Design Issues Related to Tall Buildings

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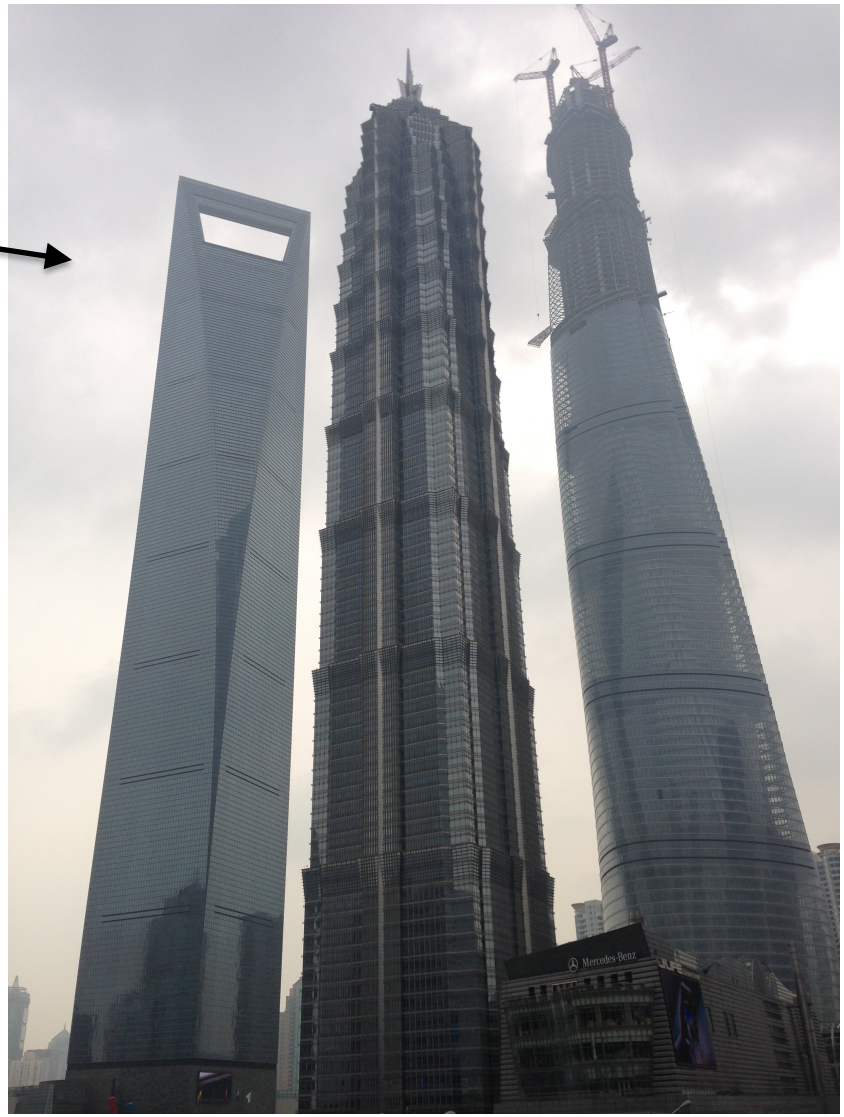
What is a “tall” building?

The new tall

The old tall

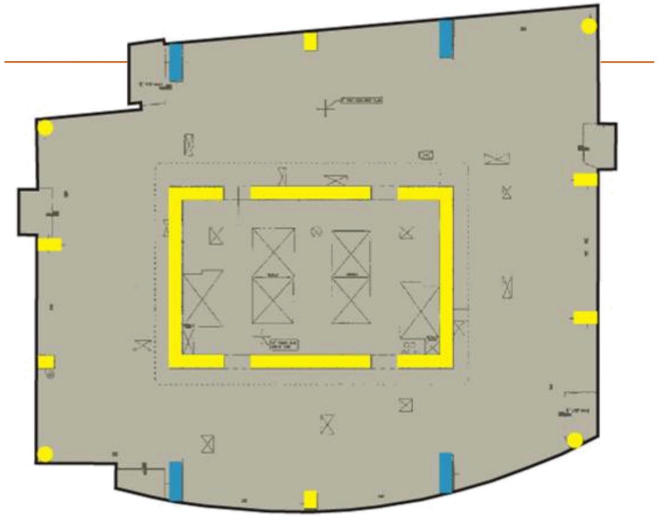


Tall Buildings under Construction In California

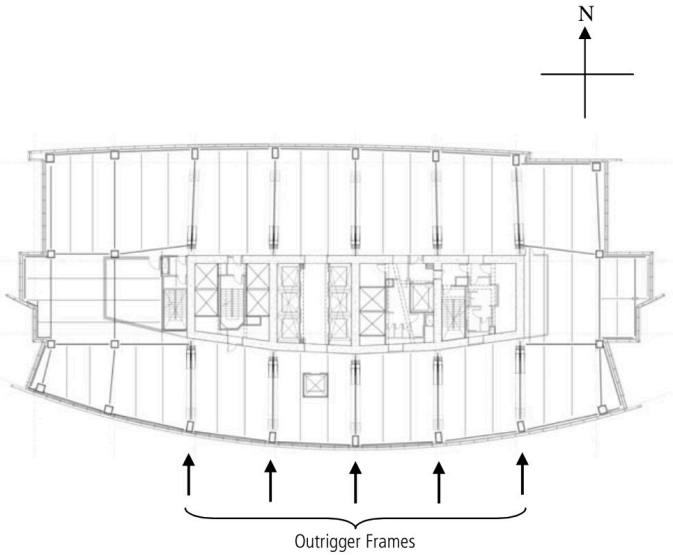
Whilshire Grand Hotel,
Los Angeles 335 m

Salesforce Tower,
San Francisco, 326 m

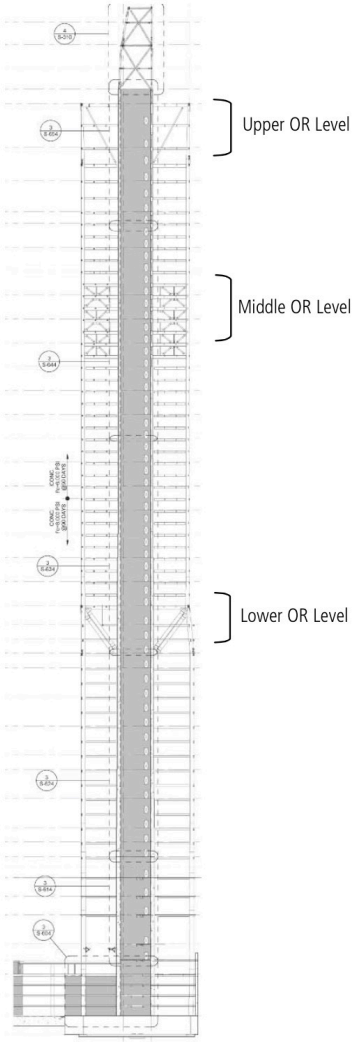
Tall Buildings:
Lateral load resisting systems



