PEER Research: Accomplishments & Impact

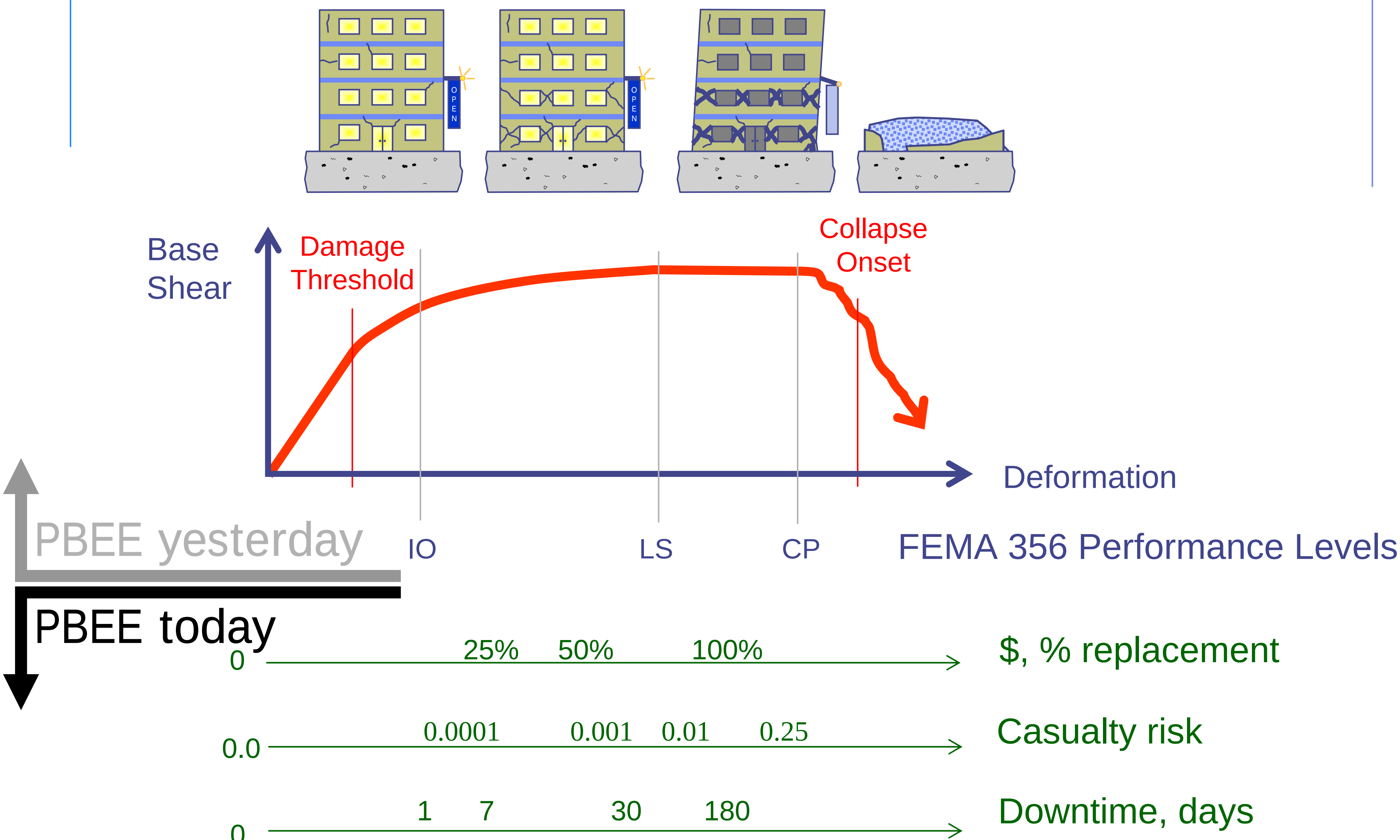
Greg Deierlein, *Stanford University*

and the

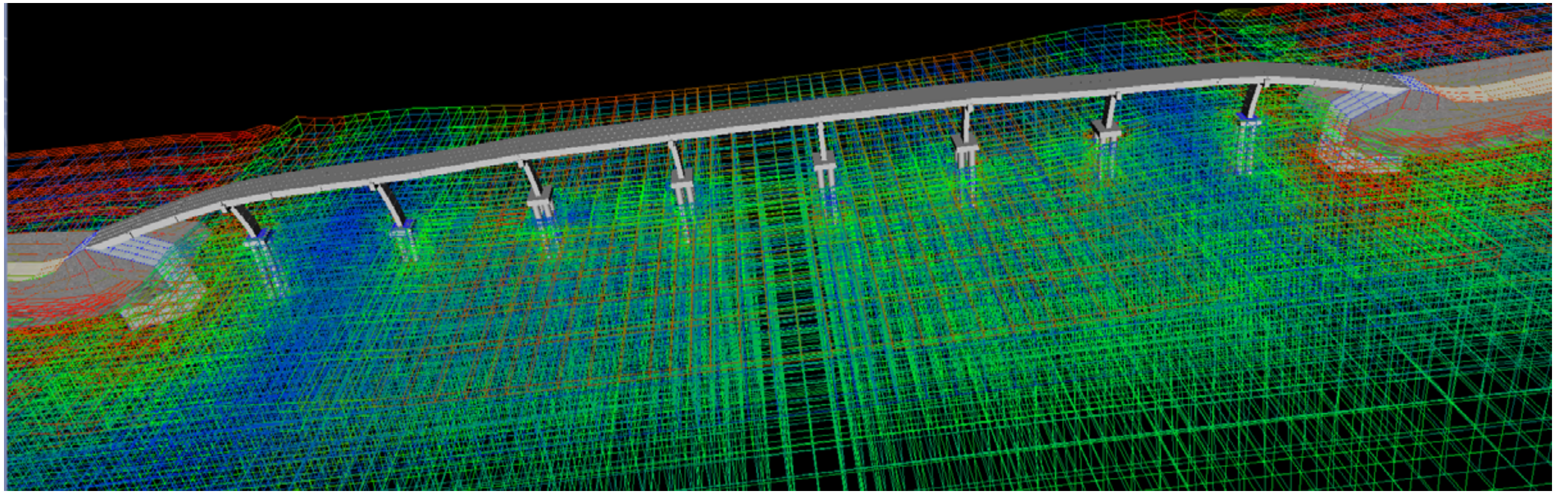
