



Seismic Collapse Safety of Modern Reinforced Concrete Moment Frame Buildings

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Project support: PEER and ATC-63

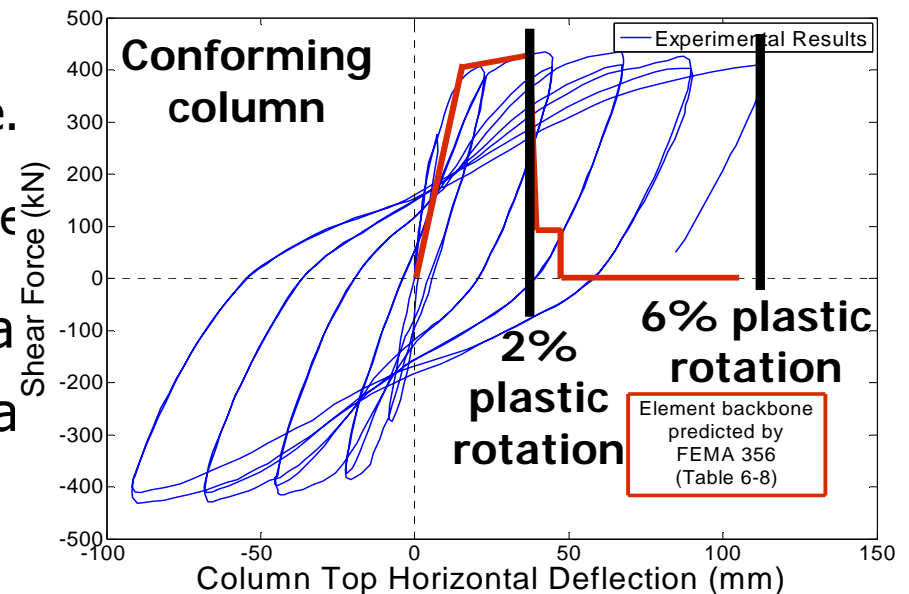


Problem and Research Motivation

- ⇒ Building codes are empirical, so the collapse safety of new buildings is not well understood.
- ⇒ Current performance-based earthquake engineering methods (i.e. FEMA 356) are not capable of accurately predicting collapse risk because they:



- ⇒ are simplistic.
 - ⇒ are deliberately conservative.
 - ⇒ do not explicitly address uncertainty.
- ⇒ As we progress toward performance-based design, we need to understand the current performance of buildings to accurately predict it.





Solution: Goals of this Research

- ⇒ Develop the tools and methods needed to rigorously predict collapse safety. Our focus is on modern reinforced concrete (RC) special moment frame (SMF) buildings.
 - ⇒ We need to ensure that these methods/tools reflect mean collapse behavior and account for all important uncertainties.
- ⇒ Use these methods/tools to benchmark the collapse safety of new RC SMF buildings (ASCE7-02 and ASCE7-05).

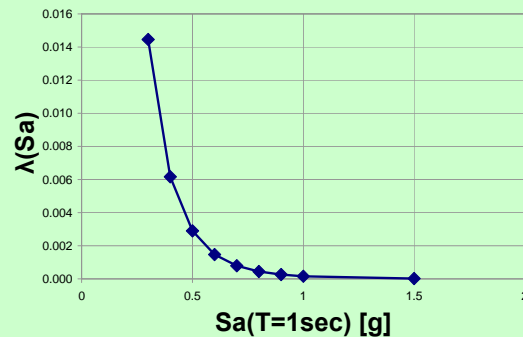


Overview of Collapse Assessment Process

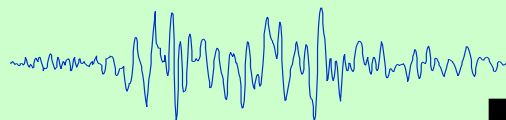
PEERs PBEE Probabilistic Framework

Ground Motions

▪ Hazard



▪ Ground motions



Structural Modeling

- Calibration to test data
- Direct modeling of sideway collapse
- Assessment of structural modeling uncertainties