Single core wall



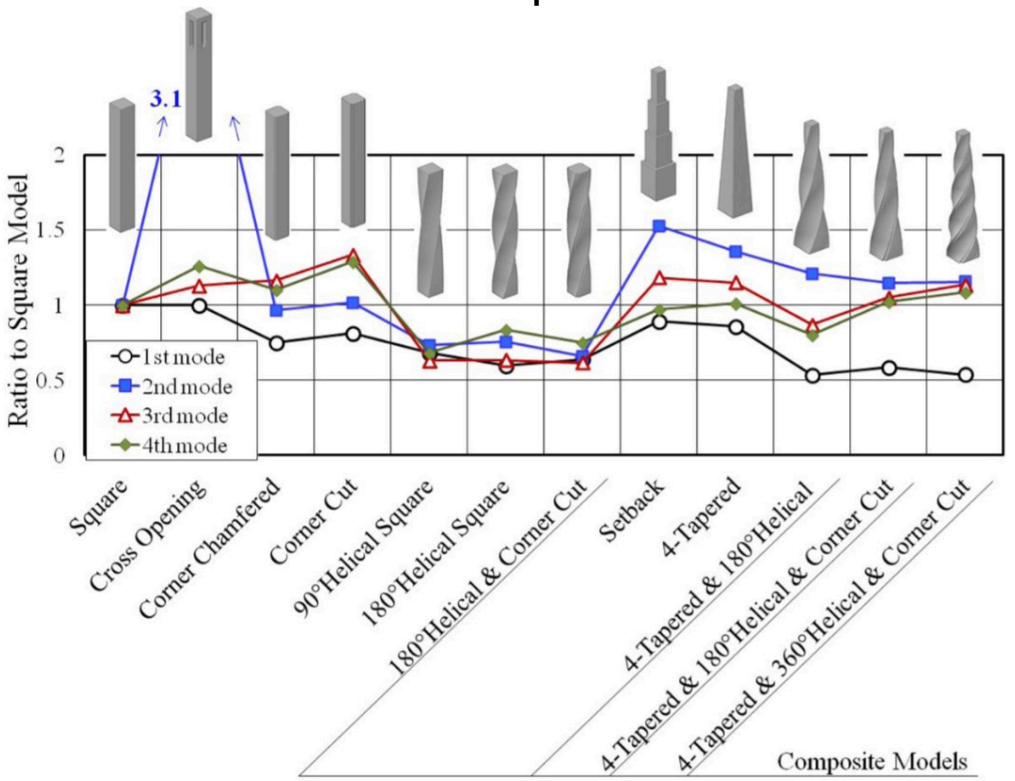
L28 Floor Plan



Core with outrigger framing

Why?

1-Year return period peak floor acceleration for different systems compared to building with square floor plan

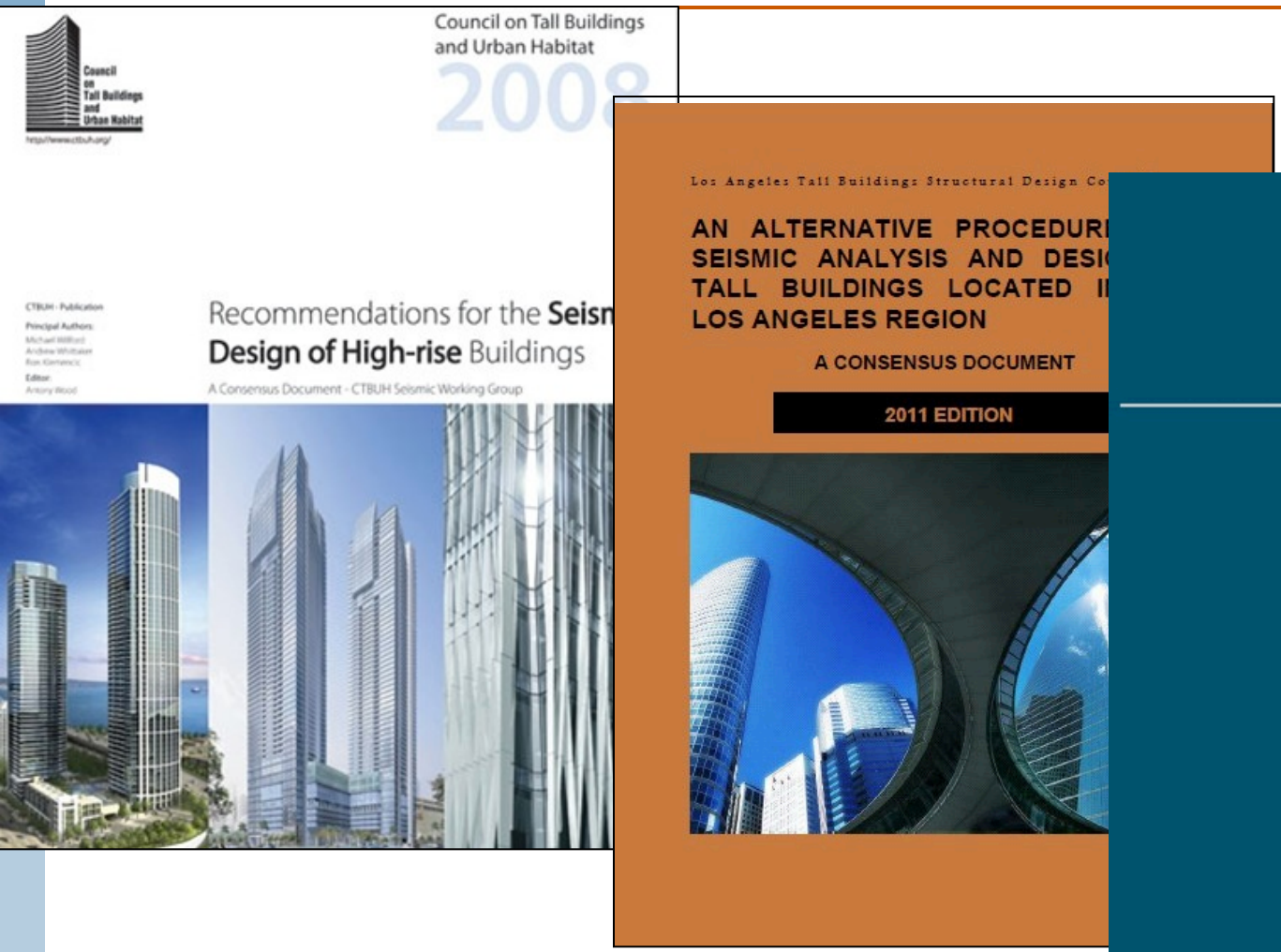


Tanaka et al. CTBUH 2013

Some structures are truly "unusual"

