Preparing New and Existing Structures for Longevity and Extreme Conditions

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Provider Number: J380
Course Number: EXTRM90

10.14.2015 | Waltham, MA

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SIMPSON GUMPERTZ & HEGER

Engineering of Structures and Building Enclosures

Course Description

Much like "sustainability" before it, the term "resilience" has come to the forefront of discussion about our built environment and the communities who occupy that environment. This presentation will explore how resilience is defined, why it is now "a national imperative" according to the National Academy of Sciences, how risks are defined, and methods to mitigate some of these risks from a structural engineering perspective. The presentation will look to the future in assessing the resilience of our building stock. Most importantly, the presentation will challenge us all to consider resilience in the buildings we design and to have candid discussions with building owners and users about their expectations for building performance in the face of extreme events.

Learning Objectives

After attending this presentation, participants will:

1. Understand the concept of resilience and its many facets.
2. Describe the four fundamental components of risk: hazard, exposure, vulnerability, and consequence.
3. Recognize the performance levels that building codes currently anticipate and how design for resilience differs from conventional code-based design.
4. Identify strategies for increasing resilience capacity of buildings subjected to wind, snow, earthquake, and flood hazards.

Presentation Outline

- Defining Resilience
- Making the Case for Resilience: Why Now?
- What is Risk?
- What Do Building Codes *Really* Intend?
- Understanding Hazards
- Where Do We Go from Here?
- Discussion

Defining Resilience

- The new buzzword
- Touches on architecture, structural design, geology, meteorology, emergency planning (policy), politics, economics, and business practices

Photo: Alec Zimmer / SGH

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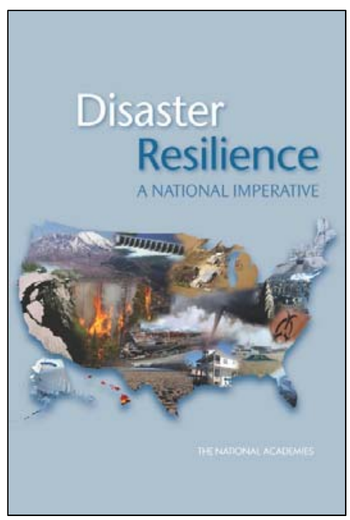
Definitions: Which One is Right?

The ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events

Disaster Resilience:
A National Imperative,
National Academies Press, 2012



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Definitions: Which One is Right?

Enterprise resilience is the ability and capacity to withstand infrastructure discontinuities and adapt to new risk environments. A resilient organization effectively aligns its strategy, operations, management systems, governance structure, and decision-support capabilities so that it can uncover and adjust to continually changing risks and better endure disruptions.

Infrastructure Risk Management (US Army, 2004)

Definitions: Which One is Right?

…the ability of social units (e.g., organizations, communities) to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future disasters.

(M. Bruneau, et al "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities." *Earthquake Spectra* 19(4), 733-752.)

EERI Earthquake Engineering Research Institute
Dedicated to reducing earthquake risk

Definitions: Which One is Right?

The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.

(Presidential Policy Directive-21, 2013)

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Definitions: Which One is Right?

The ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

(UN International Strategy for Disaster Resilience, 2007)

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Defining Resilience

- ***Resistance:*** primary ability to resist and withstand a hazard
- ***Redundancy:*** redundant elements, in case critical parts of the system fail

Resilience Capacity

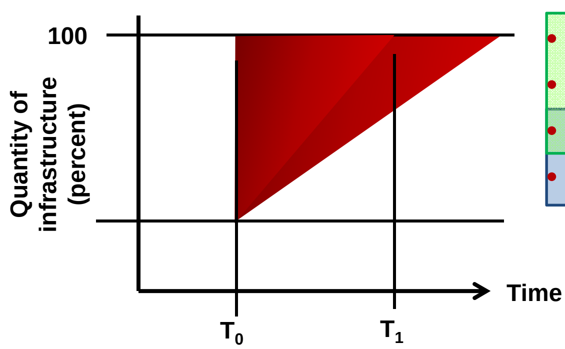
- ***Contingency***: emergency plan, in case a significant portion or the entire system fails

Emergency Capacity

Popadopoulis (2015)

Defining Resilience

- The Four Rs



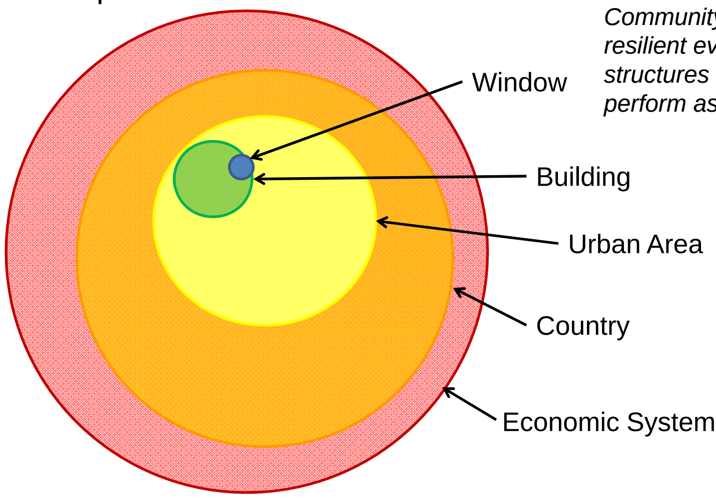
- Robustness
- Redundancy
- Resourcefulness
- Rapidity

Graphic based on Bruneau, M., et al (2003). "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities." Earthquake Spectra 19(4), 733-752.

Defining Resilience

- A system attribute, not a disjointed collection of resilient components

Community can still be resilient even if some structures fail to perform as expected.



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Defining Resilience

- Structural engineers tend to have narrow focus:
  - Focus only on individual structures
  - “Design to code”?
- Understand what owners really want:
  - Expected performance?
  - Future adaptability?

Photo: Simpson Gumpertz & Heger

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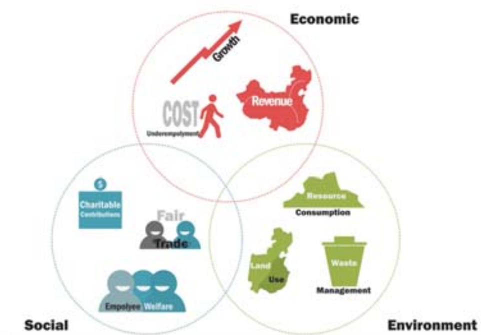
Defining Resilience

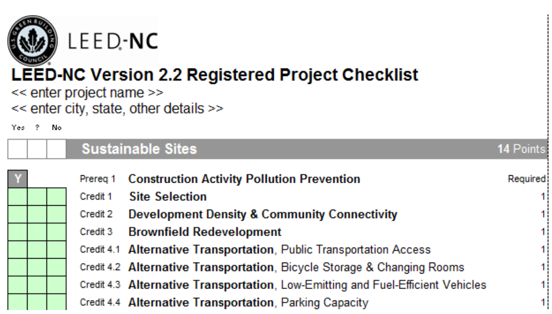
- *Aside on Sustainability*
  - *Bruntland Commission (1987) definition: "Meeting the needs of the present without compromising the ability of future generations to meet their own needs"*
  - *Triple Bottom Line*



Graphic: Wikipedia.org

Defining Resilience

- "Conventional" sustainable design vs. resilience vs. "true" sustainable design
  - Some competing interests: recycled materials may be less durable than virgin materials
- LEED has focuses on siting, energy, and air quality



LEED-NC

LEED-NC Version 2.2 Registered Project Checklist
<< enter project name >>
<< enter city, state, other details >>

Yes	?	No			
			Sustainable Sites		14 Points
Y			Prereq 1	**Construction Activity Pollution Prevention**	Required
			Credit 1	**Site Selection**	1
			Credit 2	**Development Density & Community Connectivity**	1
			Credit 3	**Brownfield Redevelopment**	1
			Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
			Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
			Credit 4.3	**Alternative Transportation**, Low-Emitting and Fuel-Efficient Vehicles	1
			Credit 4.4	**Alternative Transportation**, Parking Capacity	1

Defining Resilience

- What's missing?

