2010 Haiti earthquake: Fixtures installed without safety wires in unbraced suspended acoustical ceiling (photo: Ayhan Irfanoglu, Purdue University).

2010 Chile earthquake, Santiago International Airport: Weak connections, inadequate bracing and ties (photo: E. Miranda).

Shake table test at UC Irvine includes non-structural elements (photo: PEER Testbed Study).

An EERI Seminar

Seismic Design and Performance of Nonstructural Elements

San Francisco: October 27, 2011
Seattle: October 28, 2011
Los Angeles: November 3, 2011
San Diego: November 4, 2011

An EERI Technical Seminar funded by FEMA/Department of Homeland Security

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Northern California, Southern California, San Diego, & Washington

An EERI Seminar

Seismic Design and Performance of Nonstructural Elements

October 27, 2011
Parc 55 Wyndham
San Francisco, California

October 28, 2011
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Los Angeles, California

November 4, 2011
Holiday Inn San Diego-North Miramar
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ACKNOWLEDGMENTS:

Funding for the technical seminar is provided under a cooperative agreement (EMW-2011-CA-00082-S01) with FEMA/U.S. Department of Homeland Security.

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Seismic Design and Performance of Nonstructural Elements

Earthquake-caused nonstructural damage is costly and disrupts businesses and livelihoods. In several recent earthquakes, repair costs from nonstructural damage exceeded costs due to structural damage. Buildings were left unusable for long periods of time because of severe damage to mechanical, architectural, electrical, and plumbing systems. Only 15-25% of original construction costs are for the structure; this EERI Technical Seminar puts the spotlight on the other 75-85% of the investment. It will provide information on the performance of nonstructural elements in recent earth-quakes, current large-scale experimental research, present code requirements, the updated and newly released FEMA E-74 guide on nonstructural design, and implementation of new requirements for equipment certification.

EERI

The Earthquake Engineering Research Institute (EERI) is a nonprofit professional association with academic and professional members throughout the world who share a common interest in reducing the effects of earthquakes on society. The primary objective of EERI is to reduce earthquake risk by

- advancing the science and practice of earthquake engineering;
- improving understanding of the impacts of earthquakes on the physical, social, economic, political, and cultural environment;
- advocating comprehensive and realistic measures to reduce the harmful effects of earthquakes.

FEMA

An agency of the U.S. Department of Homeland Security, FEMA is a partner of the National Earthquake Hazards Reduction Program (NEHRP). In fulfilling this role, FEMA supports conferences that enhance the effectiveness of earthquake hazard reduction science and technology, and that increase opportunities for participation by individuals who can then contribute to the advancement and progress of the program. With FEMA support, EERI has developed a series of technical seminars to further the goals of NEHRP, and to provide the professional community in the United States with innovative techniques to mitigate the risks of earthquakes.

EERI

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An EERI Technical Seminar

Seismic Design and Performance of Nonstructural Elements

Nonstructural Earthquake Events

Seismic Design and Performance of Nonstructural Elements

Bob Reitherman, Executive Director

Consortium of Universities for Research in Earthquake Engineering (CUREE)

October/November 2011

Robert Reitherman
Executive Director
Consortium of Universities for Research in Earthquake Engineering

Bob Reitherman has been involved in architectural and other aspects of nonstructural seismic protection since the late 1970s. He authored the first edition of FEMA 74 (*Reducing the Risks of Nonstructural Earthquake Protection*) in 1983. For the Earthquake Engineering Research Institute, he led the reconnaissance team devoted to nonstructural systems after the 1994 Northridge earthquake. Currently, he is a co-principal investigator of the NSF-funded "NEES Nonstructural" project (Simulation of the Seismic Performance of Nonstructural Systems). He is the author of the in-press book, *Earthquakes and Engineers: An International History*, and co-author with Christopher Arnold of *Building Configuration and Seismic Design*.

EERI Seminar: Seismic Design and Performance of Nonstructural Elements
October-November, 2011

Introduction and Historical Overview

Robert Reitherman[1]

Nowadays, the topic of nonstructural earthquake protection is a well-known area within the broader earthquake engineering field, and even those without any particular interest in the earthquake subject are required by building codes and minimum criteria for other kinds of construction to pay attention to the topic when they do design work in seismic regions. The fact that an Earthquake Engineering Research Institute seminars, like this one today, are being devoted to this subject is one obvious piece of evidence supporting that generalization. Currently, the topic is taken note of by not only codes and standards organizations, but also construction industry manufacturers, owners and occupants, and several design disciplines. It was not always so.

This brief historical introduction, using illustrated timelines, which sets the stage for the presentations by others on today's best practices, makes two fundamental points.

1. Look at the typical nonstructural components in a building today: the suspended ceiling "sandwich" that includes not only the ceiling itself but also the various piping, ducts, conduit, and light fixtures; large glazing and nonstructural cladding units; gypsum board partitions and open plan furnishings; elevators; and, including equipment and contents in the definition of nonstructural, a vast array of computers and other equipment. **None of those nonstructural components was invented and brought to market with any thought of earthquakes.** This is analogous to the basic structural components that provide a seismically resistant building: the shear wall, braced frame, and moment-resisting frame were all invented and popularized before the advent of modern earthquake engineering, and they had to be brought into the fold of acceptable seismic systems after the fact. The earthquake engineering field, in effect, has had to retrofit these non-seismic nonstructural as well as structural products and systems to make them perform adequately in seismic regions.

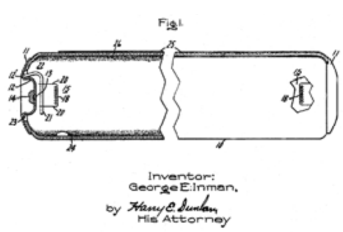
This is illustrated graphically by the timelines in this presentation, in which the non-earthquake engineering developments are seen to occur prior to the more recent era when codes and practitioners began to pay more attention to the nonstructural subject (say since the 1960s in some cases and especially since the 1970s and 1980s). It's like a race, with the non-earthquake engineering events always ahead. Today, we have the means with which the field of nonstructural earthquake protection can reduce that lead and strive to be in the lead.

2. The second conclusion is also illustrated by the timelines. **Even in recent times, earthquakes have taught us significant lessons that have led to changes in codes, practice, and products.** In this regard, we should all be appreciative of the role played by the Earthquake Engineering Research Institute in its investigations of damaging earthquakes over the decades, its Learning From Earthquakes program.

---

[1] Executive Director, Consortium of Universities for Research in Earthquake Engineering (CUREE), 1301 S. 46th Street, Richmond, CA 94804; *reitherman@curee.org*

[The animated, illustrated timeline presentation that includes video clips is summarized here in a tabular format.]

year	non-earthquake events (e.g., architectural trends, new products)	earthquake events (e.g., codes, earthquakes, research)
1906		San Francisco Earthquake not included because American reaction to this disaster did not greatly advance earthquake engineering
1916	U.S. Gypsum introduces Sheetrock	
1922	Willis Carrier air conditioning, Grauman's Chinese Theater 	
1923		Kanto (Tokyo) Earthquake: Tachu Naito and others in Japan are already using the equivalent static lateral force method 
1932		invention of strong motion seismograph (C & GS accelerograph)
1938	GE & Westinghouse fluorescent lights 	

year	non-earthquake events (e.g., architectural trends, new products)	earthquake events (e.g., codes, earthquakes, research)
1940		El Centro Earthquake (strong motion record) 
1947		NFPA 13 earthquake bracing of sprinklers
1950	UN building (ceiling "sandwich") 	
1952	Lever House (curtain wall) 	
1952		Kern County Earthquake
1956	Calder Hall (nuclear power plants) 	

year	non-earthquake events (e.g., architectural trends, new products)	earthquake events (e.g., codes, earthquakes, research)
1959	Xerox (filing cabinets)	
1961		UBC (“ornamentations and appendages”
1961	NFPA 704 (hazardous materials) 	
1964		Alaska Earthquake 
1960s	pre-cast concrete cladding 	
1967	U. Illinois Urbana-Champaign (shake tables)	
1968	Herman Miller (open plan office furnishings) 	

year	non-earthquake events (e.g., architectural trends, new products)	earthquake events (e.g., codes, earthquakes, research)
1971		San Fernando Earthquake 
1972		CISCA, UBC Standard 47-18
1973		California Hospital Act
1973		UBC post-San Fernando updates
1974	CAT scanner 	
1978		ATC 3-06
1981	Architectural Graphic Standards (gyp. bd.)	
1981	IBM PC 	

year	non-earthquake events (e.g., architectural trends, new products)	earthquake events (e.g., codes, earthquakes, research)
1983		FEMA 74 (1st ed.)
1985		NEHRP Provisions (1st ed.)
1989		Loma Prieta Earthquake
1992		FEMA 178 (existing buildings)
1994		Northridge Earthquake
1994		California SB 1953 (existing hospitals)
1997		FEMA 274 (FEMA 356, ASCE 41; ATC 33 origins 1993); existing buildings, performance-based engineering
2000		IBC
2002 2005 2010		ASCE 7-02 (05, 10)  $F_p = \frac{0.4 a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)}\left(1+2\frac{z}{h}\right)$ (13.3-1)
2010		FEMA 74 (4th ed.) 

Performance of Nonstructural Components in Recent Earthquakes

Seismic Design and Performance of Nonstructural Elements

Eduardo Miranda
Stanford University

Gilberto Mosqueda
University at Buffalo, SUNY

EERI

Eduardo Miranda

Eduardo Miranda obtained his civil engineering degree from the National Autonomous University of Mexico, UNAM. He obtained his MSc and PhD degrees in structural engineering at UC Berkeley. From 1993 to 1999, he worked as a research engineer at the National Center of Disaster Prevention in Mexico City, and lecturer at the Graduate School of Engineering at UNAM. Eduardo has been at the faculty at the Department of Civil and Environmental Engineering at Stanford University for 11 years, where he is now an associate professor. He has been a member of EERI for 24 years. One of his primary topics of research is the seismic performance of nonstructural components.

Gilberto Mosqueda

Gilberto Mosqueda is an associate professor in the Department of Civil, Structural and Environmental Engineering at the University at Buffalo, where he teaches and conducts research in the area of structural and earthquake engineering. He received his Ph.D. (2003) from the University of California at Berkeley, M.S (1998) from Massachusetts Institute of Technology, and B.S. (1996) from the University of California at Irvine, all in civil engineering. Through research supported mainly through the National Science Foundation and MCEER, he has been involved in understanding and improving the seismic performance of structural and nonstructural systems under seismic loads Dr. Mosqueda served as team leader for the MCEER reconnaissance of Hurricane Katrina funded by NSF. He was a member of the EERI reconnaissance team following the February 27, 2010, Chile earthquake. More recently he visited Japan following the March 11, 2011, earthquake and tsunami as part of a small multidisciplinary team organized by PEER/EERI/GEER.

Performance of Nonstructural Components in Recent Earthquakes

Seismic Design and Performance of Nonstructural Elements

Eduardo Miranda
Stanford University

Gilberto Mosqueda
University at Buffalo, SUNY

Outline of this Presentation

- **September 4th, 2010 (M 7.1) and February 22nd, 2011 (6.3) NZ earthquakes**
- **February 27th, 2010 (M 8.8) Maule, Chile earthquake**
- **March 11th, 2011 Great eastern earthquake**
- **August 23, 2011 (M 5.8) Virginia earthquake**

Initial Remarks

- Damage to nonstructural components typically initiates at levels of shaking well below those required to cause structural damage
- Buildings modify and often amplify ground motions therefore nonstructural elements in multistory buildings are typically subjected to higher intensity shaking
- Seismic design of nonstructural systems not as rigorous/advanced as for structural systems

2010 and 2011 Christchurch, New Zealand Earthquakes

September 4th, 2010

Magnitude 7.1

Local Time 4:35 am

No fatalities

February 22nd, 2011

Magnitude 6.3

Local Time 12:51 pm

181 fatalities

New Zealand

- A country with a long history of moderate and large earthquakes
- Long tradition in Earthquake Engineering (e.g. 3WCEE 1965)
- Very good codes. In general, very similar to U.S. codes

2010 and 2011 Christchurch, New Zealand Earthquakes

Three main types of damage in these earthquakes:

- Damage/collapse to URM structures
- Massive liquefaction and associated damage
- Large amount of non-structural damage

North banks of Kaiapoi River. Photo / Jessica Rea

Sand volcanoes. Photo / Andrew Gill

This building on the corner of Worcester St and Manchester St in central Christchurch was badly damaged by the earthquake. Photo / Danny Barê

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Damage to contents

Grocery mahem at New World Redcliffs. Photo / Chris van der Leer

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Damage to contents

Damage to contents

Halswell Hammer Hardware. Photo / Linda Perkins

Damage to contents

Photo U. of Canterbury

Damage to contents

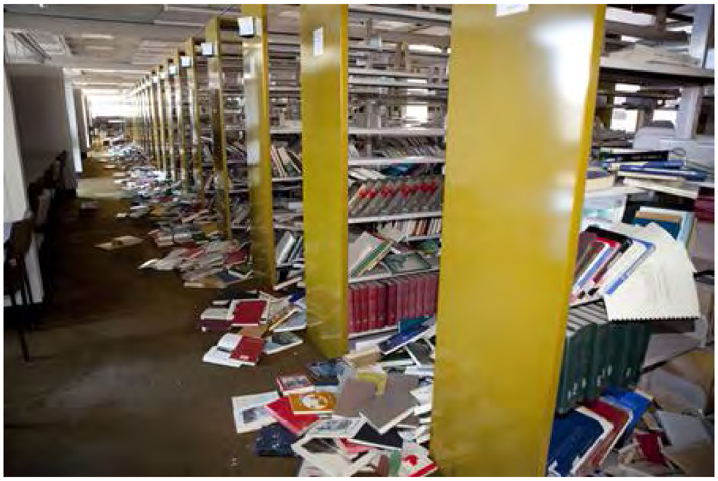

Photo U. of Canterbury

Damage to contents

Ferrymead Mitre 10 MEGA. Photo / Michelle Blakely

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Damage to ceilings

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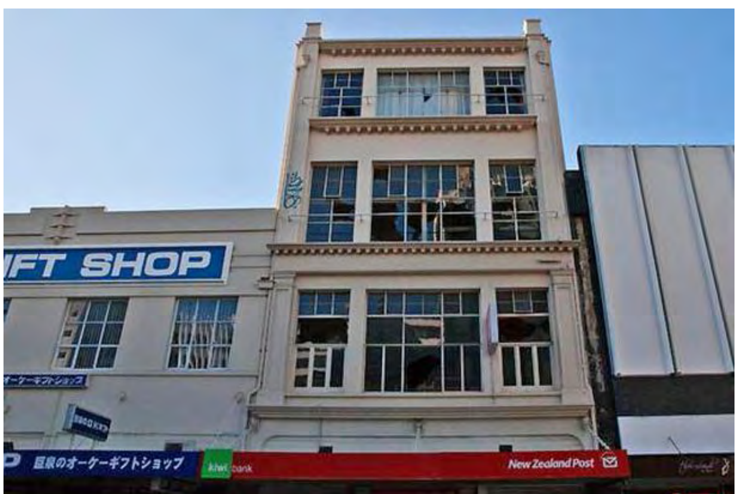
Damage to façades

Engineer Warren Lewis of the firm Lewis and Barrow says the neo-classical facade of the damaged Historic Oxford Terrace Baptist Church will have to be demolished. Photo / Carolyn Robertson

Glazing Damage



Damage to windows above NZ Post on Colombo Street. Photo / Charlene Koh

Glazing Damage

Christchurch City Council building suffers damage from the quake. Photo / Charlene Koh

Glazing Damage

Smashed sheets of glass. Photo / Janet Dean

Damage to Stairs

Damage in the main stairs inside the Christchurch City Council building in the Sept. 2010 earthquake

Photo Tao Lai

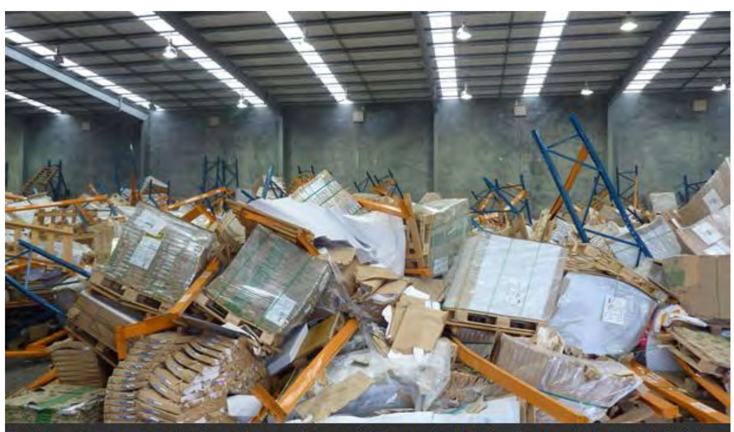
Damage to Stairs

People being lowered through the windows in the 17-storey Forsyth Barr building due to failure of the stairs in the February 2011 earthquake

Hotel Grand Chancellor's stairwells also disintegrated into rubble

Brilliant example of pragmatic, No.8 wire humour. Taken in Avonside. Photo / Meshell Edgecombe

Damage to storage racks



Hundreds of tonnes of paper in this warehouse ended up on the floor and had to be trucked away to be recycled. Photo / Hamish Kirke

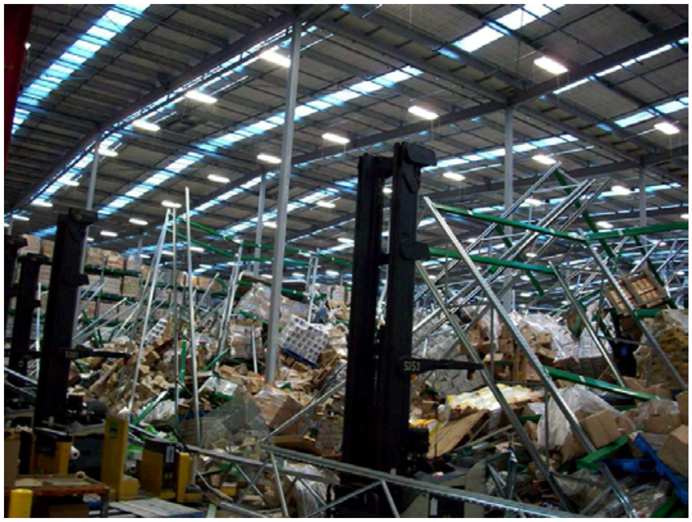
Damage to storage racks

Destroyed storage racks at warehouse. Photo / Michael Rowe

Damage to storage racks

Pallets of V energy drink that have fallen off destroyed storage shelves. Photo / Michael Rowe

Damage to storage racks



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2010 and 2011 Christchurch, New Zealand Earthquakes

September 4th, 2010

Magnitude 7.1

Local Time 4:35 am

NZ$ 6 billion (US$ 4.6 billion)

February 22nd, 2011

Magnitude 6.3

Local Time 12:51 pm

NZ$ 16 billion (US$ 12.5 billion)

Together about 13% of their GDP !

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Lessons from 2010 and 2011 New Zealand Earthquakes

- **Relatively small number of collapses/fatalities**
- **Good structural behavior of new engineered construction**
- **Extremely large economical losses (approx. US$17 billion) considering the magnitude of the events (7.1 and 6.3) and especially relative to the population of Christchurch (385,000)**
- **Nonstructural damage is costly and affects business recovery.**
- **Long-lasting effect for the economy of Christchurch specially for the downtown commercial district.**

February 27, 2010 Maule, Chile Earthquake

- **Magnitude 8.8**
- **Local Time 3:35 am**
- **Felt by approximately 80% of the population**
- **525 death**
- **Approx. 200,000 housing units affected**
- **Approx. 800,000 homeless**
- **Economic loss approx. $25B**

Chile

- **A country with a long history of large earthquakes**
- **Long tradition in Earthquake Engineering (e.g. 4WCEE 1969)**
- **Very good codes. In general very similar to U.S. codes**

Affected Area

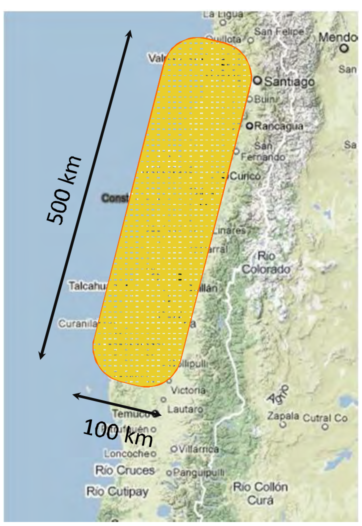

Photo E. Miranda

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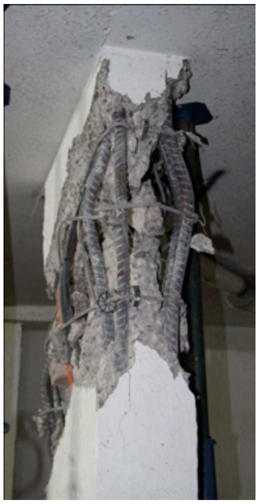

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Impact of nonstructural damage on airports

Airport terminal at Santiago shut down mainly due to nonstructural damage

Photo by G. Mosqueda

Photo by G. Pekcan

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Impact of nonstructural damage on airports

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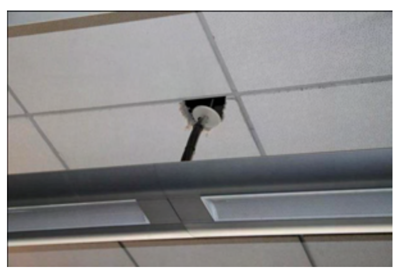

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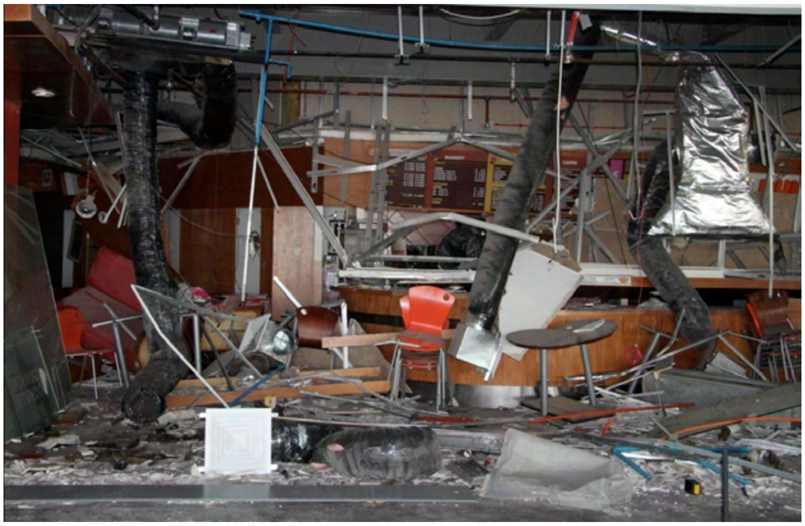

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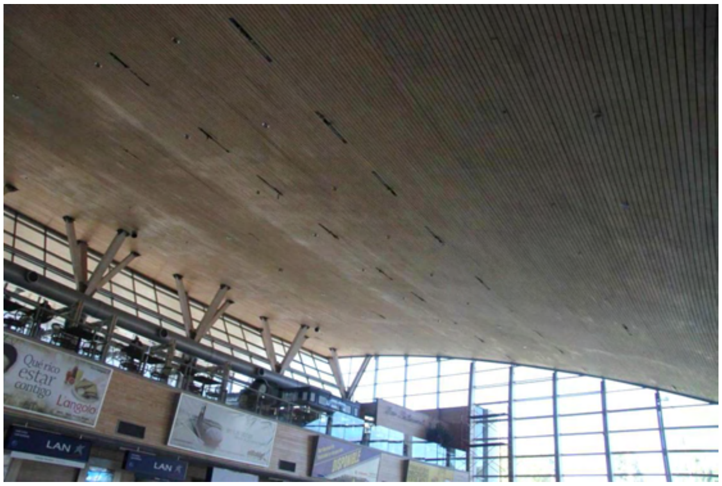

Concepcion International Airport

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Impact of nonstructural damage on airports

- **Closure of the Santiago and Concepcion International Airports**
- **US$40 million for repairs of nonstructural damage at SCL**
- **US$10 million loss to Lan Chile**
- ***Two thirds of the Chilean air traffic interrupted !***

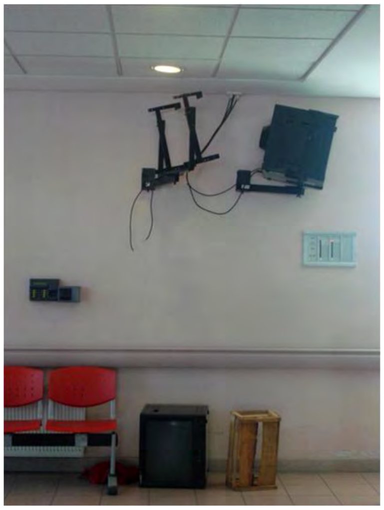
Impact of nonstructural damage on hospitals

Felix Bulne Hospital in Santiago shut down primarily due to nonstructural damage

Photo by G.Mosqueda

Photo by G.Mosqueda

Impact of nonstructural damage on hospitals



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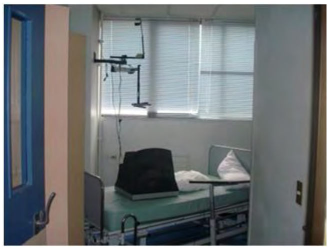

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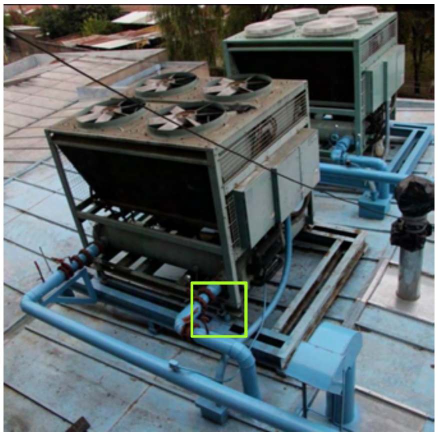
Impact of nonstructural damage on hospitals



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Impact of nonstructural damage on hospitals

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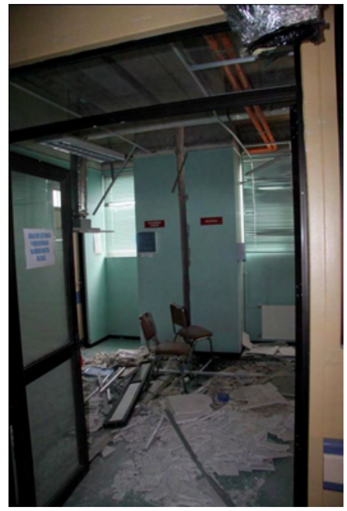

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Impact of nonstructural damage on hospitals

Photo by G. Pekcan

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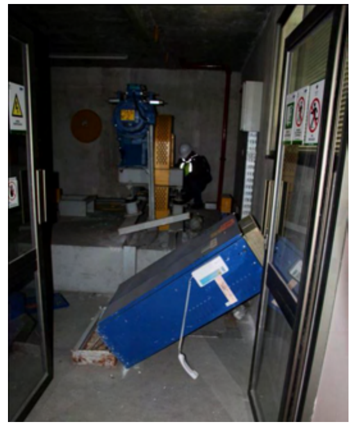
Impact of nonstructural damage on hospitals



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Impact of nonstructural damage on hospitals

- **130 hospitals were affected in six regions (*represents 71% of all public hospitals in the country!*)**
  - **4 were completely shut down**
  - **12 loss more than 75 of their capacity**
  - **8 partially loss their functionality**
- **62% required repairs or replacement**
- **18% of the hospital beds in public hospitals were lost for at least one month**
- **The ministry of health estimated it will require US$ 2,800 million to repair hospital damage**

Impact of nonstructural damage on businesses / industry

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Impact of nonstructural damage on businesses / industry

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Impact of nonstructural damage on businesses / industry

Company	Industry	Estimated Loss (USD millions)	Type of Loss
Grupo Arauco	Pulp, Plywwod Producer and Saw Mill.	400 to 600	Approximately 65% of the loss is from business interruption
Grupo Quinienco	Brewery, Winery and Manufacturing	300	60% from business interruption
CMPC	Pulp and Paper Manufacturer	170	60% from business interruption
D&S (WalMart Chile)	Retail Stores	150	Primarily physical damage
ENAP	Oil and Gas	150	Evenly distributed between physical damage and business interruption
CAP	Steel Mill (Huachipato Plant)	140	60% from business interruption
Viña Concha y Toro	Winery	110	Evenly distributed between physical damage and business interruption
Telefónica	Communications	100	Primarily physical damage
Grupo Claro	Winery, Communications, TV channel, Bottler	84	Evenly distributed between physical damage and business interruption
Censosud	Retail	72	Primarily physical damage
Carozzi	Food Manufacturer	60	Primarily physical damage
SCL - Santiago Airport	Infrastructure	40	Primarily physical damage
Fallabella	Retail - Largest chain of retail stores in Chile	42	Primarily physical damage

Source: Aon Benfield Analysis

Damage to sprinkler bracings

Photo E. Miranda

Damage to sprinkler bracings

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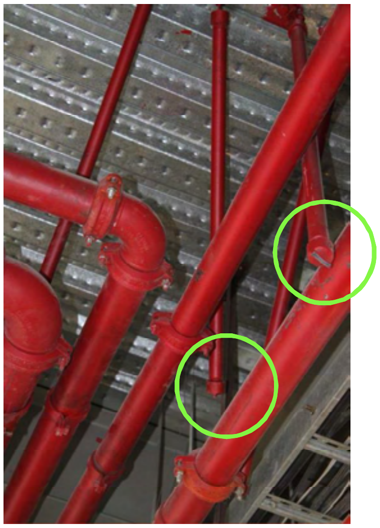
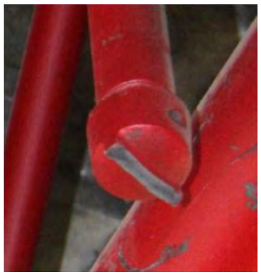
Damage to sprinkler bracings





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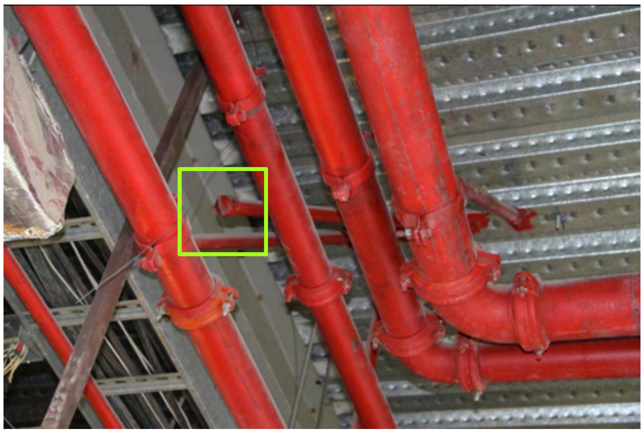
Damage to sprinkler bracings



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Damage to sprinkler bracings

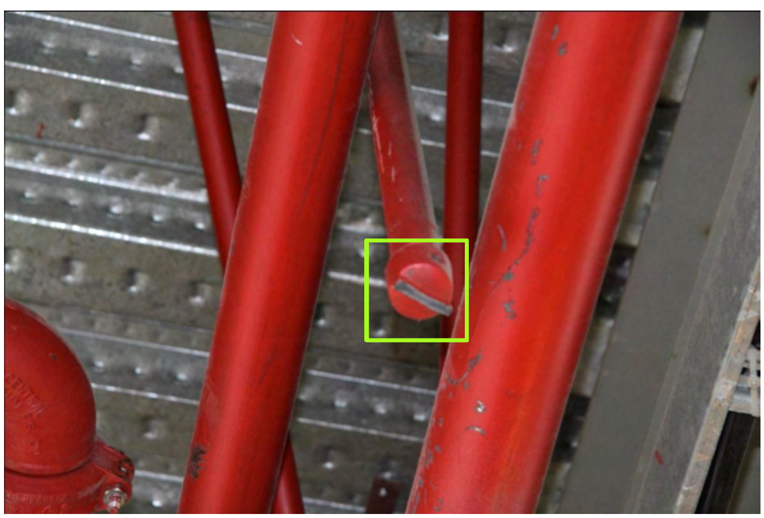

Photo E. Miranda

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October / November 2011

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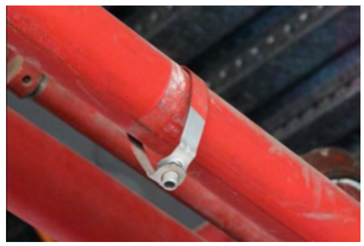
Damage to piping hangers

Photos E. Miranda



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Damage to sprinkler systems

Photo E. Miranda

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October / November 2011

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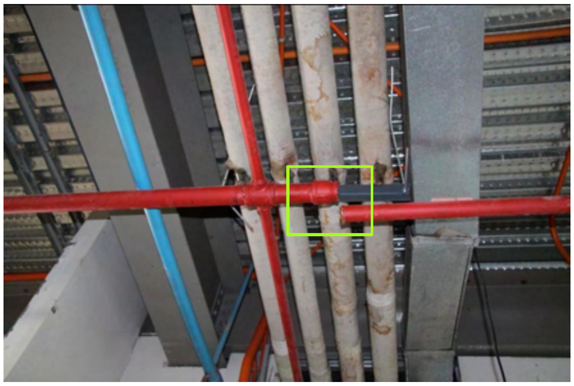
Damage to sprinkler systems



Photos E. Miranda

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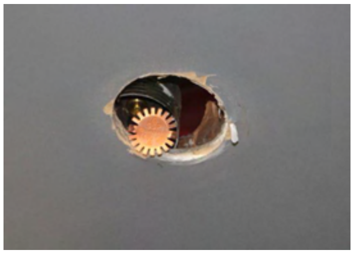
Ceiling-sprinkler head dynamic interaction



Photos by E. Miranda

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Ceiling-sprinkler head dynamic interaction

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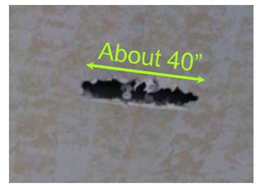

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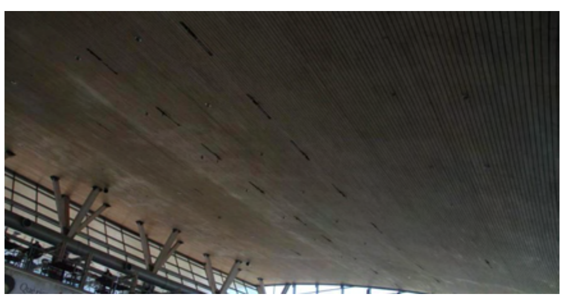
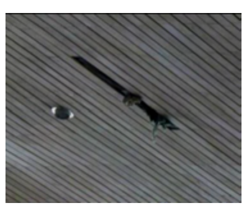
Ceiling-sprinkler head dynamic interaction





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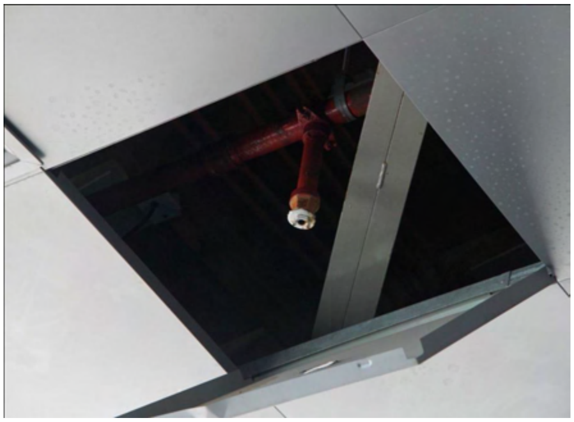