Collapse Risk Predictions

- Conditional collapse probabilities
- Mean annual rate of collapse



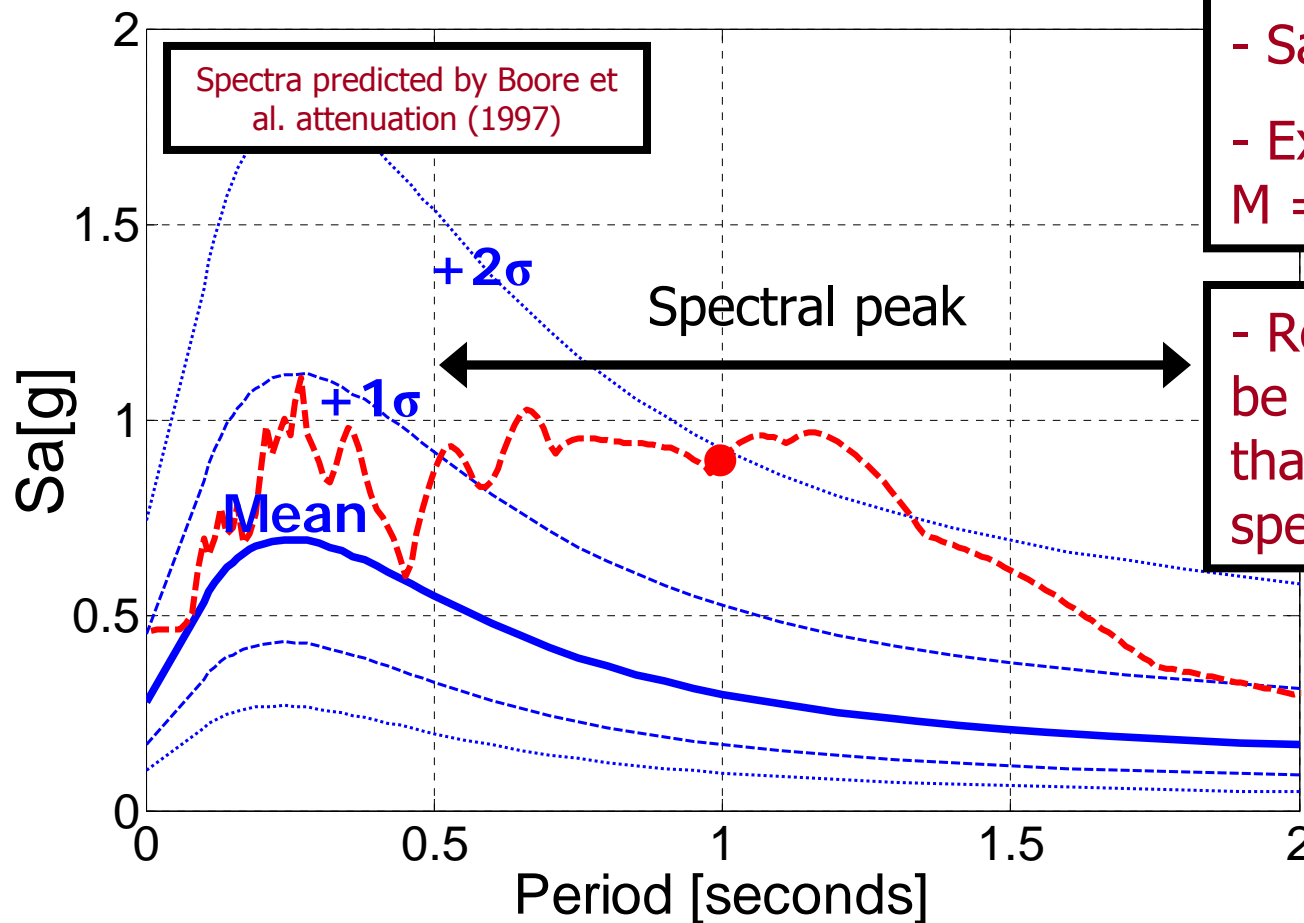
Ground Motions and Spectral Shape

- ⇒ Ground motion set (from ATC-63):
 - ⇒ Far-field motions: $R > 10\text{km}$
 - ⇒ Large motions: $M > 6.5$, $\text{PGA} > 0.2\text{g}$, $\text{PGV} > 15\text{cm/s}$
 - ⇒ This results in a set of 40 records

- ⇒ Consideration of spectral shape:
 - ⇒ Spectral shape dramatically affects collapse capacity (Baker et al.), so it is important to get the shape correct.
 - ⇒ Spectral shape is related to the ground motion intensity level, with rare motions (e.g. 2% in 50 year motions) tending to have a peaked spectral shape (Baker and Cornell).



Ground Motions: Spectral Shape



- Soil site in San Jose, California
- $S_{a_{2/50}}(T=1s)=0.9g$
- Expected event: $M = 6.9, R = 11km$