Photo: Arnold Dekker / wikimedia creative commons

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Defining Resilience

- Enhancing service life through improved durability, design for adaptability and deconstruction, disaster resilience

Olive View Hospital, Sylmar, Los Angeles, CA
Photo: USGS / Kachadoorian (public domain via Wikimedia Creative Commons)

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Defining Resilience

- Enhancing service life through improved durability, design for adaptability and deconstruction, disaster resilience

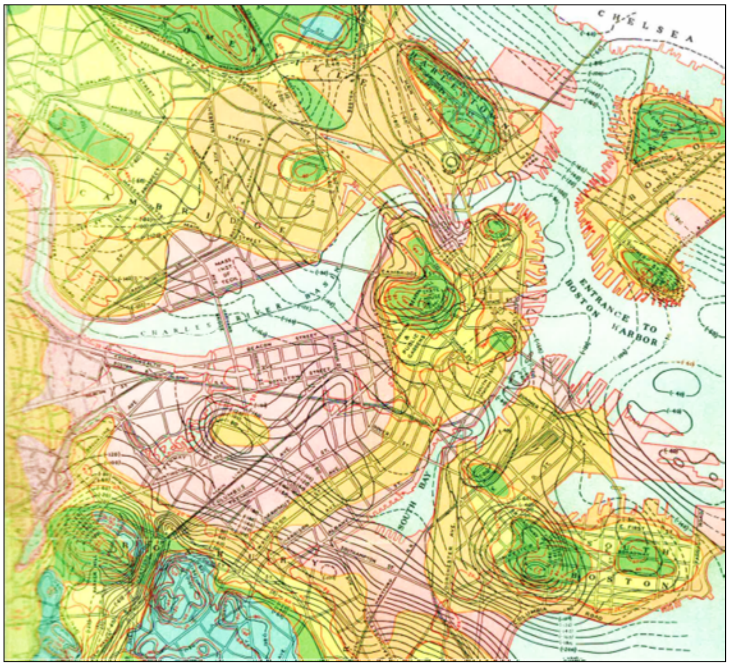
Olive View Hospital, Sylmar, Los Angeles, CA
Photo: National Information Service for Earthquake Engineering, University of California, Berkeley

Making the Case for Resilience: Why Now?

- Disasters affect communities
- Effects of urbanization
- Patterns of development

Boston Coastline in 1630 and 1995 from Mapping Boston, *A. Krieger and D. Cobb, Editors*

Detail from "Probable Relative Stability of Ground in Earthquakes" by Irving B. Crosby



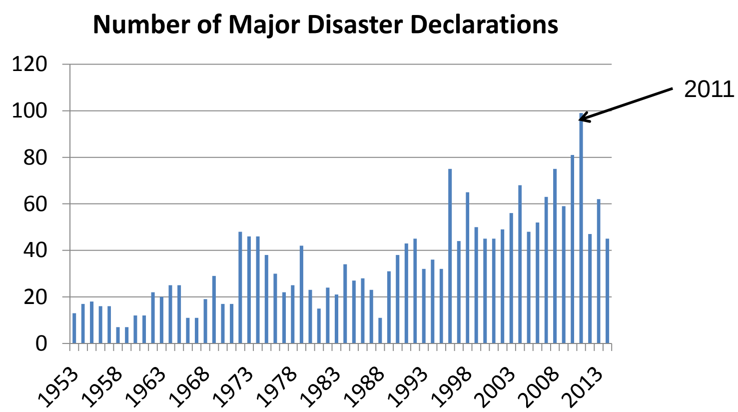
Making the Case for Resilience: Why Now?

- Our built environment is our most important investment
- Population continues to grow
- The number and severity of demands continue to escalate

Flood Damage, St. Bernard Parish, LA
Photo: Peter Nelson / SGH (2007)

Making the Case for Resilience: Why Now?

- Marked increase in FEMA disaster declarations



Source: FEMA

Making the Case for Resilience: Why Now?

- 2011: A Very Bad Year for the US
  - 14 weather and climate related events that each caused more than $1B damages.
  - Total US economic damages due to natural disasters was more than $55B = $177 per capita.

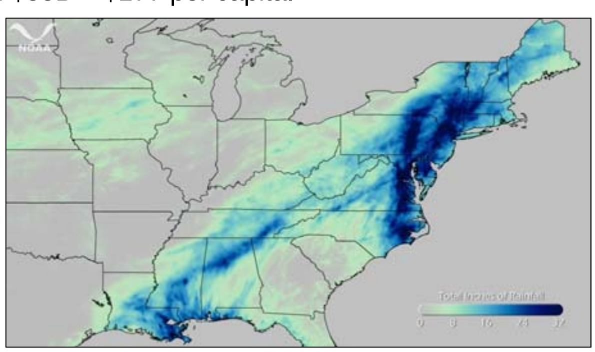


Image: National Oceanic and Atmospheric Administration

Making the Case for Resilience: Why Now?

- 2012 wasn't good either…

Long Branch, NJ, 2012
Photo: New Jersey National Guard

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Making the Case for Resilience: Why Now?

- US represents 5% of global population but 20% of global building stock
- 45% of value of US buildings is in 18 states along Gulf and Atlantic Coasts
- 15% of value of US buildings is in vulnerable coastal areas

Popadopoulis (2015)

- Pay Now or Pay Much More Later: $1 spent on pre-event mitigation (FEMA mitigation grants) yields $4 in post-event savings

Multihazard Mitigation Council of the
National Institute of Building Sciences (2005)

Graphic: National Atlas, 2000

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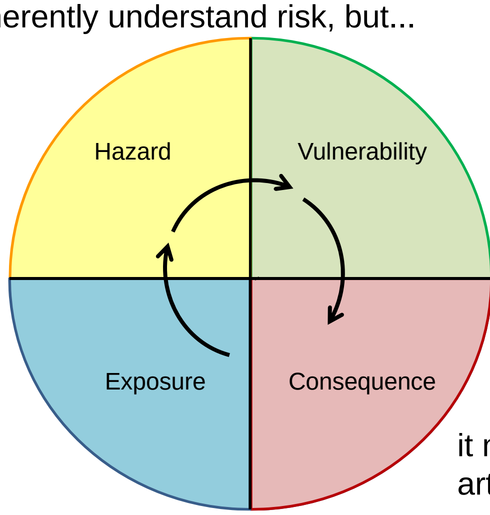
What is Risk?

What is Risk?

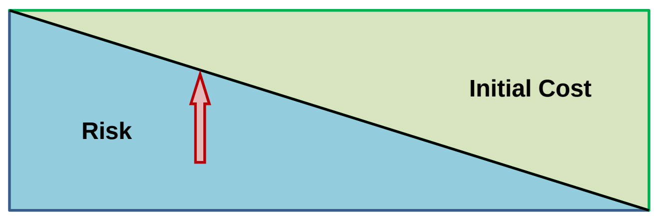
- We inherently understand risk, but...



it may be difficult to articulate.

