

Assessing the Seismic Collapse Risk of Reinforced Concrete Frame Structures, Including the Effects of Modeling Uncertainties

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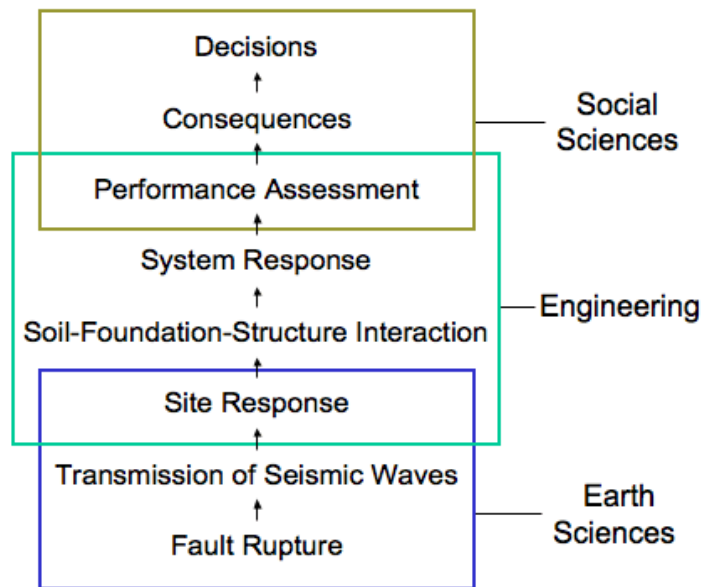




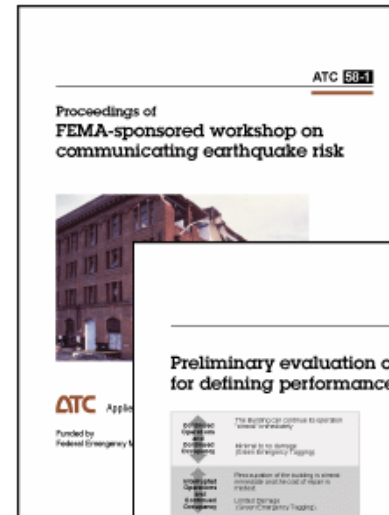
Outline

- Collapse Assessment Methodology
- Evaluation of the Effects of Modeling Uncertainties on Ductile Frame Structures (Monte Carlo)
- Comparison to Simplified Procedure (FOSM)

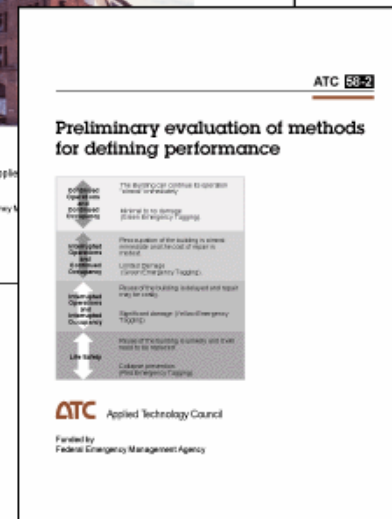
Performance-Based Earthquake Engineering



PBEE Methodology: Pacific Earthquake Engineering Research Center

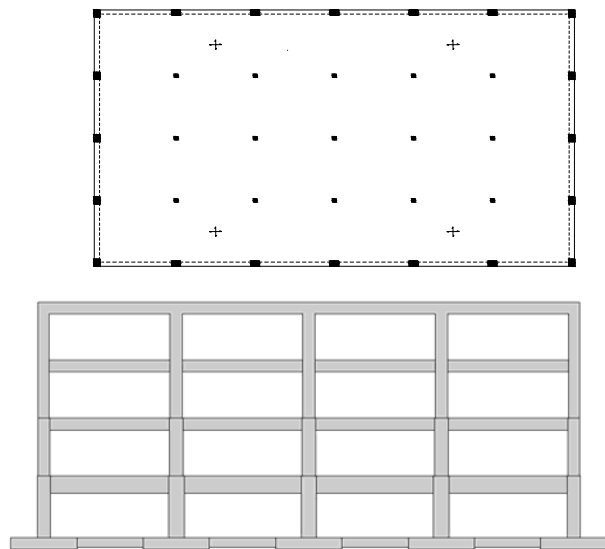


ATC-58: Development of Next-Generation Performance-Based Seismic Design Guidelines



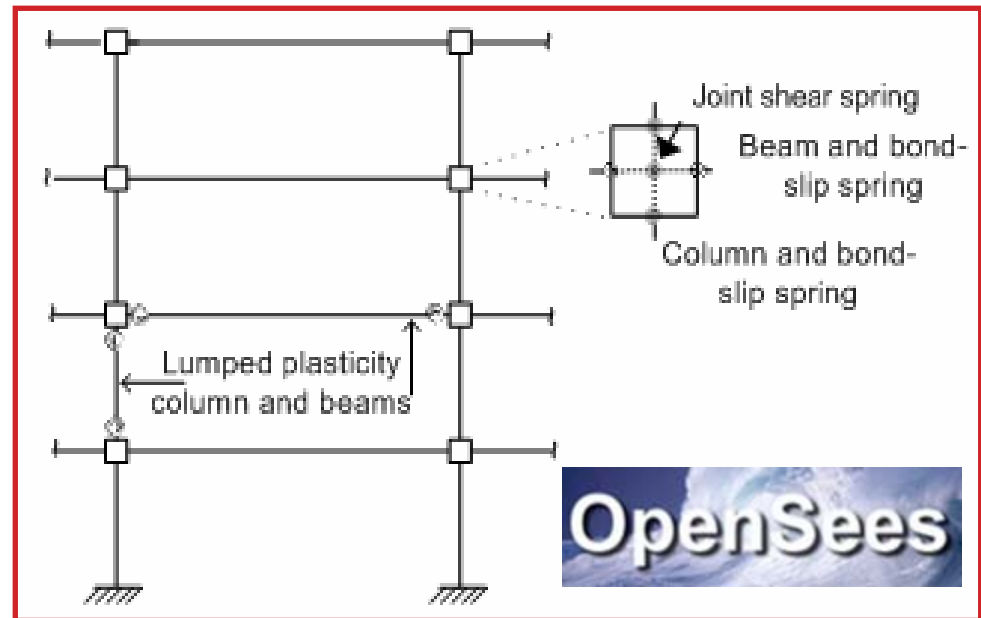
ATC-63: Quantification of Building System Performance and Response Parameters

RC Frame Example



Structural Design: Reinforced concrete ductile moment frame designed according to current code provisions (ASCE 7-05, ACI 318-02)