- Red spectrum will be less damaging than the blue +2σ spectrum



Strength/Stiffness Degrading Hinge Model

M, Column Base Moment

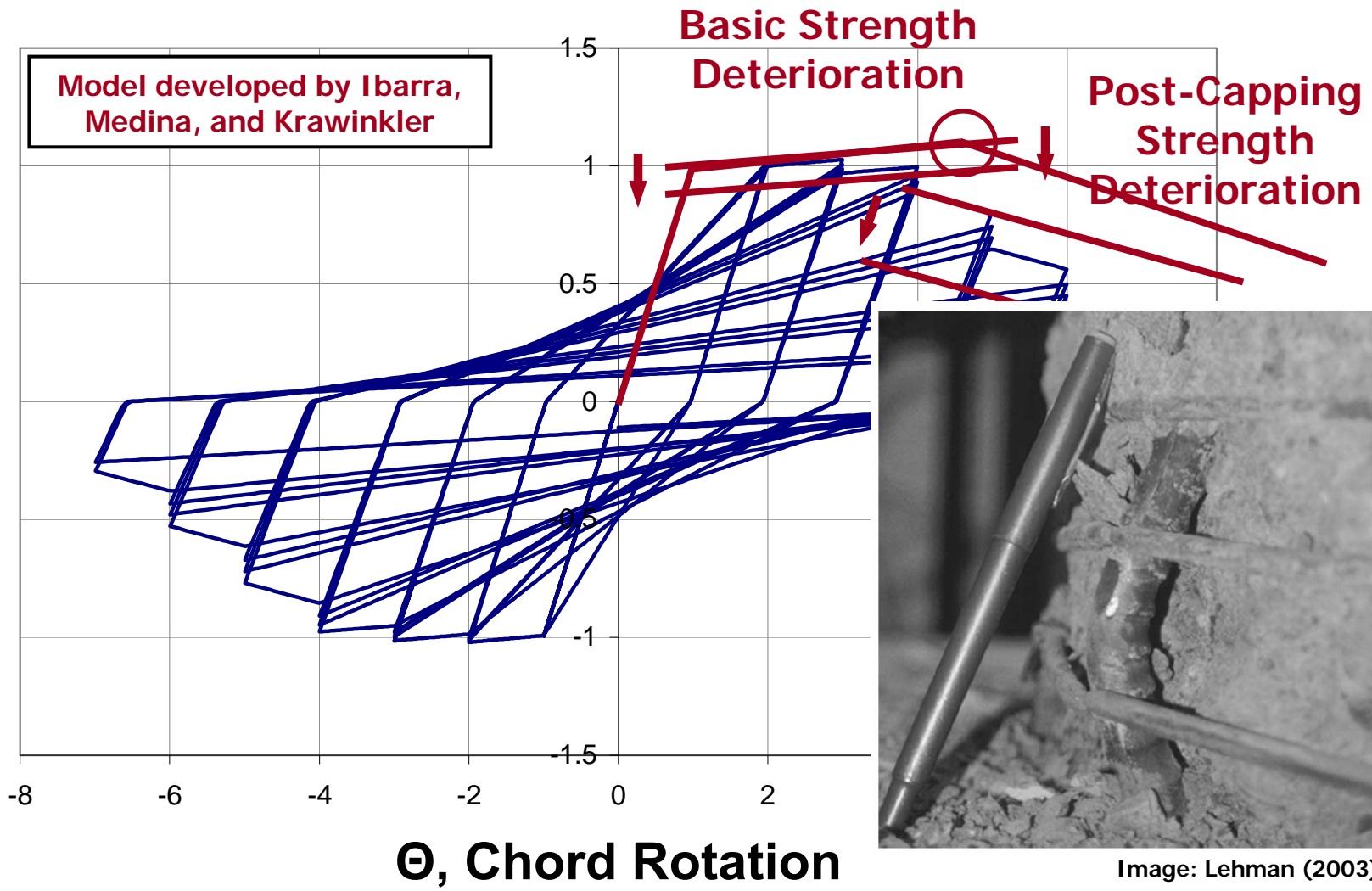


Image: Lehman (2003)

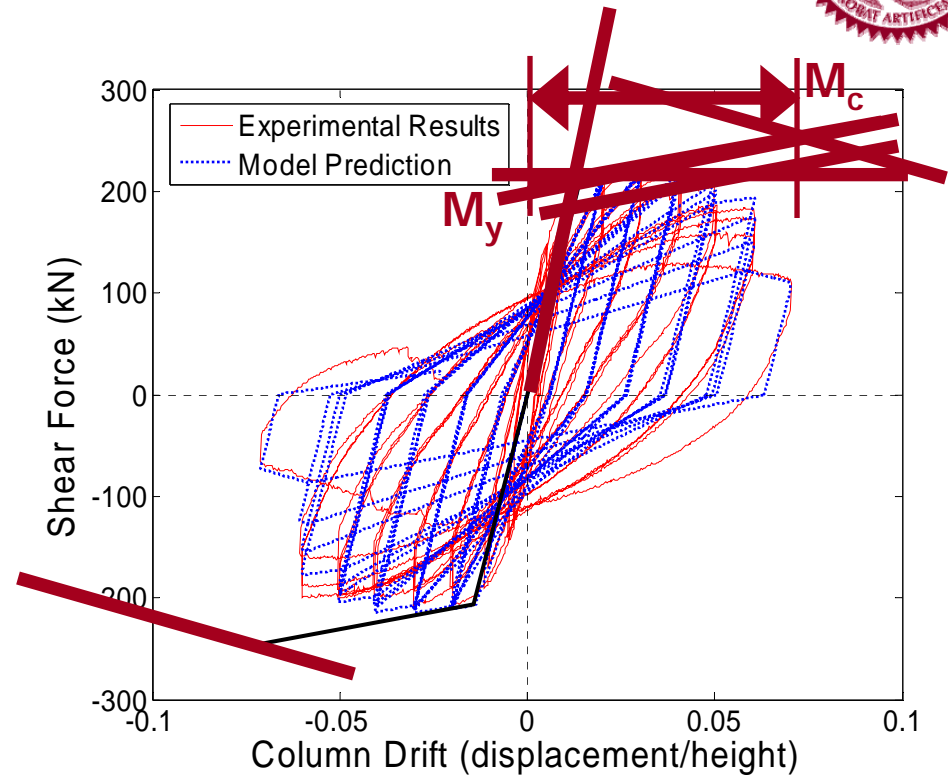


Structural Modeling: Model Calibrations

Model calibrated to 255 flexure and flexure-shear tests from PEER Structural Performance Database (Berry and Eberhard)

