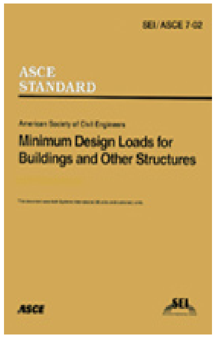
Use of PBEE to Assess and Improve Building Code Provisions

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with contributions by

Curt Haselton & Abbie Liel
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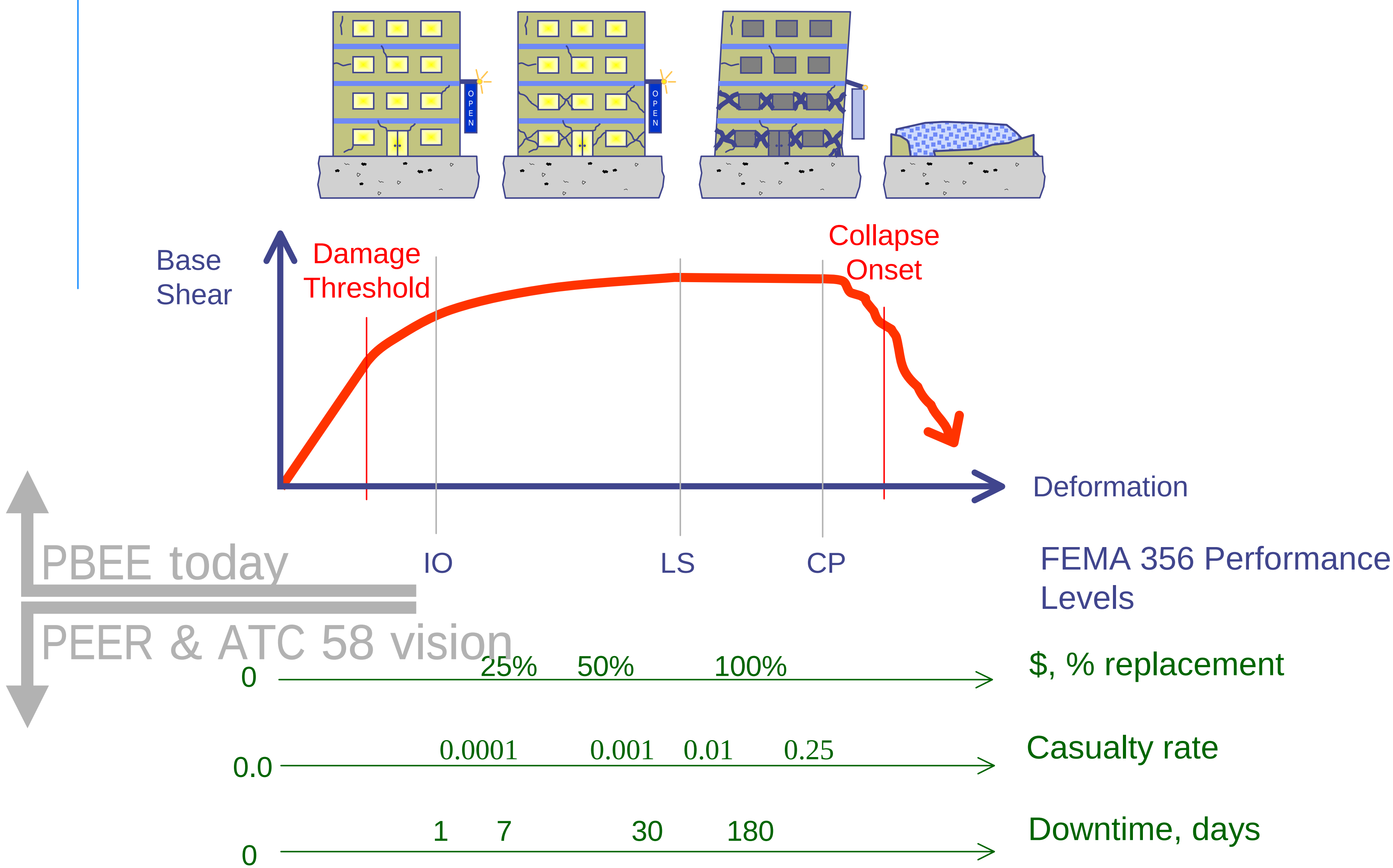
Long Term: PBEE Standards and Practice



Nearer Term: Code Improvements & Evolution

- Benchmarking Building Performance Implied by Design Codes for New Buildings
  - Basis for improving/refining current provisions
  - More informed decision making for designing “beyond the code” using enhanced performance systems
  - ATC 63: Quantification of Building System Performance and Response Parameters (for new systems and materials)
- Improvement of 1st-generation PBEE Approaches (e.g., FEMA 273/356)
  - Integration of new data and acceptance criteria using Nonlinear Time History (NLTH) Analysis
  - Definition, calibration and validation of codified models for nonlinear simulation
  - Improved procedures and criteria for selection and scaling of ground motions for NLTH analysis

