Engineering Needs for Existing Buildings
Research Perspective

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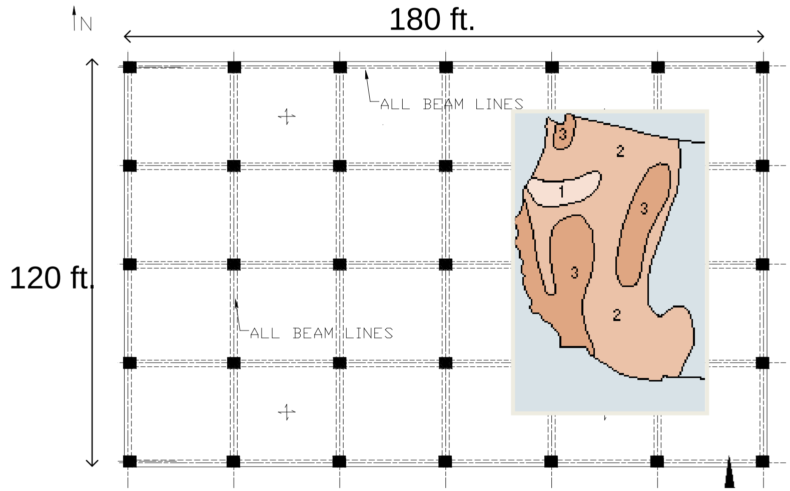
Acknowledgments: J. Baker, A. Liel, J. Maffei, B. Lizundia, J. Stewart, R. Vignos, C-M Uang, A. Whittaker, and ATC 96 team.

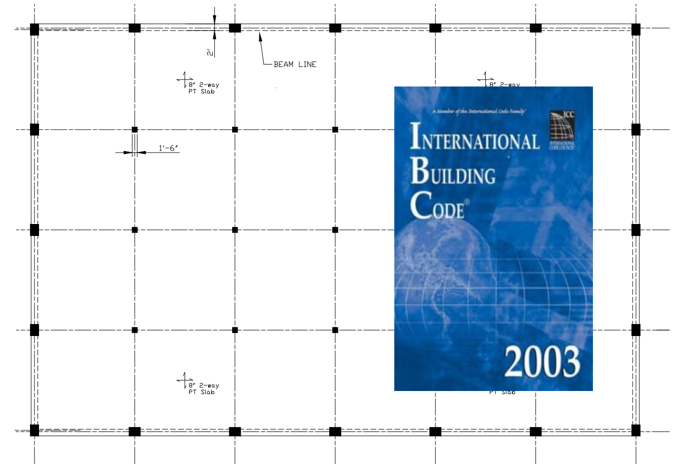
Summary of Needs

1. More Realistic Nonlinear Dynamic Analysis
2. Improved Guidelines and Criteria for Assessment
3. Benchmarking and Calibration of Acceptance Criteria
4. Assessment and Mitigation of Liquefaction and Large Ground Deformations
5. Improved Models for Soil-Structure Interaction
6. Broader Issues: Risk Mitigation Decision Making



1967 Design

- Space Frame
- 1967 UBC, Zone 4
- Design V/W: 0.068 g
- Member sizes
  - Col. 20x20 to 24x24
  - Beam depth 20 to 26
- No SCWB, no joint check, non-conforming ties

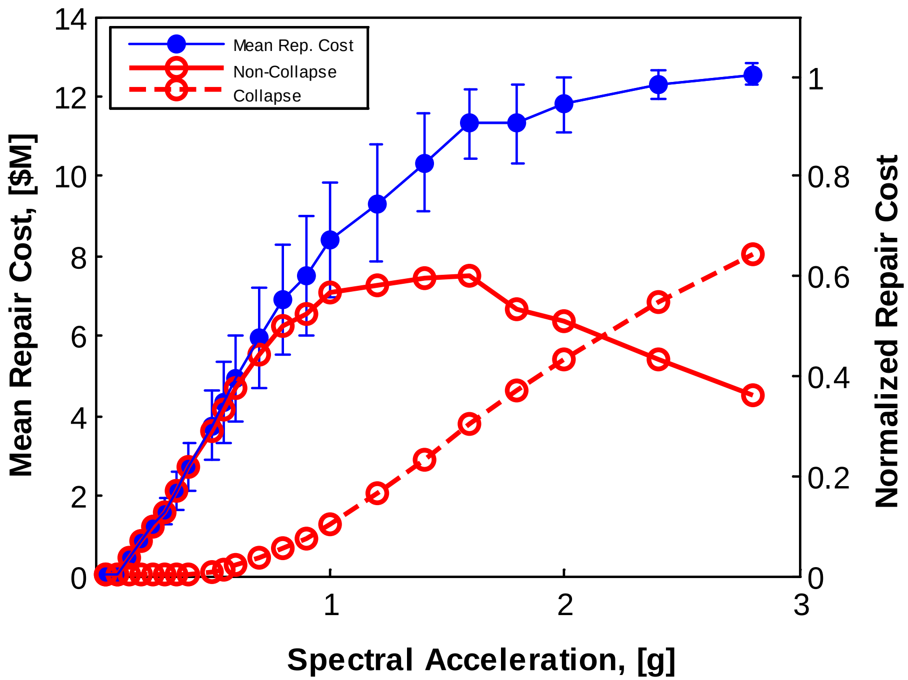


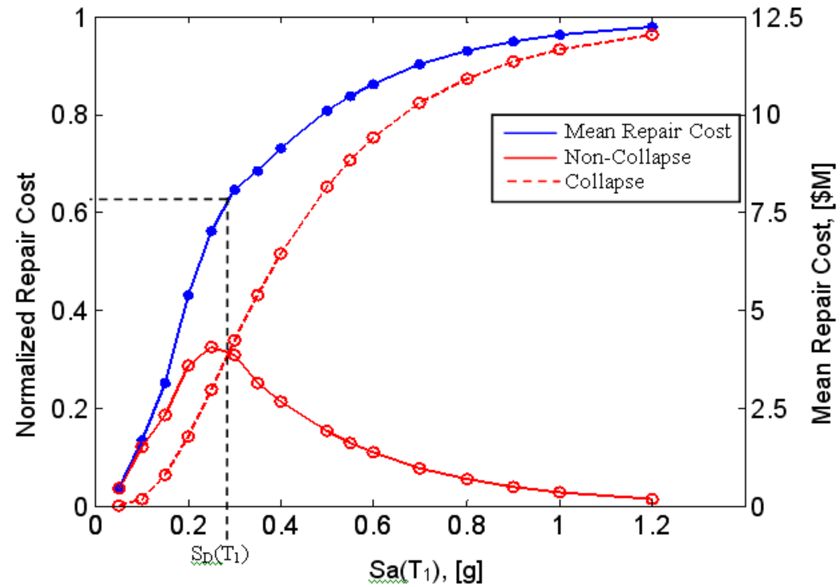
2003 Design

- Perimeter Frame
- 2003 UBC/2002 ACI
- Design V/W: 0.094 g
- Member sizes
  - Col. 24x28 to 30x40
  - Beam depth 32 to 42
- Fully conforming design

Ref: Haselton, Liel and Deierlein

Comparison of Loss Contributors





2003

P(collapse) = 0.5% in 50 yr

EAL = 1.2% of building value

1967

P(collapse) = 15% in 50 yrs

EAL = 2.3% of building value

Ref: Ramirez, Liel, Haselton, Miranda and Deierlein

PEER/PBEE: Collapse (SAFETY) Assessment

Decision Variable — **DV:** COLLAPSE

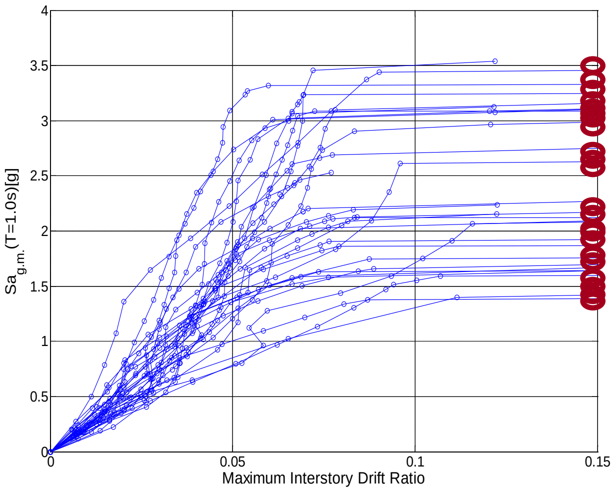
Damage Measure — **DM:** Loss of Vertical Carrying Capacity (LVCC)

