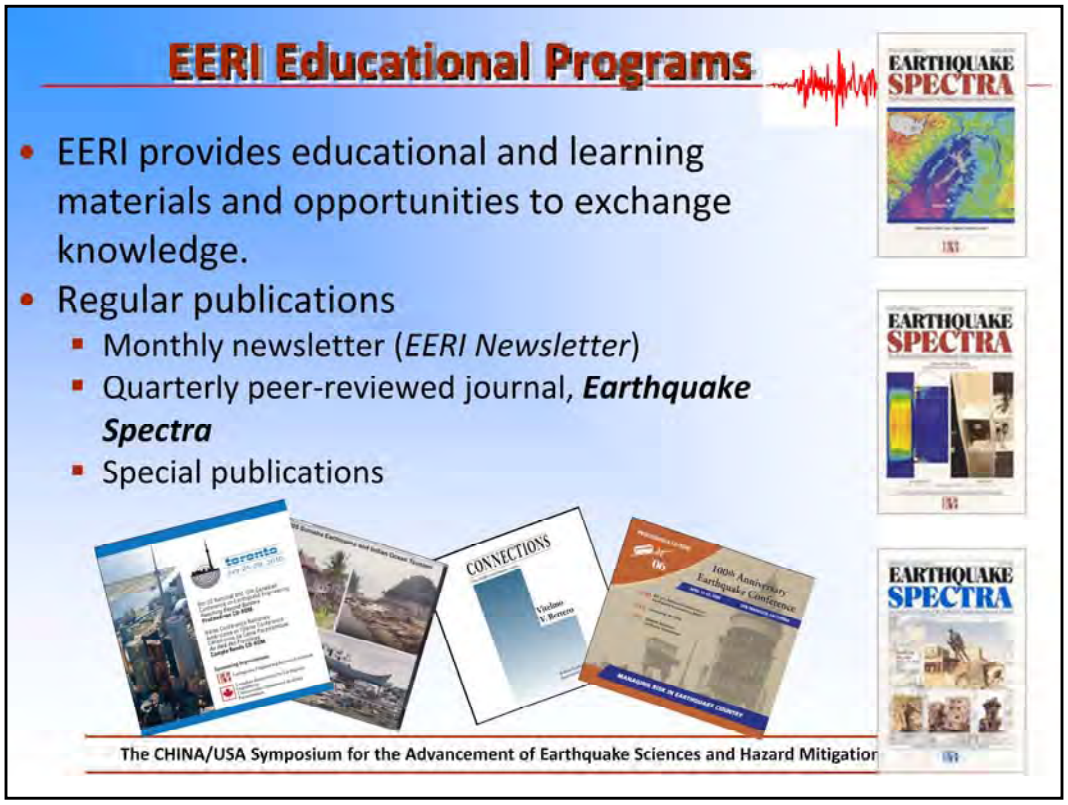
In this presentation I will briefly describe how the national association for earthquake professionals in the U.S., the Earthquake Engineering Research Institute (EERI), supports the growth and development of earthquake professionals.



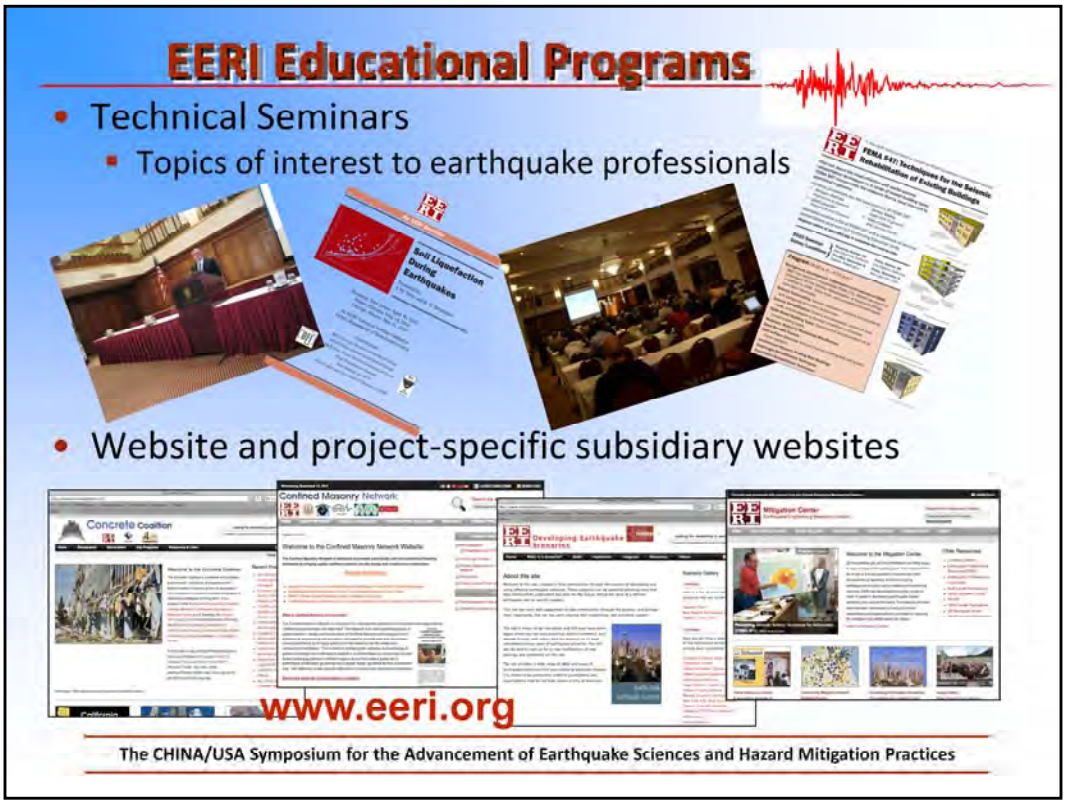
The Earthquake Engineering Research Institute, known typically as EERI, is multidisciplinary. This is one of its unique features. It is a nonprofit association that gets its funding from member dues and from various government grants. EERI has a membership of approximately 2300, with 20% of its membership coming from outside the U.S. The projects and tasks that EERI undertakes reflect its unique multidisciplinary membership.



EERI will accomplish its mission of reducing earthquake risk through advancing science and practice of earthquake engineering and advocating measure to reduce impacts. EERI is a leader in earthquake investigations and in the dissemination of earthquake risk reduction information both in the US and globally in cooperation with its international partners.



One of EERI's primary functions, as a professional society, is to provide educational and learning materials. EERI publishes a monthly newsletter and a quarterly journal. Its journal, Earthquake Spectra, has the 2nd highest Impact factor among more than 160 journals related to earthquake science and engineering.



EERI also sponsors a regular technical seminar series. The newest series, coming later this fall, is on the retrofit of existing structures. EERI's website serves as a central location for information related to recent earthquakes, as well as specific projects such as the Concrete Coalition, the Confined Masonry Network and other EERI projects.

EERI has several important programs or projects. I will briefly describe two. The Learning from Earthquakes (LFE) Program is supported by the U.S. National Science Foundation and sends multidisciplinary teams to damaging earthquakes around the world. During this past year teams have gone to Haiti, Chile, Baja California Mexico and now recently to Christchurch New Zealand. These teams bring back observations and basic lessons for U.S. practice and research. Many of the reports are available on EERI's website, and on individual earthquake clearinghouse sites that EERI establishes after a major event.

Another important project for EERI is the World Housing Encyclopedia. This project is run jointly with the International Association for Earthquake Engineering. Several researchers in China are actively participating. The project is entirely volunteer-run. The website has information on housing construction types in 41 countries or territories. Project volunteers have also written tutorials on various construction materials, and have translated these materials into several languages. Tutorials are available on adobe, reinforced concrete with masonry infill, and confined masonry construction, Soon there will be a tutorial available on stone masonry construction and next year one will be released on straw bale construction. The confined masonry tutorial has been translated into Chinese and is available on the housing website at www.world-housing.net

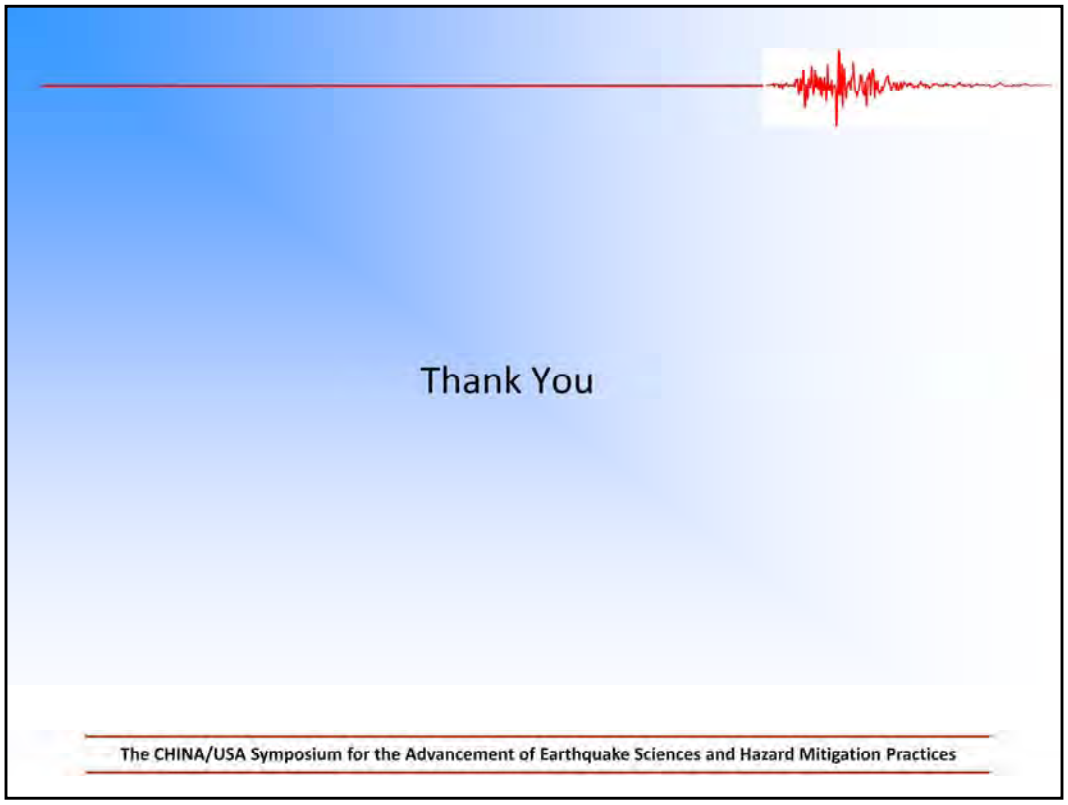
EERI has several programs that promote the development of skills in the next generation, and that encourage new and unique projects in the current generation of professionals. EERI has 29 student chapters. EERI has also recently adopted the Student Leadership Council, formerly sponsored by 3 U.S. national earthquake engineering centers. One of its main activities is a national undergraduate seismic design competition that is held each year In conjunction with the EERI annual meeting.

EERI also has a visiting professional program, endowed by the Friedman family. This program matches volunteer leading professionals with host universities, for 2 to 3 day workshops on current topics related to earthquake engineering and earthquake risk reduction. This exchange is part formal lecture and part informal discussion with faculty and students.

EERI also has an Endowment Fund and the investment income is used to stimulate new and unique projects that might not be funded with more traditional sources. The selection of these projects is made by the Special Projects and Initiatives Committee.

EERI also has a history of organizing workshops to identify research needs after important earthquakes. Such workshops are efficient and effective ways to identify the most promising research opportunities—those with the greatest potential to improve the current state of knowledge and practice. Most recently EERI has organized such workshops with researchers who investigated the Haiti and Chile earthquakes. We expect there will be very interesting lessons emerging from the New Zealand earthquake and we may organize a similar workshop for that event as well.

To close, EERI takes great pride in being at the center of earthquake risk reduction for the past 60 years, and looks forward to working with partnering organizations throughout the world to protect communitiies, through research, education and public policy, from the potentially devastating impacts of earthquakes.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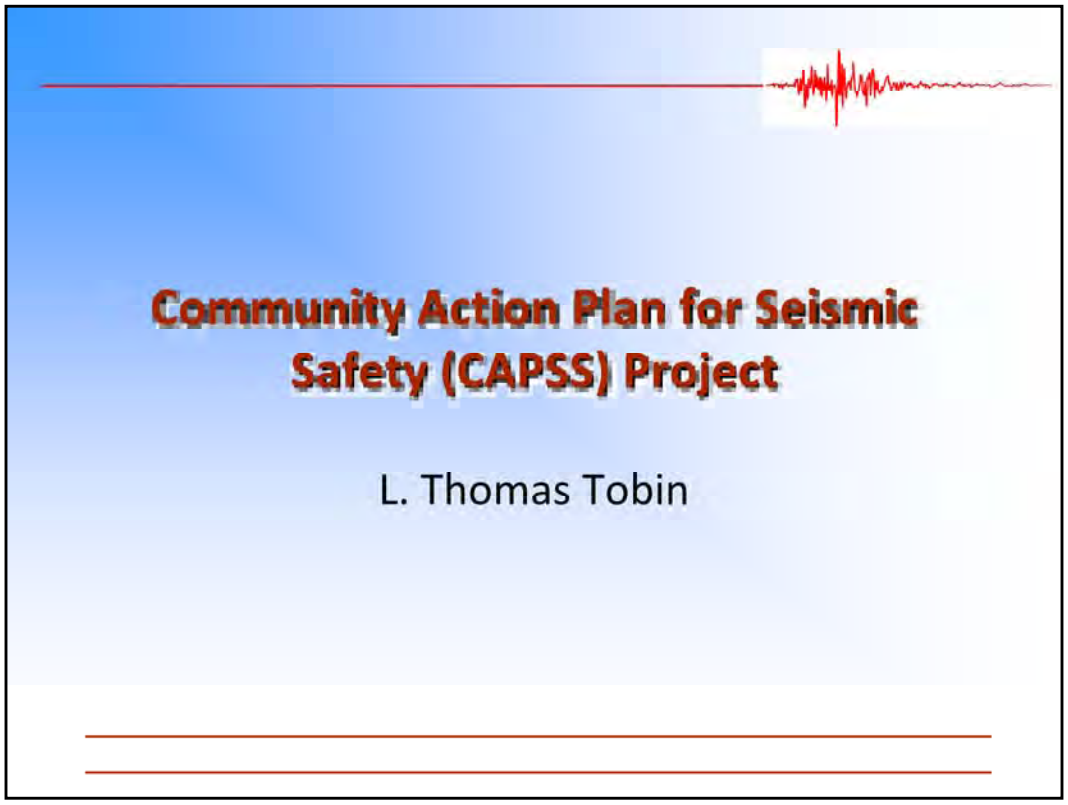
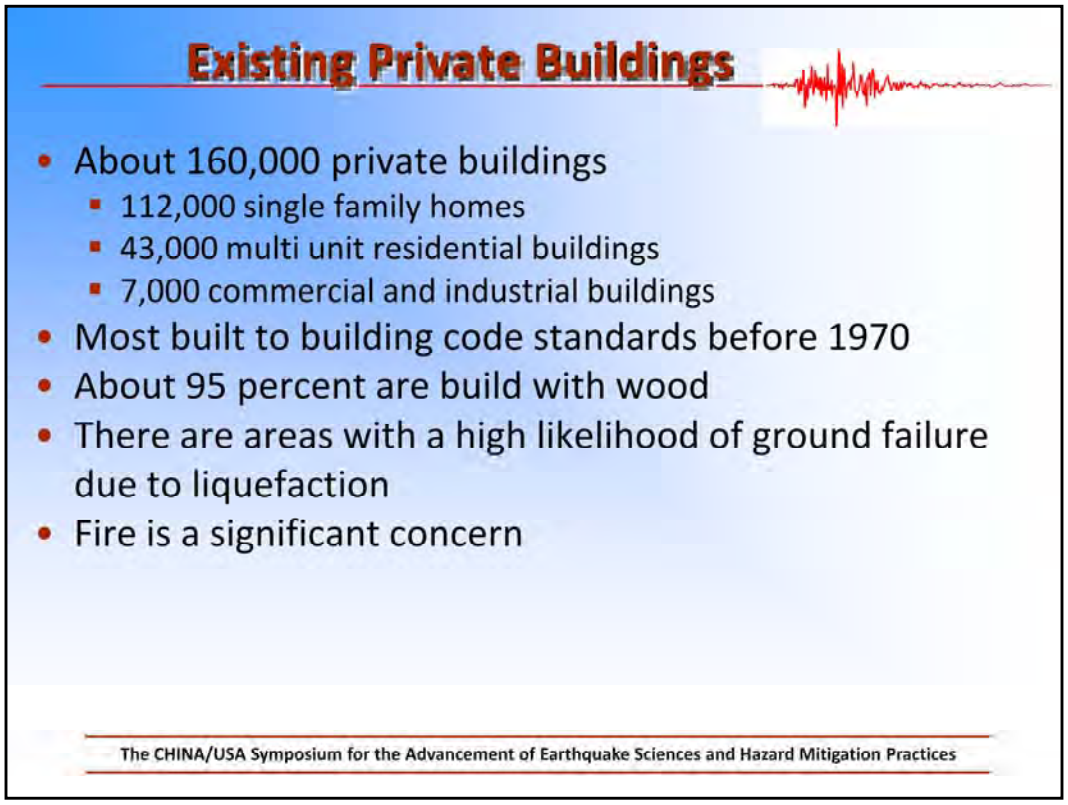


I will describe an on going study for the City of San Francisco. The purpose of the study is to recommend actions that will reduce earthquake losses and protect the people of San Francisco and the qualities they value.

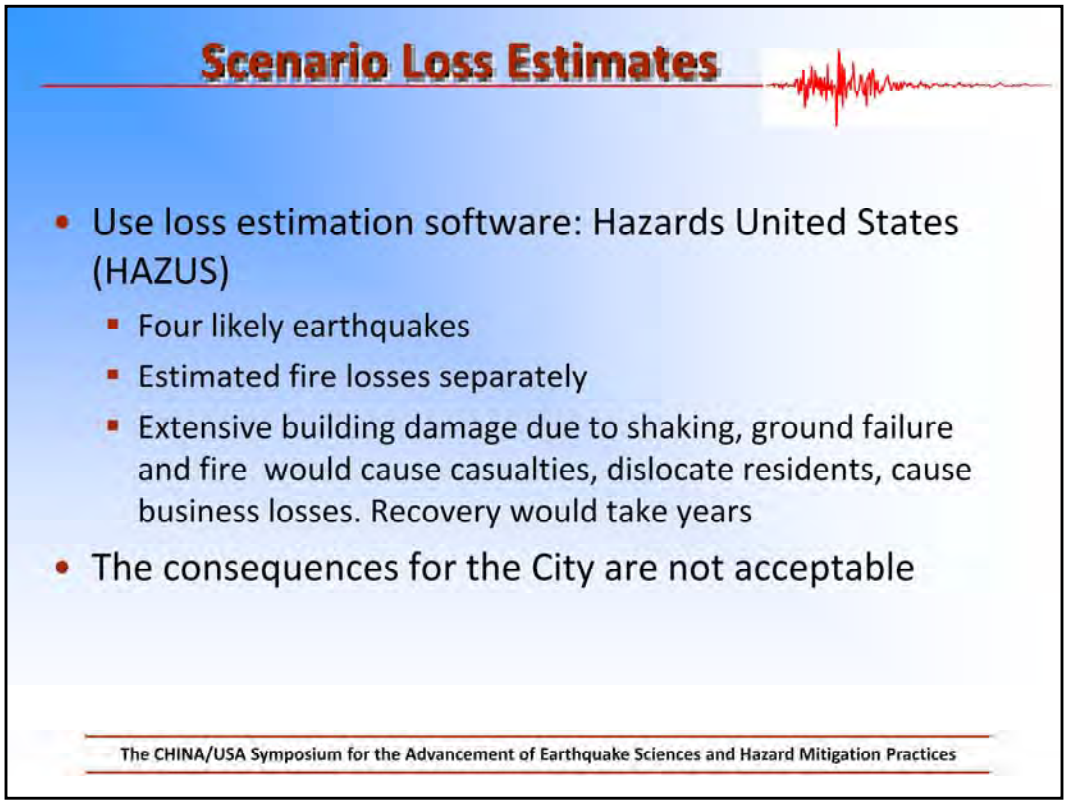


There are about 810,000 San Franciscans and about 162,000 privately-owned buildings in the City.

Most of these buildings, about 112,000 are small homes for one family. There are about 43,000 buildings with two or more residential units. There are about 7,000 other buildings used for commercial and industrial endeavors. Virtually every building is different.

By American standards, San Francisco is an old City and the vast majority of all buildings were constructed to older building code standards. Many have extremely vulnerable conditions. Most buildings are built with wood, but there are a significant number of older concrete buildings the pose a major threat to life.

