Past, Present and Future of PBEE

Helmut Krawinkler

PEER Annual Meeting, 10/15/09

<u>High-Level Objectives - 2000</u>

Develop a <u>methodology</u> and tools that will

- **Facilitate the decision making on <u>cost-effective risk management</u> of the built environment in areas of high seismicity**

- **Facilitate the <u>implementation of</u> <u>performance-based design</u> and evaluation by the engineering profession**

- **Provide a foundation on which code writing bodies can base the <u>development of transparent performance-based provisions</u>**

- **Provide <u>criteria for acceptance of innovative systems</u>**
  - Response modification devices (base isolation, dampers, etc.)
  - Hybrid control systems
  - Energy dissipating fuses, etc.

Measures of Performance - PBEE

- **Forces and deformation?**
  - Yes, but **only** for engineering calculations
  - Intermediate variables
  - **Not for communication with clients and community**
- **Communication in terms of the three D's:**
  - Dollars (direct economic loss)
  - Downtime (loss of operation/occupancy)
  - Death (injuries, fatalities, collapse)
- **Quantification**
  - Losses for a given shaking intensity
  - Losses for a specific scenario (M & R)
  - Annualized losses
  - With or without rigorous consideration of uncertainties

The Peer Framework Equation - 1999

$$v(DV) = \iiint G\langle DV|DM\rangle \,|\, dG\langle DM|EDP\rangle \,|\, dG\langle EDP|IM\rangle \,|\, d\lambda(IM)$$

Impact

Performance (Loss) Models and Simulation

Hazard

Curse?

Blessing

Performance Assessment Methodology

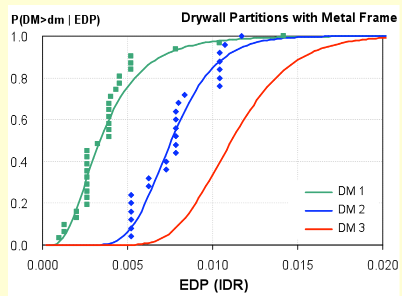
Decision Variable →

Performance Assessment types (ATC-58 definitions):

Intensity-based: Prob. facility perf., given intensity of ground motion
Scenario-based: Prob. facility perf., given a specific earthquake scenario
Time-based: Prob. facility perf. In a specific period of time

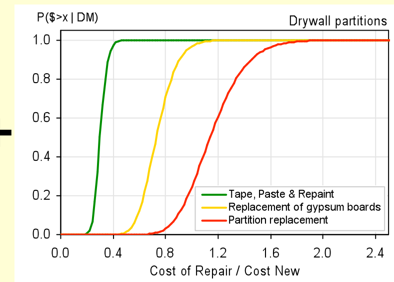
Damage Measure →

Damage Fragility Curves:



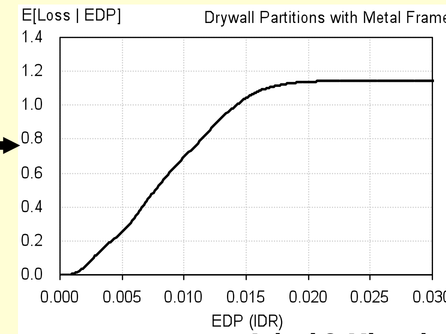
+

Cost Functions:



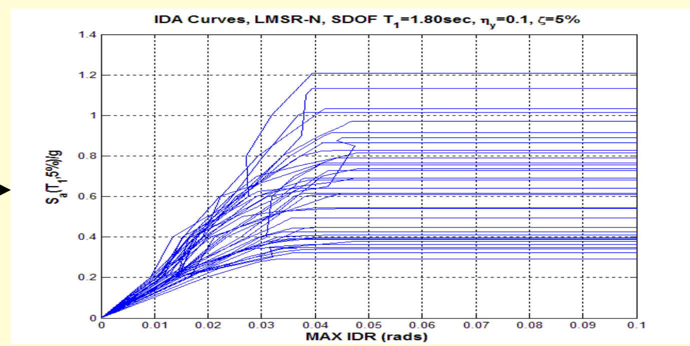
→

Mean Loss Curve:



Aslani & Miranda

Engineering Demand Parameter →



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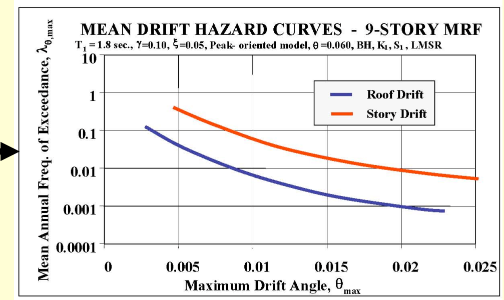
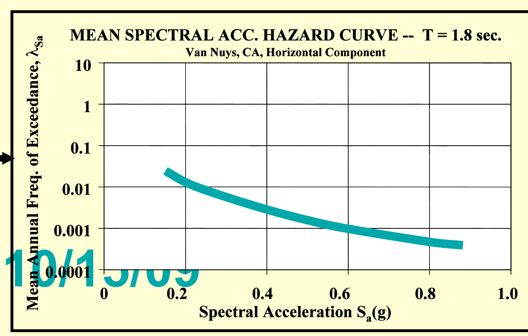


Intensity Measure →



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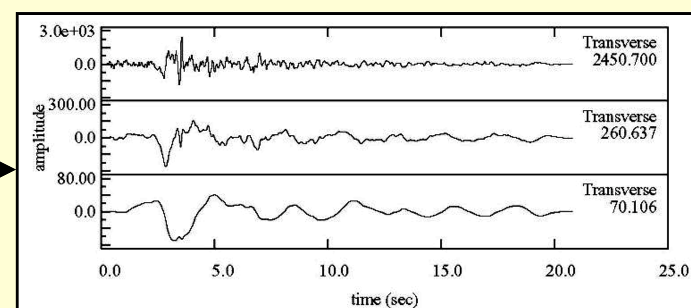
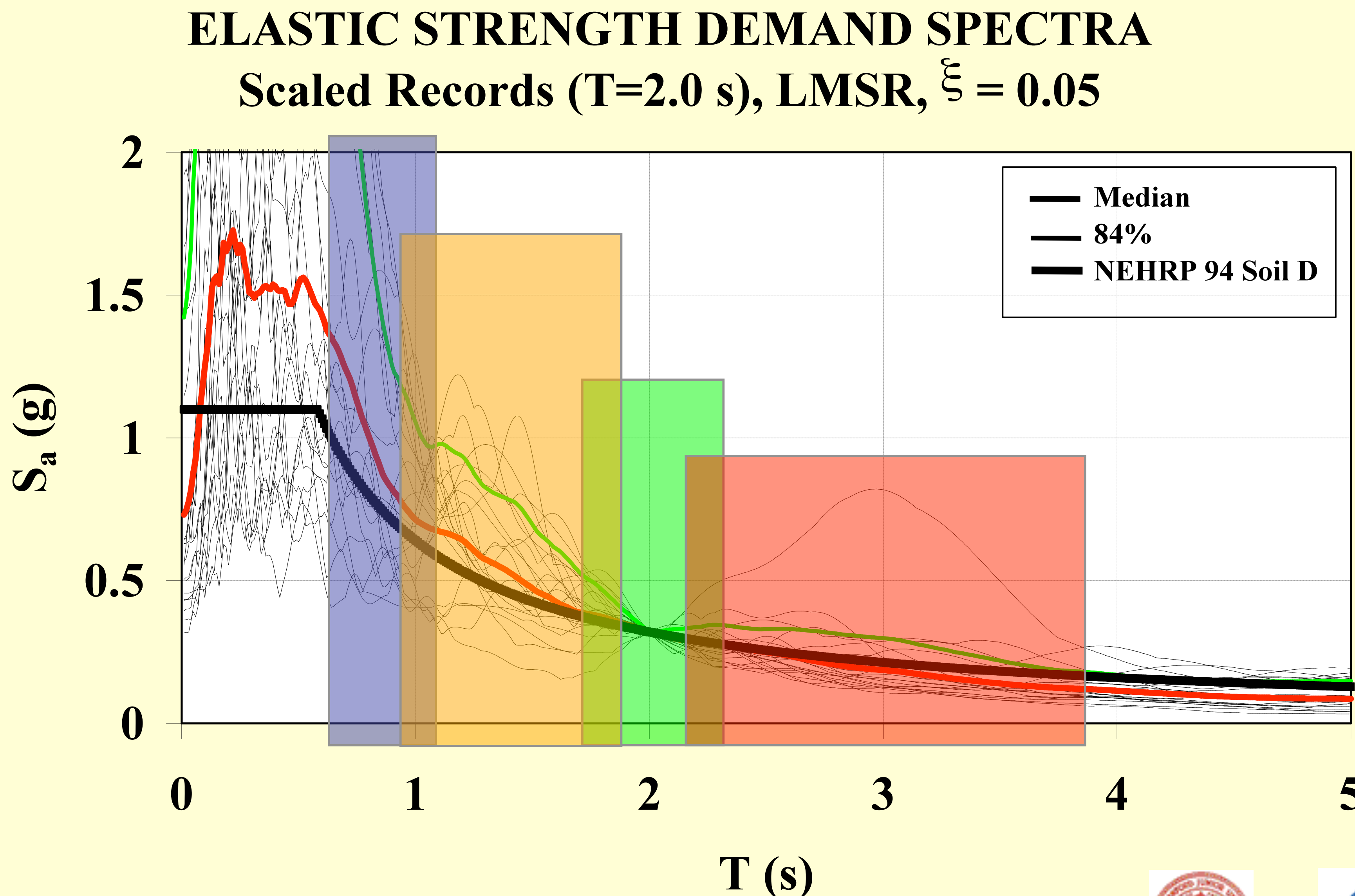
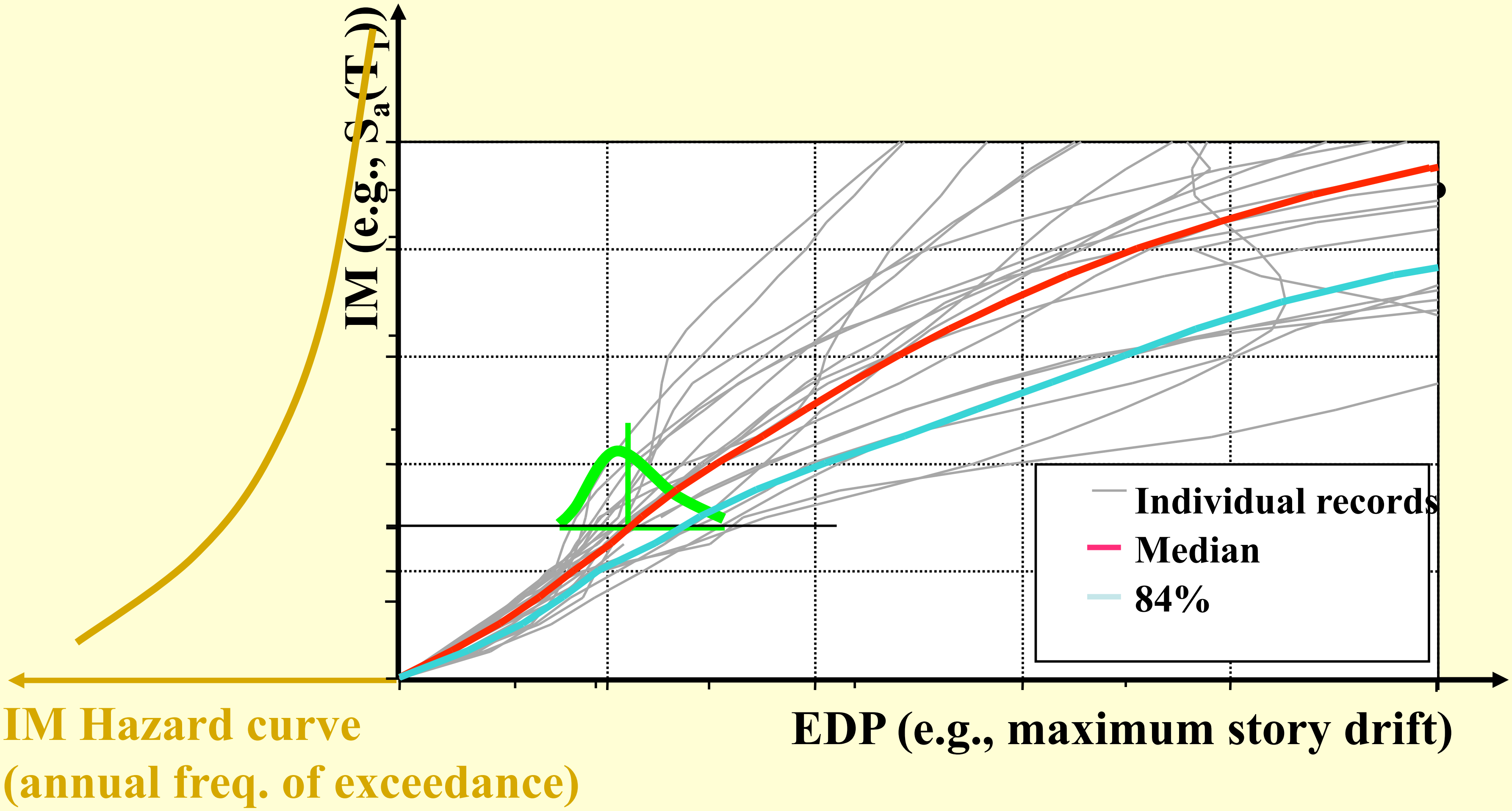