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Ceiling-sprinkler head dynamic interaction

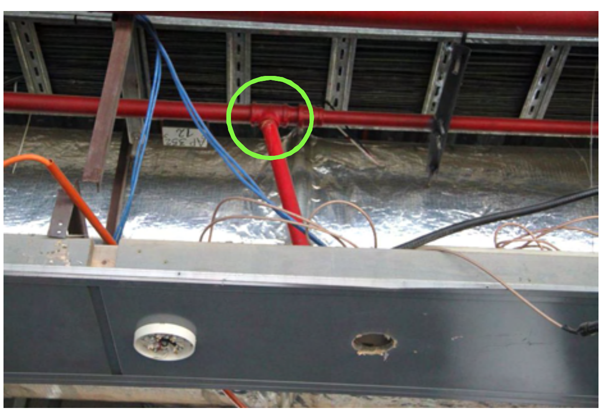


Photo by E. Miranda

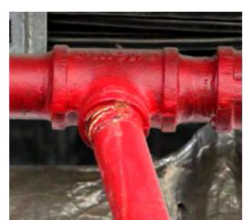
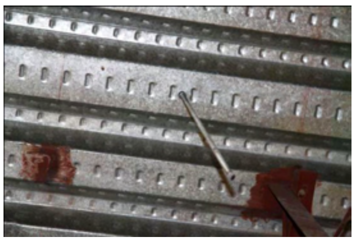


Photo by E. Miranda

Damage to threaded rods






Photos by E. Miranda

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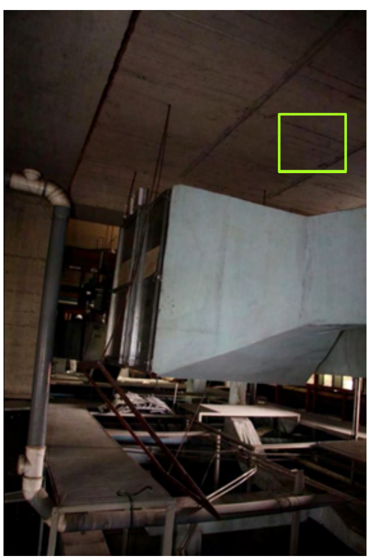
Damage to anchors




Photos by E. Miranda

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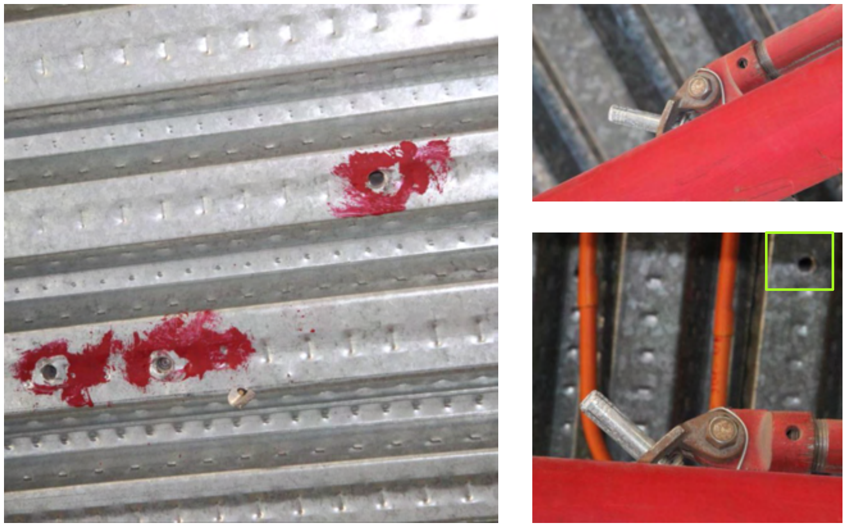
Damage to anchors



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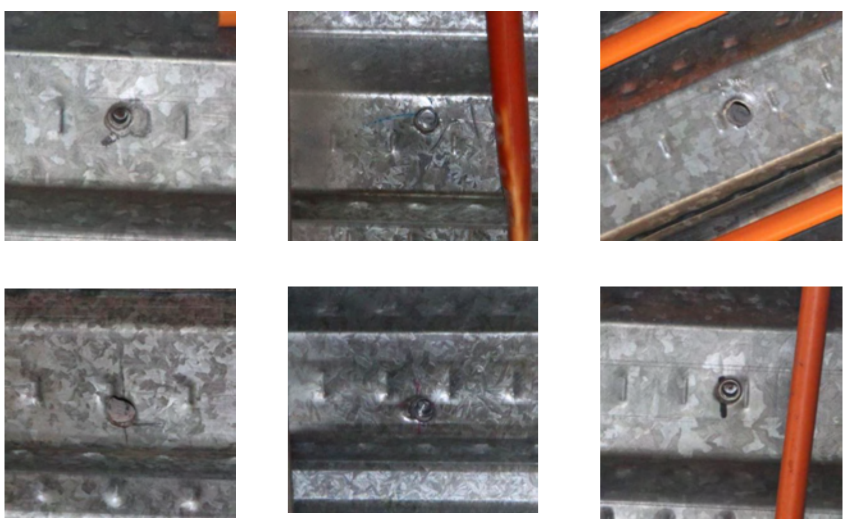
Damage to anchors



Photos by E. Miranda

Damage to anchors

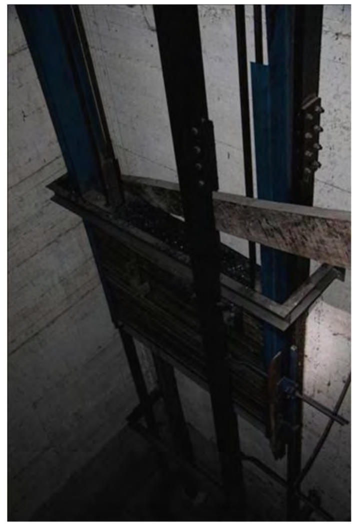
Photos by E. Miranda

Damage to Elevators

Photo by R. Retamales

Photo by G. Pekcan

Damage to Elevators



Photos E. Miranda

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Damage to Elevators

Photo E. Miranda

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Damage to Elevators

Video Elevator in Military Hospital in Santiago

Broken water pipes

Photo by G. Pekcan

Photos by G.Mosqueda

Broken water pipes

Photo by G.Mosqueda

Photos by G.Mosqueda

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Broken water pipes

Photos E. Miranda

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Broken water pipes

Photo E. Miranda

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Glazing damage

Photos E. Miranda

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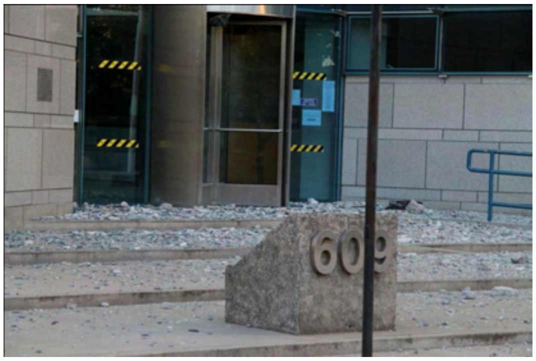
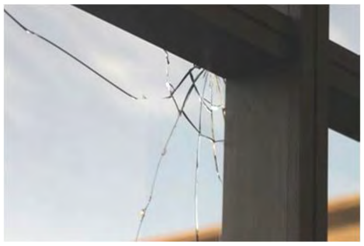
E. Miranda and G. Mosqueda

Glazing damage



Glazing damage



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Glazing damage

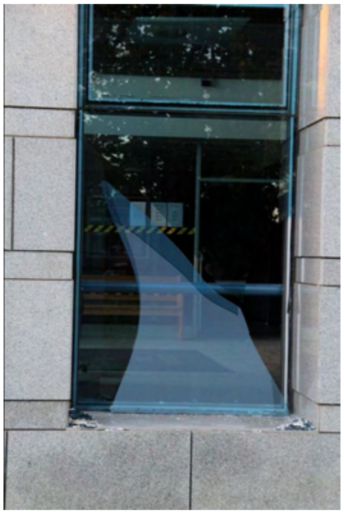

Photo E. Miranda

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Glazing damage

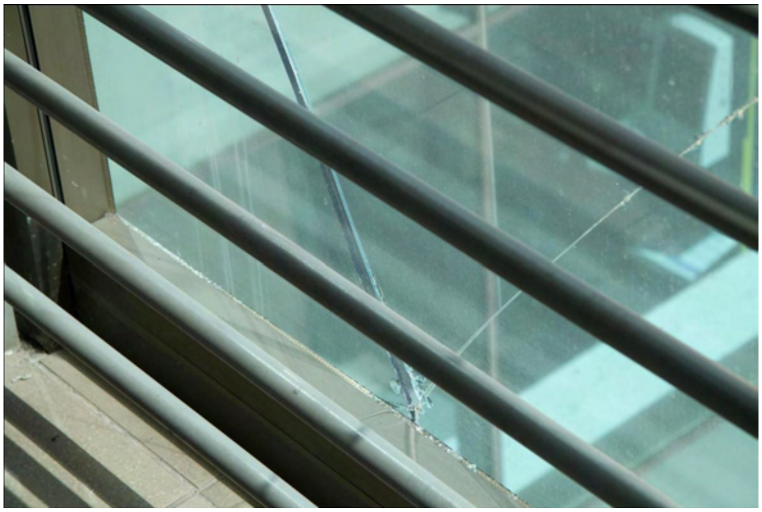

Photo E. Miranda

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Glazing damage

Photo E. Miranda

Glazing damage

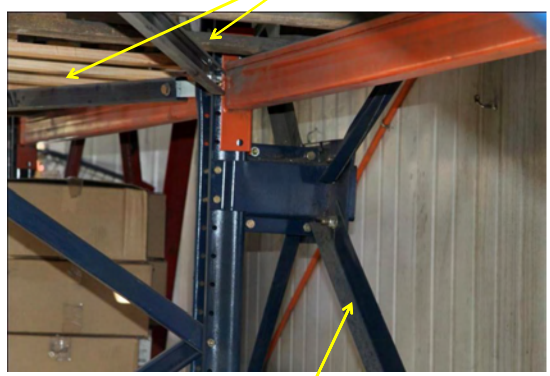
Photos E. Miranda

Damage to storage racks

Photo E. Miranda

Damage to storage racks

Horizontal bracing – diaphragm



Photos E. Miranda

Well-anchored at the base

Lateral bracing – longitudinal direction

Damage to storage racks

Photos E. Miranda

Duration of ground motion

Photo E. Miranda

Some examples of good performance

Photo E. Miranda

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Some examples of good performance

Photo by G. Pekcan

Photo by G. Pekcan

Seismic Design and Performance of Nonstructural Elements

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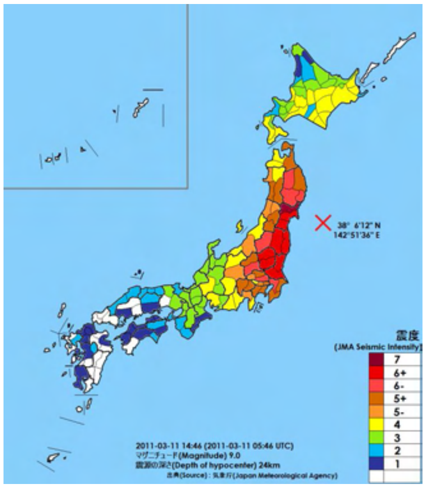
Some lessons from the 2010 Chile Earthquake

- **In general very good structural performance of building relative to the magnitude of the event (8.8)**
- **Massive amount of nonstructural damage that lead to large impact and significant disruption to Chilean society.**
- **Very large economical losses (approx. US$25 billion) which represents 12% of their GDP!**
- **There were many examples in which details, similar to those used in the U.S., were not enough to prevent significant damage and impact.**

Japan

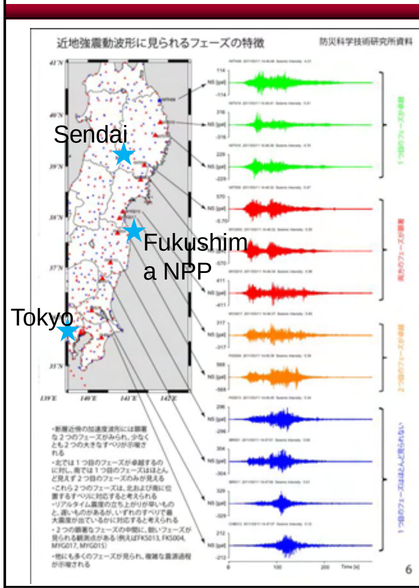
- **Large investment in earthquake preparedness – tsunami warning system and adoption of advanced technologies**
- **Strong research program in earthquake engineering (US-Japan cooperative research program in many areas)**
- **Advanced seismic codes**

March 11, 2011 Eastern Japan Earthquake



- Magnitude (Mw): 9.0
- Depth: 32 km (20 mi)
- Distance from Shore: 70 km
- Rupture zone: 500x200 km
- PGA: 2.9g measured
- Tsunami: >35 m
- Casualties: ~ 25,000
- Refugees: 151,000
- Economic Loss: >$309 B
- Cost of Recovery: >$615 B

Best recorded earthquake



Ground shaking effects on structures
- intensity
- frequency content
- duration

Japan K-Net Station
Many motions records available for analysis

Non-Structural Damage - Sendai

Drop of exterior wall of steel structure (Oroshimachi)

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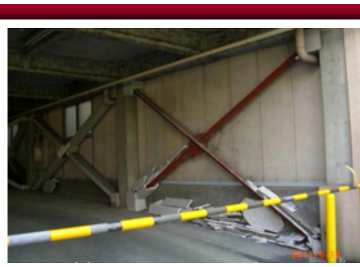
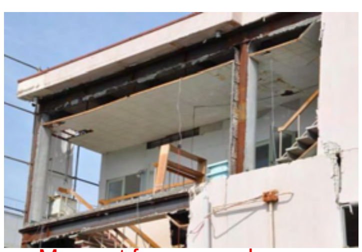
Non-Structural Damage - Sendai





Moment frame: no damage

Exterior cladding damage. (Photos courtesy of Dr. Dimitrios Lignos)

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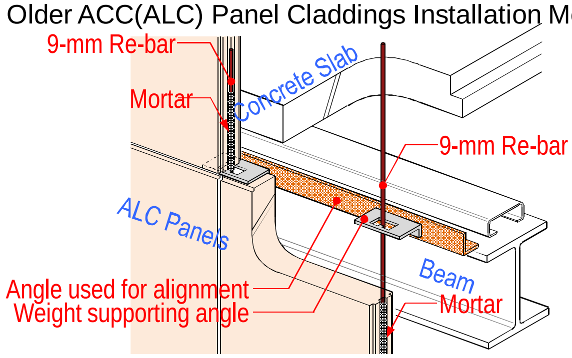
Non-Structural Damage - Sendai

Exterior cladding damage, (Photos courtesy of Dr. Dimitrios Lignos)

Damage to precast ACC (ALC) façade elements

Older ACC(ALC) Panel Claddings Installation Method



ALC panels are rigidly connected to structural frame

Minimum specified compressive strength of 3.0MPa

Min Thickness of 100mm

Typically used in 600mm modules

Typical Failure modes observed also in past earthquakes: (1) cracking and chipping of ALC, (2) debonding between rebar and mortar, (3) fracture of rebars, ALC falling

For newer Japanese residences virtually no damage in their ALC panels → The sliding or rotating panel method was adopted for those → Reinforcing bars are disconnected at the individual stories

(Summary prepared by Dr. Taichiro Okazaki, Dr. Dimitrios Lignos and Dr. Mitsumasa Midorikawa)

Non-Structural Damage - Sendai

Steel Structures: Old Construction

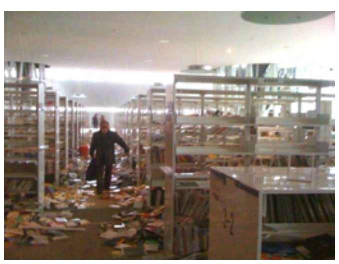
Steel MRF (EW)

Steel Braced Frame (NS)

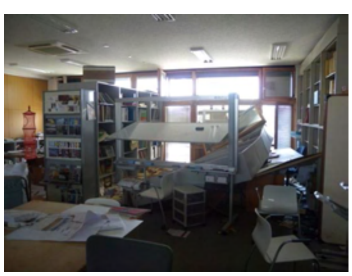
Cladding Wall Damage

(Photos courtesy of Dr. Dimitrios Lignos)

Non-Structural Damage - Sendai



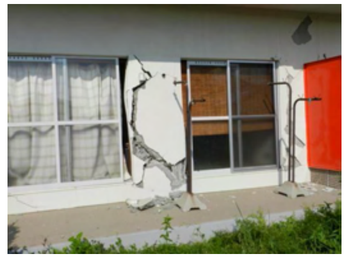
Sendai Library



Tohoku Univ.

Non-Structural Damage - Sendai

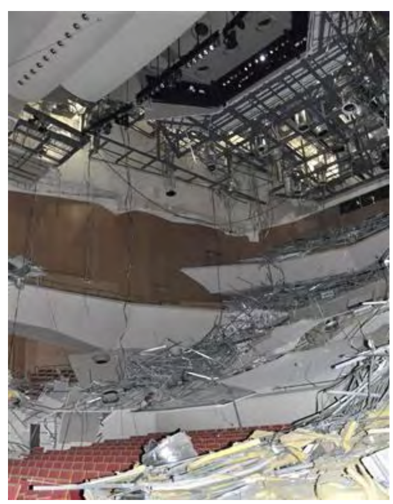
Sunny Heights: SRC



Shear cracks in non-structural components, (Photo courtesy of Dr. Dimitrios Lignos)

Non-Structural Damage - Tokyo

Concert Hall – Kawasaki (near Tokyo)



Moderate Shaking PGA ~ 0.15g

unoccupied at time of earthquake

Ref: http://sankei.jp.msn.com

Ceiling Damage - Tokyo

Bowling Alley Yokohama

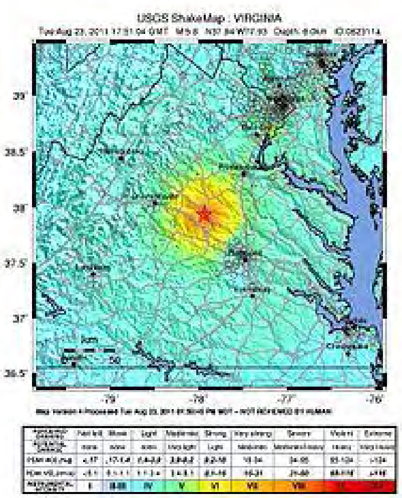
Hotel Hall Tokyo

March 11, 2011 Eastern Japan Earthquake

Lessons related to nonstructural damage

- **Not considering tsunami inundation zone, there was very little structural damage considering intensity of shaking**
- **Majority of damage in large cities including Tokyo and Sendai was mainly nonstructural**
- **Frequently observed non-structural damage**
  - **Ceiling damage / collapse**
  - **Damage / collapse older ACC façade panels**
  - **Overturning of contents**

August 23, 2011 Virginia Mw5.8 Earthquake



- Magnitude (Mw): 5.8
- 200-$300 Million in losses (<$100 Million insured)
- Several schools closed
- Airplanes grounded

Eastern United States

- Moderate earthquake for region
- Little attention given to seismic design, especially for nonstructural systems
- Shaking felt through large region

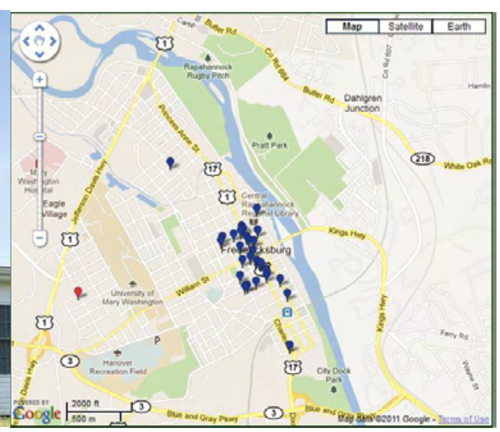
Source: EERI Clearinghouse

August 23, 2011 Virginia Mw5.8 earthquake

Source: ABC News

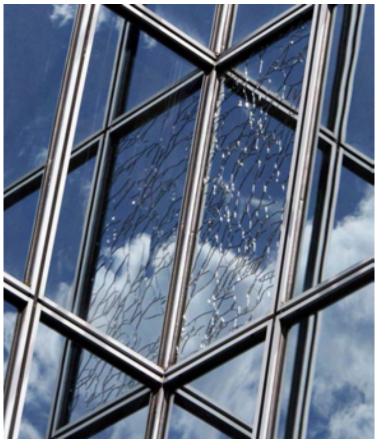
August 23, 2011 Virginia Mw5.8 earthquake

Source: EERI Clearinghouse



Chimney damage in Fredericksburg
Source: EERI Clearinghouse

August 23, 2011 Virginia Mw5.8 earthquake



Glazing damage in Philadelphia
Source: EERI Clearinghouse

Photo: Fred Turner

August 23, 2011 Virginia Mw5.8 earthquake

Source: CNBC News

August 23, 2011 Virginia Mw5.8 earthquake

Ceiling damage at the Louisa County High school, Louisa, Virginia

Source: Richmond Times Dispatch

$81 million loss in Louisa County, Virginia

August 23, 2011 Virginia Mw5.8 earthquake

Louisa County High SchoolClosed for Academic Year

http://www.cnn.com/video/#/video/us/2011/09/01/va.earthquake.damages.school.wric?hpt=hp_t2

Source: Russell Green VT

August 23, 2011 Virginia Mw5.8 earthquake

At the North Anna NP two units automatically shut down. The company (Dominion Virginia Power) declared an alert, the next to lowest NRC emergency classification for plant events, and exited the alert after the plant staff restored offsite power.

Source: Richmond Times Dispatch

PGA, OBE DBE design levels exceeded at the site.

Some deformation observed on grids of rods in spent fuel pool.

August 23, 2011 Virginia Mw5.8 Earthquake

Lessons from the Earthquake

- **Damage to suspended ceilings, masonry chimneys, masonry veneer, masonry infills was widespread**
- **Damage to contents in residential and commercial buildings**
- **Reports of pipe burst in Pentagon causing minor flooding**
- **Damage resulted in closure and reduced functionality of some builidngs including schools**

Lessons from Recent Earthquakes

- The recent earthquake we have described occurred in countries with a long strong tradition in Earthquake Engineering.
- Structural damage in these earthquakes was relatively small in structures designed according to recent codes
- Large amounts of nonstructural damage occurred that lead to significant impacts on facilities and society in general
- Nonstructural damage often occurs as a result of problems in the bracing and anchorage.

Lessons from Recent Earthquakes

- In many cases the failure is due to the deformation, vibration, and pounding of neighboring components. In current practice the deformation of the components is typically not addressed.
- These earthquakes highlight the need of performance based design for controlling economic losses and downtime in addition to life safety through enhanced seismic design of nonstructural systems

NEES Research on Nonstructural Performance

Seismic Design and Performance of Nonstructural Elements

Manos Maragakis,
Dean, College of Engineering, University of Nevada, Reno

Tara Hutchinson,
Professor, Department of Structural Engineering
University of California, San Diego

Manos Maragakis

Manos Maragakis is the Dean of the College of Engineering at the University of Nevada, Reno (UNR). He joined the faculty of the Civil and Environmental Engineering (CEE) Department in 1984, and was promoted to associate professor in 1989 and full professor in 1994. After chairing the CEE Department for 14 years, he was appointed Dean in 2009 following a national search.

Maragakis' research emphasis is in earthquake engineering. He has conducted analytical and experimental work on the seismic response of bridges, buildings, and nonstructural elements. He has received several sizeable competitive grants from the National Science Foundation (NSF) and other federal, state and private agencies. In June 2007 he was awarded a $3.6M NSF Grand Challenge project on the study of the seismic response of nonstructural systems. As the leader of this project, he is coordinating the efforts of researchers and practitioners from 23 institutions around the country and the world. He has authored or co-authored over 170 publications in journals, proceedings and technical reports. He was the founding chair of the Transportation Research Board National Committee on the Seismic Design of Bridges (2000-2006) and has participated in several committees and panels.

Maragakis received his B.S. degree in civil engineering in 1980 from National Technical University of Athens, Greece, and his MS and PhD degrees from the California Institute of Technology in 1981 and 1984 respectively. In 2005 he was awarded the title of UNR Foundation Professor, the highest award the University offers to reward academic excellence.

Tara Hutchinson

Tara Hutchinson is a professor in the Department of Structural Engineering at the University of California, San Diego. She is an earthquake engineering theoretician with a particular interest in large-scale seismic testing. Her research has focused on performance evaluation of structural and foundation components and systems. She has creatively applied information technology to the evaluation of earthquake damage to structures. Results from her soil-foundation structural analysis and seismic performance of non-structural building components have also helped in the design of these critical components.

After receiving a Ph.D. degree in civil engineering from UC Davis in 2001, Hutchinson was named assistant professor at UC Irvine. An energetic educator, she received a Chancellor’s Award for Excellence in Fostering Undergraduate Research, a Faribors Maseeh Teaching Award, and an Excellence in Undergraduate Education Award at UC Irvine. She was also a recipient of the National Science Foundation Career award in 2004.

She serves on the board of directors of the Consortium of Universities for Research in Earthquake Engineering, and is an editorial board member of EERI’s quarterly journal *Earthquake Spectra*. She has published significant papers in leading structural, civil, and earthquake engineering journals..

Contributors

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G. Mosqueda
A. Reinhorn
K. Ryan
E. Zaghi

General Description of the Presentation

- NEESR Nonstructural Projects
- NEESR–GC: Simulation of the Seismic Performance of Nonstructural Systems
  - Project Objectives
  - Research procedures
  - Results

Precast Concrete Cladding Experimental Testing

Kurt McMullin, P.E., Ph.D.
San Jose State University

Experimental Research Studies

- Three related studies of experimental testing
- All projects predominantly funded by the National Science Foundation NEESR Program.
  - San Jose State / UC - Berkeley
  - University of Nevada at Reno / E~Defense
  - UC – San Diego

Research Objectives

- Quantify the effect of displacement and acceleration on panels.
  - Goal: to construct fragility curves relating damage events to panel and floor displacement and acceleration.
- Evaluate the effectiveness of slotted steel connections to allow inter-story drift.
  - Goal: to monitor connecting rod movement while connection experiences 3D acceleration state.

SJSU/UCB Pathways Project

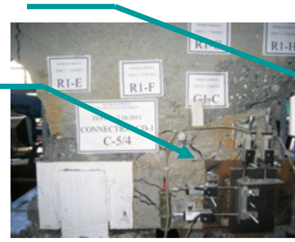
- Static loading – lateral story displacement
- Six tests specimens (3 cladding panels)
- Precast cladding with and without window glazing
- Testing: July – December 2011
- Primary Researchers: McMullin and Stojidinovic

Test Specimen

- Full-story Column Covers: Full-width Flat, Half-width Flat, Return.
- 2-inch vertical seismic joint.
- Specimen 1 shown does not include windows.
- Test site: nees@berkeley

Test Results

- Sliding of slotted connection at top of panel.
- Concrete crushing at base of panel.
- Embed damage.



Test Date: July 13, 2011

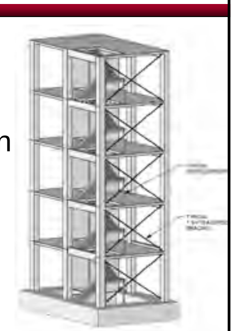
Full-Scale Structural and Nonstructural Building System Performance during Earthquakes

A Joint Venture between Academe, Industry and Government

Tara Hutchinson, Jose Restrepo, Joel Conte
University of California, San Diego

Scope of the Project

- $5 Million, multi-organizational 3 year research project
  - NSF / NEES core research project - $1.2 million
  - Remaining support from industry and government entities in the form of in-kind, materials and cash
- Testing of a full-scale five-story building fully outfitted with a range of nonstructural components and systems (NCSs)
- Structure first base isolation and then fixed base
- Post-seismic shaking “payload” fire testing (localized burn tests)



Partners

Funded by the National Science Foundation under Grant no.: CMMI-0936505

- Academic partners: University of California, San Diego (UCSD), Worchester Polytechnic Institute (WPI), San Diego State University (SDSU), and Howard University (HU)

Seismic Design and Performance of Nonstructural Elements

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Testing Site: NEES @ UCSD

- Large High Performance Outdoor Shake Table (LHPOST)
  - The world's first outdoor shake table & the largest in the U.S

Size	7.6m x 12.2m
Peak Acceleration: bare table, 400 ton payload	4.2 g, 1.2 g
Peak velocity	1.8 m/s
Stroke	±0.75 m
Maximum gravity (vertical) payload	20 MN
Force capacity of actuators	6.8 MN

Seismic Design and Performance of Nonstructural Elements

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Project Vision

- To make breakthrough advances in the understanding of total building systems performance (structural *and* nonstructural systems) under moderate and extreme seismic conditions through full-scale testing.
- Obtain data, which are sorely needed to characterize the earthquake performance of structural and nonstructural building systems, including nonstructural systems with protective measures.
- Use this data to validate nonlinear simulation tools, which in turn can be used for higher-performance code design and performance-based seismic design of nonstructural and building systems.
- Infuse findings into seismic design guidelines and codes
  - Validate current code assumptions
  - Develop more precise and specific performance objectives to cater the clients' exact needs

Seismic Design and Performance of Nonstructural Elements

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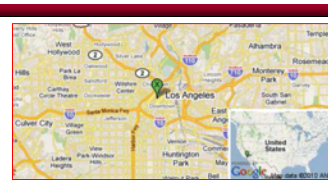
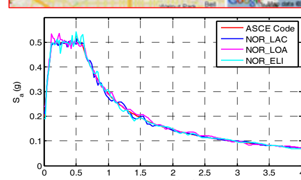
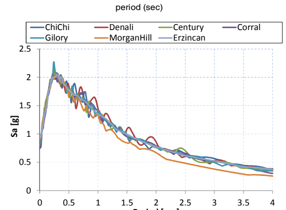
Building Design

- Site Conditions
  - downtown LA - Site Class D
  - target MCE Sv=87in/sec
- Design Ground Motions
  - 7 MCE motions: site specific spectra for a site in downtown LA
  - 3 serviceability motions (return period of 43 years): 20% code specified MCE spectra for design purpose
- Balanced Strength/Capacity Design
- Performance Targets
  - ~2-2.5% lateral drift ratio
  - ~0.7-0.8g floor accelerations







Seismic Design and Performance of Nonstructural Elements

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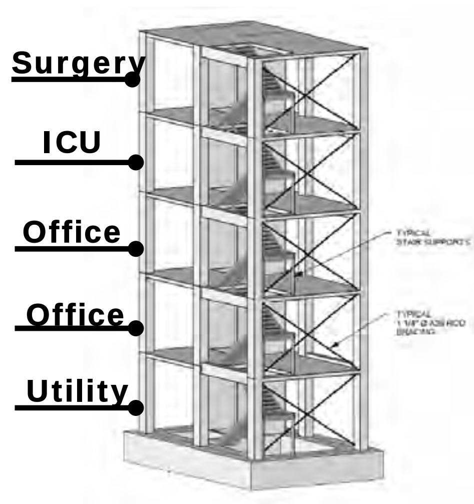
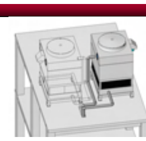
NCSs in the Building: Occupancy

- Each floor will have a different type of occupancy
  - Two floors representing hospital floors (ICU & Surgery)
  - Two floors office
  - Ground level utility floor

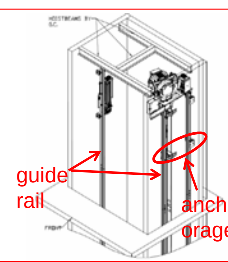


NCSs in the Building: Overview

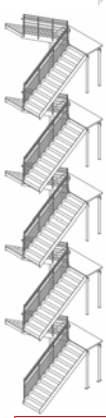
- NCSs including…
  - Operable Elevator
  - Metal stairs
  - HVAC components and subassemblies
  - Fire detection, alarm, sprinkler and riser systems
  - Ceiling subassemblies
  - Hospital equipment
  - Concrete cladding
  - Access floors
  - Roof mounted chiller
  - Roof mounted air handling unit
  - Interior partitions
  - Anchorage
  - Lighting
  - IBM servers



6kip roof mounted cooling tower



3.5k capacity full travel height passenger elevator



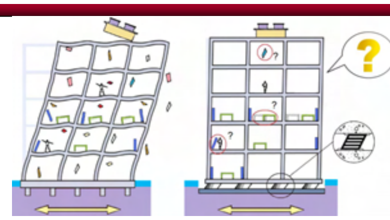
Prefabricated metal stairs

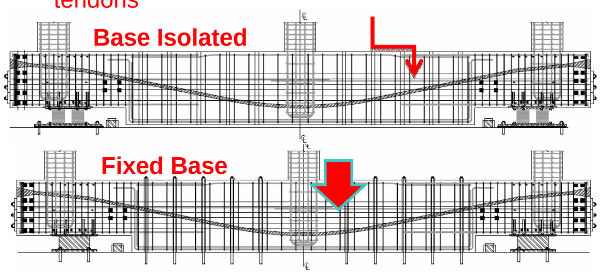
Various medical equipment

Protective Systems: Base Isolation

- Demonstrate the effectiveness of base-isolation to enhance the performance of NCSs.
- Understand total system response of a base isolated building

Complex solution for foundation using a hybrid of post-tensioned rods and tendons





Testing Sequence

1) The building will first be tested on base isolators
2) Entire structure will be jacked up, isolators will be removed
3) Foundation will be post-tensioned to table for fixed-base testing

Current Status

- Structural Skeleton complete (9/28/2011)
- Installing NCSs – Fall 2011
- Seismic Testing – Jan/Feb 2012
- http://bncs.ucsd.edu/index.html

NEESR GC: Simulation of the Seismic Performance of Nonstructural Systems

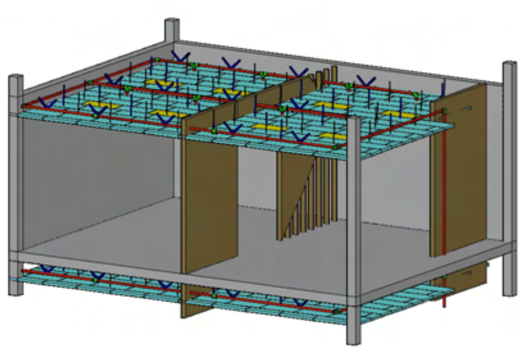
www.nees-nonstructural.org

Manos Maragakis
University of Nevada, Reno

Ceiling-Piping-Partition Systems

The system is a set of three physically interacting subsystems

- Ceiling Subsystem
- Piping Subsystem
- Partition Subsystem



Vision Statement

To significantly enhance the seismic resilience of buildings and communities by providing practicing engineers and architects with verified tools and guidelines for the understanding, prediction and improvement of the seismic response of the ceiling-piping-partition nonstructural system.

NEESR-GC: Project Team

Principal Investigator

E. "Manos" Maragakis
University of Nevada, Reno

Co- Principal Investigators

André Filiatrault (UB)
Steven French (Georgia Tech)
Tara Hutchinson (UCSD)
Bob Reitherman (CUREE)

Practice Committee

Dennis Alvarez (CISCA)
Russell Fleming (NFSA)
John Gillengerten (OSHPD)
Praveen Malhotra (FM Global)
Robert Wessel (Gypsum. Assoc.)