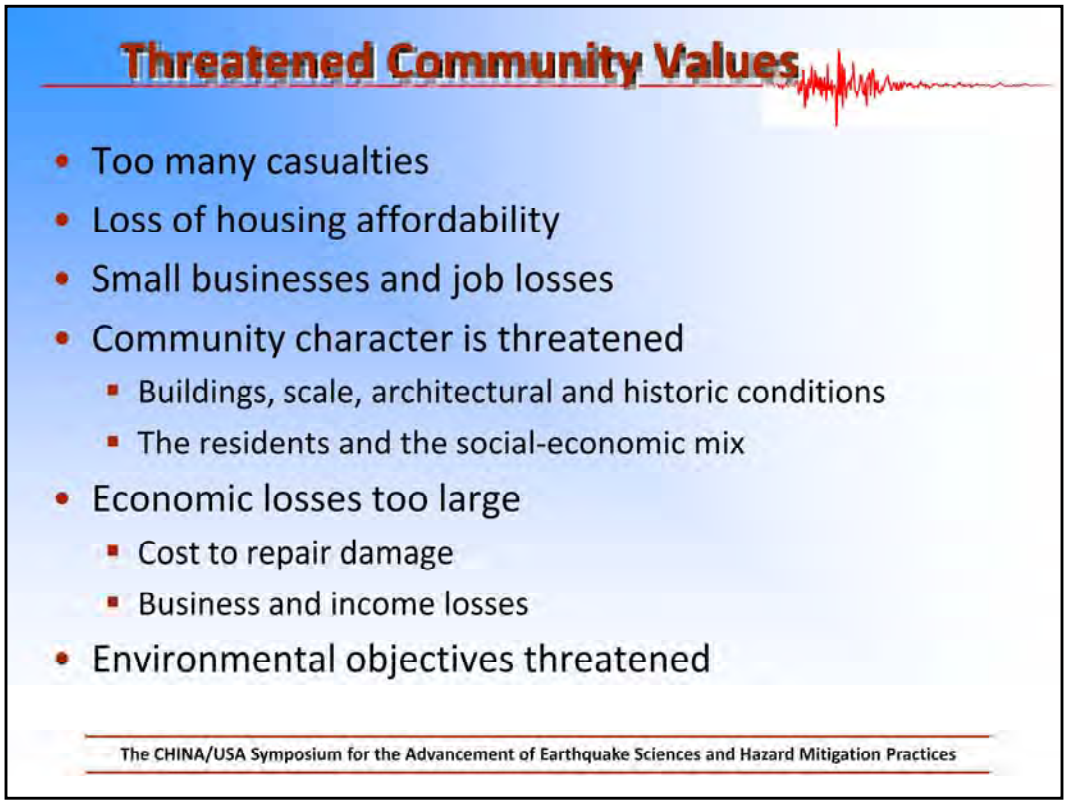
There are areas where ground failure is likely to occur due to liquefaction. Because the City is build largely with wood, and buildings are located close together, fire following an earthquake is a significant concern.



The project's insight into the earthquake threat is provided by using the loss estimation software, Hazards Unites States or HAZUS. Four likely earthquakes on nearby faults were considered, and fire losses were estimated separately.

The studies showed that extensive building damage due to shaking, ground failure and fire would cause casualties, dislocate residents and damage businesses to the extent that social and economic recovery would take years.

These consequences are not acceptable.



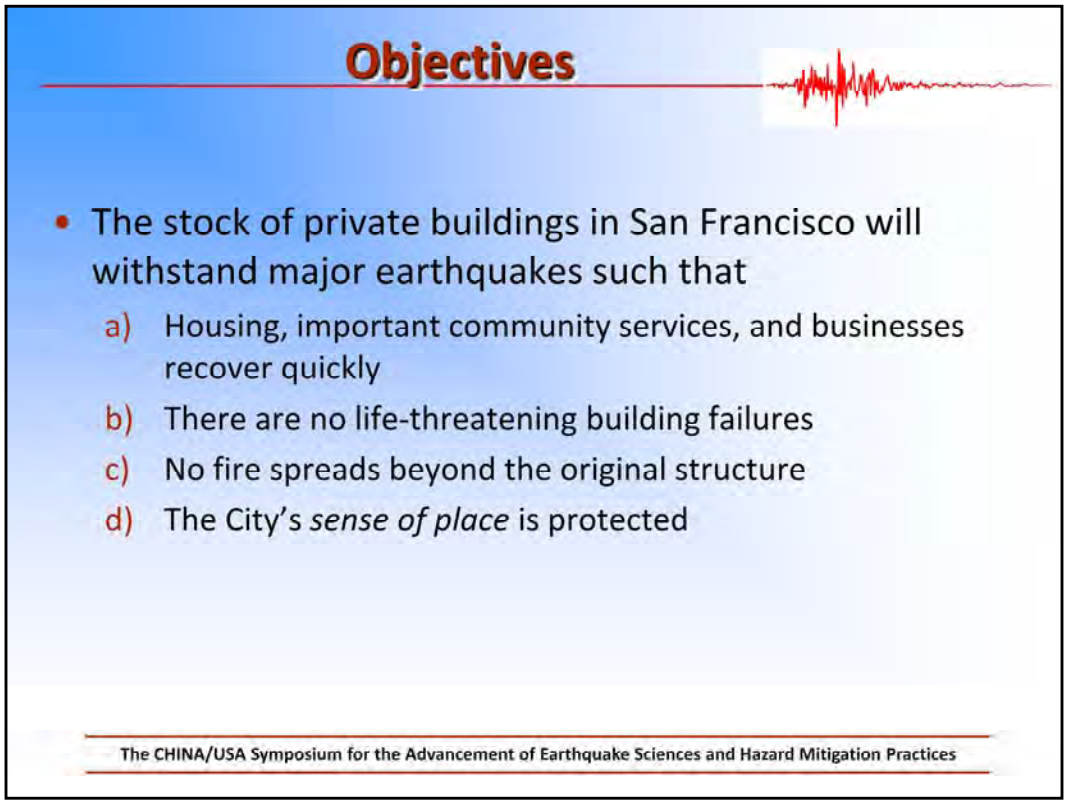
First and foremost, San Franciscans care about public safety during earthquakes. They also want to protect housing so people are not displaced and that repairs do not increase the cost of housing.

Small businesses need to recover their place of business, and they need their customers to stay in business. 95 percent of all businesses in San Francisco have 25 or fewer employees.

Community character, or sense of place, is provided by the size and architecture of existing buildings. New buildings can change these qualities. Community character also is defined by those who live there. Unfortunately, persons with disabilities and low income often are the most affected and are displaced. We believe our lives are richer when our neighbors are protected.

Economic losses due to disrupting tourism and knowledge-based businesses would affect San Francisco greatly. The buildings that support these uses must be readily repairable.

San Francisco is attempting to reduce its carbon footprint and reduce waste. The "greenest" buildings are existing buildings.



Objectives allow San Franciscans to describe the performance expected so building officials can set appropriate standards for owners and their engineers to consider when evaluating and retrofitting buildings.

The frame work is for San Francisco to be resilient; That is able to recover within targeted time frames that allow residents and business to stay in place during repairs, and to protect future generations' ability to enjoy the qualities of life we enjoy today.

The objective being discussed would establish target dates to reoccupy buildings, attempt to identify and retrofit all buildings subject to life threatening failures, enact measures to limit fire ignitions and fire spread, and protect most buildings to the extent that they can be repaired.

The "sense of place" is protected when our residents are not displaced to other cities, and our neighborhoods remain intact socially and architecturally, and historic structures are protected for future generations to enjoy.

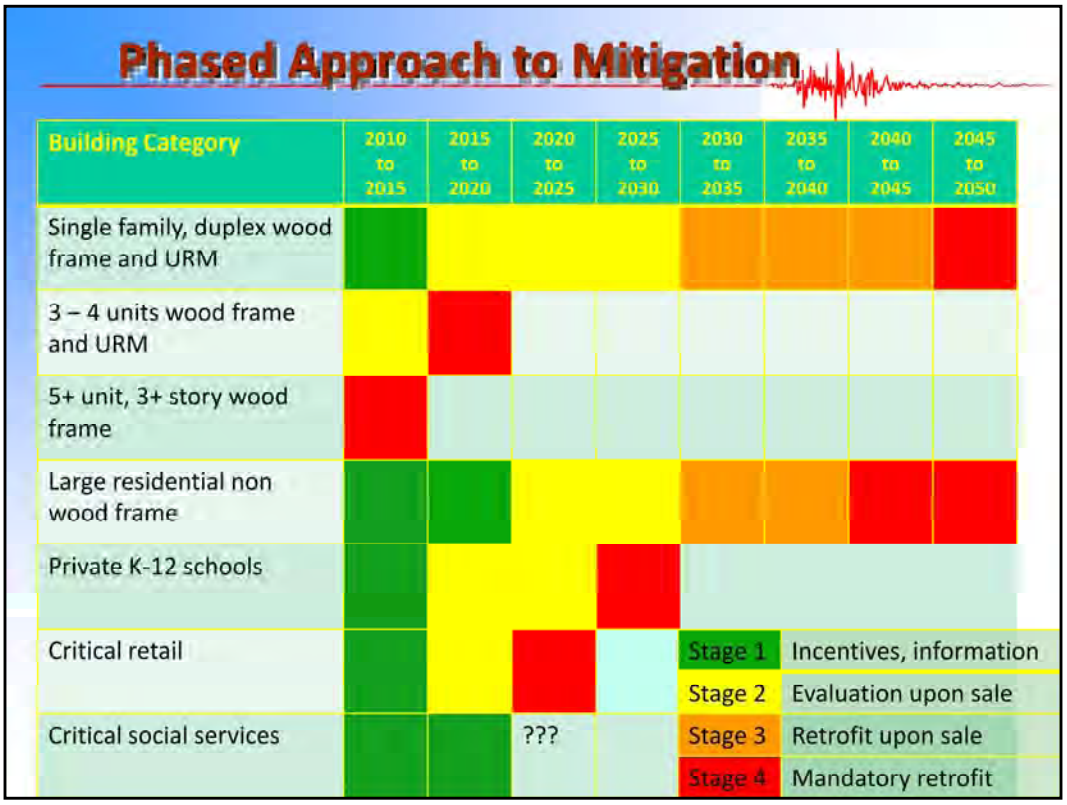
Engineering loss estimates can seem overwhelming to building owners and community leaders. Often the language used is overly technical. People must understand the message and believe those reporting.

In San Francisco, public policies will not be adopted, and even if they are, will not be carried out, unless there is community support among those affected, both owners and tenants.

The measures recommended, or required, must be seen as economically and technically sound and appropriate. Elected officials must agree and be willing to enact the laws and provide the resources needed for government employees to guide the program.

Financial and other incentives are needed to encourage owners to undertake expensive studies and retrofitting measures. In some cases, building owners cannot afford the cost of retrofitting. Government-backed loans can help.

The CAPSS project is not a technical study. The work is guided by an active citizen's advisory committee that meets monthly. These people, who represent a diverse range of San Francisco residents review results and recommendations and offer advice. They provide the insight into community attitudes.



The study is not complete, but there is a general agreement that San Francisco building owners must undertake an evaluation and that buildings that fall below the standard adopted to protect community values, must be retrofitted.

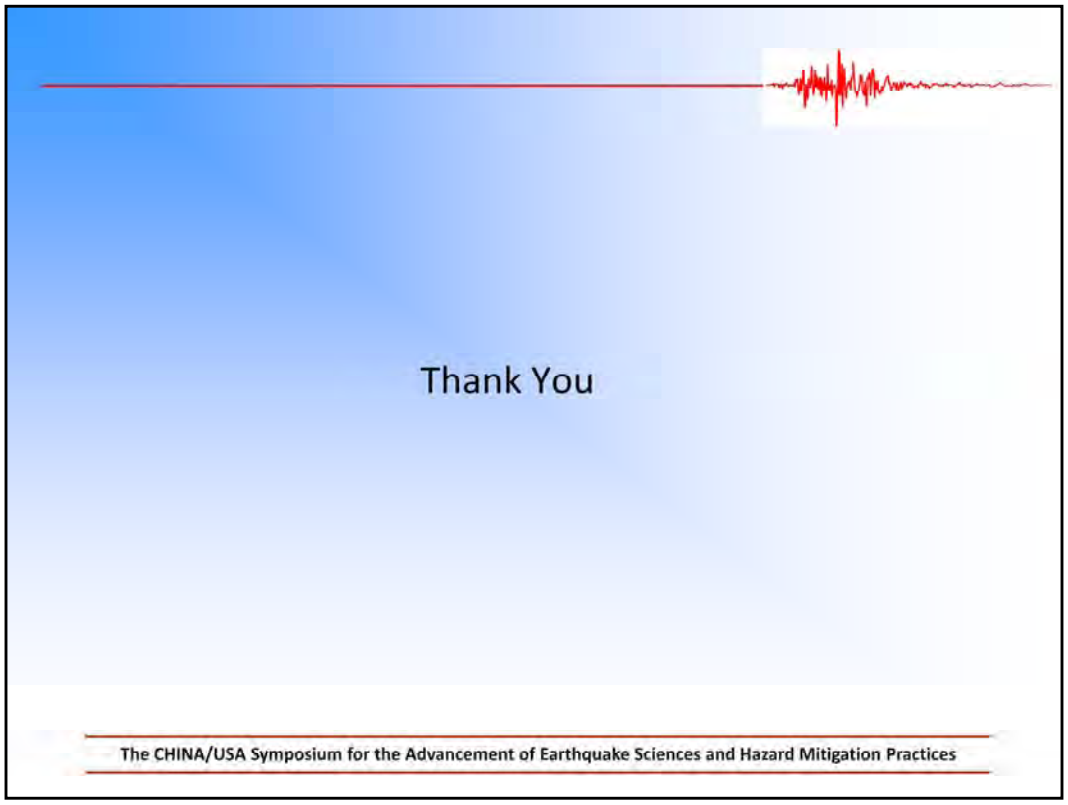
Because there are limited resources and capacity, the approach must be phased. The approach consists of four stages, each successively more likely to result in retrofitted buildings.

During the first stage, the City government would provide information and incentives to encourage owners to undertake voluntarily evaluations and retrofitting. During this time, owners who change their building's use or increase its size would be required to do an evaluation and retrofit.

During the second stage, owners would be required to evaluate their building before selling. About one to two percent of buildings are for sale each year. The owners would acknowledge the results of the evaluation, disclose this information to others, but decide what they will to to the building.

During the third stage, the option to decide is removed, and owners would be requited to retrofit earthquake deficient buildings.

During the fourth stage, the City would require owners to do an evaluation and retrofit earthquake deficient buildings according to a schedule. The schedule would apply to categories of buildings by use and construction types, and would reflect the City's priorities.



This concludes our presentations. We would be honored to discuss our presentations with you and to answer questions.

Risk Reduction and Management Responsibilities in the United States

L. Thomas Tobin

Sharing risk reduction experience and knowledge between Chinese and American professionals requires communications involving language and culture, and a mutual understanding of the governmental context regarding who does what, who is responsible (or shares responsibility), and how measures are implemented. Although both nations conduct similar activities, responsibilities are defined and distributed differently. This section describes governmental functions and authorities regarding earthquake risk reduction and management efforts in the Untied States. History is important.

The United States originated when thirteen newly independent original states voluntarily choose to unite by creating a federal government with limited powers. The federal government was given responsibility for foreign policy, national defense, commerce between the states and currency, and other selected matters. Over time the federal government assumed responsibility for some matters it can do better than individual states because of its nationwide jurisdiction and greater resources. Examples include the space program, national pension system called Social Security, research support, environmental regulation, and disaster aid. Power sharing remains an important political issue.

The Constitution reserves significant powers to the states. Most importantly, states retained responsibility for public health, safety and welfare. This limits the federal government's powers regarding mitigation, and explains why federal programs emphasize funding research, providing intellectual and political leadership, advocating mitigation measures, and providing incentives to state and local governments for dealing with the earthquake hazard. The Constitution also protects the rights of citizens and limits the extent federal, state and local government can interfere in private matters. It protects the rights to own property and to privacy, and limits the extent to which a government entity can restrict land uses or affect land values. These rights and limitations affect the nature of the government's mitigation policies affecting businesses and individuals. Government requirements and restrictions cannot prevent the use of private property unless the government goes through a legal process establishing the public interest in the property and providing just compensation. Concern for the cost of compensation tempers the nature of government intervention regarding private property.

Each state has a constitution defining its powers and dividing them among local government components, cities and counties, and its state agencies. The "police power" gives states the power and responsibility to protect health, safety and welfare and the authority to require building codes, enact land use restrictions, license professional engineers, geologists and architects, and other measures needed to reduce losses in future earthquakes. States determine whether building codes, land use planning and similar measures are to be required, or allowed. States enact a variety of statewide requirements that are imposed on county and city governments and individuals, and frequently delegate significant responsibility to local counties and cities. For example, states may enact laws requiring cities to enforce building codes or control land use, and have the power to require children to attend school. While the federal government influences the use of these powers through incentives and penalties, they remain state responsibilities. States often resist federal involvement in safety-related issues, and defend their independence based on the concept of "states' rights."

Cities are subservient parts of state government, but often resist state (and federal) pressures, and seek independence from mandates. They argue for "home rule," a concept that cities are best suited to deal with community-level issues, and that federal and state mandates—especially those not paid for with federal or state funds—should not be established. As a result, a significant number of public policies for mitigation are uniquely adopted by state and local governments in concert with the division of government powers, Constitutional guarantees, and political attitudes. These policies stress state and local government independence and result in public policies that vary from state to state. Moreover, individuals and businesses have a great measure of flexibility in how they address earthquake issues.

The vast majority of buildings in the United States are owned and constructed by private individuals and companies. In California, and most states, owners must apply for and receive approval from the city

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government before constructing a new building. Applicants must show that the building conforms to local zoning laws, and the building code. Private companies do the architecture and engineering design, and private companies subject to city inspection, does the construction. Schools and hospitals are owned and built by government agencies and private organizations. In California, the state government reviews and approves the design and construction of these critical buildings. The state and local governments occasionally enact laws to encourage private owners to reduce their risk from earthquakes.

States are responsible for emergency response, thus cities provide the first response with help from neighboring cities aid from state agencies. State governors can ask the President of the United States for federal assistance if the losses exceed state resources. The military does not assist unless the governor requests its help from the President. Regardless of the federal assistance, governors and mayors remain in command of the emergency response and recovery.

States have a great deal of autonomy and flexibility to choose what to do, and how to do it. There are no nationwide mandates for building codes, land use planning, or intra state utility or transportation system standards. Local government is generally responsible for land use controls, redevelopment of older areas, building safety, streets and roads, water supply, sewerage treatment and disposal, storm water runoff. States often retain responsibility to regulate private telecommunications, electric, gas and pipeline utilities and railroads. Some responsibilities, such as those for schools, may be shared between state and local government. Earthquake policies regarding these facilities vary from state to state, and within states, city by city.

The federal government has been active for decades in earthquake safety most notably through research by the US Geological Survey (USGS) and the National Science Foundation (NSF). In 1977 Congress passed the National Earthquake Hazards Reduction Act creating the National Earthquake Hazards Reduction Program (NEHRP), a program with objectives and funding authorizations limits. NEHRP's purpose is to reduce the risks to life and property from earthquakes. It combines the efforts of the NSF, USGS, Federal Emergency Management Agency (FEMA) and the National Institute for Standards and Technology (NIST) in a collaborative program. NEHRP has evolved during its thirty three-year existence from a nearly exclusive research program with a heavy emphasis on earthquake prediction, to a program that balances fundamental and applied research and research on mitigation with a heavy component of technology transfer in engineering and the earth and behavioral sciences.

The Stafford Act defines the federal government's responsibilities for emergencies and recovery from hazard events. This act is the basis for incentive programs to encourage state and local government mitigation efforts through matching grants.

The federal government's programs regarding earthquake research and mitigation are broader than NEHRP. For example, the National Aeronautic and Space Agency (NASA) and the Department of Energy have extensive research efforts. Many agencies respond to—or affect—seismic risk in some way, and earthquakes threaten all federal agencies' facilities and programs. Program-specific federal earthquake research and facilities investments exceed the expenditures by NEHRP.

Agencies of the federal government and private organizations provide services and do research in foreign countries as instruments of foreign policy. The Department of State and its U. S. Agency for International Development fund federal agencies to exchange technology and build relationships and provide training and build capacity in earthquake engineering and the earth sciences, and emergency management.

Each of the fifty states has responsibility for earthquake safety and emergency response. The federal government influences the states significantly by funding research, providing incentives and leadership. Local governments, cities and counties, enforce state laws and enact their own to protect the health, safety and welfare of it citizens. The private sector, owners of buildings, businesses and infrastructure, earthquake professionals, construction companies are responsible for the vast majority of the built environment and thus determine how safe Americans are during earthquakes. Government involvement is an important influence with cities, counties, states and the federal government in that order.

Emergency Preparedness and Planning in the USA National Incident Management System and the Primary Role of Local and State Governments

Richard K. Eisner, FAIA,

Introduction–The Context of Emergency Management in the United States

The organization and structure of the Emergency Management System in the United States is result of tradition, culture and the functional and constitutional relationship between the federal (national) government and the states, as prescribed by the Constitution. The United States was created as a federation of states in which the Constitution provides specific responsibilities to the national government. The 10th Amendment to the Constitution states, "The powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States respectively…."[1] This "States' Rights amendment, as it is referred to, and its implementation results in each of the 50 states with a tradition and legal framework for local control of the "police powers" that encompass responsibilities for public health and safety, land use development and regulation, building codes and primary responsibility for responding to and managing the consequences of disasters.

The delegation of emergency management responsibilities to local and state governments has historically resulted in the creation of fifty differing organization structures and procedures at the state level, and thousands of structures at the local (municipal and county) levels in the United States.

Beginning in the 1980s, the national government, through the Federal Emergency Management Agency initiated the promotion of standardized emergency management concepts, structures and procedures for emergency management based on systems that were developed in the fire response agencies in the State of California. Their objective was to create better use, sharing of resources and coordination of response by creating common terminology and organization structures that would support mutual aid and integration of federal resources in local response. The basic tenants of this effort are:

- Local governments are the "first responders" and will remain in charge of managing disaster response throughout the duration of the event
- States and local governments will provide "mutual aid" resources as requested, and will be reimbursed by the Federal government
- The primary Federal role is the provision of response and recovery resources, including personnel and equipment of from other states and Federal agencies, including resources of the armed forces
- Local government will determine policy for response and recovery to ensure that government actions are consistent with the needs and values of the local populations
- Local governments should integrate Non-Government Organizations (CBOs), Community Based Organizations (CBOs) and Faith Based Organizations (FBOs) into their response organizations to ensure that the needs of those with mobility and access needs are met.

There are some exceptions to the above tenants. For emergencies or disasters where the primary regulatory authority is at the federal government level, such as inter-state transportation (truck and rail), pipelines, and aviation, the federal government has the primary command role at the disaster site under a Unified Command while utilizing local response resources. Fire suppression, hazardous material containment, recovery of fatalities, care for injured, care and sheltering the displaced remain under local authority while the disaster or crime scene (evidence collection and arrest of responsible perpetrators) would be a federal role. For nuclear accidents or acts of terrorism, the federal level in similarly responsible for the crime scene, but the disaster response is shared with those who have appropriate resources available.