EDPs: Deformations & Forces

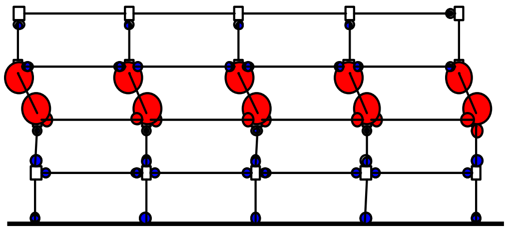
Engineering Demand Parameter — **EDP:** Interstory Drift Ratio

Intensity Measure — **IM:** *Sa(T₁) + Ground Motions*

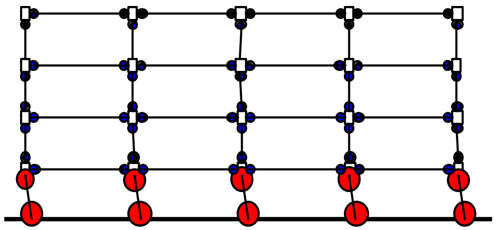
Collapse Assessment Using Incremental Dynamic Analysis



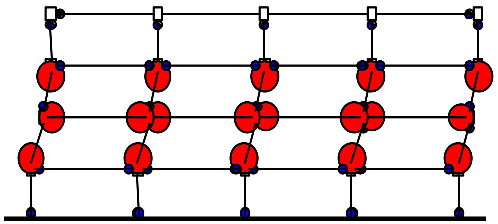
Incremental Dynamic Analysis



40% of collapses

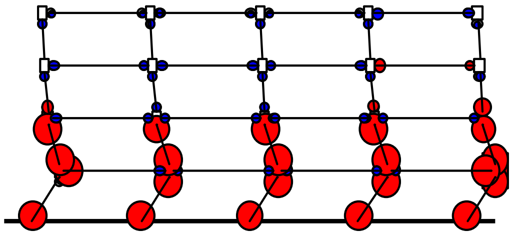


27% of collapses

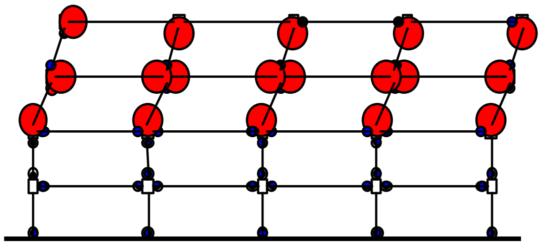


17% of collapses

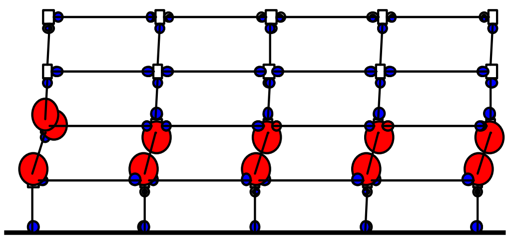
****Predicted by Static Pushover**



12% of collapses



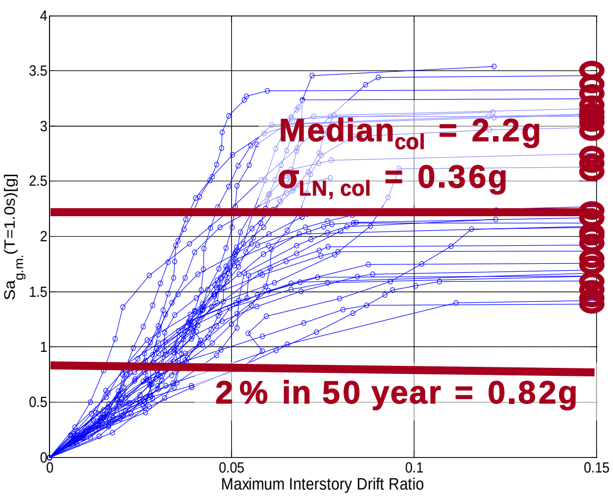
5% of collapses



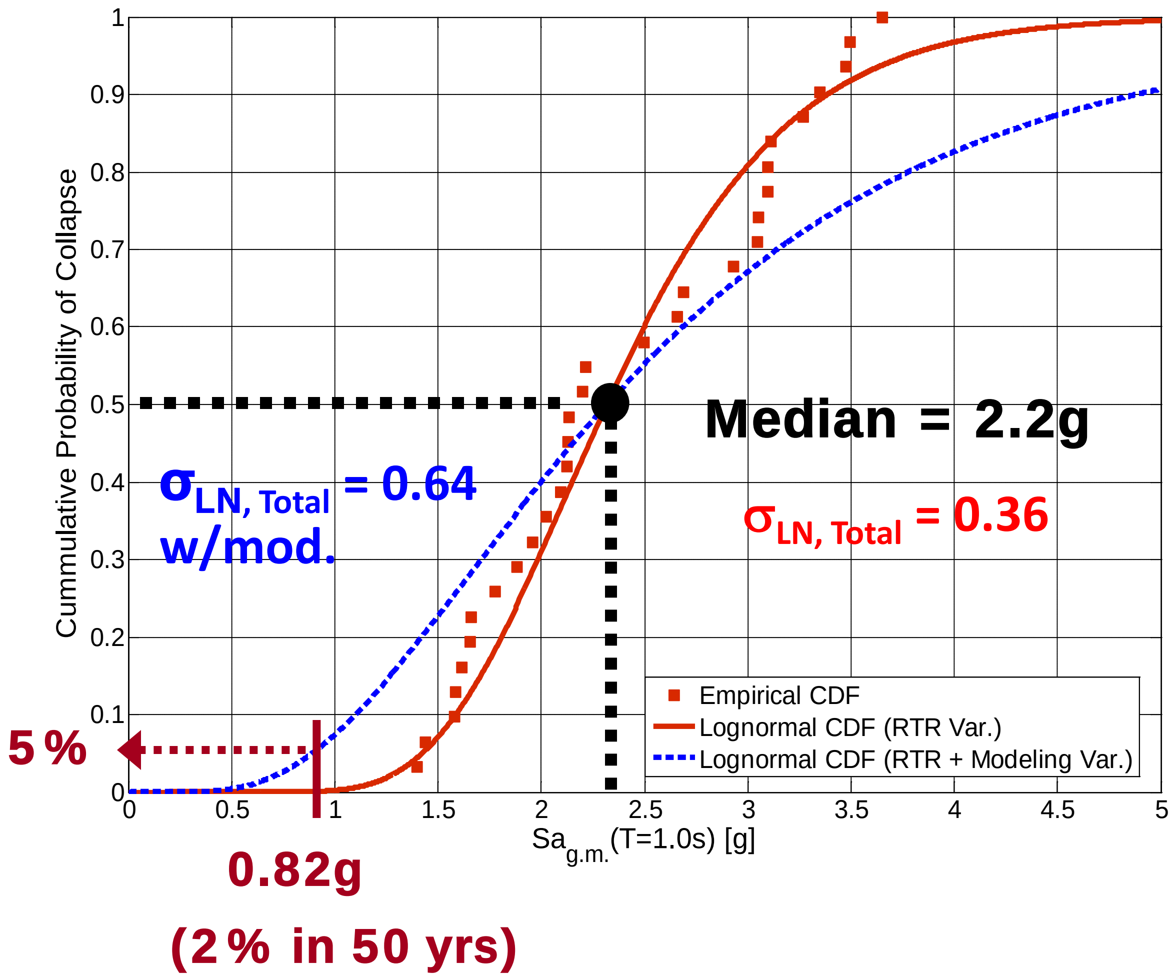
2% of collapses

Ref: Haselton and Deierlein

Collapse Fragility Curve

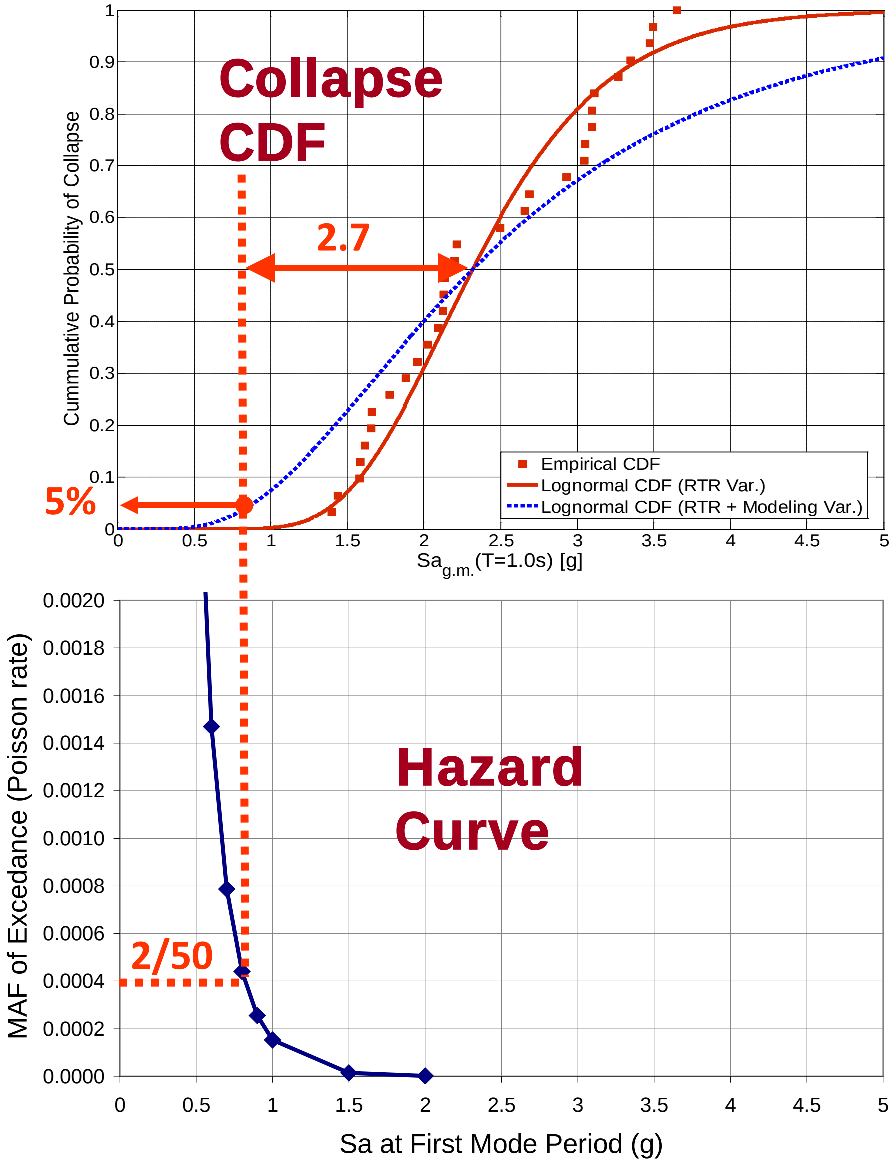


Incremental Dynamic Analysis



Ref: Haselton and Deierlein

Collapse Fragility and Hazard Curve Integration

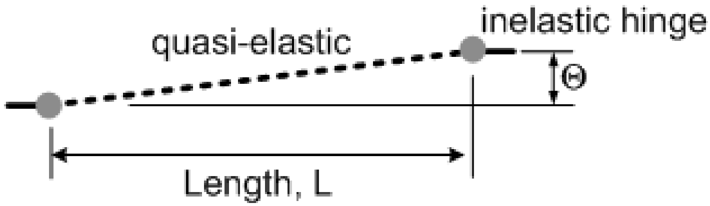


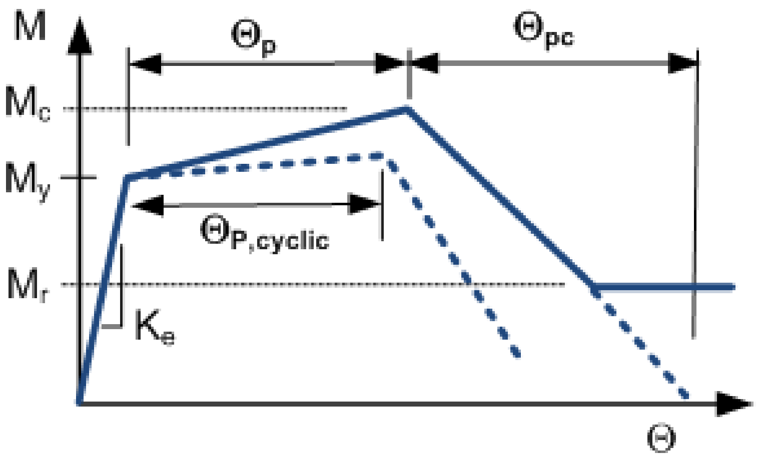
Collapse Performance

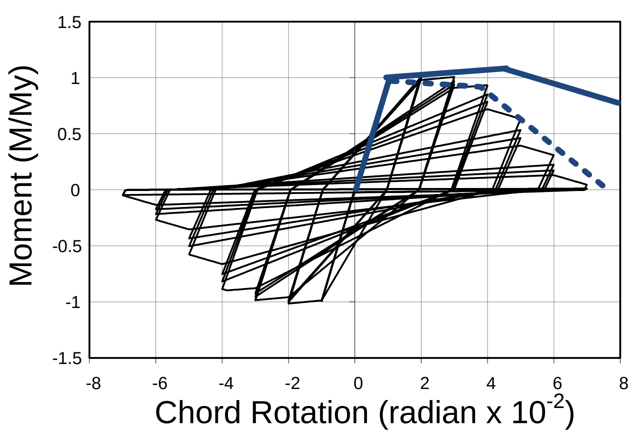
- Margin: $S_{a,collapse}$ = 2.7 MCE
- 5% Probability of collapse under design MCE = 5%
- MAF_{col} = 1.0 x 10^{-4} (0.5% in 50 years)

Ref: Haselton and Deierlein

Nonlinear RC component model







Key Parameters:

- strength
- initial stiffness
- post-yield stiffness
- plastic rotation (capping) capacity
- post-capping slope
- cyclic deterioration rate

Calibration Process:

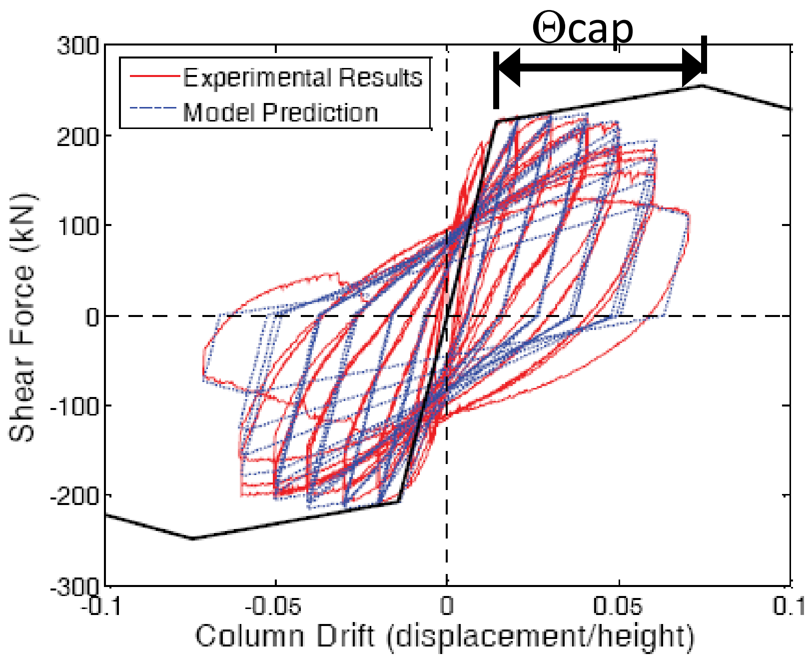
- 250+ columns (PEER database)
- flexure & flexure-shear dominant
- calibrated to ***expected*** values