PBEE COLLAPSE (SAFETY) Assessment

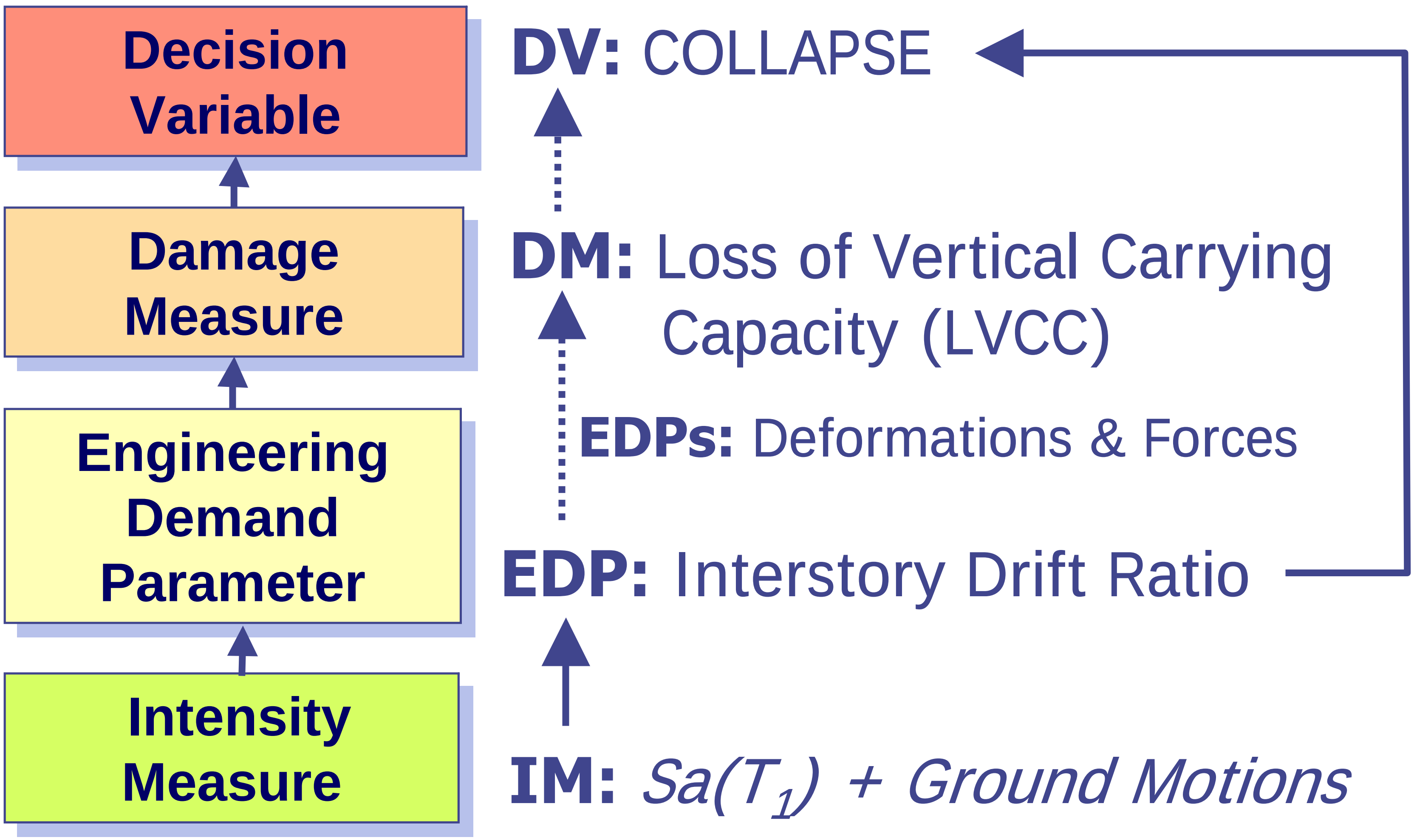
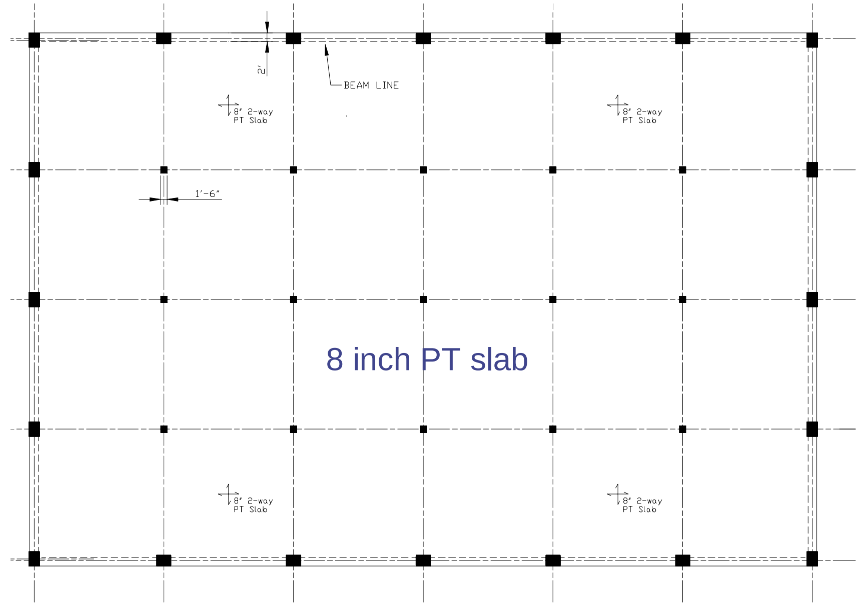


Illustration – 4 Story SMF Building

- Office occupancy
- Los Angeles Basin
- Design Code: 2003 IBC / 2002 ACI / ASCE7-02
- Perimeter Frame System
- Maximum considered EQ demands:
  - S_s = 1.5g; S_1 = 0.9g
  - $S_{a(2\% \text{ in } 50 \text{ yr})}$ = 0.82g
- Design V/W of 0.094g
- Maximum inelastic design drift of 1.9% (2% limit)



Typical Perimeter Frame Members

Beams: 32” to 40” deep

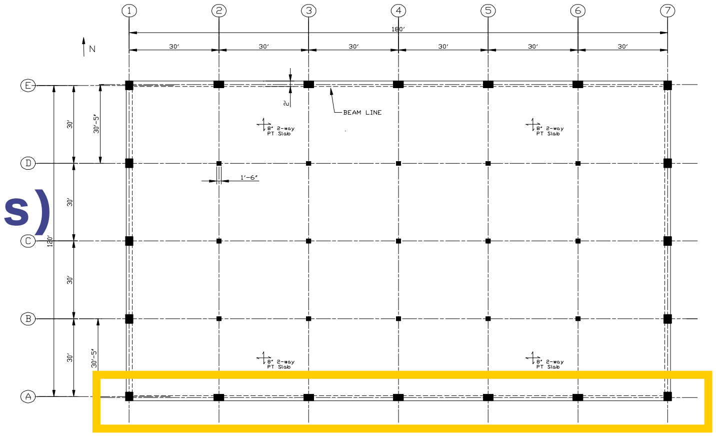
Columns: 24”x28” to 30”x40”

Governing Design Parameters

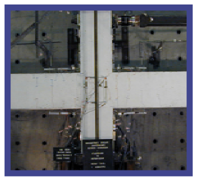
- Beams: minimum strength
- Column size: joint strength
- Column strength: SCWB
- Drift: just meets limit

Simulation Model

Gravity Frame(s)

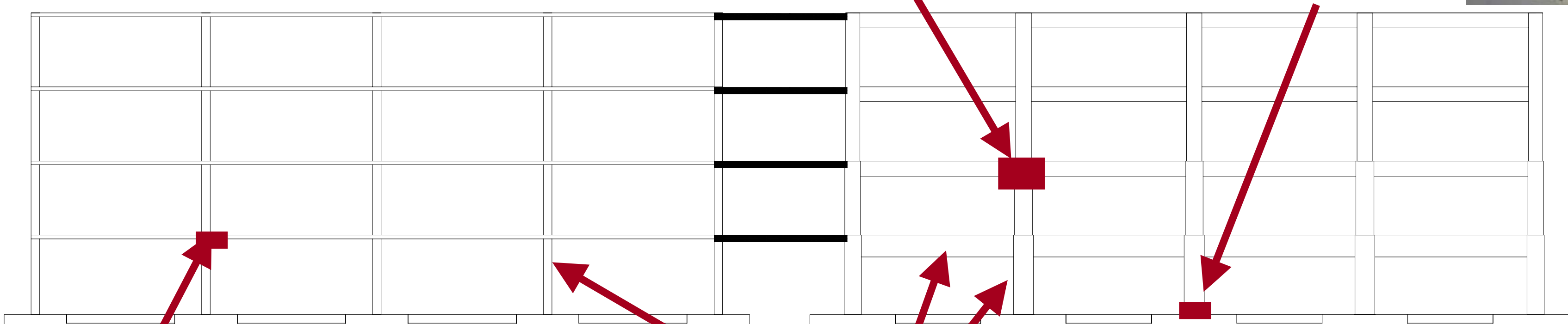


Lateral Frame



Joints with both bond-slip springs and shear springs

Column bond-slip springs



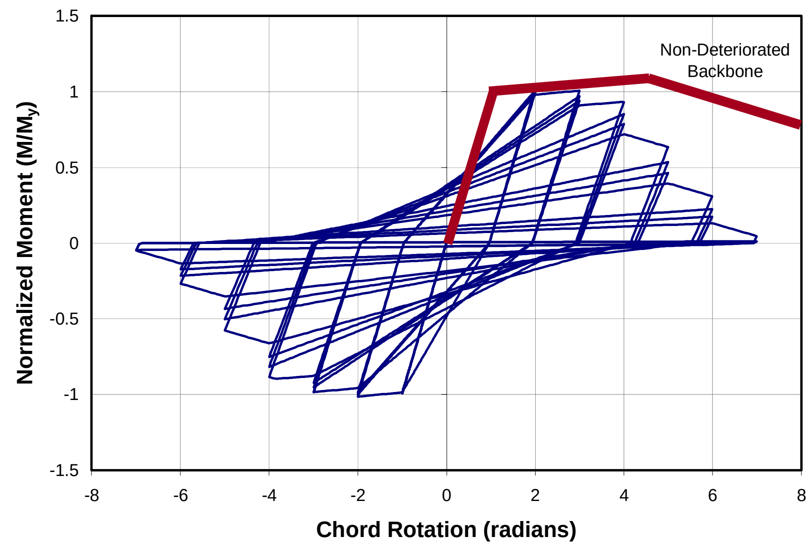
Gravity Frame(s)