What is Risk?

- Risk management: striking a balance
  - Which risks are tolerable?
  - Which risks can we not tolerate under any circumstances?



Hazards and Mitigation Strategies

- Primary Hazards
  - Flood / Wave Action
  - Snow
  - Blast
  - Wind
  - Earthquake
  - Fire
  - Deterioration
  - Landslides
- Secondary Hazards
  - Loss of electrical power
  - Gas leaks
  - Fires
  - Interior flooding
  - Release of hazardous materials

What Do Building Codes *Really* Intend?

- A lack of understanding and a false sense of security
- Most people have the mistaken beliefs
- Nascent understanding of code performance

"The truth is that when we choose our engineering standards we really are choosing to define how many deaths, how many building demolitions, and how long a recovery time we will have for various levels of earthquakes."

San Francisco Urban Planning Report, 2009

Photo: Digon3 / Wikimedia Commons

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What Do Building Codes *Really* Intend?

"These Recommendations primarily are intended to safeguard against major failures and loss of life, not to limit damage, maintain functions, or provide for easy repairs."

1990's Uniform Building Code

It is important to recognize that the requirements of ASCE 7…are intended to go beyond protection against structural failure and are also intended to provide property and economic protection for small events, to the extent practical, as well as to improve the probability that critical facilities will be functional after severe storms, earthquakes, and similar events.

ASCE 7-10 Minimum Design Loads for Buildings and Other Structures

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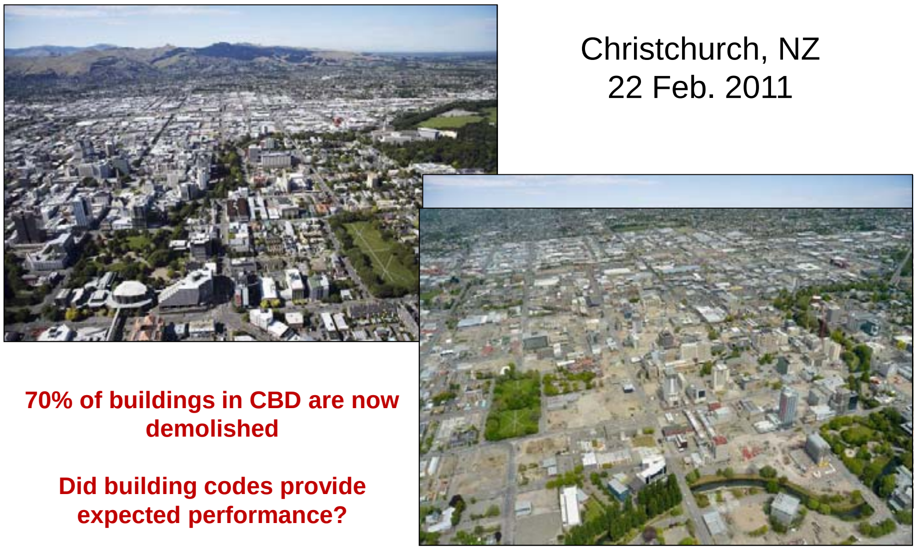
What Do Building Codes *Really* Intend?

Christchurch, NZ
22 Feb. 2011



70% of buildings in CBD are now demolished

Did building codes provide expected performance?

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What Do Building Codes *Really* Intend?

- Reaction to Major Events

ANSI A58-82
100 Pages

ASCE 7-88
94 pages

ASCE 7-93
130 pages

ASCE 7-95
205 pages

ASCE 7-05
383 pages

ASCE 7-10
608 pages

Photo: Alec Zimmer / SGH

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What Do Building Codes *Really* Intend?

- Loads Based on Mean Recurrence Interval (MRI)
  - A "100-year event" has a 1% annual probability of exceedance

$$P_a = \frac{1}{T}$$

- Probability that design level (MRI) event will occur at least once in a period of n years:

$$P_n = 1 - (1 - P_a)^n$$

What Do Building Codes *Really* Intend?

- For example, take an event with:

$$T = 100 \text{ years}$$

- Then in a 70-year period (say the lifetime of the building):

$$P_n = 1 - (1 - 0.01)^{70}$$
$$P_n = 0.51$$

What Do Building Codes *Really* Intend?

From the 2009 International Building Code:

Occupancy Category	Structure Type	Risk	I_S (SNOW)	I_W (WIND)	I_E (EQ)	Wave*
I	Agricultural, temporary, minor storage	Low	0.8	0.87	1.0	1.6
II	Everything else…	Low-Mod.	1.0	1.0	1.0	2.8
III	Moderate to large schools, auditoriums, jails, small healthcare without surgery	Mod.-High	1.1	1.15	1.25	3.2
IV	Fire, police, emergency shelters, hospitals with surgery, power stations, ATC centers, toxic storage	High	1.2	1.15	1.5	3.5

** Breaking wave dynamic pressure coefficients, Cp, vary based on occupancy category. In ASCE 24, design flood elevation (DFE) is based on Occupancy Category*

What Do Building Codes *Really* Intend?

Table 4.1.2-1 Target Building Performance Levels (after ASCE/SEI 41-06)

Target Building Performance Level	Expected Postearthquake Damage State	Target Structural Performance Level	Target Nonstructural Performance Level
Operational Level	Backup utility services maintain function; very little structural or nonstructural damage	Immediate Occupancy	Operational
Immediate Occupancy	The building remains safe to occupy; any structural or nonstructural repairs are minor	Immediate Occupancy	Immediate Occupancy
Intermediate Level		Damage Control	
Life Safety	Structure remains stable and has significant reserve capacity; hazardous nonstructural damage is controlled	Life Safety	Life Safety
Intermediate Level		Limited Safety	Hazards Reduced
Collapse Prevention	The building remains standing, but only barely; the building may have severe structural and nonstructural damage	Collapse Prevention	Not Considered

Less damage
Smaller losses
More damage
Larger losses
Enhanced Performance
Building Code

Adapted from FEMA E-74 (2011)

What Do Building Codes *Really* Intend?

- Designing Beyond Prescriptive Codes: Enhanced Performance
  - Apply larger factors to loads
  - Use stronger materials or encourage different construction techniques

$$\underbrace{\sum\left(Factor \times Load\right)}_{\text{Demand / Hazard}} \leq \underbrace{\phi \times P_n}_{\text{Resistance / Vulnerability}}$$

Demand

Hazard

Resistance

Vulnerability

CODE+

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What Do Building Codes *Really* Intend?