[1] United States Constitution, Amendment 10 - Powers of the States and People. Ratified 12/15/1791

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The National Response Framework[2]

The National Response Framework (NRF), published in 2008 after the realignment of response structure at the federal level in the aftermath of the September 11, 2001 terrorist attacks and the devastation of Hurricanes Katrina and Rita. The NRF outlines the roles and responsibilities of federal, state and local levels of government in the United States, and describes resources and procedures for coordinating and collaborating in disaster planning and response. The NRF carries forward several concepts from the earlier federal plans, including organization of federal agencies into 15 Emergency Support Functions (ESFs), coordination with states by co-locating in Joint Field Offices. The emphasis of the NRF, like previous Federal Response Plans (FRPs) is on providing state and local governments access to the capacities of federal agencies during response and recovery operations. The NRF also provides 15 National Planning Scenarios to assist in federal, state and local planning, of which 12 are terrorist attack scenarios, 1 is a pandemic disease outbreak, and two are natural hazards (earthquakes and hurricanes). Essential to effective collaboration and coordination is the common framework provided by the NRF, and to the use common terminology and organizational structures of the Incident Command System (ICS) at all levels of government. ICS enables interoperability between different levels of government and the non-government sectors and the private sector

ICS provides a flexible and scalable apparatus for managing response from small incidents such as fires to catastrophic events such as earthquakes and terrorist attacks, built on the following concepts:

- Management by establishing a common set of Objective and Strategies
- Clear organizational structure and authority
- Common overall priorities (may differ from one level to another, but are common at each level)
- Single “Action Plan”, collaboratively established and followed by all participating agencies
- Accountability and Agility to adapt to changes in the environment
- All participating agencies are represented at an Incident Command Post
- Establishing an acceptable “span of control” for effective management

Key Concepts for Emergency Management—The Incident Command Organization

At the local government or field response level, disaster management is organized in a simple ICS structure as illustrated in Figure 1. If there are multiple simultaneous incidents, such as fires or collapsed structures, there is an Incident Command Post at each incident that reports to the local government Emergency Operations Center (EOC). In multiple incidents (exceeding a reasonable span of control ~5 – 7 ICPs), an intermediate coordination level, the Area Command is created as illustrated in Figure 2. The ICP is responsible for providing Situation Reports up the hierarchy, and requesting resources from the EOC or Area Command, and managing Operations at the field incident level with the resources available..

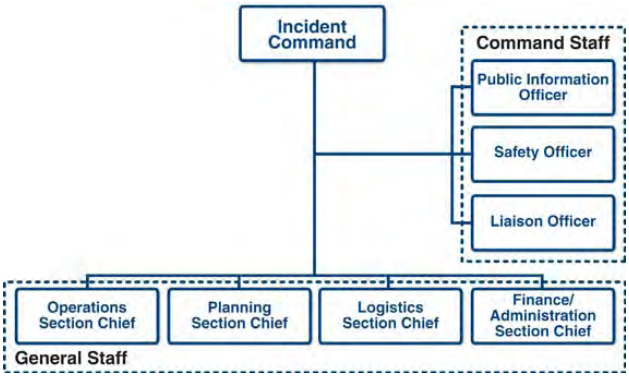

Figure 1. Field Level Incident Command Structure[3]

[2] Department of Homeland Security, 2008, National Response Framework, Available from : http://www.fema.gov/NRF
[3] Figures 1 & 2 are from Homeland Security, 2008, National Response Framework

The Area Command to Maintain Reasonable Span of Control

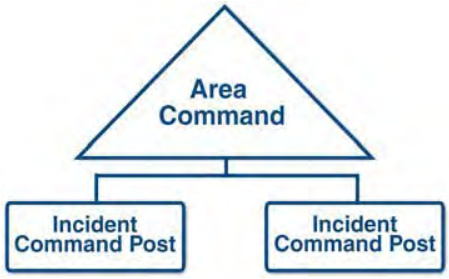

Figure 2. Area Command to Manage Span of Control

The intermediate level Area Command is responsible for aggregating Situation Reports for its Area of Responsibility, communicating requests for resources to the EOC, and setting priorities for allocating available resources to the Incident Command post level.

Unified Command to Coordinate Overlapping Jurisdictional Responsibilities

Frequently disasters occur across jurisdictional boundaries or where different jurisdictions or levels of government have shared responsibilities. For example, in wild land fires adjacent to urban areas, fire suppression responsibilities may be shared among local governments, state agencies, and federal agencies such as the Bureau of Land Management (federal Department of Interior), United States Forrest Service (federal Department of Agriculture) or the National Park Service (federal Department of Interior). In these instances they will join together in an Unified Command to collaboratively manage response through a consensus process. Most recently, in the massive oil spill in the Gulf of Mexico where the states of Louisiana, Mississippi, Alabama, Florida; the Environmental Protection Agency and the United States Coast Guard shared jurisdiction and responsibility for pollution on the coast, water quality, and navigable waters, respectively, a Unified Command was instituted that included British Petroleum as the "responsible party" to coordinate response activities at the national, state and local levels. Each jurisdiction retained its authority for its area of responsibility; each maintained their own Emergency Operations Centers and Incident Command organizations; while overall strategy and allocation of scarce resources was managed by the Unified Command.

The Federal Response is Not a First Response, but it Does Not Necessarily Wait for a State to Make a Request before Moving Resources

It is assumed in most disaster situations that the Federal level of response is not a "first response", that it may take hours to days after a sudden onset event for federal resources to become available to local responders. As noted earlier, fire, medical and law enforcement are local and state functions, so the vast majority of resources in these functions are under the control of local governments and would be in play before federal resources would be available. For slowly evolving disasters, such as fires, floods and hurricanes the federal government agencies play a "first responder role" staging equipment and personnel as close to the forecast impact as possible without being at risk. For example, prior to the landfall of Hurricane Katrina the Federal Emergency Management Agency pre-positioned staff, communication equipment, water and shelter supplies in the Gulf coast states.

FEMA liaison personnel were co-located with state officials in advance of the hurricane striking the coast and before there were either state or local declarations of a state of emergency or a Presidential Declaration. In fact, Federal agencies, including the military, have the authority to response with life saving assistance under their own authority, without waiting for a "formal Presidential Declaration of a Disaster."[4]

[4] Homeland Security, 2008, Federal Response Framework, Pg 42

Emergency Management in Practice

There are several noteworthy elements of emergency management practice in the United States, in addition of the Incident Command System and the NRF. As noted earlier, the 50 states and additional territories have evolved their own interpretations of ideal emergency management organizations and systems. In order to provide professionalism, capability building, interoperability and standardization, the Federal Emergency Management Agency has initiated the following programs in preparedness and mitigation as well as emergency response:

- **The Robert T. Stafford Relief and Emergency Assistance Act** provides authority to the President to assist states and local governments by reimbursing their disaster related costs and providing for repair and replacement of public structures. The Act also provides for mitigation grants to impact states to strengthen facilities and reduce future losses.[5]
- **Disaster Mitigation Act 2000** provides pre-disaster competitive grants from the federal government to the states to pay for hazard mitigation projects that are identified and prioritized.
- FEMA initiated and has promoted professionalism in emergency management by the development and a national standard for emergency management for governments, through the National Fire Protection Association (NFPA). **The NFPA 1600 Standard on Disaster/Emergency Management and Business Continuity Programs**[6] identified the essential characteristics and capacities of successful emergency management organizations.
- FEMA, in order to implement the NFPA Standard and assess the capacities of the emergency management functions of state and local governments, initiated and provided initial funding to the **Emergency Management Accreditation Program (EMAP)**[7] to provide peer assessments and certification of local and state government emergency management functions. EMAP provides a multi-step process that includes 1) Self Assessment; 2) Formal Application; 3) Site Visit by Peer Review Committee; 4) Peer Review and Assessment; 5) Accreditation Decision; and 6) Accreditation Maintenance.
- **The Emergency Management Assistance Compact (EMAC)** was initiated by FEMA to provide a mechanism by which states can quickly and effectively acquire mutual aid resources from other states. The program is managed by the National Emergency Management Association (NEMA). States providing mutual aid resources are reimbursed by the requesting states. Requesting states are reimbursed by FEMA. All 50 states are signatories of the EMAC and agree to provide available resources if they are available.[8]

Conclusion

The emergency management system in the United States has changed significantly in the past 3 decades with the introduction and evolution of the Incident Command System, the Standardized Emergency Management System and the National Incident Management System. Changes have occurred based on recent disasters that have motivated restructuring of the Federal Response Plans of 2004 and 2006 into the 2008 National Response Framework. These structures will continue to evolve in response to lessons learned from disasters, the influence of the American culture, traditions, growth of professionalism and standard in the field and adaptation to new technology.

Key points about the emergency management system in the United States are:

1. Local governments are the first to respond and will remain in charge of the managing response to disasters, even when intra state and federal resources are part of the response
2. The Federal role focuses on promoting professionalism, planning, mitigation, standards, training and providing resources to state and local governments
3. The US system emphasized decentralization of responsibility and providing resources to enable local levels of government to more effectively perform their jobs

[5] See: http://www.fema.gov/hazard/dproc.shtm
[6] See: http://www.nfpa.org/assets/files/pdf/nfpa1600.pdf
[7] See: http://www.emaponline.org/
[8] See: http://www.emacweb.org/

Earthquake Risk Management Approaches for Civic and Critical Lifeline Infrastructure: Applications in Oregon

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Introduction

Many seismic regions around the world are at high risk of major disasters when large earthquakes strike. Weak buildings and infrastructure will fail, with a likely concentration of damage near water bodies that are surrounded by weak soils. People will be traumatized and entire communities will be in shock. Emergency response services by fire, police, and hospitals will be in high demand. Children in collapsed schools may be among the casualties. The strength of the region's critical lifeline infrastructure including the transportation and energy sectors will dictate the effectiveness of the emergency response and recovery efforts.

This paper encourages a holistic risk management approach for preparing for earthquake disasters to minimize the impact from disasters by improving resiliency. It provides lessons learned from past earthquakes, an overview on the 10-year long effort to establish a seismic rehabilitation grant program for civic infrastructure (e.g., schools, fire stations, police stations, and hospitals), a discussion on critical lifeline infrastructure, and outlines steps to improve to reliability of civic and critical lifeline infrastructure services after major disasters.

Lessons from Past Earthquake Disasters

After every major earthquake disaster, intense human suffering is associated with damage that was or could have been predicted by earthquake professionals. The heaviest losses are often concentrated in areas of weak soils that have failed from landslides, liquefaction and lateral spreading, and in weak buildings that partially or completely collapse. Certain low lying coastal areas could have significant tsunami damages.

By applying lessons learned from past earthquakes and research findings, we can increase the effectiveness of risk reduction measures. For example, important facilities built long before modern understanding of seismic hazards should be reevaluated for public safety, or possibly other concerns, such as cultural or environmental. Two recommendations should be adopted to help manage significant earthquake risks in any seismically active regions.

- Important civic facilities including schools, fire stations, police stations, and hospitals, especially those on weak soils prone to liquefaction, landslides, or shaking amplification or in tsunami zones, should meet modern building codes and should be able to withstand strong earthquakes. Any existing important facilities at high risk should be mitigated.
- Critical lifeline infrastructure that are co-located and/or are interdependent with other lifelines should require special performance consideration to avoid multiple and/or cascading failures. Any existing lifelines at high risk should be mitigated to meet acceptable service levels. Reliable high voltage electrical transmission systems, emergency communication abilities, and emergency transportation routes are important. Any existing critical facilities at high risk should be mitigated to protect against severe socioeconomic, environmental, and culturally significant impacts.

Risk Management for Oregon's Civic Infrastructure

Oregon's Seismic Risk. The state of Oregon's extreme disaster is a magnitude 9 earthquake on the Cascadia subduction zone, which will produce minutes of strong ground shaking, coastal subsidence, landslides, liquefaction, lateral spreads, and a near-field tsunami. Building damage is expected to be severe due to the relatively recent adoption of seismic building codes in 1994 and the high percentage of vulnerable buildings. Response and recovery are expected to be slow and difficult due to highly vulnerable critical lifeline infrastructure. The state of Oregon will likely suffer severe transportation immobility of major highway systems, fuel shortages, and outages in the electrical and natural gas systems, The operational capacity of most lifelines during natural disasters requires substantial improvement to provide reliable service to communities.

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Oregon's Civic Infrastructure. Since 2001, Oregon state laws have required emergency service buildings and public schools to meet seismic life safety as set forth in the Oregon Revised Statute (ORS) 455.400, as detailed by Alesch et al. (2004). ORS 455.400 mandates public school buildings with greater than 250 occupants and fire stations, police stations and hospitals to achieve life safety standards in major earthquakes with 30- and 20-yr timelines, respectively. ORS 455.400 further requires evaluation of these public school buildings and emergency facilities using FEMA rapid visual screening methods for seismic vulnerability, which was completed in 2007. High-risk buildings are required to be mitigated (www.leg.state.or.us/ors/455.html).

Due to poor seismic resistance of many older emergency service and school buildings, over 1,000 buildings are at high-to-very high risk of collapse. Over 300,000 children attend schools in these buildings with poor seismic risk scores. Seismic vulnerability scores for school and emergency service buildings across the state are available at www.ode.state.or.us/go/quakesafeschools and www.oregongeology.org/sub/projects/rvs/default.htm (Lewis, 2007).

In 2009, the state of Oregon launched the first state-funded seismic rehabilitation grant program in the United States, which provides public monies to help strengthen public school and emergency service buildings prone to severe building damage. This 10-year effort was championed by state Senator Peter Courtney, Oregon Seismic Safety Policy Advisory Commission (OSSPAC), by Oregon Department of Geology and Mineral Industries (DOGAMI), and supported by stakeholders. The Oregon seismic rehabilitation grant program was created to eliminate collapse-prone, high-occupancy school buildings to avoid mass casualties in future major earthquakes, as well as to promote community preparedness. Under the leadership of Senate President Peter Courtney, the Oregon Legislature authorized the first seismic bond sales of $15 million for public schools and $15 million for emergency facilities, and provided funds for three staffers to administer the new seismic rehabilitation grant program (Wang, 2010).

The Oregon Seismic Rehabilitation Grant Program is administered by Oregon Emergency Management (OEM) (www.oregon.gov/OMD/OEM/). Due to Senator Courtney's dedication to seismic safety and perseverance of establishing an institutionalized funded grant program, these grants are also known as "Courtney grants." OEM announced the first grant application period in September 2009, with maximum grant awards of $1.5 million per applicant. Applicants are required to complete an application package that includes seismic engineering information, a proposed scope of work, budget, and a benefit cost analysis. A grant committee evaluates and ranks the grant proposals. OEM awarded the first grants in early 2010 to 24 recipients, and is scheduled to award a second round of grants in early 2011. In order to mitigate all schools with a high probability of collapse by the deadline of 2032, about 50 schools per year over the next 20 years will need to be seismically strengthened.

Risk Management for Critical Lifeline Infrastructure

Lifeline Resiliency. Lifelines provide the basis for our modern standard of living. Lifelines, including electricity, water, transportation, communication, are required by all sectors of our society to function. Yet, many of the lifeline systems are aging, deteriorating, increasingly overburdened by higher demands, and susceptible to failure even under normal operational conditions. Decades of under-funding and neglect have endangered the U.S.'s infrastructure to the point where $2.2 trillion in repairs and upgrades is needed over the next five years to meet adequate conditions (www.asce.org). Cities in the high seismic hazard areas around the world are vulnerable to extensive lifeline damage and untold cascading effects.

After earthquakes, it is of critical societal importance to have certain reliable lifeline services for emergency response and public safety related activities. In order to provide reliable services, critical lifeline infrastructure need to be identified and will likely need to be seismically mitigated to improve disaster resiliency. As important as lifelines are, in the U.S. lifelines are not governed by a uniform set of design and construction codes. As such, it is commonplace for older lifelines to have inadequate seismic detailing. Furthermore, many new lifelines are often constructed without adequate seismic provisions. During earthquakes and other extreme loading conditions, lifeline systems are often damaged resulting in reduced or no services for a period of time. Sometimes lifelines are damaged beyond repair and require replacement. In order to be better prepared for earthquake disasters, our communities need to become disaster resilient. Disaster resilience has

been characterized as "*reduced probability of system failure, reduced consequences due to failure, and reduced time to system restoration*" (http://mceer.buffalo.edu).

Oregon's Lifeline Risks. Portland Oregon metropolitan region, with a population of about 1.5 million, is the center of Oregon's economic activity and the region's multi-modal transportation hub. Portland has significant earthquake hazards and lifeline vulnerabilities. The historic district is filled with unreinforced masonry buildings being used for commercial purposes; much of the port, airport, rail yards, and industrial areas are built on loose river sediments and un-engineered hydraulic fill with high susceptibility for liquefaction; and major fuel yards, natural gas facilities, and electrical transmission corridors are highly susceptible to lateral spreading. A FEMA HAZUS-based risk study for the City of Portland indicates that the 500-yr earthquake equivalent is estimated to produce "limited risk to severe risk (3.8% to 57.4%)" to utility lifelines. The 100-yr earthquake equivalent is estimated to produce "limited risk to moderate risk (3.8%-8.6%)". The 100-yr mean return period earthquake in Portland would be roughly equivalent to the ground shaking that would be associated with a magnitude 5.8 earthquake in the Portland Hills fault or a magnitude 7.0 on the Cascadia subduction zone (FEMA, 2004).

Improving Resiliency

To limit the harmful effects from mega-disasters, we recommend a risk management approach. Efforts should be coordinated with government officials, community leaders, planners for emergency response and recovery, lifeline owners, and other stakeholders. Current risk management efforts are underway in Oregon, including on the energy and transportation sectors (Wang, 2008, 2010). The risk management approach involves following these main steps, which are scalable depending on the user and the situation:

1. Characterize the potential disaster.
2. Conduct a risk assessment, including the probability of the hazard, the vulnerability of the exposed elements, and the consequence of the damage. Refer to Ang and Tang (2007) for methods.
3. Determine potential interdependencies and cascading impacts. Refer to Ventura et al (2010) for discussion.
4. Establish a mitigation plan with stakeholders that includes timelines and prioritized actions. Refer to Poland (2010) for a case study.
5. Initiate a mitigation program with stable funding mechanisms to ensure timely progress.

Conclusion

It is widely understood that earthquakes are inevitable in seismic regions around the world. Like in many other seismic regions, much of Oregon's current infrastructure is decades behind the latest advances in seismic design and performance, leaving civic and critical lifeline infrastructure vulnerable to severe damage. To improve the state of Oregon's earthquake resiliency requires mitigation activity at many levels both within government and the private sector. Oregon should continue with an earthquake risk management approach involving key stakeholders, hazards identification, risk assessments, prioritization of mitigation, and mitigation activities.

A risk management approach is recommended to effectively prepare for earthquake disasters by improving resiliency to civic and critical lifeline infrastructure. Risk management involves conducting risk assessments to help prioritize mitigation and can be adopted by both public and private stakeholders. We recommend that communities develop risk management programs that include schools, emergency facilities, and critical lifeline infrastructure. Lifeline resiliency in the face of disasters is an important aspect of our modern society and requires improvements.

Applied research and technical improvements are also needed. For example, mitigation options for schools need to be improved—significantly less expensive methods that can be streamlined to be implemented during summer breaks are in demand. Certain structural building types, such as concrete buildings, have been prioritized using a risk management method (Tesfamariam et al, 2010), however, better prioritization methods and significant efforts are needed for civic and critical lifeline infrastructure in high seismic areas around the world.

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The Role and Importance of an Independent Multidisciplinary Technical Society, with Examples of the Benefits to the Earthquake Professions

Marjorie Greene, Special Projects Manager,
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Background

The Earthquake Engineering Research Institute (EERI) was founded in 1948 as an independent multidisciplinary national society of engineers, geoscientists, building officials and architects with the intention to establish a research institution. Over the years EERI evolved into an active professional association that addresses the objective of reducing earthquake risk by (1) advancing the science and practice of earthquake engineering, (2) improving understanding of the impact of earthquakes on the physical, social, economic, political, and cultural environment, and (3) advocating comprehensive and realistic measures for reducing the harmful effects of earthquakes.

Today EERI is a national, multi-disciplinary society of engineers, geoscientists, architects, planners, and social scientists with approximately 2,300 members in 48 US states, two US territories, and 56 other countries. As the field of earthquake hazard mitigation expands, EERI takes on tasks that reflect its unique multidisciplinary membership, through meetings and conferences, administrative and technical committees, publications, and a comprehensive website www.eeri.org. EERI carries out many programs with funding from U.S. federal agencies, including the National Science Foundation (NSF), Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), and the National Institute of Standards and Technology (NIST). The EERI staff handles administration, membership, publications, seminars, meetings, conferences, and programs that are supported with and without government funding. However, the lifeblood of EERI is the membership. Scores of members generously contribute untold hours of professional time to EERI's administrative and technical Committees, where much of the work of EERI is carried out. Committee leadership develops and then provides oversight for all of EERI's technical programs.

Selected EERI Educational Programs

One of the primary functions of EERI, as a professional society, is to provide educational and learning materials, and the opportunities to exchange knowledge, to its members, the broader earthquake professions, students, governmental bodies and agencies, and the general public interested in earthquakes. EERI fulfills this role through its regular publications—a monthly newsletter (*EERI Newsletter)* and a quarterly, peer-reviewed technical journal (***Earthquake Spectra***), and its special publications such as monographs on technical topics and white papers on an array of issues. In addition, EERI sponsors technical seminars on a wide range of topics of interest to earthquake engineers and scientists. Topics covered by recent technical seminars include soil liquefaction during earthquakes, deep and shallow foundation engineering, and the performance of concrete buildings. This fall EERI is sponsoring a new technical seminar series for structural engineers on seismic retrofitting of existing structures. EERI's main website, as well as a number of subsidiary websites that are purposed for individual projects and programs, serve as long term and easily accessed educational resources for the broader professional community.

Among all of EERI's activities designed to improve the gathering, exchange and application of knowledge, the Institute is probably best known for its field investigations and reports of the effects of destructive earthquakes. Its Learning from Earthquakes Program was initially funded by the National Science Foundation in 1973. At the heart of this program are the multidisciplinary reconnaissance teams sent to damaging earthquakes around the world, quickly gathering and bringing back to the professional and academic earthquake community fresh observations and lessons. In the more than 30 years since its inception, this program produced nearly 200 reconnaissance reports and contributed to many advances in engineering, the earth sciences, public policy and the social sciences. Systematic field observation has improved understanding in the basic science of earthquake ground motions and fault mechanics, soil liquefaction and ground failure, and led to fundamental changes in building codes and construction practices, better

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understanding of highway, bridge and lifeline performance, and changed emergency response, recovery and reconstruction programs and procedures.