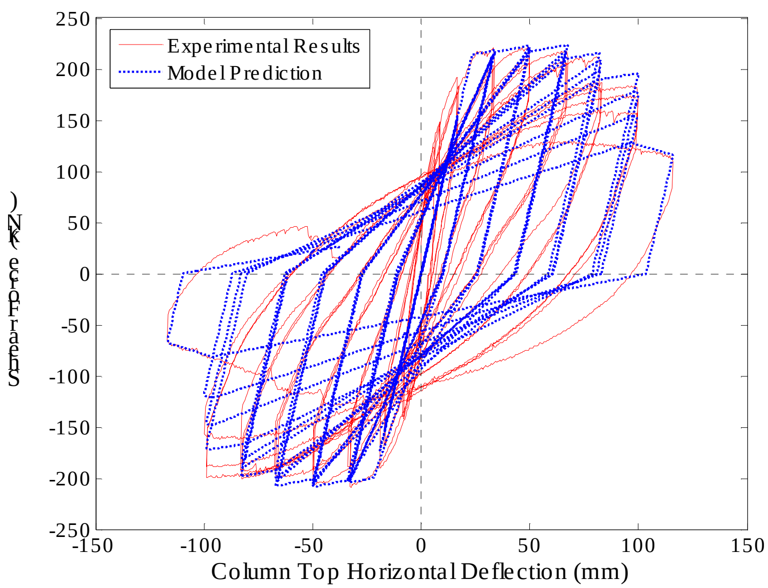
Lateral Frame

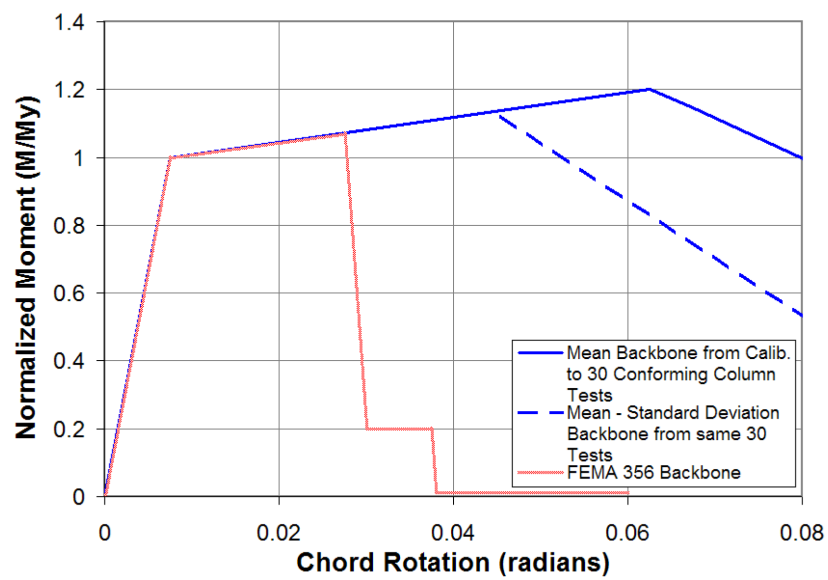
Lumped plasticity beam-columns

Realistic component simulation

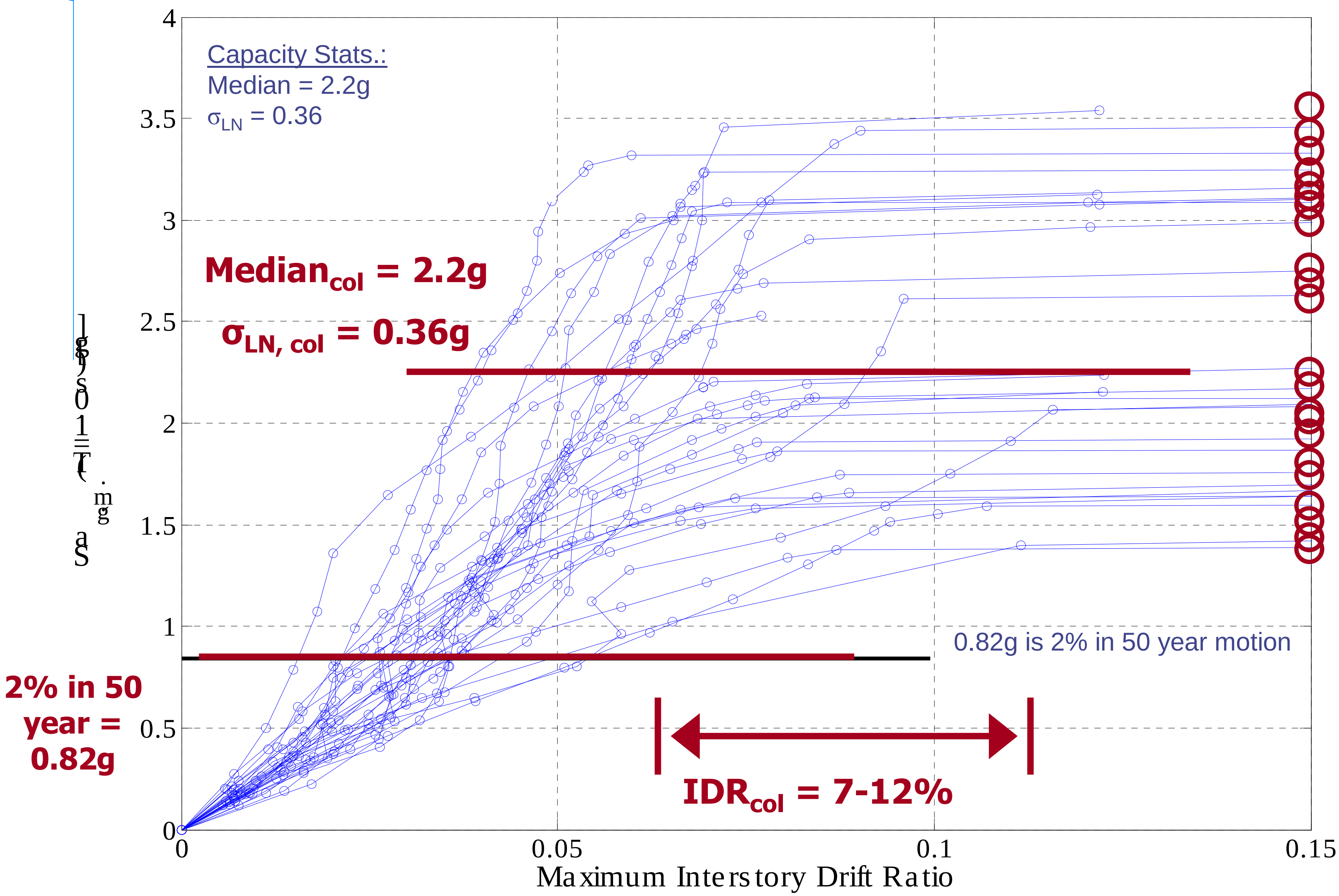
OR OTHER COMPUTER CODES



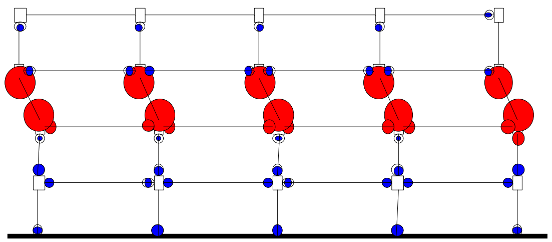




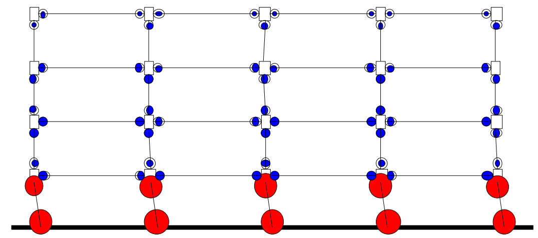
Incremental Dynamic Analysis – Collapse