- Portland Cement Association: High Performance Building Requirements for Sustainability
  - Enhancements to fire resistance
  - Enhancements to flood resistance
  - Snow – 20% higher than basic code
  - Enhancements for seismic loads
  - Wind – increases wind speed by 20%
  - Roof coverings must comply with FM Global

PCA America's Cement Manufacturers™

CODE+

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Case Study: Sacred Heart University, Fairfield, CT
Martire Business and Communications Center

Photos: Tracy Deer Mirek/SHU (Flickr)

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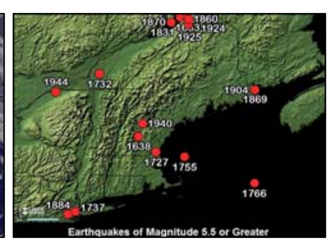
Case Study: Sacred Heart University, Fairfield, CT
Martire Business and Communications Center

- Goal: Design a "100-Year Building"
- Approach:
  - Design for 100-year MRI for snow (9% increase in snow load)
  - Design for 100-year MRI for wind (14% increase in wind load)
  - Design for 2% in 100-year seismic event (50% increase in seismic loads)



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Climate-Induced Deterioration

- Wood
  - Rot
  - Increased in termite activity

Wood preservatives

Photo: Alec Zimmer

- Concrete
  - More rapid carbonation of concrete cover and corrosion

Larger concrete cover

Corrosion inhibitors

Photo: Alec Zimmer

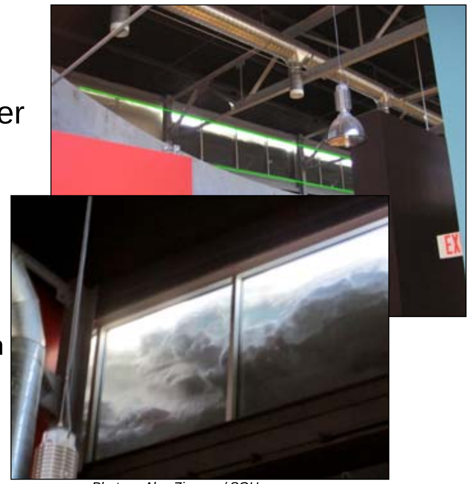
Snow – Loads

- ASCE 7 loads based on historical data and 50-year MRI (2% chance of being exceeded in any year)
- Massachusetts sets ground snow load and minimum flat roof snow load by town

City	Measured (psf)		Minimum Flat Roof Snow Load (psf)
Danvers	22.4	2/19/2015	30
Leominster	23.85	2/16/2015	35
Marlborough	24.8	2/13/2015	35
Somerville	23.1	2/14/2015	30
Stoughton	**43.1**	2/21/2015	35
Westwood	**44**	2/13/2015	35

Snow – Resilience Strategies

- Design for 100-Year Mean Recurrence Interval (20% voluntary increase in design snow load)
- Watch for Drifts and Unbalanced Snow on Older Buildings
  - Drift load provisions:
    - Boston in 1970
    - MA in 1975
    - Other states ca. 1990
  - At changes in roof elevation
  - Along parapets
  - Near equipment
  - In solar arrays



Photos: Alec Zimmer / SGH

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Snow – Resilience Strategies

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  - In solar arrays

Photo: Daniel Cook / SGH

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Snow – Resilience Strategies

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  - In solar arrays

Photo: Nathaniel Boutin / SGH

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Snow – Resilience Strategies

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  - Near equipment
  - In solar arrays

Photo: CBS4 / WBZ-TV

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Snow – Resilience Strategies

- Evaluate roof capacity during “off season”
- Develop a snow removal plan
  - Clear centers of bays perpendicular to purlin spans
  - Clear drains
  - Clear scuppers

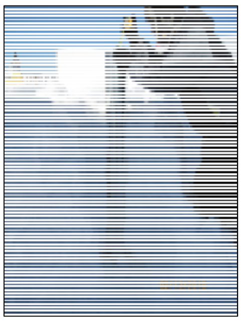
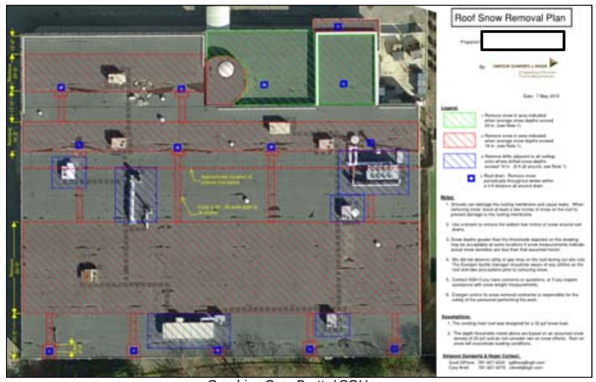


Photo: Alec Zimmer / SGH



Graphic: Cory Brett / SGH

Snow – Resilience Strategies

- Beware of adding thermal insulation – have structure evaluated for snow loads first!

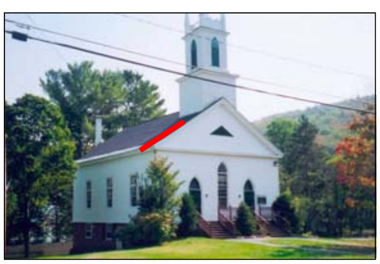


Photo: Leonard Morse-Fortier / SGH

Photo: Leonard Morse-Fortier / SGH

Fracture in top chord of truss

Wind – Loads

- ASCE 7-05 (MSBC – 8th Edition)
  - Based on 50-year MRI
  - Scalar load factor effectively yields 500 year MRI
  - Importance factor for Risk Category III and IV effectively yields increased MRI

Public Domain

Wind – Loads

- ASCE 7-10 – for non-hurricane regions, strength design

Building Risk Category	MRI	Annual Probability of Exceedance
I	300 years	0.33%
II	750 years	0.14%
III	1700 years	0.06%
IV	1700 years	0.06%

- For drift and other serviceability checks, use shorter Mean Recurrence Interval (MRI) wind speeds to reduce design loads.

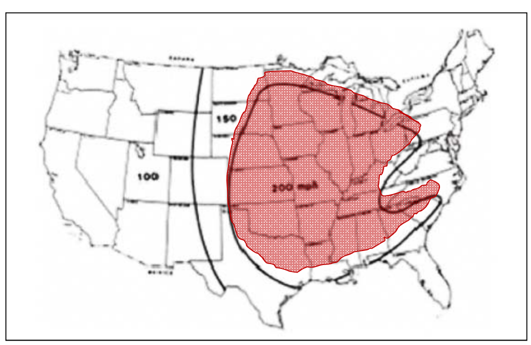
Wind – Loads

- Monte Carlo simulations
- Correlated to measured wind speeds

Location	Basic Wind Speed for Occupancy Category II Buildings and Other Structures		Basic Wind Speed for Occupancy Category III and IV Buildings and Other Structures	
	mph	(m/s)	mph	(m/s)
Bar Harbor, Maine	116	52	125	56
Hampton Beach, New Hampshire	122	55	133	59
Boston, Massachusetts	128	57	140	63
Hyannis, Massachusetts	141	63	152	68
Newport, Rhode Island	139	62	150	67
New Haven, Connecticut	126	56	134	60
Southampton, New York	138	62	148	66

Wind – Loads

- Tornados
  - Measured 150 mph to 200 mph near ground surface, MRI of 100,000 years (0.010% annual probability of exceedance)
  - Economically impractical to design for direct tornado strike except for critical emergency response buildings and safe rooms



Adapted from ASCE 7-10, Figure C26.5-2

Wind – Resilience Strategies

- Wind tunnel analysis to more accurately predict wind loads on actual structure
- Design for Mean Recurrence Interval (MRI) of 100-year for drifts

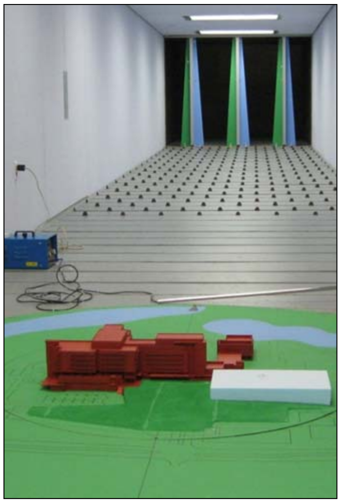


Photo: John Thomsen / SGH

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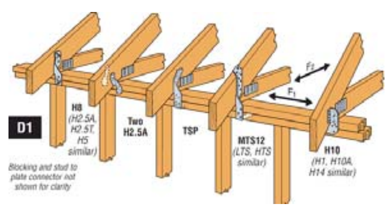
Wind – Resilience Strategies