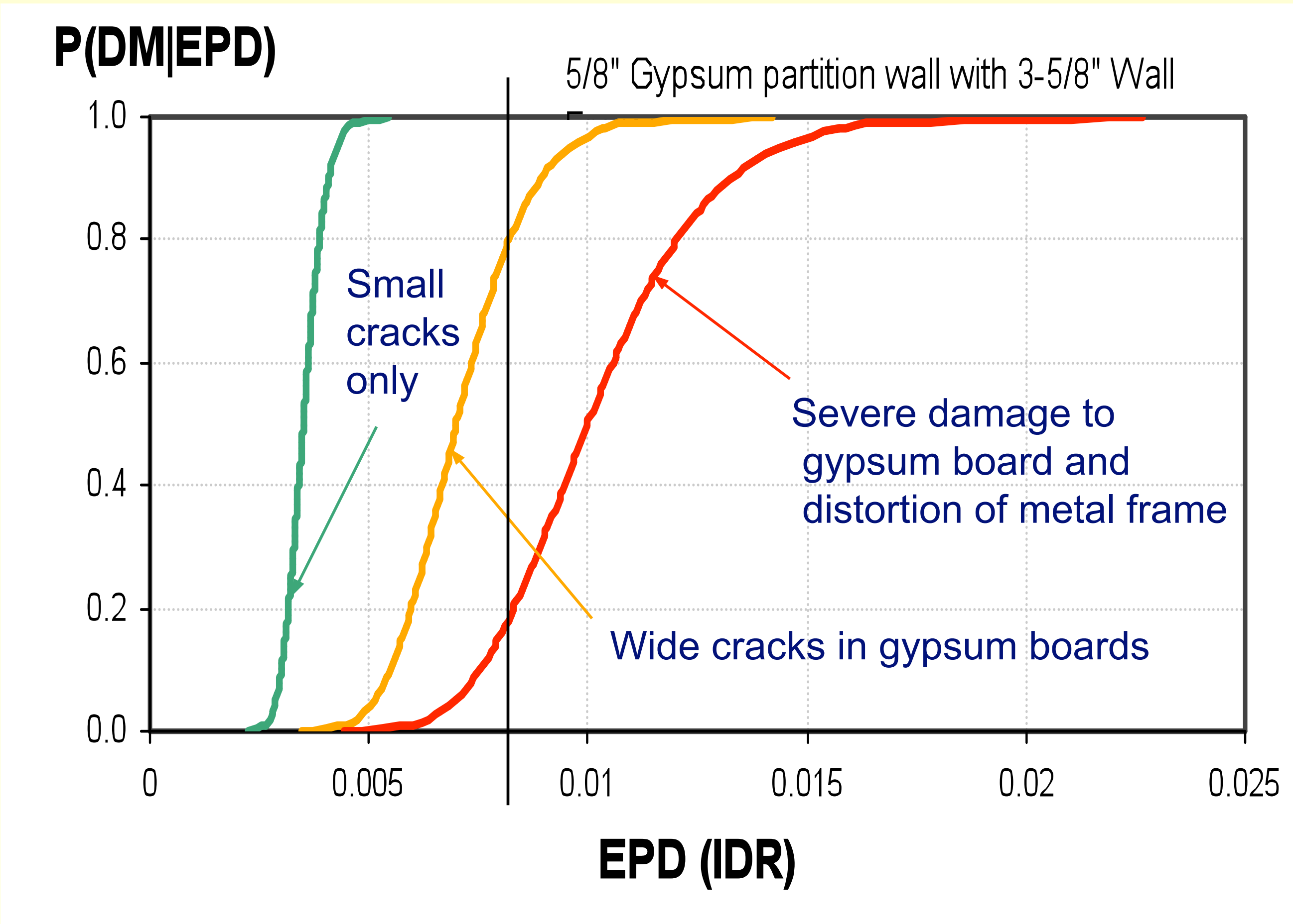
Ground Motions - Dispersion



Incremental Dynamic Analysis



Component Fragility Functions
Partition Walls

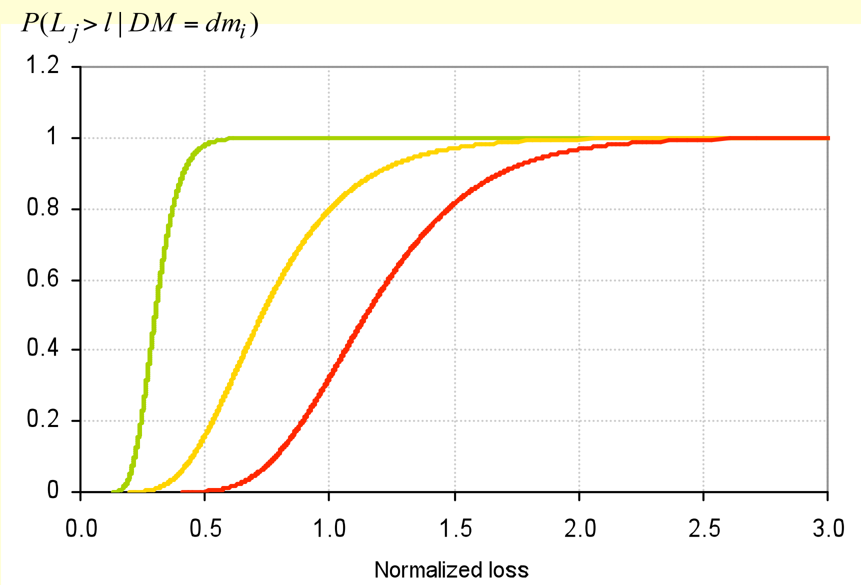


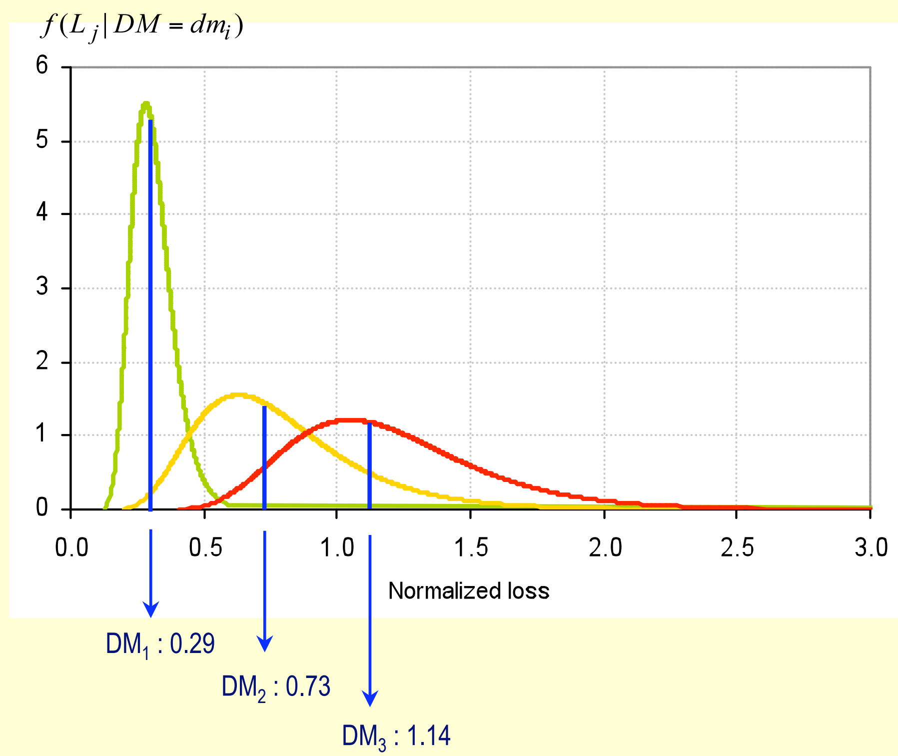
Source: E. Miranda

Cost (Consequence) Functions Partition Walls

$$P(L_j > l \mid DM = dm_i)$$

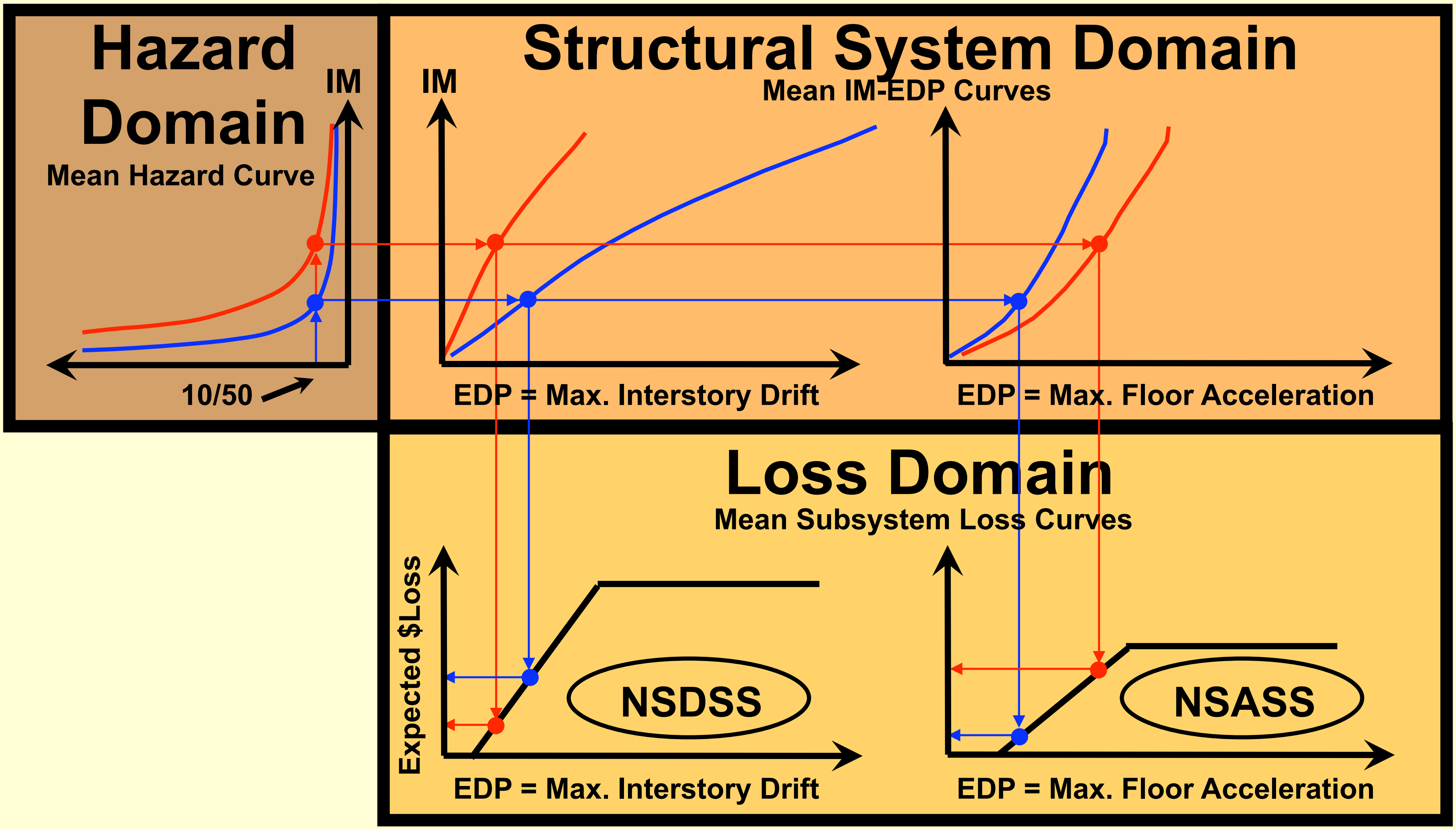
$$E[(L_j \mid DM = dm_i]$$





Source: E. Miranda

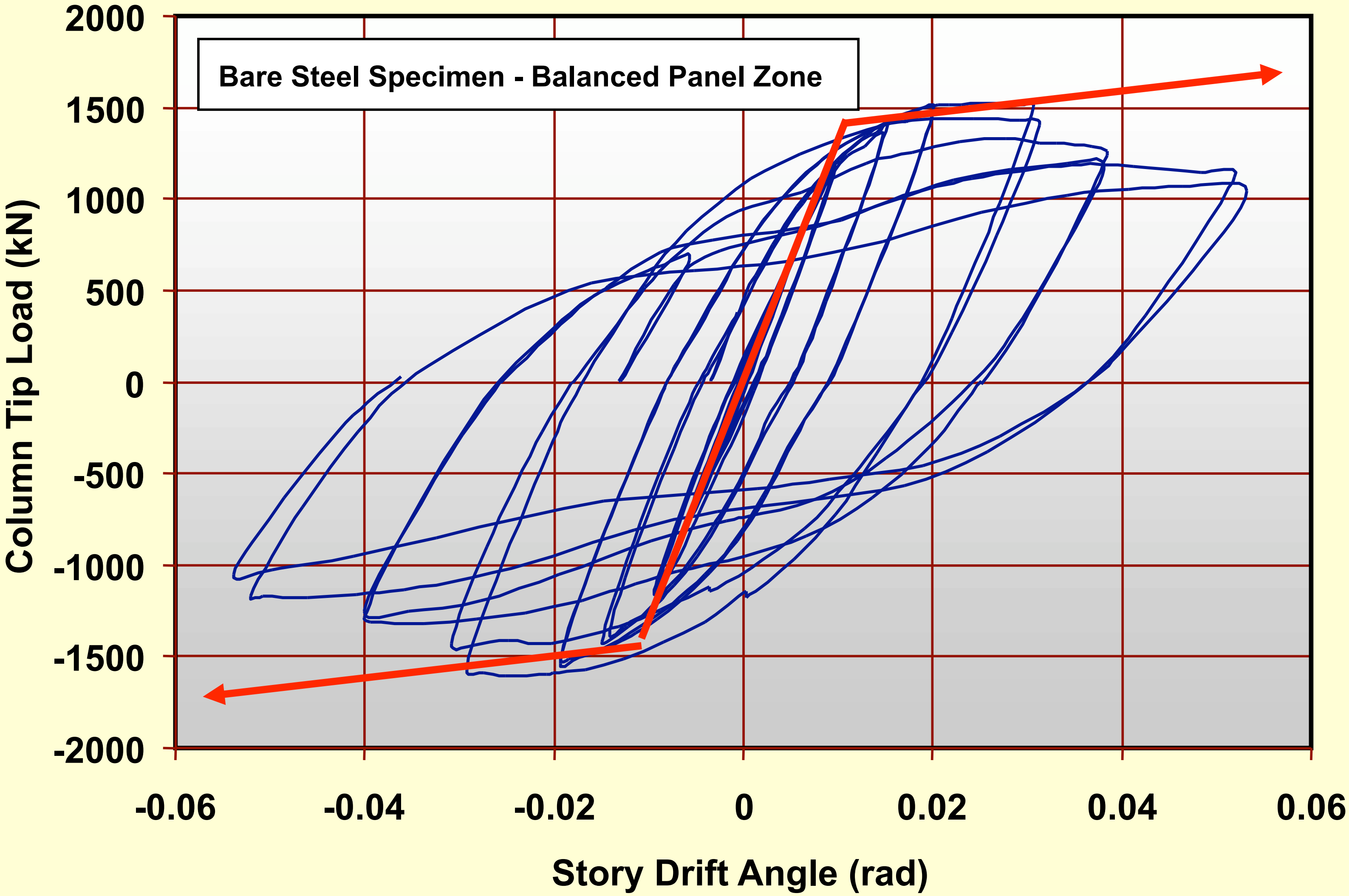
Illustration – Loss Estimation



Zareian & Krawinkler (2005)