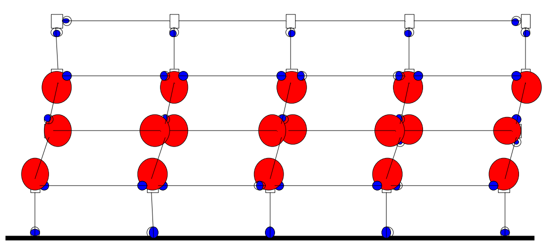
Sidesway Collapse Modes



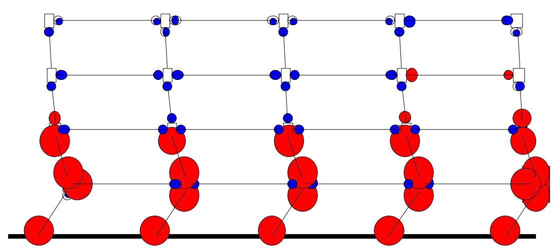
40% of collapses



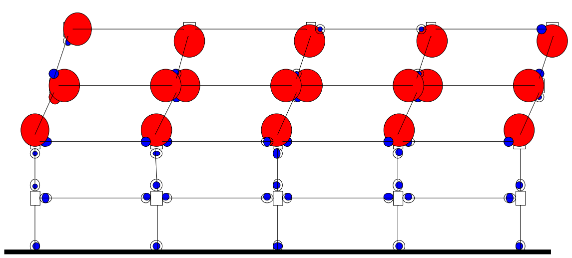
27% of collapses



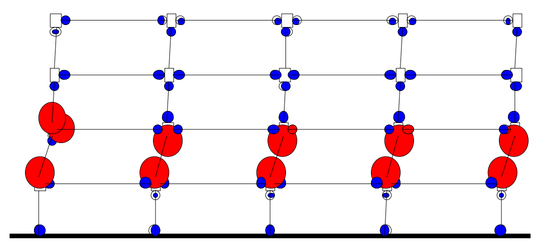
17% of collapses



12% of collapses

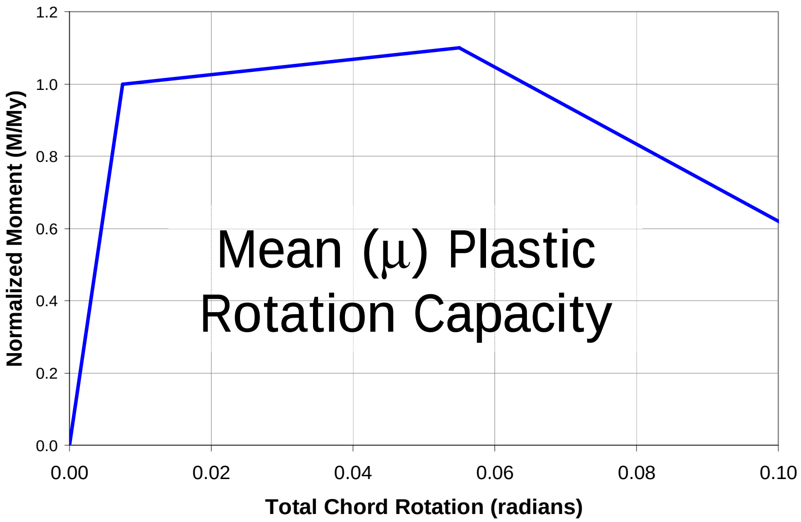


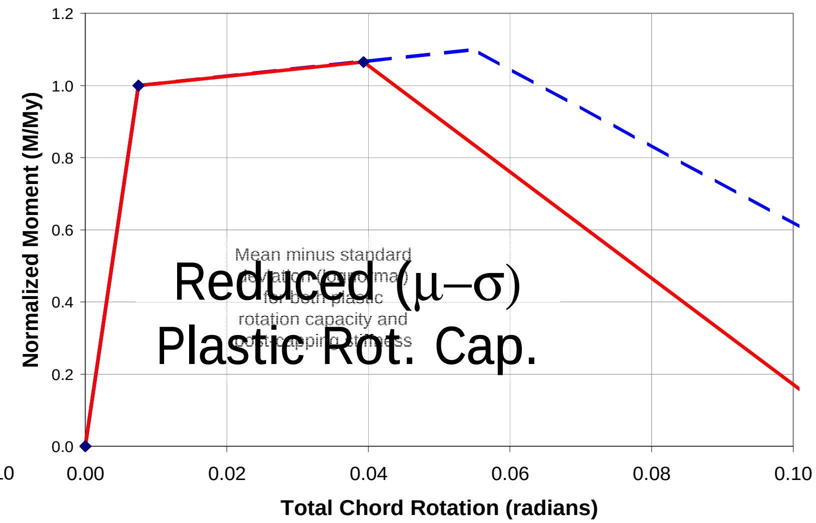