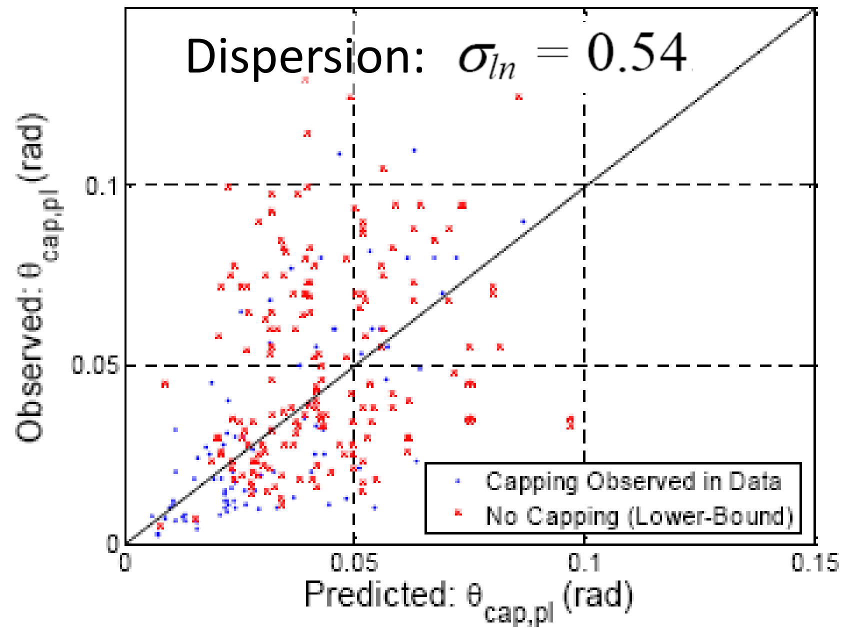
Demand Parameter Output: hinge rotation

KEY ASSUMPTION: bond slip is incorporated in the beam-column model parameters

PEER STRUCTURAL PERFORMANCE DATABASE SPD

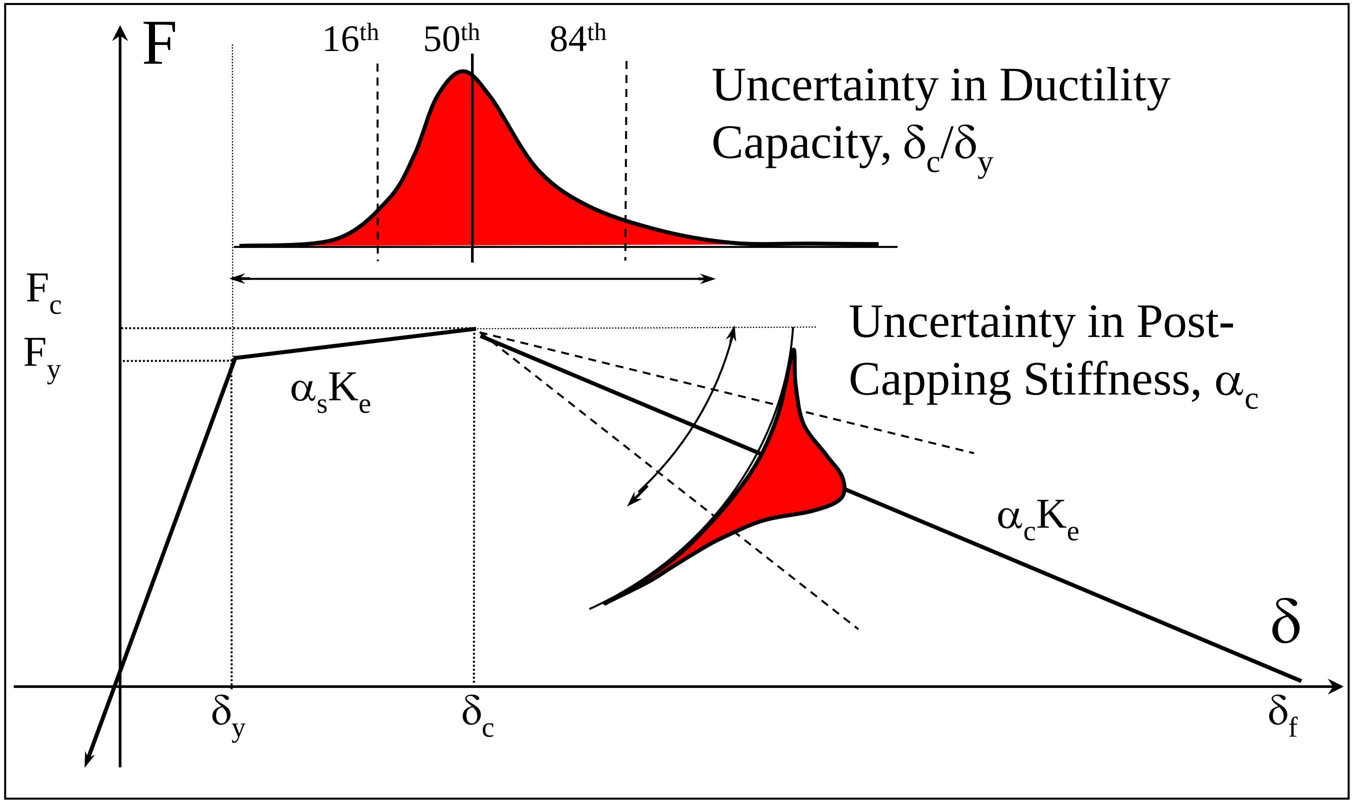
Median: $\theta_p = 0.12(1+0.55a_{sl})(0.16)^{\upsilon}(0.02+40\rho_{sh})^{0.43}(0.54)^{0.01c_{units}f'_c}(0.66)^{0.1s_n}(2.27)^{10.0\rho}$





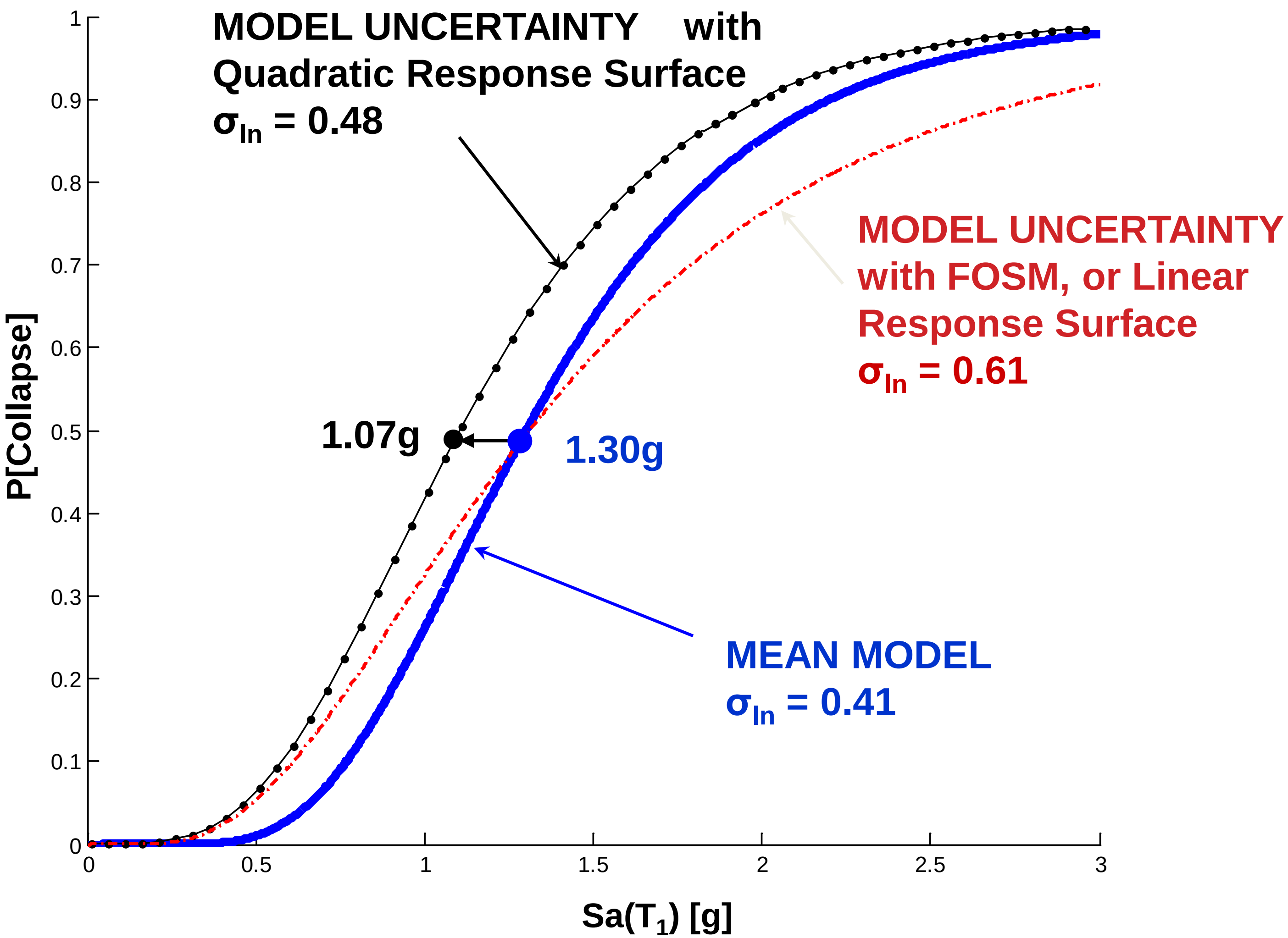
Ref: Haselton and Deierlein

Uncertainty in model parameters



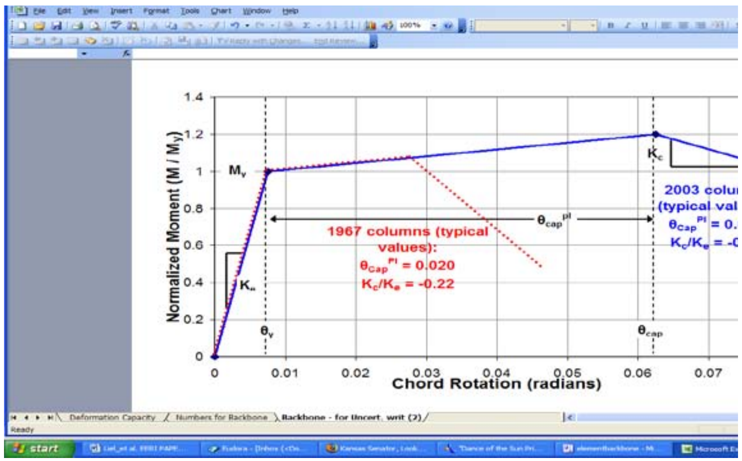
Source: L. Ibarra (2004)