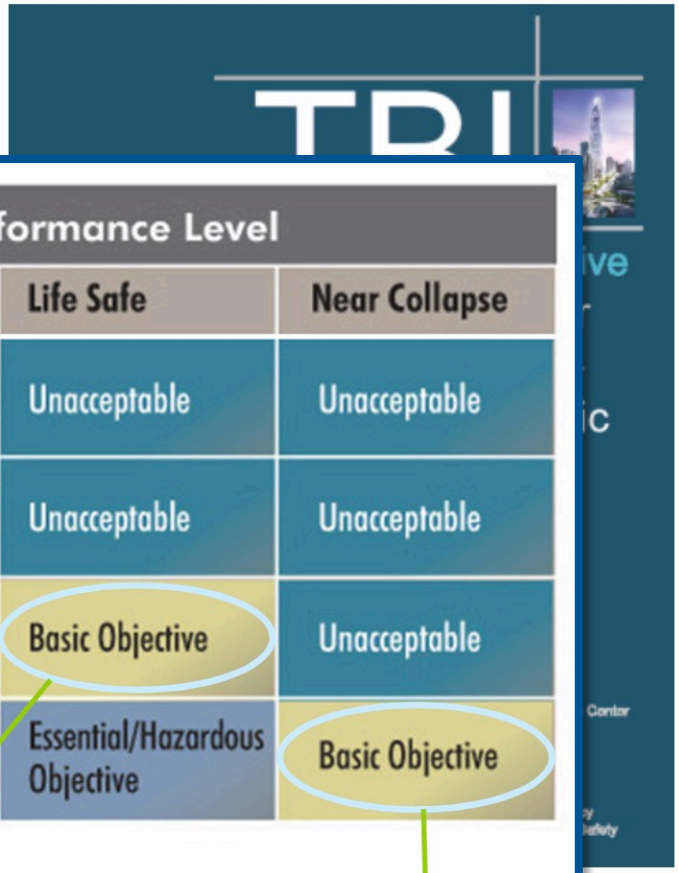
(W)rapper, Los Angeles 70 m

Guidelines for Seismic Design of Tall Buildings



TBI Guidelines Chapters

1. Introduction
2. Performance objectives
3. D
4. D
5. S
6. P
7. S
8. M
9. P
10. P



Earthquake Design Level	Earthquake Performance Level			
	Fully Operational	Operational	Life Safe	Near Collapse
Frequent (43 years)	Basic Objective	Unacceptable	Unacceptable	Unacceptable
Occasional (72 years)	Essential/Hazardous Objective	Basic Objective	Unacceptable	Unacceptable
Rare (475 years)	Safety Critical Objective	Essential/Hazardous Objective	Basic Objective	Unacceptable
Very Rare (975 years)	Not Feasible	Safety Critical Objective	Essential/Hazardous Objective	Basic Objective