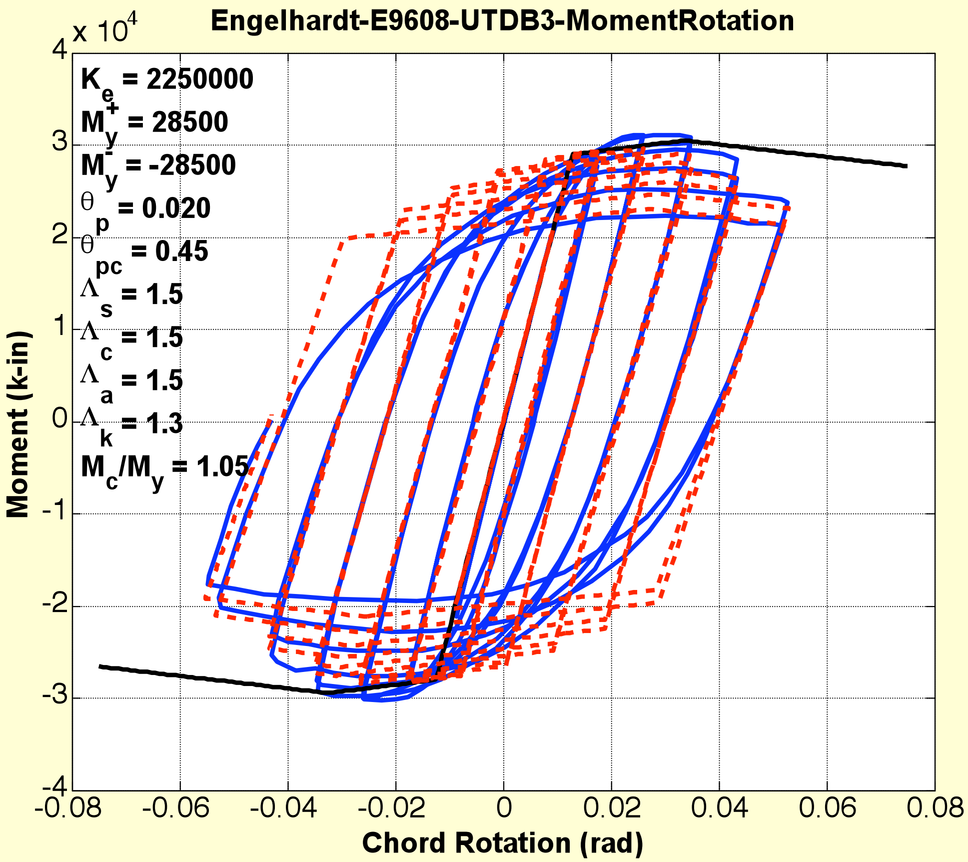
Collapse of Buildings

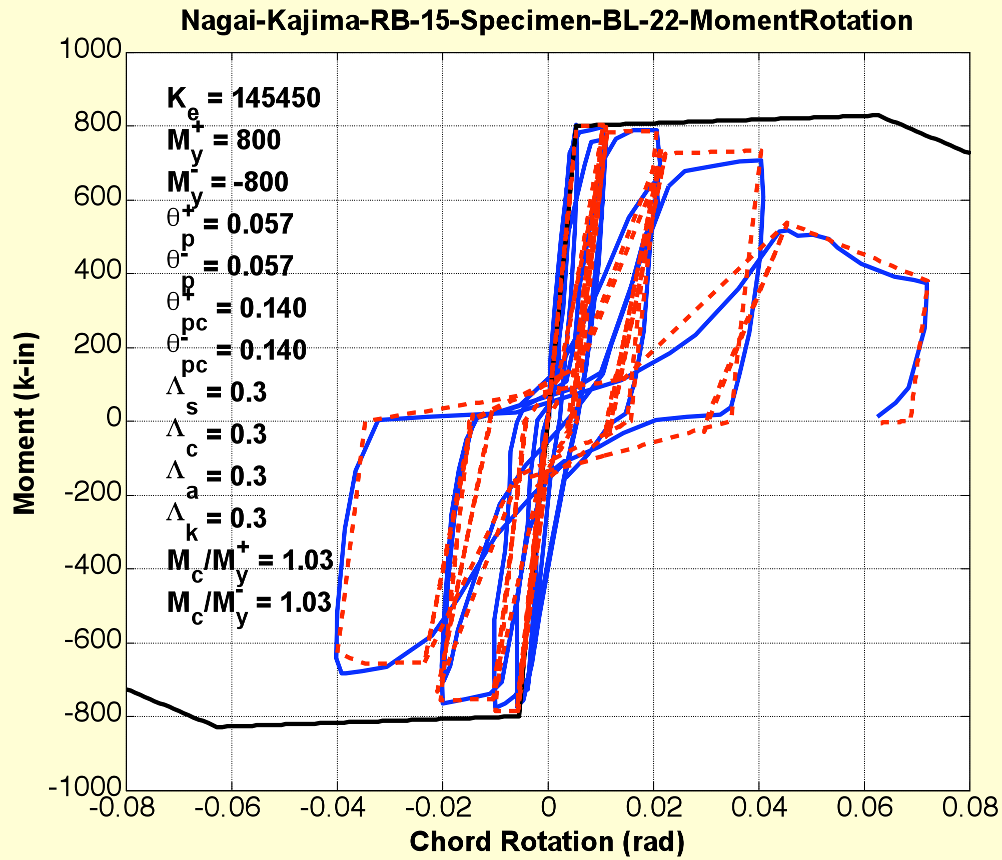
Component Behavior – Steel



U. of Texas

Model Calibrations

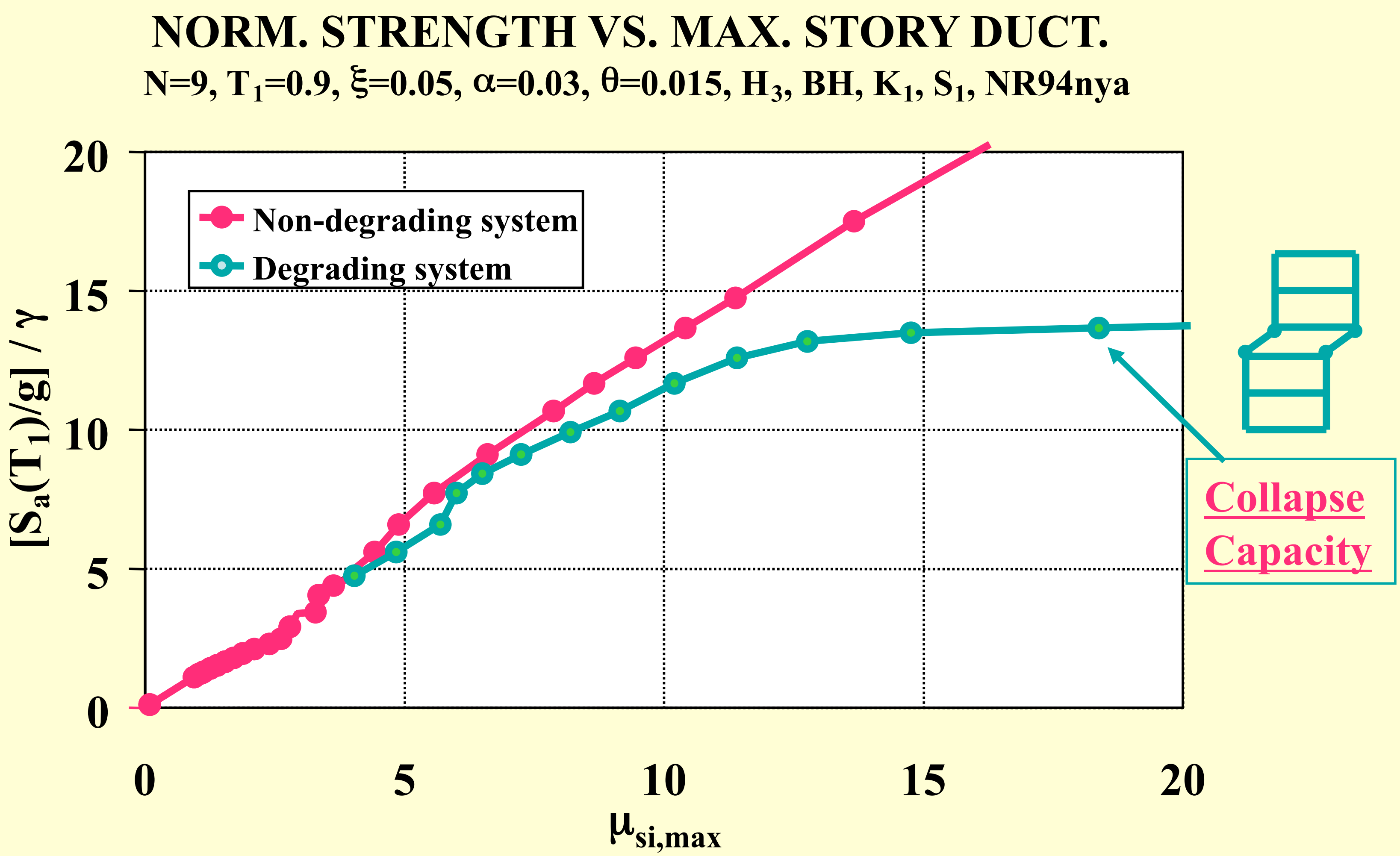




Lignos, 2008

Assessment of Collapse Potential

$\gamma = \frac{V_y}{W}$



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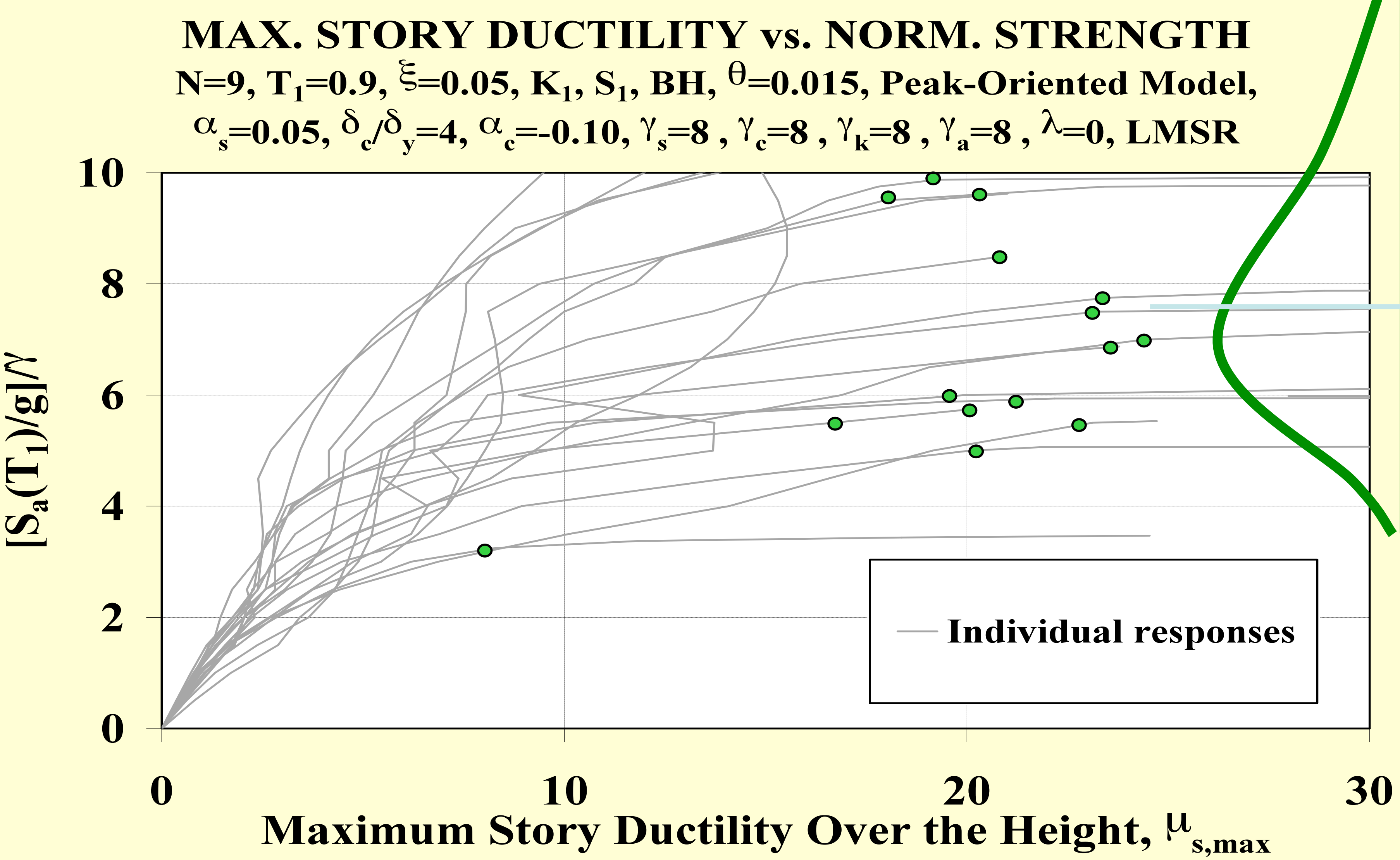
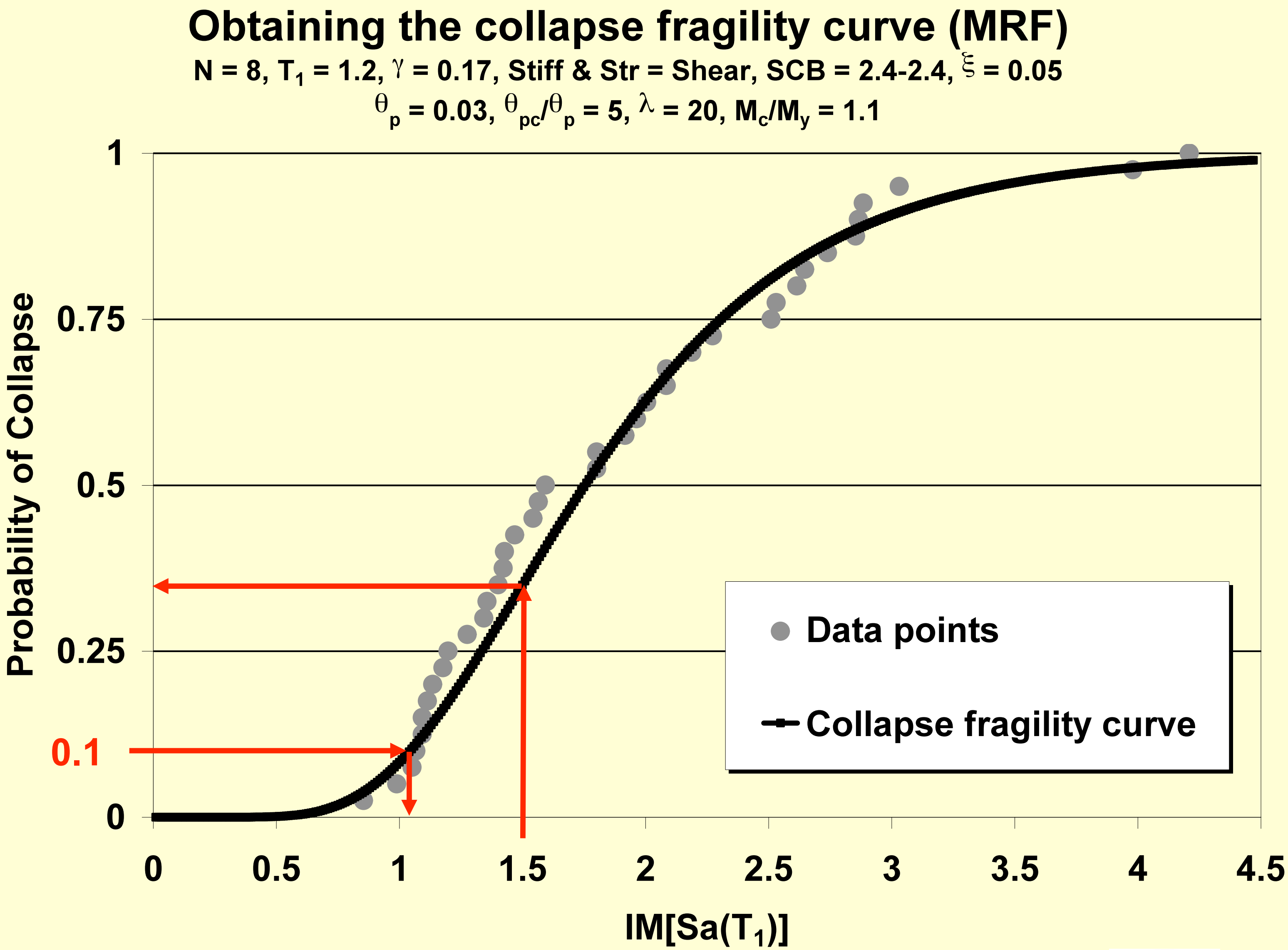
Collapse Capacity for a Set of Ground Motions