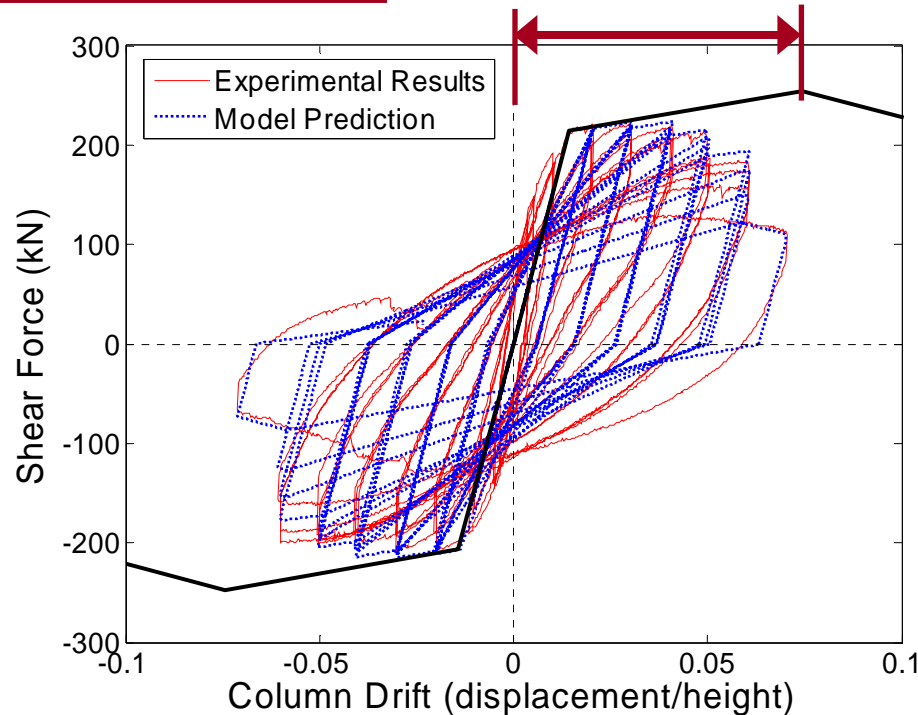
Model Parameters to be Predicted:

- Strength (easiest)
- Initial stiffness
- Post-yield stiffness (or M_c/M_y)
- Rotation capacity (total or plastic)
- Post-capping slope (or rotation capacity)
- Cyclic deterioration rate





Structural Modeling: Model Calibrations



$$\theta_{cap,tot} = 0.14(1 + 0.4a_{sl})(0.19)^v(0.02 + 40\rho_{sh})^{0.54}(0.62)^{0.01c_{uni}f'_c}$$

$$\sigma_{LN} = 0.46$$

a_{sl} – bond-slip ratio v is axial load ratio ρ_{sh} is the lateral confinement ratio f'_c is concrete strength

Haselton, C.B., A.B. Liel, S. Taylor Lange and G.G. Deierlein (2007f). *Beam-Column Element Model Calibrated for Predicting Flexural Response Leading to Global Collapse of RC Frame Buildings*, PEER Report 2007, Pacific Engineering Research Center, University of California, Berkeley, California, (in preparation).