- Strengthening roofing with ring-shank nails to limit lift off
- Strengthening roofs with strap anchors
- Strengthening wall connections to foundations (hold-downs)
- Adding lateral capacity via shear walls or braces



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Wind – Resilience Strategies

- Hurricane shutters to protect windows against penetration
- Design for safe rooms / refuge areas

Photo: Michael Rieger / FEMA

Flood and Wave Action – Loads

- ASCE 7 / ASCE 24 based on 100-year MRI
- FEMA Flood Insurance Rate Maps (FIRM)
  - 100 year MRI
  - 500 year MRI
  - Do **<u>NOT</u>** typically consider future sea level rise

Danville, PA – 9 September 2011
Tropical Storm Lee
Photo: Commonwealth of PA

Flood and Wave Action – Loads

- Boston Sea Level Rise – 10 in. to 70 in. by 2100, depending on the model *(Boston Harbor Association)*

Mean High Water in 2100

Mean High Water in 2100 + 5 ft Storm Surge

Image: Sasaki Associates

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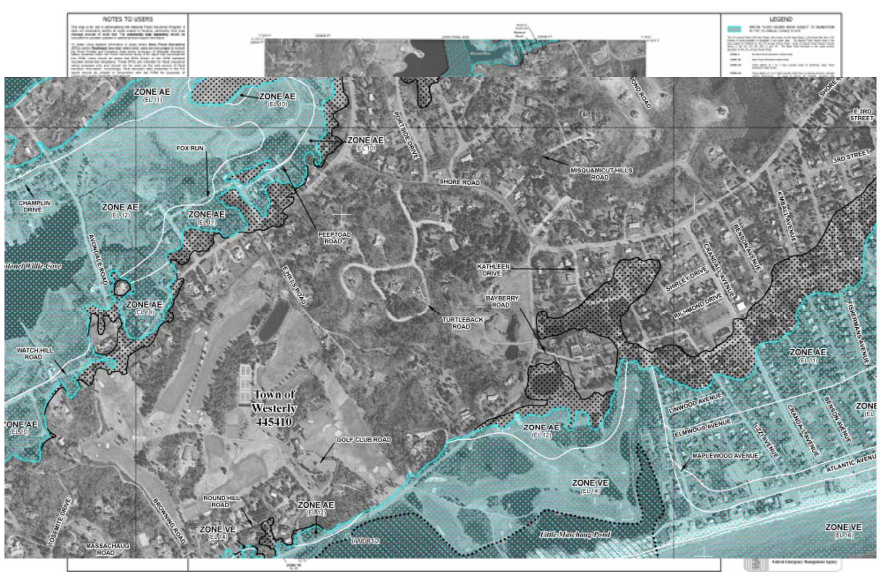
Flood and Wave Action – Loads



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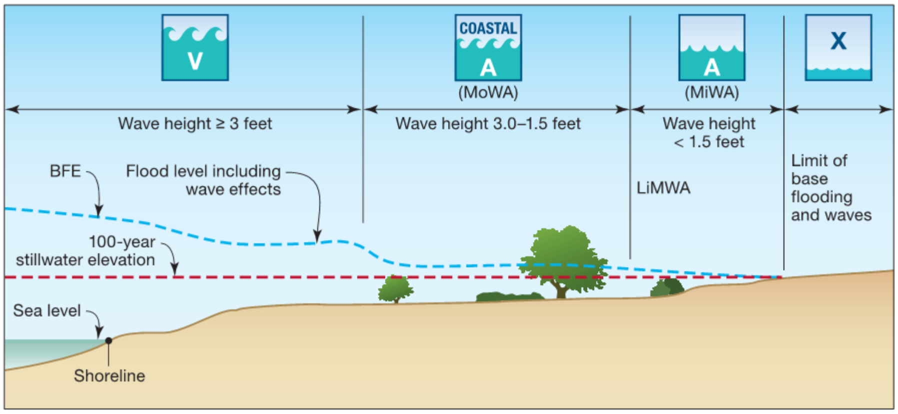
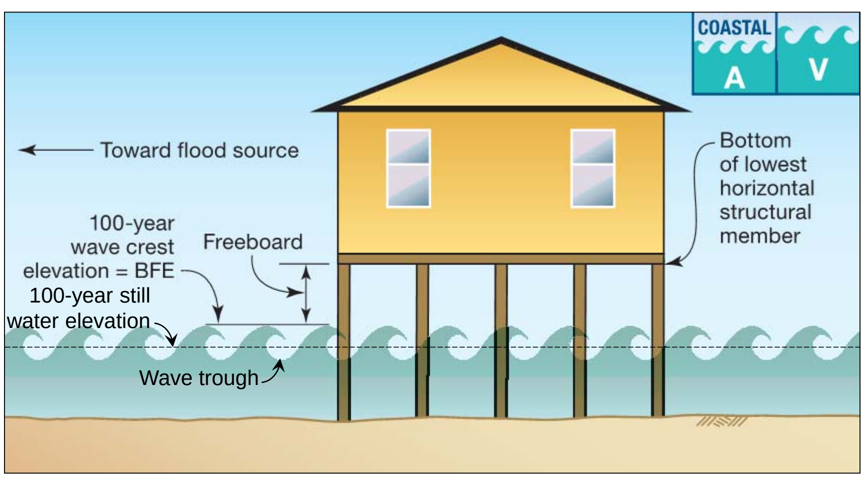
Flood and Wave Action – Loads



Adapted from FEMA P-55, Figure 3-53 (2012)

Flood and Wave Action – Loads

- Recommended practice in V and coastal A zones



Adapted from FEMA P-55, Figure 5-2 (2012)

Flood and Wave Action – Resilience Strategies

- Requirements for V Zones and recommended for Coastal A Zones:
  - Space below BFE used only for parking, access, and storage
  - Free of horizontal obstructions or enclosed by non-supporting materials
  - Open latticework preferable to break-away walls

Photo: FEMA P-55

Photo: FEMA P-499

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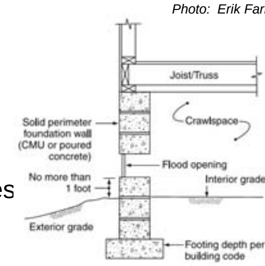
Flood and Wave Action – Resilience Strategies

- Design foundations for:
  - Embedment to resist scour and erosion
  - Embedment to resist overturning, buoyancy and uplift
  - Sliding resistance
  - Hydrostatic pressure
  - Breaking wave loads
  - Debris impact loads
  - Hydrodynamic drag
- Solid foundation walls:
  - Not permitted in wave zones
  - Permitted in no-wave zones with flood openings

Photo: Erik Farrington / SGH



Graphic: FEMA P-55

Photo: FEMA P-55

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Flood and Wave Action – Resilience Strategies

- If freeboard is small, design lowest floor for buoyant pressure
- Locate equipment above 500-year MRI elevation
- Locate equipment on landward side of building
- Anchor tanks to prevent floating

Home with break-away walls, Galveston, TX (from FEMA P-55)

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Flood and Wave Action – Resilience Strategies