Serviceability check

Code level design with exceptions

Stability check

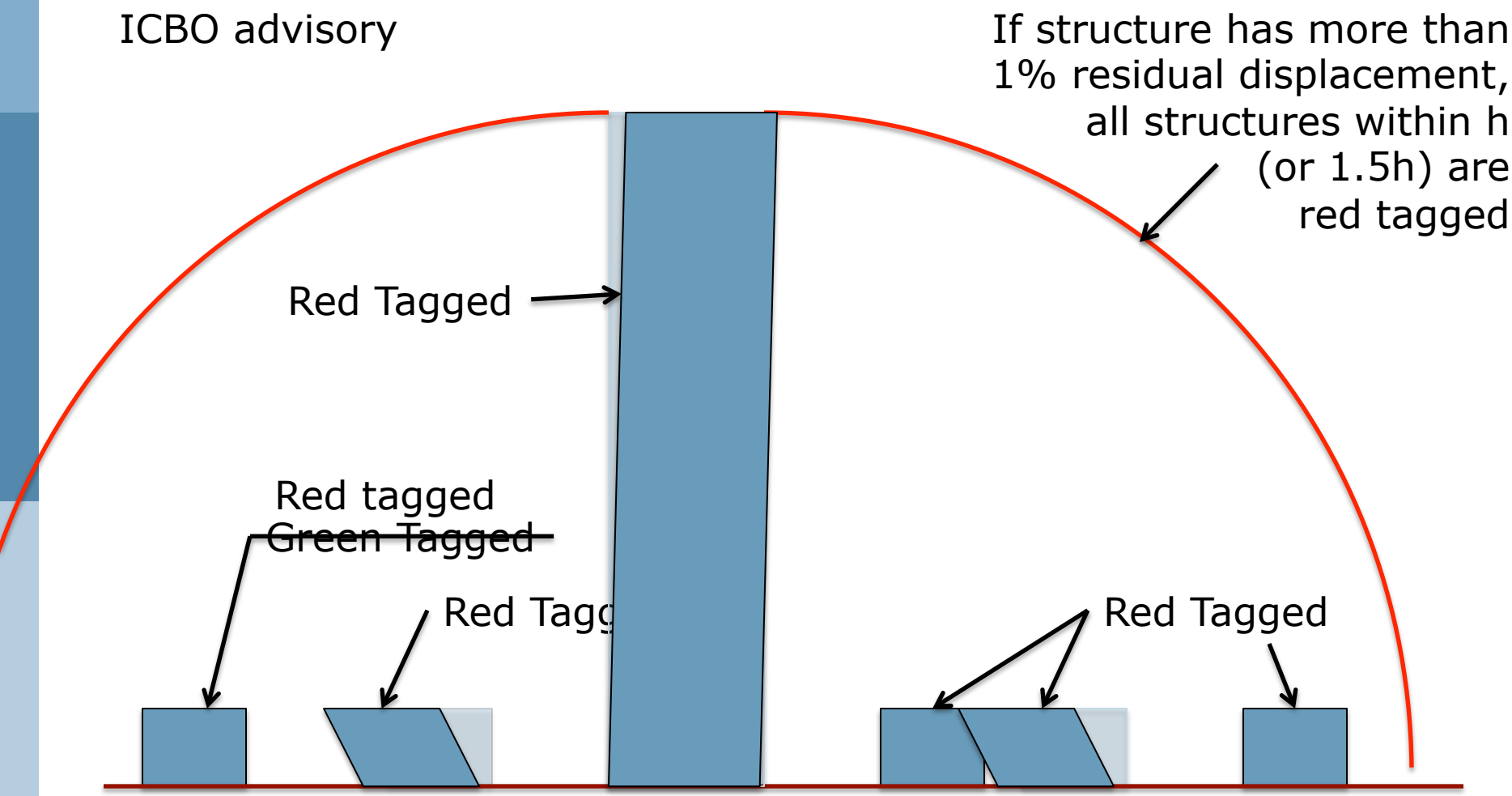
2 1 3

Performance Criteria: An issue for consideration

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life.	III
Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure.	
Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	
Buildings and other structures designated as essential facilities.	IV
Buildings and other structures, the failure of which could pose a substantial hazard to the community.	
Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released.[a]	
Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	

[a]Buildings and other structures containing toxic, highly toxic, or explosive substances shall be eligible for classification to a lower Risk Category if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 that a release of the substances is commensurate with the risk associated with that Risk Category.

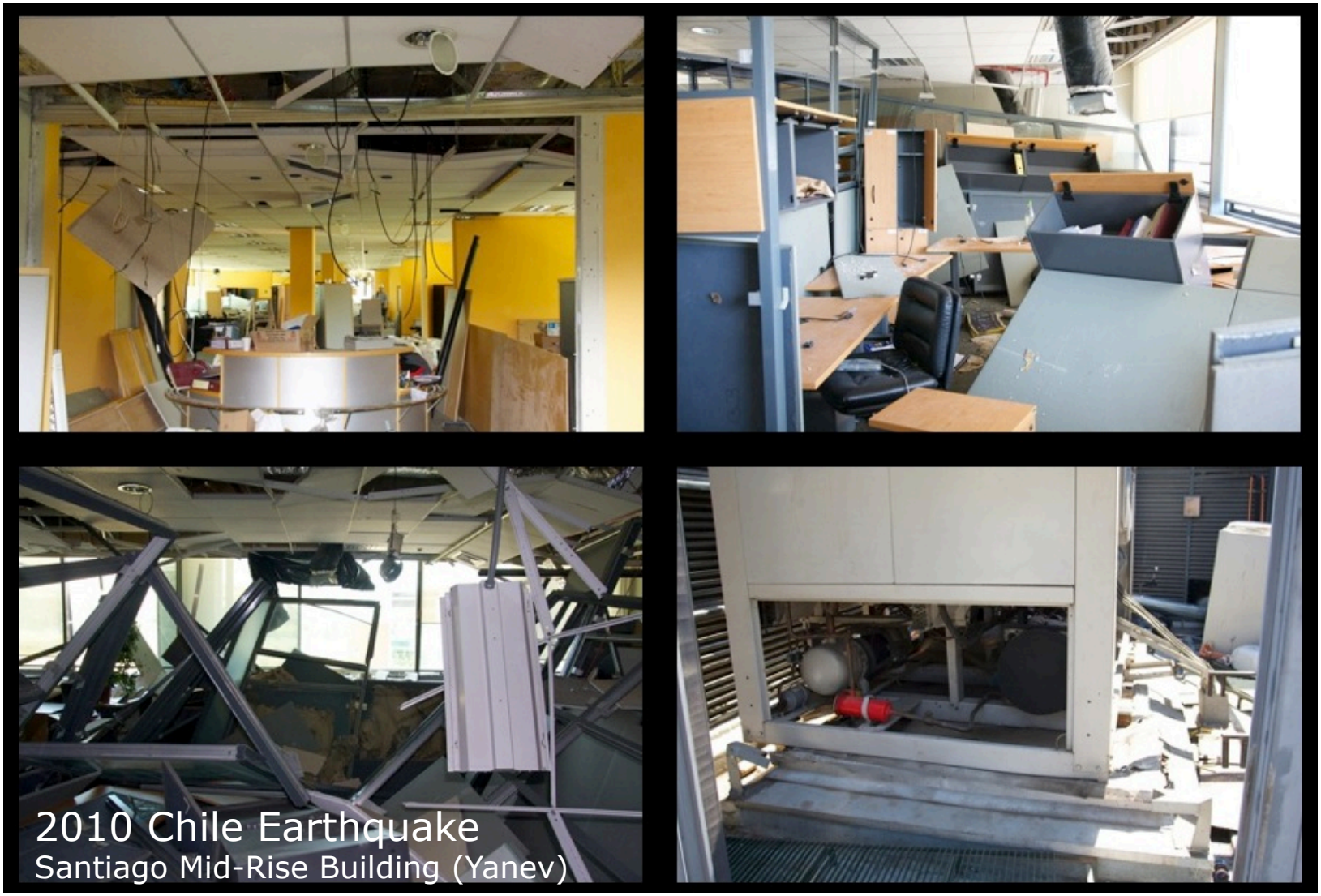
Most buildings considered individually



Damaged tall buildings can adversely effect presumed safety of adjacent buildings

Implications

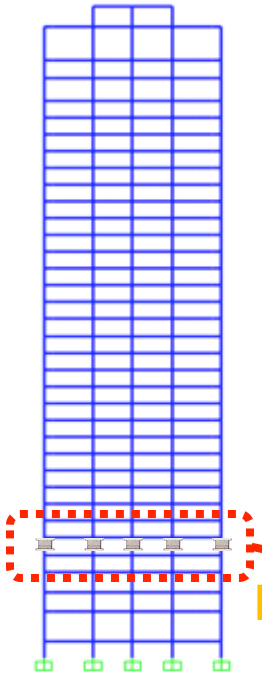
Nonstructural Elements: Life Safety and Economic Concerns



Common Characteristics of Disaster Resilient Structures

- Earthquake resisting system that controls distribution of inelastic deformations
- Durable and/or easily replaceable energy dissipation regions/devices
- Easy and safe post-event inspection