Senior Personnel

Raymond Burby (UNC at Chapel Hill)
Jaque Ewing-Taylor (UNR)
Mircea Grigoriu (Cornell)
Abhinav Gupta (NC State)
Sameer Hamoush (NC A&T State Univ.)
Gee Hecksher (Architectural Resources)
William Holmes (Rutherford & Chekene)
Ahmad Itani (UNR)
Falko Kuester (UCSD)
Gokhan Pekcan (UNR)
Andrei Reinhorn (UB)
Gilberto Mosqueda(UB)

International Collaborators

Jean-Angelo Beraldin (NRC, Canada)
Kazuhiko Kasai (Tokyo Institute of Techn)
Shojiro Motoyui (Tokyo Institute of Techn)

Industry Collaborators

Jim Hatch (Jarret Structures)
Paul Hough (Armstrong World Industries)
Doug Taylor (Taylor Devices)

Other Collaborators

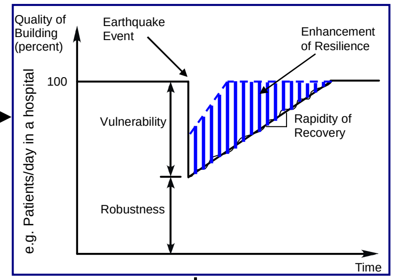
Kurt McMullin (San Jose State Univ.)
Wayne Smith (Tech Museum)
Dave Schaefer (NCSU)

CUREE Georgia Tech RUTHERFORD & CHEKENE UCSD University at Buffalo NC STATE UNIVERSITY North Carolina A&T State University

Enhancement of Resilience

For individual buildings proposed research will:

- Decrease the risks to life and property
- Limit loss of functionality after an earthquake

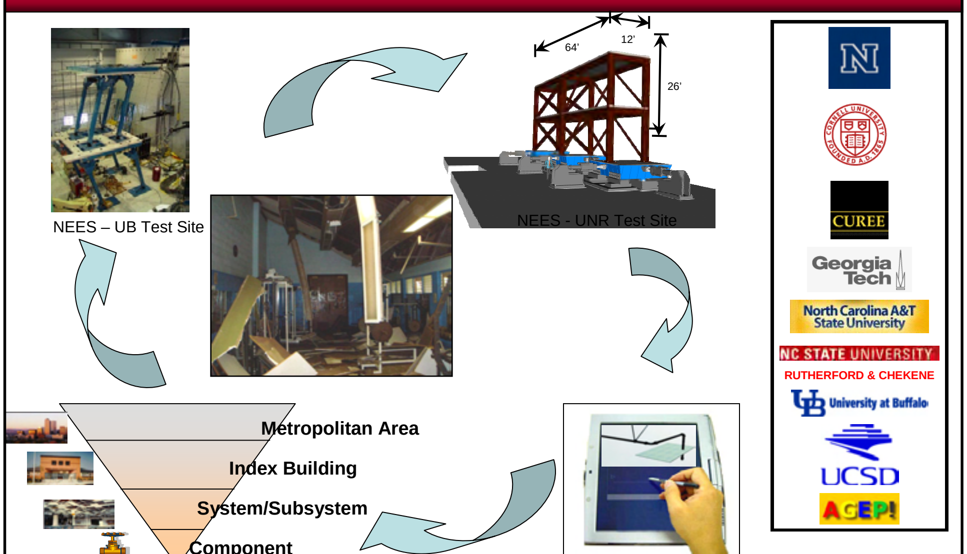


Quantify the impact of the research on the individual building and metropolitan scales - Implementation

- Reduce failure at the metropolitan scale
- Improve the community ability to recover after an earthquake

Enhancement of community resilience

NEESR-GC: Simulation of the Seismic Performance of Nonstructural Systems

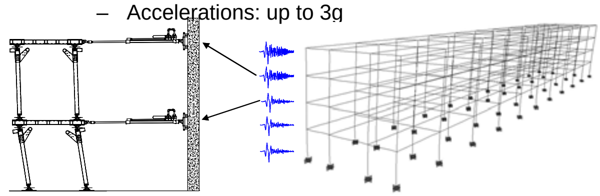


Experimental Program

Experimental Research at UB NEES site

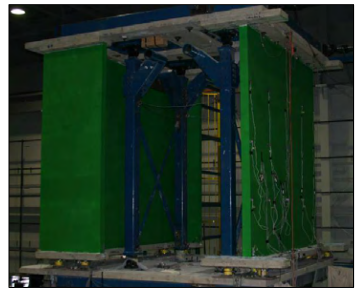
UB-Nonstructural Component Simulator

- Equipment for static and dynamic testing
- Two-level shake table capable of reproducing in real-time the full-scale floor drifts and acceleration expected at two consecutive building levels
- Characteristics:
  - Plan dimensions: 12.5'x12.5'
  - Story height: 14'
  - Load capacity: 22 kips/actuator
  - Payload capacity: 5 kips/level
  - Displacements: ± 40 in
  - Velocities: 100 in/s
  - Accelerations: up to 3g



NEESR Nonstructural GC Subsystem Experiments at UB

- Carry out an extensive experimental program to evaluate the seismic response, failure mechanisms, and fragilities of
  – cold formed steel frame gypsum partition walls
  – sprinkler piping
  – ceiling systems
- Develop protective technologies and design details to enhance seismic performance of nonstructural systems



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Seismic Design and Performance of Nonstructural Elements

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Current Status

- Partition Walls (NCS)
  – 50 12-ft wall specimens tested:
    - 36 In-Plane tests (28 quasi-static and 8 dynamic tests)
    - 14 Out-of-Plane tests (all dynamic tests)
  – experimental fragility curves completed
- Sprinkler Piping (NCS and Reaction Set ups)
  – 48 T-joint specimens tested under monotonic and cyclic loading
  – 3 configurations of a two floor layout of sprinkler subsystem tested under dynamic loading ,
- Ceiling Systems (Testing Frame)
  – Currently testing large (20 ft x 50 ft) ceiling subsystems with 1D, 2D and 3D motions

Seismic Design and Performance of Nonstructural Elements

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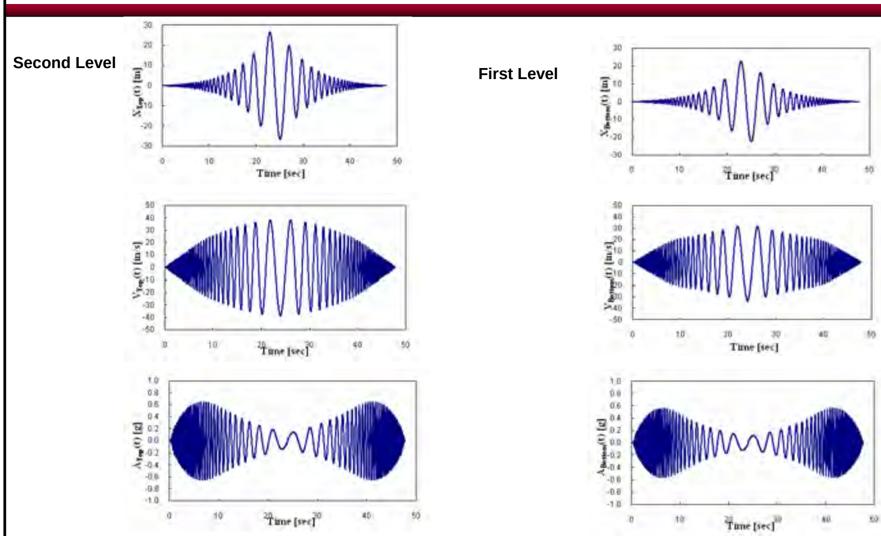
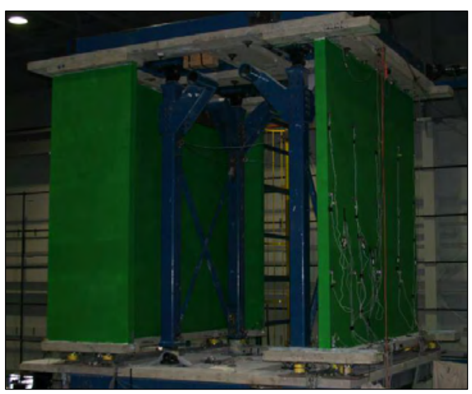
UB-NCS Dynamic Testing Protocol

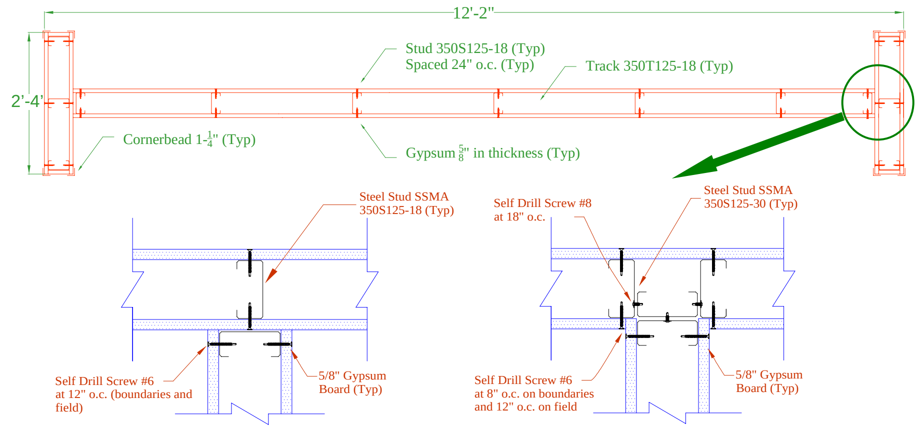


Experimental seismic fragility of steel-stud gypsum partitions walls



Partition Wall Configurations

- **Typical 12 foot wall with returns and corner details**



Commercial Construction (ASTM, 2007) Institutional Construction (SSMA, 2001)

Seismic Design and Performance of Nonstructural Elements

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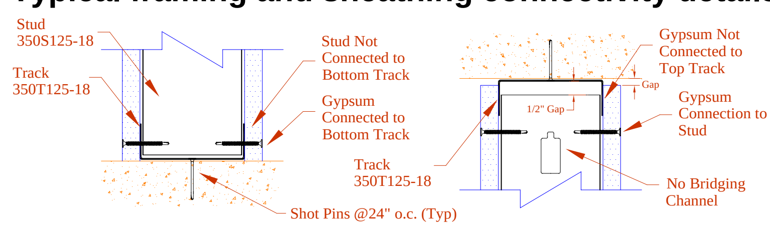
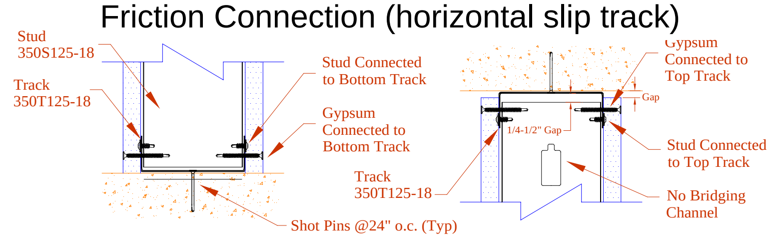
Partition Wall Configurations

- **Typical framing and sheathing connectivity details**



Friction Connection (horizontal slip track)



Full Connection

Seismic Design and Performance of Nonstructural Elements

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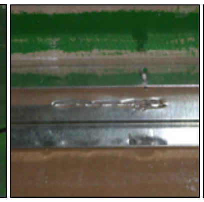
Partition Wall Subsystems

Summary of Observed Damage

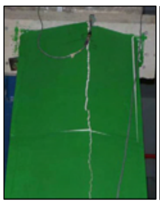

Damage in transverse wall top track

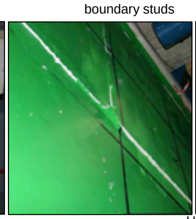

Damage along cornerbeads and boundary studs


Tearing along top track fastener


Hinges forming in studs (commercial construction)

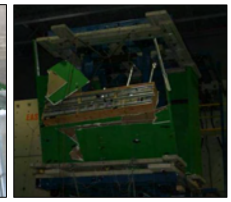

Buckling of diagonal braces


Damage in transverse walls


Damage of joints between gypsum panels

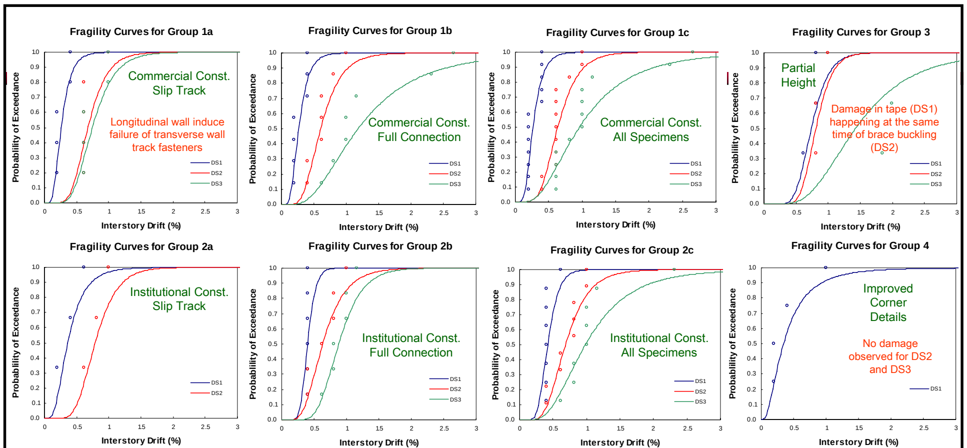

Hinges forming in studs (institutional construction)


Crushing and shearing of gypsum around screws in connection to top track


Collapse of partition wall

Damage States

Damage State		Description of Damage Associated	Repair Actions
DS_1	**Superficial damage to the walls**	Cracks along cornerbeads, cracks along joint paper tape, screws pulled out from connections of gypsum boards to steel framing, buckling of partial height wall brace	Cosmetic repairs, including: replacement of cornerbeads, replacement of screws pulled out, replacement of joint paper tape, application of joint compound, sanding, and painting, replace braces
DS_2	**Local damage of gypsum wallboards and/or steel frame components**	Crushing of wall corners, out-of-plane bending and cracking of gypsum wallboards at wall intersections, damage of screws connecting wallboards to boundary studs, bending of boundary studs, buckling of diagonal braces (partial height partition walls)	Local repairs, including: repair or replacement of gypsum wallboards, replacement of boundary studs, replacement of seismic braces
DS_3	**Severe damage to walls**	Tears in steel tracks around connectors of track to concrete slab, track fasteners passing thru track webs, track flanges bent at wall intersections, hinges forming in studs	Replacement of partition wall (Steel framing and wallboards)



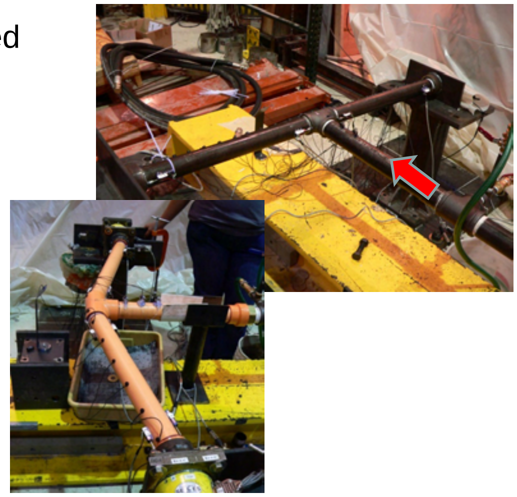
Group	Sub Group	Description	DS_1		DS_2		DS_3	
			x_m	β	x_m	β	x_m	β
0	0	All specimen data	0.35	0.56	0.69	0.39	1.04	0.55
1	1a	Full-height specimens. Commercial construction practice and slip tracks	0.26	0.45	0.68	0.35	0.75	0.36
	1b	Full-height specimens. Commercial construction practice and partial/full connections	0.27	0.44	0.61	0.41	1.18	0.59
	1c	Full-height specimens. Commercial construction practice (slip tracks and full connection)	0.27	0.43	0.64	0.38	0.96	0.61
2	2a	Full-height specimens. Institutional construction practice and slip tracks	0.36	0.55	0.79	0.34	-	-
	2b	Full-height specimens. Institutional construction practice and partial/full connections	0.40	0.25	0.63	0.43	0.88	0.33
	2c	Full-height specimens. Institutional construction practice (slip tracks and full connection)	0.42	0.31	0.69	0.40	0.98	0.52
3	3	Partial-height specimens	0.74	0.29	0.81	0.25	1.43	0.47
4	4	Specimens including improved corner details	0.34	0.77	-	-	-	-

Partition Wall Testing Summary

- A comprehensive experimental program investigated the seismic fragility of cold formed steel framed gypsum partition walls
- Damage initiates at median drifts of 0.2%
- The friction connection to top track (seismic slip track) does not increase the drift for the first damage state – damage occurs at corners and sometimes does not progress to more severe damage state
- Bracing in partial height walls provide flexibility that delays the initiation of damage in the gypsum
- Construction details were proposed that increased the drift at first damage or limited damage to sacrificial corner beads

Experimental seismic fragility of sprinkler piping components

- 48 T-joint specimens tested under cycle loading
- Specimen details and parameters selected with advice from practice committee
  - Material
  - Connection type
  - Pipe diameter

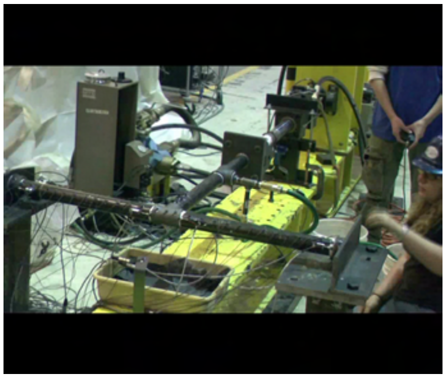


Test Matrix

Pipe / Fitting Material	Pipe / Fitting Size (inches)	Number of Monotonic Tests	Number of Cyclic Tests	Testing Status
Black Iron (Threaded)	6	1	3	Completed
Black Iron (Threaded)	4	1	3	Completed
Black Iron (Threaded)	2	1	3	Completed
Black Iron (Threaded)	1	1	3	Completed
Black Iron (Threaded)	3/4	1	3	Completed
CPVC (Cement Joint)	2	1	3	Completed
CPVC (Cement Joint)	1	1	3	Completed
CPVC (Cement Joint)	3/4	1	3	Completed
Steel (Groove Fit Connection Schedule 40)	4	1	3	Completed
Steel (Groove Fit Connection Schedule 40)	2	1	3	Completed
Steel (Groove Fit Connection Schedule 10)	4	1	3	Completed
Steel (Groove Fit Connection Schedule 10)	2	1	3	Completed
			Total Test:	48

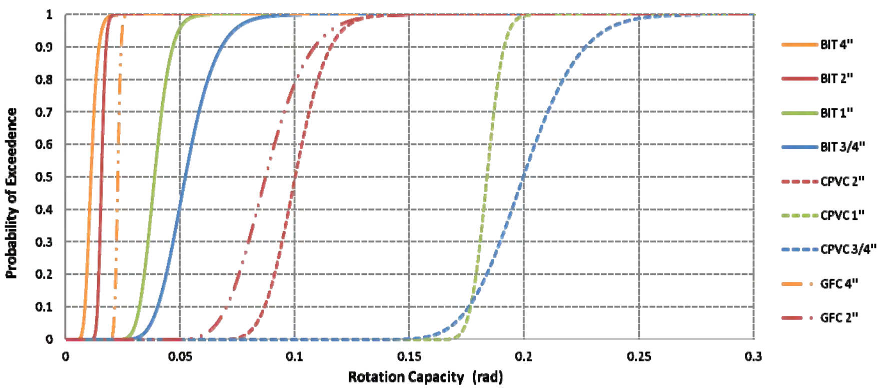
Piping Tests Phase 1

- **Identify moment and rotation at joints at which damage state occur**
  - **The 1st damage state --- first leakage**
  - **The 2nd damage state --- complete fracture at tee joint**



Piping Test Result Summary for Phase 1

- **Summary of fragility curves**



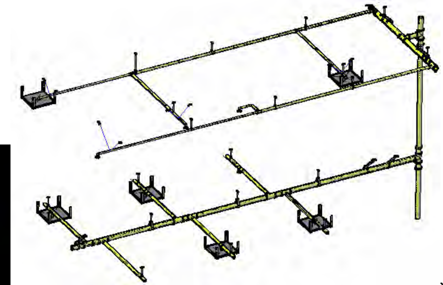
-- Same color indicates pipes of same size;

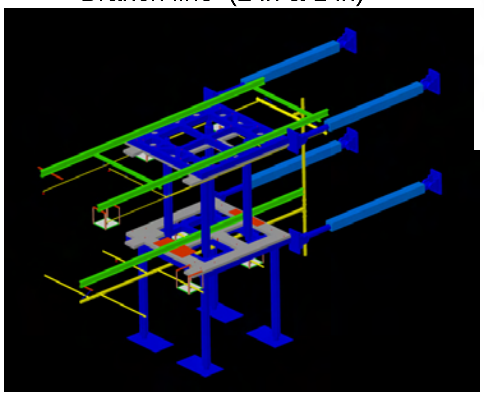
-- Same line style indicates pipes of same material.

Dynamic Testing of Sprinkler Piping System

Piping System:

- Riser (4 in)
- Main line (4 in)
- Branch line (2 in & 1 in)





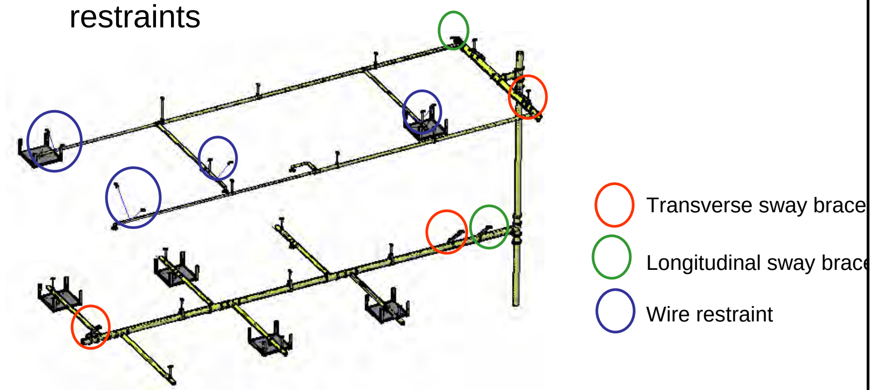
Component	Quantity
Sprinkler head	9
Transverse sway brace	4
Wire restraint	2
Ceiling box	6
Vertical hanger	16

Test matrix

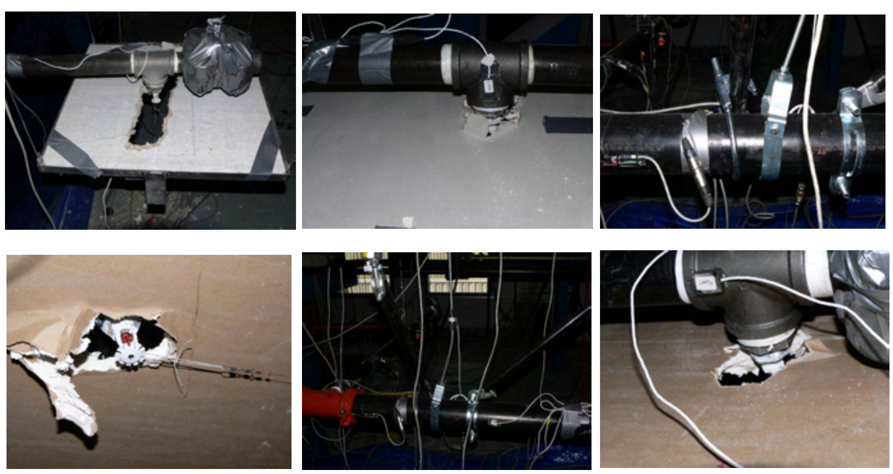
MAIN LINE & RISER MATERIAL	BRANCH LINE MATERIAL	NUMBER OF SERIES TEST
Schedule 10 Steel Groove Fit Connection	Schedule 40 Black Iron Threaded	6
	Schedule 40 CPVC (cement joint)	6
	Schedule 7 Dynaflow	6
	Total:	18

Design with input from PMC

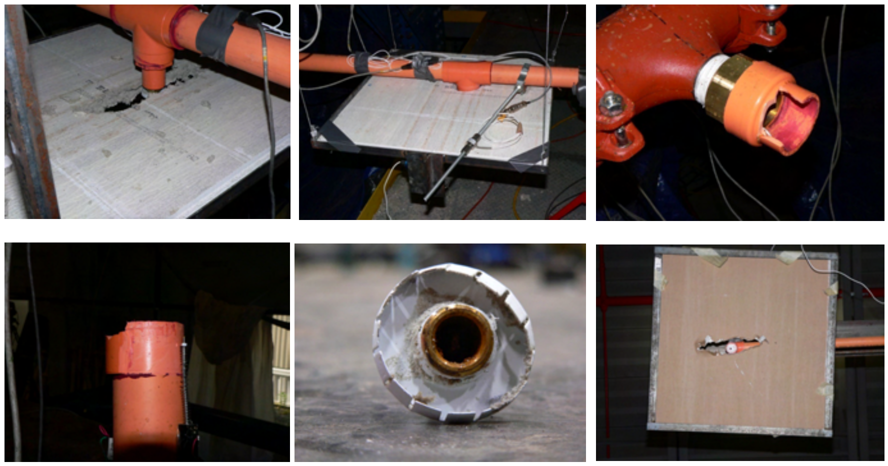
- Testing Procedure
  - Test fully braced configuration then progressively remove transverse sway braces and wire restraints



Observed Damage – Black Iron Threaded



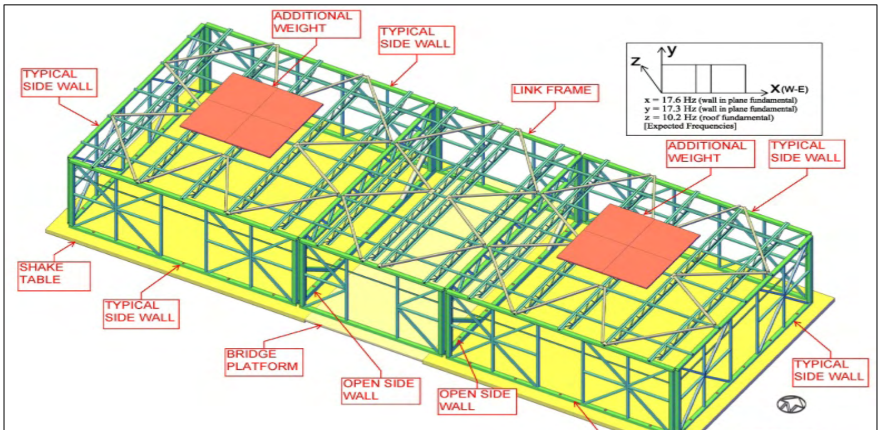
Observed Damage - CPVC



Experimental Studies

Large-scale dynamic experiments on Ceiling/Piping/Partition Subsystems at UB

Design of Test Frame of 20ft × 50 ft



Ceiling Surface over 1,000ft^2

Variable Roof Frequencies 8 ~ 22 Hz

Test Plan and Current Status

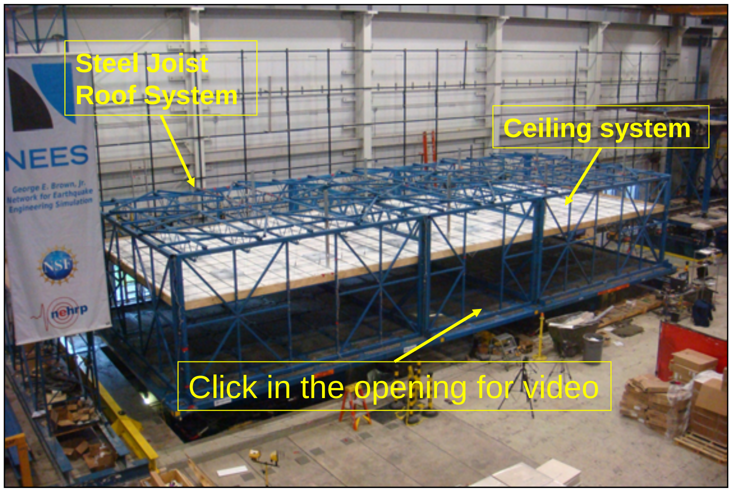
Test # 1 to #5 completed:

- Performed 1D, 2D and 3D input motion tests (per AC156 RRS) – Test #1 to #4
- Studying Compression post and splay wire contribution
- Test #7, 4psf heavy panel set up in progress

Initial Planned Test Number	Actual / Revised Test Number	Ceiling Dimensions x, ft.	y, ft.	ht, z in.	Duty rating	TileWeight	*fixtures/ weight	bracing	comp. strut?	peri. angle condition	**Shaking Direction	**Design Condition	Comment
3	1	20	50	29	heavy	1.05	2x2 distributed	yes	yes	2" angle	xyz	SDC D	Investigate effect of 3D motion
2	2	20	50	29	heavy	1.05	2x2 distributed	yes	yes	2" angle	yz	SDC D	Add vertical
1	3	20	50	29	heavy	1.05	2x2 distributed	yes	yes	2" angle	y	SDC D	One D motion; mains in 50' direction Typ unless noted
3 (Repeat)	4	20	50	29	heavy	1.05	2x2 distributed	yes	yes	2" angle	xyz	SDC D	Investigate effect of 3D motion
4	5	20	50	29	heavy	1.05	2x2 distributed	no	no	2" angle	xyz	SDC D	Investigate 1000 sf limit
7	6	20	50	29	heavy	3.00	2x2 distributed	no	no	2" angle	xyz	SDC D	investigate compression strut
10	7	20	50	29	heavy	4.00	2x2 distributed	yes	yes	2" angle	xyz	SDC D	investigate intermediate duty at SDC D
5	8	20	50	29	heavy	1.05	2x2 distributed	no	no	7/8 angle/clips	xyz	SDC D	investigate effect of clips
8	9	20	50	65	heavy	1.05	2x2 distributed	yes	yes	7/8 angle/clips	xyz	SDC D	investigate deep plenum
9	10	20	50	29	intermediate	1.05	2x2 distributed	no	no	7/8 angle	xyz	SDC C	investigate typical SDC C conditions
6	11	20	50	29	heavy	1.05	2x4 linear	yes	yes	2" angle	xyz	SDC D	Investigate fixture pattern; Main in 50' direction 2 lines of fixtures in 20' direction

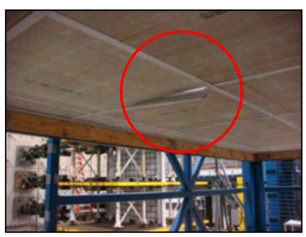
Test #7 4psf panel with Comp. post and splay wires

Test Frame 20ft x 50ft, 10ft high @ UB-SEESL



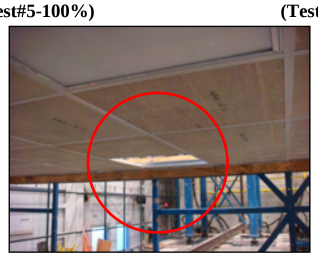
Observed Failure Modes

Rivet Pulled Out
(Test#5-100%)

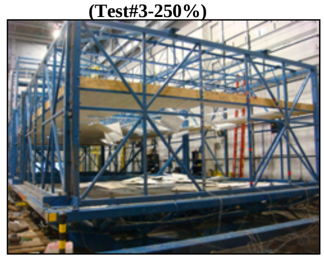


Cross Tee Joint Failure
(Test#4-150%)

Broken Main Runner Splice
(Test#3-250%)



Fallen Tile (Test#3-250%)



System Collapsed (Test#5-200%)

Initial Observation and Remarks

- Size effects are present :
  - Inertia forces are collected and exceed strength of rivets at fixed connection at low level input ~125% AC156 RRS ~ 0.30g pga)
- Suspension standards – compression struts and diagonal wires (lateral constraints):

- Effects limited to the grid lines with constraints, not to the entire system (under further investigation)

- Methodical evaluation of capacity-demand vs fragility testing:

- Collecting data through direct measurements of demands – forces-displacements – to compare to available capacity. May allow testing at lower levels then make predictions

Experimental Program

Experimental Research at UNR NEES Site

Objectives of System Experiments at UNR – NEES Site

Study configurations of Ceiling-Piping-Partition systems in multistory buildings through shake table experiments to establish:

– Response of the nonstructural components, as part of a system, under large drifts/accelerations.

– Interactions within the nonstructural components.

– Interactions between the structural and nonstructural systems.

– Effects of structural yielding on response of the nonstructural components.