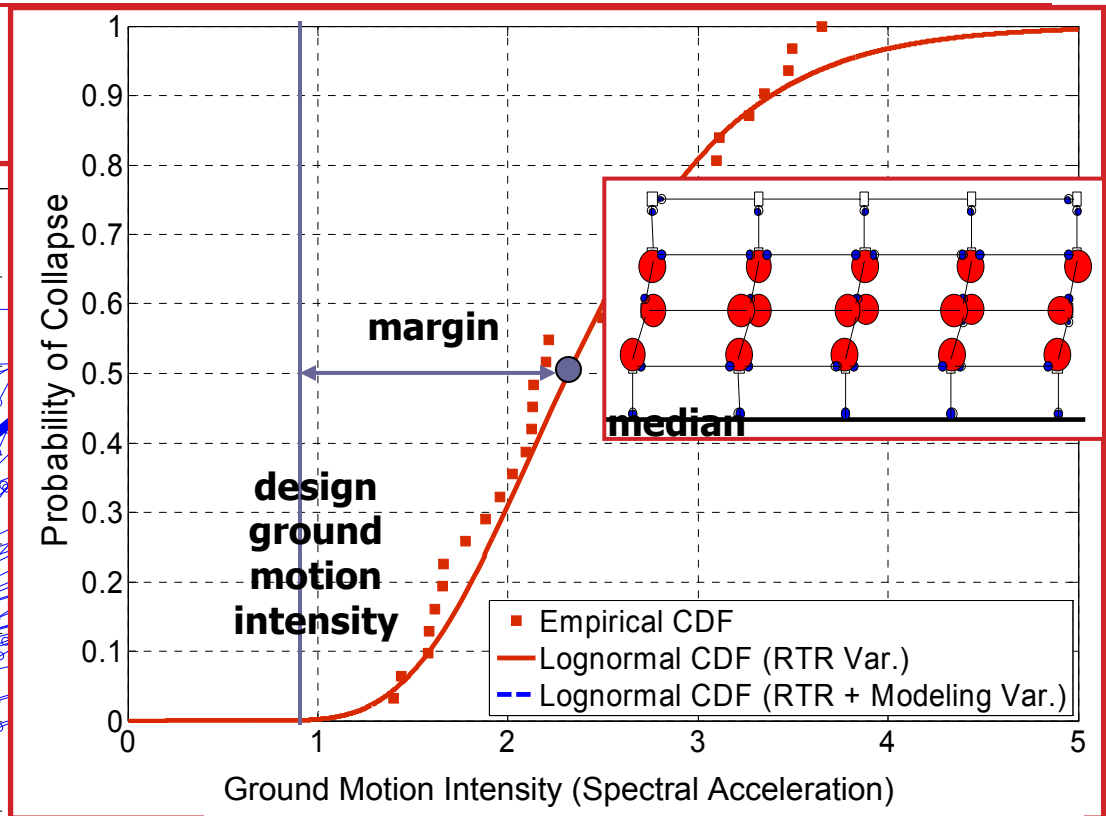
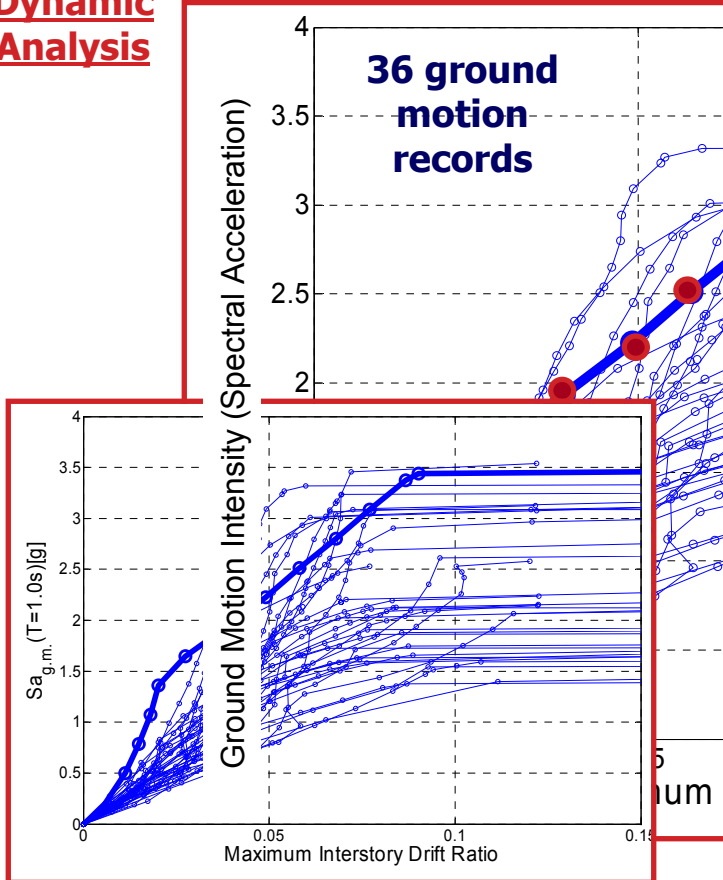
**Design Ground Motion Intensity (MCE):
 $S_a(T_1) = 0.9g$**