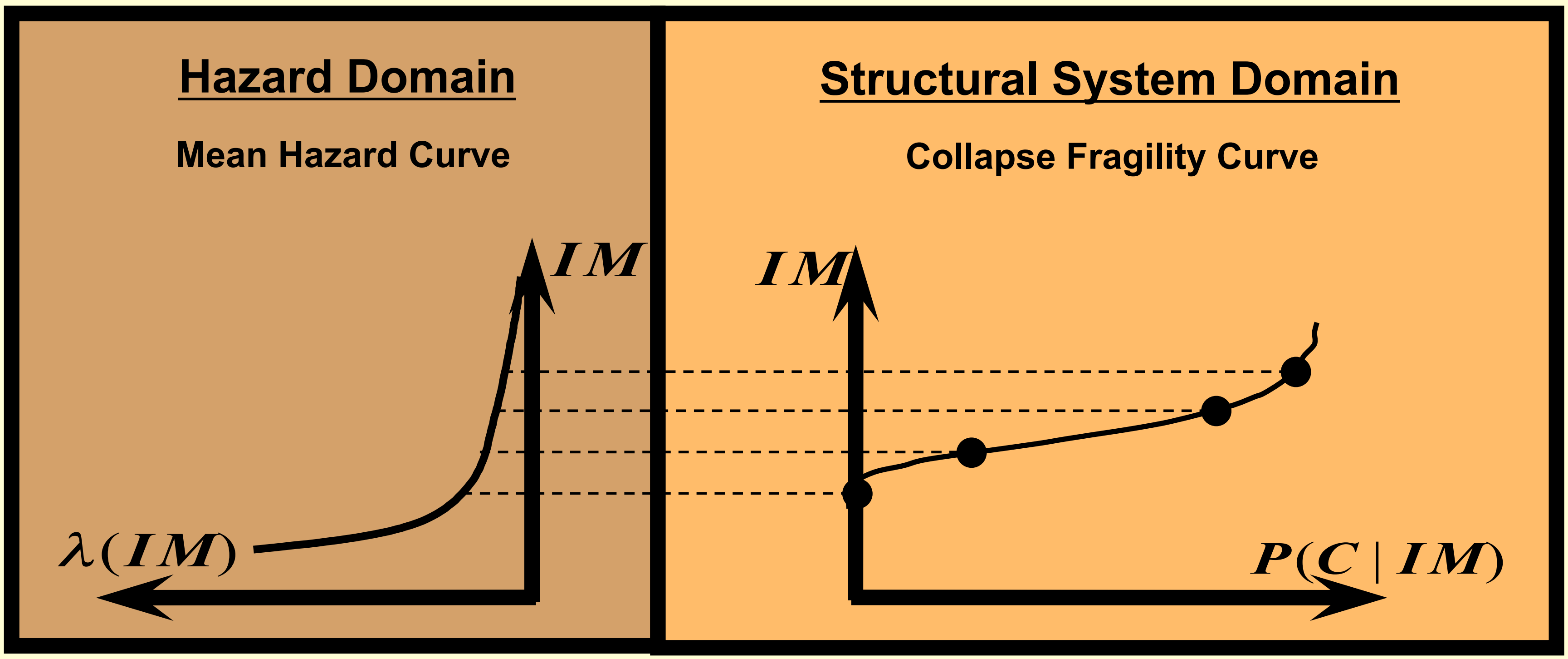
Collapse Fragility Curve



Zareian & Krawinkler (2004)

Mean Annual Frequency of Collapse

$$\lambda_C = \int_{IM} P(C \mid im) \left| d\lambda_{IM}(im) \right|$$



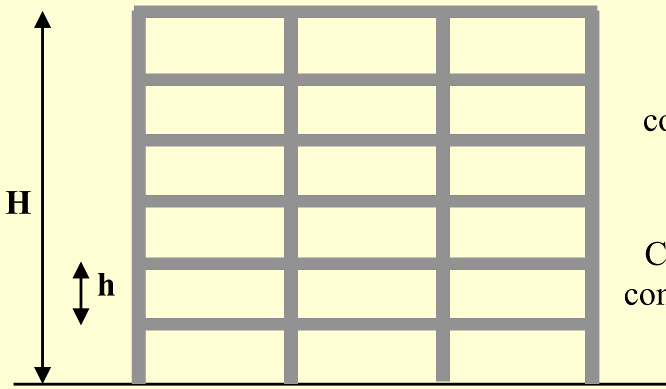
from Farzin Zareian

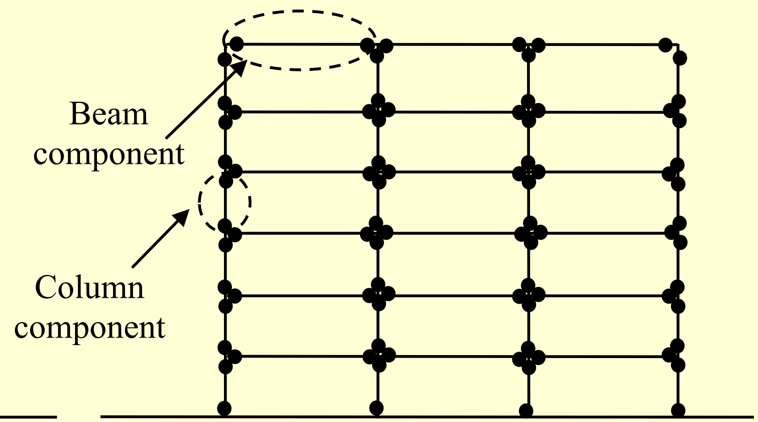
PEER Implementation Examples

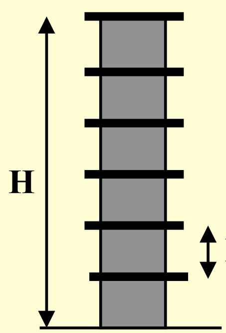
- Generic frames and walls
- Benchmark study on RC moment frames