5% of collapses

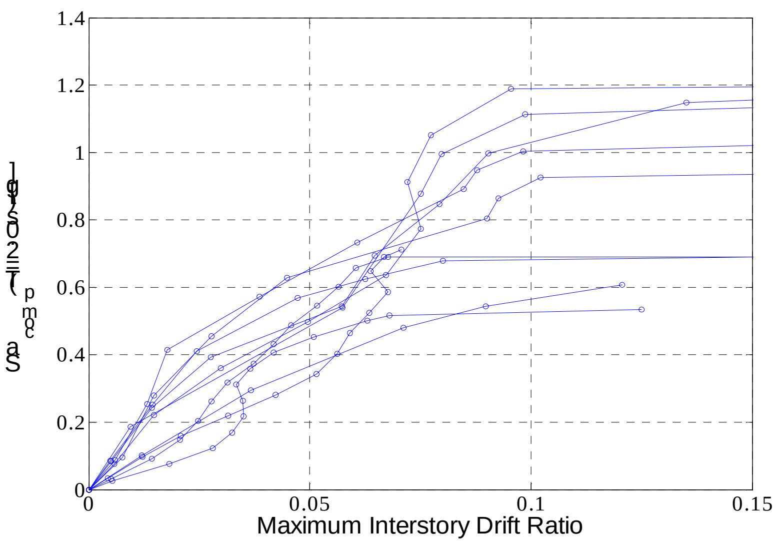


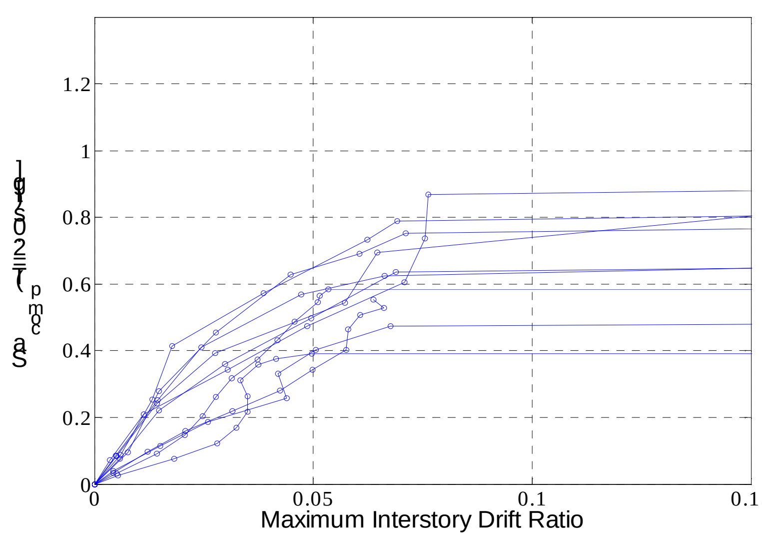
2% of collapses

Uncertainty – Plastic Rotation Capacity

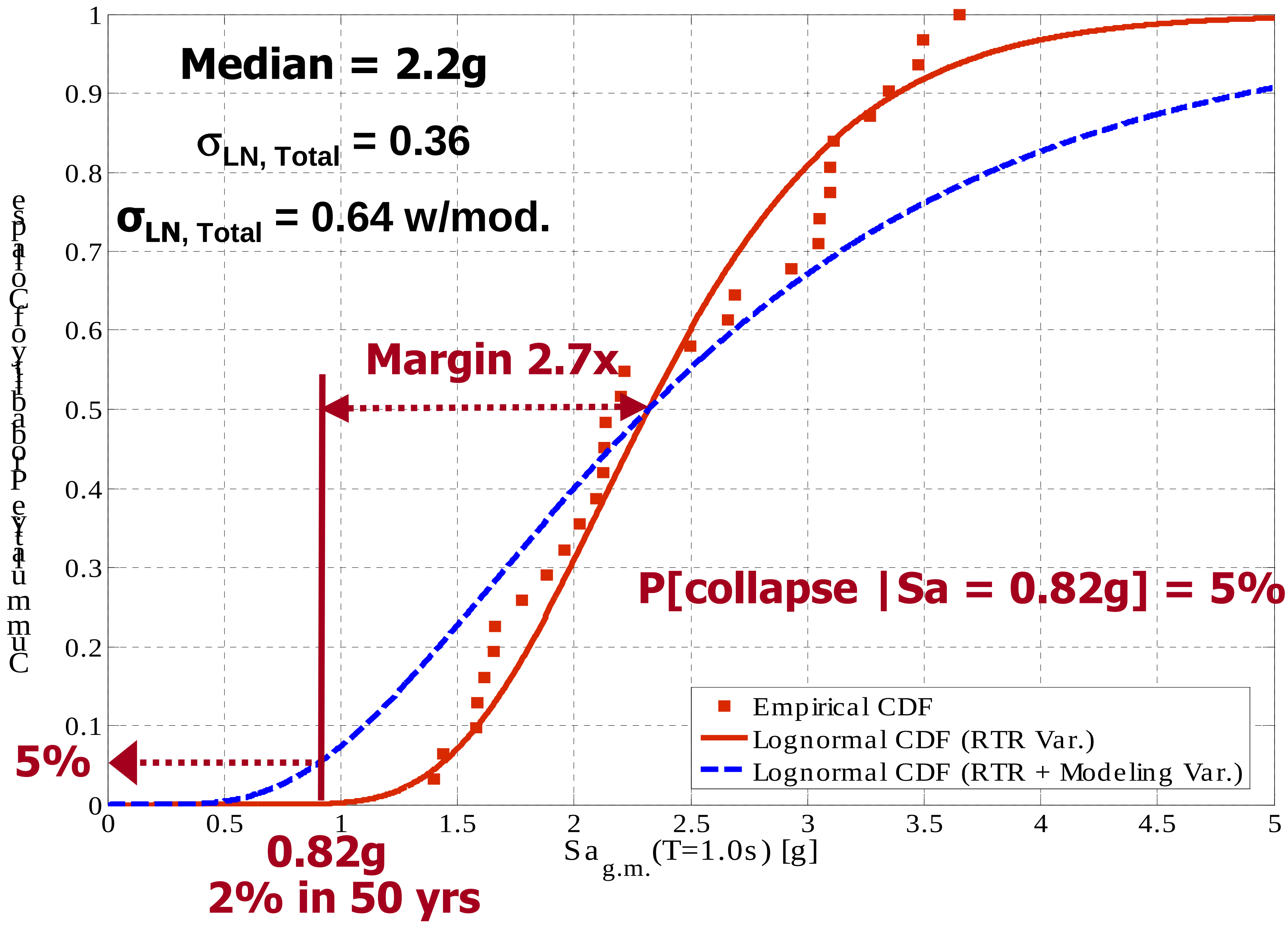




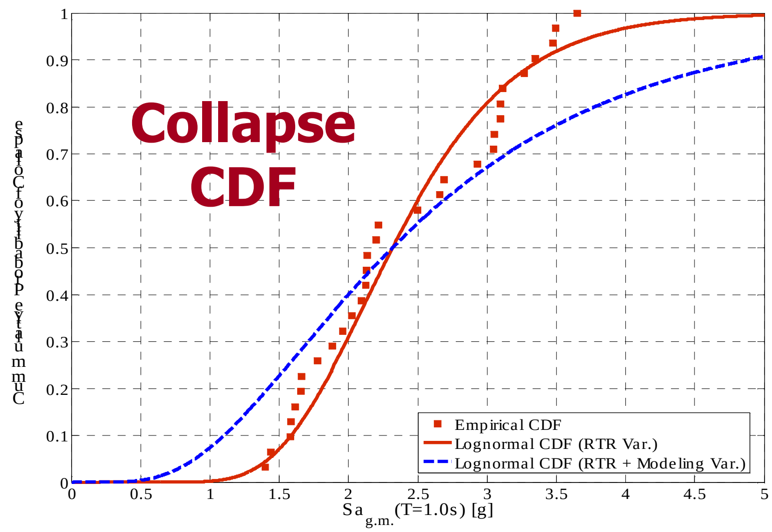


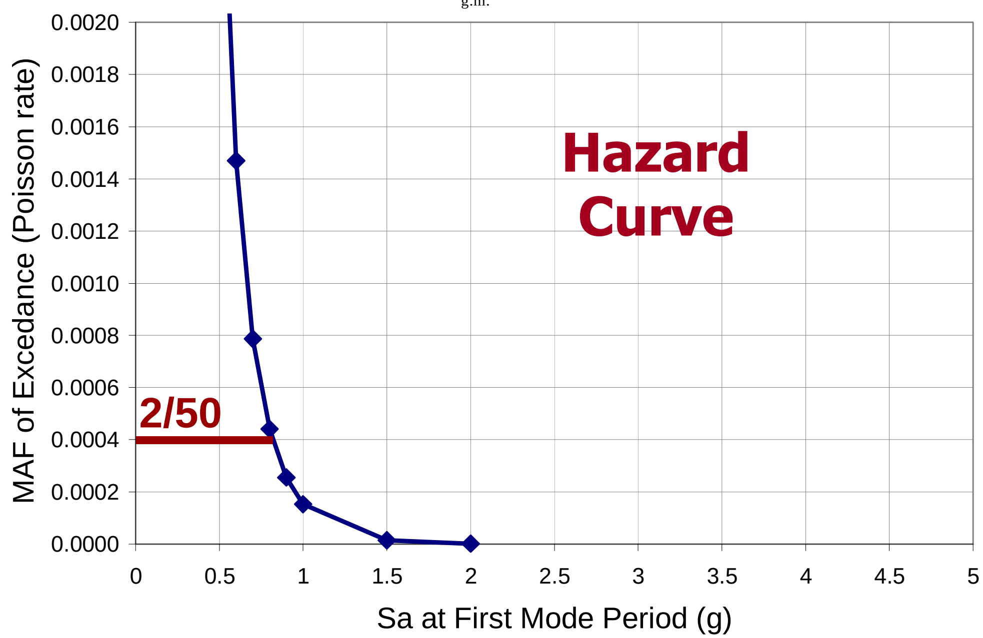


Collapse Capacity – with Modeling Uncert.