- A combination of public and private investment in *resilience capacity*:
  - Inland water management (public)
  - Coastal water level protection (public)
  - Land erosion controls (public or private)
  - Elevated construction (public or private)

Levee between Leerdam and Waardenburg
Photo: Mark Ahsmann

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Case Study:
MBTA Alford Street Bus Garage, Charlestown, MA

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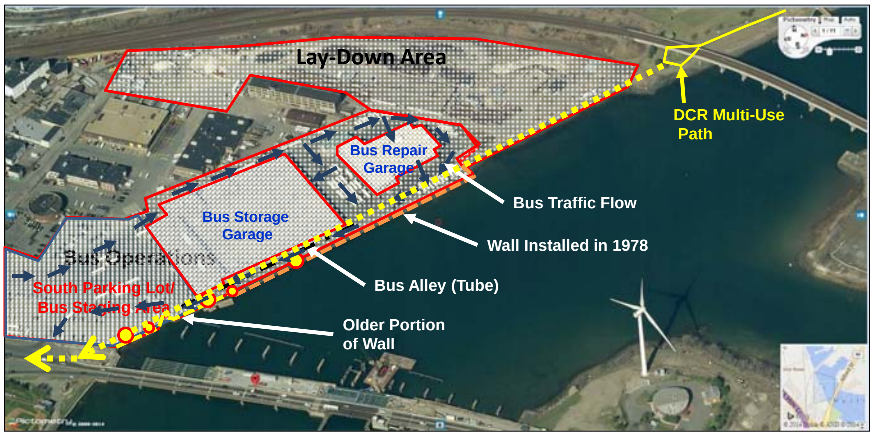
Case Study:
MBTA Alford Street Bus Garage, Charlestown, MA



Larger Areas of Soil Erosion Through Corroded Outfall Pipes

Smaller Areas of Soil Erosion Through Corroded Sheet Piles

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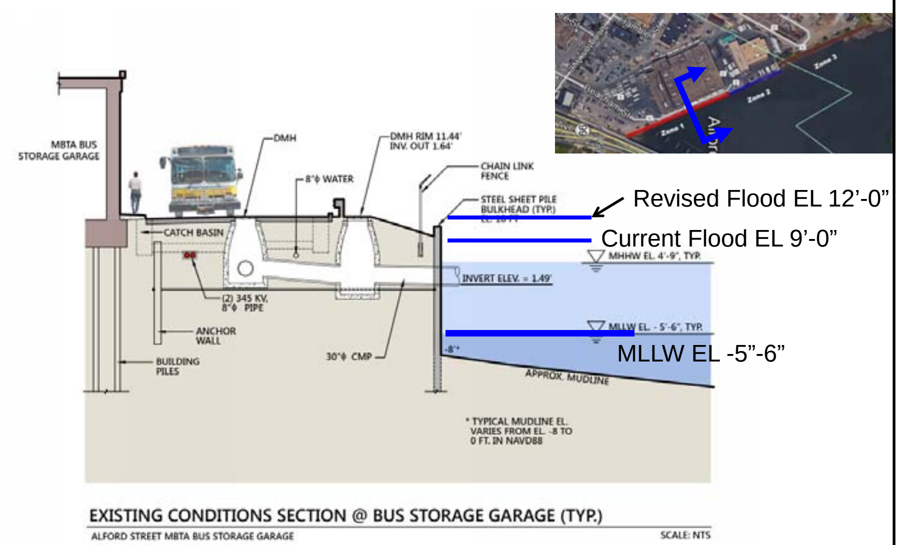
Case Study:
MBTA Alford Street Bus Garage, Charlestown, MA



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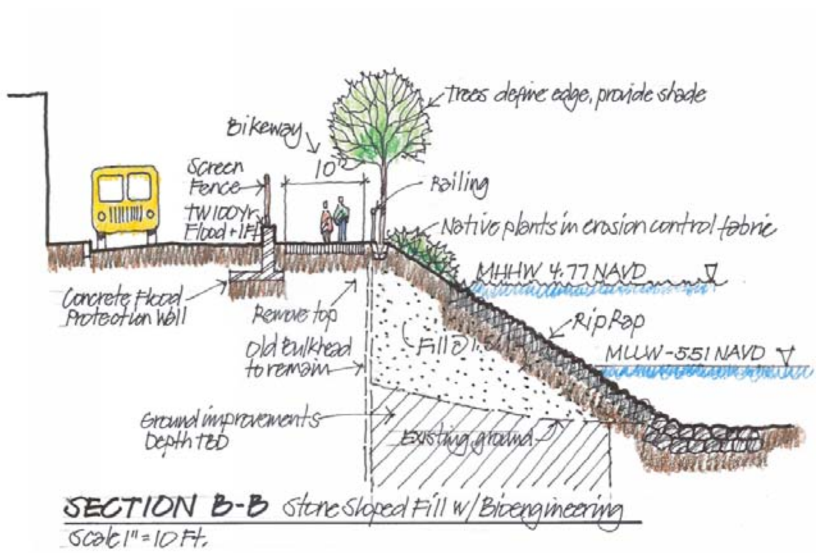
Case Study:
MBTA Alford Street Bus Garage, Charlestown, MA



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Case Study: MBTA Alford Street Bus Garage, Charlestown, MA

- Next Steps:
  - Determining sea level rise?
  - Flood elevation for various return periods?
  - Duration of high water event?
  - Probability of inundation?
  - Developing an action plan

Woods Hole Group
C&C Consulting Engineers, LLC
Epsilon Associates Inc.
Chester Engineers
Hager GeoScience Inc. Geophysical & Geological Services
McMahon Transportation Engineers & Planners
CDW
RWS R.W. Sullivan
VJ Associates

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Earthquakes – Loads

- Structures are "loaded" indirectly. Forces we use for design are intended to replicate forces a structure would experience as it vibrates in response to an actual earthquake ground motion, but forces are reduced to account for structural ductility.

Photo: Dr. Reginald Desroches / Georgia Tech

Photo: Dr. Reginald Desroches / Georgia Tech

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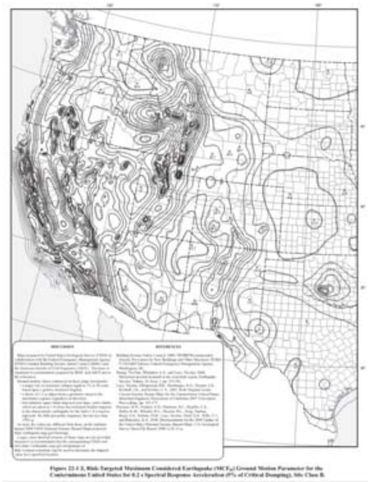
Earthquakes – Loads

- ASCE 7-10
  - Based on USGS / FEMA maps
  - Design for 1% probability of collapse in 50 years (uniform risk)
  - Risk-Targeted *Maximum Considered Earthquake* Corresponds *roughly* to ground motion with 2,500 year MRI
  - *Design* for 2/3 of the "Maximum Considered Earthquake"
  - Modify seismic loads via an "Importance Factor"



Graphic: ASCE 7-10, Figure 22-1

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Earthquakes – Loads

- Lack of adequate connections between exterior walls and building frame
- Poor ductility of building frame members, bearing walls and connections
- Interior non-structural damage