Design Concepts of UNR Test Bed

- Reconfigurable dynamic properties to simulate different dynamic environments:
  - Allow for study of both acceleration and drift sensitive components
  - Simulate adjacent floors of a typical multi-story building
  - Easy to simulate analytically
- Allow for large–scale experiments
- Allow for future payload tests
- Reusable for multiple experiments

Performance Objectives of UNR Test Bed

- Target Inter-Story Drift (nonlinear structure)

  $\Delta \geq 3.0\%$

- Target Acceleration (linear structure)

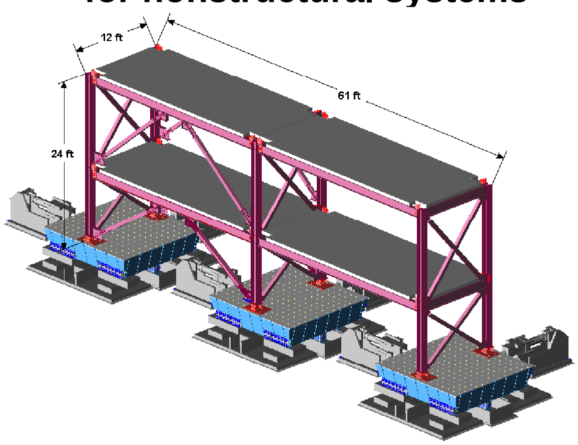
  Peak Floor Acc. ≥ 2.0 g

- Target Natural Period

  0.2 sec ≤ T ≤ 1.5 sec

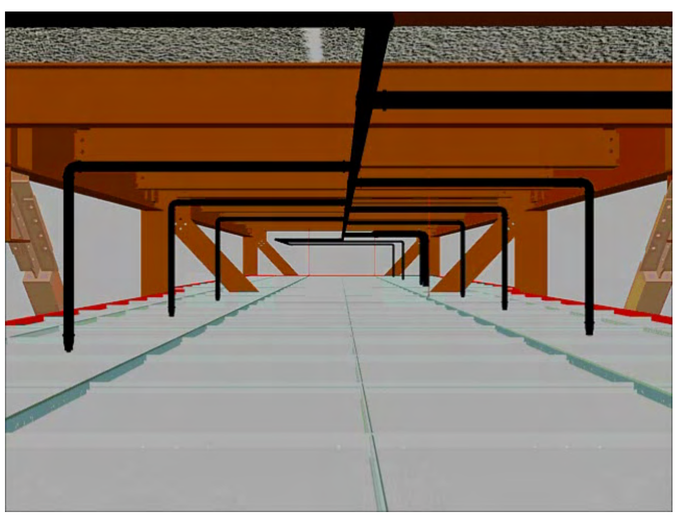
UNR Test Bed Structure

Test Bed Structure to simulate dynamic environments for nonstructural systems

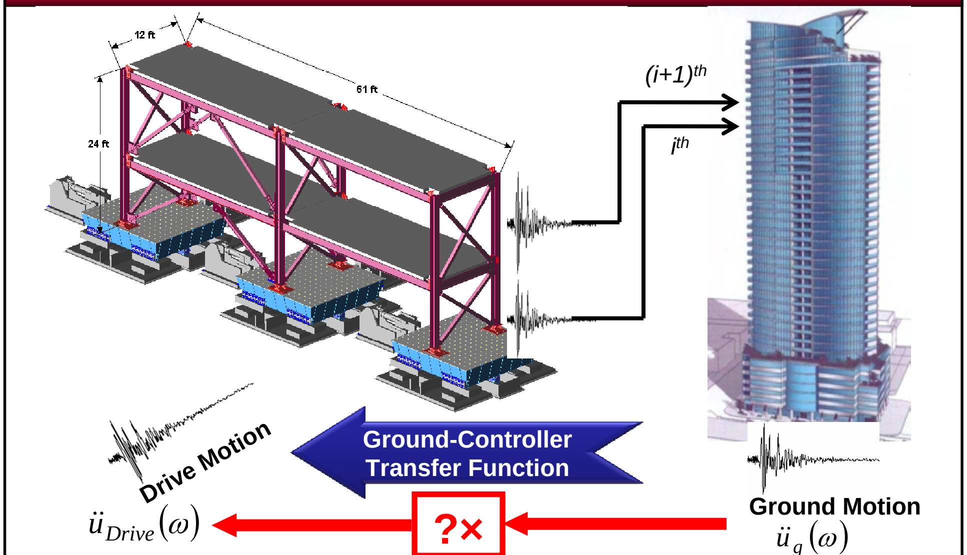


UNR Test Bed Structure- Fly Through

Ceiling System



Floor Motion Simulation

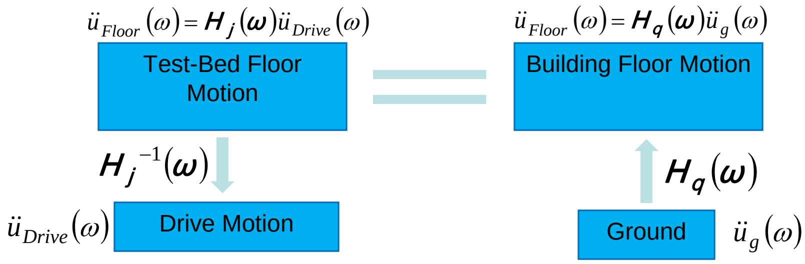


Procedure to Calculate the Ground-Table Transfer Function (TF)

1. A continuum model formulation of a generic building was adapted (after Miranda)
   - May represent a variety of structural systems
   - Represent buildings of different heights
2. Ground-Floor TF was calculated for the generic building
3. Controller-Test Bed Floor TF was obtained with consideration of multiple supports
4. Ground-Controller TF was found using TFs from steps 2 and 3

Ground-Controller TF=
(Ground-Floor TF)(Controller-Test Bed Floor TF)$^{-1}$

Ground-Controller TF



$$\ddot{u}_{Drive}(\omega) = H_q(\omega).H_j^{-1}(\omega).\ddot{u}_g(\omega)$$

Ground-Controller TF

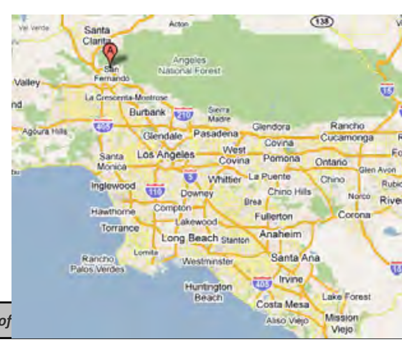
Drive acceleration introduced to controller

Acceleration applied to target building

Note: High-pass filter may be needed to reduce the table demands

Example of Implementation of the Method

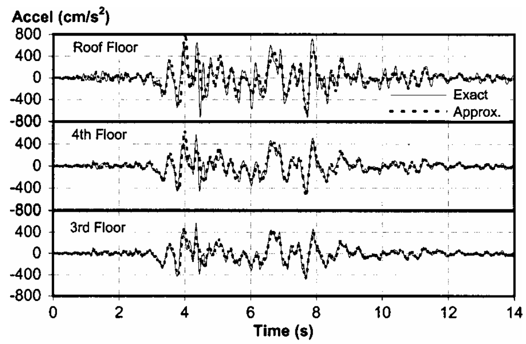
Building:	Olive View Hospital Sylmar, Los Angeles
Target Floor:	6th floor
Tuned Test Bed Floor:	Second
Earthquake:	Northridge 1994



Generic Model for Hospital Building

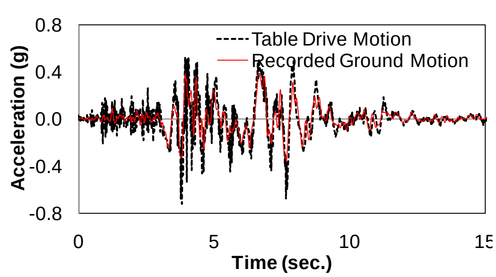
- lateral resisting system is a dual system α_o was set equal to 3.12
- First, second, third modes of vibration were0.33s, 0.09s, 0.04s
- Damping ratio of the first three modes was assumed18%

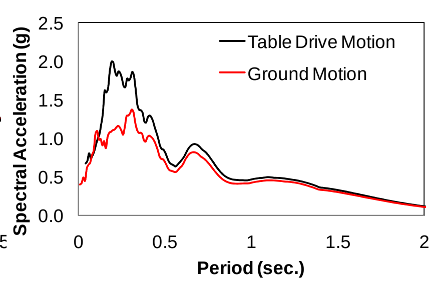
Recorded and estimated floor accelerations using generic building model (Miranda, 2005)



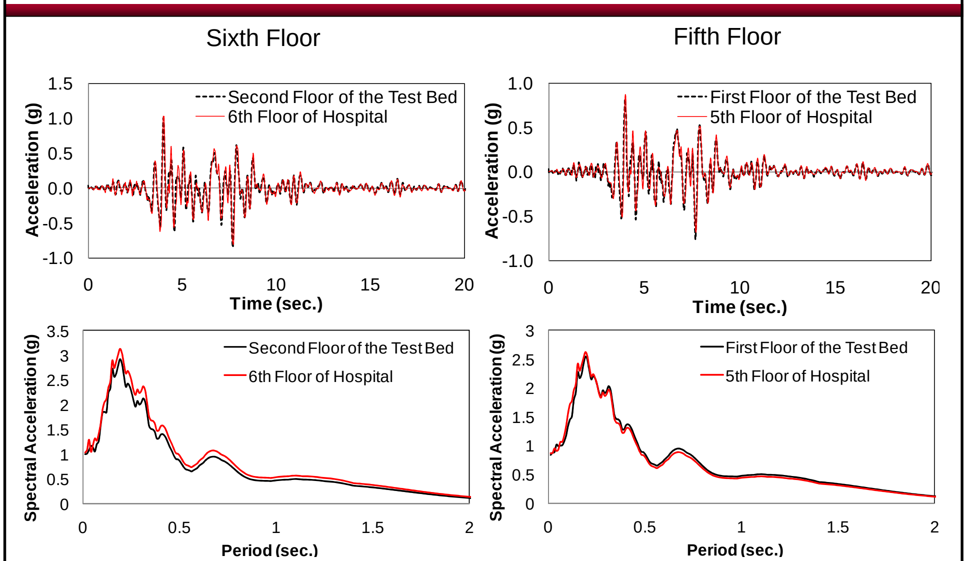
Developed Ground Motion

- Dynamic characteristics of the Test-Bed structure was obtained from an analytical model
- Table motion assumed to be the same as the drive motion
- Response of the Test Bed was obtained from analytical model and compared with the values from the generic model





Modeling Results



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Experimental Studies

E-Defense Experiments

Nonstructural Systems Tested:

- Ceilings
- Partitions
- Piping

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Overview of Tests

- **Shake table tests of a full-scale 5-story steel moment frame building**
  - **Isolated with triple friction pendulum isolators**
  - **Isolated with lead rubber bearing/cross linear slider**
  - **Fixed base**
  - Simulations designed to impose large displacement demands in isolation systems (comparable motions could not be applied to fixed-base buildings for safety reasons)
  - Simulations both with and without vertical component of ground motion

Test Protocol

- Some records were applied to all three system configurations (with different scale factors)

Record Name	*PGA (g) x-dir	*PGA (g) y-dir	*PGA (g) z-dir	Scale Factor TPS	Scale Factor LRB/CLB	Scale Factor Fixed Base
1994 Northridge - Westmorland	0.18	0.15	0.14	80%	80%	80%
1994 Northridge – Rinaldi Rec. Sta. (Horizontal Only)	0.53	1.17	0.11	88% xy	88% xy	35% xy
1994 Northridge – Rinaldi Rec. Sta.	0.71	1.19	1.29	88%	88%	35% xy 88% z
2011 Tohoku – Iwanuma Sta. (Horizontal Only)	0.42	0.58	0.04	100% xy	100% xy	70% xy

*Approximate table acceleration observed in isolated building test

Horizontal Only Loading

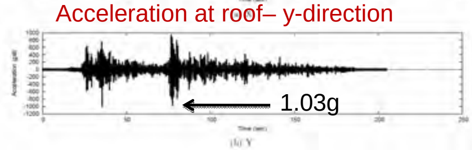
5th floor partial height wall failure

5th floor ceiling failure

- Nonstructural damage was not observed in any test of the base-isolated structure subjected to horizontal only motion
- Damage was observed in the fixed-base structure subjected to 70% Tohoku-Iwanuma x-y

Acceleration at roof – x-direction

Acceleration at roof– y-direction

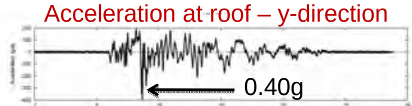


2D vs. 3D Loading – Rinaldi Rec. Sta.

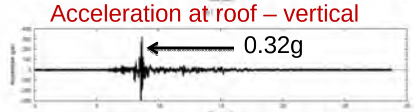
- In the isolated building, the observed vertical excitation in the structure was amplified relative to the ground by a factor of about 5. The cause is still under investigation.
- A horizontal vertical coupling appears to amplify the horizontal floor accelerations significantly compared to “horizontal only” loading.

Triple Pendulum Isolators
88% Rinaldi – Horizontal Only

Acceleration at roof – y-direction

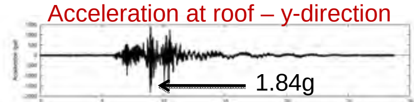


Acceleration at roof – vertical

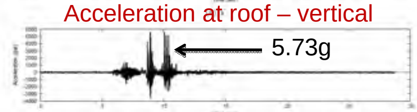


Triple Pendulum Isolators
88% Rinaldi – 3D Excitation

Acceleration at roof – y-direction



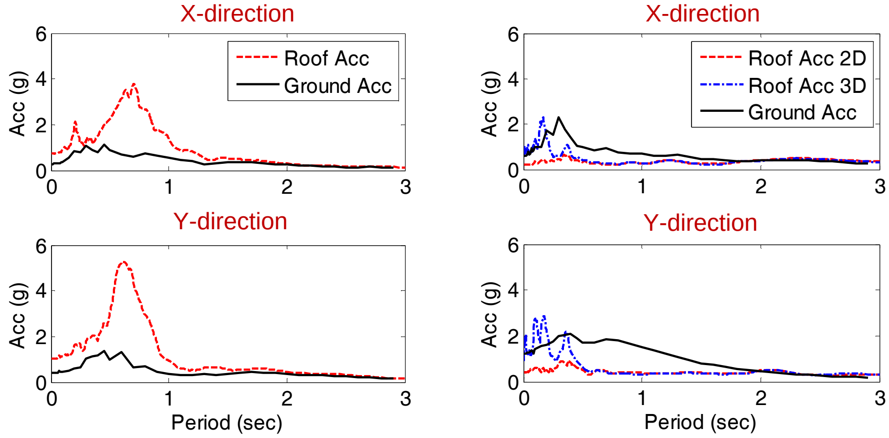
Acceleration at roof – vertical



Roof Spectra for Motions Considered

Fixed Base Building
70% Tohoku – Iwanuma

Triple Pendulum Isolators
88% Rinaldi – 2D & 3D Excitation



Damage Observed to Interior Walls

- Similar damage was observed in the nonstructural components for all 3 systems (triple pendulum,lead-rubber bearings, fixed-base) when subjected to Rinaldi 3D

Steel studs of partition walls buckled.

Connection failure and local buckling at top of steel studs.

Large cracks in some partition walls.

Damage Observed to Ceilings

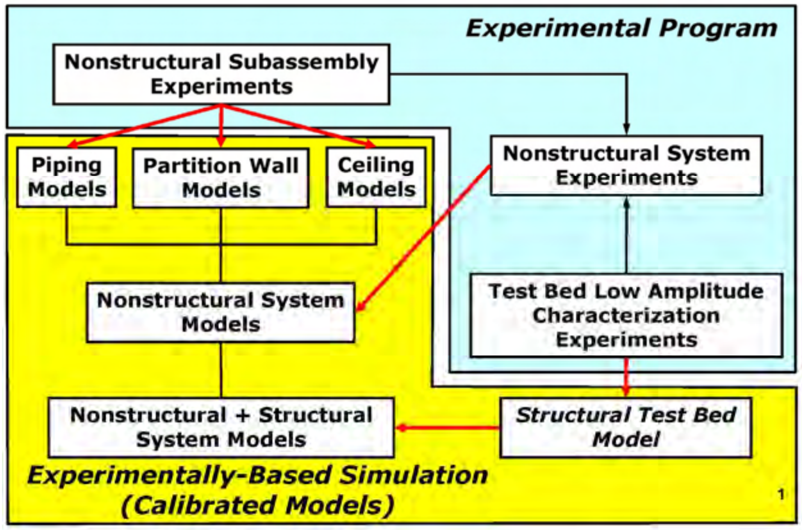
Large sections of dislodged or fallen ceiling panels and grid damage were observed.

NEESR-Nonstructural Experiment-Based Simulation Program

Approach

The proposed simulation framework requires modeling, analysis and visualization of these systems, and the unique output of this will be the integration of these concepts within a unified and validated set of computer codes to evaluate system-level fragilities.

Numerical Modeling: Task Integration

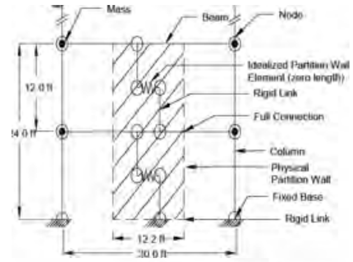


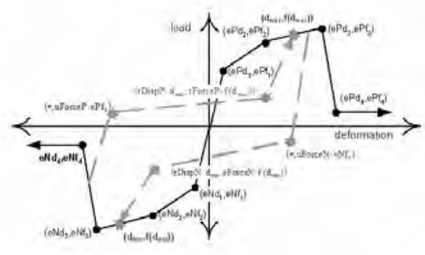
Analytical Modeling

Partition Systems

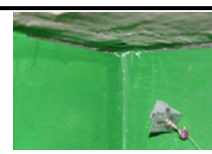
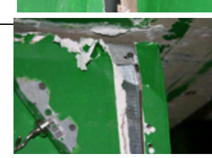
Modeling Approach

- Use of OpenSees
- Zero length elements spanning adjacent midspan floor beams
- Uniaxial material selected: *Pinching4*
  - Uniaxial material with pinched load-deformation response
  - Used in a four material parallel combination
    - Implemented for better control of hysteretic behavior
    - Vertical pinch, reloading level, unloading force level
- Parameters needed to define material
  - Four (F-Δ) backbone points
    - Determined from experimental data
  - Eight reloading and unloading relationships
    - Assume symmetric (positive=negative)
    - Iterated to initiation of reload and average hysteretic energy

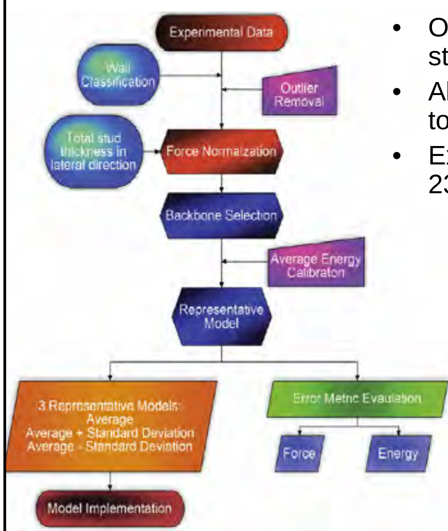




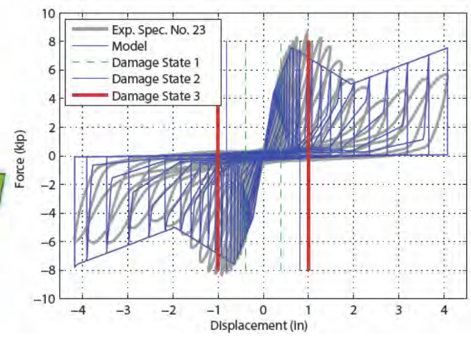
Damage State Summary

Damage State	Description and Repair	Example
1 Light	Light damage to walls, cracks along cornerbeads and joint tape, along with screw pullout. Repair requires cornerbead and screw replacement with some refinishing techniques.	
2 Moderate	Crushing in wall corners, out of plane bending, damaged boundary studs. Localized repairs of gypsum and replacement of boundary studs.	
3 Severe	Track damage (tear, bent), hinges in studs. Full replacement.	

Modeling Procedure and Example



- Outline of data processing to develop statistical (representative) models
- Allow for error assessment of the models to experimental data
- Example mean model shown with Spec. 23 (Institutional grade construction, fully connected



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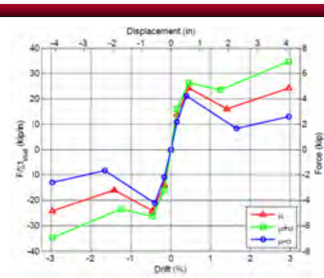
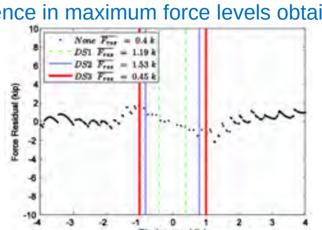
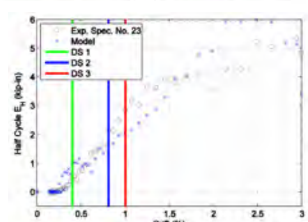
Developed Models

- Models represent 3 representative cases:
  - Average, average plus/minus standard deviation
- Error assessment
  - maximum force obtained
  - hysteretic energy on a per ½ cycle basis (per cycle excursion)
- Example shown against Spec. 23



Difference in maximum force levels obtained





Half cycle hysteretic energy comparison

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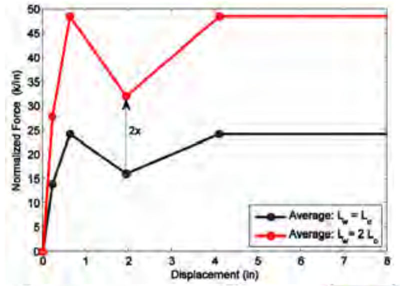
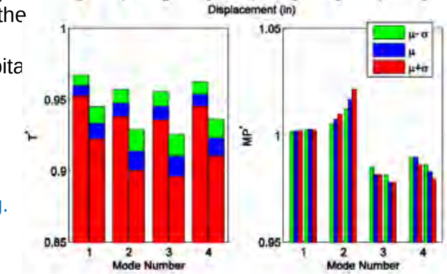
Model Implementation

- Scaling procedure:
  - Linear scaling based on the total stud thickness in the lateral direction
    - Same as model normalization parameter for fully connected specimens
- Building models considered:
  - 5 RC moment frame office bldgs of 2, 4, 8, 12 and 20 stories developed by Wood and Hutchinson (2009)
  - 5 Steel moment frame office bldgs of 3, 9 and 12 stories developed originally for the SAC project
  - 1 redesigned steel moment frame hospita of 3 stories (Wieser and Pekcan, 2011)
- Perform nonlinear time history analyses for fragility development

Building sensitivity study (period and mass participation) shown for 20 story RC building.

$$T_i^* = \frac{T_i^n}{T_i^{bare}} \qquad MP_i^* = \frac{MP_i^n}{MP_i^{bare}}$$

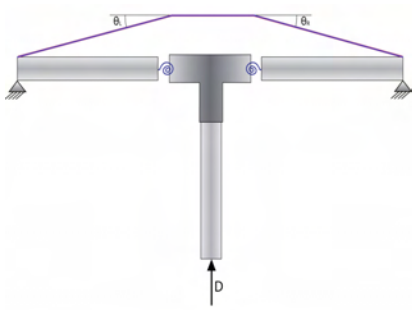


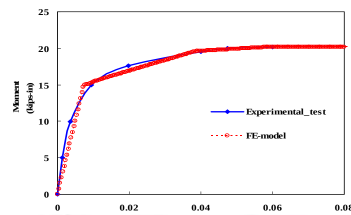


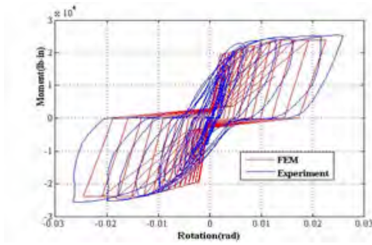
Analytical Modeling

Piping Systems

FE Modeling of Tee-Joint by OpenSees



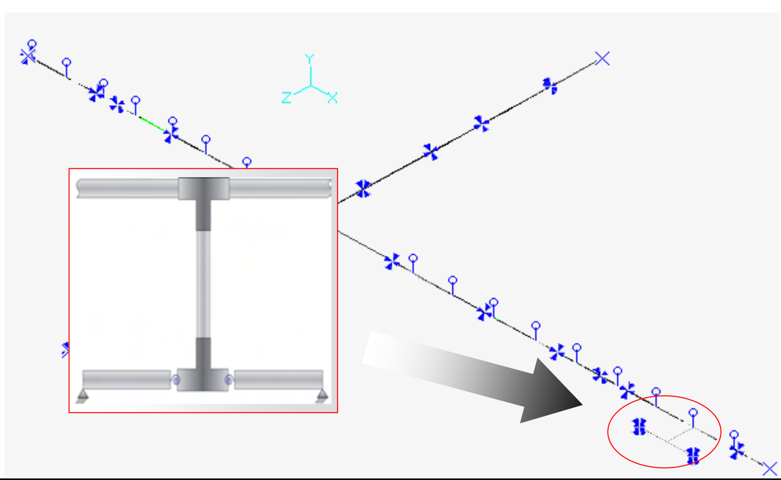




- ✓ The Tee-joint connection is modeled by two nonlinear rotational springs on either side each specified by a M-θ curve
- ✓ The spring model was Validated using OpenSees compared to Monotonic and Cyclic Test

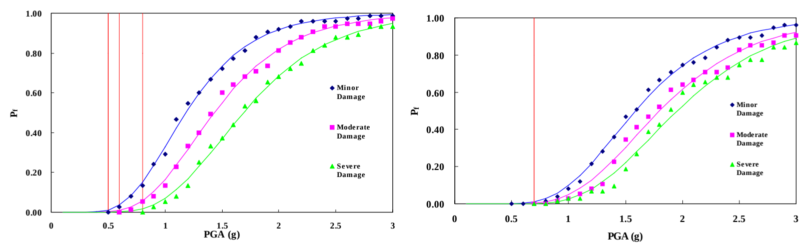
Fragility Evaluation of Tee-Joint

- ✓ Main Piping System with a branch piping system



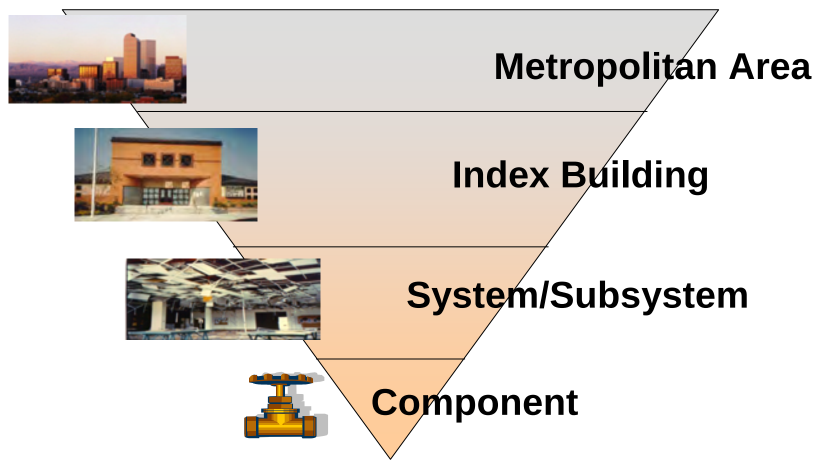
Piping Fragility Evaluation of Tee-Joint

- ✓ Seismic Fragility Evaluation at a Tee-Joint Connection
  - Monotonic & Cyclic Case



Public Policy Investigations

Integrated Analysis at Multiple Scales



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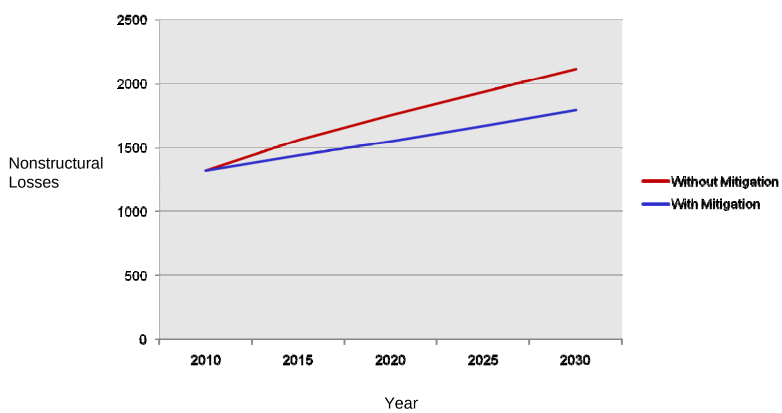
Estimating Losses Avoided by adopting Nonstructural Mitigation in New Construction



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Forecasting Future Quantities of Nonstructural Components at the Metropolitan Scale

1. Estimate current building inventories
2. Calculate building floor area per capita and per employee
3. Obtain population and employment forecasts
4. Forecast for building area by occupancies
5. Generate nonstructural index from model building plans, idealized office floor plans, and ATC 58
6. Forecast nonstructural components by occupancy

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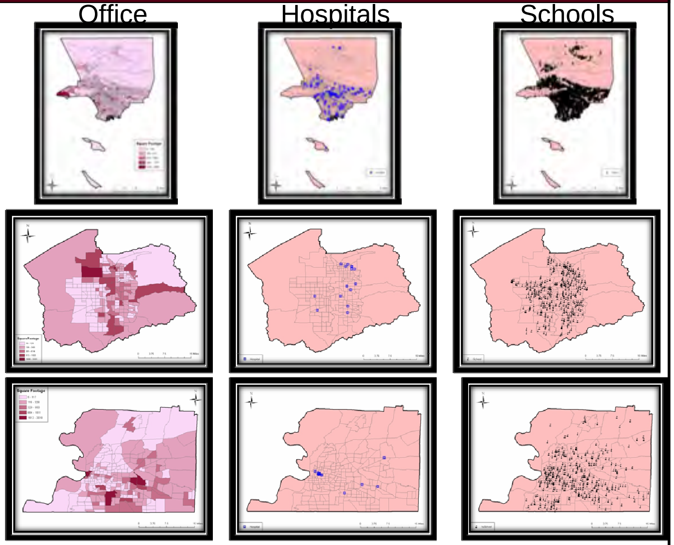
Existing Building Inventory

Office Hospitals Schools

Los Angeles County

Salt Lake County

Shelby County, TN



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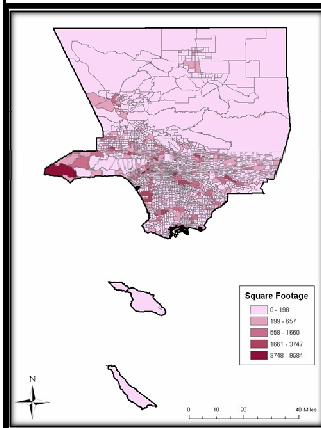
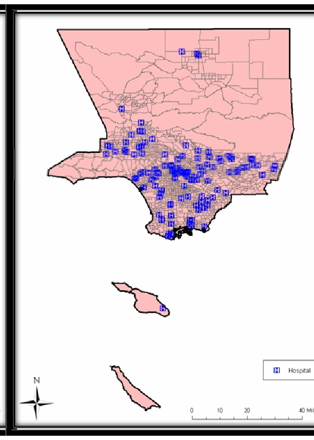
Existing Building Inventory-Los Angeles

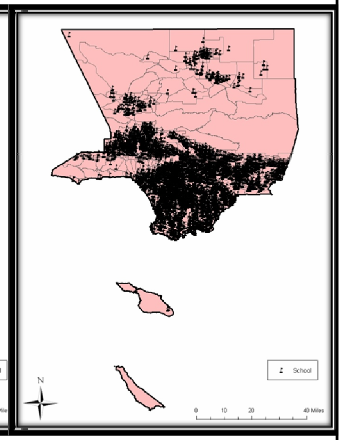
Office



Hospitals



Schools



Forecasting Building Area by Occupancy

Population and Employment Forecasts (2000-2020)

	Los Angeles Co.		Salt Lake Co.		Shelby Co.	
Year	Population[1]	Employment[1]	Population[2]	Employment[2]	Population[3]	Employment[3]
2000	9,519,338	3,953,415	898,387	445,128	897,472	631,614
2005	10,206,001	4,397,025	955,541	616,395	904,000	634,729
2010	10,615,730	4,552,398	1,037,048	695,685	910,905	645,051
2015	10,971,602	4,675,875	1,127,884	767,083	922,264	680,062
2020	11,329,829	4,754,731	1,211,775	837,366	935,318	716,120

Source:
1 Adopted growth forecast for 2008 Regional Transportation Plan prepared by Southern California Association of Governments;
http://www.scag.ca.gov/forecast/index.htm
2 Socioeconomic estimates and projections developed by Wasatch Front Regional Council;
http://www.wfrc.org/cms/index.php?option=com_content&view=article&id=30:socioeconomic-data&catid=44:socioeconomics&Itemid=76
3 Tim Moreland, Memphis Urban Area Metropolitan Planning Organization

Nonstructural Components Forecast Using ATC 58 Methods

Nonstructural Index (Quantity per sq. ft.) for Each Component

	Ceiling Index	Piping Index	Partition Index
Offices	0.90-1.00	0.17-0.22	0.07-0.13
Hospitals	0.90-1.00	0.20-0.25	0.06-0.14
Schools	0.90-1.00	0.15-0.20	0.03-0.10

HAZUS Analysis

Analyze current and future nonstructural damage for three occupancy classes" Office, Hospitals and Schools

One medium and one large scenario earthquake plus average annual losses for current and forecast building stock every five years from 2010-2030

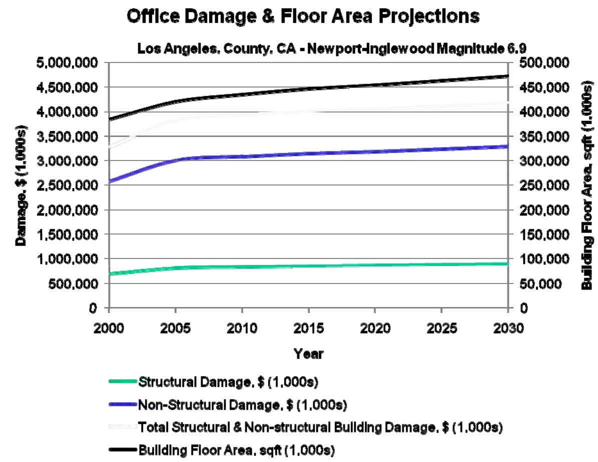
Case study areas:

Los Angeles County, CA

Salt Lake County, UT

Shelby County (Memphis), TN

Los Angeles County - Office



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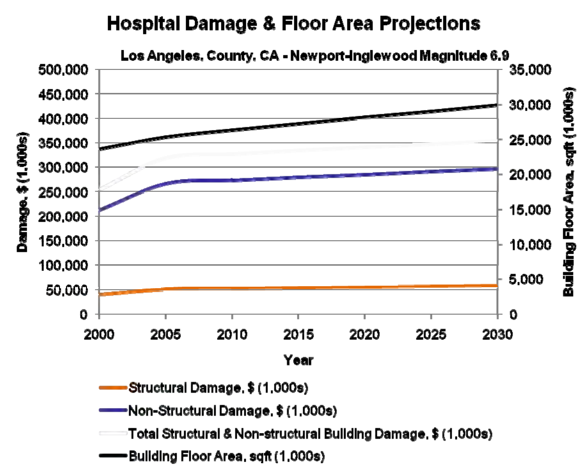
Los Angeles County - Hospitals



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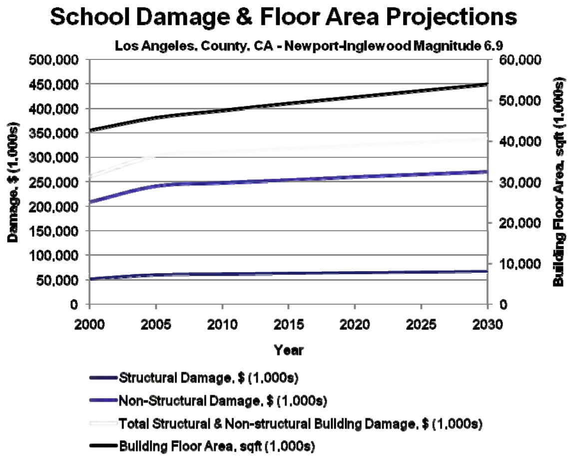
Los Angeles County - Schools



Thank You

Present Code Requirements, Development and Implications

Seismic Design and Performance of Nonstructural Elements

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Consulting Structural Engineer

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EERI

John D. Gillengerten

Consulting Structural Engineer

With 33 years' professional structural engineering and management experience in both the public and private sectors, John has extensive experience, with an emphasis in structural design, evaluation, and rehabilitation. He served as the deputy director of the Office of Statewide Health Planning and Development, Facilities Development Division, where he was the building official for all hospitals in California.

In private practice, John has been in responsible charge of a variety of different projects, involving conceptualization and design of buildings. He has performed many structural reviews for local and state jurisdictions, seismic evaluations and retrofit of existing buildings and bridges, and design and construction supervision of precast and prestressed concrete structural components. He has extensive experience working with regulatory agencies, as both a designer and regulator.

John is active in the development of codes and standards, serving on the Provisions Update Committee for the NEHRP *Recommended Provisions for Seismic Regulations for New Buildings* and the Seismic Task Committee of ASCE 7, *Minimum Design Loads for Buildings and Other Structures*, where he has chaired the Nonstructural Components subcommittees. John also serves on the Project Management Committee for ATC 58, *Development of Performance-Based Seismic Design Guidelines* and the Hanging and Bracing Subcommittee of NFPA-13, *Standard for the Installation of Sprinkler Systems*.

Topics

- Overview
- Current Nonstructural Provisions
  - Description and limitations
- Using the nonstructural provisions
- Compliance options
- Component Anchorage and the effects on design
- ASCE 7-10

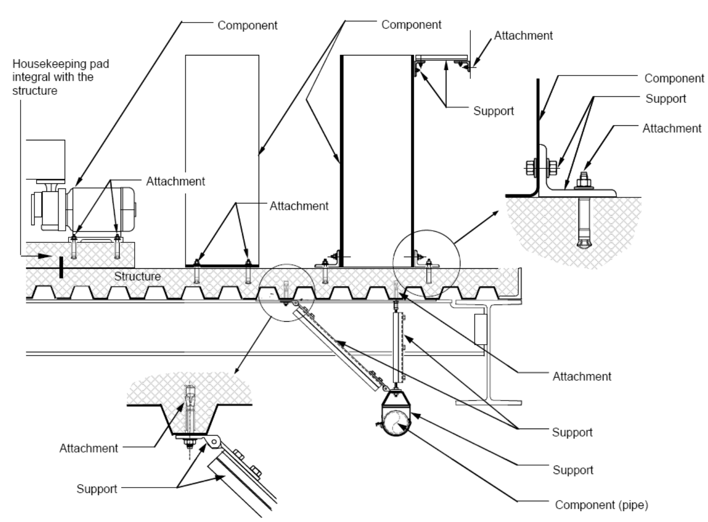
What are Nonstructural Components ?