Mean Annual Frequency of Collapse

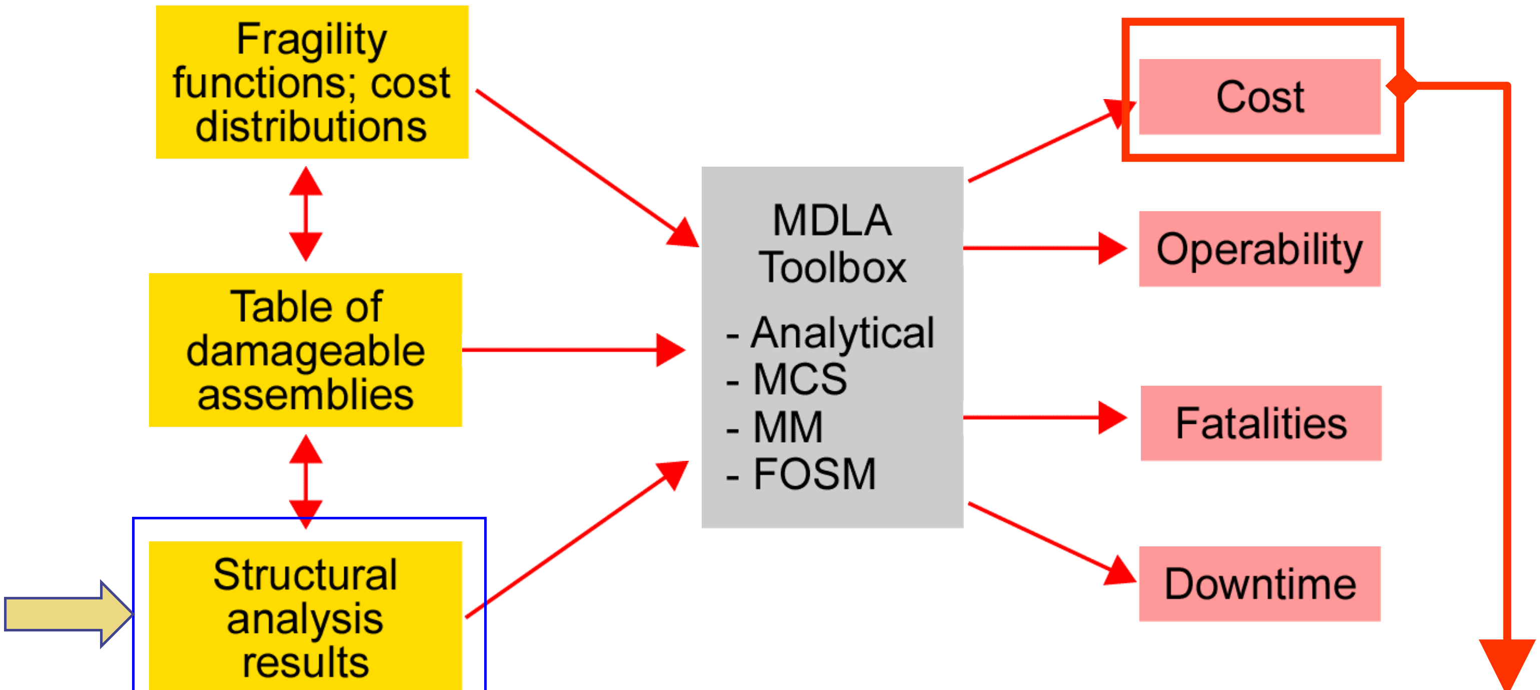


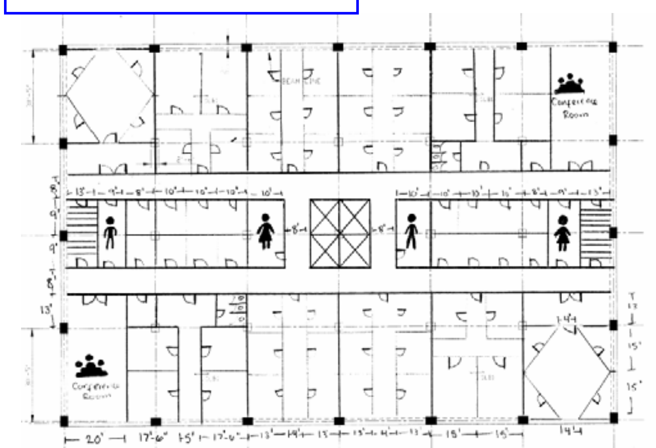


Collapse Performance

- Margin: $S_{a,collapse}$ = 2.7 MCE
- Probability of collapse under design MCE = 5%
- MAF_{col} = 1.0 x 10^{-4} (about ¼ of the MCE 2% in 50 year ground motion)

Nonstructural Damage and Losses (Caltech)





Expected Annual Loss:

about 1% of building value

Conditional Loss (10/50):

about 20% of building value

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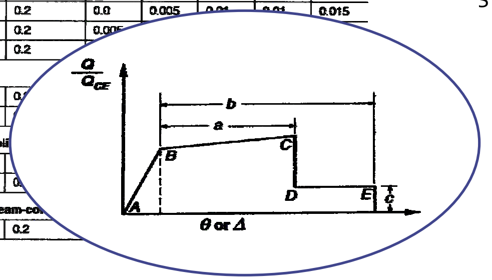
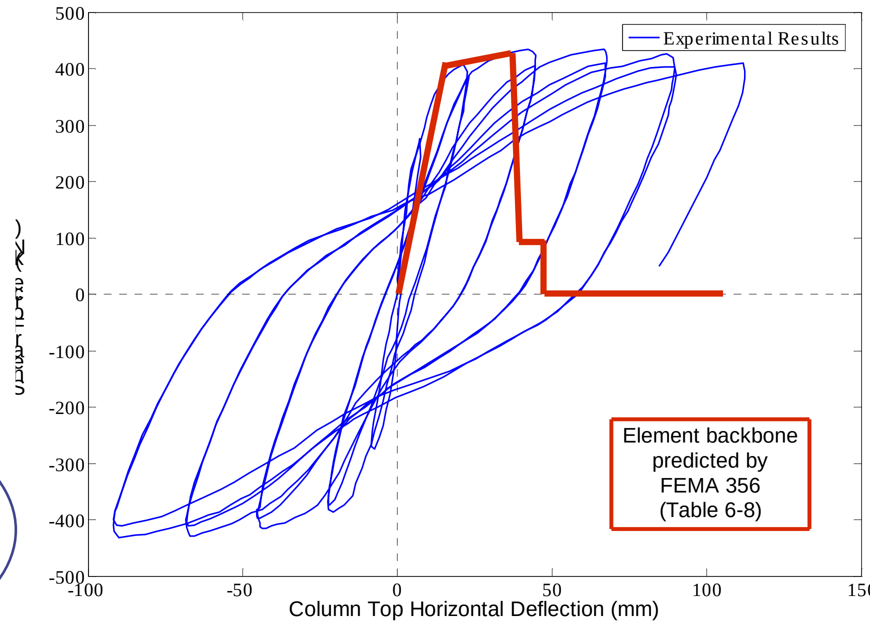
Shortcomings of FEMA 273/356