Christchurch, New Zealand, February 2011
Photo: Ronald Mayes / SGH

Nepal, April 2015
Photo: Krish Dulal / Wikimedia Commons

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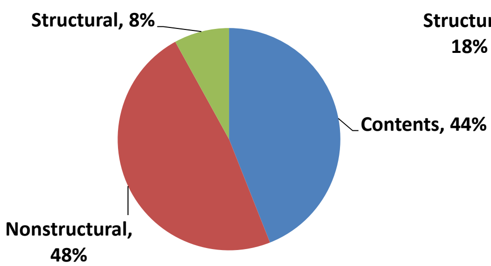
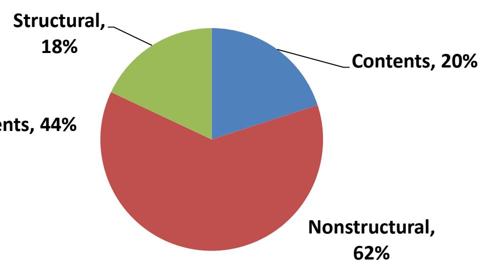
Earthquakes – Resilience Strategies

- Proportional monetary investments in buildings



Hospital



Office Building

Sources: FEMA E-74 (2011), Soong and Whittaker (2003)

Earthquakes – Resilience Strategies

- Adequately brace non-structural elements to resist damage and secondary hazards
- Consider base isolation
- Design for longer return-period event

Photo: David McCormick / SGH

Photo: Mike Renlund

Earthquakes – Resilience Strategies

- Eliminate weak or soft stories
- Add new lateral load-resisting elements to increase strength and/or stiffness

Photo: Peter Coats / Simpson Gumpertz & Heger

Photo: Dr. Reginald Desroches / Georgia Tech

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Earthquakes – Resilience Strategies

- Enhance performance of existing elements
  - Wrap columns and/or beams with carbon fiber
  - Steel column jackets
- Improve connections between components
  - Adding continuity across beam-column joints

Photo: BASF

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Earthquakes – Resilience Strategies

- Brace parapets to roof diaphragms
- Anchor exterior walls to roof and floor diaphragms at each story, particularly at the roof and at gable ends
- Reinforce egress door openings to undergo minimal drift and allow doors open

Photo: EERI / Loma Prieta Earthquake

Photo: Degenkolb Engineers / Molla High School

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Case Study: Low Seismic Region Evaluation and Voluntary Retrofit

Steel Frame

Brick Exterior Walls

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Case Study: Low Seismic Region Evaluation and Voluntary Retrofit

Likely Performance in Various Earthquakes

Earthquake	Probability of Exceedance; Return Period	Expected Performance for Essential Facility	MMI Perceived Shaking / Level of Damage	Approximate Richter Magnitude
Occasional	20% in 50 yrs; 225 yrs	Very light damage	IV. Moderate	4.0 – 4.5
Rare	10% in 50 yrs; 475 yrs	Operational – light damage	V. Moderate to Strong; little to no structural damage	5.0
Code Level (Rare to very rare)	3% in 50 yrs; 1,500 yrs	Operational – light to moderate damage	VI. Perceived Shaking is Strong, Damage is slight	5.0 to 5.5

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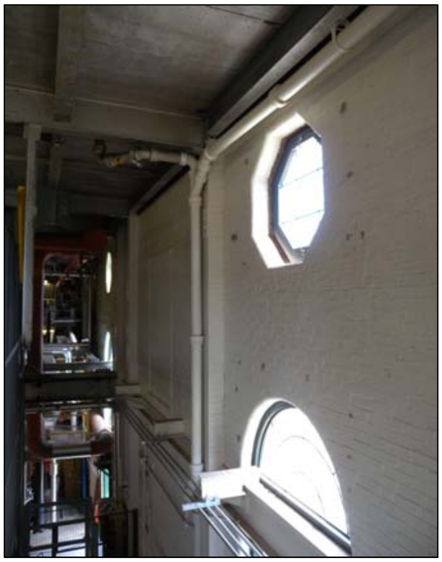
Case Study: Low Seismic Region Evaluation and Voluntary Retrofit

- Strengthening Options

1. Parapet Bracing and Roof Diaphragm
2. Parapet and Wall Bracing and Roof Diaphragm
3. Parapet and Wall Bracing, Roof Diaphragm, and Steel Braced Frames



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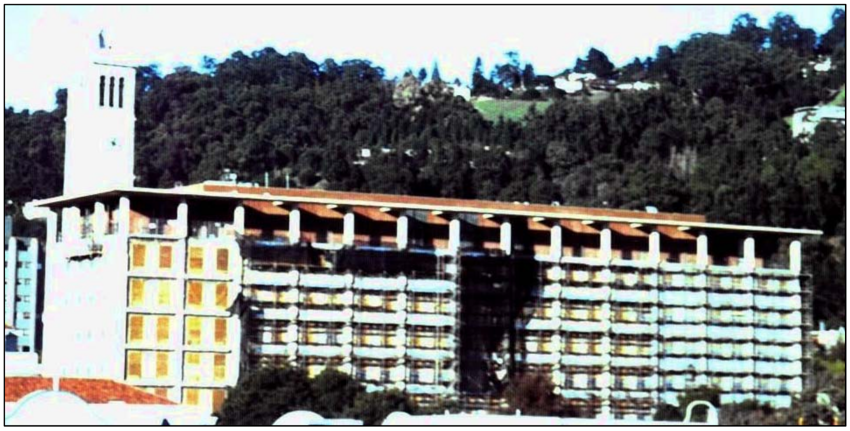
Case Study: High Seismic Region
Existing Building on Campus Near Active Fault



(Work Performed by Degenkolb Engineers in San Francisco)

Case Study: High Seismic Region
Existing Building on Campus Near Active Fault

- Concerns:
  - Will University be viable following strong ground shaking?
- University Strategic Goals:
  - Maintain teaching capability
  - Design for life-safety performance objective

Case Study: High Seismic Region
Existing Building on Campus Near Active Fault

- Project Approach:
  - Strengthen enough buildings but recognize not all buildings will perform as expected; some better and a few worse

Case Study: High Seismic Region
Existing Building on Campus Near Active Fault

1. To retrofit the building
2. And more importantly, to keep the building functional during construction

Case Study: High Seismic Region Parking Garages Designed for SFIA

(Work Performed by Degenkolb Engineers in San Francisco)

Goal of Immediate Occupancy in Major Earthquake
- Hazard Level Greater than Code Required

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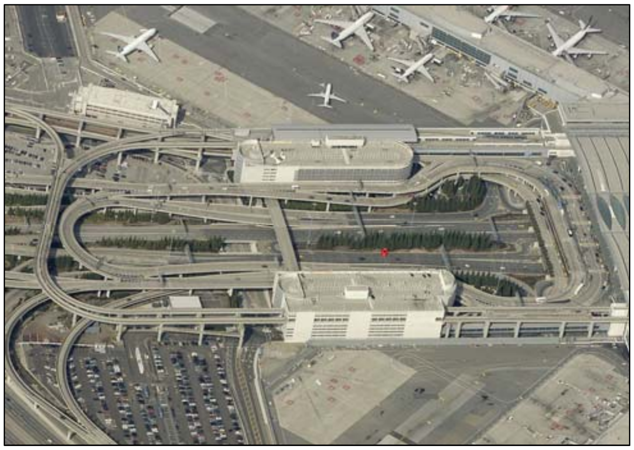
Case Study: High Seismic Region Parking Garages Designed for SFIA



- Air transit stop
- Adjacent to BART Station
- Pedestrian Bridge
- Vehicular Bridge
- Connects to Roadways

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Case Study: High Seismic Region Parking Garages Designed for SFIA

- Designed to house the Ground Transportation Center
- Deep soft soil deposit
- Airborne salt

- Design for Site Specific Ground Motion
- Performance-Based Design for shear wall system and frame
- Encapsulated post-tensioning system

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Where Do We Go From Here?