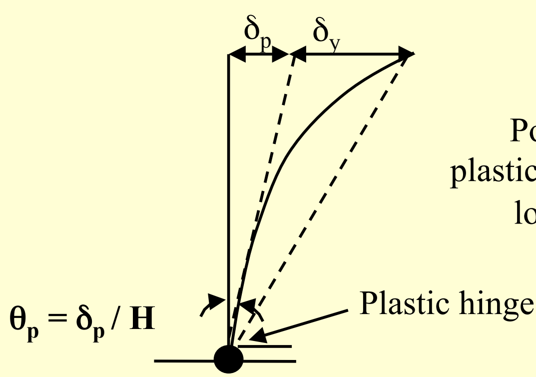
Generic Structural Systems

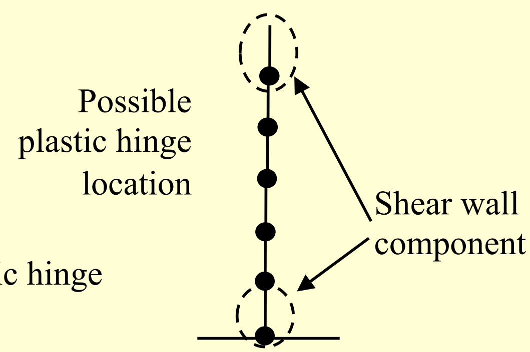
Frame and Wall Structures











Primary Variables

- # of stories, N
- Period
- Yield strength
- Parameters of M-θ model

from Farzin Zareian

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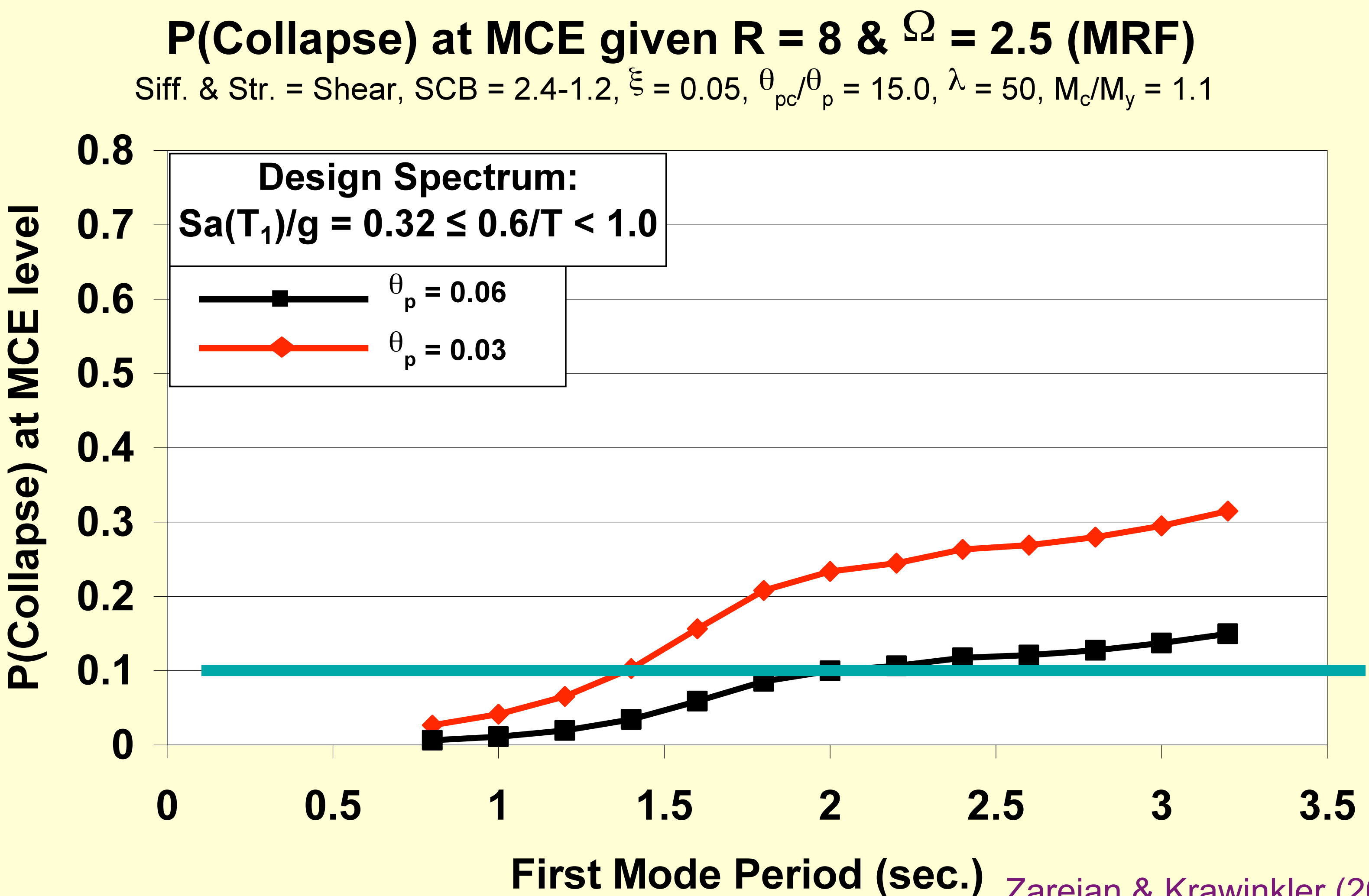
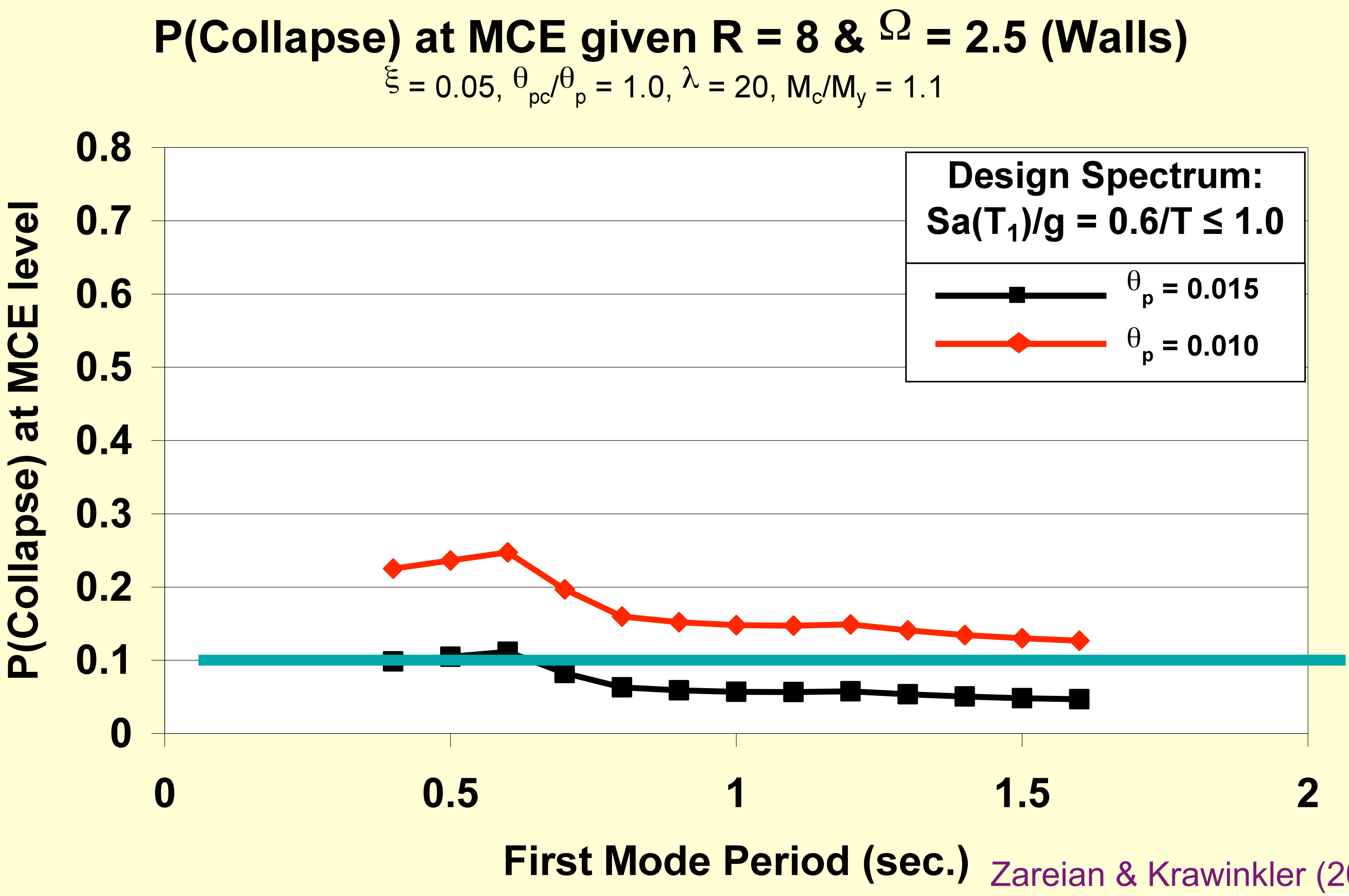
Probability of Collapse at MCE, for Frame Structures with R = 8



Zareian & Krawinkler (2007)

Probability of Collapse at MCE, for Wall Structures with R = 8



Zareian & Krawinkler (2007)

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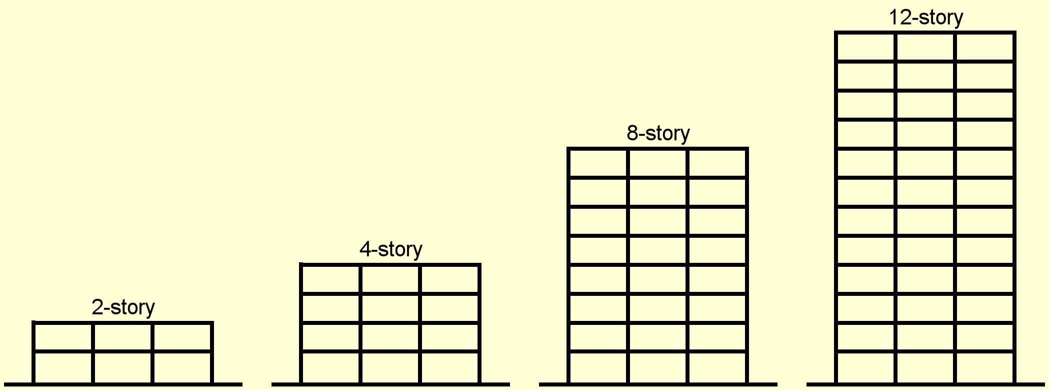
Performance of Reinforced Concrete Moment Frame Buildings

Stanford, UCLA, Caltech

Motivation and Objectives

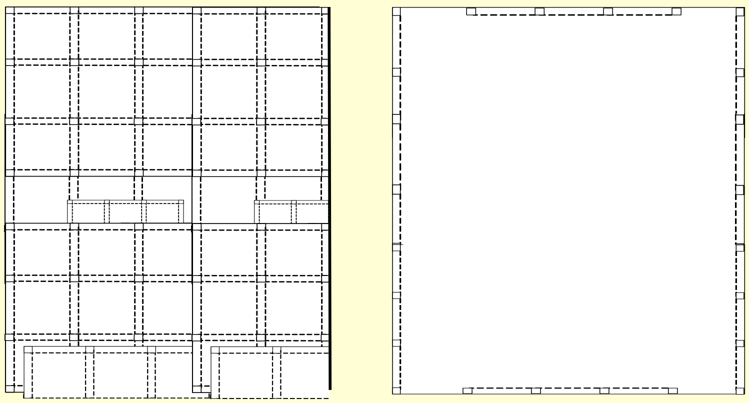
- Assess the performance of modern (2005) code-conforming buildings
- Assess the relative performance of modern versus "non-ductile" RC buildings
- Implications for
  - design codes, standards, and practice
  - Public policy for assessment and retrofit of existing buildings