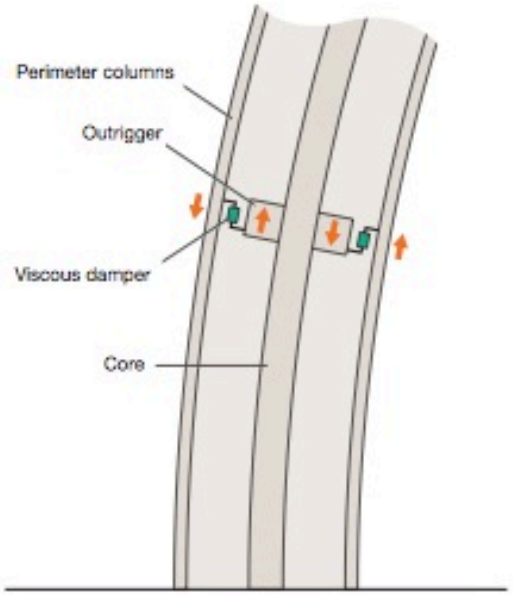
Upgrade Strategies



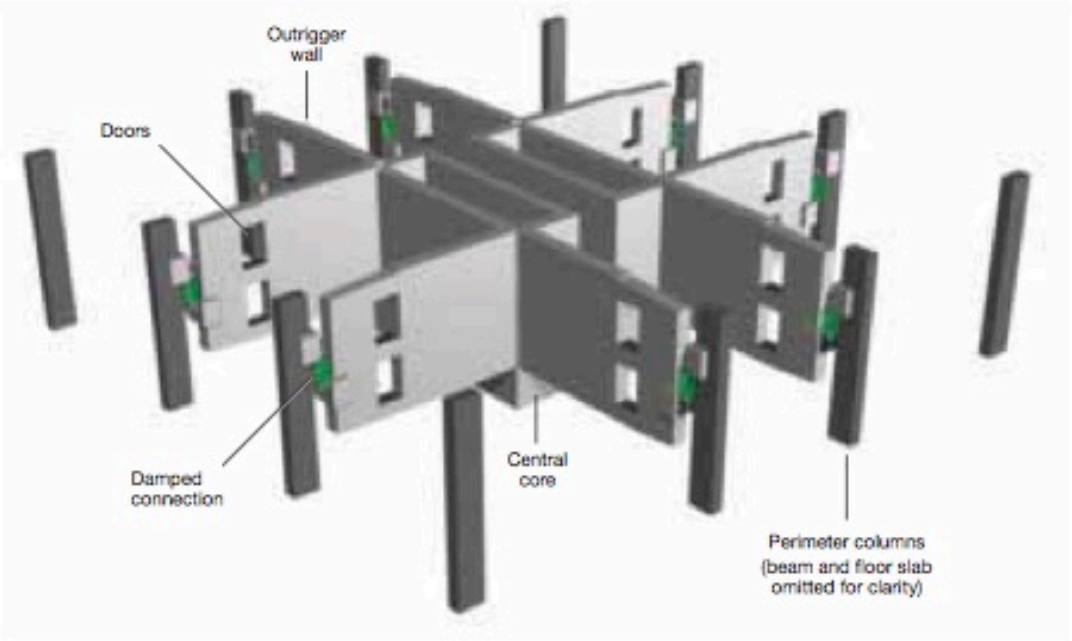
Mid-level isolation

How to improve behavior: Damped Outriggers

5. The damped outrigger concept.



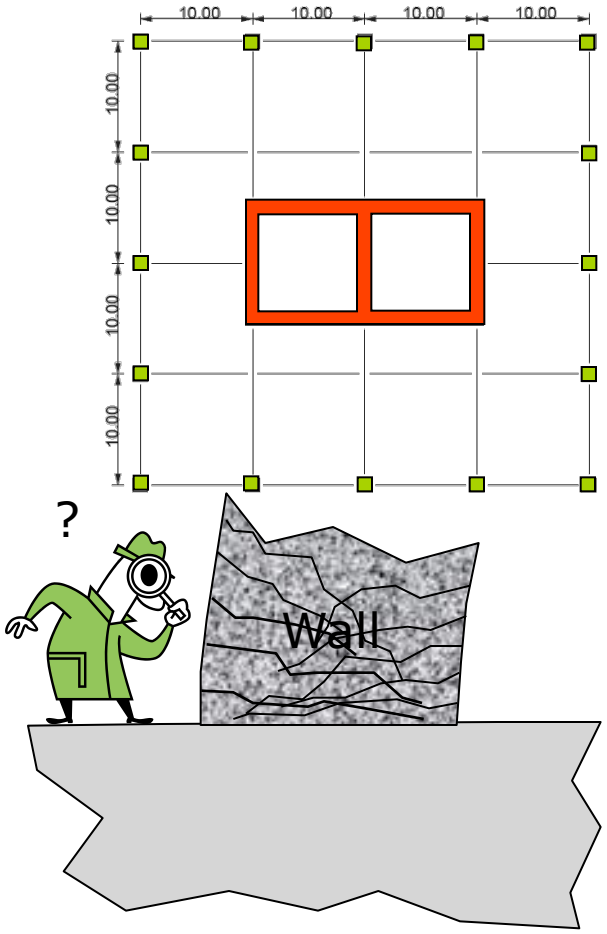
6. Isometric of core, columns, outriggers, and dampers.

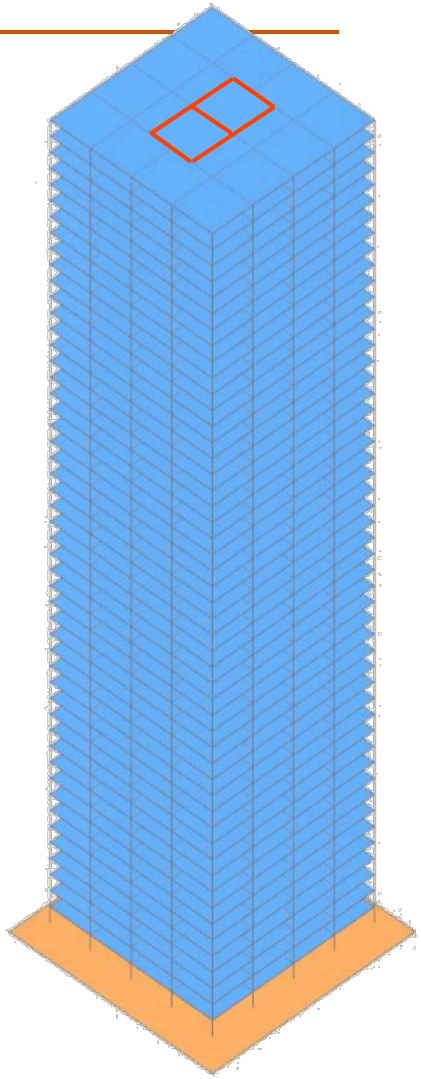


The Arup Journal 3/2008

Can We Apply Resilient Self-Centering Concepts to Tall Buildings?