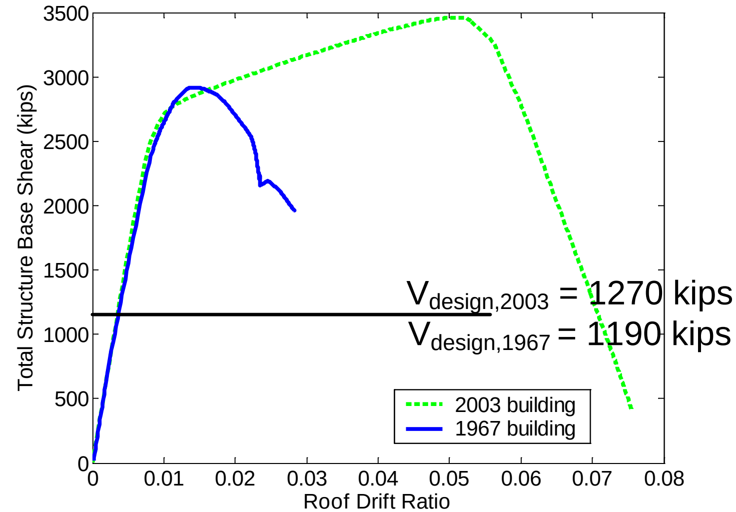
Effects of modeling uncertainties on collapse fragility (4-story RC frame example)