Nonlinear Analysis Models

RC Frame Example

Incremental Dynamic Analysis



Cumulative Distribution Function: Collapse

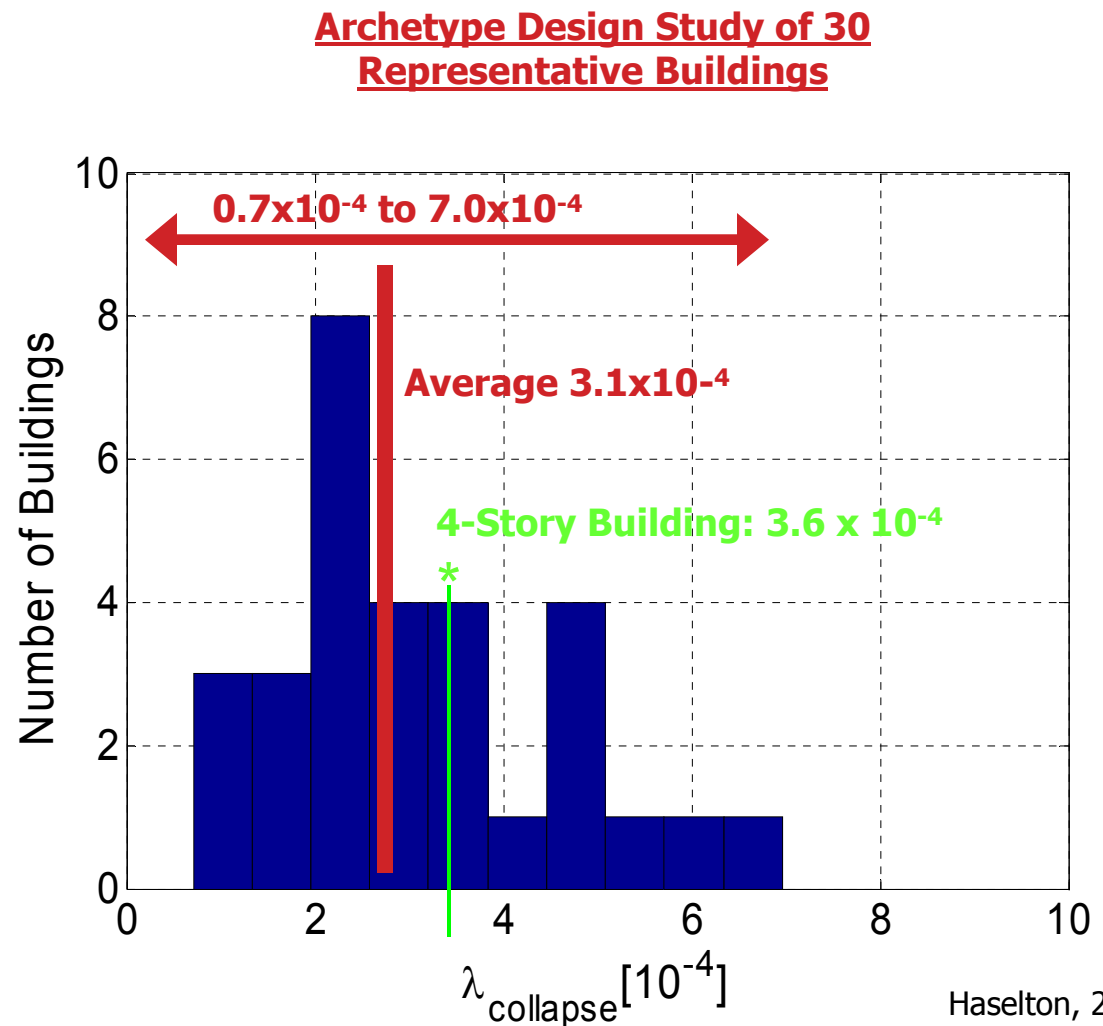
Maximum Interstory Drift Ratio

0.1

0.1

Metrics of Collapse Performance

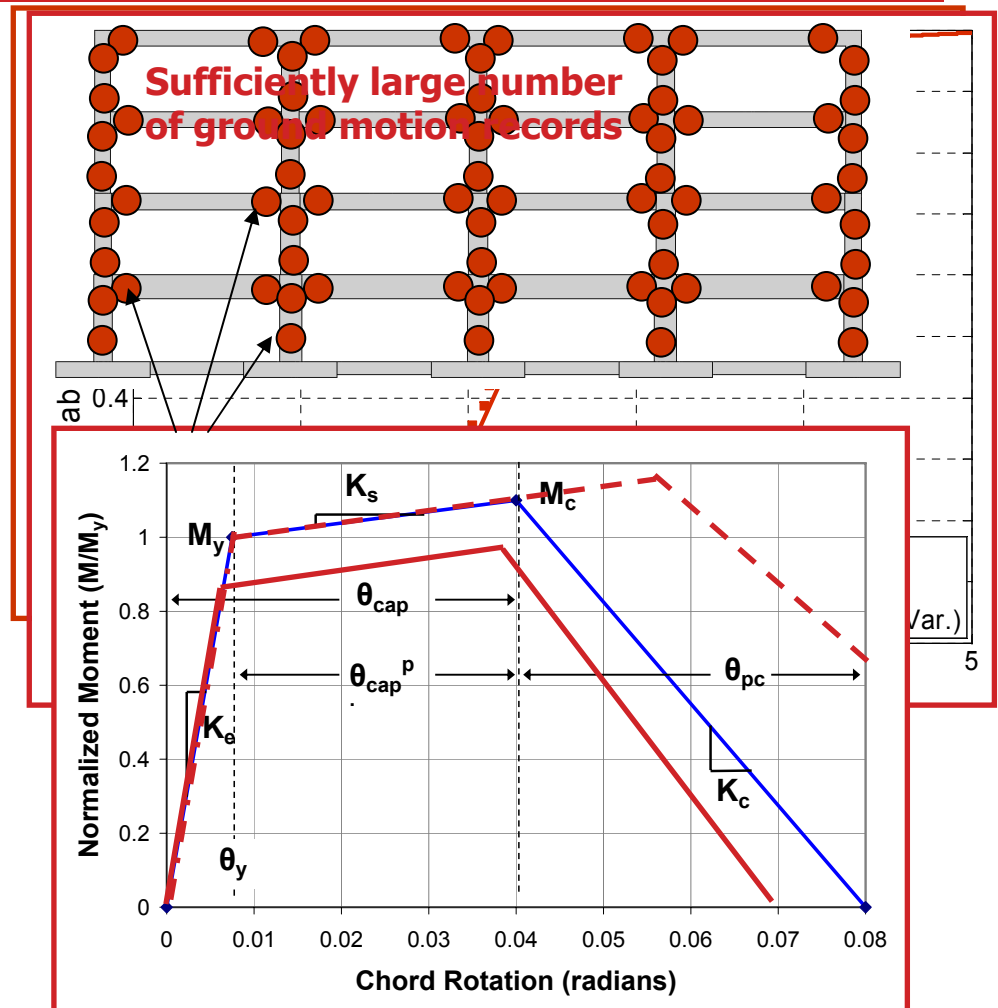
- **Margin:** ratio of median collapse capacity to design ground motion intensity
- **Probability of Collapse:** $P[\text{collapse}|\text{design ground motion intensity}]$
- **Mean Annual Frequency of Collapse** ($\lambda_{\text{collapse}}$)



Sources of Uncertainty

- Ground Motion
 - Intensity
 - Other characteristics of ground motion

- Modeling Uncertainties
 - Strength
 - Deformation Capacity
 - Damping, etc.