- Consistent code enforcement
  - "1/3 of damage sustained in Hurricane Andrew could have been avoided if FL enforced its building codes" (Kunreuther, 1996)

Photo: Bob Epstein / FEMA

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Where Do We Go From Here?

- Shift our thinking to make resilience second nature.
- Pass “Good Samaritan” laws
- Spur public policy and motivate lawmakers
  - Unfortunately, resilience doesn’t make for good politics…
  - Being there after a disaster (usually) does.

Photo: Jocelyn Augustine / FEMA

Photo: Pete Souza / White House

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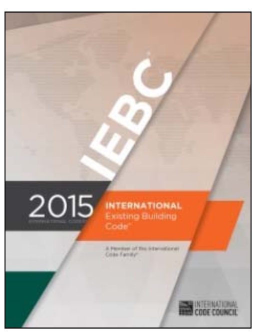
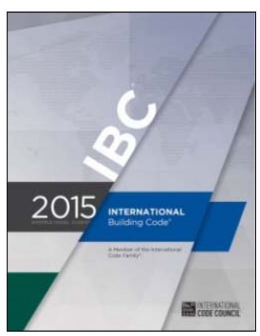
Where Do We Go From Here?

- Code-Mandatory Upgrades
- Positive Incentives to Promote Resilience
  - Subsidies, grants, tax breaks, insurance breaks
- Negative Incentives
  - Fines, penalties, insurance hikes





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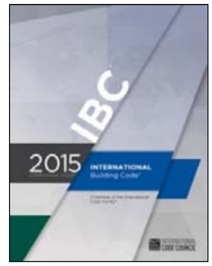
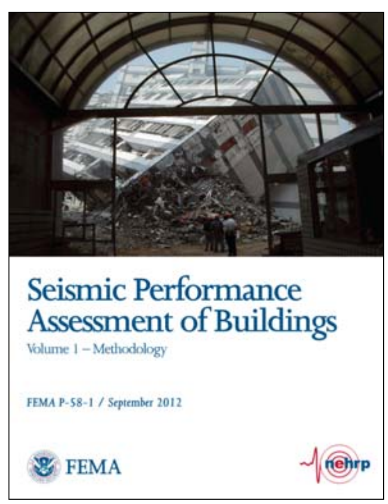
Where Do We Go From Here?

- Prescriptive-Based Design
  - Similar to business-as-usual code with rules based on location, hazard type, etc.
  - Code+ restrictions
- Performance-Based Design
  - Hammurabi's Code?
  - Probabilistic assessment of:
    - Hazard
    - Building performance
    - Cost-benefit analysis

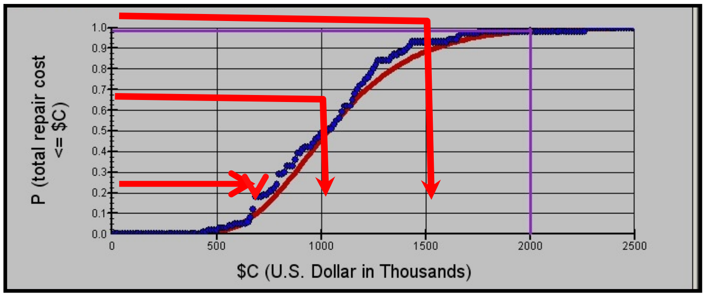


Where Do We Go From Here?

- ATC-58 / FEMA P-58
  - Seismic performance assessment:
    - Probability of experiencing a specified response
    - Probability of experiencing a specified damage state
    - Probability of incurring specified consequences
  - Mathematically rigorous framework



Where Do We Go From Here?



- 10% probability that repair cost will not exceed $700K
- 50% probability that repair cost will not exceed $1M
- 90% confidence losses will not exceed $1.5M
- 80% probability losses will be between $700K and $1.5M
- Average annual loss is $50,000/year

Where Do We Go From Here?

- US Resiliency Council

Where Do We Go From Here?

- US Resiliency Council
  - Developing better ways to communicate with clients and public
  - Resilience rating system counterpart to LEED
  - Rating system currently for earthquake performance:

Earthquake performance expressed in
Deaths, **D**ollars, and **D**owntime

  - Other hazard ratings are being developed

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Where Do We Go From Here?

Immediate Occupancy
Life Safety

- US Resiliency Council

Safety	
5★	Injuries and blocking of exit paths unlikely
4★	Serious injuries unlikely
3★	Loss of life unlikely
2★	Loss of life possible in isolated locations
1★	Loss of life likely in the building

Repair cost	
5★	Minimal damage (< 5%)
4★	Moderate damage (< 10%)
3★	Significant damage (< 20%)
2★	Substantial damage (< 40%)
1★	Severe damage (40%+)
NE	Not Evaluated

Recovery	
5★	Within hours to days
4★	Within days to weeks
3★	Within weeks to months
2★	Within months to a year
1★	More than one year
NE	Not evaluated

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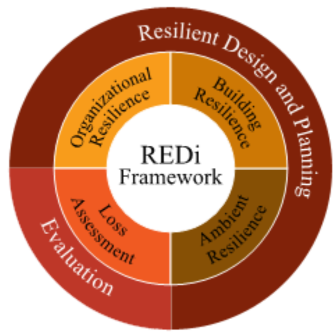
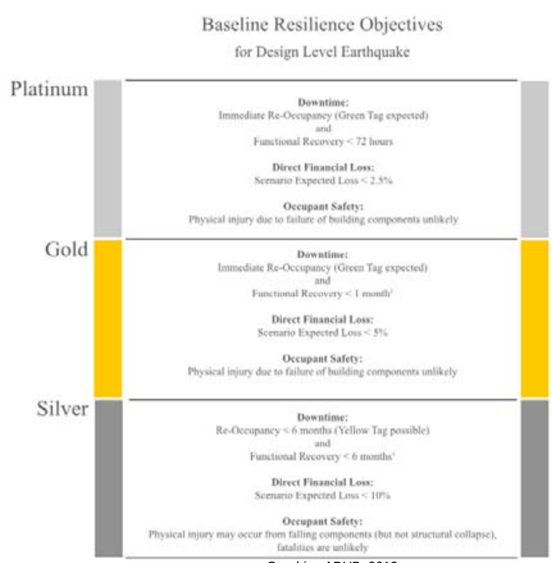
Where Do We Go From Here?

- Resilience-Based Earthquake Design Initiative (REDi) by ARUP
- FEMA P-58 process
- Considers holistic hazard network:
  - Resilience planning workshop
  - Contingency planning
  - Hazard reduction around building



Graphic: ARUP, 2013

Where Do We Go From Here?



Graphic: ARUP, 2013

Where Do We Go From Here?

- Does designing for resilience "raise the bar" for designers?
- What about professional liability?

Photo: Scott Ray (Wikimedia Commons)

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Closing Thoughts

- Not just about designing for higher loads
- Expand our evaluation capabilities
- Engage a wider audience

Photo: Hurricane Irene, August 2011 / NOAA

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DISCUSSION

Photo: Ronald Mayes / SGH

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This concludes The American Institute of Architects
Continuing Education Systems Course

SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures

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CONTINUING EDUCATION AIA

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