- Core-only buildings common in US for residential structures
- Higher mode effects are significant
- Ductile design may lead to permanent residual displacements that will make repair difficult, costly and time consuming.





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- Core-only buildings common in US for residential structures
- Higher mode effects are significant
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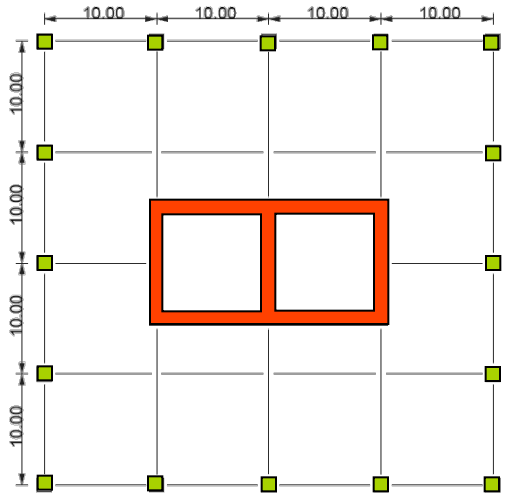
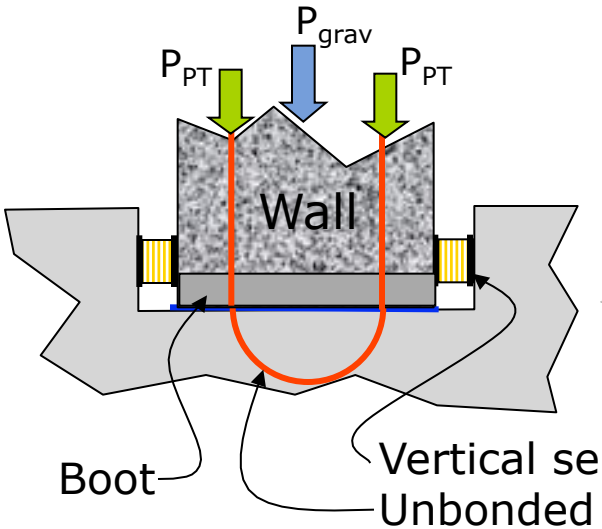
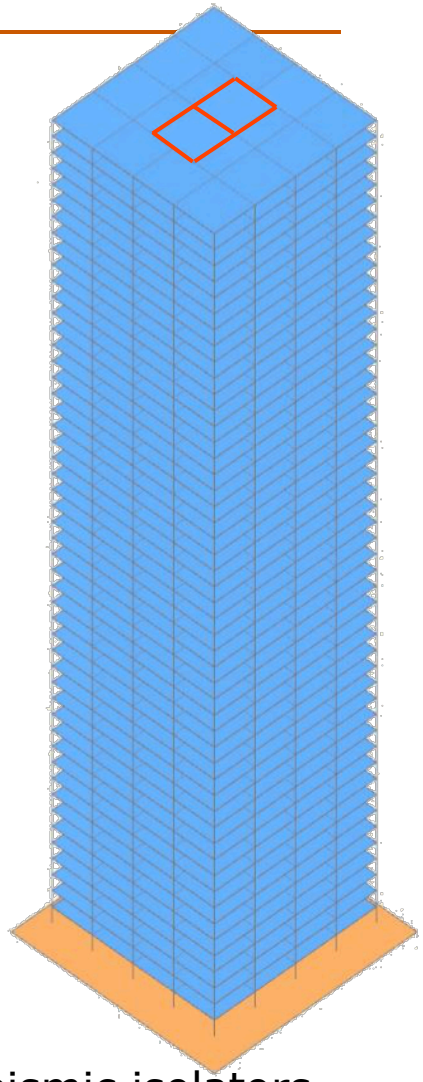
- Can we use self-centering or rocking wall?
  - Armor rocking location avoid local damage
  - Add post-tensioning and hysteretic or viscous dampers as needed







Can We Apply Same Self-Centering Concepts to Tall Buildings?