Plastic Hinge Spring Model

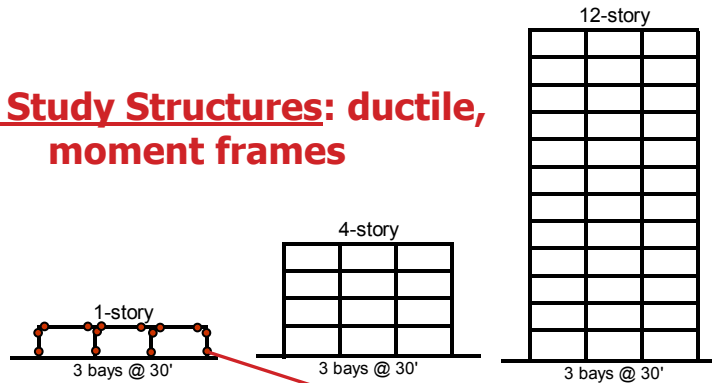


Treatment of Modeling Uncertainties

- Sensitivity Analysis
- FOSM
- Monte Carlo Simulation
- Monte Carlo Simulation with Response Surface Analysis

Study of Modeling Uncertainties

Case Study Structures: ductile, moment frames

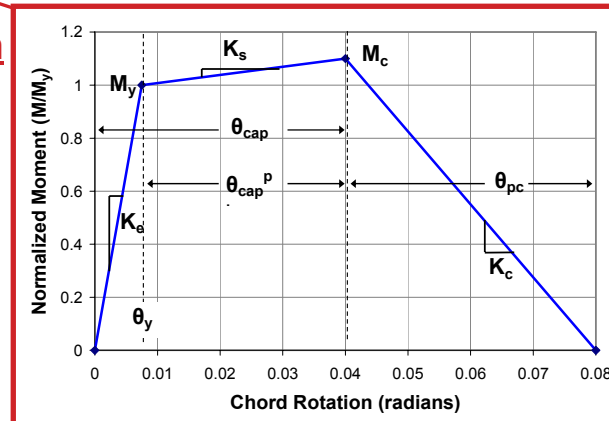


Uncertainties in Modeling Parameters for RC Elements

Parameter	σ_{in}
Effective Stiffness to Yield	0.28
Effective Initial Stiffness	0.33
Plastic Rotation Capacity	0.54
Total Rotation Capacity	0.45
Post-capping Rotation Capacity	0.72
Cyclic Energy Dissipation Capacity	0.49

Haselton et al., 2007

Identification of Key Random Variables



Strength

Stiffness

Deformation Capacity

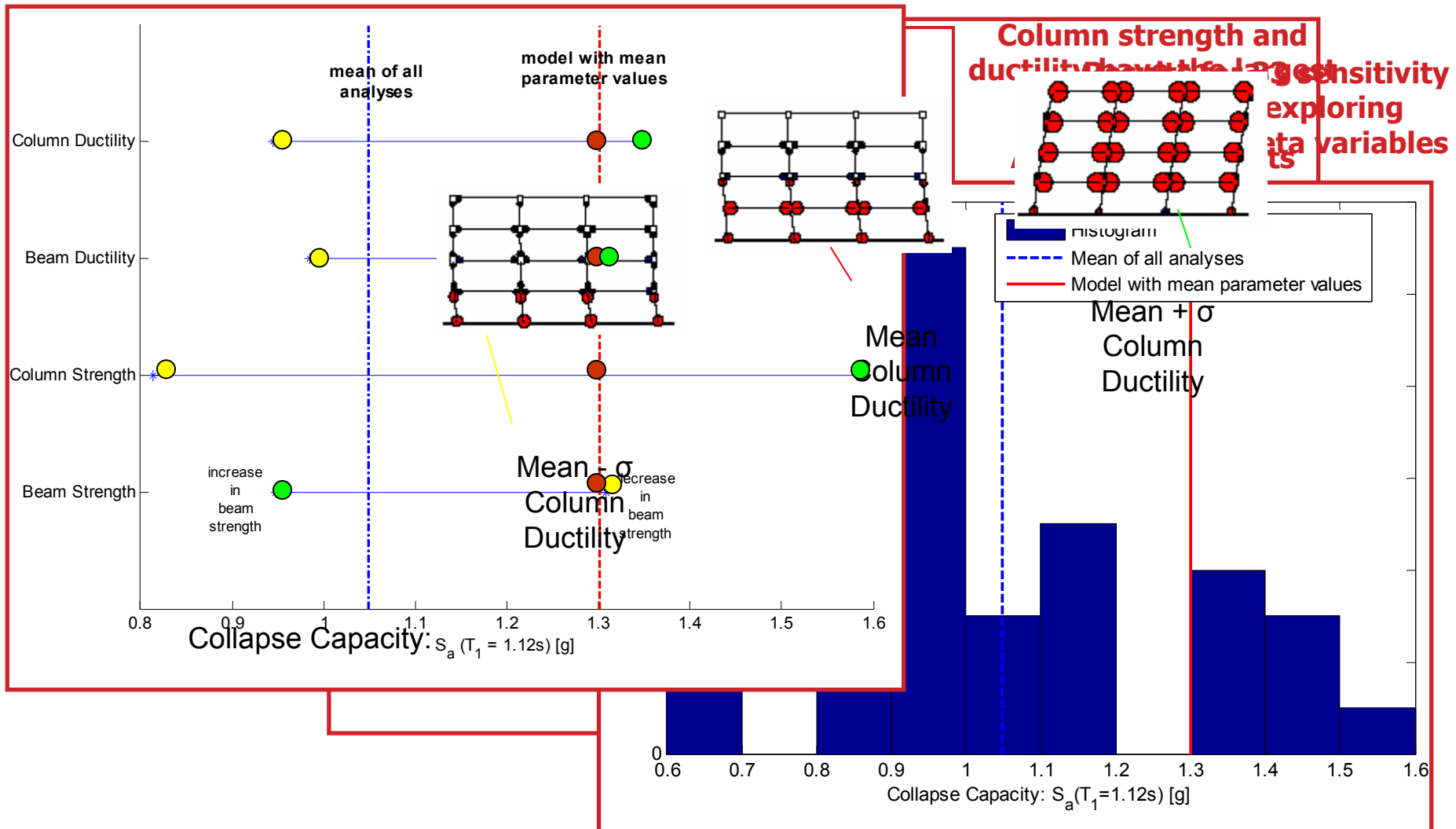
Cyclic Deterioration

Correlation Assumptions

Meta variables assume correlations at element and building level: "Beam Strength", "Beam Ductility", "Column Strength", and "Column Ductility"