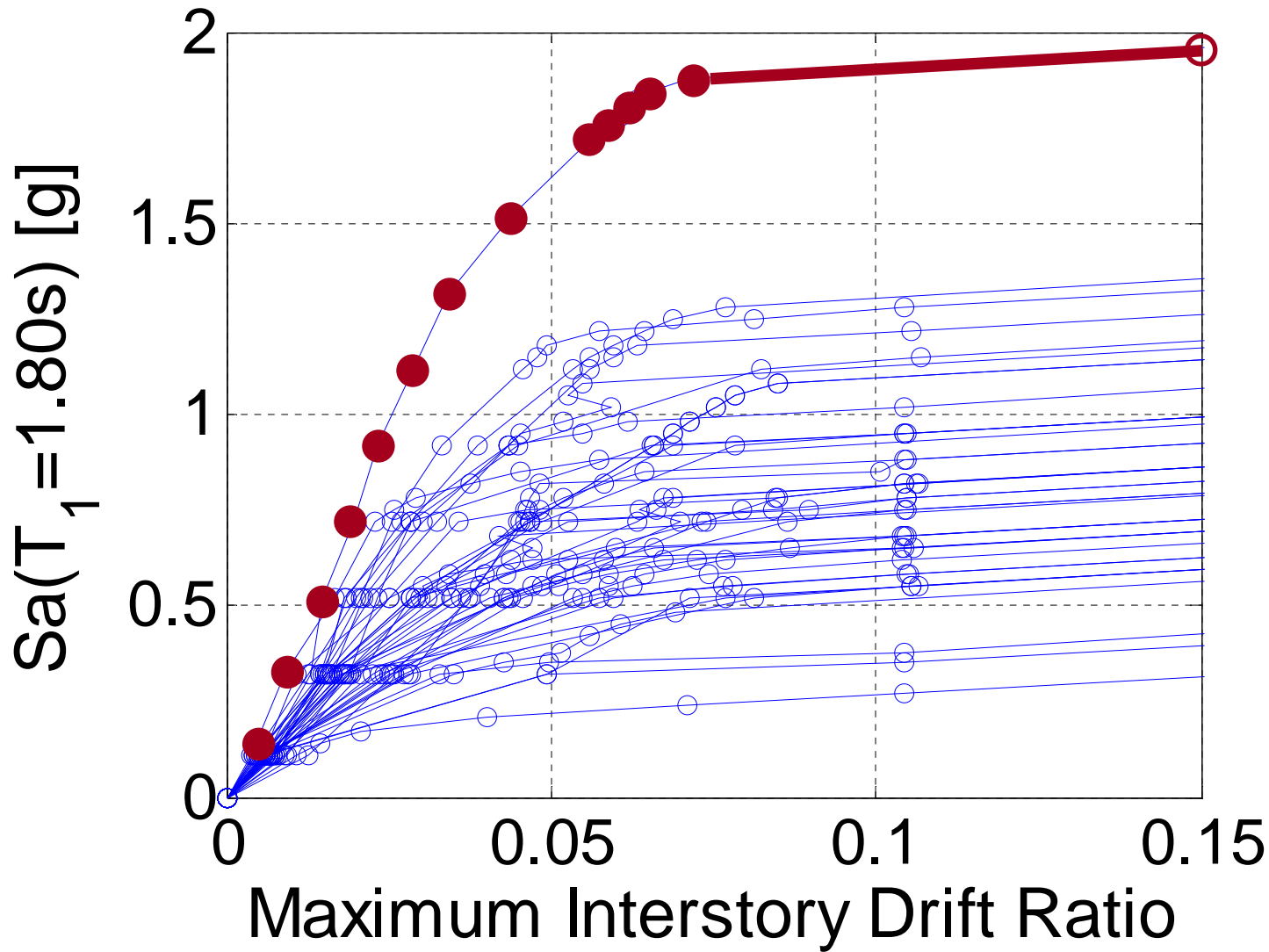
Structural Designs and Models

- ⇒ 30 RC SMF buildings designed per ASCE7-02 (and -05), to cover range of common design.
- ⇒ Heights: 1, 2, 4, 8, 12, and 20 stories
- ⇒ Space and perimeter frame systems
- ⇒ Bay widths: 20'-30' (20' typical)
- ⇒ Various strength and stiffness distributions over height

- ⇒ Look at sample results for 8-story space frame...



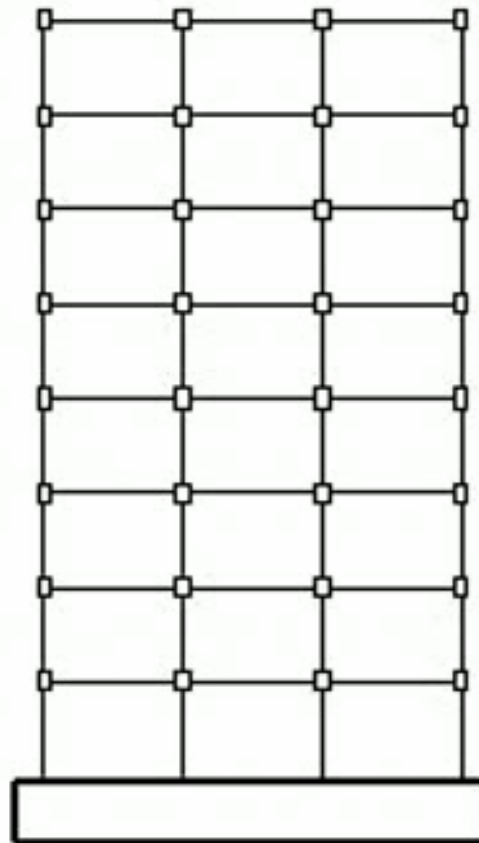
Collapse Performance Predictions: Method



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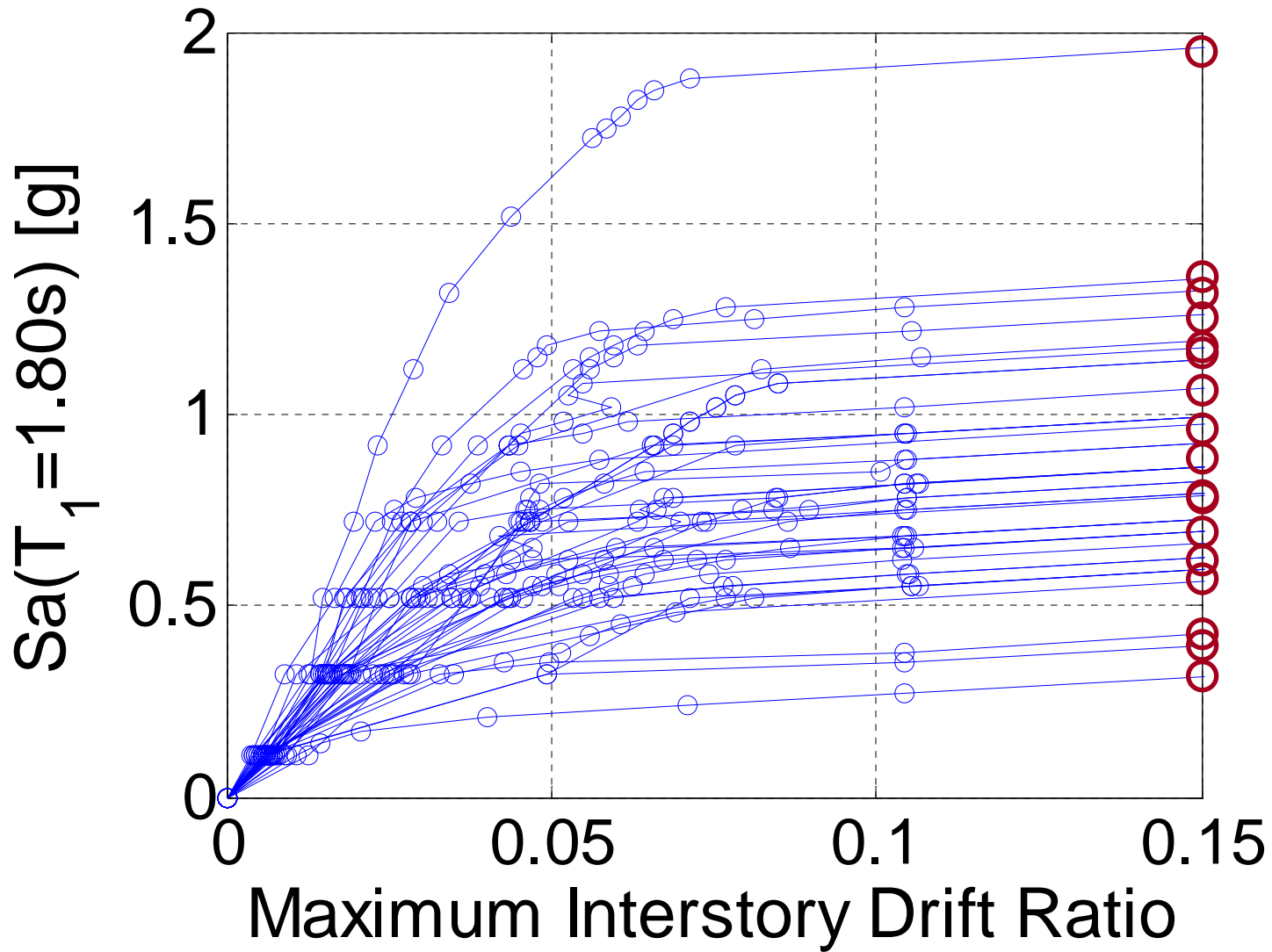