- Those items in a structure that are not part of the structural system.
  - **Architectural components** including: cladding, ceilings, glazing, curtain walls, partitions and finishes, raised computer floors, etc.
  - **Mechanical and electrical** components and systems (utilities) including: tanks, piping and vessels.
  - **Contents** including: medical equipment, communications equipment, computers, shelves and bookcases, valuable contents on shelves, etc.

Elements of a Nonstructural Component

- **Nonstructural components include:**
  - – Anchorage
  - – Attachments that connect the components to the primary structural system
  - – The component itself

Definition of component, support and attachment

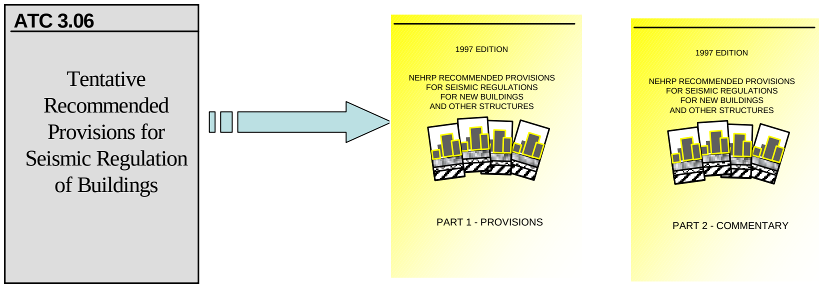


Component, Supports, and Attachment

Nonstructural Seismic Requirements

- Based on the NEHRP *Recommended Seismic Provisions for Buildings and Other Structures* – Technical Committee 8
- The changes to ASCE 7 are developed by Task Committee 8 of the ASCE 7 Seismic Subcommittee (SSC)
- The NEHRP PUC and ASCE 7 SSC are closely aligned

Evolution of the NEHRP *Provisions*



- First published by BSSC in 1985
- Updated on 3-year cycle (1988, 91, 94, 97 ,00, 03) – now on 5 - 6 year cycle
- 1992 - Adopted by BOCA, SBCCI
- 1993 – Adopted by ASCE 7 for Seismic
- 1995 - IBC resolves to adopt as basis for IBC
- 2009 – Adopted ASCE-7-05 as the basic reference

Seismic Design and Performance of Nonstructural Elements

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ASCE 7-05

- Currently referenced in the building code
- Nonstructural requirements in ASCE 7-05 are based on the 1994, 1997 and 2000 NEHRP Provisions.
- The Seismic Requirements for Nonstructural Components were located in Chapter 13
- <u>Make sure you have all current errata</u>
- **The 2009 NEHRP Recommend Provisions includes a commentary on ASCE 7-05 Seismic Requirements.**

Seismic Design and Performance of Nonstructural Elements

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Performance Goals

- To avoid serious injury or loss of life
- To avoid loss of function of critical facilities (I_p = 1.5)
- To minimize repair costs to the extent practical
- Nonstructural component requirements and performance expectations are only tied the Design Earthquake
- There are no performance expectations for Nonstructural Components that are tied to the Maximum Considered Earthquake.

Performance Expectations

Intensity of ground motion	Performance expectation (I_p=1)
Minor (not defined)	Minimal damage, functionality impairment unlikely
Moderate (not defined)	Some damage, functionality potentially impacted
Design Earthquake (defined)	Major damage, significant falling hazards mitigated, functionality loss likely

ASCE 7 Chapter 13 - Organization

- 13.1 General
- 13.2 General Design Requirements
- 13.3 Seismic Design Force
- 13.4 Nonstructural Component Anchorage
- 13.5 Architectural Components
- 13.6 Mechanical and Electrical Components

Limits of Applicability

- Nonstructural provisions apply throughout the US with following exemptions:
  - Mechanical and Electrical Components in SDC A and B
  - Mechanical and Electrical in SDC if I_p = 1.0
  - Architectural in SDC A
  - Architectural in SDC B if I_p = 1.0 except for parapets supported by bearing or shear walls
- Other exceptions for light items, piping and ductwork

Exemptions Based on Weight

- Mechanical and electrical components in SDC D, E and F are exempt if:
  - Weight is 400 lbs or less, mounted less than 4 ft or less above floor level
  - Weight is 20 lbs or less, or less than 5 lb/ft for distribution systems
- Flexible connections between the components and associated ductwork, piping, and conduit must be provided

Design Requirements

- Supports and attachments must be designed
  - Mechanical and Electrical Components with $I_p = 1$
- Supports, attachments and the component itself must be designed
  - Architectural Components
  - Mechanical and Electrical Components with $I_p > 1$

Nonstructural Seismic Demands

- Equivalent Static Forces – F_p Equations
  - Independent of building structural properties
  - Strength Level Forces
  - ASCE 7-05 provides option for determining building specific forces
- Relative Displacements for Selected Components
  - Anticipated relative displacements at Design Earthquake Level (D_p)
  - Provides equations to bound displacements
  - Option of determining demands using building structural properties

Force Demands

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

Amplification Factor

Component Response Factor

Amplification over height of structure

Design Force

- Limits on Design Force
  - F_p is not required to be taken as greater than
    - $F_p = 1.6 S_{DS} I_p W_p$
  - F_p shall not be taken as less than
    - $F_p = 0.3 S_{DS} I_p W_p$
- Concurrent vertical force $\pm 0.2 S_{DS} W_p$
  - Exemptions for lay-in access floor panels and lay-in ceiling panels

Nonstructural Importance Factor - I_p

- The value of I_p is based on:
  - Requirements of the component to function after a DBE , or
  - Hazardous materials
  - Occupancy Category of the structure or facility
- I_p = 1.0 or 1.5
- Nonstructural components/systems which are assigned an I_p = 1.5 are *Designated Seismic Systems*.

Amplification Factor

- Represent dynamic interaction between the structure and the component
  - Rigid – a_p = 1.0
  - Flexible – a_p = 2.5 (includes closely restrained isolated components)
  - Isolated Components that are not closely restrained have an effective a_p = 5.0
- Values for a_p are tabulated for different types of components
  - a_p can be taken as less than 2.5 based on dynamic analysis.

Amplification factor in ASCE 7

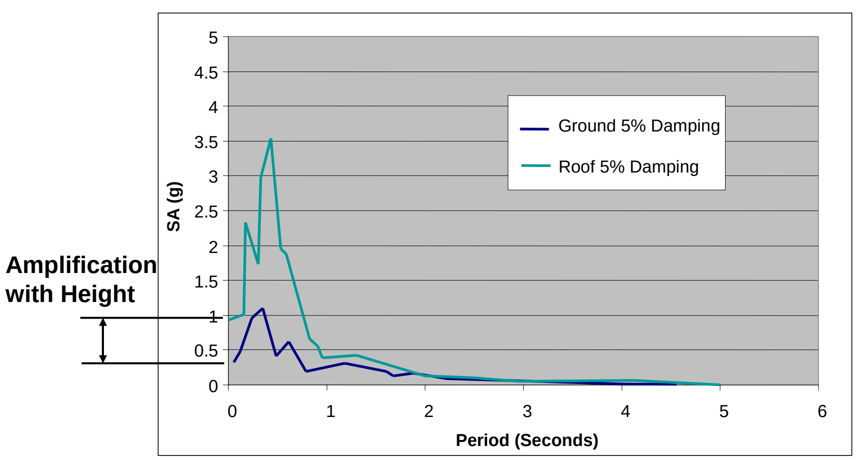
- Simplified approach for design
- Limit design loads (we do not design for the peak theoretical response)
- A more precise calculation of the amplification factor requires:
  - Detailed information on the dynamic properties of the structure (floor spectra, for example)
  - Detailed information on the dynamic properties of the component or system
  - This information is not available for the typical project

Should the Amplification Factor be Higher?

- Theoretical studies and alternative nonstructural design procedures suggest the use of amplification factors greater than 2.5
- Illustrate amplification effects on nonstructural components
  - *Response of Instrumented Buildings to 1994 Northridge Earthquake, An Interactive Information System*
    - Farzad Naeim, John A. Martin & Associates, Inc.
    - Prepared for State of California, California Geologic Survey, Strong Motion Instrumentation Program (SMIP)

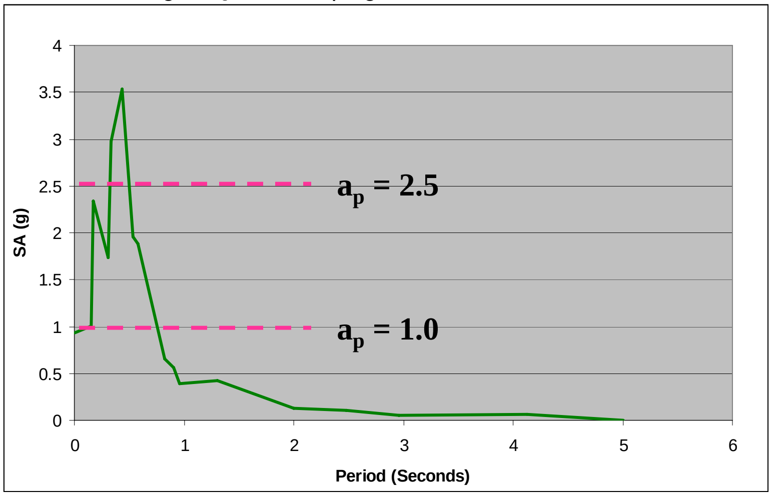
LA 3-story Building

1994 Northridge EQ Spectra, 5% damping



LA 3-story building Roof Spectra

1994 Northridge EQ, 5% damping



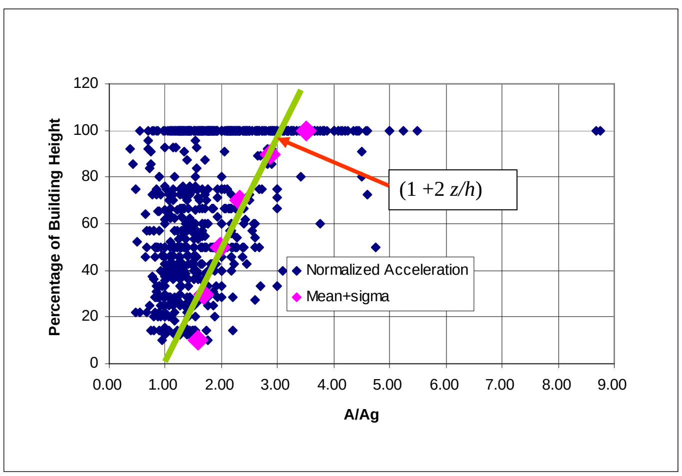
Response Modification Factors

- R_p factors assigned in tables that are used in lateral force equations
- R_p values range from 1.0 to 12.0
  - 1.0 for fasteners of nonstructural walls
  - 2.5 for ceilings
  - 6.0 for Air-side HVAC components
  - 12.0 for welded ASME B31 piping
- The values of R_p may be assigned based on ductility and deformability

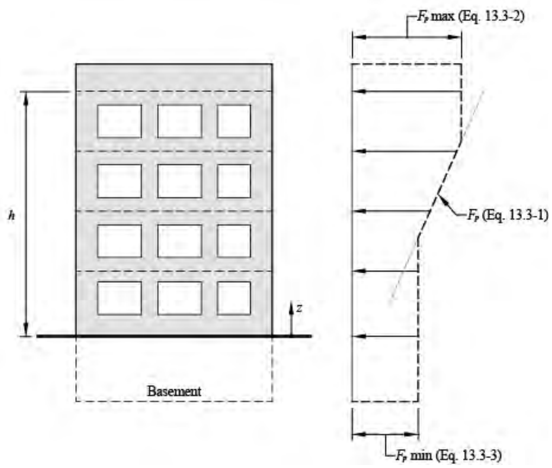
Amplification with Height

- Introduced in the 1994 NEHRP *Provisions*
- Accounts for increase in shaking intensity on upper levels of structures
- Concept originally in the UBC
  - Forces reduced by a third for components at grade

Amplification over Height



Amplification with Height



Use of Modal Response Parameters

- Force equation may be inaccurate for longer-period structures
- Alternate equation uses modal response parameters (taken with *R*=1.0)

$$F_p = \frac{a_i a_p W_p}{\frac{R_p}{I_p}} A_x$$

- a_i = acceleration at level i obtained by modal analysis
- A_x = torsional amplification factor

Interactions and Consequential Damage

- Consideration of the consequences of failure of a component on an essential component is required in Section 13.2.3
  - Limited to components with $I_p = 1.5$
- To be a concern, an interaction must be credible and significant.
  - A credible interaction is one that can take place
  - A significant interaction is on that damages the target
  - The fall of a light fixture on a 20-inch steel pipe may be credible (the light fixture being above the pipe) but may not be significant (the light fixture will not damage the steel pipe)

Nonstructural Displacement Demands

- Required for Architectural Components which pose a life safety hazard including exterior wall elements and glazing
- Required for Mech/Elect components and systems where I_p is greater than 1.0.
- Except for glazing – no specific acceptance criteria is provided
  - No requirement to stay within elastic limits or allowable stresses

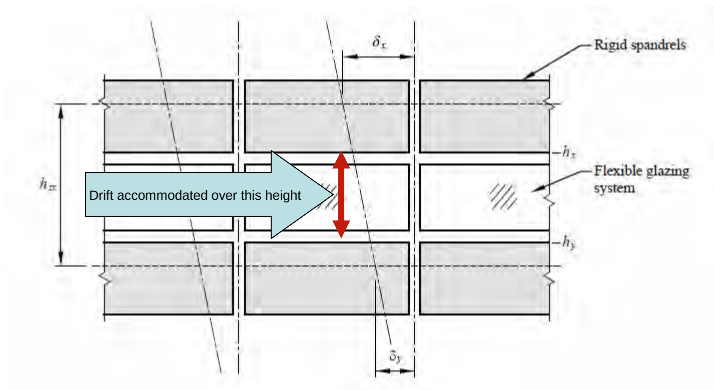
Seismic Displacements

- Types of displacement that must be considered
  - Displacements due to drift on components supported by different levels in the same structure
  - Relative displacements for components supported by multiple structures (systems crossing a seismic isolation joint)
- Maximum Relative Displacements for DBE level motions are used

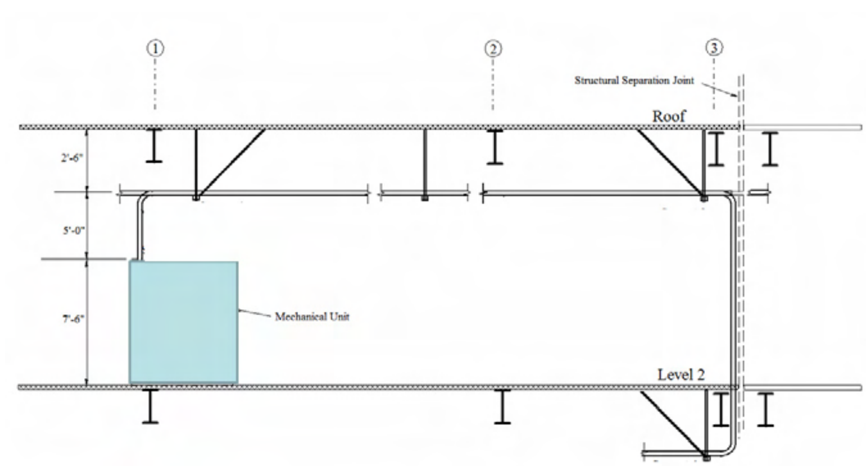
Displacements Due to Drift

- Components that span from level to level in a structure must be able to accommodate drift
- Can be accommodated by rocking, sliding, deformation of the component, or flexible connections
- Depending on the component configuration, the displacement demand must be accommodated over less than the full story height

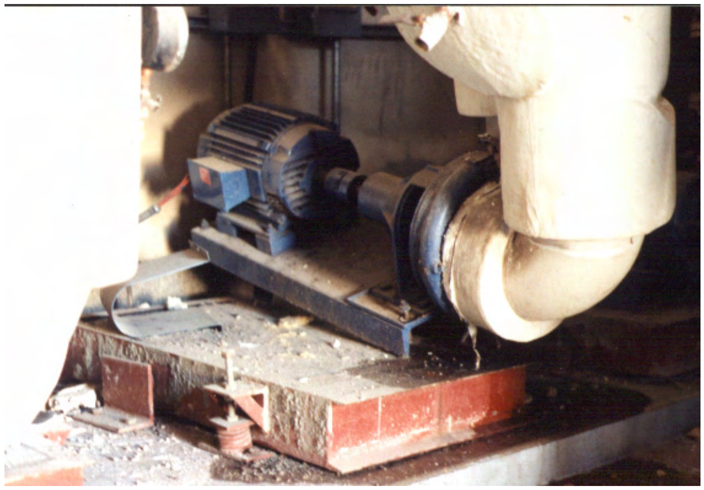
Displacements over less than story height



Displacements over less than story height



Displacement due to drift

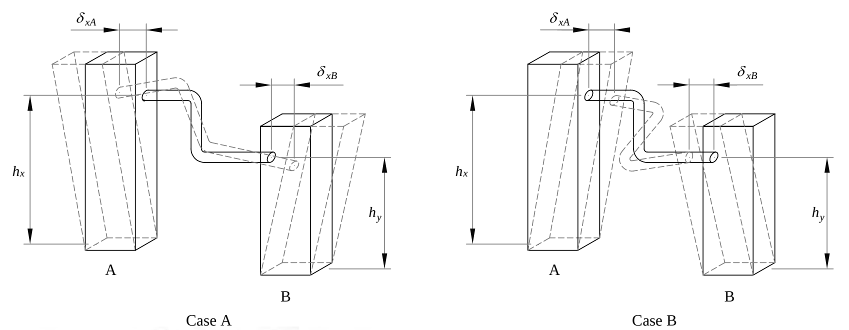


Seismic Relative Displacement

- The effects of seismic relative displacements must be combined with displacements caused by other loads as appropriate
- Actual structural displacements (drifts) may be used if known, otherwise requirements are based on the code drift limits

Seismic Relative Displacement

ASCE 7-10



$$D_p = |\delta_{xA}| + |\delta_{yB}|$$

D_p is not required to be taken as greater than

$$D_p = \frac{h_x \Delta_{aA}}{h_{sx}} + \frac{h_y \Delta_{aB}}{h_{sx}}$$

Component Anchorage

- Unless exempted, components must be anchored to the structure
  - All required supports and attachments must be detailed in the construction documents
- For many components, the anchor bolt may be the yielding element in the load path
- Anchors in concrete or masonry must be designed to have ductile behavior or to provide a specified degree of excess strength

Anchors in Concrete and Masonry

- Anchors must be proportioned to carry the least of the following:
  - 1.3 times the force in the component and its supports due to the prescribed forces, or
  - The maximum force that can be transferred to the anchor by the component and its supports.

Limits on R_p for Anchorage

- For anchorage to concrete or masonry, the value of R_p determine the forces in the connected part shall not exceed 1.5 unless:
  - The component anchorage is governed by the strength of a ductile steel element, or
  - Post-installed anchors in concrete are pre-qualified for seismic applications in accordance with ACI 355.2, or
  - The anchors meet ACI 318 Appendix D, as modified in Chapter 14

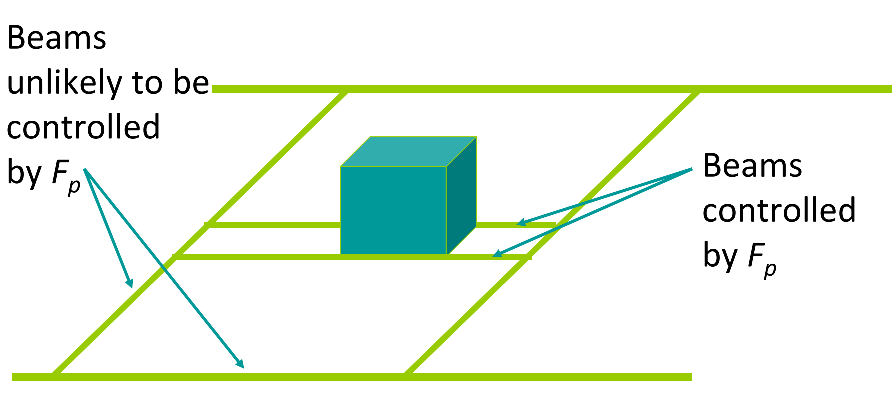
Checking the Load Path

- A continuous load path of sufficient strength and stiffness is required
- Local elements of the structure including connections must be designed for the component forces (F_p) where they control the design
  - Modifications to F_p and R_p due to anchorage conditions need not be considered

Seismic Design and Performance of Nonstructural Elements

October/November 2011

Verifying the Load Path



Seismic Design and Performance of Nonstructural Elements

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Architectural Components

- Design and Detailing Requirements
  1. Specific demands exterior walls and connections
  2. Suspending Ceilings – CISCA & ASTM standards
  3. Glazing – Drift capacity AAMA 501.6
  4. Access Floors – special access floor details
  5. Tall Partitions – independent bracing

Mechanical and Electrical Equipment

- Design and Detail Requirements
  1. Sprinkler systems – NFPA 13 with amendments
  2. Escalators and Elevators – ASME A17.1
  3. Vessels – ASME B& PV
  4. Piping – ASCE B 31.1 & NFPA-13
  5. HVAC Ducting – (SMACNA not specifically referenced)
  6. Lighting fixtures – Prescriptive detail requirements
  7. Many specific prescriptive details for Mechanical and Electrical Equipment – Section 13.6.5.5

Reference Documents

- Reference documents that provide a basis for the earthquake-resistant design of a particular type of system or component may be used
  - Design earthquake forces must be equal to or greater than ASCE 7
  - Interactions with other components and supports must be considered
- Examples - NFPA 13, ASME B31

ASCE/SEI 7-10

- Was published in April 2010 – Seismic Chapters still 11 - 23
- Has been adopted by the 2012 IBC
- Areas of changes are generally identified by dark vertical line in margin but not always
- Number of pages increased by about 40% primarily caused by change in Font Size.
- Eratta – go to www.Seinstitute.org click on publications, click on errata, click on ASCE/SEI 7-10
- There will be an enhanced seismic commentary for ASCE/SEI 7-10 published by ASCE/SEI in the next year.

Changes in ASCE 7-10

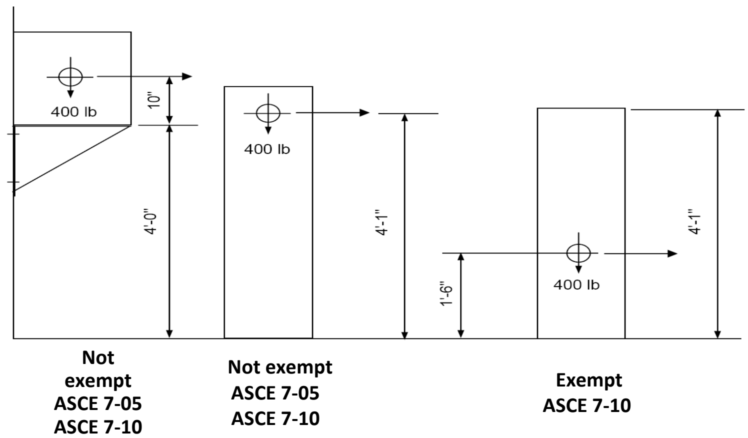
- General provisions and exemptions
- Seismic qualification and certification of components
- Seismic relative displacements
- Anchorage provisions
- Ceiling provisions
- Reorganization of mechanical/electrical sections
- Elevator switch requirements

Changes to Section 13.1 General

- Egress stairs added to list of components in Section 13.1.3 that are assigned an I_p = 1.5 (required to function after Design Earthquake level motions.
- Furniture (except storage cabinets as noted in Table 13.5-1) and temporary or moveable equipment added to the list in Section 13.1.4 of items exempt from the requirements of Chapter 13.
- Added clarification that small equipment items must be positively if exempted from Chapter 13 per Section 13.1.4.6 – SDC D, E or F
- For equipment using reference standards as their basis of design – specified that anchorage requirement shall not be those specified in Section 13.4

Exemptions – ASCE 7-10

When determining exemptions for small items, height above floor is measured from center of mass



Changes General Design Requirements

- Clarifies wording in Section 13.2.2 on what items really require seismic certification by shake table testing or experience data.
- Permits inherently rugged items to be exempt from testing provided documentation is provided
- Other parts of the equipment can be seismically certified by analysis per Section 13.2.1.

ASCE 7-10

Seismic Demands

- No changes to the seismic force equations in Section 13.3.1.
- Revised displacement demand by multiplying it by I (not I_p)
  - Displacement demand determined per Chapter 12 does not include I factor
  - Nonstructural components for essential facilities had lower displacement demand requirement that normal occupancies
  - The displacement demand requirements for nonstructural component will now be the same for all occupancies

ASCE 7-10

Nonstructural Component Anchorage

- When designing component anchorage, R_p can not be taken greater than 6.0
- Significantly revised Section 13.4.2 – Anchors in Concrete and Masonry
  - Reference to TMS 402/ASCI 530/ASCE 5 requires anchors in Masonry to be designed as ductile steel elements unless ductile yielding is provided in attachment

ASCE 7-10

Nonstructural Component Anchorage

- Comprehensive revision to anchorage to concrete section
  - Post installed anchors must be pre-qualified.
  - Added exception for Power Actual Fasteners that allows them to be used in light load situations for distributed systems (90 lb maximum in concrete and 250 lb maximum in steel)
- In Section 13.4.6 Friction Clips (generally prohibited for SDC D, E or F), allows C-type beam and large flange clamps to be used provided restraining straps equivalent to those required by NFPA 13 are used.

ASCE 7-10

Concrete Anchorage Requirements

- Greatly simplified in ASCE 7-10
- Design anchorage per ACI 318 Appendix D
- Post Installed Anchors – shall be pre-qualified per ACI 355.2 or other approved qualification procedure.
- Removes the R_p = 1.5 and the factor of 1.3.
- To be consistent with ACI 318-11, we will need to soon define an Ω_o factor for nonstructural components or the default will be 2.5. This would need to added to Section 13.4.1

ASCE 7-10

Section 13.5 Architectural Components

- Revised Table 13.5-1 (R_p table) to apply to storage cabinets over 6 feet tall including contents
- Added to Table 13.5-1 permanent floor supported library shelving, book stacks and bookshelves over 6 feet tall including contents (a_p = 1.0 and R_p = 2.5)
- Significantly revised Suspended Ceiling Section
  - Reference ASTM E-580 for most of the requirements instead of CISCA
  - Most of the requirements in ASCE 7-05 are now in ASTM E-580, greatly reducing the need for additional requirements

ASCE 7-10

Mechanical and Electrical Components

- No changes to the R_p Table (Table 13.6-1)
- Significantly reorganized, combined and clarified:
  - Section 13.6.5.5 – Additional Requirements for Component Supports
  - Section13.6.5.6 – Conduit, Cable tray and other Electrical Distribution Systems (raceways)
  - Section 13.6.7 - Ductwork to combine requirements
- Revised Section 13.6.8 – Piping System
  - References ASME and NFPA 13 standards
  - Provides allowable stresses for materials not covered by the standards

ASCE 7-10

Reorganization of MEP sections

ASCE 7-10

- Electrical
  - First statement list general requirement
  - Exceptions/special cases follow
  - Term "raceways" adopted for electrical distribution systems
  - Term "trade size" adopted for conduit
- Ductwork (formerly HVAC) similarly reorganized
- Piping exceptions: ASME B31.1, NFPA 13, ASME 17.1

Elevator switch requirements

- Trigger modified to conform to ASME A17.1
- Intended to avoid unnecessary shutdowns, enable faster re-starts (switch in machine room)
- Vertical orientation, locate near column with a trigger level of 0.15g
- If not possible to locate near column:
  - Ground Floor - 0.2g horizontal
  - Above Ground - 0.5g horizontal

ASCE 7-10

New Edition of FEMA 74: Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide

Seismic Design and Performance of Nonstructural Elements

Maryann Phipps, Estructure
Cynthia Perry, BFP Engineers
Eduardo Fierro, BFP Engineers

EERI

Maryann Phipps

Maryann Phipps has 30 years of experience evaluating, designing and renovating buildings in California. She assists both public and private clients in understanding and addressing the risks associated with earthquake hazards. The mainstay of her practice is renovation of existing hospitals with a focus on the seismic protection of nonstructural components. Maryann has been responsible for the design of replacement hospitals and medical office buildings, renovations to all hospital departments, infrastructure upgrades and hospital-wide seismic restraint of nonstructural components. She is professionally very active in the engineering community and is a past president and Fellow of the Structural Engineers Association of California. She is the lead technical author of *FEMA E-74 Reducing the Risks of Nonstructural Earthquake Damage*.

Eduardo Fierro

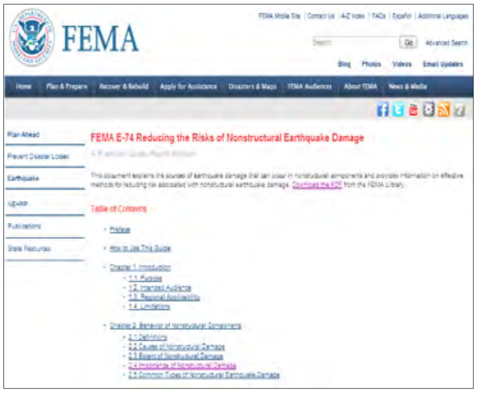
Eduardo Fierro is a founding partner of BFP Engineers, Inc. (Bertero, Fierro, Perry) along with Prof. Vitelmo Bertero and Cynthia Perry. He has 37 years of experience in structural design and analysis, forensic engineering, and all aspects of earthquake engineering. He previously worked at URS/John A. Blume & Associates; Dames & Moore; and Wiss, Janney, Elstner & Associates. He has been involved with earthquake reconnaissance following numerous earthquakes, including Loma Prieta 1989, Columbia 1999, Northridge 1994; Guam 1993, Kobe 1995, Peru 2001 and 2007, Chile 2004 and 2010, and Haiti 2010 and has many thousands of photos of nonstructural items including damage, repair, and new installations. He has performed facility surveys and post-earthquake damage assessments of structural and nonstructural items in hospitals, power plants, U.S. embassies, manufacturing facilities, and other commercial buildings. His reconnaissance to Haiti in 2010 was facilitated by colleagues in the Dominican Republic where he has been giving classes and seminars on earth-quake hazards since 2004. He is currently involved in establishing the first master’s program in structural engineering offered in the Dominican Republic.

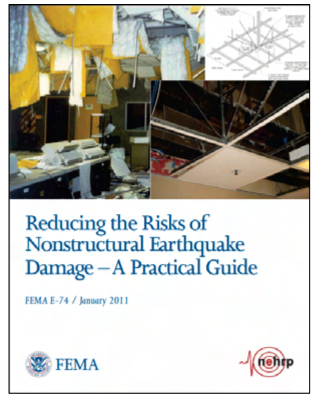
Cynthia Perry

Cynthia Perry is a founding partner of BFP Engineers, Inc. (Bertero, Fierro, Perry) along with Prof. Vitelmo Bertero and Eduardo Fierro. She has 36 years of experience in structural design and analysis, forensic engineering, and all aspects of earthquake engineering. She previously worked at URS/John A. Blume & Associates; Dames & Moore; and Wiss, Janney, Elstner & Associates and has been involved with earthquake reconnaissance following numerous earthquakes since the late 1970s. Her introduction to nonstructural anchorage began in the nuclear industry in the late 1970s, working on pipe and equipment supports at Diablo Canyon and later on the restraint or anchorage of all “transient materials” at the Palo Verde nuclear plant in Arizona. She has been involved with facility surveys and post-earthquake damage assessment or nonstructural items in manufacturing facilities, power plants, and other commercial and residential facilities. She worked on the 1994 edition of *FEMA 74* while at WJE and has been involved with the latest, vastly expanded edition, now called *FEMA E74*, since 2006.