Archetype Structures



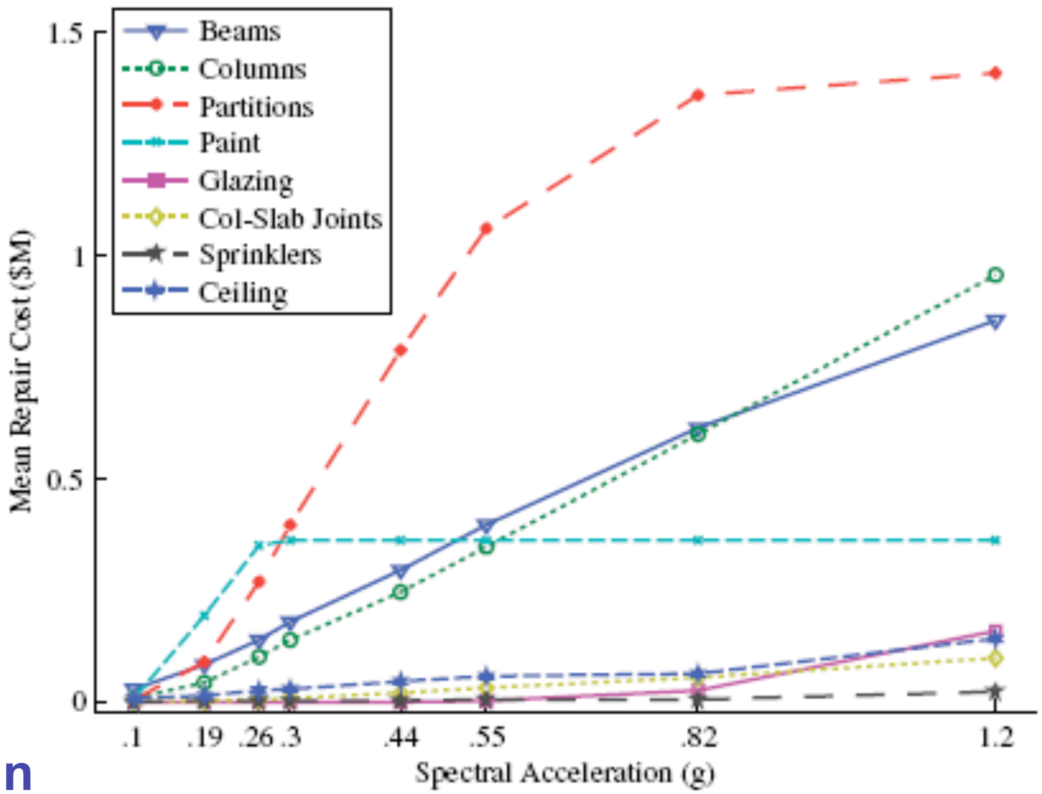
Building Height: 2 to 12 Stories

Source: G. Deierlein



Space and Perimeter Frame Systems

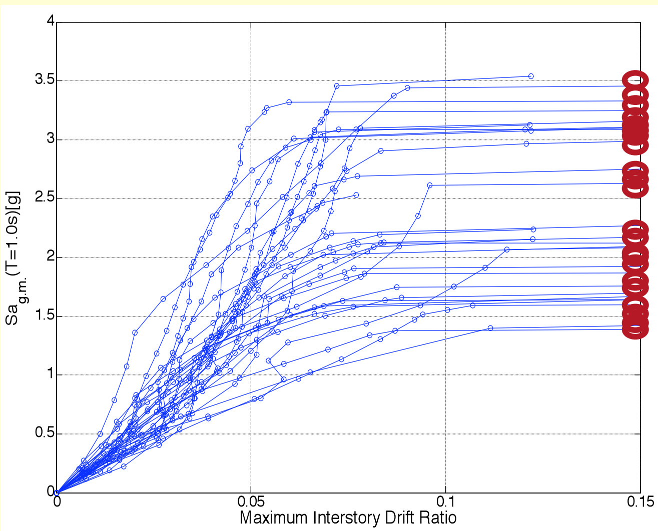
Nonstructural Losses Caltech Toolkit



Source: G. Deierlein

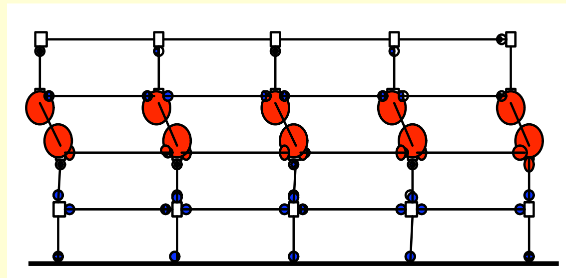
Figure 7. Total repair costs broken down into contributions of cost for each damageable building component for baseline perimeter-frame design (variant #1, design A).

Collapse Modes – 4-story SMF

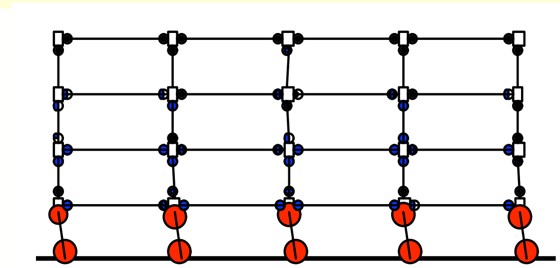


Incremental
Dynamic Analysis

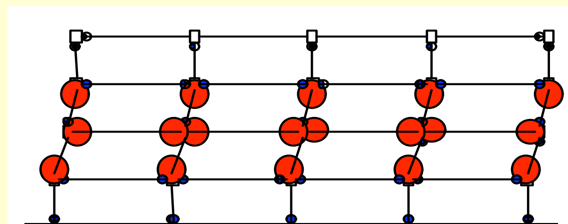
Source: C. Haselton



40% of collapses

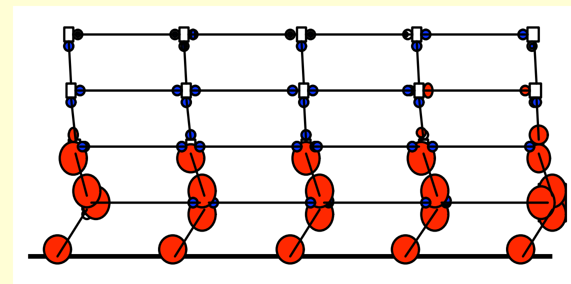


27% of collapses

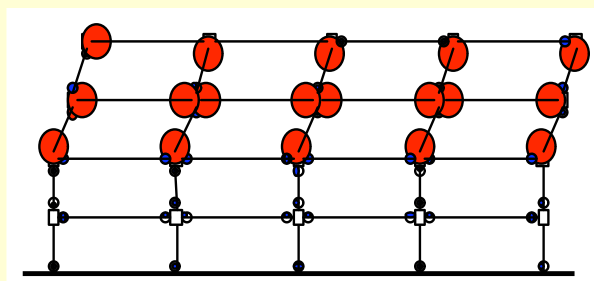


17% of collapses

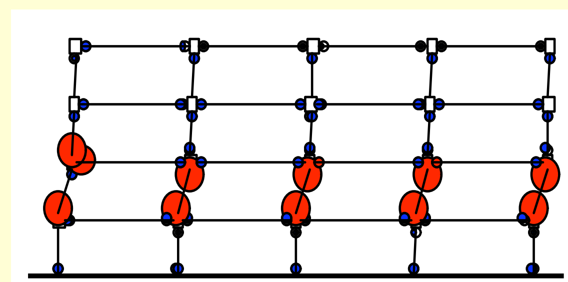
****Predicted by Static Pushover**



12% of collapses



5% of collapses



2% of collapses

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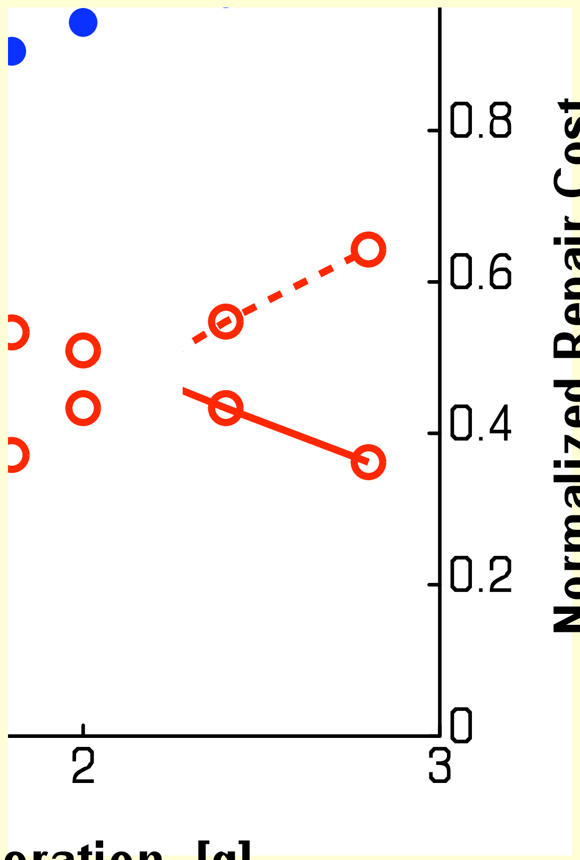
Loss as Function of IM [$S_a(T_1)$]

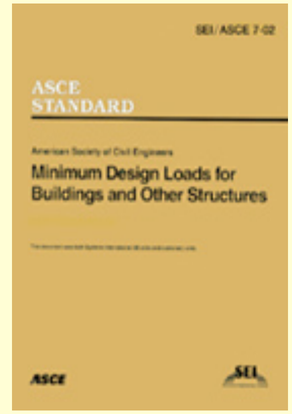
Mean Repair Cost, [$M]

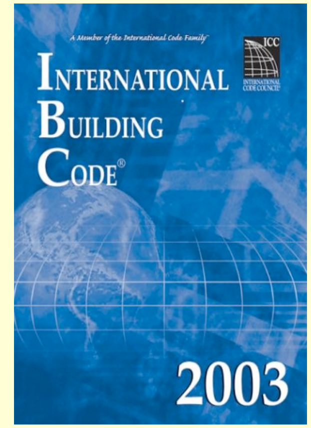


Spectral Acceleration, [g]

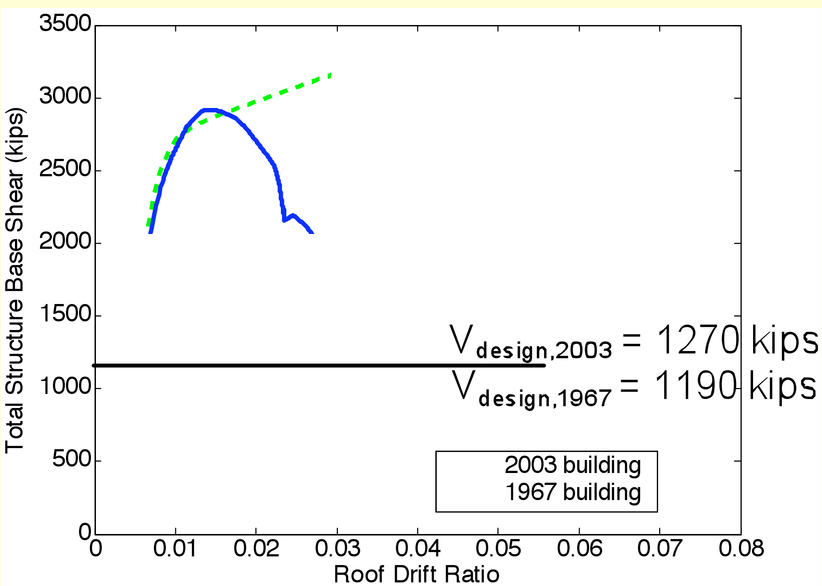
Source: G. Deierlein

1967 vs. 2003 Designs





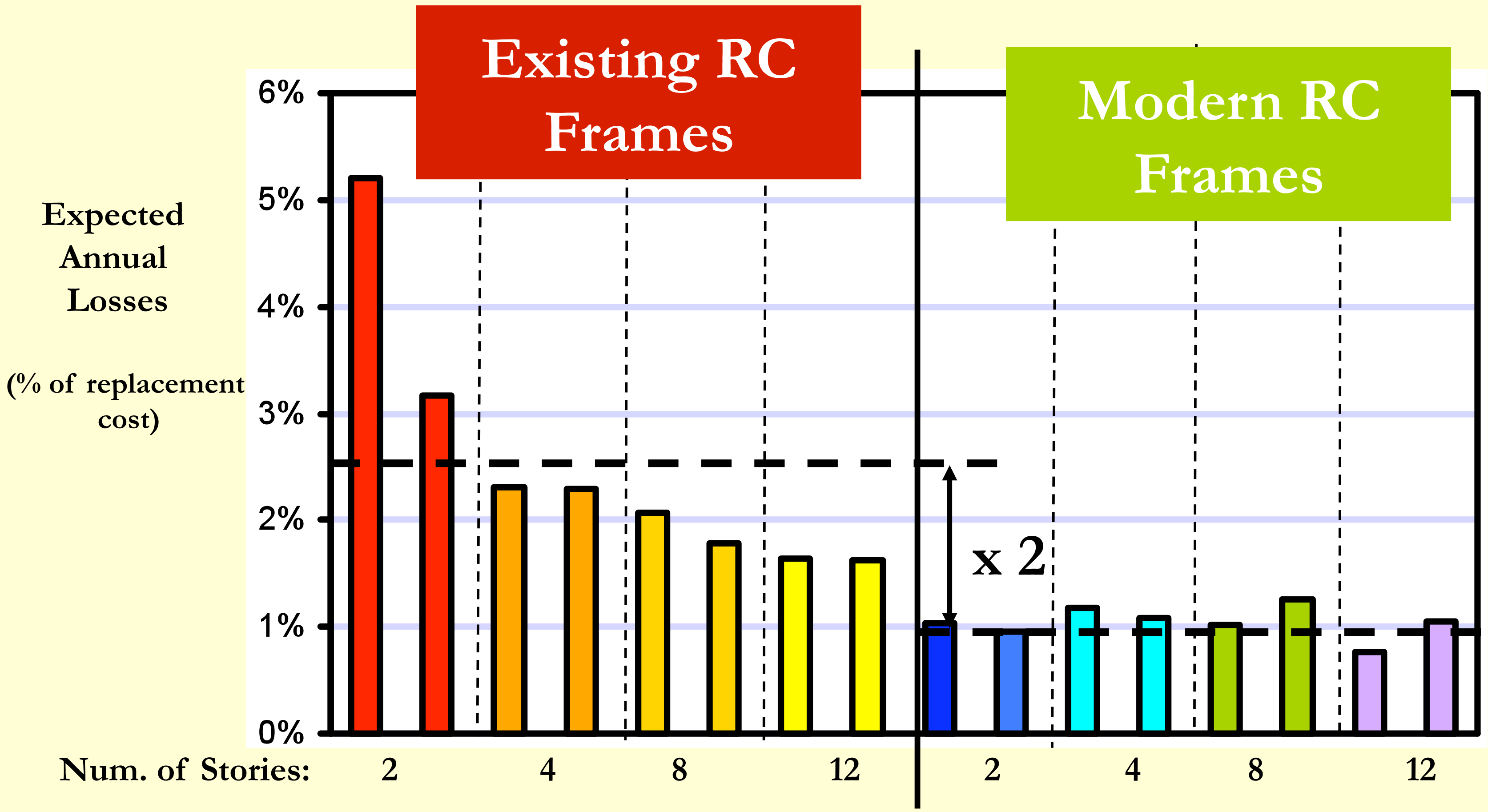
2003 Design Codes



Building	Collapse Risk	
	$P_{col.}$/MCE	$MAF_{collapse}$
2003	5%	1 x 10^{-4}
1967	40 to 80%	20 to 50 x10^{-4}