Sensitivity Analysis

4-Story Frame

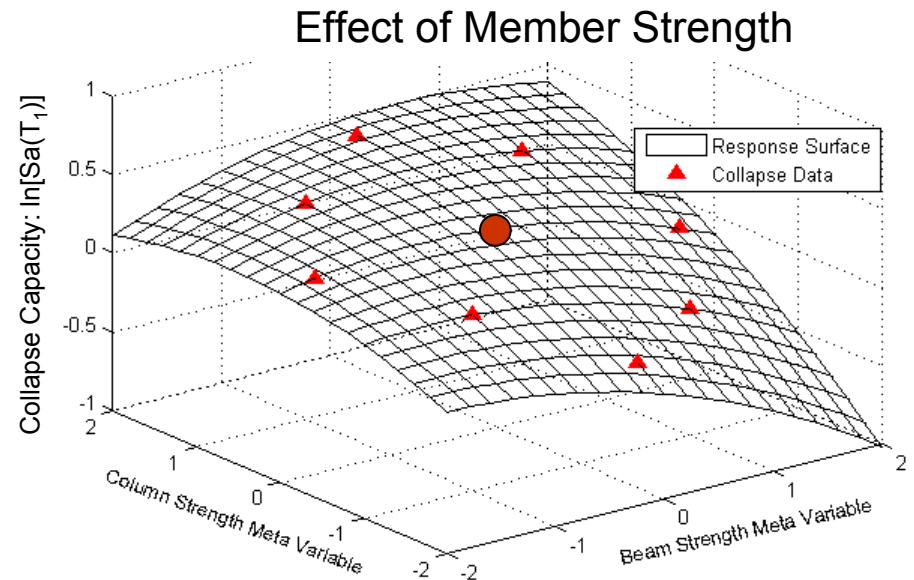
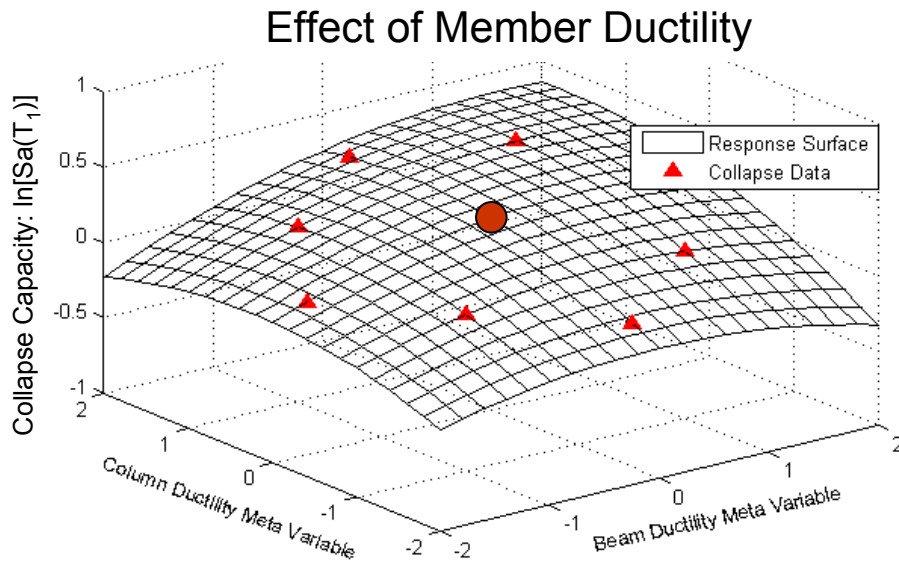


Response Surface

- Use regression analysis to predict collapse capacity from modeling random variables

$$Ln [\text{Median Collapse Capacity}] = 0.26 - 0.08(BS) + 0.20(CS) + 0.07(BD) + 0.01(CD) - 0.05(BS^2) + \dots$$

$R^2 = 0.99$



Monte Carlo Simulation

Create collapse response surface (obtained from nonlinear sensitivity analyses)

Obtain realizations of lognormally distributed meta random variables

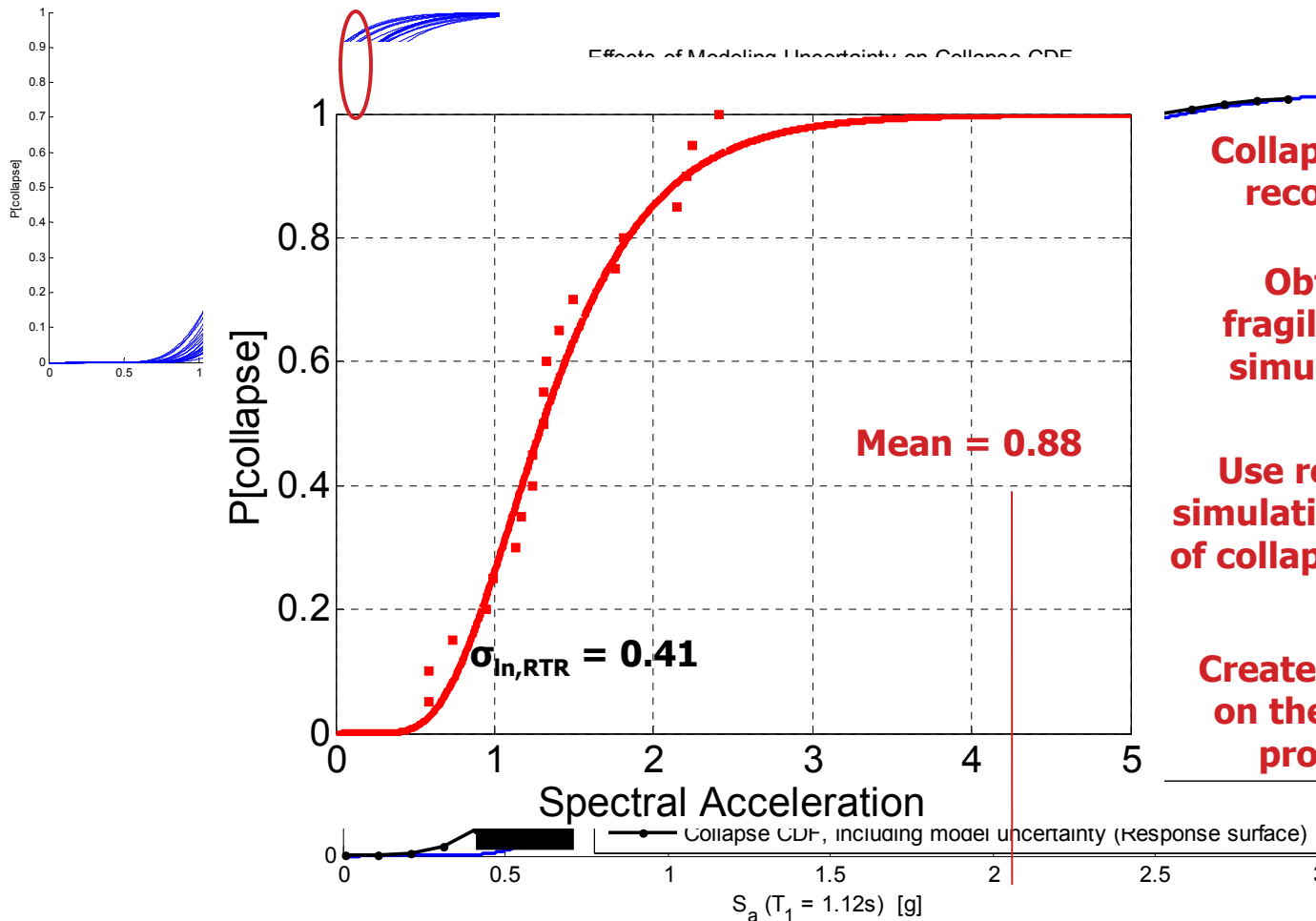
Correlation assumptions between meta random variables