Recognizing the need to always nurture and promote the education of the next generation, EERI has established Student Chapters at 29 universities throughout the U.S., plus Canada, Mexico and Italy, to encourage participation of students in earthquake-related education, research and professional practice. Most recently EERI agreed to adopt the Student Leadership Council (SLC) formerly sponsored by the three U.S. national earthquake engineering research centers. One of SLC's signature activities is a national Undergraduate Seismic Design Competition that is held each year in conjunction with the EERI Annual Meeting. The 2010 competition in San Francisco, California, attracted over 200 students from 22 universities throughout the country.

In 1996 EERI established a Visiting Professional Program. The purpose of this program is to match volunteer leading professionals with host institutions, usually universities, for a two to three day workshop on current topics related to earthquake engineering and earthquake risk reduction. This exchange is part formal lecture and part informal discussion with faculty and students. The visiting professionals come from a wide range of disciplines, including engineering, earth science, seismology, architecture, planning, public policy and the social sciences. In 2001 David Friedman of Forell/Elsesser Engineers, and his family, endowed the program with a generous gift to keep the program running in perpetuity. At the time the gift was made, the name of the program was formally changed to the Friedman Family Visiting Professional Program.

Selected EERI Support for Research

In 1993 EERI created an Endowment Fund, and in each subsequent year EERI has carried out an annual appeal to members seeking financial contributions to the fund. Currently the Endowment has over $1 million and the investment interest is used to stimulate new and unique projects that address gaps in research, improve application and practice, or facilitate public policy to reduce earthquake risks. A series of White Papers documented the results of several Endowment projects over the past decade. Projects supported by this Endowment Fund are selected by the Special Projects and Initiatives Committee. In the last year, projects receiving funding include: a reinforced adobe training program being developed by colleagues at the Catholic University in Peru; a study of the soft story identification and retrofit program of the City of Berkeley, California; the final development and dissemination of confined masonry design and construction guidelines; and the development of a tutorial on straw bale construction, targeted at developing countries.

EERI has a history of organizing workshops to identify research needs after important earthquakes. In 1999, workshops were held on the major events in Turkey and Taiwan. Such workshops are an efficient and effective way to identify the most promising research opportunities—those that have the greatest potential to improve the current state of knowledge and practice throughout the world's seismic zones. Currently EERI is organizing workshops for the National Science Foundation to help identify research needs and opportunities emerging from the 2010 Haiti and Chile earthquakes. Both the Haiti and Chile earthquakes present major learning opportunities of different types for the U.S. engineering and scientific community. The Haiti earthquake has research lessons emerging from the many complex response and rebuilding activities that are still struggling to gain ground on the devastating effects of that disaster, and these lessons will inform future research across many disciplines. A different set of research needs and lessons will emerge from Chile, which is one of the most significant earthquakes for the U.S. earthquake engineering community in the last several decades. Building codes are similar to the U.S. for concrete and steel buildings, there are many strong motion records that provide important data, the geologic setting is similar to the Pacific Northwest, there are similarities and lessons from the transportation, lifelines, critical facilities sectors, and there are similar social and political issues in the response and recovery.

In 2000 EERI, in partnership with the International Association for Earthquake Engineering (IAEE), launched the World Housing Encyclopedia (WHE) project under the auspices of the EERI Endowment. Today the WHE is a uniquely successful web-based global network of over 200 individuals from 57 countries committed to making communities safer in earthquakes. The network is committed to improving global construction practices by sharing technically accurate, peer-reviewed, consensus-based resources on appropriate construction materials and technologies, leading to the improved performance of housing in earthquakes, in an environmentally appropriate and sustainable manner. All publications and resources developed by project participants and other authoritative sources are available free of charge on the project web site (www.world-

housing.net). At the core of this network are reports on housing construction practices and technologies from 40 countries. Today the network continues to expand, with a new emphasis on the development and publication of tutorials dealing with common building construction technologies and practices, with an emphasis on techniques to improve seismic performance. The tutorials offer recommendations to improve earthquake-resistant construction practices for new buildings and for strengthening existing buildings at risk, and include links to relevant publications and web sites as well as video clips. The following tutorials are available on the WHE website: Adobe Buildings (English/Spanish); Confined Masonry Dwellings (English/Spanish/Chinese/Kreyol [modified version]); Reinforced Concrete Frame Buildings (English, Bahasa Indonesian).

WHE project participants from multiple continents are currently contributing information on the seismic vulnerability of basic construction types in collaboration with the U.S. Geological Survey PAGER project. The project is making pioneering use of the internet as a tool to create and maintain a global community.

Soon after the Haiti earthquake in January 2010, EERI put out a call to its members and their networks of professionals to contribute to a web-based damage assessment project, using high resolution pre and post satellite and aerial imagery. This was part of an effort organized by ImageCat for the World Bank, and complemented additional damage assessment efforts performed by several UN agencies and the European Commission. The consortium of organizations and individuals created has been given the name GEO-CAN (Global Earth Observation Catastrophe Assessment Network). The effort was considered very successful—over a short period of time volunteers were able to identify over 30,000 severely damaged or collapsed buildings out of almost 100,000 buildings that were assessed through aerial imagery. EERI is exploring ways to institutionalize this capability of "crowd-sourcing" of engineering expertise for future catastrophic events (EERI 2010).

Selected EERI Advocacy and Contributions to Public Policy

The founders of EERI were cognizant of the significant role that EERI would play advising governmental agencies on issues pertaining to seismic risk. For many decades EERI has been sought out as an unbiased, responsible voice and a credible source of expertise on earthquakes, earthquake risk and the impacts of earthquakes on natural and built environments.

In 1984, FEMA contracted with the Applied Technology Council (ATC), the Building Seismic Safety Council (BSSC), and EERI, who formed the ABE Joint Venture, to prepare an Action Plan to improve the seismic safety of the nation's existing buildings. The resulting workshop produced *An Action Plan for Reducing Earthquake Hazards of Existing Buildings* (FEMA 90) that laid out a systematic program to develop engineering and societal tools "to reduce the potential for loss of life and life threatening injuries in earthquakes" (FEMA 1985.)

In 1994 the NSF asked EERI to help the National Earthquake Hazard Reduction Program (NEHRP) agencies assess national earthquake research and test facilities, as required in the 1994 NEHRP authorizing legislation. EERI's Experimental Research Committee commissioned papers presented at a workshop funded by NSF and the National Institute of Standards and Technology (NIST) (EERI 1995). The results led to the development of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). Developed with $85 million from the U.S. Congress, today NEES Inc. functions with an annual research and operations budget of over $30 million.

In recent years, EERI's leaders played key roles in promoting and increasing support for the NEHRP, the national program that currently funds seismic research and implementation programs. In 2003, EERI convened a panel of earth scientists, engineers, and social scientists to develop a broad research and outreach plan (EERI 2003 outreach plan). *Securing Society Against Catastrophic Earthquake Losses* provides a vision for the future of earthquake engineering research and implementation that builds on previous accomplishments, but calls for a fundamental shift in mitigation of earthquake risks that takes into account new technologies and new thinking about performance of structures and societal choices. It creates a bold initiative for seismic safety. The report was presented to Congress and its recommendations were reflected in the 2004 NEHRP reauthorization (EERI 2003).

The Future: Continuing a Culture of Multidisciplinary Innovations

Advances in earthquake risk reduction are accomplished through the collective enterprise of architects, emergency managers, engineers, geoscientists, and social scientists. This integrated approach is reflected in hazard-resistant design, guidelines, and codes; a national loss estimation methodology; performance-based engineering; lifeline systems management; improved decision-making; and loss reduction partnerships. Federally funded earthquake hazard reduction programs consistently emphasize the social, economic, and policy factors that govern the adoption and implementation of loss reduction measures. Strategies for research and development are guided by the broader community and socioeconomic contexts in which they are applied. This multidisciplinary nature of earthquake engineering is one of its most significant legacies, providing a model for the future mitigation of natural hazards and human threats. Substantial opportunities exist for the earthquake community to continue its leadership, with the recognition that its contributions have extraordinary value not only for seismic risk reduction, but also for multihazard mitigation and the improved performance of critical infrastructure.

EERI takes great pride in being at the center of earthquake risk reduction for the past 60 years and looks forward to working with partnering associations throughout the world to protect communities, through research, education and public policy, from the potentially devastating impacts of unavoidable earthquakes and tsunamis.

Acknowledgments

This paper builds from an earlier paper by Tubbesing and Anagnos, previous EERI executive director and president, respectively, presented at the 14th World Conference on Earthquake Engineering in Beijing China in October of 2008: *The Earthquake Engineering Research Institute, a Short History of the U.S. National Earthquake Engineering Society.*

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Community Action Plan for Seismic Safety (CAPSS) Project

L. Thomas Tobin and Laura Samant

Introduction

The Community Action Plan for Seismic Safety (CAPSS) is a project conducted by the Applied Technology Council (ATC) for the City and County of San Francisco, Department of Building Inspection. (http://www.sfcapss.org/) San Francisco is a city of 810,000 people located in the State of California. CAPSS will recommend an action plan to reduce earthquake risks in existing buildings regulated by the Department, and to develop repair and rebuilding guidelines that would expedite recovery after an earthquake.
CAPSS describes earthquake damage and consequences as transparently as possible so those affected can understand them and actively participate in the discussion about how to manage these risks. An active citizens' committee meets monthly to advise the project consultants. The committee is comprised of people representing diverse interest groups, such as commercial building and apartment owners; tenants; neighborhood associations; engineers and architects; building contractors; real estate professionals; and City employees responsible for emergency management, disaster recovery planning, land use planning, and building regulation. The committee helps identify what is important to San Franciscans and the consequences of building damage on these values. While knowing building structural types and vulnerabilities is important, building uses and their occupancies determine the social and economic consequences.
CAPSS will report on how the earthquake affects the following issues important to San Francisco:

- Housing availability and affordability
- Small businesses and jobs
- Community character
    - The buildings, scale, architectural and historic building values
    - The people and socio-economic mix
    - Changes caused by constructing larger buildings designed in a modern style
- Number of casualties
- Environmental objectives to reduce the carbon footprint and eliminate waste
- Economic losses
    - Cost to repair damage
    - Business losses
    - losses in income

Risk reduction activities would only be implemented and would only succeed if citizens understand the need, and applicability to their personal situation. Proposals must make sense financially, culturally and politically. While based on technically sound information, CAPSS relies on an advisory committee to comment on which mitigation approaches make sense in all of these ways and are, therefore, good public policy. Because the City of San Francisco is responsible for public safety and welfare, any program would be in the form of an ordinance adopted by the Board of Supervisors and signed by the Mayor. The City might provide incentives, but the cost of retrofit would fall on owners. Success would depend on motivating the entire community, as well as political leaders.

When complete, CAPSS will produce the following four major reports:

- *San Francisco's Earthquake Risk: Report on Potential Earthquake Impacts in San Francisco* (working title)

  This report will present expected damage to San Francisco's privately owned buildings in four scenario earthquakes, and the consequences of that damage to the City's way of life. This includes evaluations of impacts to housing, businesses, City government, and vulnerable populations. This report is expected in Fall 2010.

- *The Road to Resilience* (working title)

Tobin & Associates and Laura Samant Consulting, San Francisco, California

This report will present comprehensive mitigation recommendations for San Francisco's privately owned buildings, based on the analysis of risk described in the previous report and community discussions of consequences, priorities, and feasible mitigation alternatives. It is expected in Fall, 2010.

- *Development of Post Earthquake Repair Provisions* (working title)
  This report recommends improvements to San Francisco's post-earthquake repair policies, specifically, clarifying when damaged buildings can repair to their pre-earthquake conditions and when they also must seismically retrofit their building. It introduces the concept of disproportionate damage, which aims to use small and moderate earthquakes to identify problem buildings and require them to retrofit. This report is expected in Fall, 2010.
- *Here Today-Here Tomorrow: Earthquake Safety for Soft-Story Buildings*
  This report evaluates the earthquake risk of one common residential building type in San Francisco: large wood frame soft-story buildings. These buildings are found to be vulnerable to major damage in future earthquakes, and CAPSS recommends the City to require owners of these buildings to evaluate them, and retrofit if they are found to be vulnerable. This report was released in February 2009.

This paper discusses the overall loss assessment and mitigation planning effort, which are described in the reports discussed in the first two bullets points. The CAPSS project's analysis and recommendations are limited to the City's privately owned buildings. They do not cover public buildings (public schools; city, state, and federal buildings; the San Francisco International airport; and port facilities) and infrastructure (water, sewer, power, gas, transportation, bridges, piers, and tunnels).

Four Scenario Earthquakes

San Francisco is made up of approximately 160,000 buildings, mostly residential, which are owned by more than 150,000 different people or companies. These buildings range from small homes built over a century ago to newly-constructed high-rises. They house the many activities that take place in the City. They also contribute to San Francisco's unique sense of place: they provide the character, sense of history, and structure for the family and community life that makes the City what it is.

CAPSS estimated damage to all privately owned buildings in four possible earthquakes that could strike the City. The four scenario earthquakes are:

- A magnitude 6.9 earthquake on the Hayward fault in the East Bay.
- A magnitude 6.5 earthquake on the portion of the San Andreas fault closest to San Francisco.
- A magnitude 7.9 earthquake on the San Andreas fault, which is a repeat of the 1906 earthquake.
- A magnitude 7.2 earthquake on the peninsula segment of the San Andreas fault.

The magnitude 7.2 earthquake on the San Andreas fault illustrates the consequences the City can expect in future large earthquakes. This earthquake would produce a level of shaking in many areas of the City that is similar to the level of shaking that the building code requires new structures be designed to resist, which makes it a logical choice to focus on. Such an earthquake could be considered expected because enough strain to produce an event of this size has built up on the San Andreas since 1906. Table 1 presents estimates of the number and value of buildings used for various purposes and their estimated damage states following the magnitude 7.2 scenario earthquake. Some key findings of the loss estimates are:

- Around 27,000 buildings in the City would not be safe to occupy after the earthquake. About 73,000 more buildings would have moderate damage but would remain usable. Most of the damaged buildings would be wood frame soft-story buildings, which make up more than half of all buildings in the City. Other structure types, notably concrete buildings built before 1980, would also suffer heavy damage.
- 85,000 housing units—a quarter of the City's total—could not be occupied and would require significant repairs or replacement.
- Two hundred to three hundred people could be killed, and 7,000 more could have injuries requiring medical care. If the earthquake occurs during the day, older concrete commercial buildings would be

responsible for the largest share of casualties. If it occurs at night, soft-story residential buildings would cause the most casualties. Casualties could be much higher if a large, densely occupied building collapses.

- Earthquake shaking sparks fires. It is expected that more fires would occur than the San Francisco Fire Department can address simultaneously, meaning some would burn unchecked for hours.
- Economic losses would be huge. The cost for owners to repair or replace their damaged buildings could be $30 billion. Most of this damage would be uninsured. An additional $10 billion could be lost in damage to building contents, loss of inventory, relocation costs, income losses, and wage loss directly linked to this damage. Post-earthquake fires would add to these losses. Secondary economic losses, stemming from reduced business and household spending, would add additional losses.
- Around 3,600 buildings would need to be demolished and rebuilt. Many of these would be older and architecturally valuable buildings; some would be historic. The City would permanently lose the character and feel that these buildings contribute.

Building occupancy	Estimated number of buildings	Estimated replacement value of buildings ($ billions)	Number of buildings in various states of damage			
			Usable, light damage	Usable, moderate damage	Repairable, cannot be occupied	Not repairable
Single Family Residences	112,000	53	45,000	54,000	11,000	1,700
Two unit residences	19,000	22	8,200	7,400	3,200	290
Three or more unit residences	23,000	45	7,200	7,500	7,200	1,100
Other Residences	800	13	300	400	80	40
Commercial Buildings	5,000	48	1,600	2,400	630	290
Industrial Buildings	2,100	7.7	750	820	320	210
Other	700	2.6	330	280	60	30
Total	160,000	$190	63,000	73,000	23,000	3,600

Table 1. Estimated damage states of buildings in a Magnitude 7.2 earthquake on the San Andreas fault, by building use.

The next major earthquake that strikes San Francisco would change the City and its people. San Francisco is a world-class city with many special attributes that draw businesses, innovative people who want to live here, and visitors from around the world. In the long-term, San Francisco would recover and thrive, but it would be a different San Francisco. It is possible that the new, post-earthquake San Francisco would have less socio-economic diversity. The destruction of many affordable housing options, exacerbated by a limited housing market in the years it would take to rebuild the City, would make it difficult for middle and low-income people to remain in San Francisco. Earthquake damage would stress businesses and the jobs they provide, particularly the many small and independent businesses in the City. It would change the way the City looks, with some of its most interesting and beautiful buildings and neighborhoods changed forever. Despite the damage, San Francisco would retain many of the elements that make it an economically successful and socially desirable place—physical beauty, cultural amenities, and proximity to world-class universities, to name a few.

The scenarios analyzed by CAPSS present what is likely to happen if San Francisco makes no changes to its preparations for earthquakes. Much of this damage may be preventable. It is up to San Franciscans to decide how much to invest in steps to reduce the consequences of the next major earthquake.

Objectives

Programs should define what is to be accomplished before defining priorities and implementation schedules. The objectives also provide a baseline for measuring progress and assuring accountability. San Franciscans are beginning to evaluate earthquake damage, mitigation and preparedness programs considering their values and using a framework of resilience. The advisory committee will discuss the following draft objectives: By 2050 the stock of private buildings in San Francisco will withstand major earthquakes such that the following objectives would be met:

- Recovery target dates are met for housing, buildings with important community uses, and businesses
- No life-threatening failure of a single large occupancy building;
- No fires spread beyond the original structure;
- The City's sense of place, neighborhoods, historic and architecturally important buildings are protected;

The San Francisco Planning & Urban Research Association, better known by its acronym, SPUR, defined by recovery target dates for a variety of short and long-term services required to get the City back up and running. (Reference: *Urbanist*, Issue 479, February 2009) The recovery targets applicable to the stock of private buildings are as follows:

- Residential buildings
    - 95 percent of residents can shelter-in-place within 24 hrs
    - All residential buildings are repaired, replaced or relocated within four months
- Neighborhood retail buildings
    - 90 percent of neighborhood retail businesses are open within 30 days
    - 95 percent of neighborhood retail businesses are open within four months
- General business buildings
    - 50 percent of offices/workplaces open within four months
    - All business buildings are open within three years

Strategy for Implementation

Implementation requires motivating 150,000 building owners to invest significant resources to retrofit or replace their buildings as well as political leaders to adopt, fund and enforce a program that would compete for resources and other worthy causes.

CAPSS believes the strategy must use market forces to encourage evaluation of buildings and retrofitting or replacement of those found deficient. This approach requires an active information campaign and training program so all building owners, engineers and architects, builders, lenders, renters understand the risk from vulnerable buildings and that there are feasible measures to reduce vulnerability citywide and building-by-building.

The second element is to encourage or require building owners to have their building evaluated and to disclose the results to their tenants, prospective tenants and buyers. Building-specific knowledge allows individuals to consider potential earthquake damage when deciding what they are willing to pay to own or rent buildings; the assumption is that knowledgeable people would value earthquake performance along with other values. The owners who voluntarily decide to reduce vulnerability would lead to improve and more efficient analysis methods and retrofit measures. Information encouraging evaluations and disclosure might not be sufficient to cause owners to take the required actions. Because the entire community would benefit from private investments in retrofitting, the City might offer significant incentives. Incentives such as relaxed land use controls or density bonuses, loans or waived fees would make retrofitting easier to accomplish and economically more attractive.

Early adopters would begin to establish a community norm valuing earthquake performance and owners who take steps to improve earthquake performance. Because not every owner would voluntarily decide to spend money to evaluate buildings and improve earthquake performance as appropriate, public policy is needed to

require it. The next step is to require evaluations and retrofitting, if necessary, when buildings are sold or when buildings are expanded or the use is changed.

Voluntary and triggered evaluations and retrofitting projects would further the improvements mentioned above and in establishing the community norm. The assumption is that once a significant number of owners, either by neighborhood or building use, have evaluated and, if necessary, retrofitted, a “tipping point” would be reached and others would want to evaluate and retrofit their buildings. This condition is considered “going viral.”

Ultimately, not everyone will voluntarily comply, and triggers would not affect every building, so the laggards must be required to evaluate and retrofit by a deadline. Knowing that there is an ultimate deadline also reinforces the underlying market-based approach; owners would know there is a deadline and that the City believes strongly in the program.

The time required to evaluate nearly 160,000 buildings and to retrofit those found deficient is significant. Owners need time to plan for the expenditures, arrangements and disruptions inherent in any project. There are a finite number of qualified engineers and architects and building contractors, and the City can process a finite number of permit applications and inspect a finite number of construction sites each year. CAPSS is suggesting that this might take about 40 years.

The Action Plan for Seismic Safety

An action plan will be drafted, discussed and adopted during the fall of 2010. This plan might consist of implementing actions, and setting priorities and an implementation schedule for categories of buildings. A possible program could take 40 years to accomplish and might look something like the draft schedule illustrated in Table 2. This approach gives priority to multi unit residential uses, neighborhood serving retail businesses and private schools. It uses the strategy described above, encouragement through information and incentives, triggered evaluations and disclosure of earthquake vulnerable buildings, and ultimately requiring retrofitting.

The first step in this action plan was addressed in a February 2009 report, titled Here Today-Here Tomorrow: Earthquake Safety for Soft-Story Buildings. The report recommended that the City require owners of wood frame buildings with three or more stories and five or more residential units to evaluate the earthquake resistance of the ground floor. Those buildings found to have a weak or soft floor, would be required to retrofit the ground floor.