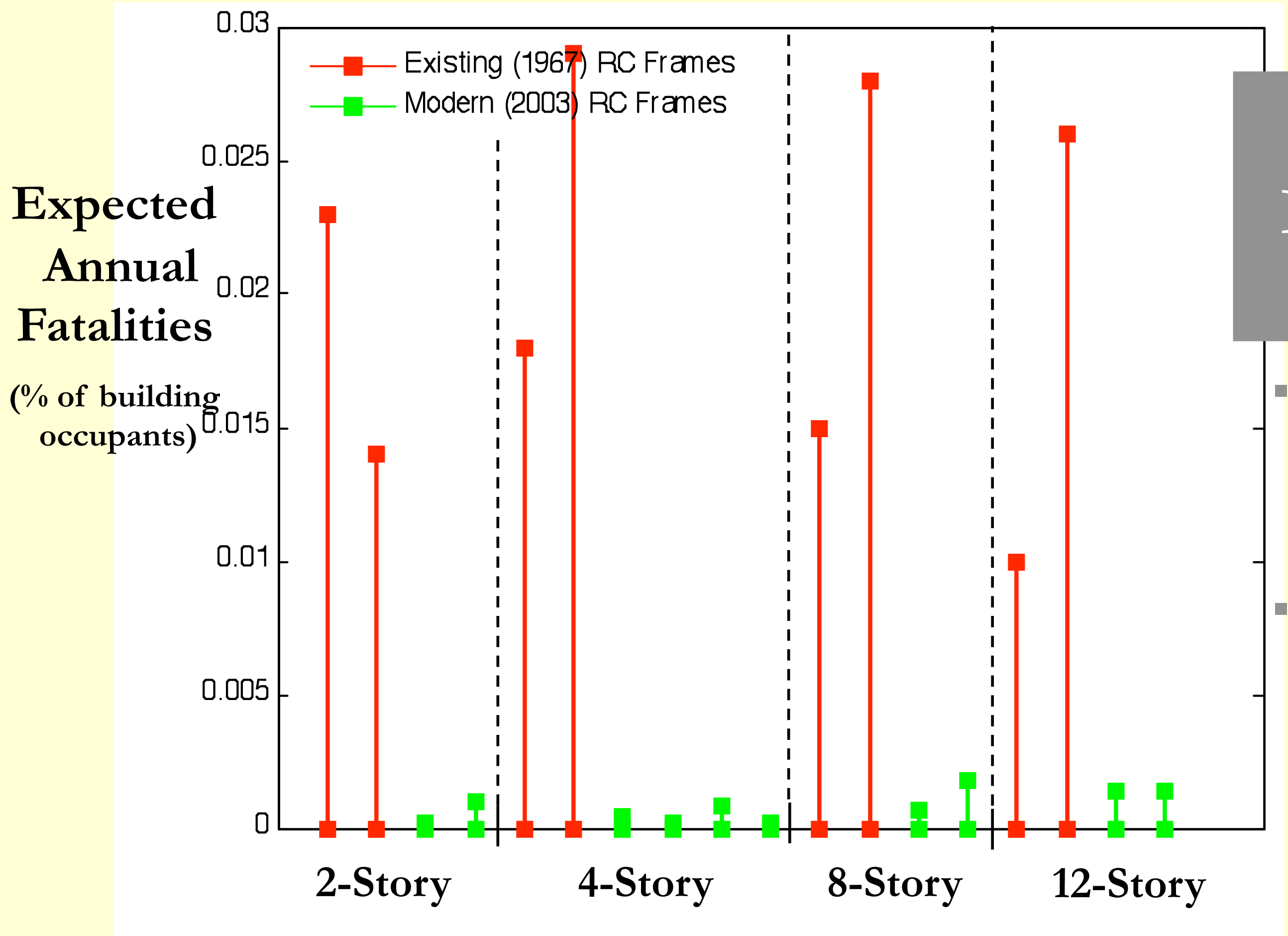
Source: G. Deierlein

Estimated Economic Losses



Source: G. Deierlein

Fatality Predictions 2003 vs 1967 RC Frames



Comparison of Earthquake-Related Fatalities

- Comparison: modern buildings about 15 to 50 times safer (fewer fatalities)
- Seismic codes have been very effective at reducing earthquake-related fatalities

Source: G. Deierlein

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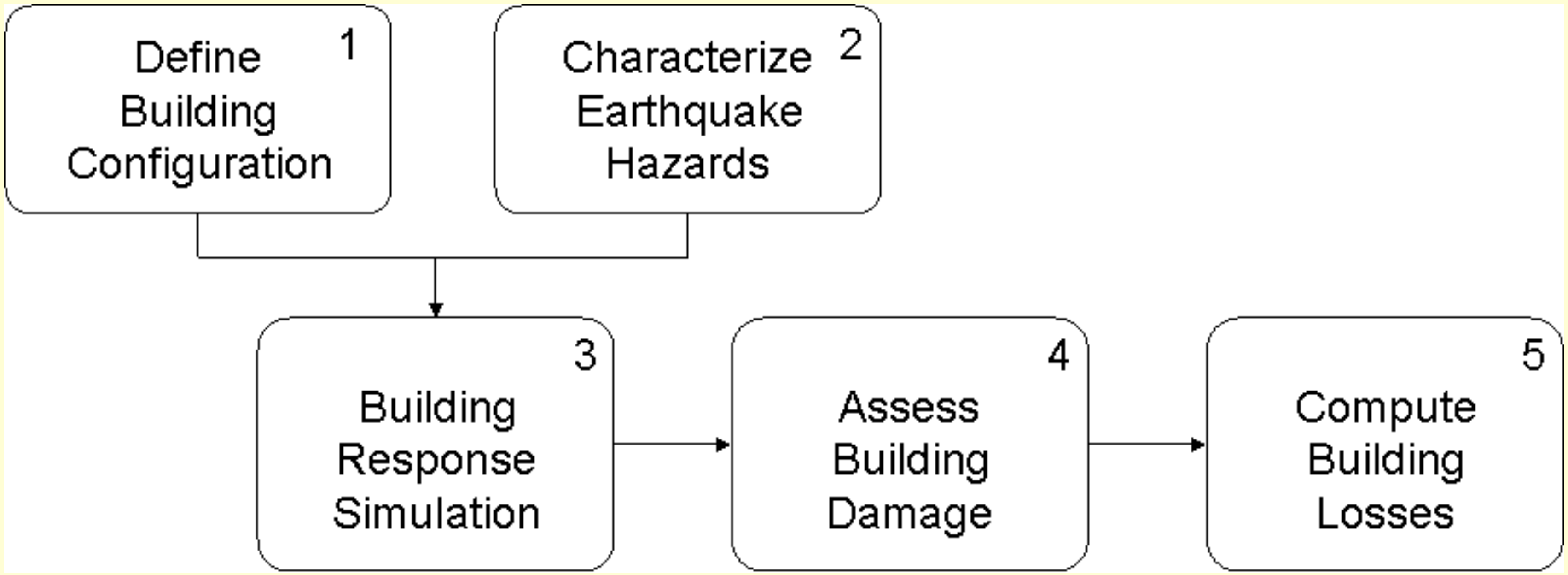
Present Implementation of PBEE in Practice

- ***ATC-58*** – Guidelines for Seismic Performance Assessment of Buildings
- ***ATC-63*** – Recommended Methodology for Quantification of Building System Performance
- ***TBI*** – Tall Building Initiative

ATC-58 - Seismic Performance Assessment of Buildings

Implementation Chart



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ATC-58 - Nonstructural Fragilities

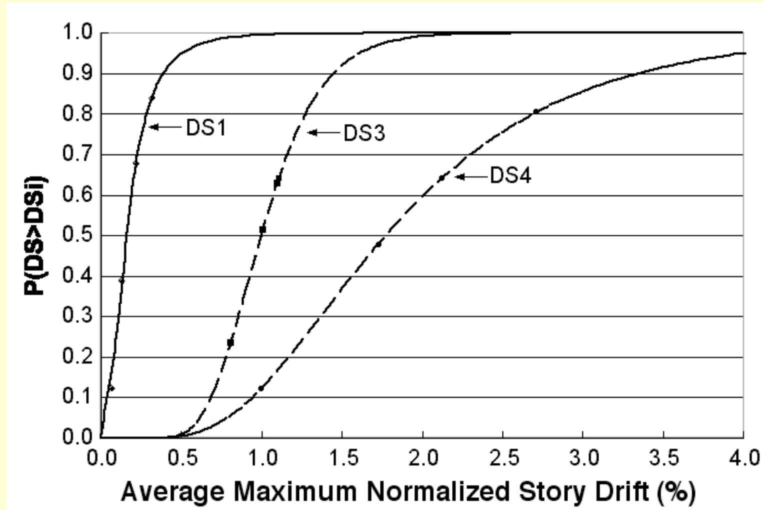
- Interior partitions
- Exterior skin-glass curtain walls
- Ceiling systems – acoustical
- Ceiling GWB on wood joists
- Exterior roofing concrete tiles
- Conveying - hydraulic elevators
- Roof mounted equipment
- Miscellaneous housewares and art objects
- Home entertainment equipment
- Desktop computers
- Servers and network equipment
- Tall file cabinets
- Unanchored bookcases

ATC-58 - Structural Fragilities

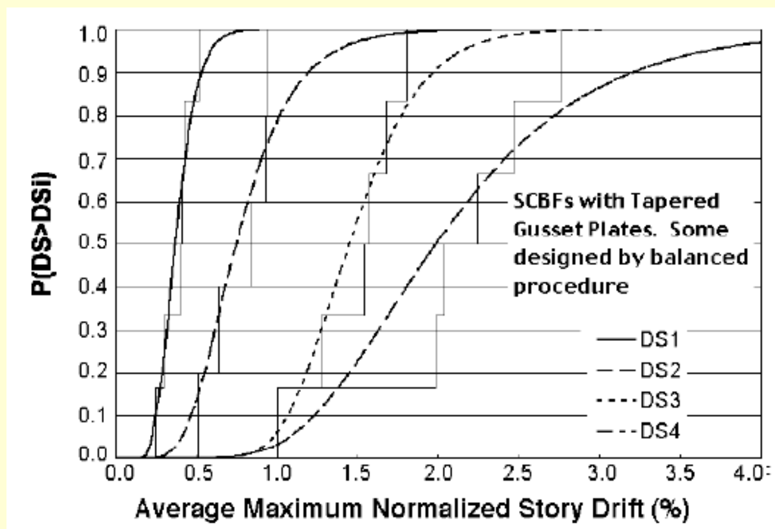
- Steel SMFs
- Steel CBFs
- RC SMFs
- RC walls – slender
- RC walls – squat
- Masonry walls
- Wood

Concentrically Braced Frames - CBFs

OCBFs



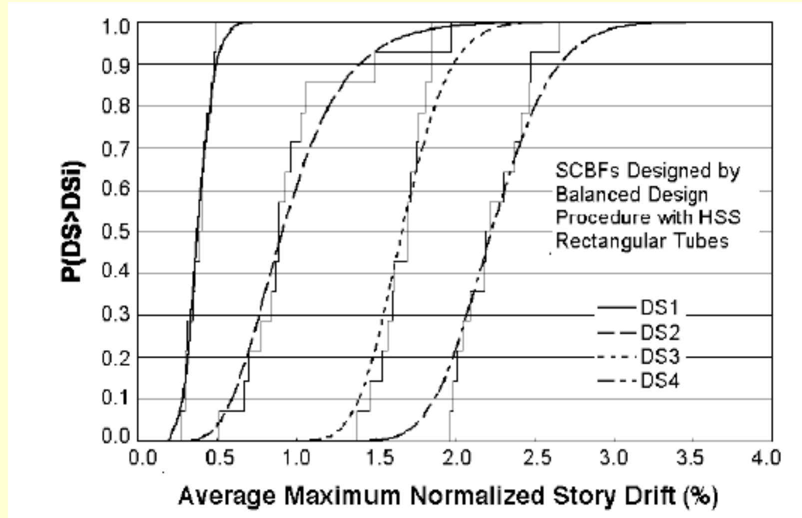
SCBFs
(tapered gusset plates)