FEMA E-74

http://www.fema.gov/plan/prevent/earthquake/fema74/





Introduction and Overview

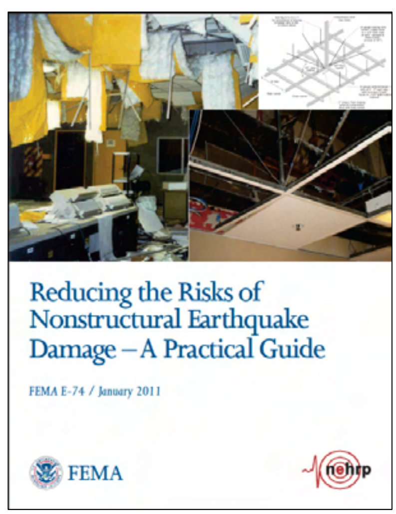
- Purpose
- Intended audience
- Scope
- Tools

Introduction and Overview

- Purpose
- Intended audience
- Scope
- Tools

Introduction and Overview

- Explains the causes and consequences of earthquake damage to nonstructural components
- Provides examples of earthquake damage that can occur for each nonstructural component
- Provides information on effective methods for reducing risk associated with nonstructural earthquake damage



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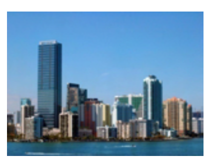

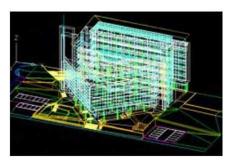

Architectural Components

- Partitions
- Ceilings
- Storefronts
- Glazing
- Cladding
- Veneers
- Chimneys
- Freestanding walls

Seismic Design and Performance of Nonstructural Elements

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Mechanical, Electrical, & Plumbing

- Emergency generators
- Pumps, Chillers, Boilers
- Fans, Air handling units
- Distribution panels
- Transformers
- Ductwork and conduit
- Piping and plumbing
- Lights

Seismic Design and Performance of Nonstructural Elements

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Furniture, Fixtures & Contents

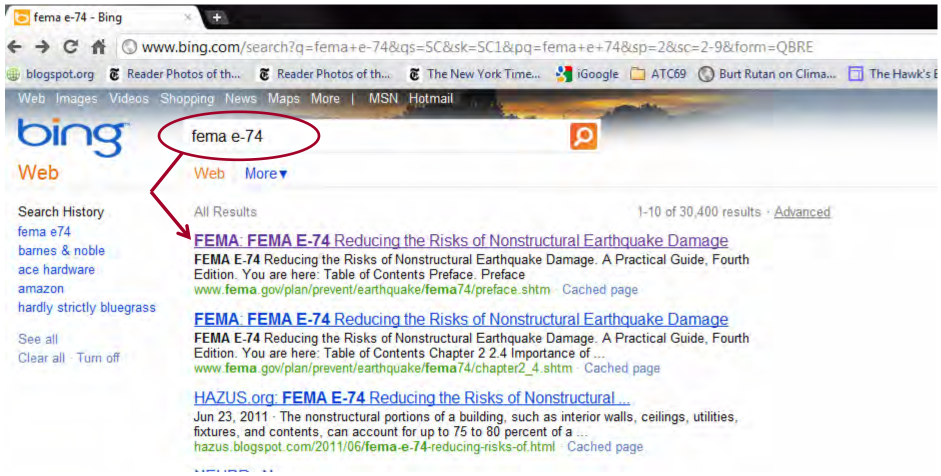
- Shelving and file cabinets
- Book cases and library stacks
- Industrial storage racks
- Retail merchandise
- Books and medical records
- Computers and TVs
- Chemicals or hazardous materials
- Artifacts and collectibles
- Demountable partitions

Introduction and Overview

- Purpose
- Intended audience
- Scope
- Tools

- •Background
- •Historical performance
- •Examples
- •Specification
- •Survey forms
- •Checklist
- •Risk ratings

FEMA E-74 Navigation



Seismic Design and Performance of Nonstructural Elements

October/November 2011

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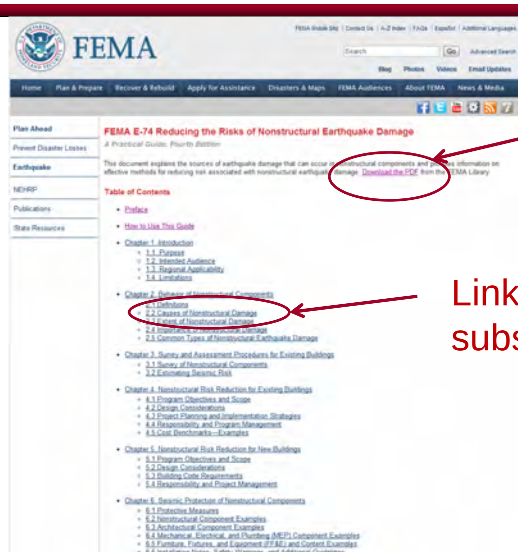

Download the PDF

Links to each chapter or subsection

Seismic Design and Performance of Nonstructural Elements

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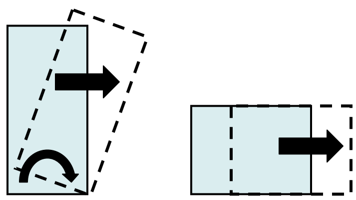
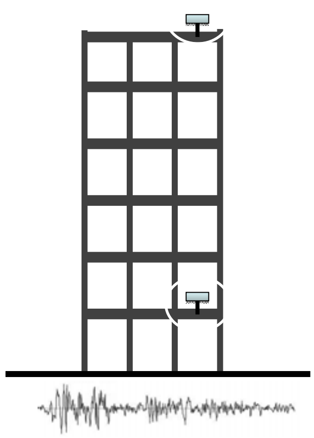
Causes of Nonstructural Damage

- Inertial or shaking effects cause sliding, rocking or overturning



Building interaction with components



Element Motion Larger

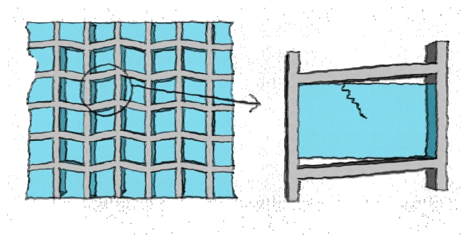
Roof Floor Motion Larger

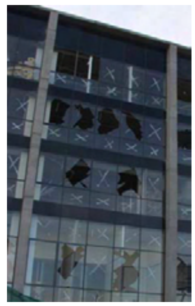
Element Motion Smaller

2nd Floor Motion Smaller

Causes of Nonstructural Damage

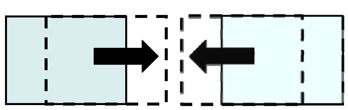
- Building deformations cause damage to interconnected nonstructural components

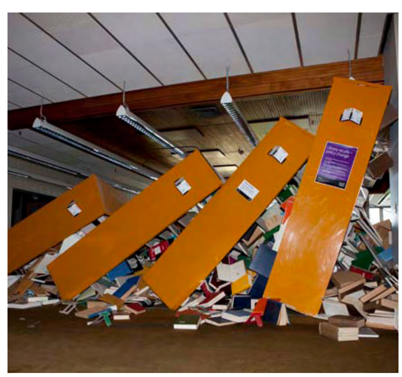




Causes of Nonstructural Damage

- Interaction between adjacent nonstructural components cause damage





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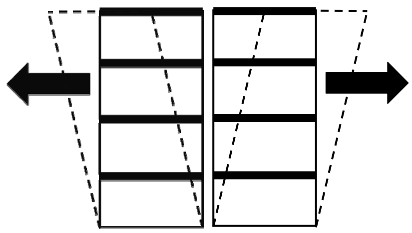
Causes of Nonstructural Damage

- Separation or pounding between separate structures damage nonstructural components crossing between them



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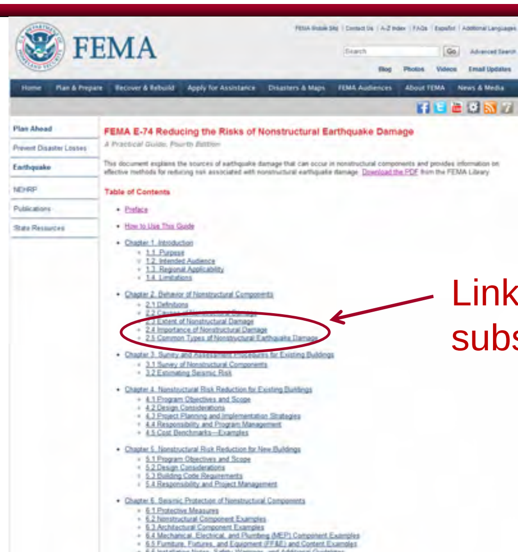

Links to each chapter or subsection

Consequences of Nonstructural Damage

Life Safety
- Deaths or casualties

Property Loss
- Dollar loss

Functional Loss
- Downtime

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Can it hurt someone?

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Can it hurt someone?

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Can it hurt someone?

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Can it impact life safety systems?

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Can it block egress routes?

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Will it cause property loss property loss?

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Will it cause property loss property loss?

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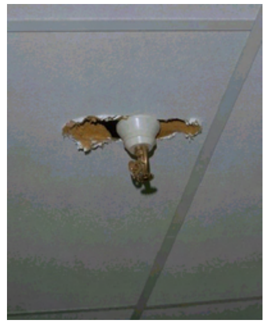
Will it interrupt operations?



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How do we avoid this?

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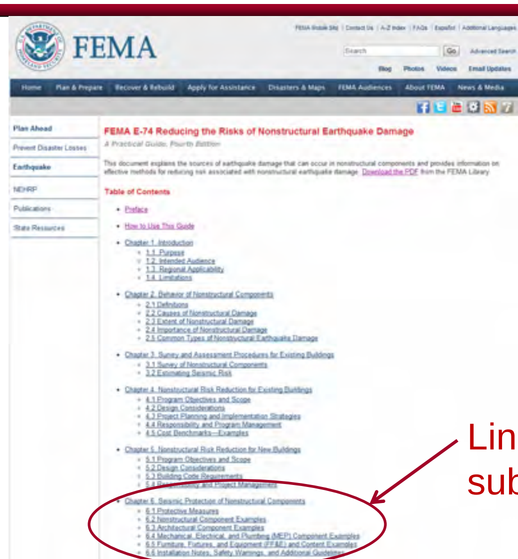
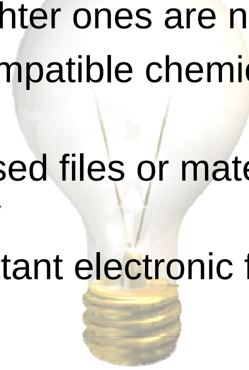


Links to each chapter or subsection

Simple solutions



- Relocate tall or heavy objects to not block exits
- Rearrange shelving so heavier items are on the bottom and lighter ones are near the top
- Separate incompatible chemicals to prevent mixing
- Move rarely used files or materials to an offsite storage facility
- Back up important electronic files

Mitigation Strategies

- Retrofit
- Replace
- Relocate
- Replicate (i.e. provide a back-up)
- Plan for the consequences of failure

Seismic Design and Performance of Nonstructural Elements

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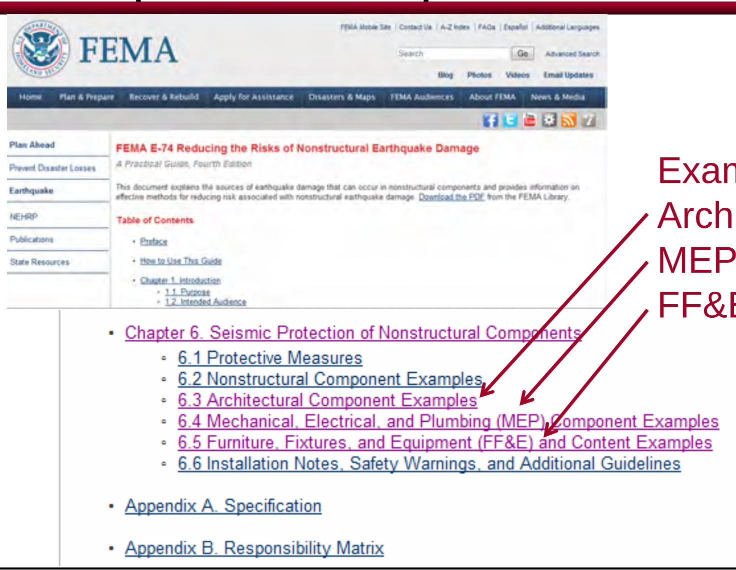
Chapter 6 Examples



Examples:
Architectural
MEP
FF&E

Seismic Design and Performance of Nonstructural Elements

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Mitigation Example Format

E-74 Chapter 6 : Seismic Protection of Nonstructural Components

- Typical Causes of Damage — *discussion*
  - Damage Examples — *photo(s)*
- Seismic Mitigation Considerations — *discussion*
  - Mitigation Examples — *photo(s)*
  - Mitigation Details — *schematic detail(s)*

Nonengineered	**NE**
Prescriptive	**PR**
Engineering Required	**ER**

Types of nonstructural components

ASCE 41 component list used as basis for FEMA E-74

Architectural Components

Mechanical, Electrical, and Plumbing (MEP) Components

Furniture, Fixtures & Equipment (FF&E) and Contents

Nonstructural Component Categories

Nonstructural Component	No. of Categories	No. of Mitigation Examples
Architectural	9	17
Mechanical, Electrical, Plumbing (MEP)	11	39
Furniture, Fixtures & Equipment (FF&E) and Contents	6	16
Total FEMA E-74	*26*	*72*

Architectural Components

Architectural Components

9 categories *17 examples*

- 6.3.1 Exterior Wall Components *5*
- 6.3.2 Interior Partitions *3*
- 6.3.3 Interior Veneers *1*
- 6.3.4 Ceilings *3*
- 6.3.5 Parapets and Appendages *1*
- 6.3.6 Canopies, Marquees, and Signs *1*
- 6.3.7 Chimneys and Stacks *1*
- 6.3.8 Stairways *1*
- 6.3.9 Freestanding Walls or Fences *1*

6.3 Architectural Examples

6.3 Architectural Component Examples

The following table lists the architectural subcategories and component examples included in this chapter:

SUBCATEGORY	COMPONENT EXAMPLE	TYPE OF DETAIL
6.3.1 Exterior Wall Components	6.3.1.1 Adhered Veneer	ER
	6.3.1.2 Anchored Veneer	ER
	6.3.1.3 Prefabricated Panels	ER
	6.3.1.4 Glazing	ER
	6.3.1.5 Glass Block	ER
6.3.2 Interior Partitions	6.3.2.1 Interior Partition Walls, Heavy	ER
	6.3.2.2 Interior Partition Walls, Light	ER
	6.3.2.3 Glazed Partitions	ER
6.3.3 Interior Veneers	6.3.3.1 Stone, Tile, and Masonry Veneer	ER
6.3.4 Ceilings	6.3.4.1 Suspended Acoustic Lay-in Tile Ceiling Systems	PR
	6.3.4.2 Ceilings Applied Directly to Structure	NE
	6.3.4.3 Suspended Heavy Ceilings	PR
6.3.5 Parapets and Appendages	6.3.5.1 Unreinforced Masonry Parapets	ER

Anchored Veneer

Anchored Veneer Example

Link Back to Table of Contents

You are here: Table of Contents » Chapter 6 » 6.3 Architectural Component Examples » 6.3.1 Exterior Wall Components ← You are here

6.3.1.2 Anchored Veneer

Download "6.3.1.2 Anchored Veneer" (PDF 603KB) ← Download pdf this example

Anchored veneers are typically masonry, stone or stone slab units that are attached to the structure by mechanical means. These units and their connections must be designed to accommodate the anticipated seismic drift; otherwise they may pose a significant falling hazard.

- Typical Causes of Damage
  - Damage Examples
- Seismic Mitigation Considerations
  - Mitigation Examples
  - Mitigation Details ← Link to Mitigation Details

Typical Causes of Damage

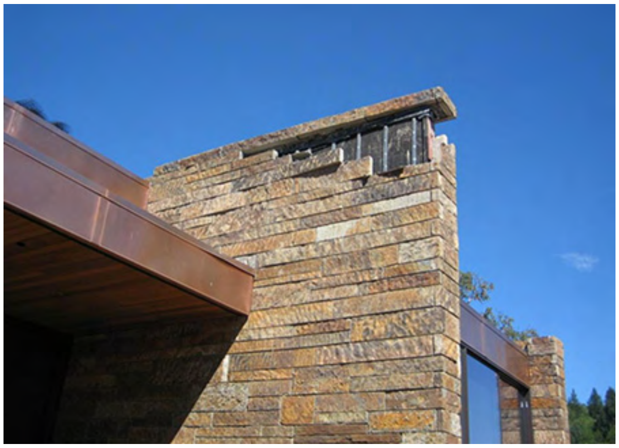
- Anchored veneers and their connections may be damaged by inertial forces and by building distortion; units located at corners and around openings are particularly vulnerable.
- Rigid connections may distort or fracture if they do not have sufficient flexibility to accommodate the seismic drift; veneer units may crack, spall, or become completely dislodged and fall.
- Deterioration or corrosion of the mechanical connections is a significant concern; corroded connections may fail prematurely. Maintaining watertightness at joints is important for the longevity of the anchors.

Back To Top ← Back To Top of Example

Anchored Veneer

- Falling veneer – life safety hazard
- ASCE 7-10
  - Prescriptive requirements and code limits on height, drift, deflections, use of combustible substrate, wind speed, cavity size, mortar bed thickness, tie spacing
- Corrosion problems
  - Requires watertight joints and periodic inspection; corrosion of anchors may lead to premature failure

Anchored Veneer Damage



Fallen sandstone veneer in Northern California from M4.4 earthquake; dovetail channels visible at top of wall

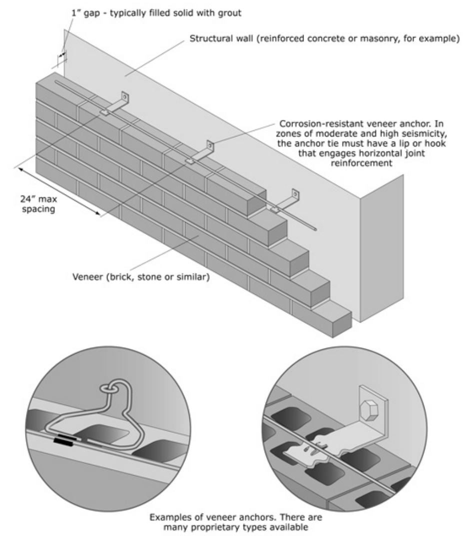
Anchored Veneer Damage

Inspection revealed missing dovetail anchors, missing pencil rods, and weak stone-to-stone mortar

Anchored Veneer Mitigation Example

- Stone veneer
- Backing substrate (fully grouted masonry wall)
- Dovetail channel bolted to wall
- Galvanized steel dovetail anchor
- Horizontal joint reinforcement (pencil rod)
- Detailing at corners and openings critical

Anchored Veneer Mitigation Details



ER

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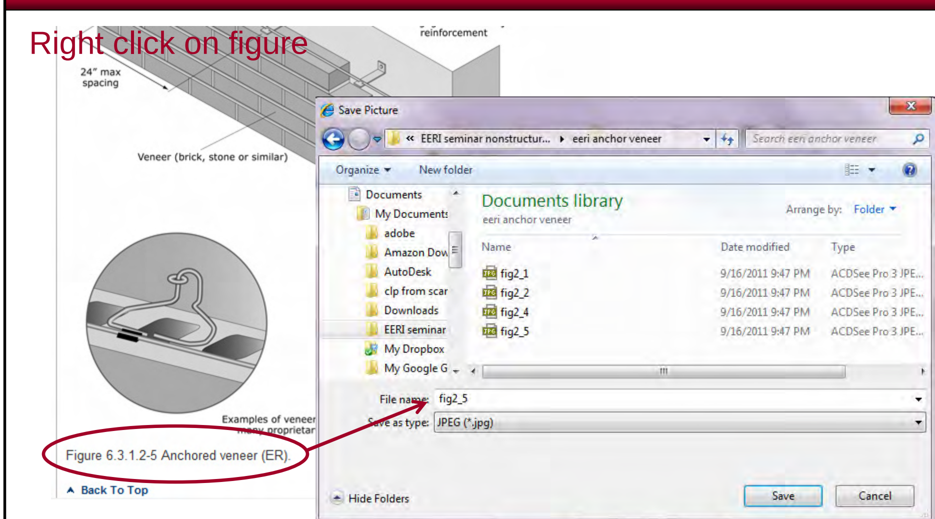
Save Photo or Figure as jpg file



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Interior Partition Walls, Light

- Damage due to differential movement
  - May cause injury, block egress routes, require repair/replacement and costly downtime
  - May result in cracking, spalling, deformed framing, failed connections, or collapse
  - May result in failure of supported electrical panels, wiring, shelving, etc
- Details for light nonbearing stud walls
  - Full-height partitions should be isolated
  - Partial-height partitions should be braced
  - Special consideration required for adjacent perpendicular walls

Interior Partition Damage

Failure of inadequately braced partial-height metal stud partitions in the 1994 Northridge Earthquake

Interior Partition Damage

Damage to wood stud wall spanning floor-to-floor in the 1994 Northridge Earthquake

Seismic Design and Performance of Nonstructural Elements

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Interior Partition Mitigation Example

Out-of-plane bracing of partial-height metal stud partition to floor slab above

Seismic Design and Performance of Nonstructural Elements

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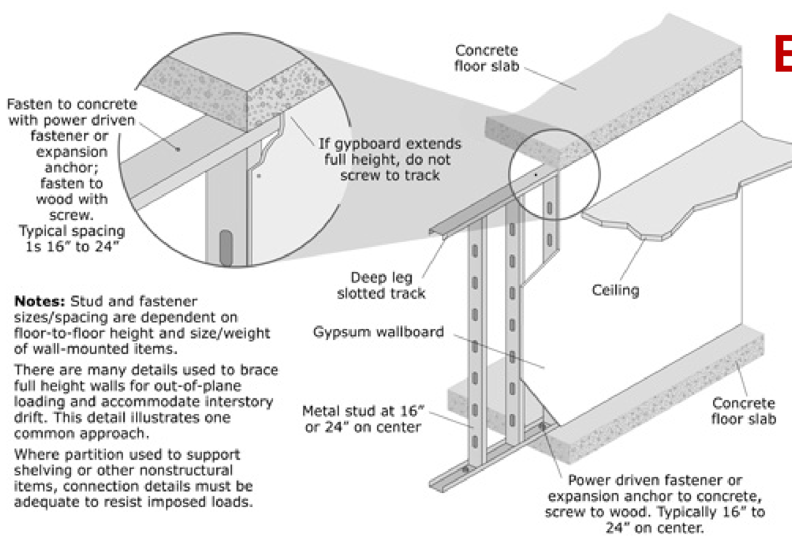
Partitions

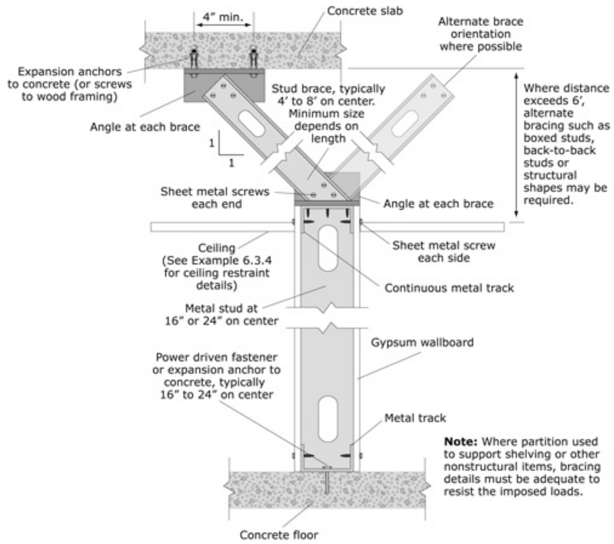
Full-height Partition Details

ER



Partial-height Partition Details

ER



Seismic Design and Performance of Nonstructural Elements

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Suspended Heavy Ceilings

- Includes suspended gypsum board, lath & plaster, metal or wood panels, historic finishes
- Significant falling hazard, life safety concern; grid may also fall
- Damage due to acceleration and displacement
- Typical details provide fixity at two adjacent sides, sliding connections on opposite sides. Alternatively, ceiling may be designed for diaphragm action.

Seismic Design and Performance of Nonstructural Elements

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Suspended Heavy Ceiling Damage

Damage to historic, ornate wire lath and plaster ceiling in the 2010 M8.8 Chile Earthquake. Wire lath is attached to arches or to wood furring suspended from the roof framing

Suspended Heavy Ceiling Damage

Complete collapse of a large suspended gypsum board ceiling over a swimming facility in Japan. This type of failure has been replicated on the E-defense shake table

Suspended Soffit Damage

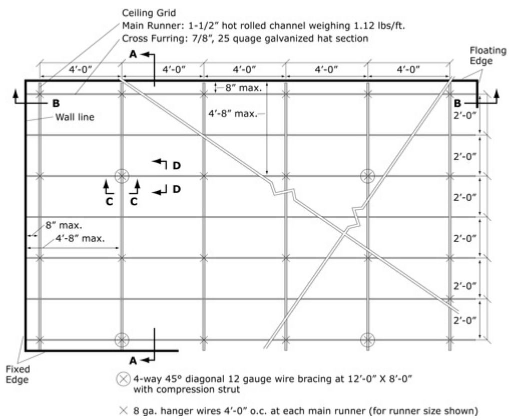
Collapse of exterior soffit at Jefferson Elementary School in Calexico in the 2010 Baja California Earthquake; approximately 1200 sq ft of soffit collapsed at this school built in the 1960's

Heavy Ceiling Mitigation Example

- Suspended and braced gypsum board ceiling in California hospital
- Rigid bracing at 6 ft x 8 ft centers (unistrut)
- Main runner (black channel)
- Cross furring runs below main runner; saddle tied
- Supplementary framing for lights runs above main runner; saddle tied

Heavy Ceiling Mitigation Details

PR



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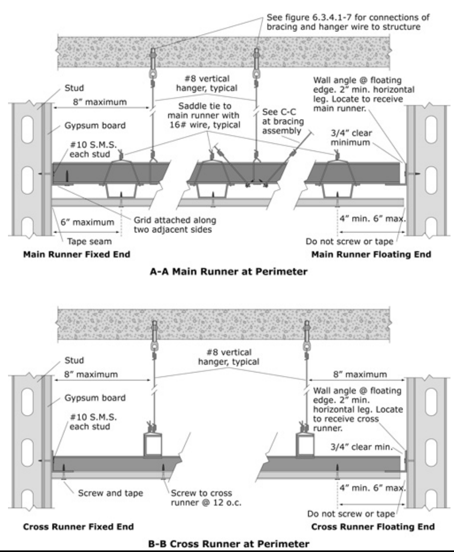
Heavy Ceiling Mitigation Details

PR



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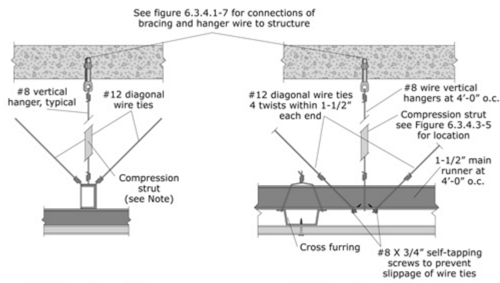
Heavy Ceiling Mitigation Details

PR



C-C Brace Assembly **D-D Brace Assembly**

Note: Compression strut shall not replace hanger wire. Compresion strut consists of a steel section attached to main runner with 2 - #12 sheet metal screws and to structure with 2 - #12 screws to wood or 1/4" min. expansion anchor to concrete. Size of strut is dependent on distance between ceiling and structure ($l/r \leq 200$). A 1" diameter conduit can be used for up to 6', a 1-5/8" X 1-1/4" metal stud can be used for up to 10'. See figure 6.3.4.1-6 for example of bracing assembly.

Stairs

- Stairs are primarily damaged by interstory drift. They can act like unintended diagonal braces and/or become dislodged and drop.
- The walls surrounding a stairway may be damaged during an earthquake causing debris to fall into the stairwell and rendering the stairs unusable.

Stair Damage

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Stair Damage

Seismic Design and Performance of Nonstructural Elements

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Stair Damage – Forsyth Barr

Seismic Design and Performance of Nonstructural Elements

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Stair Damage – Grand Chancellor

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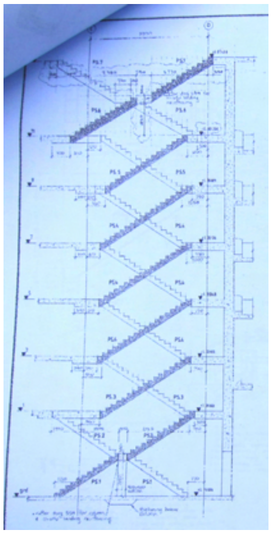
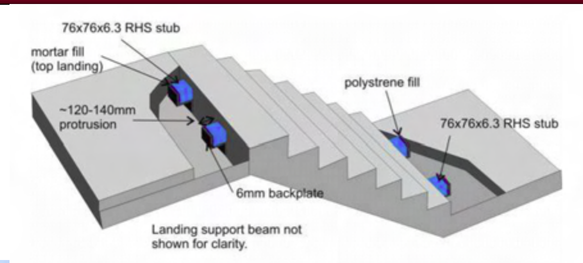
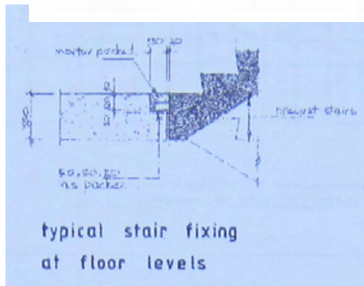
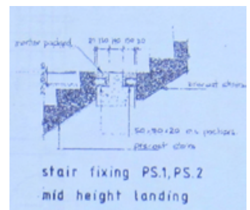
Stair Damage

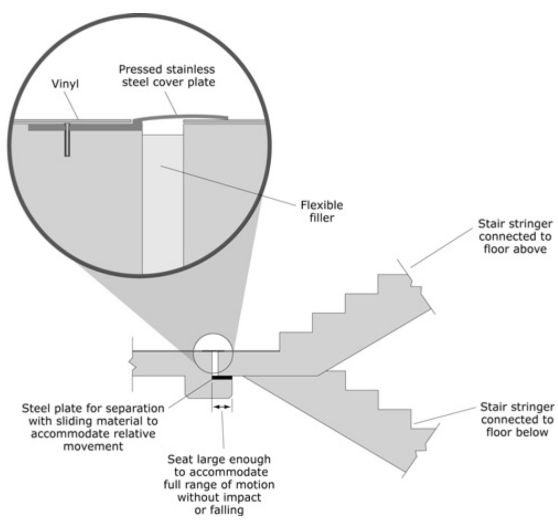








Stair Mitigation



Stair Mitigation

Slotted holes to accommodate interstory drift

MEP Components

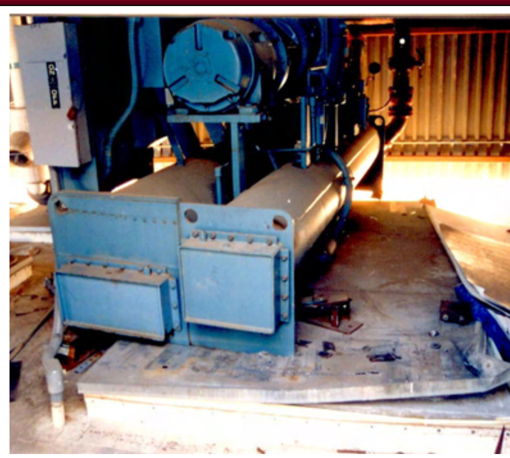
FEMA E-74, Section 6.4

11 Categories	*39 examples*
• 6.4.1 Mechanical	*6*
• 6.4.2 Storage Tanks and Water	*4*
• 6.4.3 Pressure Piping	*8*
• 6.4.4 Fire Protection	*1*
• 6.4.5 Fluid Piping, Not Fire Protection	*2*
• 6.4.6 Ductwork	*2*
• 6.4.7 Electrical and Communications Equipment	*6*
• 6.4.8 Electrical & Communications Distribution Equipment	*2*
• 6.4.9 Light Fixtures	*4*
• 6.4.10 Elevators and Escalators	*3*
• 6.4.11 Conveyors	*1*

HVAC Equipment w/Isolation

- Vibration isolated equipment particularly vulnerable
  - Use open springs with snubbers or bumpers
  - Use restrained springs with rated lateral capacity
  - Designated seismic systems may require equipment certification

HVAC w/Isolator Damage

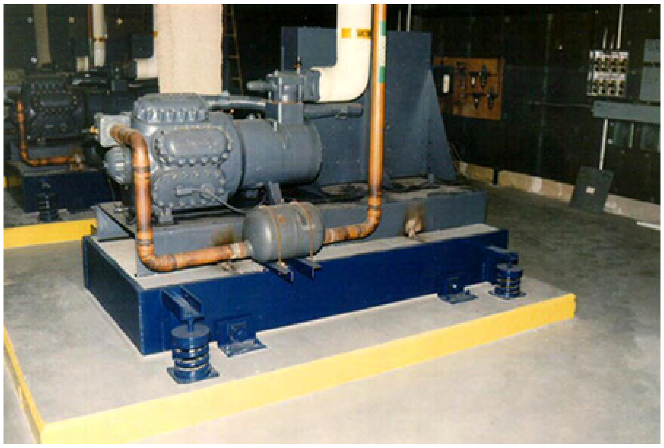


Failures of equipment mounted on vibration isolators in the 1994 Northridge Earthquake

HVAC w/Isolator Damage

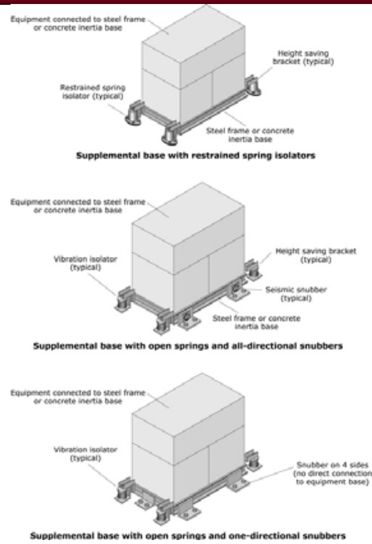
Failure of pump mounted on three vibration isolators including damage at wall penetration in the 1994 Northridge Earthquake

HVAC w/Isolator Mitigation Example



Open springs in conjunction with snubbers used to support equipment

HVAC w/Isolation Mitigation Detail

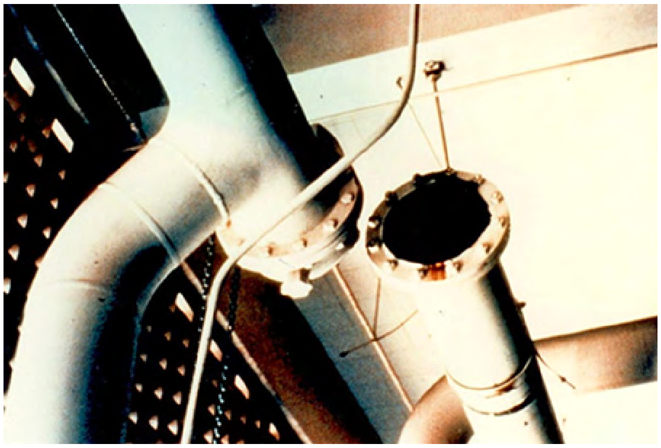


ER

Suspended Pressure Piping

- Falling hazards can cause injury, result in water/fluid damage, loss of function
- FEMA 414 has many details for suspended or wall-, floor-, or roof-mounted pipe and duct
- ASCE 7-10 requirements and exemptions

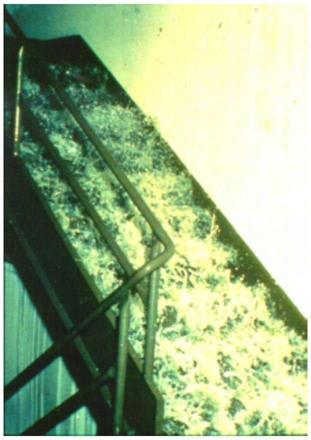
Suspended Pressure Pipe Damage



Pipe joint failure in the 1971 M6.6 San Fernando Earthquake

Suspended Pressure Pipe Damage

Leakage caused by pipe damage at joint; 1994 M6.7 Northridge Earthquake

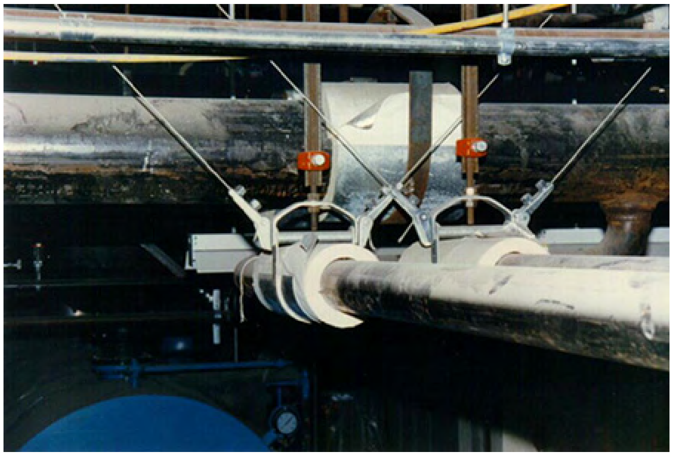


Water flow in stairwell due to pipe break at floor above

Suspended Pressure Pipe Damage

Pipe brace failed at connection in 1994 Northridge Earthquake

Suspended Pipe Mitigation



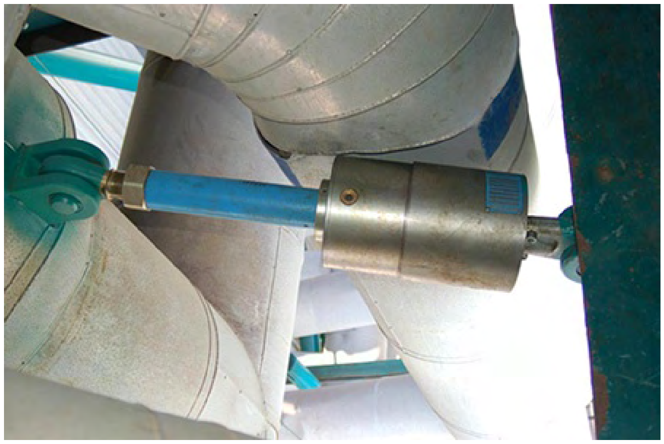
Suspended Pipe Mitigation

Pipe clamp used for longitudinal angle brace; note pipe clamp in direct contact with pipe. Clevis hanger used for transverse brace

Suspended Pipe Mitigation

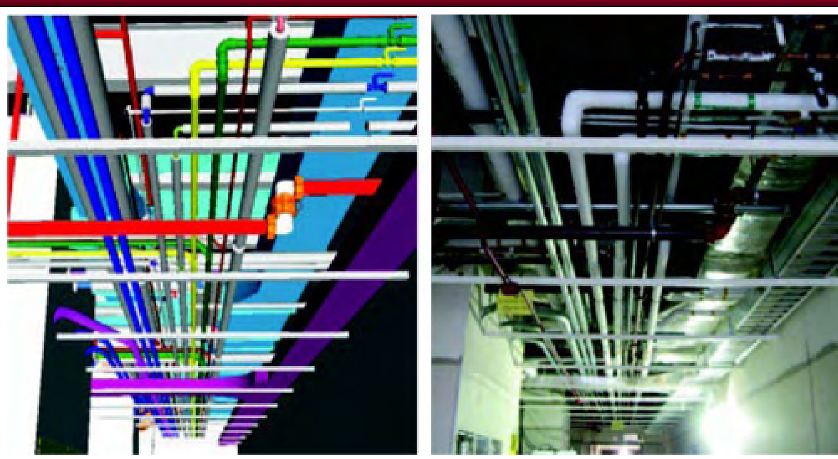
All-directional cable bracing of suspended piping; rod and cables attached to welded lug