Conclusion

The CAPSS project is an innovative approach to addressing the earthquake performance of the 160,000 buildings in San Francisco. It is based on understanding the consequences of earthquake damage on the values held by the residents and leaders of San Francisco, and the desire to be resilient. An active citizens’ advisory committee selected to represent the variety of interests and neighborhoods that make San Francisco special provides advice. The project is making a difference. The Mayor of San Francisco is pursuing the initial recommendations to evaluate 4,400 large wood frame residential buildings and to retrofit those found vulnerable to earthquakes. Recommendations to guide building repair following damaging earthquakes would be completed during the fall of 2010. Because San Francisco faces multiple earthquakes, this policy would consider building damage and earthquake intensity when balancing the need to retrofit overly vulnerable buildings with the need to repair and resume occupancy quickly. Addressing the vulnerability of the remaining vulnerable buildings would be a long-term effort, about 40 years, and rely on a market-based approach that emphasizes evaluation of buildings and disclosure of performance expectations. Ultimately, the City government would set a deadline, such as the year 2050, for all buildings to comply.

Building Category	2010 to 2014	2015 to 2019	2020 to 2024	2025 to 2029	2030 to 2034	2035 to 2039	2040 to 2044	2045 to 2050
Single family and duplexes, wood frame								
3 – 4 units, wood frame								
5+ units, 3+ stories, wood frame								
Large residential, non wood frame								
Private K-12 schools								
Critical retail								
Critical social services			???					

Key to Table Interventions

Intervention	Shade
Information/Incentives	
Triggered requirements	
Analyze and retrofit on sale	
Compliance Required	

Table 2. A Possible Action Plan for Seismic Safety for Private Buildings: Schedule of Interventions

Mianyang Field Visit October 20, 2010

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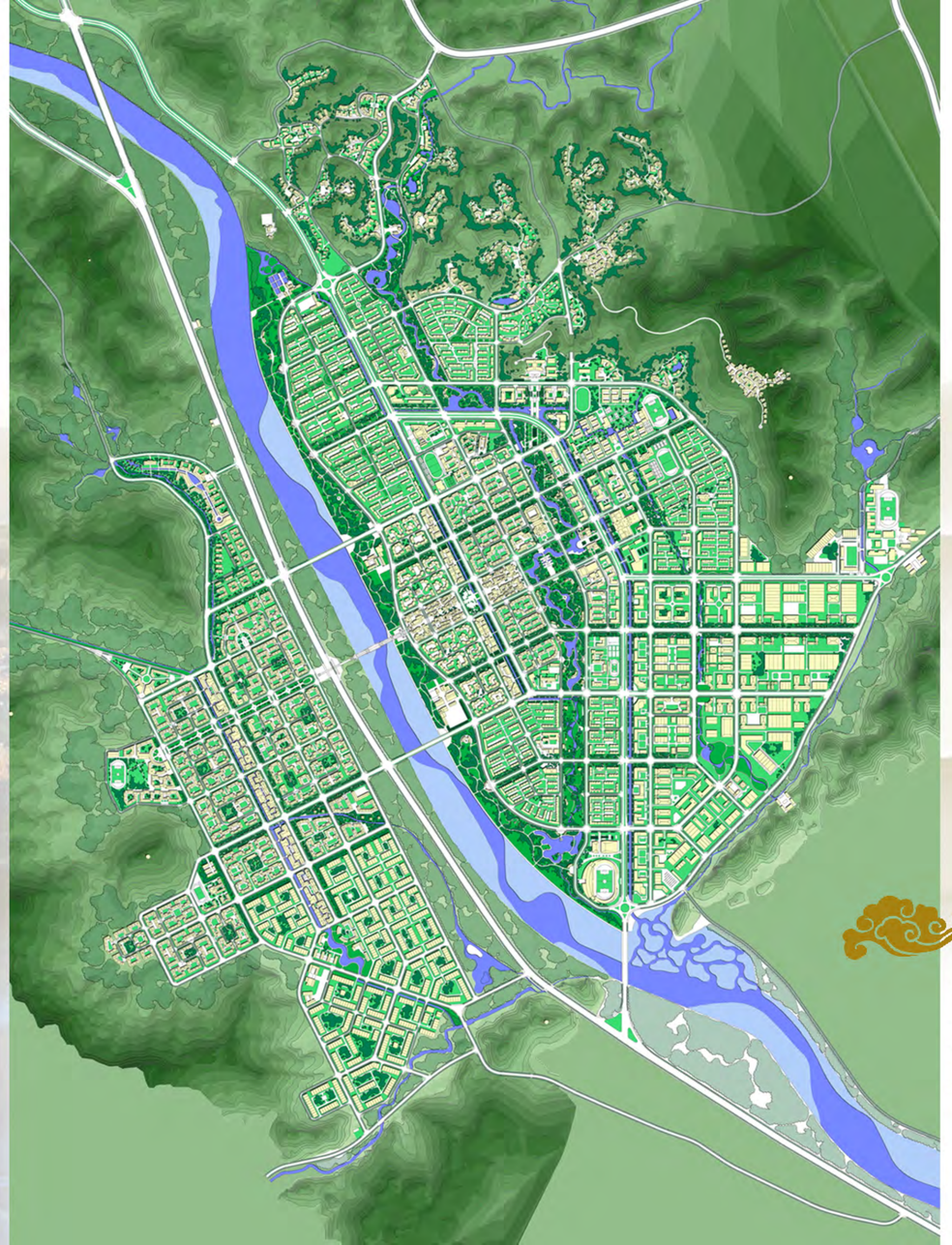
2008
5.12
14:28

北川新县城

10 风貌特色 TOWNESCAPE

北川新县城规划融入城市设计的思想和方法，通过**突出地域特色、优化山水格局和塑造宜人尺度**等三个方面，彰显北川新县城的风貌特色。



城市设计总图

山东临沂援建安居房工
滨河北路
滨河北路
西寺公街

Mianyang Seminar October 21, 2010

China-US Advancement of Earthquake Science and Hazard Mitigation Seminar
Mianzhou Hotel Conference Room B
Mianyang, Sichuan
Thursday, October 21, 2010 09:30 – 12:00

Meeting Minutes

Attendees:

China:

LI Zhengshi, Deputy Commander-in-Chief of the New Beichuan County Seat Construction , and Deputy Director-General of Mianyang Planning Bureau
LI Xiaojiang, President of the China Academy of Urban Planning & Design
ZHU Ziyu Vice-General Planner, CAUPD
WANG Tao Deputy Chief of the Beichuan County Seat
HE Wang Deputy Chief of Construction

USA:

Dr. ABRAMS, Daniel
Mr. BAUSCH, Douglas
Mr. CHOCK, Gary
Mr. EISNER, Richard
Mr. FRANCIS, Mathew
Ms. GREENE, Marjorie
Mr. HWANG, Dennis
Dr. LUCO, Nicolas
Ms. LUO, Chaoying
Dr. MIRANDA, Eduardo
Dr. PETERSEN, Mark
Dr. ROBERTSON, Ian
Dr. SINGH, J. P.
Dr. STOKOE, Kenneth II
Dr. THEODOROPOULOS, Christine
Mr. TOBIN, Thomas
Ms. WANG, Yumei
Mr. WONG, Ivan
Dr. YU, Guangren

09:30 Welcome – LI Zhengshi, Deputy Commander-in-Chief of the New Beichuan County Seat Construction , and Deputy Director-General of Mianyang Planning Bureau

Beichuan County suffered about 20,000 causalities and RMB 57B in losses. On May 19, 2008, the China Academy of Urban Planning & Design visited the area to select a new site for the County Seat. Four potential sites were considered, and the final site selection was made only 10 days after the earthquake. Relocation is away from mountain valley and near-fault seismic zone that is also

subject to landslides and flood. The new County Seat is 24 km away from the old town and 4 km from the near fault "zone".

Over 4000 experts were involved in planning & design of the new County Seat, representing about 50 organizations. There were over 100 meetings in this government driven process. The new Beichuan County Seat construction was comprised of 221 separate projects with aggregate RMB 15.37 construction cost. Quality was a main priority during this planning effort.

Comment [N1]: Gary, my notes show 4000 experts involved.

Some funding came from:
RMB 4.3B from Shandong Province
RMB 3.25B from Investments
RMB 2B from Local Financing
RMB 5B Other

The Beichuan industrial zone is 2.68 km^2 in which RMB 1.71 was invested for the following employment sources:

- Manufacturing
- Food Processing
- Regional Products and Crafts

Thirty one enterprises have already signed contracts for locations within the industrial zone. Four of these companies have already opened their facilities.

Future plans include an educational center for public policy, earthquake research, and natural hazard mitigation.

Presentation on Preservation of Old Beichuan Town by HE Wang:

Old Beichuan town is approximately 73.9 hectares (approximately 3 km^2)

Phase I Structural Preservation

- Steel brace buttressing
- Frame back-up of walls
- Foundation retrofits
- New supplemental foundations
- New dams to stop mud flows
- Rockfall nets installed

Phase II

- Landslides area clearing of debris and floodways
- Grouting for landslide stabilization

Q&A:

FRANCIS: Was there an investigation of the depth of the landslide? A [deferred since no China engineers present]
EISNER: What is the lifespan of the Phase I bracing and the long-term effectiveness? A [future work includes retrofits internal to the buildings]
ROBERTSON and HWANG: Retaining the old structures as an educational memorial was an excellent idea
PETERSEN: The fault rupture used to be visible, going through the town, but is now concealed. Are there any plans to show this extent? A [The rupture was located outside of the town]
CHOCK: It is recommended that the original type and configuration of structural systems be documented for visitors to better understand the performance of the various damaged and collapsed buildings. A [A museum is being created to include such information; Rao Jie: the posters of each building could include depiction of the original architecture]
EISNER: It would be educational to add the Search & Rescue actions taken at each of the collapsed buildings

Presentation on New Beichuan County Seat Planning & Construction by ZHU Ziyu [CAUPD]

Old town was approximately 3 km^2 with a population of over 20,000.
Architecture reflected the Qiang minority
4 possible locations for the new town were considered. The location reached by the central government was the place furthest from the old town, which also has more potential for development. It was formerly farmland. The site is 10 km^2.

Surveys of original inhabitants indicated that 90% desired to move out of the old town, and that 80% of them also preferred a flat land site.

5 km^2 of it is now developed for a population of 35,000. Later, up to 70,000 to 100,000 people are projected to live in the master planned town, and will have a resort area. To the west of the current site is an industrial zone where 37 companies have built facilities covering 1 km^2 that will employ 10,000 people.

Roadways were laid out to establish smaller blocks, with pedestrian ways, which is more efficient for residents. Street lights are LED. The green zone in linear with canal ways. The canals separate the land uses. In the commercial zone, some of these canals are artificial.

Buildings were designed in Beijing emulating Qiang style architecture in three modes:

1. Original Qiang: commercial areas and hospitals
2. Modern Qiang: housing
3. Future Qiang: public buildings

Maximum building height is six stories.

Buildings include:

- 300-bed hospital
- Nursing homes
- Elderly Center
- Rehabilitation Center
- Bridge with retail shops
- 8,000-seat stadium
- Hotel
- Office building for local government
- Performing Arts Center
- Exhibition Hall
- Memorial Plaza
- Regional Bus Station
- Weather Service
- Fire Station
- Police Station
- TV building
- High School for 3,000 to 5,000 students from the county
- Vocational School
- Housing [survivors of old Beichuan can purchase units at less than cost; relocated former farmers can get free units]
- Shandong Province Industrial Park Administration building
- Dormitory for workers

Q&A:
ABRAMS: How are the residential units owned? [A: the housing is subsidized for survivors. The units can be resold.]

THEODOROPOULOS: Is this a model city for development of other cities [A: it is an example for small towns only]

Will there be more towns similar to this? This is a useful concept demonstration [A: Construction was highly subsidized by the central government at no profit. Therefore, normal circumstances would not support similar development. Housing prices would be much higher in commercial development.]

TOBIN: What planning controls will there be in future development design? [CAUPD will be monitoring this. For example, no construction greater than 12 stories will be allowed.]

GREENE: It appears that job training will be necessary for relocated residents of the old Beichuan. [A: There is a training program. Shandong Industrial Park will

employ 10,000; the Commercial Zone will employ 4,000, and tourism will be a third sector.]

ROBERTSON: I suggest arranging a USA student exchange program (e.g., NSF funding for USA participation) where they can visit the old Beichuan ruins.

LI: This is a good idea; we can accommodate that concept.
Currently, China sends 10 Chinese students to UCLA for a year, sponsored by the Chinese government. 20 USA graduate planning and architecture students visit CAUPD for about 3 to 6 weeks.
We (CAUPD) are trying to start a long-term international forum. This USA group is invited to be a co-founder. The concept is for the forum to be a center for the study of:

1. New Beichuan as a case study of urban planning
2. Emergency Management studies
3. Earthquake hazard mitigation and research
4. The center can also become another educational component of economic development for the new Beichuan town

TOBIN and GREENE: EERI is quite interested in becoming a co-sponsor to create this international forum, and we would request information on your idea for our follow-up with you.

BAUSCH: What community involvement was there is the planning process? [A: surveys were used in the development of housing reconstruction. Some of the new residents were involved in construction.]

GREENE: What was the main source of construction workers? [A: there were 35,000 workers at the peak. They came from Shandong and Sichuan Provinces. Construction management was by Shandong Province.]

STOKOE: Old Beichuan represents a unique learning opportunity for students, including speaking with local resident survivors. USA students could visit for 1 to 2 weeks.

LI: CAUPD would like to establish a base for interns and experts to participate in this program. Small forums are proposed as while any ongoing issues are worked out.
RAO Jie: The involvement of multi-disciplinary experts is needed. For New Beichuan, this could be a form of educational tourism for planners and design professionals. We (China) would like to explore this concept further with this group, through Dennis Hwang and the Chinese Chamber of Commerce of Hawaii as an intermediary.
HE: We will formulate planning further on this idea.

ROBERTSON: President LI asked us the question earlier today, "Is the new development safe?" At the time we did not have enough information to give an answer, however I would now say "Absolutely yes", for the following reasons:

1. The old site was hazardous primarily because of potential landslides; the new site is not subject to landslides.
2. The old construction had construction detailing for low seismic hazard areas. The new town is presumably built to the post-Wenchuan building code with higher seismic design standards. Some of the reinforcement detailing and steel construction we observed at the new development indicates far better seismic design than the old town construction.

The one possible issue is flooding from the river; a warning system for flooding may be needed.

HE: The Anchan river flooding has been addressed. Also the design of the landscape green zones with canals had flood control purposes in mind.

LI: (with respect to item 2 above) Quality Control in construction is a national issue. However, we note that the political system and economic resources available for reconstruction is far greater than after the Tangshan earthquake.

WANG Yumei: The construction of the new Beichuan County Seat is a great example for the entire world.

LI: However, I think in general that China, in similar fashion to other larger countries like the USA, soon becomes too complacent, or too comfortable and forgetful about earthquake safety concerns. Smaller countries such as Japan appear to be more attentive to earthquake and disaster preparedness.

Hwang: We should continue this valuable dialogue and maintain contact with you to make further progress on joint collaboration with CAUPD.

12:00 Adjourn

Contact Information:
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China-US Advancement of Earthquake Science and Hazard Mitigation Seminar
Mianyang, Sichuan
Thursday, October 21, 2010

Sitting – Left to Right – David BENNER – US Consulate Chengdu, HE Wang – Deputy Chief of Construction, Douglas BAUSCH – FEMA, Dr. Dan ABRAMS – University of Illinois, LI Zhengshi – New Beichuan County Seat Construction, Marjorie GREENE –

EERI, Dr. Christine THEODOROPOLOUS – University of Oregon, ZHU Ziyu – China Academy of Urban Planning and Design, WANG Tao – Beichuan County Seat ??, Gary CHOCK – Martin & Chock; Standing Mathew FRANCIS – URS Corp., Dr. J.P. SINGH – JP Sing & Associates, Dr. Ken STOKOE – University of Texas, Tom TOBIN – EERI, Jeff GRAHAM – US Consulate Chengdu, Dr. Li ZHENGSHI, CAUPD, Minnie ???????, Dennis HWANG – Chinese Chamber & NOAA, Tessa MA – Beichaun County Government, Dr. Mark PETERSEN – USGS, Ivan WONG – URS Corp., Richard EISNER – Kyoto Unviersity, Rao JIE – China Science Center – International Eurasian Academy of Sciences, Dr. Nicolas LUCO – USGS, Dr. Eduard MIRANDA – Stanford University, Chaoying LUO – Office of John Martin, Dr. Ian ROBERTSON - University of Hawaii, Yumei WANG – Oregon Department of Geology & Minerals, ZHANG Baiping – Architectural Society of China, Dr. Guangran YU – Martin & Chock.

Meetings of October 22, 2010

Beijing Normal University – Academy of Disaster Reduction and Emergency Management (ADREM)

Meeting - October 22, 2010, 9:00-11:30 am

Present – Dr. Christine Theodoropoulos, Yumei Wang, Dennis Hwang, Ivan Wong, Tom Tobin, Dr. Ken Stokoe, Marjorie Greene, Rich Eisner, Douglas Bausch

ADREM Faculty

Dr. LI Jing** -lijing@ires.cn - Geomorphologist – cartographer – Head of Department – willing to collaborate and they have many projects that they work on internationally. He wants to work more on preparedness before disaster rather than response. Attended farewell dinner.
Dr. Saini YANG** – yangsaini@ires.cn – PHd – Associate Professor – www.espre.cn – 15010882575 cell – tel 8610-5880181

- She works on: infrastructure risk assessment – trying to introduce more guidance into the government – reinforcement – more is being done after earthquake –work on pre disaster and mitigation.
- Is earthquake insurance possible? –they are looking into it. New possibility for regulation. Rich Eisner to meet her in Kyoto in a few weeks. Attended farewell dinner. Collaborators – Eisner, Tobin, Hwang

Dr. LIU Jifu** – liujifu@bnu.edu.cn – Research in geology, seismology, and architecture at the Geophysical Institute Interested in post-disaster management based on impacts. Attended farewell dinner. Key collaborators – Bausch, Eisner
Dr. MENG Yaobin – Environmental concerns – disasters considered in a broad way – exposure and chemical impacts – impact caused by chemicals.
Dr. Zhao ZHANG - PhD – Surface processes including hydrology, forest watershed, risk, biology, climate change and human health. (Studied in Japan) Associate Professor – zhangzhao@ires.cn
Dr. WANG Ming is currently working on the research of earthquake insurance and flood insurance. He was not present at the meeting. Contact information forwarded to him.

Six Graduate Students Attended – Areas they work on included:
Work on Disaster Research – GIS – Typhoon and Storms;
Doctoral Student – Ecology;
Wai Yuen – Remote Sensing – GIS;
Mr. Wang – Cartography; and
Sui Yung – GIS – going for doctorate

Presentation by Dr. Li on Background and work of ADREM

- ADREM wasscreated atBeijing Normal University in 2006 by the Ministry of Civil Affairs and the Ministry of Education – Its main task is Research and

Development, Training, and International Cooperation in Disaster and Emergency Management. 34 professors from Beijing Normal University

- 4 of its Professors are on the Board of Experts. There are 39 Experts in entire country
- ADREM - 4 Institutes and one Key Lab
    - Disaster Institute
    - Geoinformation Institute
    - Institute of Arid and Desert
    - Risk Institute
    - On Environmental Change and Natural Disaster
- They have completed:
    - Atlas – for Earthquakes
    - Text books for high school and undergraduate
- 2008 Earthquake - technology books for disaster risk reduction andpolicy – copies given to Tom Tobin – in Chinese – (no Figures)
- 2010 Yushu earthquake- 10 cm resolution remote sensing
- Conduct Landslide monitoring
    - Using camera to create vector maps
    - Remote Sensing
    - Data after earthquake –data sent to Beijing
    - Field Stations
- Disaster Assessment – table maps
- Studied March 2010 Landslide
- Risk Assessment – before disaster they analyze risk
    - Their audience is China's insurance company and local governments
    - Flood Risk assessment. Flood risk areas identified
        - But there appears to be no guidance on their use– this may be of interest to them
        - No flood insurance; it is something they are looking into
- They have a wind tunnel to test for typhoons, located in Beijing but off campus
- International Cooperation – They have 7 International Projects – one with Daniel Sui – Department of Geography – Texas – but then moved to Ohio State on Disaster Management
- Ministry of Civil Affairs – they work with and try and develop rules and policy based on their research. This is an area of collaboration with USA.
- Insurance Company – a government company in China wants to know where high and low risk. In the context of earthquake or flood insurance.

In General – They would like to spend more time and resources on preparation, planning and mitigation before disaster. Currently most of their effort is devoted to post- disaster response. They want to work more on mitigation and pre-disaster preparation. They are in charge of natural sciences—there is another group at Beijing Normal University that researches the social science issues; that group is called Public Policy and Social Safety.

Presentations by USA side:

Earthquake Response Presentation by Richard Eisner – information after an earthquake through California Integrated Seismic Network – Different maps through internet. One source of information for natural hazards – always running on the internet - California and from USGS – not a website but a JAVA push – tool for emergency managers, researchers. The delivery system is supported by three servers that are processing the data from the regional networks and the Global Seismic Network one at Caltech in southern California, one at Berkeley in northern California and one at the USGS in Menlo Park. Users have to subscribe; the system can support 20,000 users. Includes Pager Notification, Pop-Up Shake Maps, and notification of issuance of tsunami information. Can be delivered to remote locations over internet or satellite ISP.

HAZUS Presentation by Douglas Bausch – Review of loss estimation – Earthquake, Flood and Hurricane Wind Modules – to help identify vulnerabilities, mitigation strategies, awareness and to trigger action based on many scenarios. Also Shakemaps using different scenarios leads to many hazard and inventory improvements.

Implementation and Converting Science into Guidance, Policy and Laws – Presentation by Dennis Hwang – Described the seven key elements for implementation by scientists, agencies, and law makers as a continuum including knowledge, information, guidance, industry standard, policy, existing authority, and new regulation. Work on Guidance is an emphasis for agencies working to reduce hazard risk such as FEMA and NOAA. It is what Universities are capable of doing along with their research to determine risk and put it in a planning perspective. Guidance developed by scientists and engineers can be readily implemented with policy so that it can become a standard, be used within existing authority or form the basis of new rules.