Concentrically Braced Frames - CBFs

SCBFs

(improved balanced design)



SCBFs

(wide flange braces)

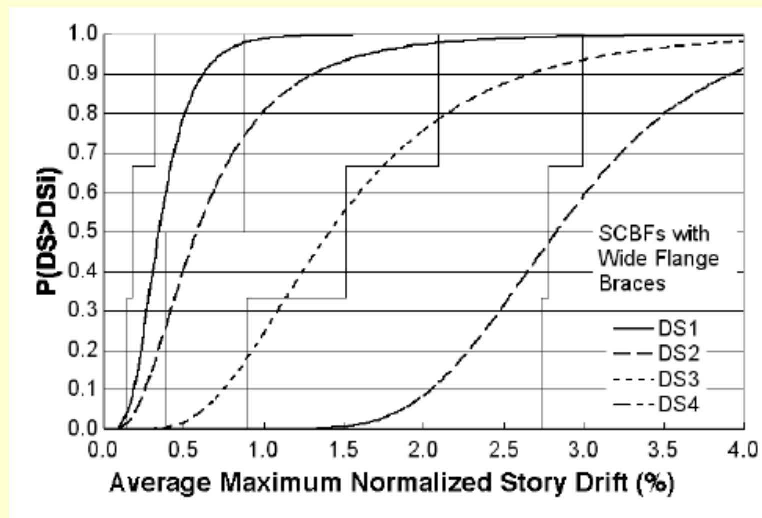


Figure 15. Fragility Curves for SCBFs with Wide Flange Braces

ATC-63 = FEMA P695
Methodology for Quantification of Building System Performance

Objectives

- **Primary** – Create a methodology for determining Seismic Performance Factors (R-factor, C_d-factor, overstrength factor) for different lateral-force-resisting systems
- **Secondary** – Evaluate a sufficient number of different lateral-force-resisting systems to provide a basis for Seismic Code committees to develop more rational Seismic Performance Factors that will more reliably achieve the inherent earthquake safety performance objectives of building codes

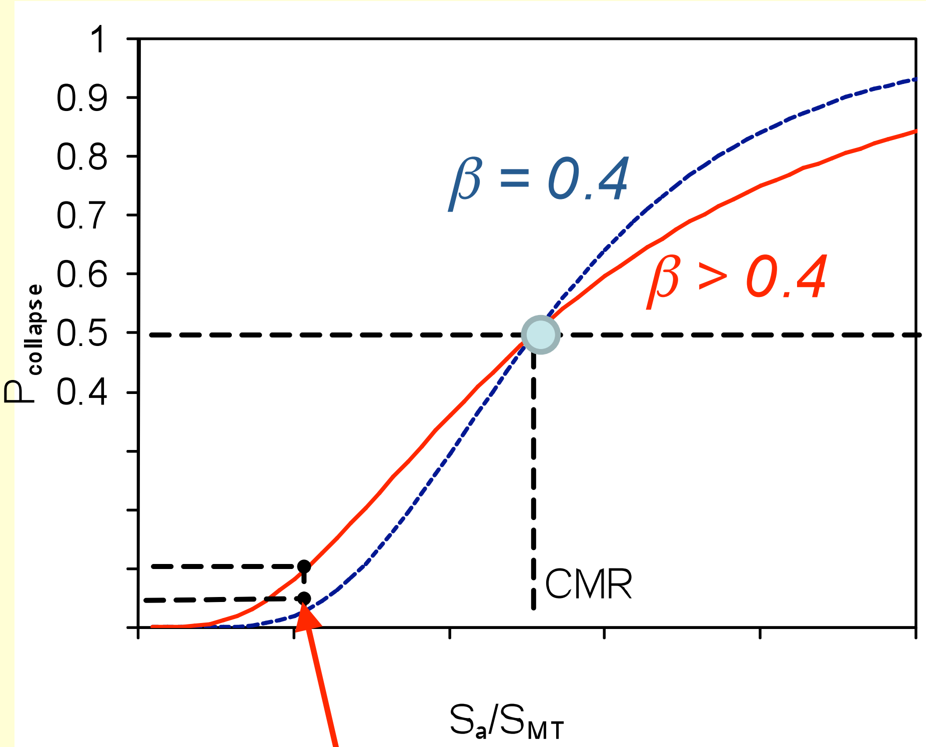
Collapse Fragility Curves - Uncertainties

FOUR CONTRIBUTORS:

1. **record-to-record variability (β = *0.4*)**
2. **design requirements**
3. **quality of test data**
4. **analysis model quality**

$$\beta_{TOT} = \sqrt{\beta_{RTR}^2 + \beta_{DR}^2 + \beta_{TD}^2 + \beta_{MDL}^2}$$

Source: C. Kircher



Collapse Probability at MCE?

Quantification of ATC-63-based Building System Performance

- RC special moment frames
- Wood light frame systems
- Steel special moment frames
- Steel concentrically braced frames
- RC shear wall structures
- Masonry wall structures

PEER - Tall Building Initiative

- **Task 2** Develop consensus on performance objectives
- **Task 7** Guidelines on modeling and acceptance values (ATC-72 report)
- **Task 10** Performance-based seismic design guidelines for tall buildings
- **Task 12** Quantification of seismic performance of tall buildings

Types of Occupancy

CONDO

HOTEL

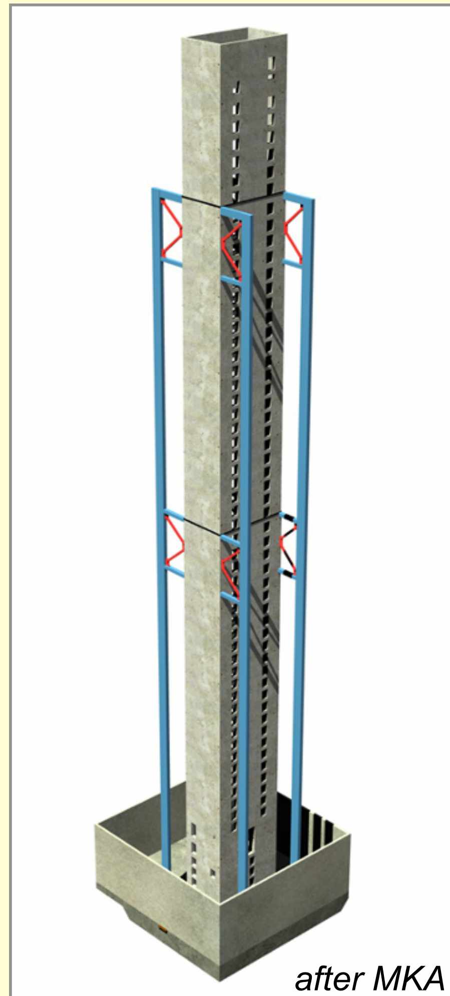
$ RETAIL

PARKING

Source: Maffei & Moehle

What is different about these buildings?

- High-performance materials
- Framing systems not satisfying code prescriptive limits
- Non-prescriptive designs are accepted in the code by demonstrating at least equivalent seismic performance.



Source: Maffei & Moehle

Future - Missing Pieces

- **For damage/loss assessment:**
  - Fragility curves for damage in structural and nonstructural components
  - Consequence functions and loss curves
  - Effects of correlations
- **For downtime assessment**
  - Length of downtime
  - Consequences are strongly scenario dependent
- **For collapse prediction and life safety**
  - Better analytical modeling rules for incorporation of all deterioration and brittle failure modes at the component level
  - Collapse of wall structures
  - Modeling of propagation of local collapse
  - Incorporation of intangible contributions
  - Relationship between collapse and casualty rate

Future - Excitement

Implementations in practice

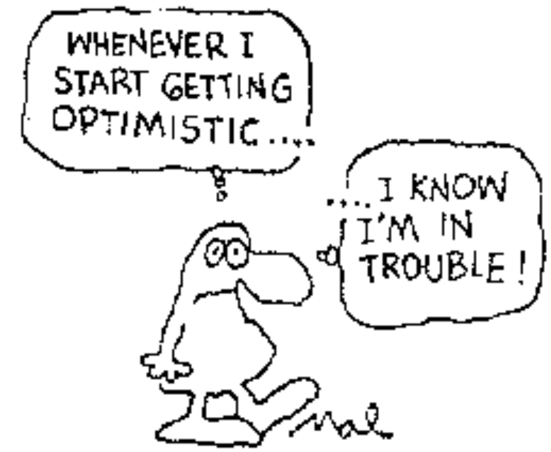
- ATC-58
- TBI
- Project 07 (risk-based ground motions)

Exciting topics for the future

- Loss assessment for tall buildings, including collapse
- Hospitals
- Campus and industrial complex
- Design for repairability
- Response modification devices
- **Sustainability – energy efficiency and climate change**

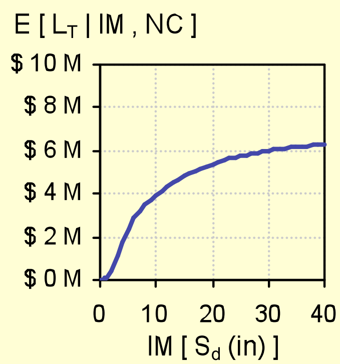
Concluding Remarks - 1999

- Performance based engineering is here to stay
- It enforces a transparent design/assessment approach
- Much more emphasis should be placed on $ losses and loss of function (downtime)
- Performance based design should be reliability based
- We have a long road ahead of us



Loss Conditioned on IM (scenario loss)

$$E[L_T \mid IM] = E[L_T \mid NC, IM] \cdot P(NC \mid IM) + E[L_T \mid C] \cdot P(C \mid IM)$$



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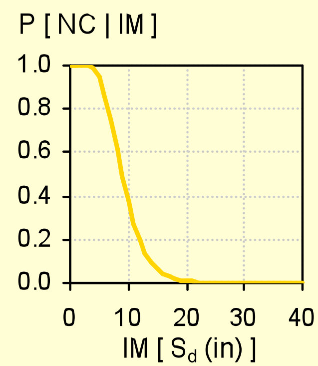

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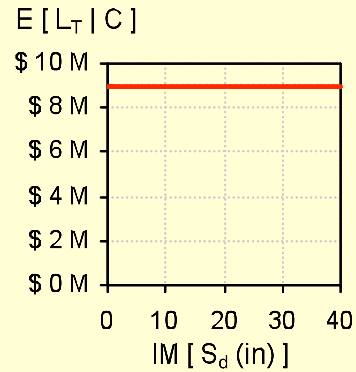

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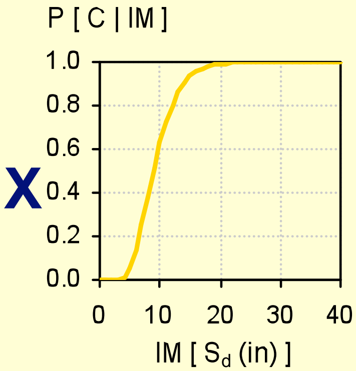

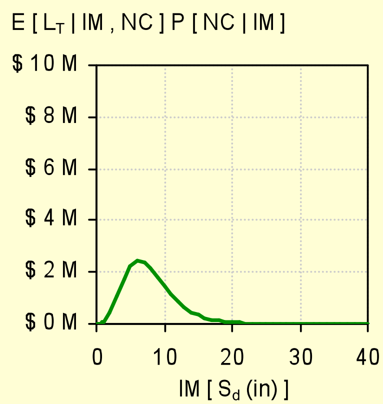

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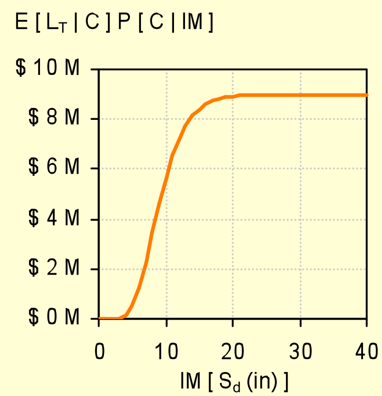

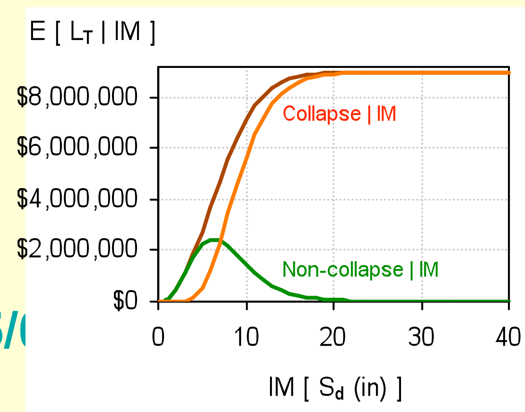

Source: E. Miranda