Suspended Pipe Mitigation



Viscous damper used as restraint on large insulated pipe at industrial facility

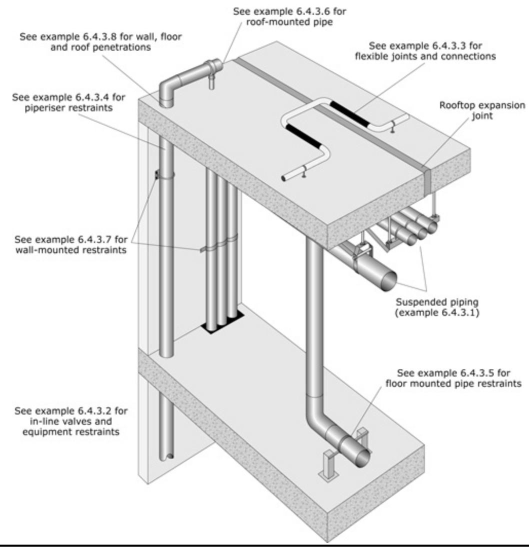
Suspended Pipe Mitigation



Example of BIM Model (left) compared to installed piping (right)

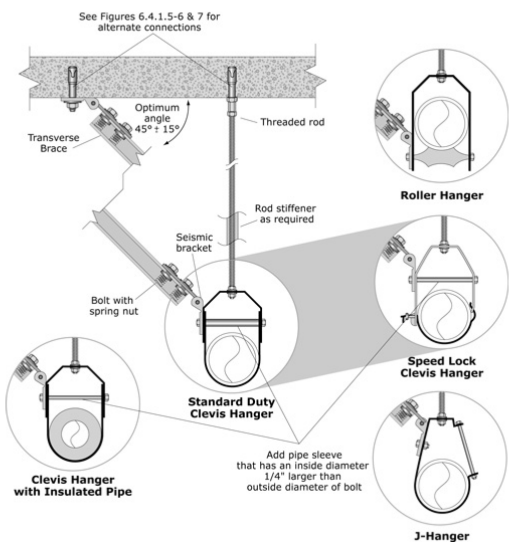
Suspended Pipe Mitigation Example

ER

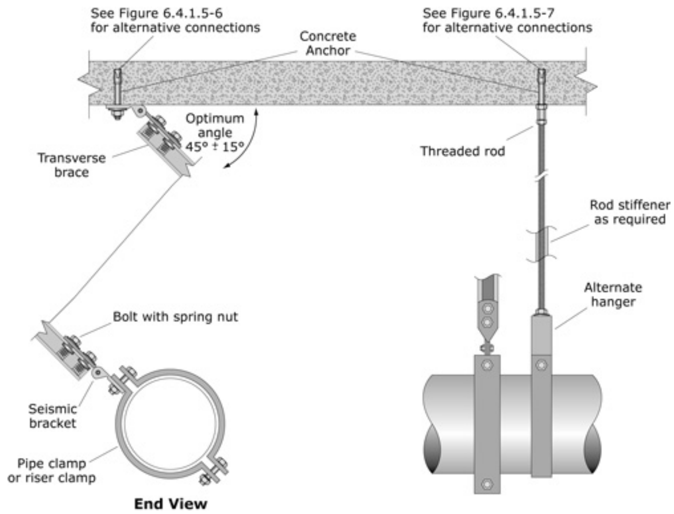


Suspended Pipe Mitigation Example

ER



Suspended Pipe Mitigation Example



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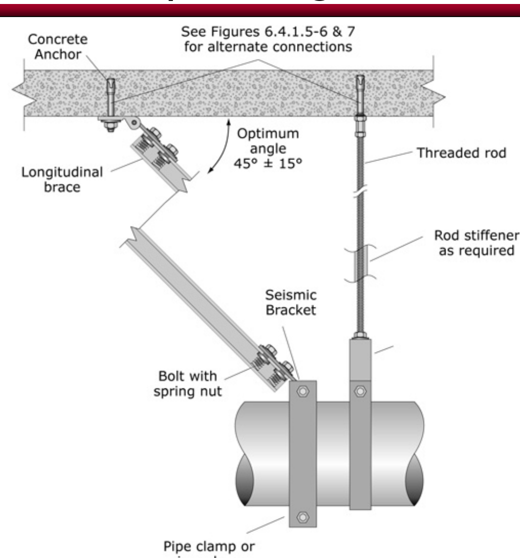
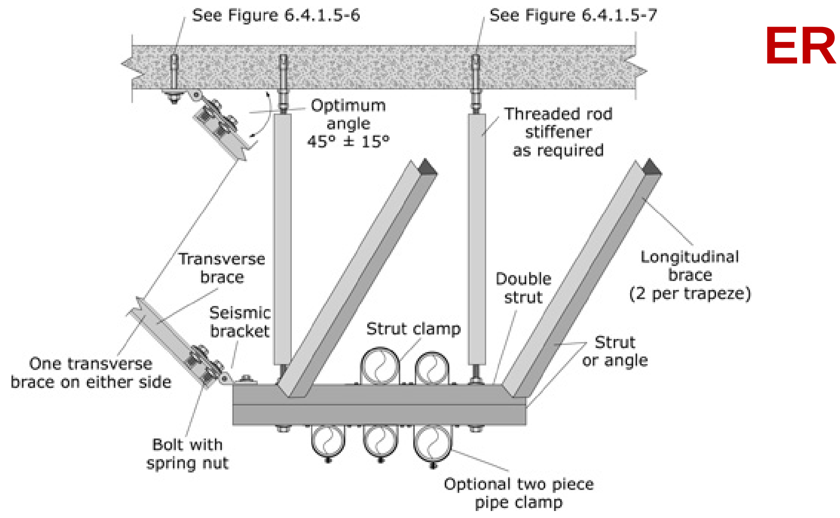
Suspended Pipe Mitigation Example



ER

Suspended Pipe Mitigation Example



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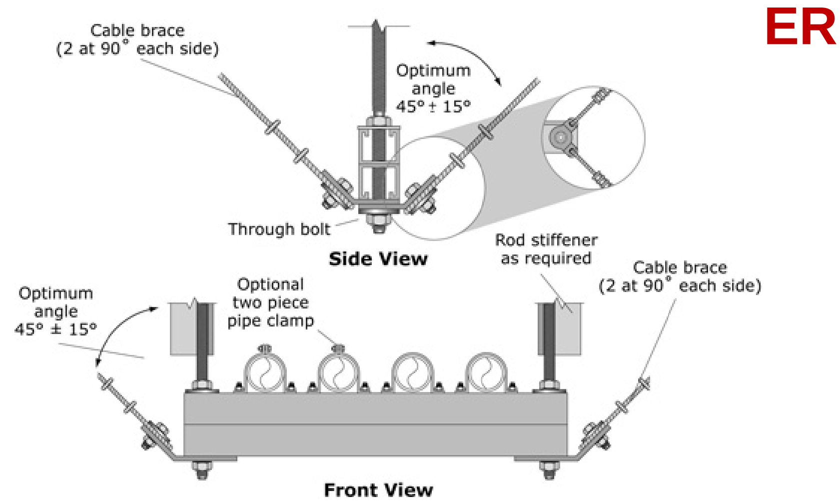
Suspended Pipe Mitigation Example



Seismic Design and Performance of Nonstructural Elements

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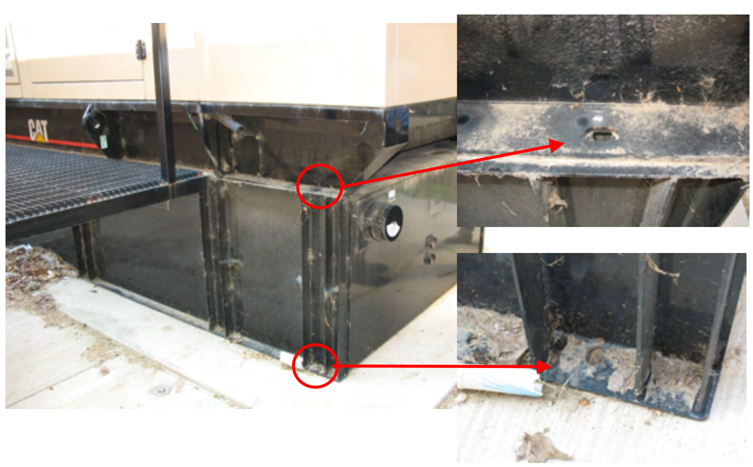
Emergency Generator System

- Emergency generator systems includes generator, fuel tank, fuel line, batteries, battery racks

Emergency Generator Installation



2002 installation in hospital; missing anchorage from generator to skid and missing anchorage at base of skid

Emergency Generator Mitigation

Ineffective chain restraints installed as nonengineered solution. This generator needs engineered anchorage details.

Seismic Design and Performance of Nonstructural Elements

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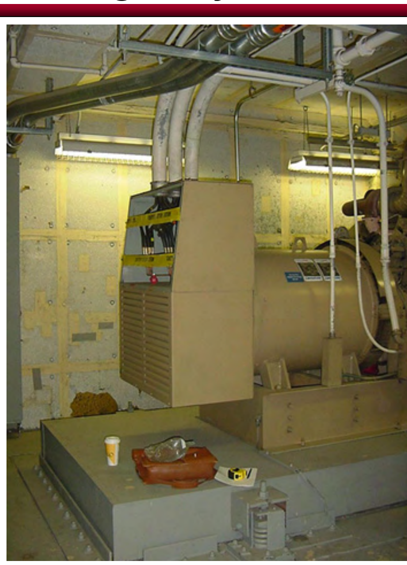
Emergency Generator Mitigation



- Emergency generator is anchored to a concrete inertia base
- Inertia base is mounted on spring isolators and restrained by steel angle snubbers on all sides

Seismic Design and Performance of Nonstructural Elements

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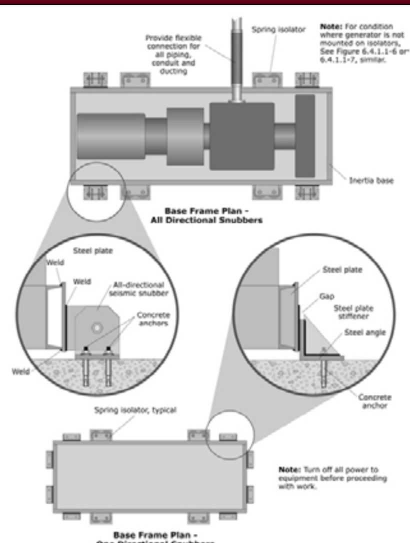
Emergency Generator Mitigation

Emergency generator with skid mount on housekeeping pad; shear lugs added following the 2001 Peru Earthquake

Emergency Generator Details

ER



Pendant Light Fixtures

- Heavy fixtures are a falling hazard and life safety concern
- Fixtures should have safety cables attached directly to structure to prevent falling
- Fixtures that can swing and impact other items should be restrained

Pendant Light Damage

Failure of a strip of pendant light fixtures at Dawson Elementary School library in1983 M6.4 Coalinga Earthquake; support stems failed at the ceiling connection and stems came down with the lights

Pendant Light Damage

Failure of pendant light fixtures at Northridge Junior High School in the 1994 Northridge Earthquake; the support stems failed at the fixture connection and the stems are still attached at the ceiling

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Pendant Light Damage

Failure of pendant light fixture in the 2010 M7 Haiti Earthquake; stem of fixture broke and the conduit pulled loose when the fixture fell

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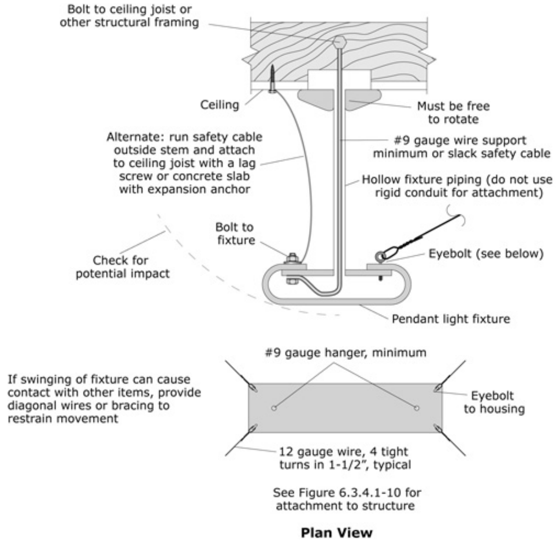
Pendant Light Mitigation Detail



NE

FF&E Components and Contents

FEMA E-74, Section 6.5

6 categories	*16 examples*
• **6.5.1 Storage Racks**	*2*
• **6.5.2 Bookcases**	*2*
• **6.5.3 Computer & Communication Equipment**	*4*
• **6.5.4 Hazardous Materials Storage**	*1*
• **6.5.5 Miscellaneous FF&E**	*3*
• **6.5.6 Miscellaneous Contents**	*4*

FF&E and Content Examples

- **6.5.2 Bookcases, Shelving**
  - ***Bookshelves***
  - Library and Other Shelving
- **6.5.3 Computer & Communication Equipment**
  - Computer Access Floors and Equipment
  - ***Computer and Communication Racks***
  - Desktop Computers and Accessories
  - Televisions and Video Monitors

Bookshelves

- Falling hazard; can cause injury, block exits, result in loss or damage to contents
- ASCE7-10 requires design for permanent floor supported shelving or storage cabinets more than 6 ft. tall
- Details provided are for wall or floor anchorage of units up to 6 ft.
- Locate away from exits/emergency egress
- Provide shelf restraints or sloping shelves

Bookshelf Damage

Failure of poorly anchored wood and metal book shelves at the Lawrence Livermore Laboratory, Livermore, California

Bookshelf Damage

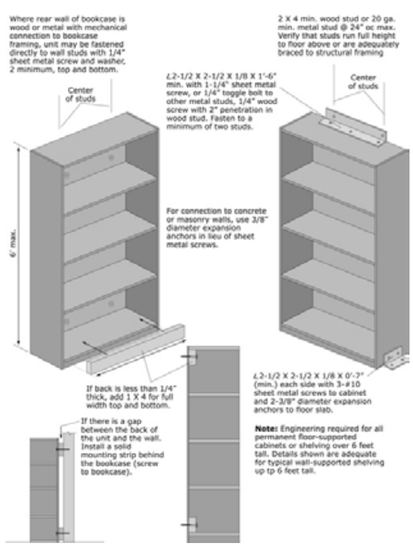
Failure of poorly anchored shelving; toggle bolt pulled out of gypsum board wall in the 1994 M6.7 Northridge Earthquake

Bookshelf Damage

Bookcase overturned onto desk in the 1971 M6.6 San Fernando Earthquake

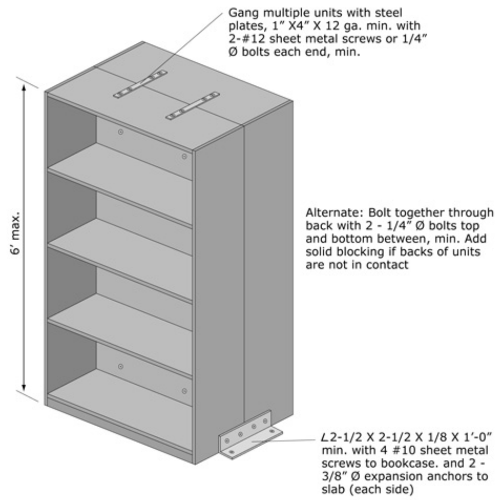
Bookshelf Mitigation Details

NE



Bookshelf Mitigation Details

NE



Note: Engineering required for all permanent floor-supported cabinets or shelving over 6 feet tall. Details shown are adequate for typical shelving 6 feet or less in height.

Computer & Communication Racks

- Damage may result in costly business interruption; loss of data
- Primary damage due to failure of anchorage or internal damage to units
- Secondary damage due to water leakage or failure of power backup systems

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Computer Rack Damage

Damage to communication and computer racks

Computer Rack Damage

- Damage to communication and computer racks

Computer Rack Water Damage

Damage to ceiling and sprinklers resulted in water damage in room full of computer racks

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Computer Rack Mitigation Example

Base anchorage details for data cabinets

•top photo shows internal anchorage

•bottom photo shows external anchorage

Seismic Design and Performance of Nonstructural Elements

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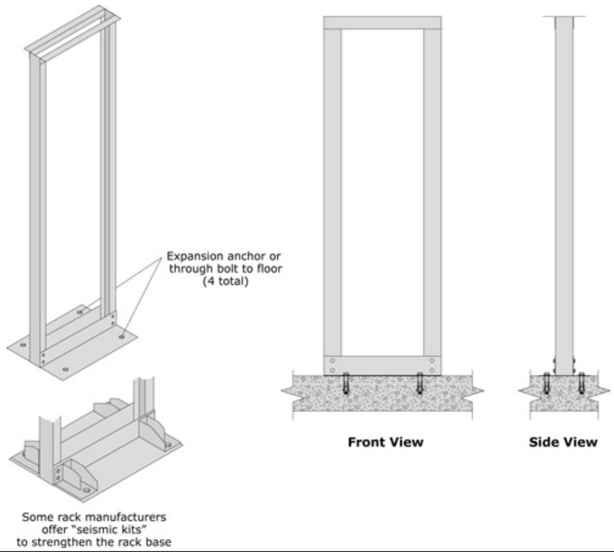
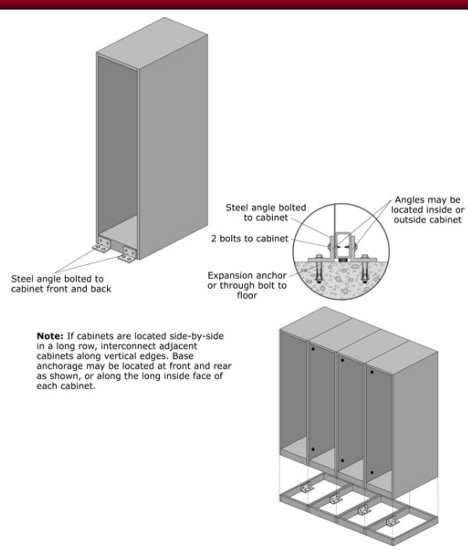
Computer Rack Mitigation Details

NE



Computer Rack Mitigation Details

NE



Responsibility

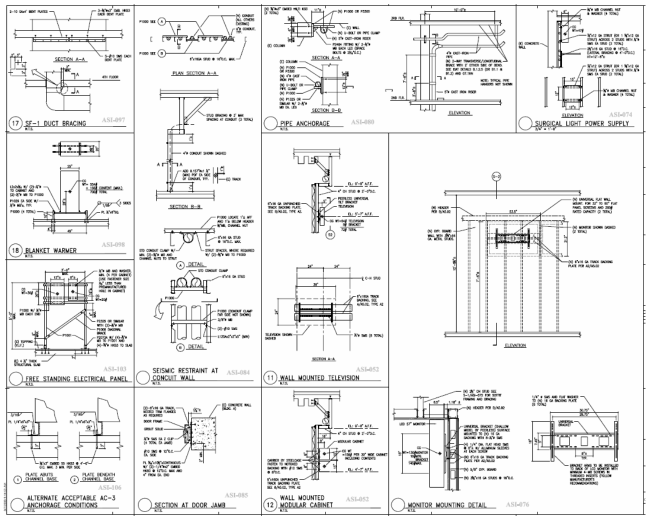
Who is responsible for protecting nonstructural components?

Responsibility

- Engineers
  - Structural
  - Mechanical
  - Plumbing
  - Fire protection
  - Electrical
  - Telecom
- Architects
- Building Officials
- Owners

•General Contractor
•Subcontractors
  •Fire protection
  •Cladding
  •Mechanical
  •Plumbing
  •Electrical
  •Drywall
  •Ceiling
•Installers
•Vendors
•Inspectors
•Tenants

Responsibility



Responsibility Matrix

RESPONSIBILITY MATRIX

FOR THE SEISMIC PROTECTION OF NONSTRUCTURAL COMPONENTS

SEISMIC DESIGN CATEGORIES D, E & F

	NONSTRUCTURAL COMPONENTS								
	General categories shown with sample entries (in blue); insert line items for project specific components	Is Seismic Design Required? (yes/exempt)	Component Importance Factor, Ip (See Note 1)	Party Responsible for Design of Seismic Details (See Note 2)	Party Responsible for Preparation of Seismic Shop Drawings (See Note 2)	Party Responsible for Preparation of Seismic Calculations (See Note 2)	Is Special Seismic Certification Required? (See Note 3) (yes/no)	Is seismic design being handled as a Deferred Approval?	Party Responsible for Site Inspection of Installed Component/System
ITEM	**DESIGNATED SEISMIC SYSTEMS (See Note 1)**	**Yes**	**Ip=1.5**				**Yes**		
S.1	**Component required to function for life-safety purposes after an earthquake, including fire protection sprinkler systems and egress stairways. (per 13.1.3.1)**	**Yes**	**1.5**				**Yes**		
	Fire protection sprinkler system								
	Egress stairways not part of the building structure								
S.2	**Component conveys, supports or contains toxic or explosive substances. (per 13.1.3.2)**	**Yes**	**1.5**				**Yes**		
	Natural gas piping over 1" nominal diameter and trapeze-supported natural gas piping where the total weight supported by the trapeze assembly exceeds 10 plf.								
	Bulk oxygen tank and associated piping								

Responsibility Matrix

	NONSTRUCTURAL COMPONENTS		
	General categories shown with sample entries (in blue); insert line items for project specific components	Is Seismic Design Required? (yes/exempt)	Component Importance Factor, Ip (See Note 1)
ITEM	**STANDARD NONSTRUCTURAL COMPONENTS**		**Ip=1.0 (UON)**
	ARCHITECTURAL COMPONENTS		
A.1	**Exterior Wall Components**	**Yes**	**1.0**
	Metal stud walls		
	Curtainwall		
	Precast panels		
	Glazing		
A.2	**Interior Partitions**	**Yes**	**1.0**
	Metal stud walls		
	Glazing		
	Granite veneer		
A.3	**Ceilings**	**Yes**	**1.0**
	Suspended acoustic tile ceilings		

Responsibility Matrix Example

- Fire Sprinkler System – SDC D, E, F
  - Is seismic design required? *Yes*
  - Component Importance Factor: $I_P = 1.5$
  - Who is responsible for:
    - Seismic Details
    - Seismic Shop Drawings
    - Seismic Calculations
    - Site Inspection of installed component/system

Specification

SECTION 130541

SEISMIC RESTRAINT REQUIREMENTS FOR NONSTRUCTURAL COMPONENTS

[NOTE TO SPECIFIER: This section is intended to aggregate requirements for seismic restraint of nonstructural components. It should be cross referenced from each specification section that includes nonstructural components requiring seismic protection. This specification has been written to address nonstructural components for which the Contractor is assigned responsibility for both design and construction. Items that have been explicitly designed by the design team and included on the drawings may be removed from this section, or the relevant section may be modified to indicate that the Contractor is required to furnish and install restraints only.]

PART 1 - GENERAL

1.1 DESCRIPTION

A. Provide seismic restraint of nonstructural components to withstand seismic forces and seismic deformations without displacing or overturning. For designated nonstructural components, provide installations capable of providing post-earthquake functionality.

Specification Excerpt

1.6 REGULATORY REQUIREMENTS

A. Comply with the International Building Code (IBC) latest adopted Edition by the jurisdiction where the Project is located and applicable local and/or statewide adopted amendments.

B. Special Seismic Certification – Provide certification in accordance with IBC, Chapter 17 and ASCE 7 Chapter 13 requirements for designated seismic systems as indicated on the Responsibility Matrix.

Specification Excerpt

1.7 PROJECT SEISMIC DESIGN CRITERIA

A. Seismic Design Category – X

B. Seismic Design Force – Calculation of seismic design force shall be based on the requirements of Chapter 13 of ASCE 7 with the following seismic design parameters

1. S_{DS} = X.XX
2. $I_{building}$ = X
3. I_p = X.X (1.0 or 1.5 as indicated in ASCE 7 Section 13.1.3)
4. a_P, R_P = in accordance with ASCE 7 Tables 13.5-1 and 13.6-1
5. z = XX (roof elevation)
6. h_1 = XX (floor 1 elevation)
   h_2 = XX (floor 2 elevation)
   h_3 = XX (floor 3 elevation)
   etc.

C. Seismic Relative Displacement – Design shall accommodate seismic relative displacement of 0.02 times the story height in addition to thermal movement that may be present.

Specification Excerpt

1.8 QUALITY CONTROL

A. Shop-Drawing Preparation:

1. Seismic restraint shop drawings shall be prepared or their preparation shall be overseen by a professional engineer experienced in designing seismic restraints for nonstructural components as required by the authority having jurisdiction. The use of proprietary restraint systems with a certificate of compliance verified and listed by an IAS accredited inspection body is acceptable.

B. Seismic Calculations Preparation:

1. Seismic restraint calculations shall be prepared and stamped by a registered professional engineer experienced in the area of seismic restraint for nonstructural components. Comply with the applicable code specified in Paragraph 1.6.

C. Special Seismic Certification of Mechanical and Electrical Equipment and Distribution Systems:

1. Each manufacturer of designated seismic system components shall provide a certificate of compliance…

Specification Excerpt

PART 3 - EXECUTION

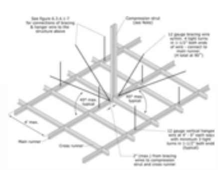
3.1 CONSTRUCTION, GENERAL

A. For items identified in the Responsibility Matrix furnish and install supports, braces, connections, hardware and anchoring devices to withstand code-required seismic forces and seismic deformations without shifting or overturning. For components with Ip = 1.5, in addition to providing code-required seismic forces and deformations, provide installations capable of providing post-earthquake functionality.

B. Construct seismic restraints and anchorages that do not inhibit thermal expansion and contraction of distribution systems. Utilize ASME Standard B31 when utilizing common supports for both thermal and seismic loading.

C. Maintain fire ratings of assemblies as specified elsewhere or on the drawings in addition to compliance with the criteria set forth below.

Specification Excerpt

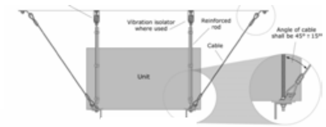


3.4 CEILINGS

A. Suspended acoustic tile ceilings:

1. Design and install ceiling in accordance with ASTM E580.
2. For Seismic Design Categories D, E and F, provide bracing at regular intervals to resist code design forces and limit vertical and lateral movement. Suspended ceilings with areas less than or equal to 144 square feet and that are surrounded by walls or soffits that are laterally braced to the structure above are exempt from seismic design requirements.
3. Where ceilings are unbraced or splayed wire bracing is used to resist seismic forces and limit lateral deflections, provide 1 inch clearance around all penetrations through the ceiling sprinkler drops. If flexible sprinkler drops are used and have been certified to accommodate 1 inch of movement, the 1 inch clearance requirement may be waived.
4. Provide independent support of lighting fixtures, diffusers, cable trays, electrical conduit and other ceiling appurtenances.
5. Ceiling system design load Wp shall be taken as not less than 4 psf.

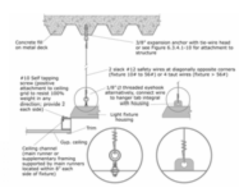
Specification Excerpt



3.9 MECHANICAL AND PLUMBING COMPONENTS

A. Suspended mechanical equipment
  1. Design support and bracing to resist seismic design force in any direction.
  2. Provide flexible connection between equipment and interconnected piping.
  3. Brace equipment hung from spring mounts using cable or other bracing that will not transmit vibration to the structure.
  4. As an alternate to project-specific design of seismic bracing, use of proprietary restraint systems with a certificate of compliance verified and listed by an accredited inspection body is acceptable. Use of a certified product does not preclude the requirement for shop drawings.

Specification Excerpt



3.10 ELECTRICAL EQUIPMENT

A. Light fixtures
  1. For lights in suspended ceilings:
     a. For lights weighing 56 pounds or less, provide positive mechanical connection between fixtures and ceiling framing to resist seismic design force and gravity load. Provide 2 independent wires at diagonally opposite corners connected to structural framing. For lights weighing more than 56 pounds, provide independent support and bracing.

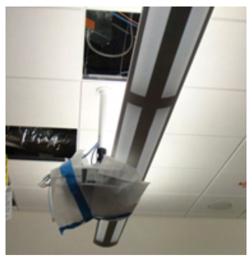
Specification Excerpt

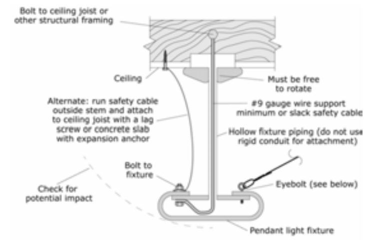
3.10 ELECTRICAL EQUIPMENT

A. Light fixtures

2. For pendant mounted fixtures:

a. Verify that fixture will not displace in such a manner as to hit adjacent lighting and/or architectural elements or other suspended items. Connection to the structure shall allow a 360 degree range of motion. If pendant fixture could come in contact another item when swinging in a 45 degree arc from vertical in any direction, provide bracing to limit movement and avoid interaction. Design load shall be 1.4 times the operating weight acting down with a simultaneous horizontal load of 1.4 times the operating weight.





Tools for Existing Buildings

- Survey (inventory) form

- Checklist of questions ???????

- Risk ratings H, M, L

Survey (Inventory)

PRIORITIZED INVENTORY

ID	Description	Location	Quantity	Units	LS	PL	LF	Detail Type	Notes
						"H", "M", or "L"		NE, PR, ER	
1	Bookcase in the south east corner	Room 13	2	each	H	M	M	NE	The two wooden bookcases are unanchored an could tip over during an earthquake blocking egress. Relocate the bookcases away from the doorway or anchor them to the supporting floor or adjacent wall.
6	Flat screen monitor	04-N3	1	each	H	H	M	NE	Equipment stored less than four feet above the floor, like this computer monitor, is not a significant life safety hazard. However consideration should be made to securing these types of equipment to the desk top or adjacent wall. This inexpensive mitig
13	Metal flat files	04-W4	3	each	L	L	L	NE	These flat files are three individual units stacked on top of each other. Without lateral restraints, they can easily slide off each other. They can be grouped together to act as a unit; high friction pads can be placed between each unit; or they can be
16	Hot water heater	04-W7	1	each	H	H	M	PD	Gas hot water heaters should be anchored to the floor or adjacent wall to prevent tipping and damage to water and gas lines.
17	Refrigerator	04-W8	1	each	L	L	L	NE	FEMA 74 suggests laterally bracing existing refrigerators due to the potential of electrical damage or leaking refrigerant.
63	Computer hub	02-14a	1	each	L	H	H	NE	Computer hub should be anchored to the floor or adjacent wall to limit potential damage.
65	Vending machine	02-15	1	each	M	L	L	NE	FEMA 74 suggests laterally bracing existing chillers due to the potential of sliding and potential leaking refrigerant.

Checklist of Questions

Appendix D. Architectural Components Checklist

ITEM NO./ SUBCATEGORY	EXAMPLE NO.	COMPONENT NAME(S)	PRINCIPAL CONCERNS	C	NC	NA	CHECKLIST QUESTIONS (YES=COMPLIANCE; NO OR UNKNOWN=NONCOMPLIANCE; NA=NOT APPLICABLE)
6.3.1 Exterior Wall Components *[Exterior falling hazards are a primary concern, especially items situated above 10 feet and items that may fall over exits, walkways, or sidewalks.]*	6.3.1.1	Adhered Veneer	Falling hazard				Is the adhered veneer adequately attached to the structure? [This includes relatively thin sections of tile, masonry, stone, terra cotta, ceramic tile, glass mosaic units, stucco, or similar materials attached to a structural wall or framework by means of an adhesive].
							Based on visual observations and/or tapping, is the veneer free of cracked or loose sections that may fall during an earthquake?
	6.3.1.2	Anchored Veneer	Falling hazard				Is the anchored veneer adequately attached to the structure? [This includes thicker masonry, stone, or stone slab units that are attached to the structure by mechanical anchors].
							Is the masonry or other veneer supported by shelf angles or other elements at each floor?
							Is the masonry or other veneer connected to a structural back-up wall at adequate

Checklist of questions

- 6.3.4 Ceilings, Soffits: Suspended Acoustic Lay-in Tile Ceiling
  - Principal Concern: Dropped acoustical tiles, perimeter damage, separation of runners and cross runners; falling hazard if grid and lights come down
- Checklist Questions:
  - Does the suspended ceiling have adequate diagonal bracing wires and compression struts to support seismic loads from the ceiling grid plus all lay-in items that do not have independent lateral supports?
  - If the ceiling supports lay-in lighting or diffusers, do the lay-in items all have independent vertical supports consisting of wires located at least at two diagonally opposite corners?
  - Do lay-in fixtures weighing over 50 pounds additionally have independent lateral bracing wires at all four corners?
  - If located in a high seismic zone, is the suspended ceiling supported by a heavy duty ceiling grid with adequate capacity and does the grid include supplemental hanger wires at light fixtures or other mechanical items?

Seismic Risk Rating

Appendix E. Architectural Components Seismic Risk Ratings

ITEM NO./ SUBCATEGORY	EXAMPLE NO.	COMPONENT NAME(S)	SHAKING INTENSITY	LIFE SAFETY (LS)	PROPERTY LOSS (PL)	FUNCTIONAL LOSS (FL)	TYPE OF DETAIL
6.3.1 Exterior Wall Components	6.3.1.1	Adhered Veneer	Low	M	M	L	ER
			Mod	H	H	L	
			High	H	H	L	
	6.3.1.2	Anchored Veneer	Low	M	M	L	ER
			Mod	H	H	L	
			High	H	H	L	
	6.3.1.3	Prefabricated Panels	Low	M	M	L	ER
			Mod	H	H	L	
			High	H	H	L	
	6.3.1.4	Glazing	Low	L	L	L	ER
			Mod	M	M	L	
			High	H	M	M	
	6.3.1.5	Glass Blocks	Low	L	L	L	ER
			Mod	M	M	L	

Appendix C Inventory Form

Appendix C. Nonstructural Inventory Form

The intent is that Appendix C, Appendix D and Appendix E be used together as tools for the facility survey. The first step is to review the map in Figure 3.2.1-1 and discussion in Section 1.3 to see if nonstructural hazard mitigation is a concern for the facility in question. If so, then Appendix C and Appendix D can be used in tandem to perform the survey. Risk ratings from Appendix E could be added to the inventory form during the field survey or added later in order to help prioritize the items in the list.

The questions in Appendix D are stated in such a way that the answer "No" or "Unknown" indicates that the component may be noncompliant and likely to pose a nonstructural earthquake hazard. All of the noncompliant components should be entered as individual line items on the facility inventory form in this Appendix. As shown below, the form provides columns for the following information:

- Priority: This can be added at the end after the priorities have been established.
- Nonstructural Item: Name or description of nonstructural component.
- Location: Information such as building, floor, or room number.
- Quantity: Number of items, lineal feet, or square feet.
- Risk Rating for Life Safety (LS), Property Loss (PL) and Functional Loss (FL) from Appendix E.
- Notes: Space for comments regarding the current condition, presence or absence of anchorage details, proximity to other hazardous items, issues with secondary damage such as leaks or hazardous materials release, and whether the component in question is important for functionality of the facility. This might also include a photo number if photos of each item are taken to assist with the survey.