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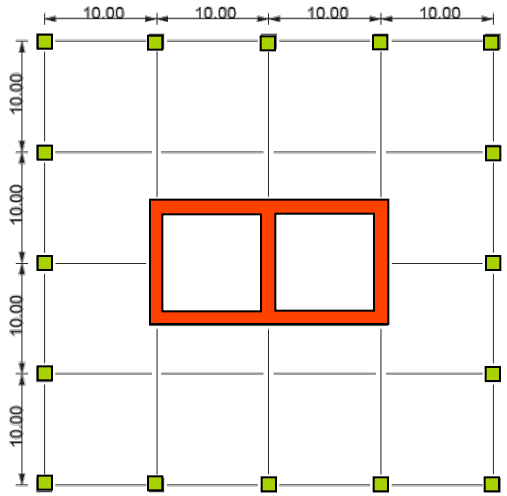
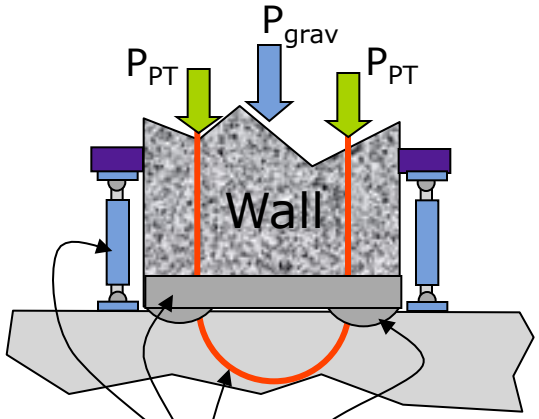
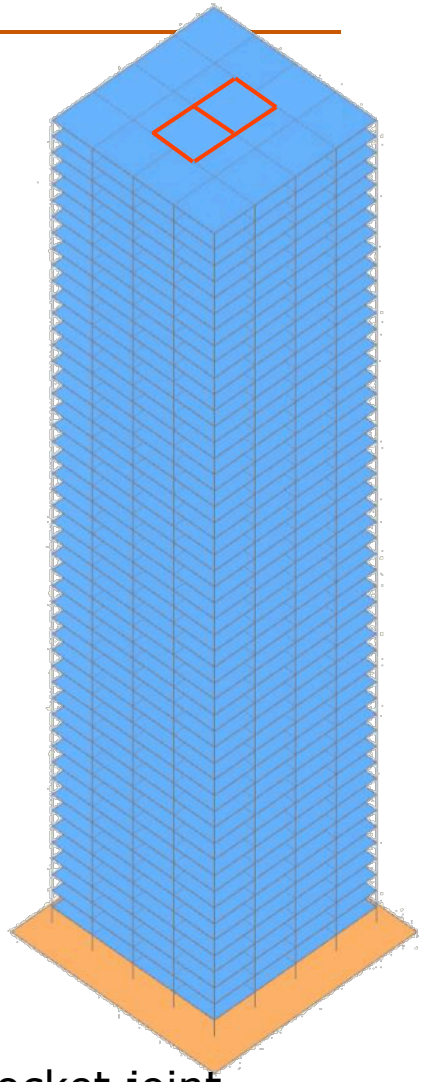
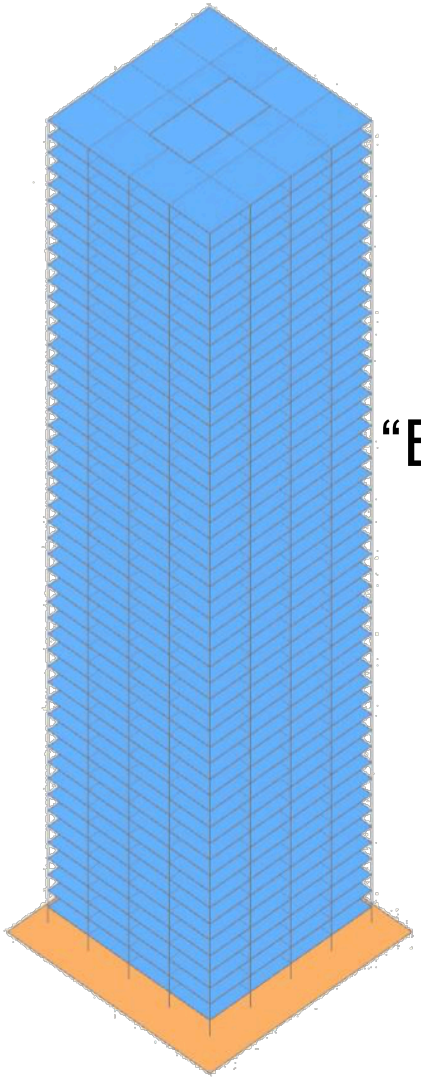
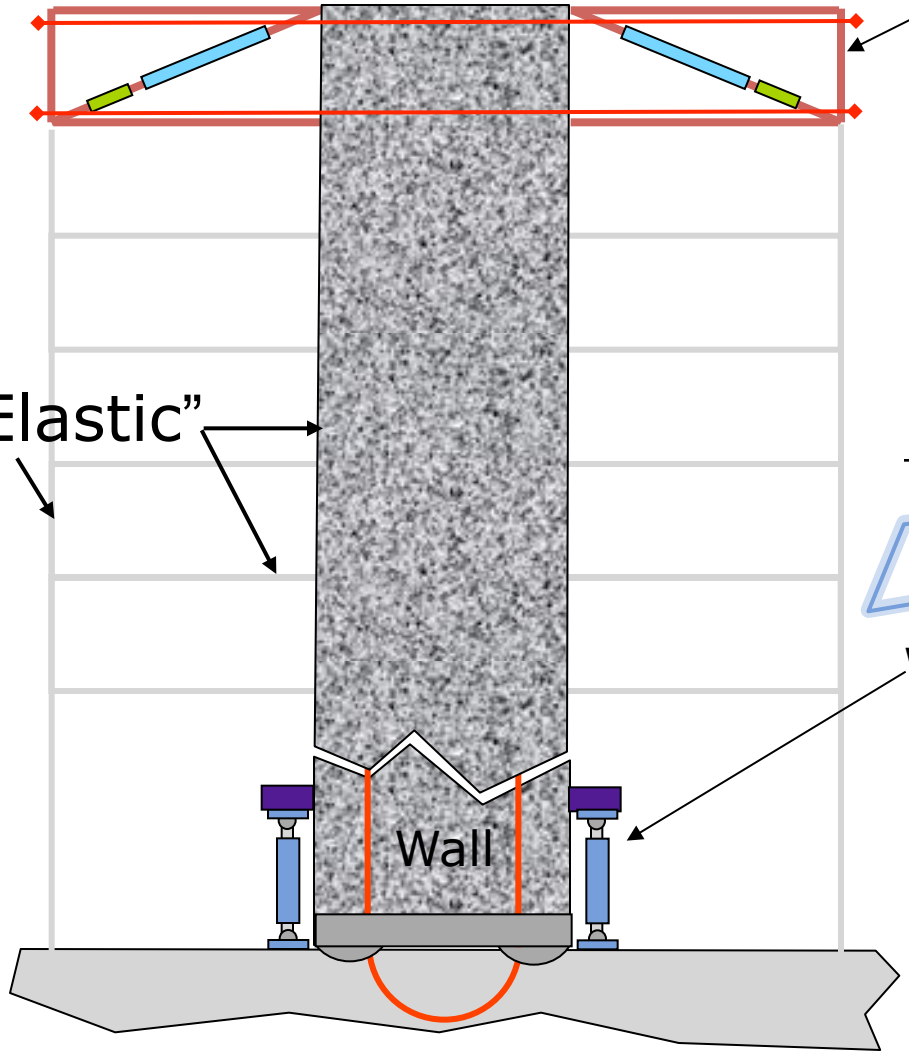






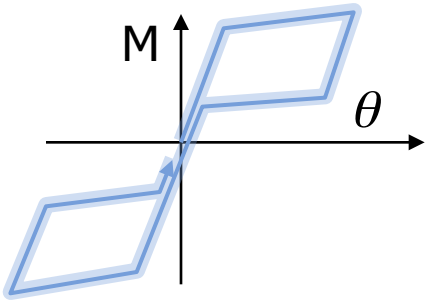
New concept: Essentially elastic behavior except at special fuses