Table 6-6 *Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Beams*

Conditions			Modeling Parameters[3]: Plastic Rotation Angle, radians		Modeling Parameters[3]: Residual Strength Ratio	Acceptance Criteria[3]: Plastic Rotation Angle, radians — Component Type: Primary — Performance Level			Secondary	
			a	b	c	IO	LS	CP	LS	CP
i. Beams controlled by flexure[1]										
$\frac{\rho-\rho'}{\rho_{bal}}$	Trans. Reinf.[2]	$\frac{V}{b_w d \sqrt{f'_c}}$								
≤ 0.0	C	≤ 3	0.025	0.05	0.2	0.005	0.02	0.025	0.02	0.05
≤ 0.0	C	≥ 6	0.02	0.04	0.2	0.005	0.01	0.02	0.02	0.04
≥ 0.5	C	≤ 3	0.02	0.03	0.2	0.005	0.01	0.02	0.02	0.03
≥ 0.5	C	≥ 6	0.015	0.02	0.2	0.005	0.005	0.015	0.015	0.02
≤ 0.0	NC	≤ 3	0.02	0.03	0.2	0.005	0.01	0.02	0.02	0.03
≤ 0.0	NC	≥ 6	0.01	0.015	0.2	0.0	0.005	[illegible]	[illegible]	0.015
≥ 0.5	NC	≤ 3	0.01	0.015	0.2	[illegible]				
≥ 0.5	NC	≥ 6	0.005	0.01	0.2					
ii. Beams controlled by shear[1]										
Stirrup spacing ≤ $d/2$			0.0	0.02	[illegible]					
Stirrup spacing > $d/2$			0.0	0.01						
iii. Beams controlled by inadequate development or spli[illegible]										
Stirrup spacing ≤ $d/2$			0.0	0.02						
Stirrup spacing > $d/2$			0.0	0.01	[illegible]					
iv. Beams controlled by inadequate embedment into beam-co[illegible]										
			0.015	0.03	0.2					





Over-reliance on

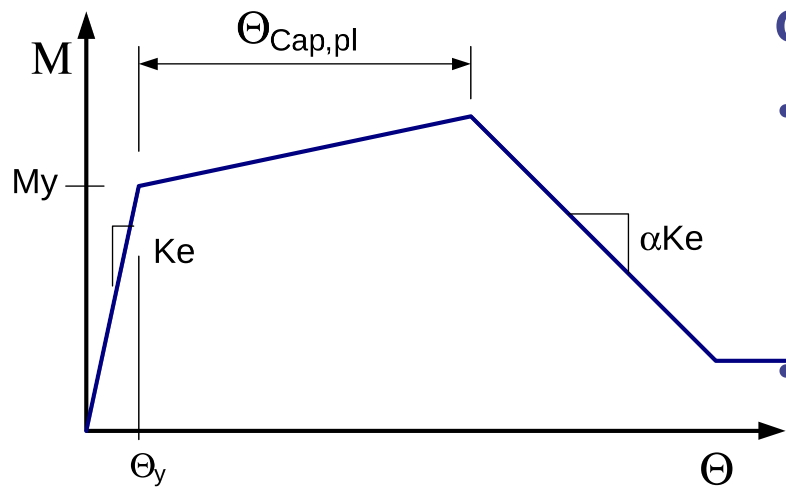
- static pushover method
- highly idealized (and conservative) backbone curves
- discrete deterministic component acceptance criteria

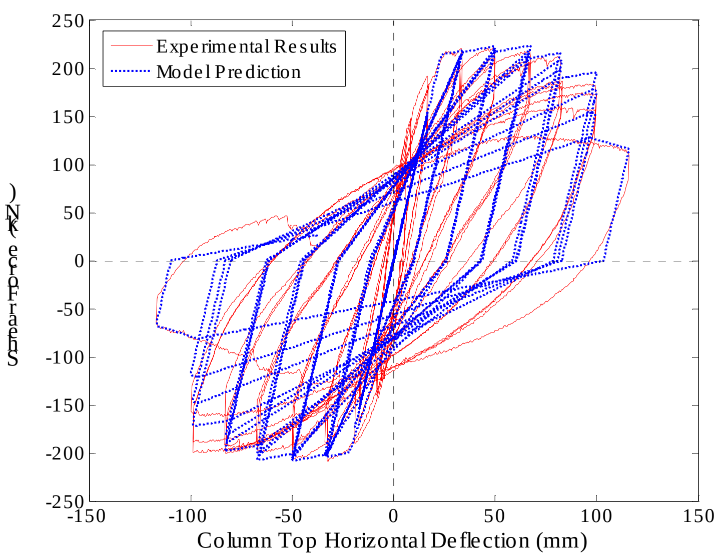
“Enhanced FEMA 356”

- Realistic Inelastic Model
- Nonlinear Time History Analysis
- 20 ground motions (10 pairs) with their geometric mean scaled to hazard at Sa(T1)
- Statistical evaluation of deformation demands to input ground motions
- Probabilistic assessment of component acceptance criteria to test data

$$Probability[\Theta_p > \Theta_{p,limit\text{-}state}] = X$$

RC Beam-Column Simulation Model Calibration





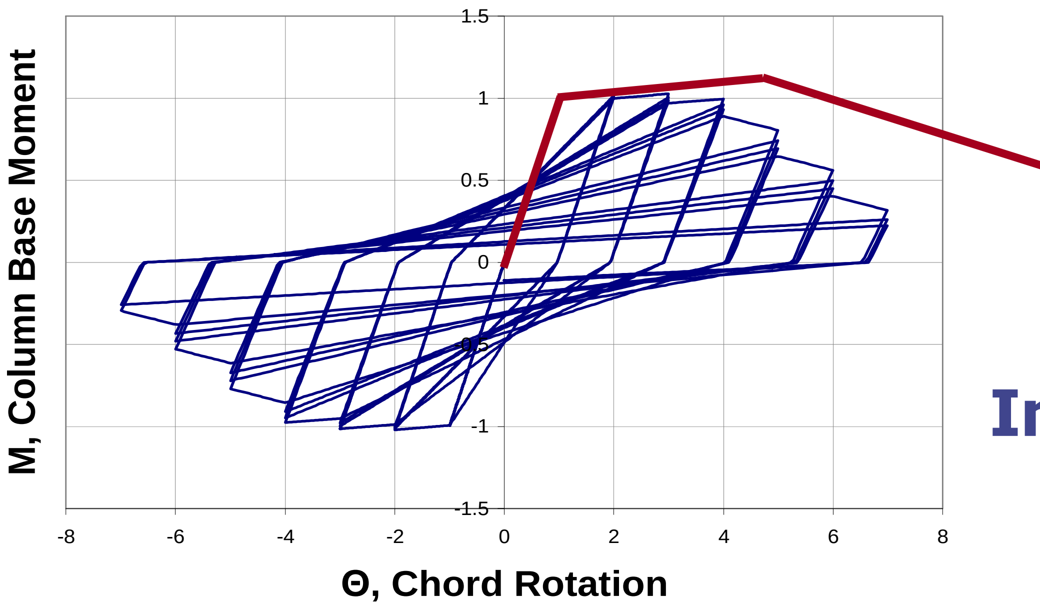
OVERVIEW OF CALIBRATION EFFORT

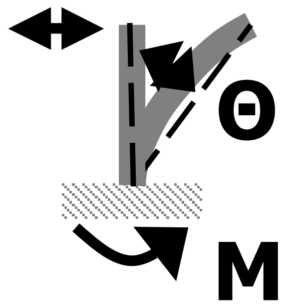
- Basic Hysteretic Model
  - 5 parameter backbone curve
  - 2 (x4) hysteretic parameters
- Previous RC Behavioral Studies
  - -Fardis et al. (Θcap, Θu)
  - -Eberhard et al. (EDP criteria for spalling and bar buckling)
- Current effort: Systematic calibration to 226 flexurally dominated columns