⇒ Collapse prediction for 8-story frame

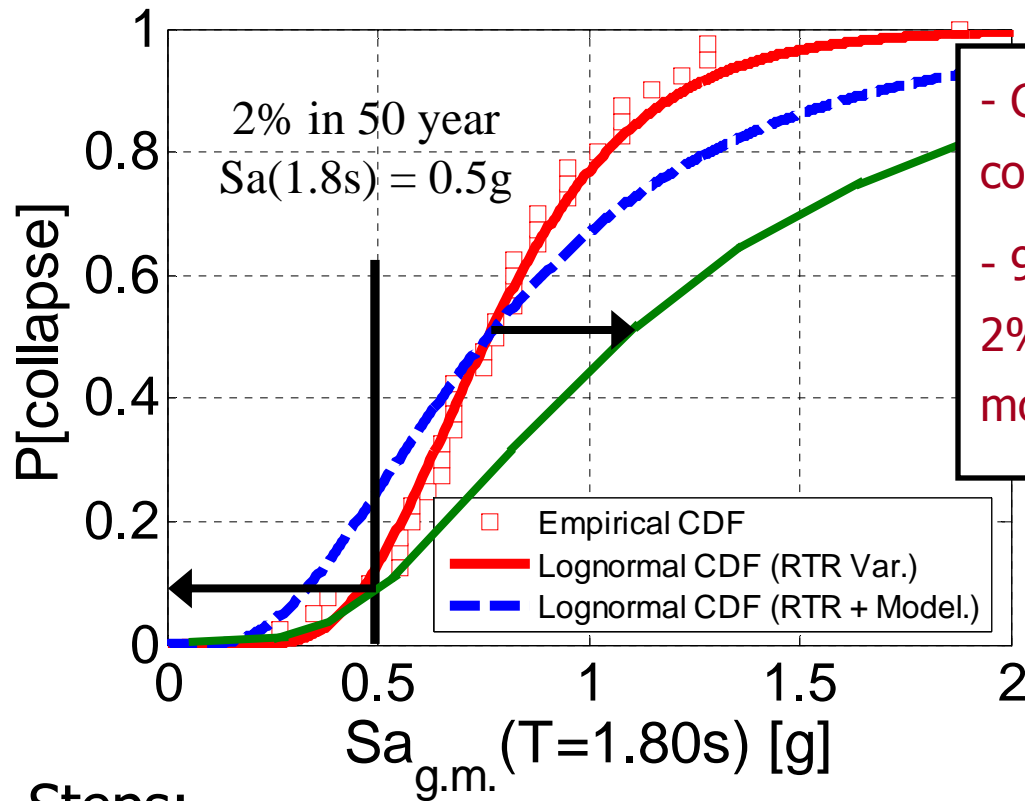




Collapse Performance Predictions: Method



Collapse Performance Predictions: Method



- Green CDF is best estimate of collapse capacity
 - 9% probability of collapse for the 2% in 50 year level of ground motion

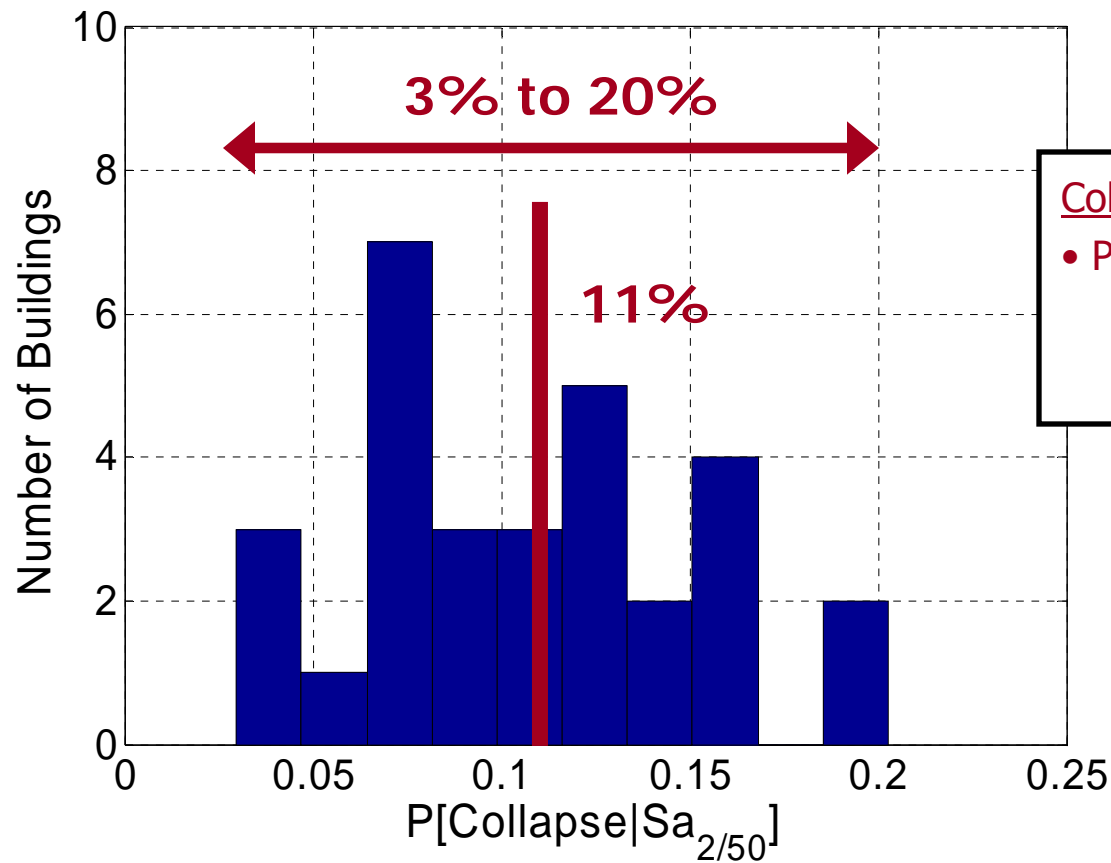
⇒ Steps:

- ⇒ Find the collapse capacities for the 40 ground motion records (red).
- ⇒ Increase variability to account for modeling uncertainty (blue).
- ⇒ Adjust capacity to account for proper spectral shape (green).

} Long stories



Collapse Performance Predictions: 30 Bldgs.



Collapse performance predictions:

- $P[\text{Collapse}|S_{a_{2/50}}]$:
 - Average: 11%
 - Range 3% to 20%



Collapse Performance Predictions: 30 Bldgs.

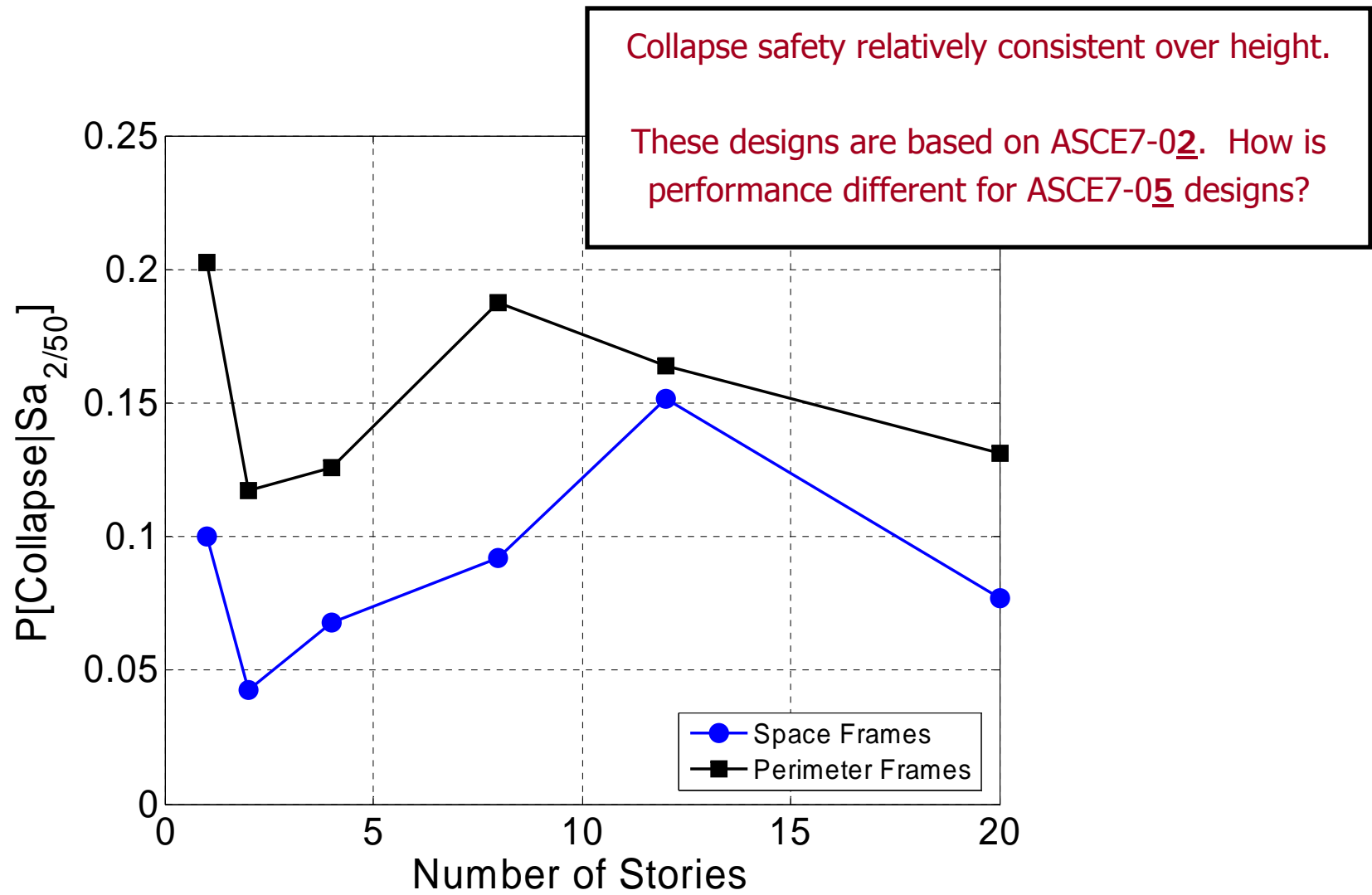
- ⇒ Given these collapse risk predictions, it is difficult to judge if RC SMF buildings are “safe enough.”
- ⇒ Now that we are moving toward directly predicting collapse, our profession (along with other stakeholders) needs to decide on an acceptable target for collapse risk.
- ⇒ ** Collapse prediction is complex, but these estimates give us a *good general idea* of collapse risk. A more important strength of these methods is for *relative* comparisons, such as effects of height.