One or More Outrigger Levels:

- Hybrid BRB/FVD bracing for damping and to limit forces
- Post-tensioning to self-center

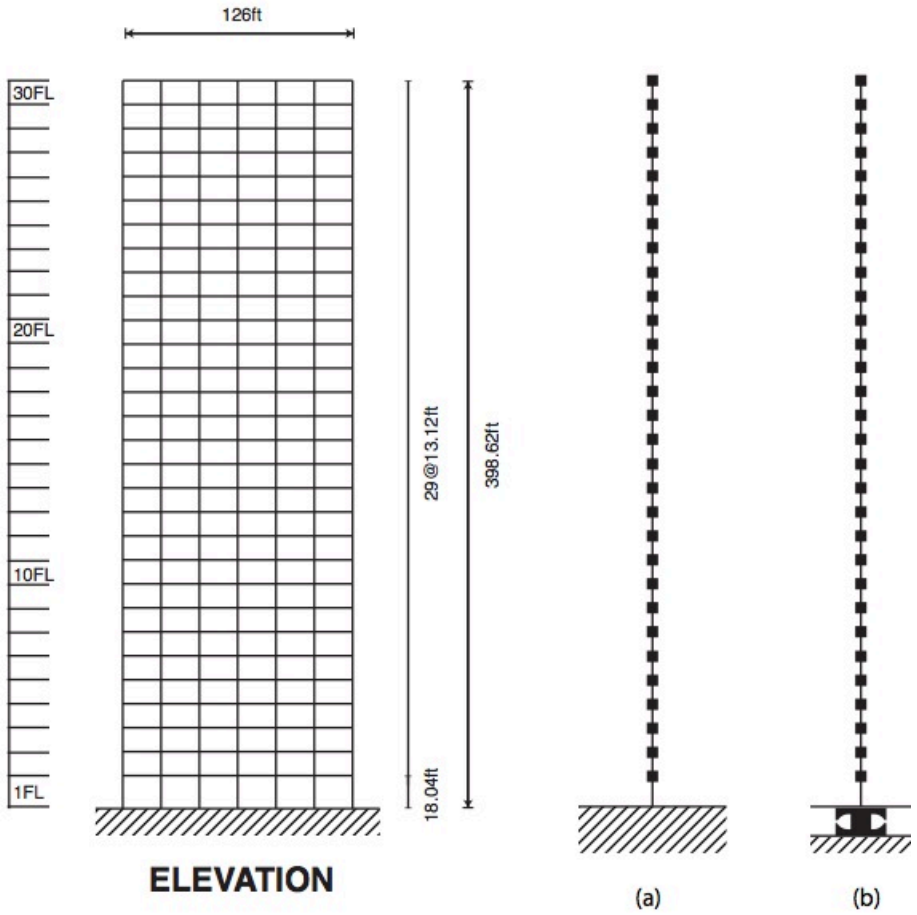


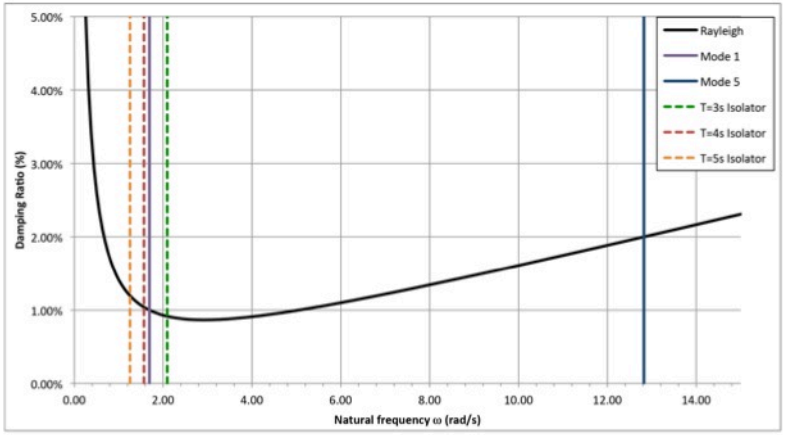
Wall base:

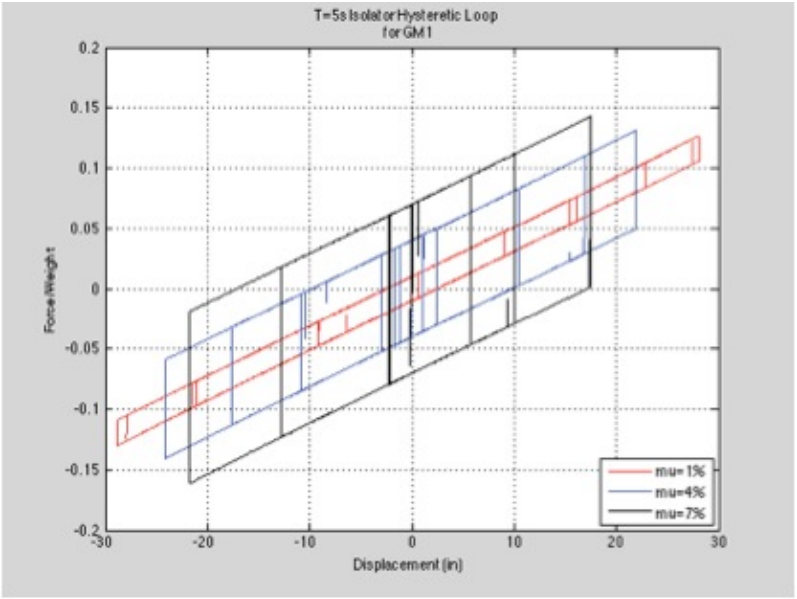
- Mixed BRB/FVD bracing for damping and to limit forces
- Post-tensioning and gravity to self-center

Taketori (Kobe) Record times 1.25 - EPS TP isolators with 5.5s period

Structural Model







Baseline bearing:
7% friction, Tiso = 5 sec

Concluding remarks

- Performance-based design concepts are very applicable to tall buildings
  - High occupancy & high cost
  - Potentially high business interruption costs
  - Potentially large consequence of residual displacement
- Provide a good platform for studying different approaches to increase resilience
- Opportunity to utilize innovative systems and HPC
- Interaction of wind and seismic design considerations
  - Human comfort
  - Nonstructural
  - Extend EDP->DM->DV

Thanks