Obtain prediction of collapse capacity from response surface

Repeat 10,000 times

Create Collapse Fragility from Simulation Results

4-Story Frame



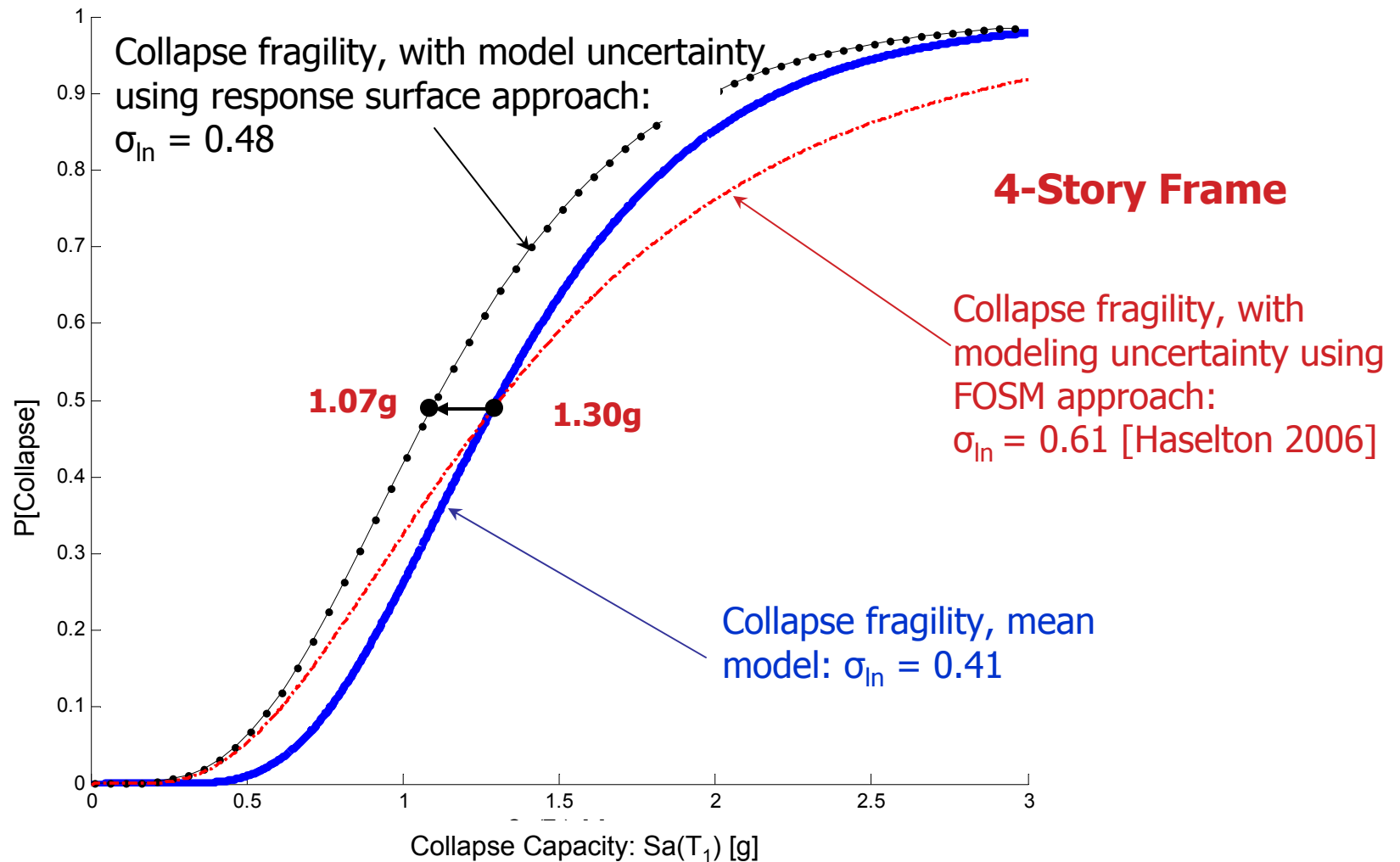
Collapse CDF with record-to-record uncertainties only

Obtain 10,000 collapse fragilities from Monte Carlo simulation ($\sigma_{\text{In,RTR}}$ assumed constant)

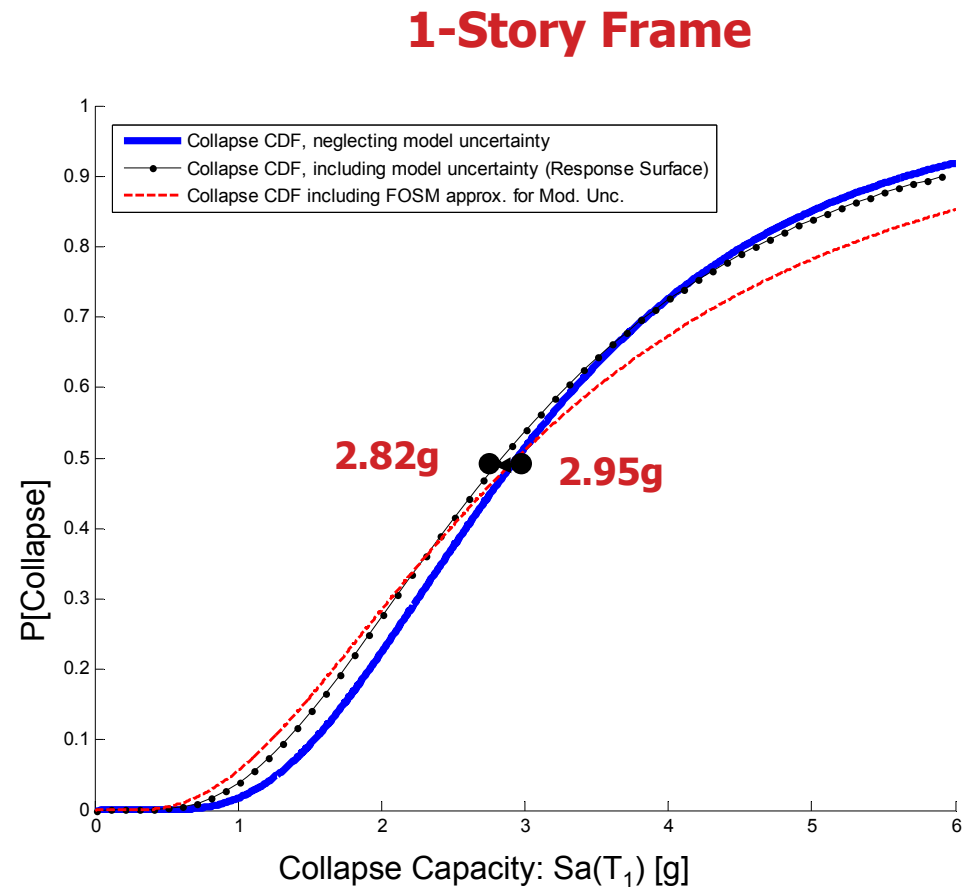
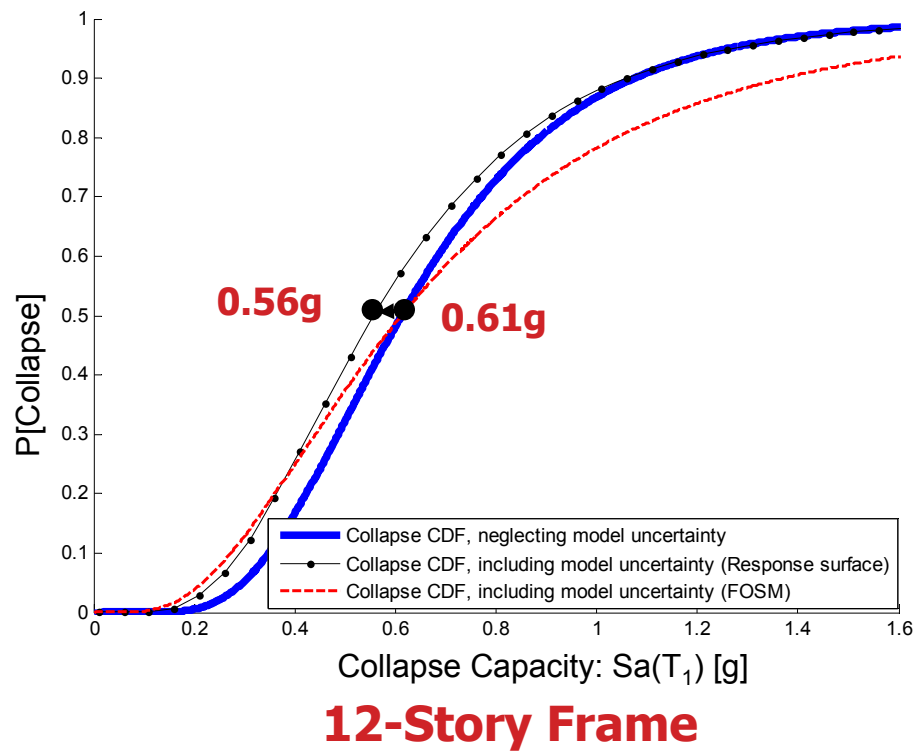
Use results of Monte Carlo simulation to create histogram of collapse probabilities at each S_a level