Ref: Liel and Deierlein

Modern vs. Older RC Buildings: Component and Pushover Ductility





Column Hinge Backbone Parameters

$\Theta_{p,cap}$: *1967 = 0.02 rad (COV 50%)*

2003 = 0.06 rad

K_c/K_e: *1967 = -0.22 (COV 60%)*

2003 = -0.08

Static Pushover Response

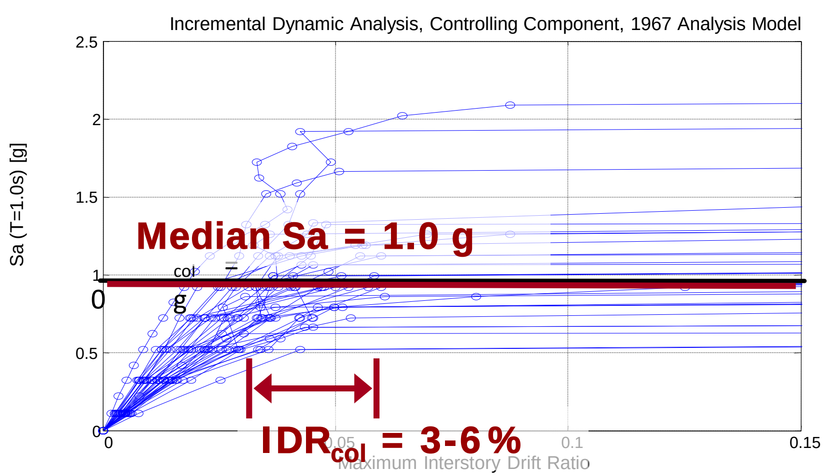
Ω_u : *1967 = 2.4*

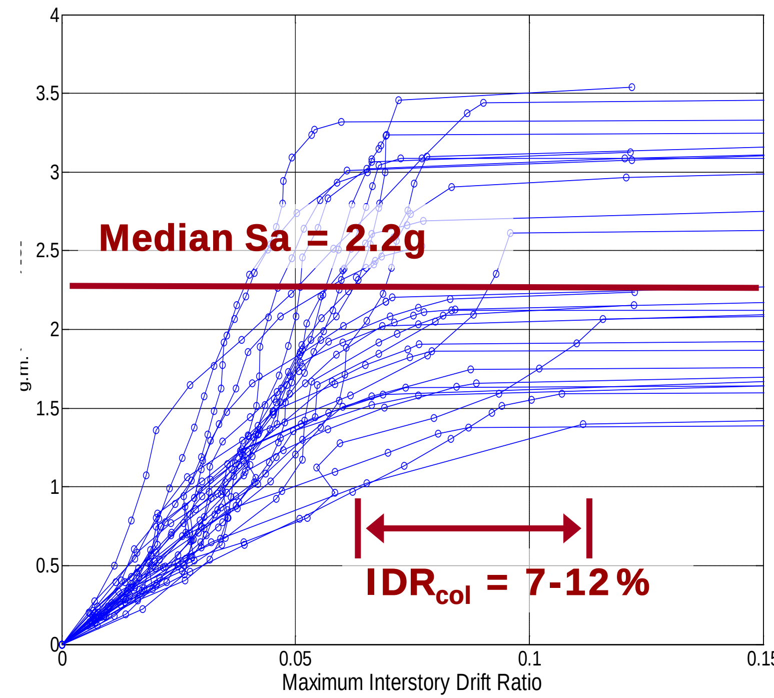
2003 = 2.7

Δ_u: *1967 = 1.5% roof drift ratio*

2003 = 5.0%

Comparison of Dynamic (IDA) Response





1967 Design

Strength: Median Sa = 1.0g, COV = 30%

Deformation: IDR_{max} = 3 to 6%

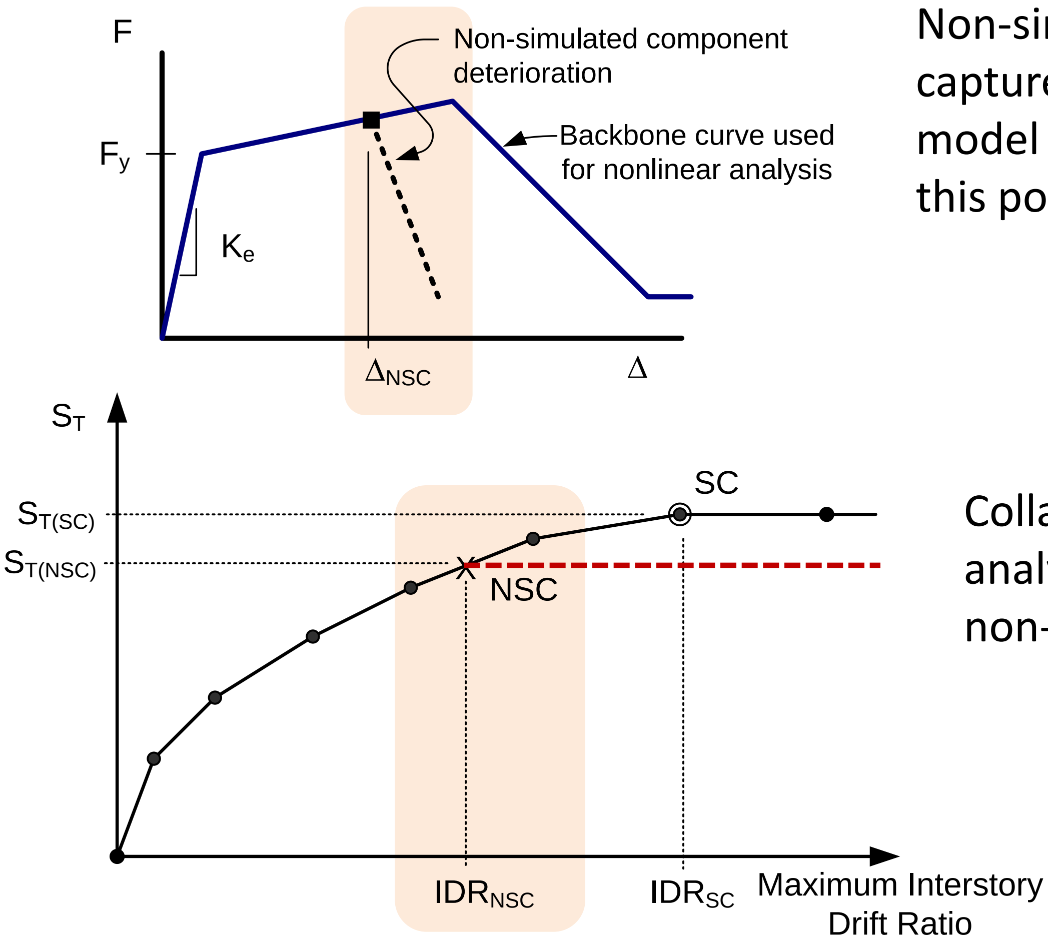
2003 Design

Strength: Median Sa = 2.2g, COV = 36%