Discussion

- Christine Theodoropolous – Students as part of education can analyze building stock performance.
- Tom Tobin – Have an interest in recommendations for schools, specifically what knowledge is given to children – for example, text books prepared for Chinese. Leadership for Earthquake Hazards comes from the University – but are social scientists involved? – What is the relationship with policy? – Who is in charge of social science part?
- Yumei Wang – Suggested the FEMA disaster resistant university program as a possible area of collaboration

Areas of Collaboration

1) Exchange of students to work on projects like the development of disaster plans – Geography – geology – possible – For example, small towns don't have resources in Oregon – so the students help create the plans - They are curious. Maybe GIS based.

2) EERI – interested in institutionalizing use of remote sensing data after earthquakes to help in damage assessment. Hope to develop an interface so researchers from around the world can participate online.
3) HAZUS and other risk analyses – they are open – to demonstration Sichuan project. Bausch
4) Emergency Planning – How to build and implement emergency plan – HAZUS used scenarios to develop and test plan. Example: SFBA Regional Emergency Coordination Plan (2006) and Golden Guardian Exercise 2006 (tested plan) Interested in taking into account impacts. Dr. Liu very interested in this and can work with Bausch and Eisner.
5) Analyzing and researching need and mechanism for earthquake insurance, flood insurance. Dr. Wang Ming.
6) Developing Guidance for Government on pre-disaster planning and mitigation based on hazard maps, or converting research knowledge into a useful form for disaster risk reduction.
7) Their lab is very active in relevant research and they have many international collaboration efforts. They hope we can get a good research topic soon.
8) Invitation requested for Dr. Saini Yang to attend the Boulder Natural Hazards Workshop July 9-12, 2011 – Bausch
9) Interest in collaborating with NERSS on a demonstration project that integrates HAZUS - Bausch

On October 31, 2010, Professor Li Jing e-mailed the group and expressed an interest in collaborating on the following items:

- remote sensing and use of GIS for disaster management
- disaster risk analysis;
- knowledge transfer on disaster reduction;

First Row – Left to Right – Dennis Hwang – Chinese Chamber – University of Hawaii Sea Grant - NOAA, Marjorie Greene _EERI, Dr. Saini Yang, Yumei Wang – Oregon Dept. of Geology & Minerals, Dr. Li Jing, Dr. Christine Theodoropolous – University of Oregon, Dr. Liu Jifu; Second Row – Ivan Wong _ URS Corp., Douglas Bausch - FEMA, Tom Tobin - EERI, Rich Eisner – Kiyoto University, Dr. Ken Stokoe – University of Texas, Dr. Yaobin Meng

Meeting with China Academy of Building Research [CABR]
Institute of Earthquake Engineering
Friday, October 22,2010
09:00 – 12030

Meeting Minutes

09:00 Welcoming Remarks – by CABR

The China Academy of Building Research consists of four main branches:

- The Institute of Earthquake Engineering
- The Institute of Building Structures
- The Institute of Building Materials, and
- The Institute of Building Engineering Software

The China Academy of Building Research establishes many standards for design and construction, including:
Code for seismic design of buildings, building design loads, and material-specific standards

Copies of the CABR brochure were distributed. http://www.cabrtech.com

09:05 Overview of meeting objective: Identification of Areas for Engineering Research Collaboration - Mr. CHOCK

09:10 Self-introduction of China and USA participants

Attendees:

China:

Professor WANG Cuikun, Executive Vice President & Deputy Chief Engineer wangcuikun@cabrtech.com , (86) 13501070723 mobile

Dr. ZHOU Xiyuan, Director, Beijing Laboratory of Earthquake Engineering & Structural Retrofit, zhouxy@bjut.edu.cn , *6-10-67392499

Dr. XUE Yantao, Deputy Director, yantaoxue@sina.com , (86) 13501034240 mobile

Professor YANG Shen Deputy Director, Institute of Earthquake Engineering, CABR, ysthomas@sohu.com [note: Guangren Yu's college classmate]

Dr. TIAN Chunyu, Director Engineer, tianchunyu@cabrtech.com , 86 13661105693

Note: HUANG Shimin Tel: +86 10 64517435 <hsmcabr@yahoo.com.cn> who spoke at the opening of the Symposium on behalf of CABR as co-organizer
and WANG Yayoung <yayongwang@sina.com> Tel: 86 10 84282354 were not in attendance due to other commitments

USA:

Mr. CHOCK, Gary
Ms. LUO, Chaoying
Dr. YU, Guangren

Dr. ROBERTSON, Ian
Dr. MIRANDA, Eduardo
Dr. ABRAMS, Daniel
Dr. LUCO, Nicolas
Dr. SINGH, J.P.

CABR members in attendance (left to right): Yang, Wang, Zhou, Tian, Xue

09:20 Seismic Comparison of Current USA and China Seismic Codes - Presentation by Mr. CHOCK and Dr.YU and discussion

A short version of the presentation of the Symposium paper, Comparison of USA and China Seismic Design Procedures

Dr. ZHOU remarked that in the 1974 Chinese seismic code, R factors had been used. However, in the 1980 Chinese code these were abandoned and the design shifted to the frequent earthquake level, which also results in a reduction of load.

The seismic drift criteria for R/C structures in China is about 20% stricter than in the USA.

It was not known how the loads would compare for other material such as brick.

Eduardo MIRANDA noted that the R factors should really be period dependent.

Chaoying LUO said that the experience with steel structures was that member sizing under each code would yield similar results.

It was the consensus that further comparisons of base shear, drift requirements, and detailing requirements should be done for other structural systems.

Nico LUCO remarked that the base shear coefficient should be derived directly from the seismic hazard curve.

WANG Cuikun stated that CABR has a customized China version of ETABS and a integrated design program package called PKPM, which includes architectural design, structural design, building services, and statistical analysis of building quantities and budget. This might be useful for developing these comparative designs.

09:40 Lessons learned from the Wenchuan and Qinghai earthquakes towards improving seismic safety of buildings, including schools and emergency response buildings such as hospitals – Presentation by Dr. XUE of CABR and discussion:

The May 12, 2008 M8 Wenchuan earthquake had 7 aftershocks of greater than M7

Intensity for design had been 7 per the code of the period but intensities of 11 to 12 were experienced.

Although Beichuan was ~300 km from the epicenter, the fault rupture extended through Beichuan.

R/C moment frames of up to 2001 code vintage and pre-1990 masonry buildings tended to suffer collapses.

The April 14 2010 Yushu (Qinghai) earthquake:

There were many self-built no-code masonry buildings:

CMU URM and concrete column and beam gravity frames and fired brick bearing wall buildings

Lessons:

1. Siting and planning for seismic hazards
2. Seismic hazard level determination should be improved
3. Housing and no-code buildings are especially hazardous
4. R/C and Masonry building design provisions have been improved in the 2010 China Seismic Design Code
5. There is a need to retrofit existing low-code and no-code buildings

10:00 Design Criteria for Enhanced Reliability of Schools and Emergency Response Buildings such as Hospitals – Discussion lead by Dr. ROBERTSON and Dr. XUE

Schools:

Typically have long-span conditions and longitudinal walls only at the perimeter.

Most schools were built prior to the 1990's and most were URM and did not have reserve strength.

According to the Chengdu Design Institute, 104 schools built in the post- 2000 era preformed acceptably.

School retrofits have included BRB's, ECB's and Base Isolation techniques.

Hospitals:

Originally, there were no special requirements for hospital designs. Some minor to moderately damaged hospitals were not staffed by physicians because of concern about structural integrity and had to be evacuated. Special design requirements are needed, such as column elements requirements for higher forces and improved detailing.

Any near Fault condition requirements (say, within 5 km)? Just for buildings with Performance-Based designs. The code assumes uniformly scaled amplifications based just on soil types.

10:15 Seismic testing –- Discussion lead by CABR's TIAN Chunyu:
The CABR seismic shake table is 6m x 6m and is the largest in China
They can test payloads of up to 60 tons
The shake table has been used for high-rise, special structures, and large-scale structures. Some of these models are up to 1:40 scale. The models are built with mortar and wire. The larger models may take up to 3 months to build. They have over 30 model constructors and about 10 testing personnel in the laboratory.

They have also studied 1:10 scale prototypical R/C frames to collapse for prescriptive design rules for stiffness, varying the first story column heights from 5.8m (strong column behavior exhibited), 6.8m (first story column failures), to 7.8 meters (first story column failures). The frames were also modeled with ABACUS. There is a paper in Chinese relating to the relative stiffness parameter limitations.

Other quasi-static tests have been done at 1:5 to 1:10 scale, including joints, composite columns, concrete filled tubes, and steel-plate reinforced shear walls.
Collaborations also exist with universities such as Tsinghua and Beijing University of Technology (which is Dr. ZHOU's academic affiliation)

10:45 Discussion and plans for future contact and research collaboration areas– Lead by CABR and Mr. CHOCK
NEES has a special emphasis on joint research with China in the next research announcement. NEES will fund the portion done in the USA. NEES hub can also provide an IT collaborative platform for dissemination of results.
Post-Wenchuan earthquake seismic design improvements could be an area of study. Hybrid simulation techniques could be utilized.
It may also be worthwhile to examine drift-sensitive nonstructural provisions

11:00 Seismic Design Provisions for Masonry Buildings – Discussion lead by Dr. ABRAMS

The 2011 MSJC code for the USA will be printed in the spring, covering:
Unreinforced Masonry, URM

Reinforced Masonry, RM
Infill walls
Confined Masonry
Different detailing requirements for different R factors
Prescriptive, allowable stress, and strength design approaches
ASCE 41 displacement-driven rehabilitation methods

At the NEES@University of Illinois, research into Hybrid Masonry is ongoing, consisting of a steel frame and masonry panels with a contact gap inbetween. This is a 3-year project with testing occurring in 2011. Multiple performance points will be established.

EERI is also examining the performance of confined masonry in earthquakes

11:20 Wrap-up comments by CABR and USA team leaders – CABR and Mr. CHOCK

- The USA team will prepare a research digest with links to ongoing work
- Dr. TIAN will prepare a research digest of ongoing and future CABR work.

From this, the projects of common interest will be identified. Note that NEES projects could result in USA students going to China for collaborative research.

Preliminary areas of potential joint research:
Hybrid masonry
Collapse simulation
Hybrid simulation
Infill masonry
Confined masonry
Nonstructural element damage performance
Design comparisons between the USA and China

In about a month, serious work on a draft joint research proposal should be substantially completed. The NEES research grant program has a March 2011 due date.

11:50 Adjournment

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Meeting at the Center for Earth Observation and Digital Earth
China Academy of Sciences
Friday, October 22, 2010

Dr. ZHANG Bing, Deputy Director (zb@ceode.ac.cn)
Dr. LIU Liangyang
Dr. FAN Xiangtao
Dr. BI Jiantao (jtbi@ceode.ac.cn)
Dr. CHEN Mingmei, International Affairs Office (mmchen@ceode.ac.cn)
[I might still be missing someone—does anyone have a card with another name?]

Doug Bausch
Ivan Wong
Ken Stokoe
Marjorie Greene
Yumei Wang

CEODE was established in 2007. They are part of the Chinese Academy of Sciences. They have an annual budget of 60 million RMB (+/- $8m U.S), 250 permanent scientists, a staff of several thousand, and 150 graduate students. More information at www.ceode.ac.cn. They also host the International Programme Office for the Integrated Research on Disaster Risk program. The director of this program is an American scientist, Dr. Jane Rovins (http://www.icsu.org/1_icsuinscience/ENVI_Hazards_1.html)

As a result of the Wenchuan earthquake in 2008 and Yushu in 2010 they have had significant experience implementing remote sensing in earthquakes. The majority of the products from Wenchuan were high res aerial optical imagery, with collapse analysis and transportation analysis done manually. However, it appeared they turned it around very quickly and for Wenchuan that was 20,000 sq km of .33M imagery. Their main aerial platform is a former 90 passenger plane and it appeared they do a lot of processing in the air that expedited the analysis. They utilized their .5M Synthetic Aperture Radar (SAR) platform for the landslide and earthquake lake assessment that was very impressive. They have also done a lot of work documenting the recovery, including the building of new Beichuan. CEODE experimented with auto extraction using texture and spectrum features for Beichuan, and they calculated house collapse ratios with spatial interpolation methods. Comparing the collapse ratios to the ShakeMaps could be very valuable, however, information on building types would also be critical. They used RS for agricultural damage monitoring, panda habitat loss monitoring, and civilian rescue and monitoring. After the Yushu earthquake they flew the data during the same day (immediately), and analyzed it at night. They calculated a house collapse rate of 53%, but on the Zhaxike alluvial fan the collapse rate increased to 82%. The house collapse ratio fell to 0 at 4 km from the fault.

CEODE also uses products through the International Charter, including the InSAR platform following Wenchuan.

Dr. BI Jiantao made an extensive presentation on their use of RS after Wenchuan and Yushu. It's 85 MB, but we can make it available to researchers who are interested.

CEODE has no direct relationships with any U.S. groups, but they do have international relationships with IAPR (possibly International Association for Pattern Recognition) and IAP-NDM (Inter Academy Panel—Natural Disaster Mitigation. This appears to be a global panel of science academies).

They are very interested in exploring possibilities for collaboration, particularly workshops where information and research findings can be exchanged as well as opportunities for research collaboration. Two immediate possibilities that seem worth exploring—involve this group in the Remote Sensing workshop series organized by ImageCat, and explore possibilities for support from either NSF or NAS for a small workshop to meet and identify possible joint research programs that might then be supported by NSF and CAS. The Integrated Research on Disaster Risk program appears to cover a wider range of topics than just remote sensing, so there might be some possibility there for collaboration with the broader earthquake community.

(from left: BI Jiantao; Fan Xiangtao; Ivan Wong; Marjorie Greene; Doug Bausch; ZHANG Bing; Ken Stokoe; Yumei Wang; LIU Liangyan)

Meeting with Tsinghua University

Friday, October 22, 2010, 14:30 – 16:30

Meeting Summary

Attendees:

China: Prof. SHI Yongjiu (Head of School of Civil Engineering)
Prof. SONG Erxiang (Vice Head of School of Civil Engineering)
Prof. MA Zhiliang (Vice Head of School of Civil Engineering, International)
Prof. HAN Linhai (Director of Department of Civil Engineering)
Prof. QIAN, Jiaru
Prof. YE, Lieping
Dr. JI Xiaodong
Dr. YU Hongxia
Dr. ZHAO Zuozhou
Dr. GANG Shi
Dr. LU, Xinzheng
A number of students from Tsinghua were also in attendance

USA: Dr. MIRANDA, Eduardo
Dr. ROBERTSON, Ian
Mr. CHOCK, Gary
Dr. ABRAMS, Daniel
Dr. LUCO, Nicolas
Ms. LUO, Chaoying
Dr. SINGH, J. P.
Dr. THEODOROPOULOS, Christine
Dr. YU, Guangren

SHI Yongjiu welcomed the US team to Tsinghua University.

ROBERTSON provided a brief overview of the meeting objectives, with emphasis on the desire for collaborative research on topics of common interest.

HAN Linhai gave on overview of the Department of Civil Engineering of Tsinghua University.

Tsinghua University was founded in 1911. Beginning in 1952, it became a university focused on technology. It has 56 departments in 15 schools, and has approximately 32,000 students.
The School of Engineering has 64 Professors, 50 Associate Professors and 22 lecturers, and offers the four degree programs.

The B.Eng. degree is a 4 year program with around 210 freshmen each year.
The B.Sc. degree is a 2-3 year program with about 140 freshmen per year.
The M.Eng. degree is a 3-5 year program including coursework and research.
The Ph.D. degree is a 4-5 year program after the B.Eng. degree.

The Civil Engineering Department began in 1926 and has 22 Professors, 20 Associate Professors and 9 Lecturers. There are 480 undergraduate, 180 Masters and 150 Ph.D. students. See http://civil.tsinghua.edu.cn for more information.

The Hazard Prevention and Mitigation Group has the following areas of interest:

- City Planning
- Earthquake Resistance
- Fire Resistance
- Reliability of Structures
- Structural Health Monitoring

International Exchanges occur at both the student and faculty levels, and through seminars, workshops, and conference participation.
The laboratories at Tsinghua have very high load test capabilities.

LU Xinsheng gave a presentation on "Research on Collapse Resistance of Building Structures". This included consideration of building performance under seismic conditions as well as progressive collapse. He outlined some of the extensive research being performed at Tsinghua in this area, including laboratory testing of building components and systems, and computer simulations of building performance, including collapse.

Damage vs. Building Construction Date:
Benchmark modern construction eras are 1979-1988, 1989 – 2001, and 2002 to the present. Lesser amounts of earthquake damage occur with each step towards the present era.

Schools have experienced the most damage, especially those without ring beams. The effects of slabs and infill walls on seismic performance should be considered.

Failure analysis studies are ongoing both as physical and numerical simulations. They are looking at Importance Indexes for structural elements, varying by type of element and its location. Essentially, this would comprise Importance Factors applied individually, rather than a single value applied to the total structural system.

Design Guides have been published on:
Collapse Simulations of Super High-Rise Buildings
Progressive Collapse Simulations
Fire Collapse Simulation

YU Hongxia gave a presentation on "Research on Fire resistance and Regional Disaster Prevention". She highlighted on-going research at Tsinghua into better understanding of building performance during fires. This included evacuation of building occupants during a fire. She demonstrated a computer simulation of such an evacuation for a Zhenjing City building. This work was funded by NSF-China, as a decision support tool for the following hazards:

Earthquake
Fire
Flood
Landslides

Fire spread following earthquake has been modeled by building, including the phases of ignition, flashover, development, collapse, and extinction. Components of this modeling include:

- Fire evacuation: CFD modeling of fire spread and smoke
- Testing of elements and connections for fire
- Fire loading of frames - analysis of joints by Finite Elements
- Parametric structural system performance for temperature-loading effects on deformation and load capacity

MIRANDA, Eduardo, gave a presentation on "Building Specific Loss Estimation for Performance Based Design", highlighting the recent PEER development of Performance Based Earthquake Engineering. (See symposium ppt)

Performance-Based Engineering for the "3-D" losses of:

Dollars
Downtime
Deaths

In a 2008 study, it was shown by Deierlein and Haselton that the reliability of R/C frames designed to code was highly variable.

The framework for analysis using the Risk Integral encompasses the conditional probabilities of Ground Motion, Structural Response, Building Damage, and 3D losses.

YU, Guangren, gave a presentation on "Comparison of USA and China Seismic Design Procedures". (See symposium ppt by Yu, Chock, and Luo)

This presentation included comparison of a multi-story moment frame building designed for the same earthquake demands, but using either the US or China building design code. It was noted that the China code resulted in significantly larger members, particularly column size. Discussion followed about the expected performance of these buildings, given the substantial difference in design.

LU: Recently a similar study comparing Japanese and Chinese building codes for 4 prototypical buildings had shown that the Japanese design would likely result in even larger structural members than both the Chinese and US codes. In particular, the Japanese designs had bigger columns in R/C frames of 4, 7, and 9 stories. The effect of infill walls on stiffness and response were ignored.

CHOCK and ROBERTSON requested the report on that comparison.

All agreed it would be useful to extend these comparisons to include USA designs and other prototypes.

It was noted that in Sichuan Province and in schools it is more common to have shear wall structures, so these should be included in any code comparisons.

A number of participants were interested in pursuing this topic both in terms of design requirements and also in expected building performance during a scenario earthquake.

Participants discussed the following potential research topics for future collaboration:

LU: Tsinghua research goals are for
High-performance Structures
Recommendations for new seismic hazard –based design codes
Design guidelines for collapse prevention

Ongoing work includes:
NSF-C sponsored research
Chinese Academy of Engineering

Subject matter:
Collapse mechanism
Collapse prevention of R/C frames
Collapse prevention of schools
Regional disaster loss prediction modeling based on the Wenchuan earthquake data set

USA:

NEES-NSF
International Collaboration with China is specifically encouraged. A joint research project including several NEES facilities, on standardized designs, and the use of international participation should be of great interest to NSF, including one on R/C Frames, shearwalls or reinforced masonry. This could include comparative design studies.

Potential comparative studies of prototypical buildings designed using US and Chinese seismic design standards.

- Concrete buildings using moment frames and/or shear walls
- Steel buildings using moment frames or eccentric bracing
- Non-linear analysis of final design to evaluate push-over performance
- Non-linear time history analysis of final designs to evaluate scenario earthquake performance
- Laboratory testing of selected critical components highlighted by non-linear analysis

Hospital Design Code Development
R/C frame gap research [Jack Moehle, Grand Challenge Project]

Other Programs

LU: The equivalent of FEMA 356 and ASCE 41 are needed in China.

The formal meeting adjourned at 16:00.

LU, Xinzheng, and ____ gave the US participants a tour of the Structural Testing facilities at Tsinghua University, including descriptions of a number of current and recent research projects.

- New large capacity compression test frame with ability to apply biaxial lateral loads (Figure 1).
- Full-scale column tests planned for new test frame (Figure 2).
- Beam-Slab-Column connection tests (Figure 3).
- Precast hollow-core concrete wall systems (Figure 4).
- Concrete beam to concrete-filled steel tube column connection tests (Figure 5).
- Steel beam-to-column connection tests (Figure 6).
- Prestressed composite beam flexural tests (Figure 7).
- Truck impact on bridge girder tests (Figure 8).

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YU, Guangren gyu@martinchock.com Tel 1-808-521-4513
LUO, Chaoying, cy@johnmartin.com, Tel: 86 10 85261800 ext.801

Figure 1: New large capacity test frame.

Figure 2: Full-scale column test program

Figure 3a: Interior Beam-Slab-Column test specimen in test frame.

Figure 3b: Beam-Slab-Column exterior and corner connection test specimens

Figure 4: Precast hollow core shear wall test specimens

Figure 5: RC Beam to Concrete-filled steel tube column connections under fabrication

Figure 6: Steel Beam-Column connection test specimens

Figure 7: Prestressed composite beam flexural test specimens

Figure 8: Testing of prestressed bridge beam impacted by tanker truck (inverted).