Link to US Bureau of Reclamation Excel Spreadsheet

The inventory form provided here has been adapted from the spreadsheet provided by the U.S. Bureau of Reclamation on their website under the heading "Online Orders/Free Tools." The website contains two types of downloadable survey forms: one in spreadsheet format (Microsoft Excel) and one in database format (Microsoft Access). Both of these forms have built-in sorting algorithms so that components with high risk in any category can be shifted to the top of the list. These sorting criteria may be adjusted to suit individual needs. Survey forms can be customized to include cost data, which may be useful for prioritization and planning. Proprietary forms are also available for purchase from specialty vendors.

PRIORITIZED INVENTORY									
ID	Description	Location	Quantity	Units	LS	PL	LF	Detail Type	Notes
					"H", "M", or "L"			NE, PR, ER	

Rank by LS | Rank by PL | Rank by LF | Rank by Highest Rank

US Bureau of Reclamation Tool

Reclamation's
Building Seismic Safety Program

Online Orders

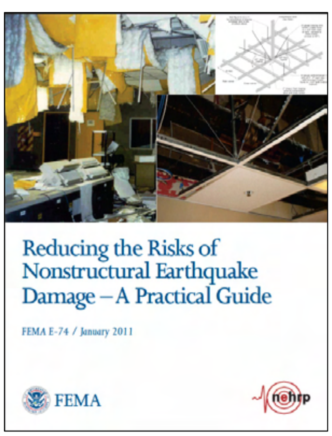
Free Tools

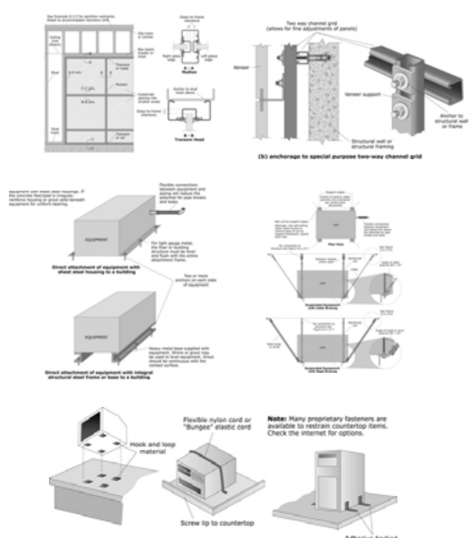
- *FEMA 74, Reducing the Risks of Nonstructural Earthquake Damage, Survey and Assessment Switchboard, Version 2.0*
  Bureau of Reclamation, Building Seismic Safety Program, Updated March 10, 2009
  Microsoft Access - 9,172 KB .mdb File
- *FEMA 74, Prioritized Inventory*
  Bureau of Reclamation, Building Seismic Safety Program, Updated March 10, 2009
  Microsoft Excel - 4,151 KB .xls File

View/ Download/ Print

View, Download or Print pdf file of entire document, individual chapters, groups of detail examples, or Appendices

Questions?





Seismic Certification

Requirements, Enforcement, and Practice

A Collaborative Presentation by:

Seismic Design and Performance of Nonstructural Elements

Joe La Brie, SE, President

MakeItRight Inc. and Dynamic Certification Laboratory

Matthew Tobolski, PhD, PE President

Tobolski Watkins Engineering Inc.

Matthew Tobolski

Matthew Tobolski is president and CEO of Tobolski Watkins Engineering Inc., a California-based structural and earthquake engineering firm providing services to the healthcare, nuclear, building and bridge markets. He received his Ph.D. and M.S. from the University of California, San Diego, in structural engineering. Tobolski is active in the analysis, design, and review of complex structural systems with a focus on the development of modular systems for the acceleration of on-site construction. Additionally, he is a recognized expert in the seismic qualification of components and systems for post-earthquake functionality of critical facilities, with particular attention to dynamic testing.

Tobolski is a member of a number of committees focusing on improving the design and performance of essential facilities such as hospitals and nuclear facilities.

Joseph L. La Brie

Joseph La Brie is a registered civil and structural engineer in California and Nevada. The primary focus of La Brie's efforts over the years has been in the development of health care facilities. He is the president and founder of MakeItRight Inc., a progressive multidiscipline design firm specializing in hospital facilities and the important utility systems and nonstructural components within them. He stays current with the technical developments of California's Hospital Building Seismic Upgrade Program (Senate Bill 1953) and is coordinating the implementation of this work at several facilities. In May 2010, La Brie and key expert partners created Dynamic Certification Laboratory (DCL). This shake table laboratory has been used extensively for the certification of a broad range of equipment types.

La Brie serves on the Board of Directors of the Structural Engineers Association of Southern California. In November of 2008, he was elected chairman of the Hospital Building Safety Board (HBSB) through 2012.

Presentation Outline

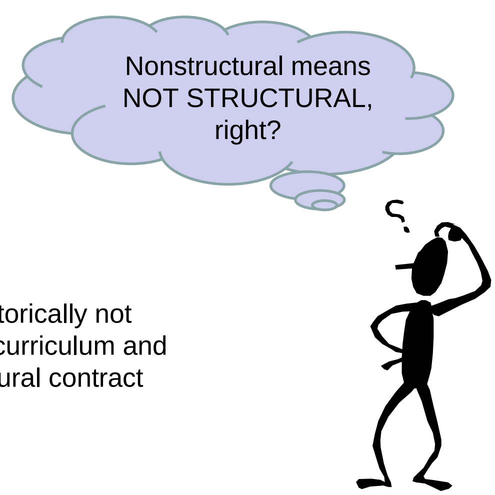
- Introduction
  - Background / History
  - Standards
  - Enforcement
- Regulations
- Certification Methods
- Exemptions
- Responsibilities
- Certification Documentation Processing
- Lessons Learned / Conclusion

Seismic Design and Performance of Nonstructural Elements

October/November 2011

Introduction

Nonstructural Components – No man's Land



Nonstructural components are historically not covered in structural engineering curriculum and often outside scope of main structural contract

Seismic Design and Performance of Nonstructural Elements

October/November 2011

Introduction

What about the “Black Box”?

Seismic Design and Performance of Nonstructural Elements

October/November 2011

Introduction

What is Special Seismic Certification?

Spe·cial Seis·mic Cer·ti·fi·ca·tion:

[**spesh**-*uh*l **sahyz**-mik sur-*tuh*-fi-**key**-sh*uh*n]

- noun

The certification of equipment and components to not only withstand the effects of earthquakes, but also function following a seismic event

Required to ensure essential facilities are able to provide services or protect the public following a catastrophic geological event

origin:

1. 1970’s nuclear power industry
2. 2000 International Building Code

Seismic Design and Performance of Nonstructural Elements

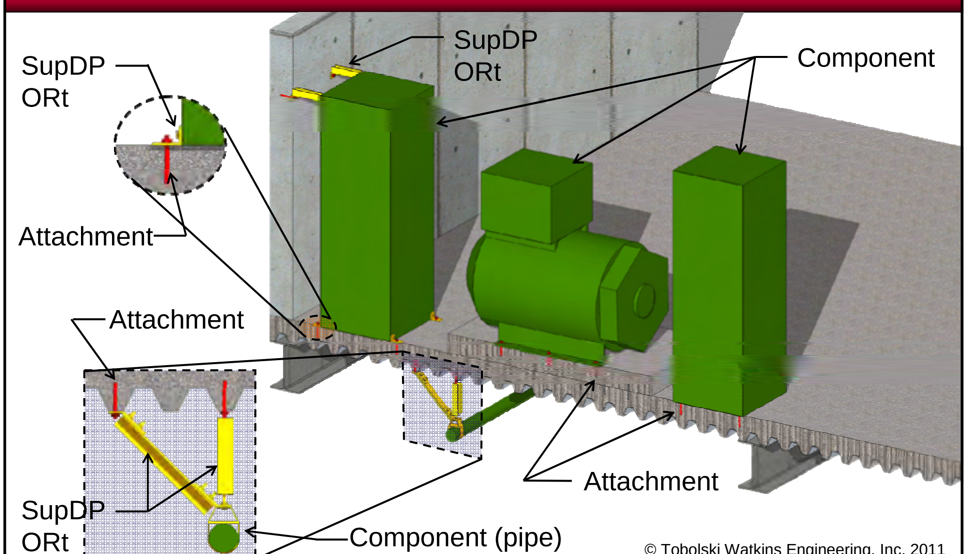
October/November 2011

Background and History

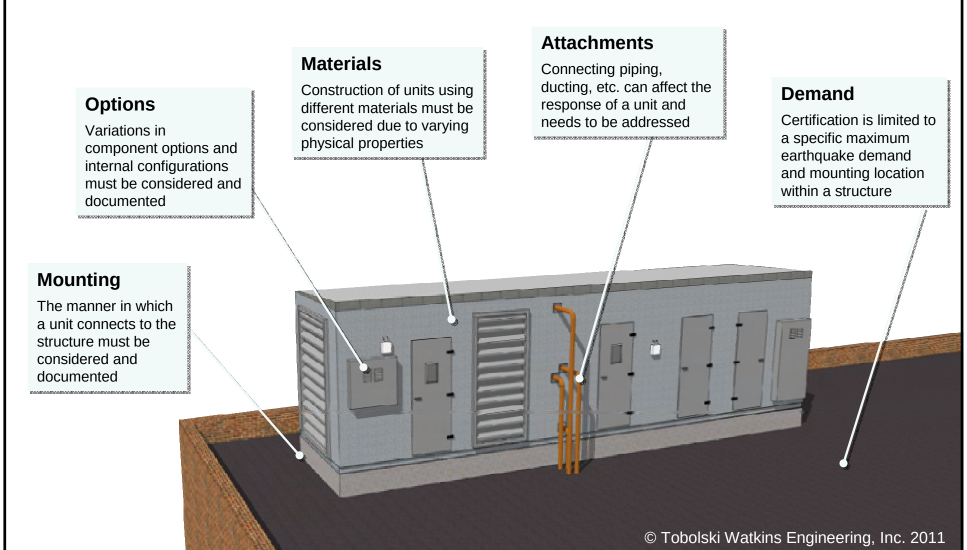
What is Special Seismic Certification?

- **Structural Integrity**
  - Vertical and lateral systems in tact, only limited yielding
  - No fracture of critical structural members/connections
- **Functionality**
  - Post-test unit equivalent functionality as pre-test
  - Minor repairs allowable for functionality
  - No release of hazardous materials into environment beyond code limits

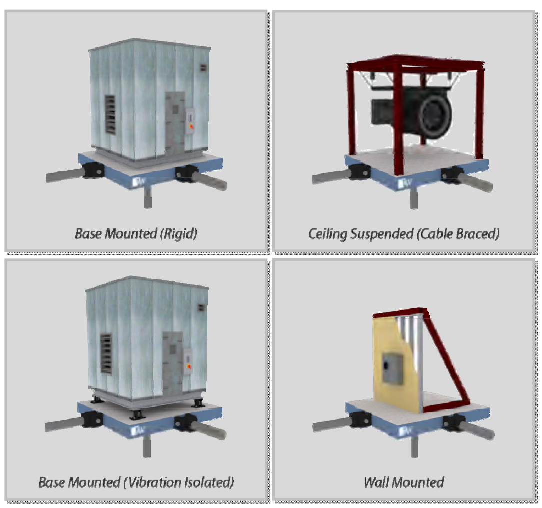
Components, SupDPORts and Attachments



Certification Considerations



Certification Considerations



Engineering for Non-Structural Components

- Essential Site / Building Information
- Essential "Building Systems Components" Information

Seismic Design and Performance of Nonstructural Elements

October/November 2011

Introduction

1976 UBC

(k) Essential Facilities. Essential facilities are those structures or buildings which must be safe and usable for emergency purposes after an earthquake in order to preserve the health and safety of the general public. Such facilities shall include …

…**The design and detailing of equipment which must remain in place and be functional following a major earthquake shall be based upon the requirements of Section 2312 (g)** [Lateral Force on Elements of Structures] and Table No. 23-J.

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Background and History

2000 IBC

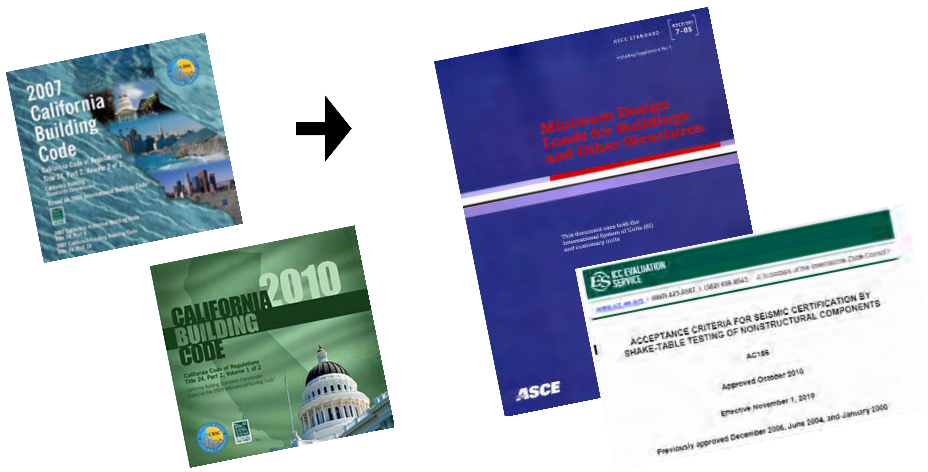
1708.5 Mechanical and electrical equipment. Each manufacturer of designated seismic system components shall test or analyze the component and its mounting system or anchorage and shall submit a certificate of compliance… **The evidence of compliance shall be by actual test on a shake table, by three-dimensional 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 a more rigorous analysis providing for equivalent safety.**

2006 IBC / 2007 CBC

1708.5 Seismic qualification of mechanical and electrical equipment. The registered design professional in responsible charge shall state the applicable seismic qualification requirements for designated seismic systems on the construction documents…

…Qualification shall be by 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 a more rigorous analysis providing for equivalent safety.

Codes and Standards



What Changed?

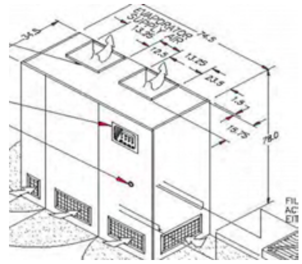
- IBC vs CBC: No Major Difference in Requirements for SSC.
- Enforcement has been the Source of PERCEIVED CHANGE.
- On January 1, 2008 OSHPD began to enforce the requirement for SSC as prescribed in the 2007 CBC.
- Many jurisdictions still do not enforce this part of the building code.

Analysis vs. Testing

Analysis can be implemented as a part of a well structured certification program.

However, per ASCE 7, all active and energized items in a systems <u>must</u> be shake table tested.

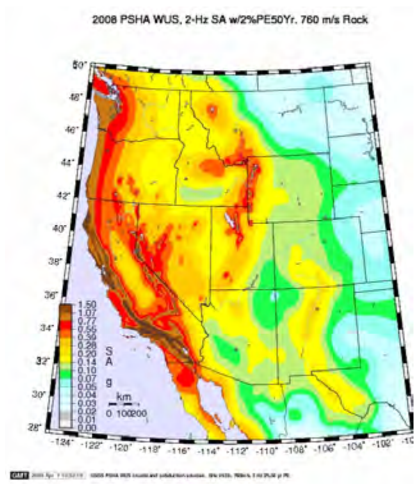
Realistic dynamic properties and response must be considered in analysis.



Special Seismic Certification

- Applies to SDC C,D,E, & F.
- Required for Equipment that is part of the Designated Seismic System. Ip=1.5
- Equipment must remain Operable following an Earthquake
- Shake Table Testing is Required for all practical purposes. There is no way to calculate Functionality.

Design Demands



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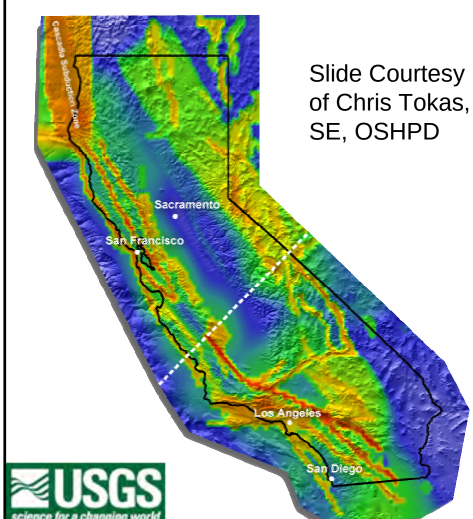
Regulations

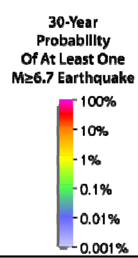
Design Demands



Slide Courtesy of Chris Tokas, SE, OSHPD

30-Year Probabilities

	Magnitude ≥6.7	Magnitude ≥7.5
Northern Area	93%	15%
Southern Area	97%	37%



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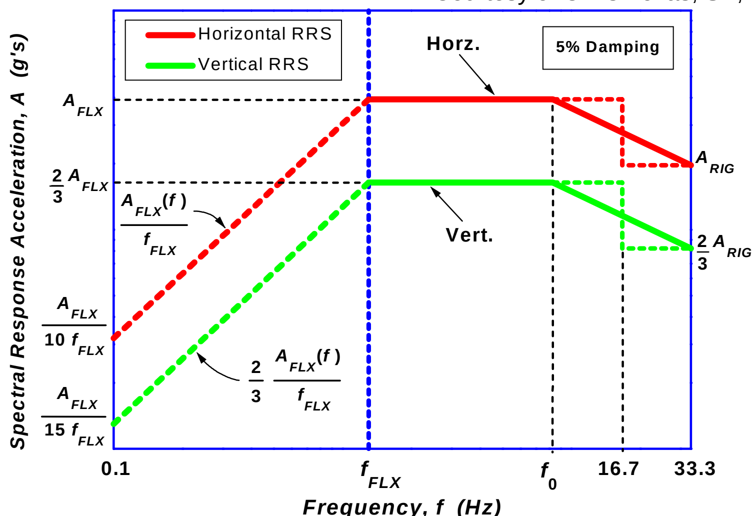
Regulations

Design Demands

Courtesy of Chris Tokas, SE, OSHPD



Essential Site / Building Information

- Site Class
- Spectral Accelerations
- Occupancy Category
- Seismic Design Category
- Existing Building: Conforming or Non-Conforming Building
- Permanent or Temporary Installation
- General Structural System
- Support Compatibility

Site Class

- Table 1613.5.2
- A classification assigned to a site based on the types of soils present and their engineering properties.
    - Soil Shear Wave Velocity
    - Standard Penetration Resistance
    - Undrained Shear Strength

Spectral Accelerations

- CBC Figure 1613.5 (1 thru 14)
- Mapped Spectral Accelerations for short and 1-sec periods (Ss, S1)
- ***2003 Design Ground Motion Maps***. These maps are the basis for ASCE 7-05, 2007 CBC, and 2010 CBC.
- http://earthquake.usgs.gov/hazards/designmaps/datasets/

Spectral Accelerations

- NSHMP HazardApp (National Seismic Hazard Mapping Program)
- Critical Acceleration for Building System Components: **$S_{DS:}$ DESIGN Spectral Response Acceleration at SHORT PERIODS**
- Highest Sds in California: 1.93g

Spectral Accelerations Distribution: S_{DS}

% of Zip Codes	w/ S_{DS} Levels
92%	>0.50g
76%	>0.75g
52%	>1.00g
30%	>1.25g
25%	>1.50g
6%	>1.60g
3%	>1.70g
1%	>1.80g

Top 10 S_{DS} Spectral Accelerations

91214	1.83g	Los Angeles
91702	1.83g	Los Angeles
91711	1.83g	Los Angeles
91750	1.84g	Los Angeles
95519	1.93g	McKinleyville
95521	1.85g	McKinleyville
95525	1.91g	Blue Lake
95550	1.91g	Korbel
95564	1.85g	Samoa
95570	1.92g	Westhaven

Occupancy Category

- Essential Buildings: IV (CBC Table 1604.5)
  - I-2 Occupancies (Hospitals)
  - Fire, Rescue ambulance, Police Stations
  - Designated Earthquake Shelters, Emergency Preparedness, communications and operations centers.
  - Structures Containing Toxic Materials
  - Aviation Control Towers, Buildings having National Defense Functions
  - Water Storage and Pump Structures for Fire Suppression

Seismic Design Category

- CBC Section: 1613.5.6
- A classification assigned to a structure based on its occupancy category and the severity of the design earthquake ground motion at the site.
- Lower Level Ground Motions: CBC Tables 1613.5.6 (1 and 2)

Seismic Design Category

- CA Level Ground Motions:
  - Occupancy Category I, II, III where S1>0.75, SDC: E
  - Occupancy Category IV where S1>0.75, SDC: F
  - Hospitals not assigned to either SDC: E or SDC: F, SDC: D

Essential "Building Systems Components" Info

- Component Importance Factor
- Designated Seismic Systems
- Exemptions to design requirements of ASCE 7-05, Chapter 13
- Manufacturer Special Seismic Certification
- Manufacturer OSHPD Pre-Approvals (Voluntary Programs)
- Manufacturer Product Data Information (Cut Sheets)

Essential "Building Systems Components" Info

- Manufacturer's Certification by Analysis, Shake Table Testing or Experience Data. (NOT Special Seismic Certification)
- Manufacturer Installation Drawings
- Support Conditions (Flexible / Rigid, Floor, Overhead, Wall Mounted)
- Specialty Support Documentation (Vibration Isolation)

Component Importance Factor (Ip)

- All components shall be assigned an Ip value.
- Ip = 1.0 except where…
  - The component is required to function for life-safety purposes. (Fire Alarm and Fire Sprinkler Systems). Ip=1.5
  - The component contains hazardous materials. (Fuel Tanks etc). Ip=1.5
  - The component is in or attached to an Occupancy Category IV Structure. (Hospitals). Ip=1.5

Response Modification Factor (R_p)

- The ratio of R_p/I_p is considered to be a design reduction factor to account for inelastic response.
- Allowable inelastic energy absorption capacity of the component's force-resisting system.
- R_p/I_p=1.0 for Special Seismic Certification by Testing
- R_p=1.0 & I_p=1.5 should be used for analysis part of Special Seismic Certification, since functionality can't be verified by analysis.

Response Modification Factor (R_p)

- ASCE 7-05 does not provide R_p and a_p values for Special Seismic Certification.
- R_p and a_p values in ASCE 7-05 can be used for design of supports and attachments

Designated Seismic Systems

- The seismic force-resisting system and those architectural, electrical, and mechanical systems or their components that require design in accordance with ASCE 7-05, Chapter 13 and for which the component Importance Factor is greater than 1.0.
- Equipment that is part of the Designated Seismic System must remain Operable following an Earthquake

Certification Methods

- Project Specific Special Seismic Certification
  - Applicable to the Site and Project Conditions Only.
- Pre-Approved Special Seismic Certification (OSHPD OSP Program).
  - Applicable to Multiple Sites where Site Conditions and Product Construction are Acceptable

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Certification Methods

Certification Methods

- Code Compliance is not Voluntary, OSHPD Pre-Approval Programs are.

O SHPD
P reapproval of
A nchorage

O SHPD
S pecial seismic certification
P reapproval

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Certification Methods

Site / Project Specific Certification

- The Design Professionals of Record for the project are responsible to VALIDATE the application of a Special Seismic Certification for their specific project.
- Must include specific information from shake table testing.

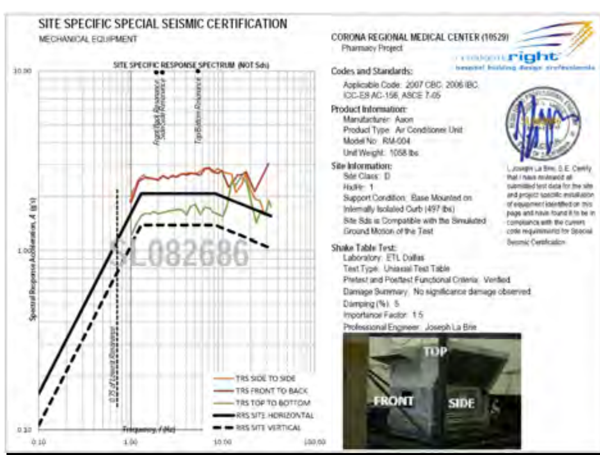
Site / Project Specific Certification

- Manufacturer's Contact Information
- Shake Test Laboratory Contact Information
- Description of UUT
- Seismic Parameters: Sds, z/h, Aflx, Arig
- Verification of Functionality
- Justification of Product Line Interpolation

Site / Project Specific Certification

- Installation Instructions
- Anchorage Design Parameters: Fa, Ss, Sds, Ip, ap, Rp
- Statement that tests were completed in all three principal axes.
- Transmissibility Information (Ratio of measured response on UUT to the response on top of the table)

Site / Project Specific Certification



OSHPD OSP Preapproval

OSP program is a voluntary preapproval program for special seismic certification under OSHPD jurisdiction

Preapproval for CA hospitals only (other jurisdictions may accept OSP listing as well)

Can only be obtained through testing (minimum 2 tests)

http://www.OSHPD.CA.gov/FDD/Pre-Approval/Special_Seismic_Cert_Pre-Approval.html

OSHPD OSP Preapproval

- First OSP was issued in June of 2009.
- Currently >200 OSPs on file with OSHPD. OSP Requirements have been posted for download.
- Shake Table Testing is Essential and must be in accordance with ICC AC-156 Standard.
- OSHPD CAN 2-1708A.5

OSHPD OSP Preapproval

- Active and Energized Components must be Functional Before and After the Shake Test.
- Specifying Equipment with OSP Pre-Approval does not relieve the Engineers of Record of Responsibilities to Verify Applicability and Compatibility of the Certifications and Tests.

OSHPD OSP Preapproval

- Program allows Certification of an entire product line by testing smallest and largest.
- Two tests are required for every Active Component and EVERY variation of :
  - Manufacturer of Components
  - Mounting Configuration (Wall, Floor, Overhead, Flexible, Rigid)
  - Materials (Stainless Steel, Carbon Steel)

OSHPD OSP Preapproval

- Testing Laboratory shall have ISO 17025 Accreditation or…
- Testing shall be under the Responsible Charge of a California Licensed Engineer
- Test Reports shall be prepared by a California Licensed ENGINEER
- Test Reports shall be reviewed and accepted by a California Licensed Structural Engineer.

OSHPD OSP Preapproval

- Emergency and Standby Power Systems
- Elevator Equipment
- Components with Hazardous Contents
- Smoke Control Fans
- Exhaust Fans
- Switchgear
- Motor Control Centers

OSHPD OSP Preapproval

- X-Ray Machines
- CT Scanners
- Air Conditioning Units
- Air Handling Units
- Chillers
- Cooling Towers

OSHPD OSP Preapproval

- Transformers
- Electrical Substations
- UPS and Batteries
- Distribution Panels
- Control Panels

OSHPD OSP Preapproval

- The Design Professionals of Record for the project are responsible to VALIDATE the application of an OSP to their specific project.
- OSP is nullified when:
  - Design, Construction, or quality control /quality assurance methods are MATERIALLY ALTERED as defined in 2010 CAC, Section 7-111.
  - Strength, Stiffness, Size, Weight, or Materials and Component Configuration are altered so that they are no longer equivalent to the approved OSP

Exemptions

- Temporary Installations
- Permanent Installations into buildings with established usable life.
- Low Ground Motion Potential and Occupancy Category (SDC A and B)

Exemptions by ASCE 7-05, Ch 13

- Exemptions, ASCE7-05, Section 13.1.4
- Architectural, Mechanical, Electrical Components in SDC B (Does not exist in California)
- Mechanical and Electrical Components, SDC C, Ip=1.0

Exemptions

- OSHPD CAN 2-1708A.5, Frequently Asked Questions No. 8.
- Special Seismic Certification is not required for equipment installed in nonconforming hospital buildings unless the equipment and nonstructural components provide services / systems or utilities to a conforming building.

Responsibilities

Equipment Manufacturer:

•Responsible for financial expense of obtaining certification
•Retain independent Structural Engineer to perform certification
•Provide equipment to projects in accordance with certification limitations and construction details
•Provide certificate of conformance (CoC) showing unit is certified
•Properly label unit when provided on site showing certification

Responsibilities

Certification Engineer

•Review manufacturer's product offering for scope of certification
•Review construction details to determine required testing
•Adequately document products and options to define limitations
•Oversee shake table testing and review functionality of systems
•Provide detailed documentation relating to scope and limitations for review by building officials
•Stamp certificate of conformance as engineer accepting liability for cert

Responsibilities

Structural Engineer of Record:

•Review manufacturer provided CoC and ensure unit is certified for level at least equal to project demand
•Shop drawing stamp CoC
•Ensure attachments will not load unit in manner differing from certification (piping, duct, etc.)
•Review anchorage limitations of seismic certification and design anchorage in accordance with equipment certification limitations
•For structural observations, review field anchorage and labeling

Responsibilities

Building Official

•Review basis of certification as provided by manufacturer and retained certification engineer
•Check Structural Engineer of Record shop drawing review of CoC
•Ensure unit is certified for level in excess of site demand
•Review anchorage design
•IOR and SEOR site review of unit anchorage and labeling

Responsibilities

Inspector of Record:

•Confirm correct manufacturer and model of equipment is provided
•Ensure approval has been provided for certification and anchorage
•Ensure equipment is installed and anchored in accordance with project approved documentation
•Ensure unit is properly labeled showing seismic certification levels and equipment identifier

IOR: Does NOT have authority to inspect unit construction details!

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Responsibilities

What to Expect as SEOR/EOR

• Manufacturers to provide Certificate of Compliance for Special Seismic Certification stating that the specified equipment is compliant with applicable building codes

• Certified components are required by IBC to carry a mark identifying the specific unit as seismically certified.

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Certification Documentation Processing

Equipment Labels

- Label Requirements
- CBC 1703.5

Courtesy of M.R. Karim, SE, OSHPD

Certificate of Compliance
Seismic Certification Label
California Building Code

OSHPD Special Seismic Certification Preapproval: OSP-0XXX-10
Product Name: XXXX
Product Type: XXX
Anchorage: XXXXX
Seismic Performance Characteristics: S_{DS}(g) =x.xx, z/h = 1.0, I_p = 1.5
Manufacturer's Identification Number: XXXXXXXXXXXXX

Company Logo

Label Tracking Number (IF any)

Certificate

MANUFACTURER LOGO

SPECIAL SEISMIC CERTIFICATION
CERTIFICATE OF COMPLIANCE
September 28, 2010

Certification Basis:
Seismic simulation using shake table testing as prescribed in the referenced Codes and Standards. Active and/or energized components were tested for the verification of pre-test and post-test functionality. Two of each component type were tested for the qualification of a range of components based on manufacturer, model, and mounting configuration. For detailed information of component functionality and to confirm component configuration refer to MIR Report 90600-1001.

Site / Project Requirements:
It is the responsibility of the Structural Engineer of Record to:
- Provide engineering for the anchorage and restraint of the unit.
- Validate Certification Design Parameters with actual site conditions.
- Provide engineering of all equipment support structures.
- Confirm component configuration.

Certification Design Parameters:

Site Class: D	Rp: 2.5	Fp/Wp: 2.88
Fa: 1	Ip: 1.5	Fp/Wp min: 0.72
Ss: 2.4	ap: 2.5	Fp/Wp max: 3.84
Sds: 1.6 g		

NOTES:
1. Example parameters for use in anchorage design.
2. Project specific values for Site Class, Fa, Ss, and Sds may be different.
3. z/h shall be based on the location of the equipment in the building
4. Shake Table Test Reports are available upon request.

Codes and Standards:
Applicable Codes and Standards: 2010 CBC, 2009 IBC, ICC-ES AC-156, ASCE 7-05

Manufacturer:
McQuay International

Product Line:
WATER-COOLED CENTRIFUGAL CHILLERS

Models:
WMC, WME, TSC, HSC, WSC, WDC, AND WCC

Support Conditions:
Unit is Mounted to Rigid Base through Neoprene Pad

Issued by:

Company International
Nathan Hathaway
nathan.hathaway@mcy.com

MakeItRight, Inc
Joseph La Brie
labrie@makeitright.net

Processes for Approval / Permitting / Installation

- SE provides SSC based on shake table tests
- DPOR validates the contents of the SSC
- DPOR submits SSC for Agency review / approval.
- Equipment is delivered to the project with the approved SSC Certificate and Label.
- Inspector verifies the label contents

Processes for Approval / Permitting / Installation

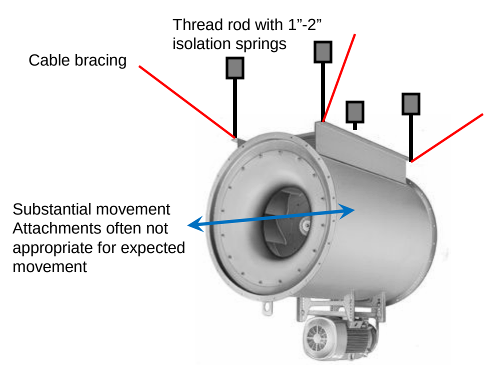
- Architect or Engineer of Record, Professional of Record (DPOR), Submits Calculations, Drawings, Specifications, Certifications, Pre-Approvals to Agency for permitting.
- All Project documentation must be submitted to Agency by the DPOR.

Lessons Learned

- Need to have anchorage and attachment in compliance with testing for field installations
- Do not be afraid to push back on manufacturer for more information
- Attachments are not considered in testing (usually)
- Majority of failures observed from testing are structural in nature
- Requirements for every piece of equipment for structural integrity!

Lessons Learned

Sheet metal duct separated from suspended fan unit (Photo from FEMA E-74 courtesy of Wiss, Jenney, Elstner Associates)



Past Damage Observations

Standard Industry Details

Lessons Learned

- Vibration isolation especially susceptible to real dynamic loadings
- Numerous failures observed in testing of “OPA appoved” isolators

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Lessons Learned

Conclusion

- Benefits to industry
  - Improvements to construction details and practices for nonstructural components
  - Ability of systems to operate and serve public after seismic event
  - Understanding of component response under dynamic loadings
  - Notable effort by manufacturers to improve the construction of equipment for seismic safety

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Conclusions

EERI Technical Seminar

Seismic Design and Performance of Nonstructural Elements

EVALUATION OF PRESENTATIONS

Using a scale of **1** to **5**, with **5** as the highest rating, please rate today's presentations.
Please include comments. Thank you.

Introduction/Overview (*Robert Reitherman)*

Did this presentation contain useful information?

Was the material clear?

How do you rate the quality of the visuals?

Nonstructural Performance in Recent Earthquakes

Circle one:
San Francisco/Seattle (Eduardo Miranda),
Los Angeles/San Diego (Gilberto Mosqueda)

Did this presentation contain useful information?

Was the material clear?

How do you rate the quality of the visuals?

NEES Research on Nonstructural Performance

Circle one: *San Francisco/Seattle/Los Angeles (Manos Maragakis),*
San Diego (Tara Hutchinson)

Did this presentation contain useful information?

Was the material clear?

How do you rate the quality of the visuals?

Present Code Requirements, Development and Implications *(John Gillengerten)*

Did this presentation contain useful information?

Was the material clear?

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New Edition of *FEMA 74: Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide*

Circle one:
San Francisco/Seattle (Maryann Phipps),
Los Angeles/San Diego (Eduardo Fierro)

Did this presentation contain useful information?

Was the material clear?

How do you rate the quality of the visuals?

Implementation of New Requirements for Equipment Certification

Circle one:
San Francisco/Seattle (Matthew Tobolski),
Los Angeles/San Diego (Joseph LaBrie)

Did this presentation contain useful information?

Was the material clear?

How do you rate the quality of the visuals?

Is the notebook helpful?

Do you have any other comments about the seminar? (use reverse side if necessary)