Deformation: IDR_{max} = 7 to 12%

Ref: Liel and Deierlein

Non-Simulated Collapse Mechanisms

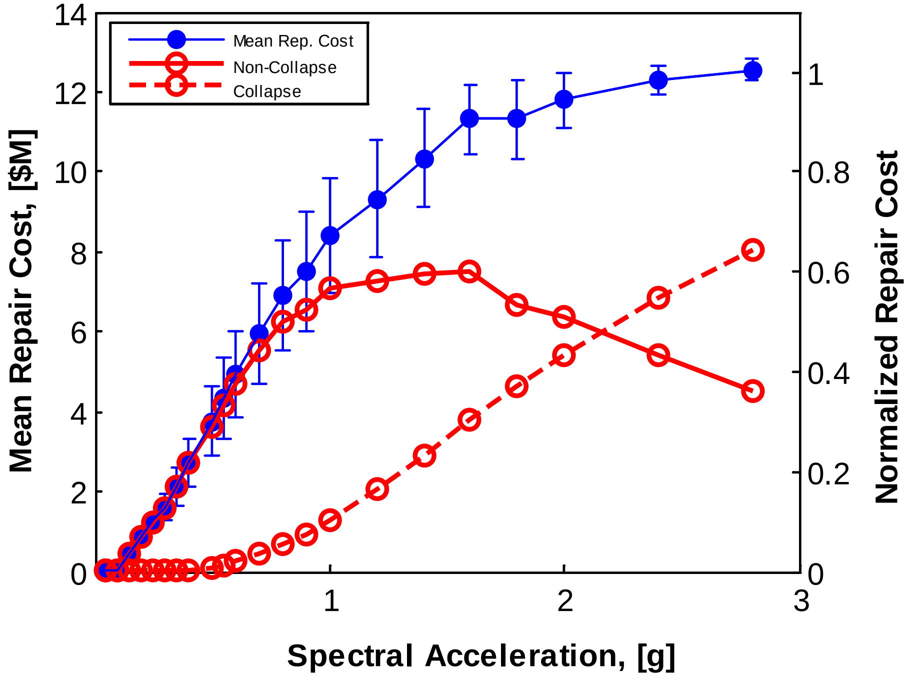


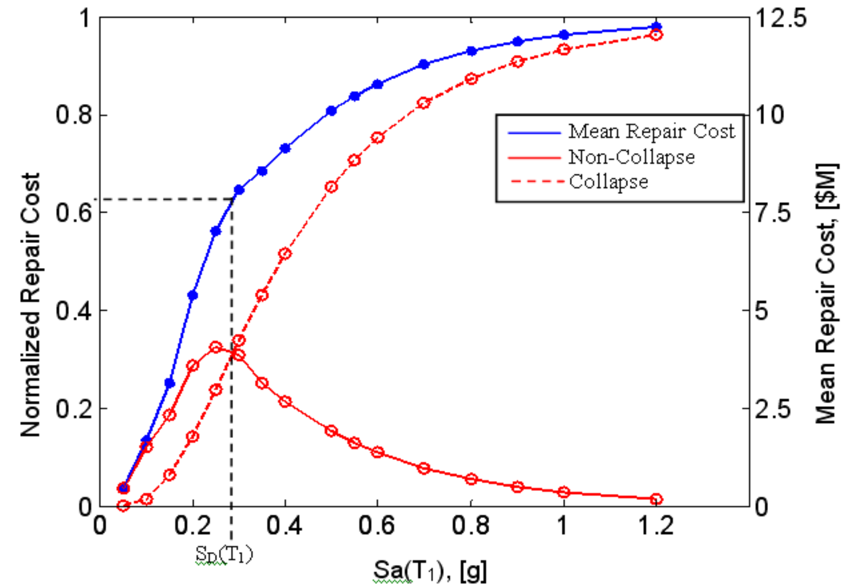
Non-simulated component deterioration is not captured by backbone curve of hysteretic model and invalidates analysis results beyond this point

Collapse point from nonlinear time history analysis is modified (reduced) to account for non-simulated limit state

Ref: Liel and Deierlein

Comparison of Loss Contributors





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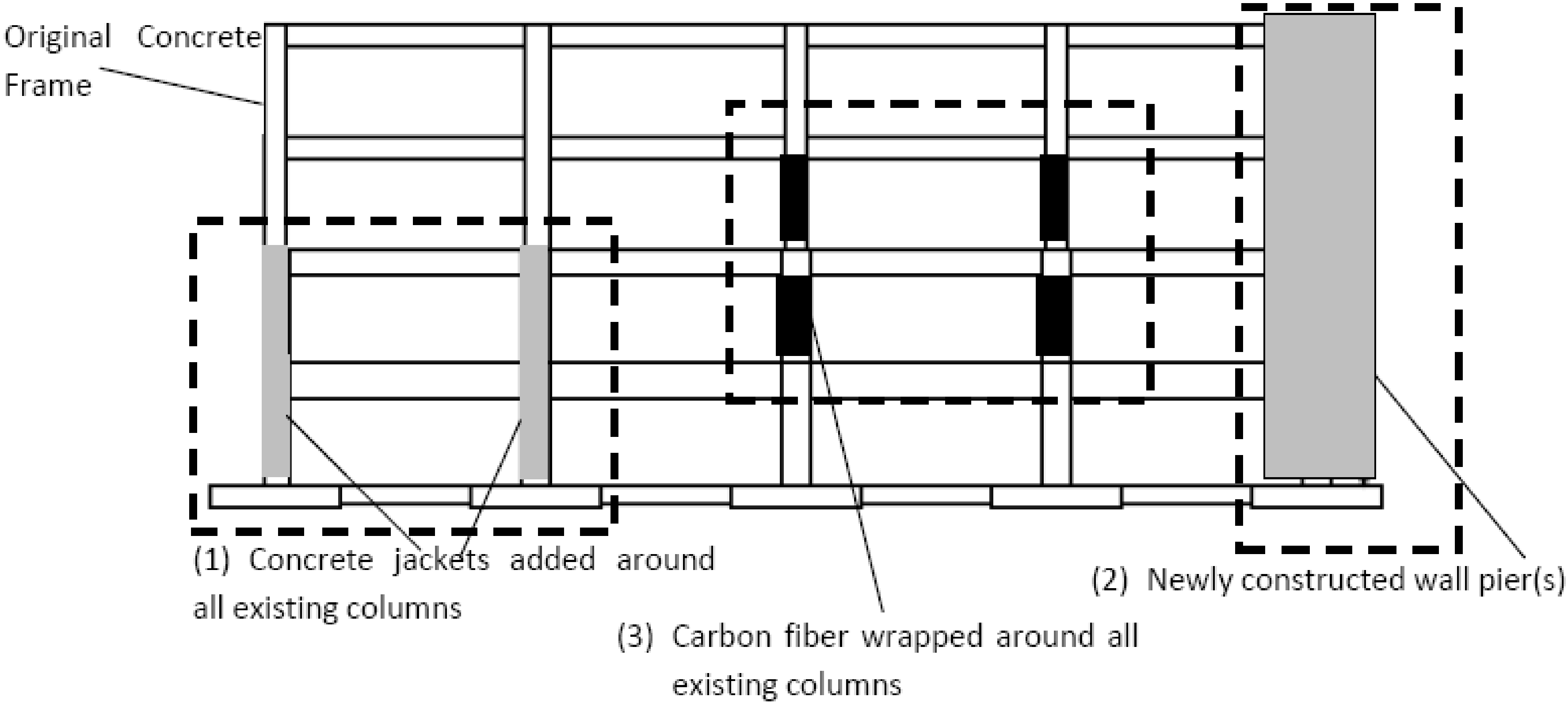
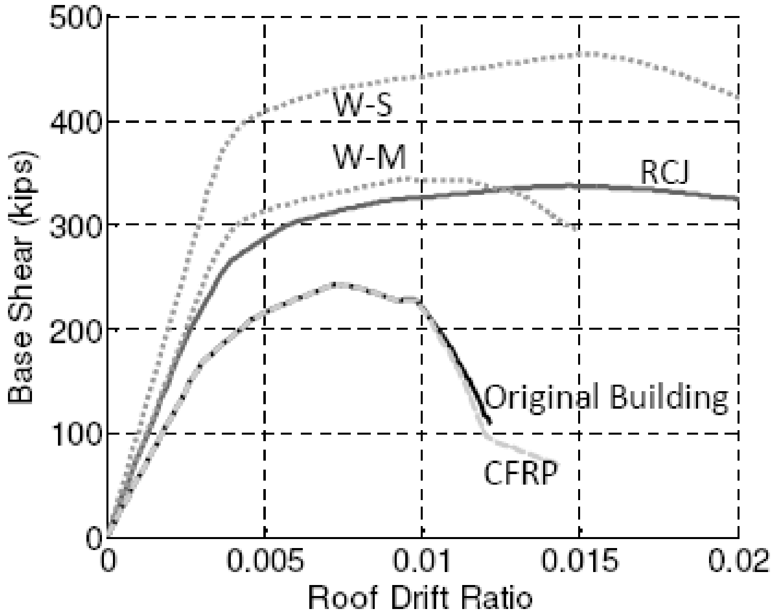
Seismic Retrofit Strategies