Researches on Collapse Resistance of Building Structures

Lieping YE, Xinzheng LU

Department of Civil Engineering
Tsinghua University
October 22, 2010

1

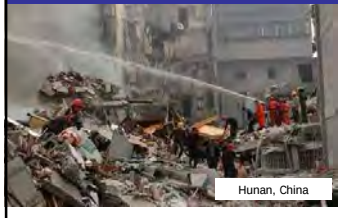
Gas Explosion

Shandong, China

Strong Earthquake

Sichuan, China

Fire



Hunan, China

Typhoon

Fujian, China

Vehicle Collision

Henan, China

Heavy Snow

Shandong, China

Subsidence

Guangdong, China

Failure of Pile

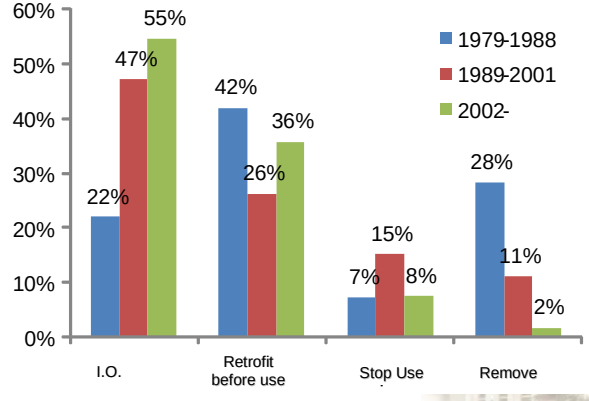
Shanghai, China

2008 Wenchuan M8.0 Earthquake

4

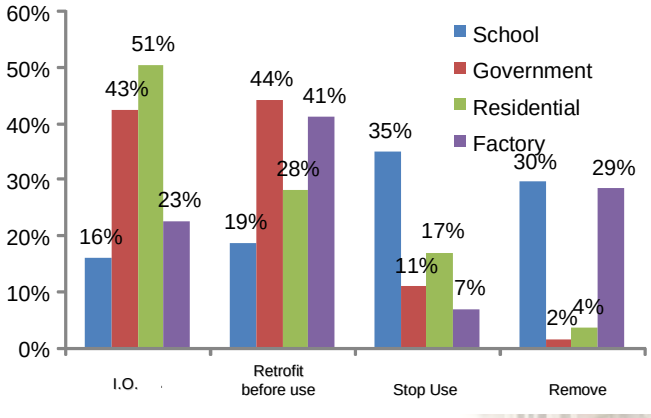
2010 Yushu M7.1 Earthquake

Comparison of Building Damage



Ye LP, Lu XZ, Analysis on Building Seismic Damage in Wenchuan Earthquake, *Journal of Building Structures*, 2008, 29(4):61-9.

Comparison of Building Damage



Ye LP, Lu XZ, Analysis on Building Seismic Damage in Wenchuan Earthquake, *Journal of Building Structures*, 2008, 29(4):71-9.

Introduction

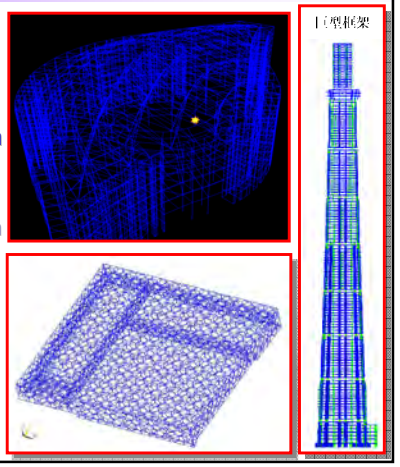
- **Current structure design:**
  - **Ensure the structural safety based on elemental safety**
- **Under extreme events and accidental loads:**
  - **Some elements may be failure and loss its function from the structure system**
- **The ultimate state of current design method is for structural element, not for whole structure**
- **Collapse ultimate state for the whole structure must be considered**

8

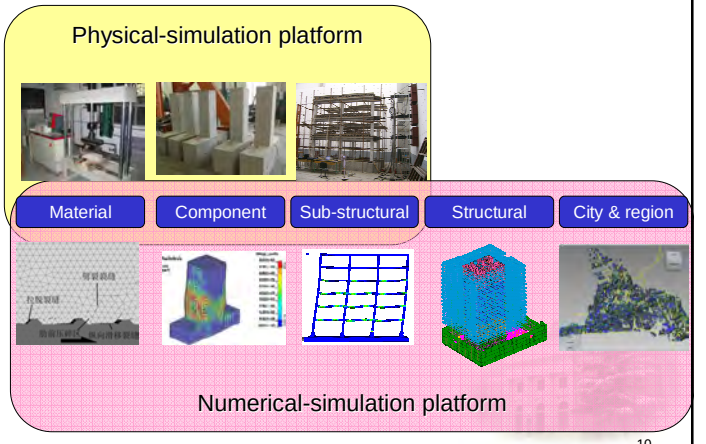
Introduction

- Structure is a complex system. The weakest position control the collapse ultimate state of the structure system
- It is important to find the weak position and to enhance its strength or deformability, or provide alternative paths

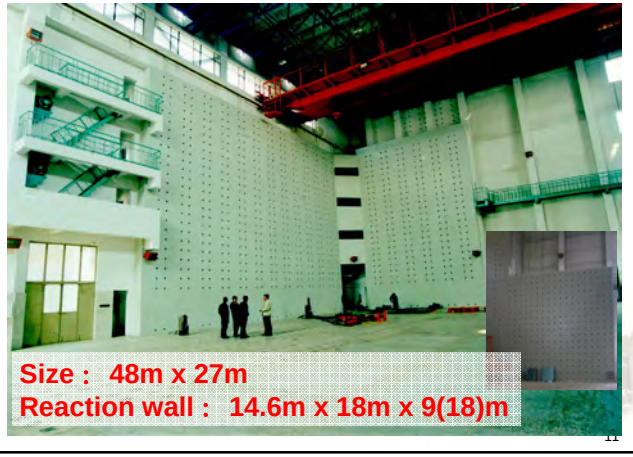
- **How to find?**



Introduction



Physical-simulation platform

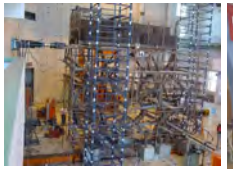


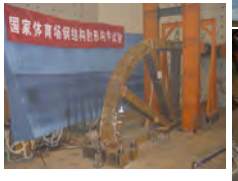
Physical-simulation platform

Physical-simulation platform

Full-scale Tests

Physical-simulation platform





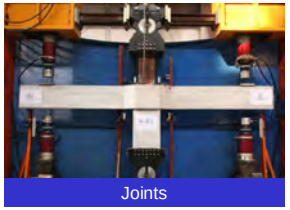
Participate in important projects

Physical-simulation platform

Pseudo dynamic

Nuclear safe shell

BRB

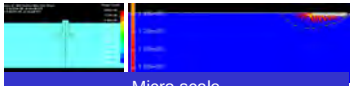


Joints

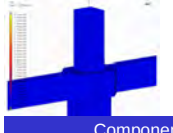
FRP Retrofit

Numerical-simulation platform

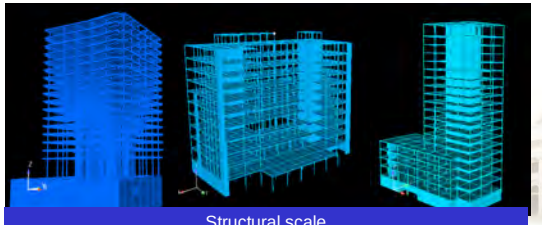
Single structure level



Micro scale

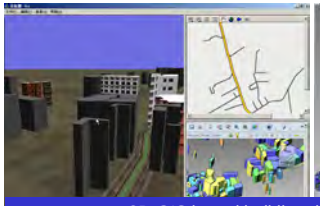


Component scale



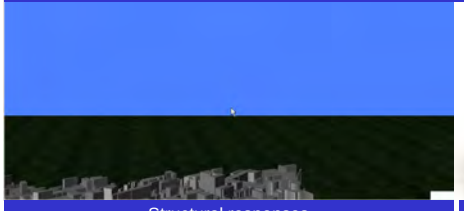
Structural scale

Numerical-simulation platform



Region or city level

3D-GIS based building damage prediction



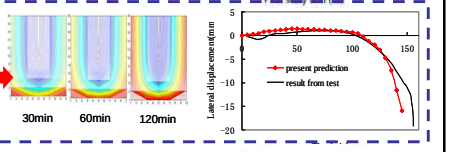
Structural responses

Earthquake induced fire

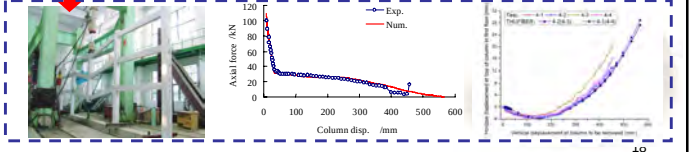
Validation of numerical models

Earthquake

Fire



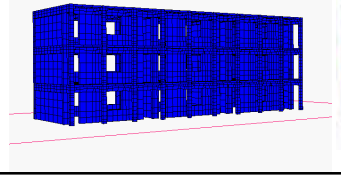
Progressive collapse

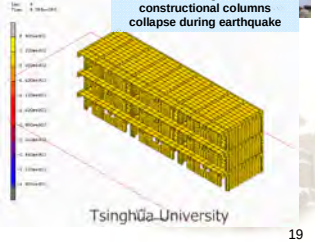


Application after Wenchuan EQ

Without RC ring beams and constructional columns collapse during earthquake

With RC ring beams and constructional columns survived





Tsinghua University

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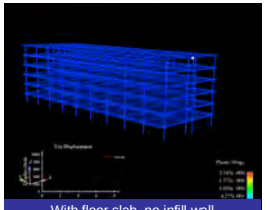
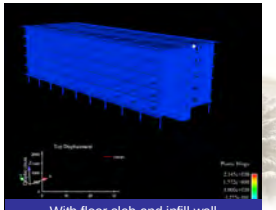
Application after Wenchuan EQ

Real structure

No floor slab, no infill wall



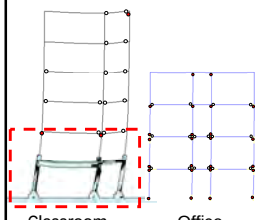
With floor slab, no infill wall

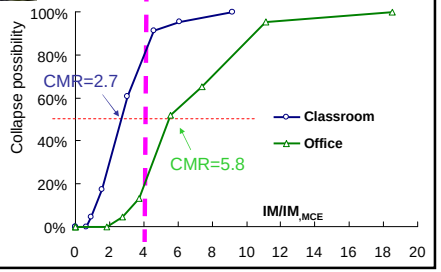


With floor slab and infill wall

20

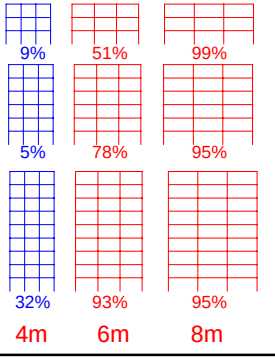
Application after Wenchuan EQ

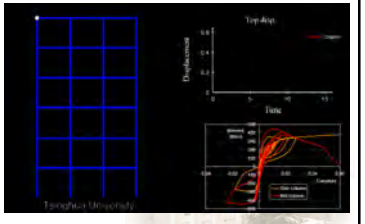




Application after Wenchuan EQ

- Collapse possibilities of frames in Wenchuan Earthquake





22

Optimized design

•Classify structural elements with different important levels
→ Rational safety margin

$$I = \frac{U' - U}{U'} = 1 - \frac{U}{U'}$$

Original structure

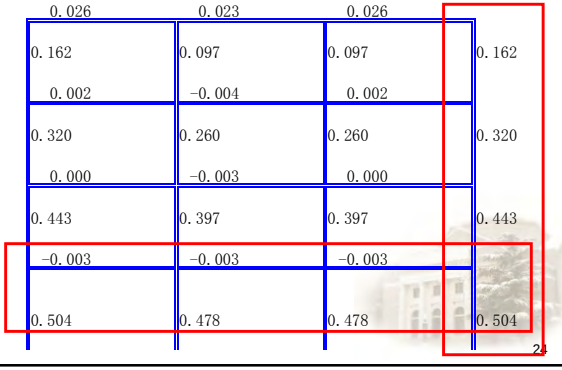
Importance index

Damaged structure

23

Optimized design

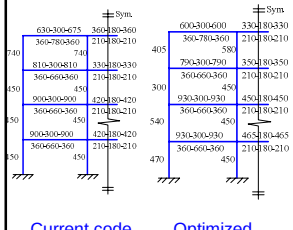
•Classify structural elements with different important levels
→ Rational safety margin



24

Optimized design

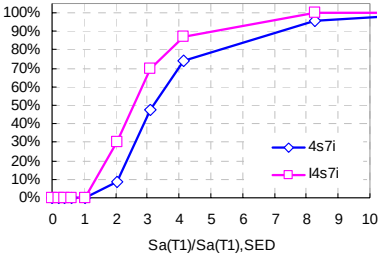
•Classify structural elements with different important levels
→ Rational safety margin



Current code Optimized

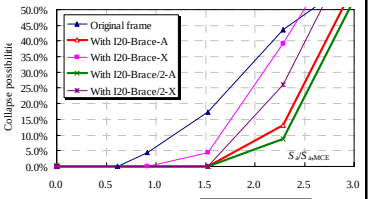
Cheaper and better

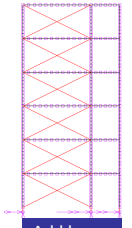
10% reinforcement reduction



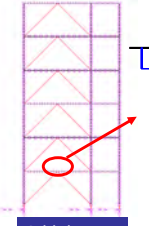
Lin XC, Lu XZ, Ye LP, Safety margins based on the important indices of structural elements

Application after Wenchuan EQ

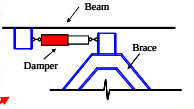


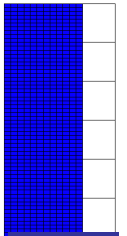


Add brace



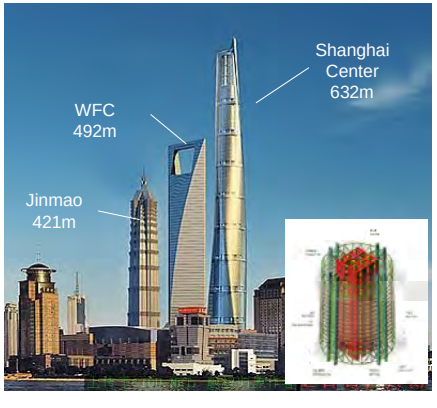
Add damper

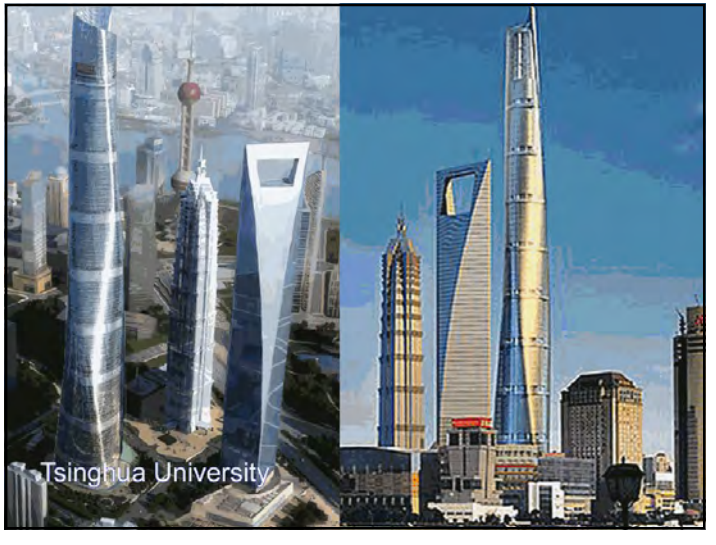




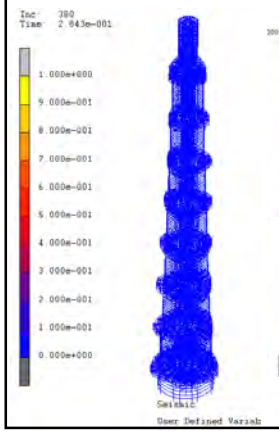
Add RC wall

Collapse Sim. Super high-rise Bld.





Collapse Sim. Super high-rise Bld.



T=2.68s, As the hole layout of the core tube changed, the shell wall at the bottom of zone 7 begins to crush.

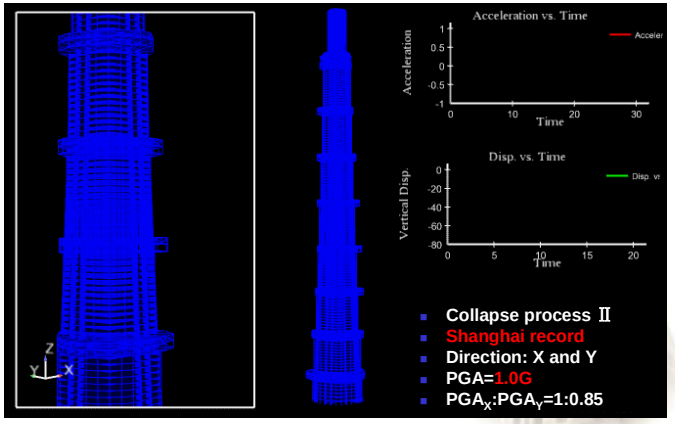
T=2.54s, coupling beams at zone 5 begin to failure and gradually develop to the up and down.

T=3.92s, shell wall at zone 5 begin to crush for the abrupt changing of stiffness.

T=6.40s, mega-columns at zone 5 begin to flexural failure.

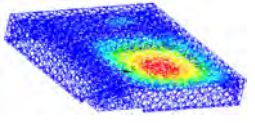
T=8.92s, core tube and mega-columns at zone 5 destroy completely and collapse begins.

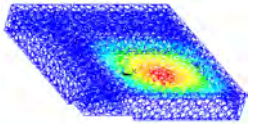
Collapse Sim. Super high-rise Bld.

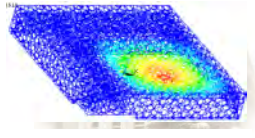


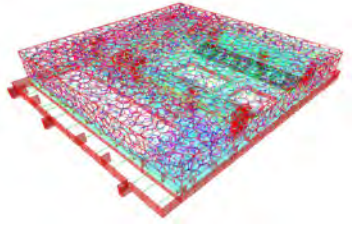
- Collapse process Ⅱ
- Shanghai record
- Direction: X and Y
- PGA=1.0G
- PGA_X:PGA_Y=1:0.85

Progressive collapse



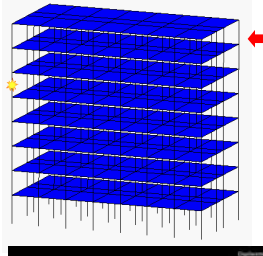






Progressive collapse simulation

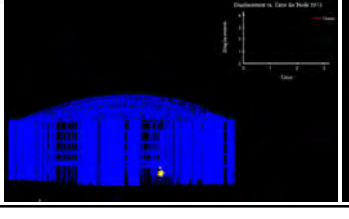
Progressive collapse

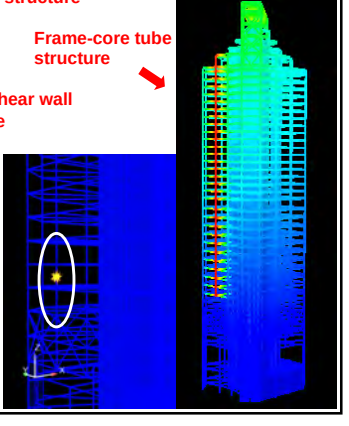


Frame structure

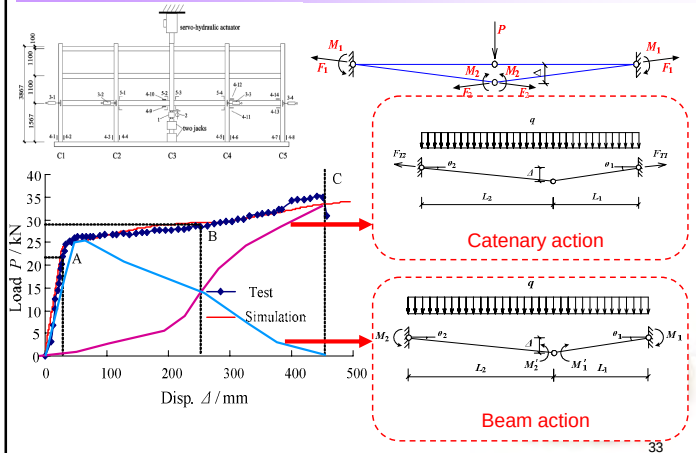
Frame-core tube structure

Frame-shear wall structure





Progressive collapse resistance



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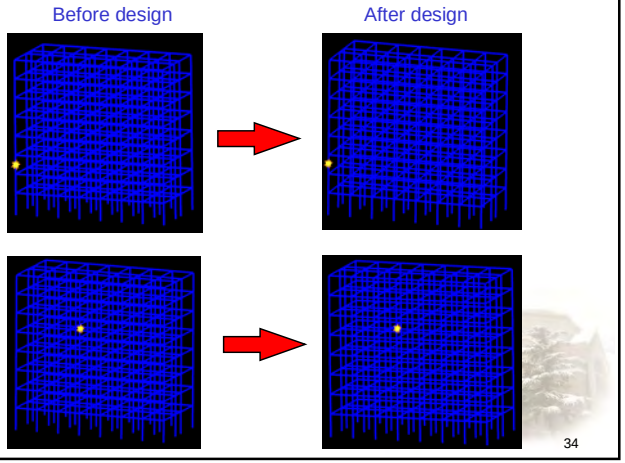
Progressive collapse prevention



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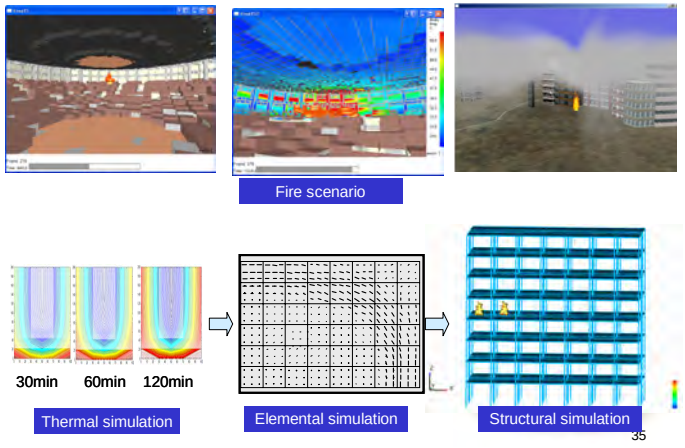
Collapse in Fire