Create collapse fragility based on the expected value of the probability (at each S_a)

Effects of Modeling Uncertainty

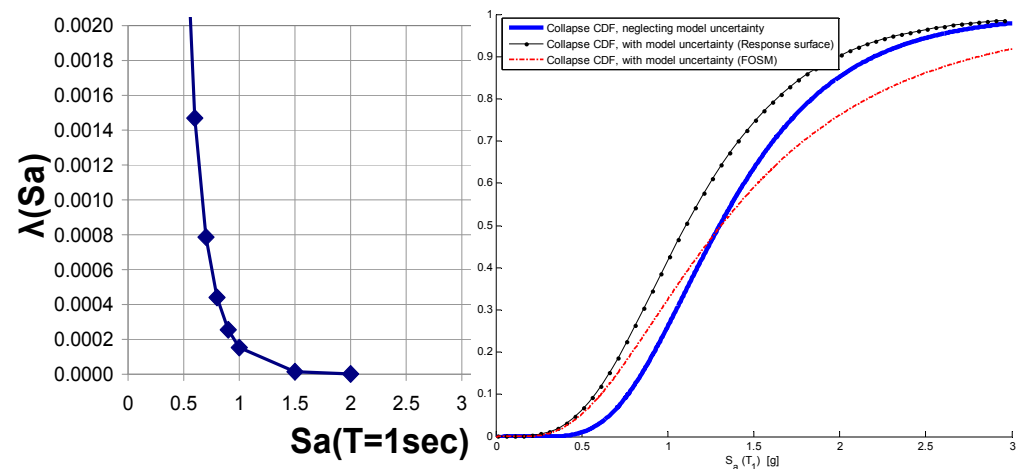


Effects of Modeling Uncertainty



Effects of Modeling Uncertainty

Num. of Stories	Effect of Modeling Uncertainty in this Study		$\lambda_{collapse} (x 10^{-4})$		
	% change in median	% change in dispersion	No consideration of modeling uncertainty	FOSM ³ , where $\sigma_{In,modeling} = 0.45$	This study
1	-5%	16%	1.2	4.1	1.6
4	-21%	23%	1.7	6.1	5.9
12	-9%	18%	6.7	17.0	12.0