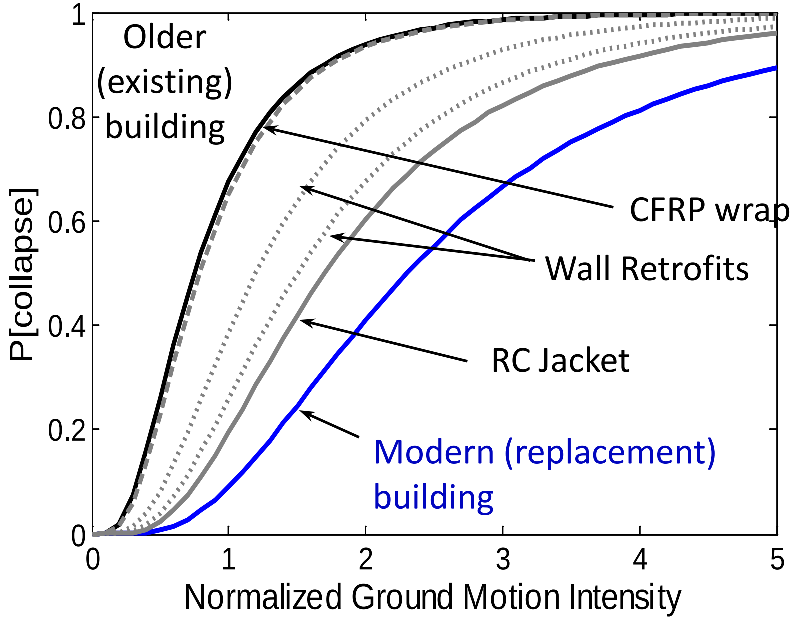


Ref: Liel and Deierlein

Seismic Retrofit – Collapse Fragility
8-Story Space Frame



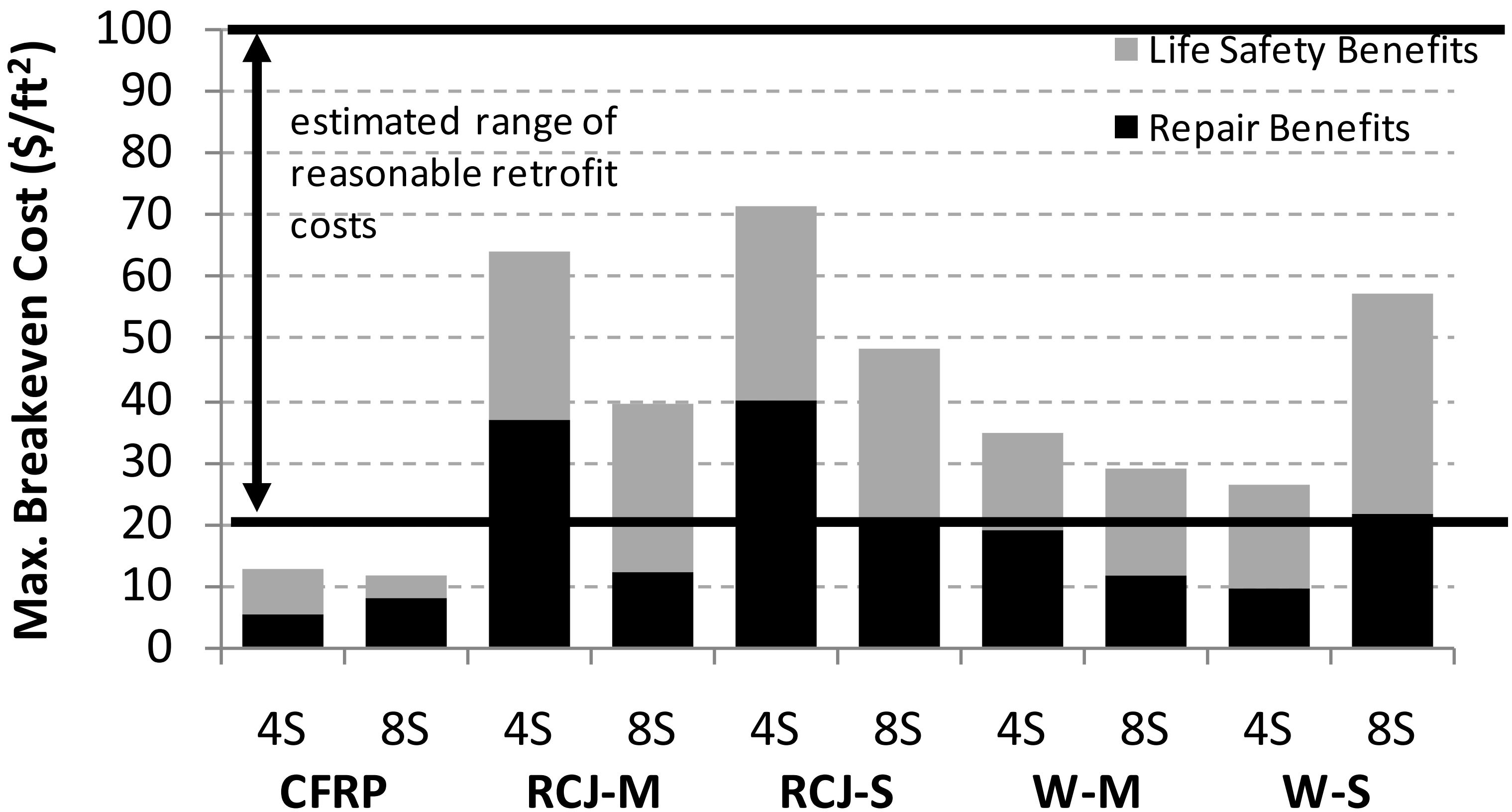
static pushover



collapse fragility

Ref: Liel and Deierlein

Seismic Retrofit – Cost/Benefit Analysis



BENEFITS:

- LIFE SAFETY - assume $2M per life saved
- ECONOMIC – repair costs
- *DOWNTIME – business interruption (NOT INCLUDED)*

1) More Realistic Nonlinear Dynamic Analysis

- **Challenges for dynamic response of existing buildings**
  - cyclic models with strength & stiffness degradation
  - multitude of deterioration & failure models
  - modeling uncertainties
- **Validation and calibration of nonlinear models**
  - integrate test data, analysis & judgment
  - develop & utilize system response data
  - effects of loading rate and load protocol
- **Development of more realistic models**
  - phenomenological vs. fundamental
  - minimize reliance on "non-simulated" collapse criteria

1) More Realistic Nonlinear Dynamic Analysis

- **Non-ductile RC Systems**
  - beam-columns (3D P-M-V)
  - shear walls (flexural and squat)
  - Infill walls, splices, joints, slab-column
- **Non-conforming steel systems**
  - beam-columns w/T-F buckling, local buckling
  - brace and moment frame connections (yielding-fracture)
  - braces w/buckling and fracture
- **Masonry walls incl. diaphragm/collector interactions**
- **Wood walls and diaphragms, w/ architectural finishes and partitions**