Collapse performance predictions:

- P[Collapse | $S_{a_{2/50}}$]:
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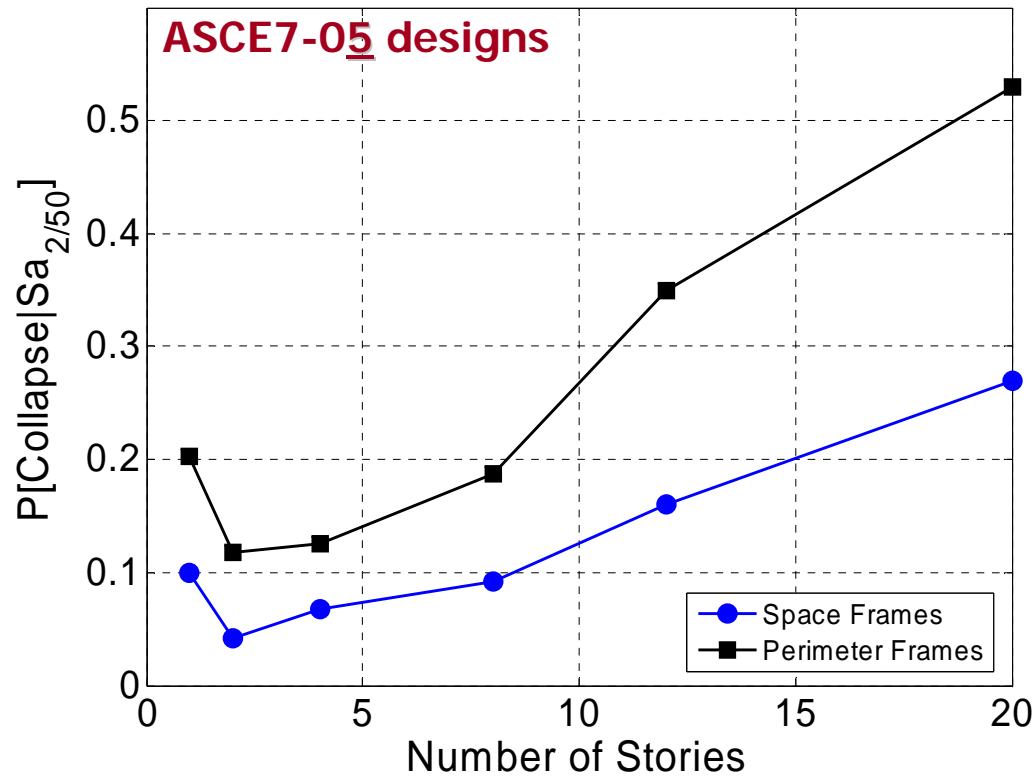


Collapse Performance: Effects of Height





Collapse Performance: ASCE7-05 Changes



Reason for Difference:

- In ASCE7-05, the minimum base shear demand was reduced in some regions (where $S_1 < 0.6g$).
- For example, the 20-story buildings are now designed for a base shear coefficient (C_s) of 0.024g instead of 0.044g.

Collapse Performance: Ranked Importance



Relative Importance of Design Assessment Item	Findings and Implications:
Structural modeling uncertainty	<ul style="list-style-type: none"> The <i>assessment</i> issues are more critical than the <i>design</i> differences within a class of buildings. Therefore, if we define acceptance criteria for collapse risk, we would also need to clearly define how the collapse risk should be predicted. Without clear guidance, the final conclusion of "safe" or "not safe" would depend 99% on who did the assessment and what they considered.
Spectral shape adjustment	
Building height (1-20 stories)	
Space/perimeter frame	
Foundation fixity in design (pinned)	
Uniform size and reinforcement over	
Weak story (up to 65% strength)	
Bay spacing (20'-30')	



Key Findings, Development Needs

- ⇒ Collapse risk predictions for modern RC Special Moment Frames
 - ⇒ $P[C|Sa_{2/50}] = 3\% \text{ to } 20\%$, with average of 11%
- ⇒ Performance-Based Design/Assessment issues:
 - ⇒ Need to set an acceptable level for collapse risk, and provide clear guidance for collapse assessment methods.
 - ⇒ These are our primary objectives on the current Applied Technology Council (ATC) 63 Project.
- ⇒ Collapse predictions to quantitatively inform building codes (ASCE7-02 vs. ASCE7-05):
 - ⇒ Taller RC SMF buildings have higher collapse risk when designed by ASCE7-05 (at sites with $S_1 < 0.6g$).
 - ⇒ This suggests that the minimum base shear requirement was important for consistent safety of buildings with various height.



Closing

- ⇒ Thank you for your attention.
- ⇒ Questions/Comments/Suggestions?