PEER STRUCTURAL PERFORMANCE DATABASE SPD

- **Goal:** *Validated model to be vetted through consensus process*

Consensus on Parametric Models

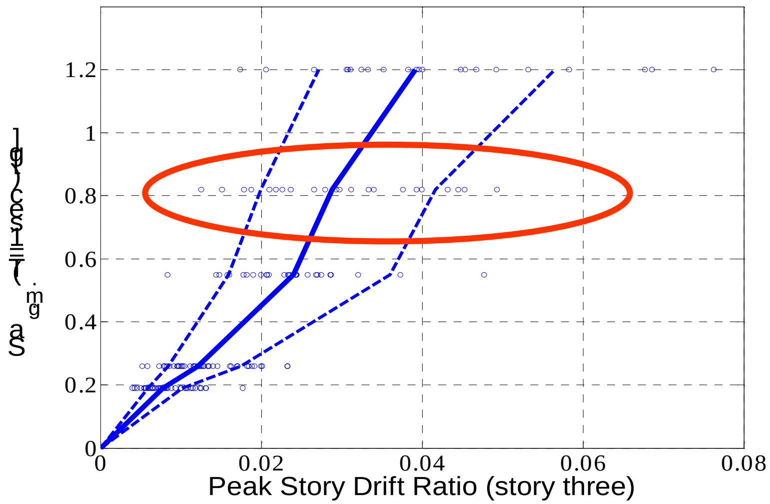


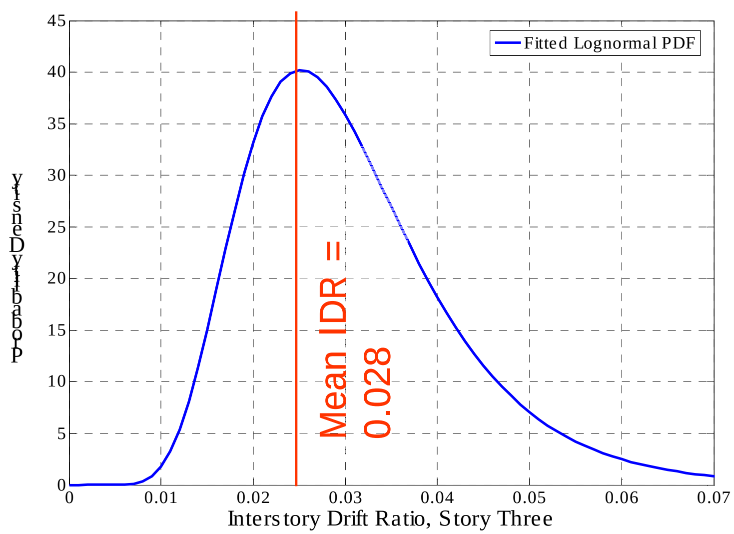


Input: material, config. & geometry, details, ...

- Response Parameters:
  - strength and deformation anchor points
  - cyclic hysteretic response
- Damage Parameters (EDP – DM)
- Characteristic **Mean & COVs**

Probabilistic EDP Statistics (e.g. drift, Θ_p)





PDF (probability density function)

At 2% in 50 year (MCE) Sa:

Drift:

IDR_{max} = 0.016 to 0.050

Mean IDR_{max} = 0.028

COV = 37%

Beams:

$\Theta_{p,max}$ = 0.012 to 0.045

Mean $\Theta_{p,max}$ = 0.025

COV = 43%

(vs. FEMA 356 Θ_{cp} < 0.025)

Columns:

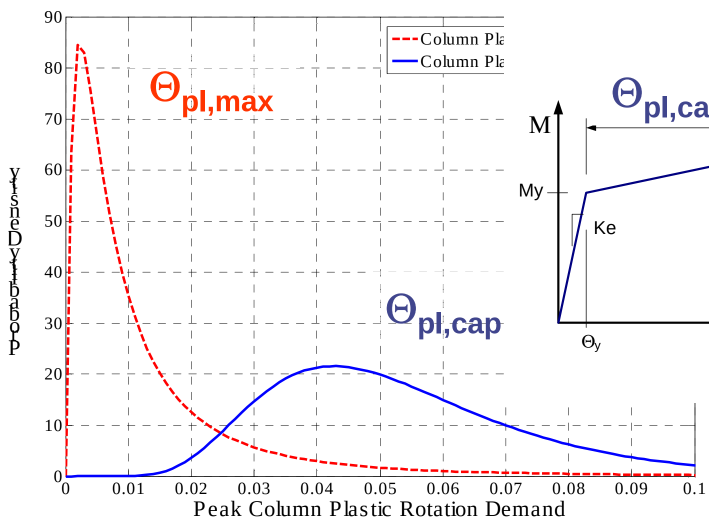
$\Theta_{p,max}$ = 0 to 0.03

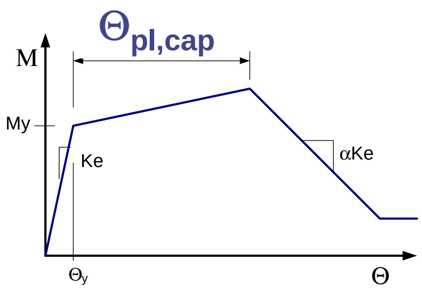
Mean $\Theta_{p,max}$ = 0.010

COV = 110%

(vs. FEMA 356 Θ_{cp} < 0.020)

Probabilistic Limit State Assessment





	Demand ($\Theta_{pl,max}$)		Capacity ($\Theta_{pl,cap}$)	
	μ	σ_{ln}	μ	σ_{ln}
Beams	0.025	0.43	0.065	0.40
Col's	0.010	1.10	0.050	0.40

$$P[D \geq C] = 1 - \Phi\left(\frac{0 - \mu_{\ln,z}}{\sigma_{\ln,z}}\right)$$

where: $\mu_{\ln,z} = \mu_{\ln,D} - \mu_{\ln,C}$

$$\sigma^2_{\ln,z} = \sigma^2_{\ln,D} + \sigma^2_{\ln,C}$$

Φ (standard normal table)

Component Limit State Checks:

Beams *P[D>C] = 6 %*

Columns *P[D>C] = 6 %*

(just a coincidence that they turn out the same)

IMPACT – Future PBEE Codes (e.g., ATC 58)

- Framework
  - Transparent, Scientific, Modular, Extendable
- Standardize Component Models & Criteria
  - Structural Component Simulation & Damage Models
  - Nonstructural Damage (Fragility) Models
- Systematize Decision Support
  - Articulation of Decision Variables (Metrics)
  - Design Support – EDP to DV relationships
- Consistent Approaches across:
  - Hazards, Materials, Disciplines