2) Improved Assessment Guidelines and Criteria

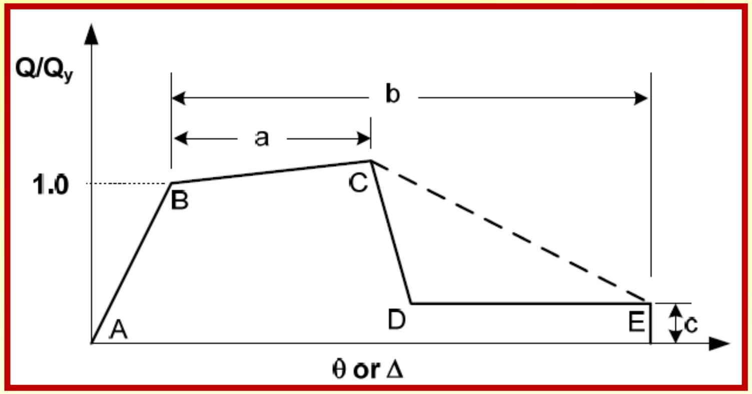
- **next generation of FEMA 273/ASCE 41**

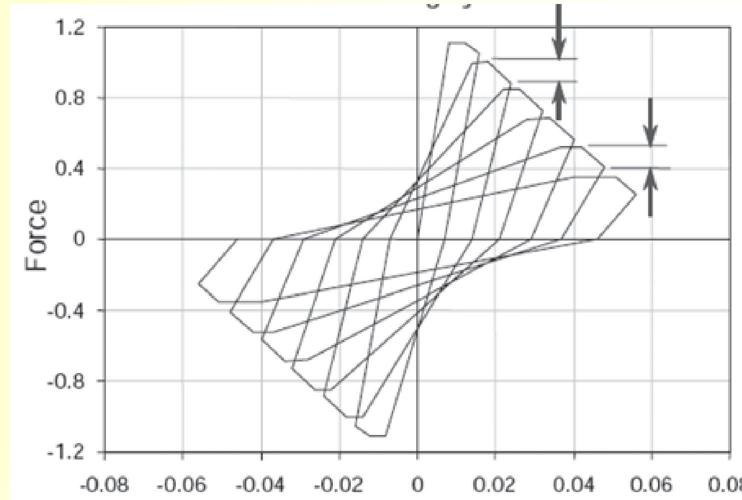
  overcome limitations to be more realistic

- **nonlinear DYNAMIC analysis**

  - generalized cyclic model

2) Improved Assessment Guidelines and Criteria





ASCE 41: Generalized Force-Deformation (cyclic backbone)

Generalized Cyclic Model

- initial (monotonic) backbone
- strength/stiffness degradation
- hysteresis rules
- energy dissipation capacity

2) Improved Assessment Guidelines and Criteria

- **next generation of FEMA 273/ASCE 41**
  overcome limitations to be more realistic
- **nonlinear DYNAMIC analysis**
  - generalized cyclic model
- **modeling uncertainties**
  - central values (mean or median) & dispersion
- **more realistic continuum vs. fixed categories**
  - e.g., deformation vs. force-controlled elements
- **facilitate use of alternative model types**
  - phenomenological (hinge) vs. fundamental (strain)

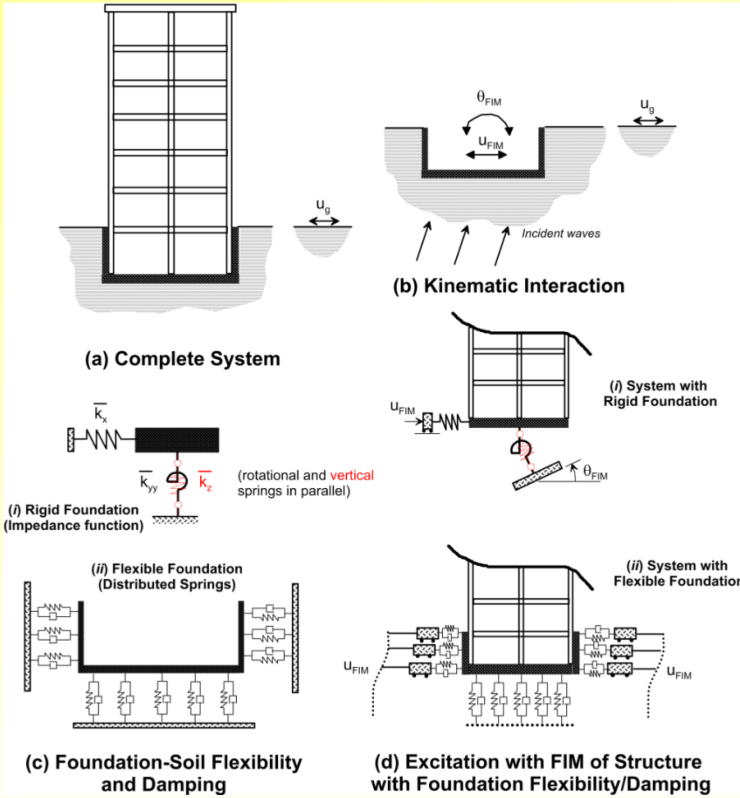
3) Benchmarking/Calibration of Performance Criteria

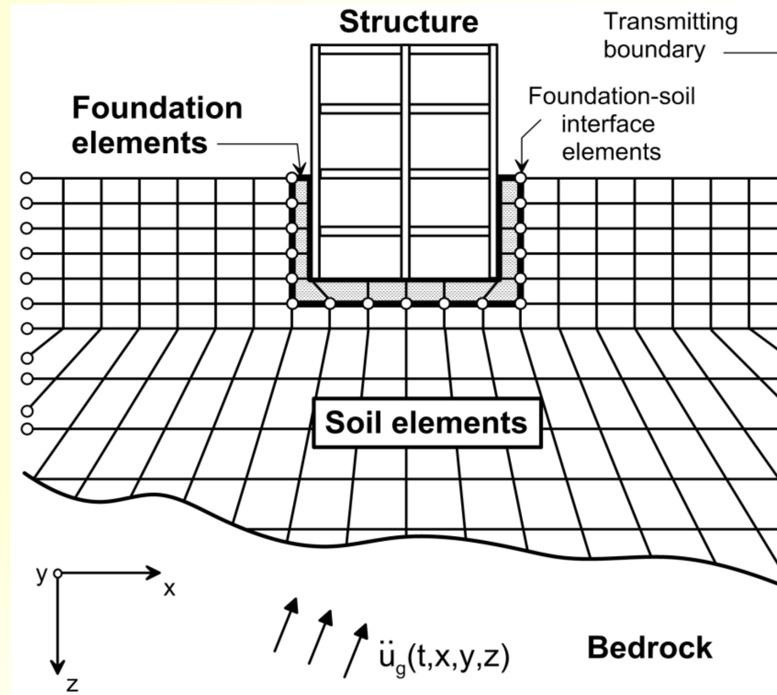
- **ASCE 41 Performance Metrics**
  - component-base acceptance criteria
  - quantitative meaning of IO, LS and CP?
- **Evaluation Technologies**
  - Collapse: FEMA P695
  - Losses: FEMA P85
- **Assess performance of simplified prescriptive performance limits with the aim to:**
  - refine/calibrate prescriptive criteria
  - Inform practices and policies for evaluation and retrofit

4) Assessment and Mitigation of Liquefaction and Large Ground Deformations

- **Criteria for triggering & prediction of liquefaction and ground deformations under buildings**
  - overburden pressures & SSI effects
- **Consequence and mitigation of ground deformations on buildings**
- **Evaluation of non-ductile RC piles in soil layers with variable properties that can lead to localization of deformations**

5) Improved Models for Soil-Structure Interaction





indirect models (substructure)

direct models (continuum)

5) Improved Models for Soil-Structure Interaction

- **Foundation rocking and sliding**
  - reduce earthquake effects on low-rise (stiff) buildings
  - variable effects on mid- to high-rise buildings
- **Incoherence of ground motions in plan and depth (kinematic interaction)**
  - characterization of ground motions
  - analytical techniques for software implementation
- **More realistic assessment of dynamic earth pressures on retaining walls**
  - assumed mobilization of shear strength is unrealistic

6) Broader Issues: Risk Mitigation Decision Making

- **Post-EQ Occupancy Issues**
  - exogenous factors (lifeline & community performance)
  - resilience metrics and planning
- **Seismic Building Rating System**
  - What metrics? How to calculate them?
- **Strategies for Building Instrumentation**
  - pre-analysis and instrument system design
  - effectiveness and best-practices guide
- **Cost-Benefit Methodology to Assess Retrofit**
  - benefits: life safety, functionality and losses
  - inform decision making by owners and communities, including incentives and allocation of costs

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