35

Design code

Design Guides of Collapse Prevention for Building Structures

- Progressive Collapse Prevention
- Seismic Collapse Prevention
- Fire Collapse Prevention
- Collapse Prevention for Construction Temporary Structure
- Collapse Prevention for Exterior Structure/Non-structure

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Chinese Academy of Science and Technology for Development (CASTED)
www.casted.org.cn

Meeting - October 22, 2010, 2:00-3:30 am

Present –Dennis Hwang, Tom Tobin, Rich Eisner

CASTED Faculty

WANG Fengyu – Research Director – International Cooperation – Academic Exchange and Manages Research - +8610-5888-4666; Fax - +8610-5888-4678; mobile - 13910702723; P.O. Box 3814, Beijing 100038 China – wangfy@casted.org.cn
Dr. ZHAO Yandong – Sociology – Professor – Deputy Director – +8610-5888-4656; Fax - +8610-5888-4655; zhaoyd@casted.org.cn
Dr. GAO Changlin – Director – Dept. of Research – Management – Professor – Interested in Cooperation - +8610-5888-4580; fax - +8610-5688-4588 – gaocl@casted.org.cn
Dr. Jon PEDERSEN – Research Director – originally from Norwegian Institute – Social Anthropology and Conflict Areas – cell Chinese +86-1501 67 9410; cell Norway - +47 971 40 362; jon.pedersen@fafo.no
Dr. SHE Changhui – Law and Sociology – Research - +8610 5888 4650; fax. +8610 5888 4655; shich04@gmail.com
Dr. MA Ying – Sociology – How social contacts influence recovery - +8610 5888 4662/4650; fax. +8610 5888 4655; may@casted.org.cn
Dr. KONG Xinxin – Economics – Recovery Economy after Disaster - +8610-5888-4652; +8610-5888-4655; kongxx@casted.org.cn
Dr. He Guangxi – Sociology of Disasters – Social Equality Data - +8610-5888-4661/4650; fax +8610-5888-4655; hegx@casted.org.cn

Sitting – Left to Right - Director WANG Fengyu; Thomas TOBIN, Richard EISNER, Dennis HWANG, Dr. GAO Changlin; Standing – Dr. SHI Changhui; Dr. MA Ying; Research Director Jon PEDERSEN; Dr. ZHAO Yandong; Dr. HE Guangxi

Presentations by Director WANG Fengyu on CASTED and Dr. Zhao Yandong on follow up after the Earthquake

- Following the May 12, 2008 Wenchuan Earthquake- Extensive field surveys were mobilized to assess the needs of those affected by the earthquake.
- The All Needs Assessment was supported by the Department of Social Development and the Department of International Cooperation of the Ministry of Science and Technology.
- CASTED was commissioned to develop the rapid needs assessment to support the General Plan for recovery. During a 12 day period in July, much of the data was collected for many cities, districts and counties. The study took less than a month from design to completion.
- Students and teachers were involved from Sichuan University and Mianyang Normal University to conduct the field interviews.
- The survey was put together and organized in a very short amount of time.
- The ministry of Foreign Affairs of Norway helped sponsor, provided technical support and researchers. Dr. John Pedersen offered technical assistance.
- Dr. ZHAO Yangdong was the director. Also involved and present at the meeting were Wang Fenyu, Dr, HE Guangxi, Dr. MA Ying, Dr. Kong Xinxin and several others that were not at the meeting.
- Rapid Needs Assessment – is a new type of research technology to find basic information on the people who need aid in a rapid and accurate way. It guides emergency rescue operations and recovery by identifying the most critical needs.

- It targets assessing three main areas – (i) What resources (housing, food, shelter that still remains to assist the population, (ii) what are the main needs of the population, and (iii) what are the opinions of the people with regard to recovery and assistance. Through this assessment, the needs of the people can be better addressed.
- Probability sampling helps to insure that the households picked at random could represent the affected population.
- Assessment determined
    - Extent of housing damage
    - Housing the major concern
    - Difference between what homeowners expected and can receive from government
    - Percentage expecting reduction in mortgages
    - Population percent satisfied with water and electricity needs
    - Percent with poor sanitary conditions
    - How did people receive information
    - Unemployment rated and needs
    - Impact on businesses of various types (farming and non-farming)
    - Percent willing to relocate:
        - 41% willing to move from damaged houses
        - 14% not willing to move but will obey government
        - 18% already thinking of moving after damage
        - 14% - even if required – don't want to move
    - Relocation localities
    - Health and injury impacts
    - Psychological impacts
    - Educational impacts – to schools, educational programs, boarding school
    - Satisfaction with;
        - Life
        - Various levels of government
        - Relief distribution
        - Education of relief policies
        - Reliance on government for reconstruction
    - Social Support Network
        - Who received aid and what
        - Who assisted in providing aid
        - Trust in government and foreigners providing assistance

Areas of Collaboration

The multi-disciplinary approach to assist disaster recovery can be of assistance in the United States. After the meeting with CASTED, Tom Tobin suggested that Dr. ZHAO Yandong be in contact with Dr. Dennis WENGER of the NSF, who supports social science research and earthquakes in the U.S.

Post-Symposium Activities

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October 31, 2010

Honorable Lu Yongxiang
Vice Chairman
National People's Congress
c/o Deputy Secretary General Rao Jie
China Science Center International Eurasian Academy of Sciences

Re: China/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices

Dear Vice Chairman Lu Yongxiang:

On behalf of the USA team members, the Earthquake Engineering Research Institute (EERI) and the Chinese Chamber of Commerce of Hawaii, we want to thank you and congratulate you for a very successful Symposium and meetings from October 18-21, 2010. It would not have been possible without your leadership. All of the participants from the USA side were very impressed with the organization, wonderful venues and also our Chinese scientific and engineering colleagues. There was much open exchange and each side learned significantly, for example about the great risk of earthquakes to our own civilian population. We were also impressed with the speed of recovery in the construction of the new town of Beichuan. The USA team members have expressed a strong interest in continuing the open and friendly exchange of such an important topic as the reduction of risks from earthquakes in our countries.

Please send our deepest thank you and warmest regards to the organizers, Chairman and Executive Vice President Wang Guangtao, Professor Jiang Zhenghua, Secretary General Peng Gongping, Standing Vice Chairman Dai Feng and Deputy Secretary General Shao Yisheng from the China Science Center of International Eurasian Academy of Sciences (CSCIEAS). We would also like to thank the co-organizers, Secretary General Zhou Chang of the Architectural Society of China (ASC), President Wang Jun and Dr. Zhou Xiyuan of the China Academy of Building Research, President Li Xiaojiang of the China Academy of Urban Planning & Design and Chief Planner Qiu Jian from the Bureau of Urban & Rural Construction of the Sichuan Provincial Government. The USA team was also grateful to be able to work with the supporters Secretary General Chen Zhuming and Director Lake Zhao from the China Association of International Friendly Contact, and the coordinators, Deputy Secretary General Zhang Baiping from ASC and Deputy Secretary General Rao Jie from CSCIEAS. We were very glad to have become good friends with all of them.

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Tel: (808) 533-3181 • Fax: (808) 537-6767 • E-mail: info@chinesechamber.com

The USA team looks forward to future collaboration and exchange. The Chinese Chamber will continue to assist when needed to coordinate and will rely on the Earthquake Engineering Research Institute for technical content and participation. Thank you once again for helping to make the Symposium a reality and to our new friends and colleagues.

Best regards,

Sincerely yours,

Dennis Hwang
USA Organizing Committee
Immediate Past President, CCCH

L. Thomas Tobin
President-Elect
EERI

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執行副會長	林文忠

October 31, 2010

Honorable Wang Guangtao
Executive Vice President
China Science Center of International Eurasian
Academy of Sciences
c/o Deputy Secretary General Rao Jie CSCIEAS

Re: China/USA Symposium for the Advancement of
Earthquake Sciences and Hazard Mitigation Practices

Dear Executive Vice President Wang Guangtao:

Congratulations. The members of the USA team as well as the Earthquake Engineering Research Institute (EERI) and the Chinese Chamber of Commerce of Hawaii would like to thank you and CSCIEAS for helping to make the China/USA Symposium a great success. We appreciate the considerable effort that was put into the symposium and the meetings by those in the CSCIEAS. We thank you for your role in leading the organization of this project and in accepting our last minute changes from the USA team on personnel. It was an honor to work with and meet those from CSCIEAS including Professors Jing Zhenghua and Gongbing Peng as well as Deputy Secretary General Rao Jie. We must mention that your staff, including Xie Nan were most courteous and friendly to the US team from helping with the hotel arrangements to the transportation to and from the airport. The USA team was very happy with all the arrangements, venues and technical exchanges.

The scientific exchange for this Symposium was the most important we can think of since it deals with reducing the risk to lives and property from natural hazards and can make a significant difference in both our countries. We look forward to working with CSCIEAS on this and many other areas of scientific exchange. These efforts can only help to make the China and the USA safer from natural hazards while increasing mutual friendship and cooperation. Thus a true win-win situation. Once again, thanks to you and all at CSCIEAS for a successful and most productive Symposium.

Best Regards,

Sincerely yours,

Dennis Hwang
USA Organizing Committee
Immediate Past President, CCCH

L. Thomas Tobin
President-Elect
EERI

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October 31, 2010

Secretary General Zhou Chang
Architectural Society of China

Re: China/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices

Dear Secretary General Zhou Chang:

The members of the USA team as well as the Earthquake Engineering Research Institute (EERI) and the Chinese Chamber of Commerce of Hawaii would like to thank you, Deputy Secretary General Zhang Baiping and all of ASC for the hard work and leadership that helped to make the Earthquake Symposium a success. There was much preparation since the beginning of the year and it could not have been done without your leadership and the efforts from everyone in your organization. We would also like to thank Deputy Director Wang Xiaojing for all his assistance in the past going back to April.

The USA team members have very positive memories of the informative technical exchanges and beautiful venues at the National Peoples Conference Center. The field trip to Mianyang went very smoothly and it was most instructive to see the old town of Beichuan as well as the new town. We hope there can be future technical exchanges on hazards and perhaps the American Institute of Architects can be involved also. Thank you once again and we look forward to hearing from you and working with you in the future.

Best regards,

Sincerely yours,

Dennis Hwang
USA Organizing Committee
Immediate Past President, CCCH

L. Thomas Tobin
President-Elect
EERI

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China/USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices **November 21, 2010**
Summary of China/USA Research Collaboration Follow-up Action Items
Prepared by Gary Chock gchock@martinchock.com

This summary compiles the follow-up actions identified to develop an agenda of mutual interest for the future, which includes potential research collaborations, further dialogue and future meetings in the four Symposium earthquake topic areas:

1. Hazard Assessment and Mapping, Geotechnical Hazards and Siting
2. Building Codes and Multi‐Hazard Design
3. Hazard Mitigation of Critical and Important Building Construction
4. Pre‐Disaster Planning and Mitigation and Emergency Response

This document is based on the minutes of the China/USA meetings of October 18-22, 2010 and the November 9 and 17, 2010 teleconferences of USA participants. For additional background, consult the individual meeting minutes.

Further correspondence with the institutes listed below from the lead USA Point of Contact (POC) groups should be copied to Dennis Hwang and Gary Chock. Assistance with phone contacts to China can be arranged with the Chinese Chamber of Commerce or Martin & Chock, Inc. Lead POC's are considered the responsible parties for pursuing the identified collaborative areas on behalf of USA interests (and thus must remain open to other areas of collaboration beyond those listed here in *any* of the four topic areas).

Please provide a December 17th status report on progress of these collaborative efforts.

Organization	Point of Contact	Collaborative Areas	Lead USA POC's
China Earthquake Administration – Institute of Engineering Mechanics	DAI Junwu <jwdai@iem.net.cn >	Obtain Information on CEA-IEM load testing of PP Band retrofits of URM developed by CDRF DAI Junwu has been active in EERI's confined masonry project, and Greene asked him to consider being on the editorial board of the EERI World Housing Encyclopedia	Marjorie Greene
China Earthquake Administration – Institute of Geophysics [minutes being drafted by Wong based on Hwang notes]	GAO Mengtan gaomt@sina.com	1. USA would like to learn more about their data and what they learned from the data. Ivan Wong requested their ground motion data and IG stated they are willing to share. 2. Comparisons in small and large quakes – Ken Stokoe 3. Walter Mooney visits every year 4. China/USA biennial Symposium was suggested. 5. NEES – NSF: Interested in working on a project on site characterization –Ken Stokoe II NEHRP ACEHR meeting discussion about comparing Wenchuan and New Madrid (attenuation relationships, risk, etc).	Ivan Wong Mark Petersen (for USGS) Ken Stokoe II Also: Weimin Dong (RMS) Walter Mooney (USGS)

Summary of China/USA Research Collaboration Follow-up Action Items

Prepared by Gary Chock gchock@martinchock.com

Organization	Point of Contact	Collaborative Areas	Lead USA POC's
China Earthquake Administration – China Earthquake Network Center [minutes being drafted by Francis based on Hwang notes]	Deputy Director HE Qin heqincn@yahoo.com.cn	Centralized Emergency Operations Center for everything from collecting seismic data to coordinating emergency response and rescue, to coordinating efforts between central government and local governments	Dennis Hwang
China Academy of Building Research (CABR)	WANG Cuikun wangcuikun@cabrtech.com TIAN Chunyu tianchunyu@cabrtech.com Also: ZHOU Xiyuan, CAS, Director, Beijing Laboratory of Earthquake Engineering & Structural Retrofit, zhouxy@bjut.edu.cn and WANG Yayoung yayongwang@sina.com	The USA team will prepare a research digest with links to ongoing work. Dr. TIAN will prepare a research digest of ongoing and future CABR work. CABR seismic shake table is 6m x 6m and is the largest in China. Consensus that further design comparisons between the USA and China should be done, especially concrete and masonry; Post-Wenchuan earthquake seismic design improvements; Hybrid Masonry; Hybrid Simulation; Collapse simulation: Infill masonry; Confined Masonry: Nonstructural element performance Ian Robertson to prepare white paper with outline of a NEES joint research project	Ian Robertson, Gary Chock, Dan Abrams, Chaoying Luo
Tsinghua University	LU Xinzheng xinzheng.lu@gmail.com, luxz@tsinghua.edu.cn	Potential comparative studies of prototypical buildings designed using US and Chinese seismic design standards: CHOCK and ROBERTSON requested the report on the comparison of Japanese and Chinese seismic designs. A number of participants were interested in pursuing this topic both in terms of design requirements and also in expected building performance during a scenario earthquake. Tsinghua research goals are for: High-performance Structures; Recommendations for new seismic hazard –based design codes; Design guidelines for collapse prevention o Concrete buildings using moment frames and/or shear walls o Steel buildings using moment frames or eccentric bracing o Non-linear analysis of final design to evaluate push-over performance o Non-linear time history analysis of final designs to evaluate scenario	Ian Robertson, Gary Chock, Guangren Yu, Eduardo Miranda

Organization	Point of Contact	Collaborative Areas	Lead USA POC's
		earthquake performance o Laboratory testing of selected critical components highlighted by nonlinear analysis A joint research project including several NEES facilities, on standardized designs, and the use of international participation should be of great interest to NSF, including one on R/C Frames, shearwalls or reinforced masonry. This could include comparative design studies. Ian Robertson to prepare white paper with outline of a NEES joint research project	
National Disaster Reduction Center of China (NDRCC)	FAN Yida, Expert Committee of China National Committee for Disaster Reduction Secretary-General fanuyida@ndrcc.gov.cn Suju LI, Deputy Director lisuju@ndrcc.gov.cn	Space technology and risk assessment, early warning, monitoring and damage assessment. They also have a group that does disaster reduction policy research. And they are interested in international exchanges and cooperation.	Marjorie Greene to explore their interest in participating in a 2nd Symposium in the USA Doug Bausch
China Earth Observation & Digital Earth (CEODE) Chinese Academy of Sciences	ZHANG Bing, Deputy Director (zb@ceode.ac.cn) liuj@ceode.ac.cn	Remote Sensing after Disasters: extensive presentation on their use of RS after Wenchuan and Yushu is 85 MB; we can make it available to researchers who are interested. Remote Sensing workshop series organized by ImageCat, and explore possibilities for support from either NSF or NAS for a small workshop to meet and identify possible joint research programs that might then be supported by NSF and CAS. The Integrated Research on Disaster Risk program appears to cover a wider range of topics than just remote sensing, so there might be some possibility there for collaboration with the broader earthquake community	Doug Bausch Marjorie Greene Ron Eguchi Also: Dr. Jane Rovins (http://www.icsu.org/1_icsuinscience/ENVI_Hazards_1.html)
National Earthquake Response Support Service (NERSS) China Earthquake Adminstration	QU Guosheng Deputy Director, Chief Engineer qgsh@263.net	A. New Global USGS Loss PAGER System and related activation levels for domestic China application with data needs identified. B. Response of FEMA, theory and practice of Search and Rescue, and mechanism of Management & Training C. Use of Twitter feeds for rapid earthquake notification and situational awareness and case examples from the USA	Doug Bausch Gary Chock Doug Bausch prepared an invitation letter for Dr Qu and his colleagues to visit the FEMA facilities in Denver

Organization	Point of Contact	Collaborative Areas	Lead USA POC's
		D. Methodology of Loss Estimation, Impact Analysis and Applications in the USA and China a. Early warning estimation, faster time estimates and ground-truthing, and dealing with data gaps E. HAZUS applications in China: a. Applications in emergency management and Search and b. Building information in rural areas. F. Collaborating with Beijing Normal University on a demonstration project in Southwest China that integrates HAZUS A joint MOU will need to be drafted for presentation to the China Earthquake Administration. (The task of preparing the first draft was later requested by Dr. QU to be done by the USA.) Doug Bausch requests copy of the CEA-USGS MOU.	December 17 and continue collaboration on the loss modeling potential. A visit to the NEIC will also be incorporated. A joint workshop in the USA in August-2011 was proposed, perhaps in conjunction with a NorthCOM conference in Denver or Colorado Springs. NERSS invited to a mid-July 2011 Natural Hazards Conference at the University of Colorado, Boulder. Topics: • Emergency Management • Search & Rescue • Loss Assessment • Establishing training for provincial teams and certification
Beijing Normal University (ADREM)	LI Jing lijing@ires.cn LIU Jifu** – liujifu@bnu.edu.cn	Preparation before disaster rather than response, i.e., pre-disaster hazard mitigation planning. Ministry of Civil Affairs – they work with and try to develop rules and policy based on ADREM research; this is an area of possible research collaboration with USA. Public Policy and Social Safety group at Bejing Normal University researches social science issues. Areas of Collaboration discussed: General Areas identified by Li Jing: • remote sensing and GIS for disaster management • disaster risk analysis;	Doug Bausch Richard Eisner Dennis Hwang Marjorie Greene Yumei Wang

Organization	Point of Contact	Collaborative Areas	Lead USA POC's
		• knowledge transfer on disaster reduction 1) Exchange of students to work on projects like the development of disaster plans 2) EERI – interested in institutionalizing use of remote sensing data after earthquakes to help in damage assessment. Hope to develop an interface so researchers from around the world can participate online. 3) HAZUS and other risk analyses – they are open – to demonstrating Sichuan project. - Bausch 4) Emergency Planning – How to build and implement emergency plan – HAZUS used scenarios to develop and test plan. Example: SFBA Regional Emergency Coordination Plan (2006) and Golden Guardian Exercise 2006 (tested plan) Interested in taking into account impacts. Dr. Liu very interested in this and can work with Bausch and Eisner. 5) Analyzing and researching need and mechanism for earthquake insurance, flood insurance. Dr. Wang Ming. 6) Developing Guidance for Government on pre-disaster planning and mitigation based on hazard maps, or converting research knowledge into a useful form for disaster risk reduction. 7) Their lab is very active in relevant research and they have many international collaboration efforts. 8) Invitation requested for the Boulder Natural Hazards Workshop July 9-12, 2010 – Bausch 9) Interest in collaborating with NERSS on a demonstration project that integrates HAZUS - Bausch	
China Academy of Urban Planning & Design (CAUPD)	LI Xiaojiang lixj@caupd.com also per note: RAO Jie hwbrj@126.com	Per President LI Xiaojiang: CAUPD is trying to start a long-term international forum to be a center for the study of: 1. New Beichuan as a case study of urban planning 2. Emergency Management studies 3. Earthquake hazard mitigation and research CAUPD would like to establish a base for interns and experts to participate; small forums are initially proposed as while any ongoing issues are worked out. RAO Jie (China Science Center – International Eurasian Academy of	Marjorie Greene Rob Olshansky EERI committee TBD Laurie Johnson Dennis Hwang Richard Eisner Yumei Wang Also: Gary Chock

Organization	Point of Contact	Collaborative Areas	Lead USA POC's
		Sciences): The involvement of multi-disciplinary experts is needed. We would like to explore this concept further with this group, through Dennis Hwang and the Chinese Chamber of Commerce of Hawaii as an intermediary.	
Chinese Academy of Science and Technology for Development (CASTD) Ministry of Science and Technology	WANG Fengyu – Research Director – International Cooperation– wangfy@casted.org.cn Dr. ZHAO Yandong – Deputy Director zhaoyd@casted.org.cn Jon PEDERSEN – Research Director – jon.pedersen@fafo.no	Rapid Needs Assessment to identify most critical needs for recovery- Multi-disciplinary approach to assist disaster recovery	Dennis Hwang Dennis WENGER of the NSF Tom Tobin
China Development Research Foundation (CDRF)	FENG Wenmeng <fengwm@cdrf.org.cn >	Richard Eisner discussed the VOAD [Voluntary Organizations Active in Disaster] as a model for how NGO's are utilized in disaster response and recovery in the United States. A webcast link on this subject would be sent to Dr. Tang. PP Band retrofit technique for adobe and brick construction for the EERI World Housing Encyclopedia. More information and the test reports were requested from Dr. Feng.	Marjorie Greene Richard Eisner Also: Elizabeth Hausler

China-USA Symposium for the Advancement of Earthquake Sciences and Hazard Mitigation Practices

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Appendix

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