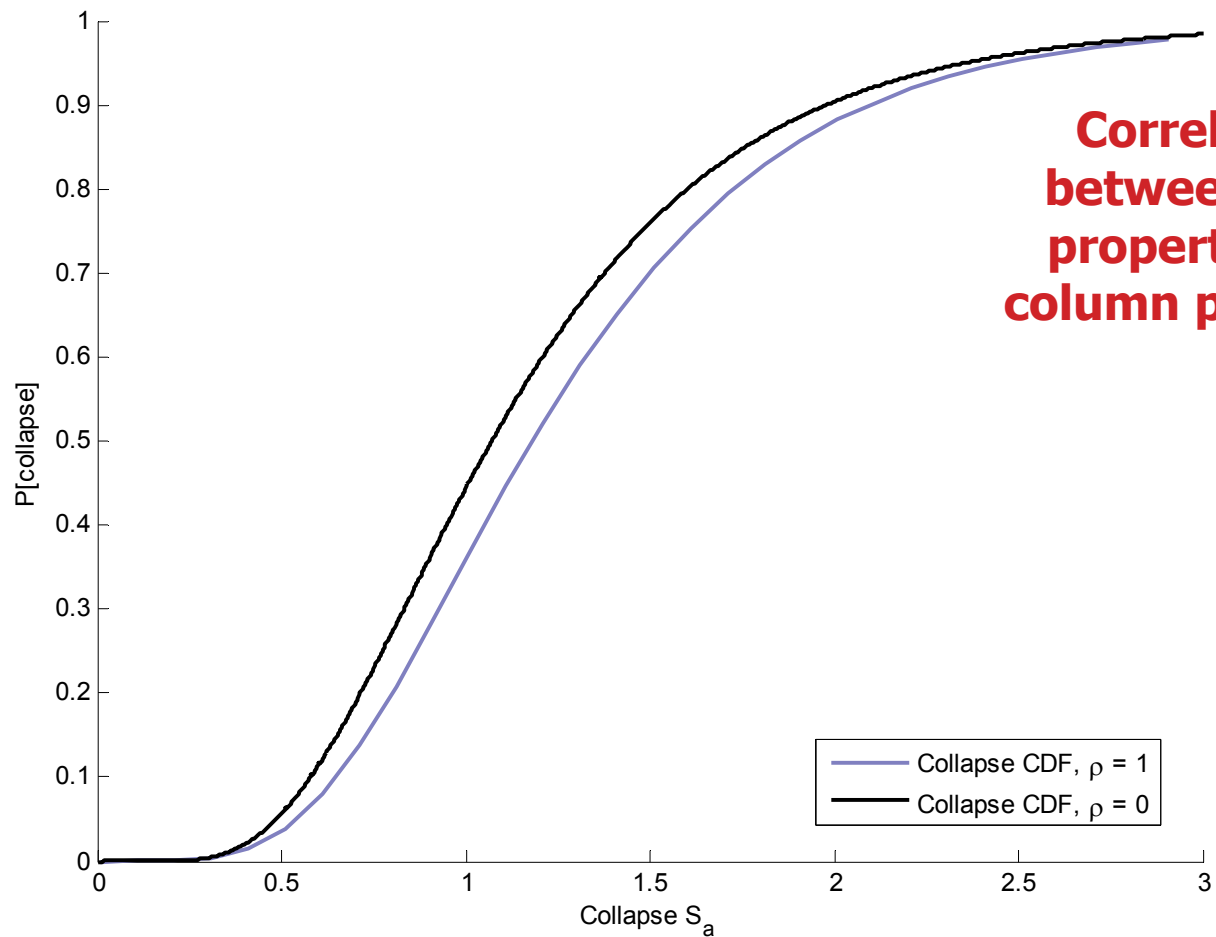


Conclusions

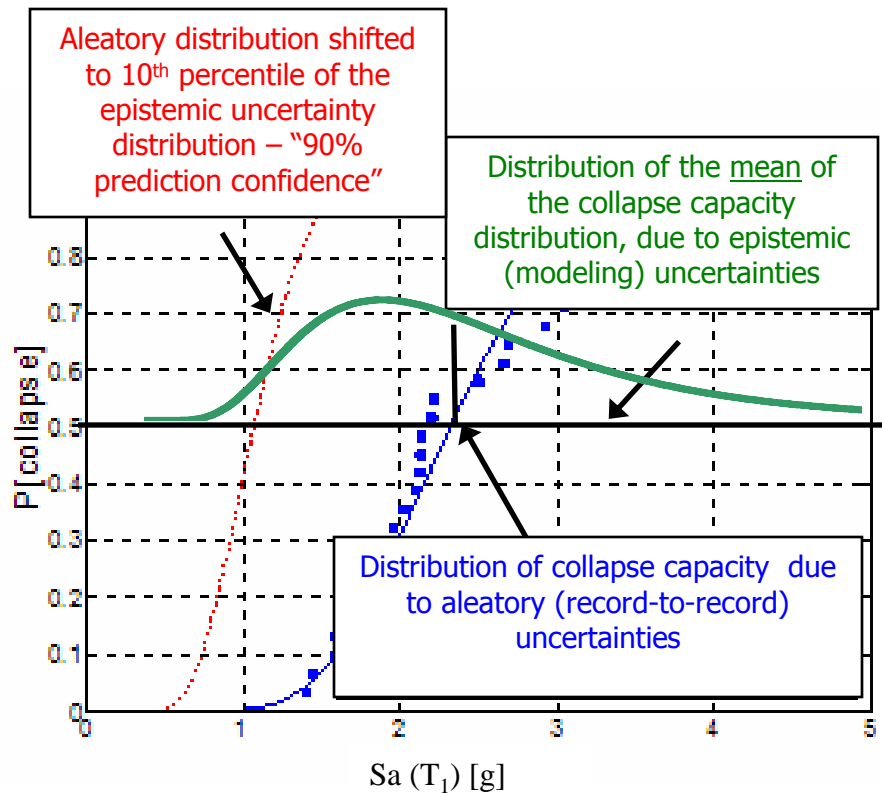
- Method can account for important sources of uncertainty
- Neglecting modeling uncertainties in analysis is non-conservative
 - Reduction in median collapse capacity
 - Increase in predicted dispersion
 - Effects depends on the structure, asymmetric effects of modeling random variables, variability in failure modes, etc.
- FOSM with mean estimates
 - Provides a reasonable approximation for ductile structures in some cases
 - Not likely to be a good approximation for non-ductile (existing) structures
- Future studies: non-ductile structures, effects of building level correlation assumptions, simplified procedures



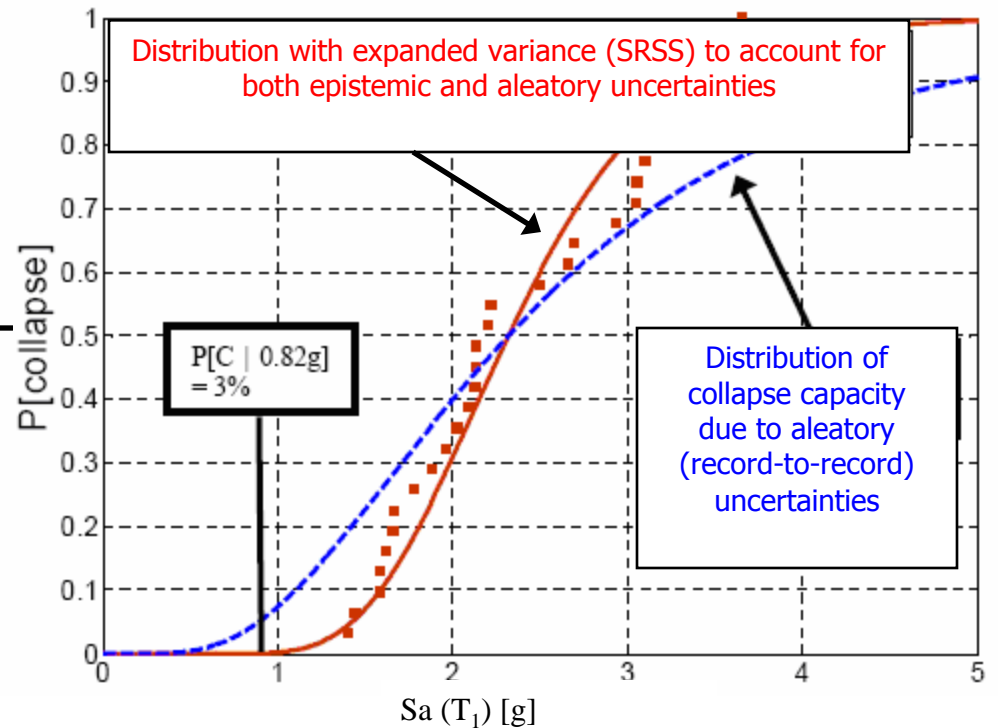
Correlations



Treatment of Modeling Uncertainties



Confidence Interval Approach



Mean Estimates Approach