PEER Research Committee

PEER Summative Meeting – June 13, 2007

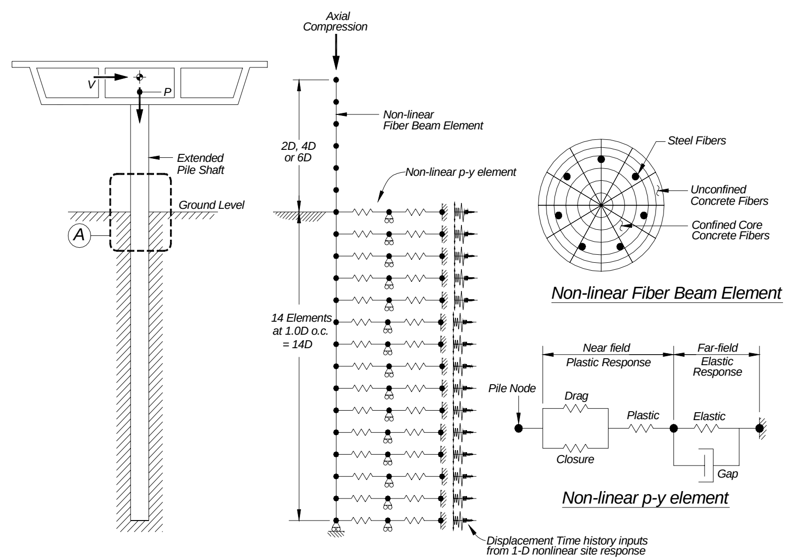
Evolution of PBEE



Comprehensive System Simulation



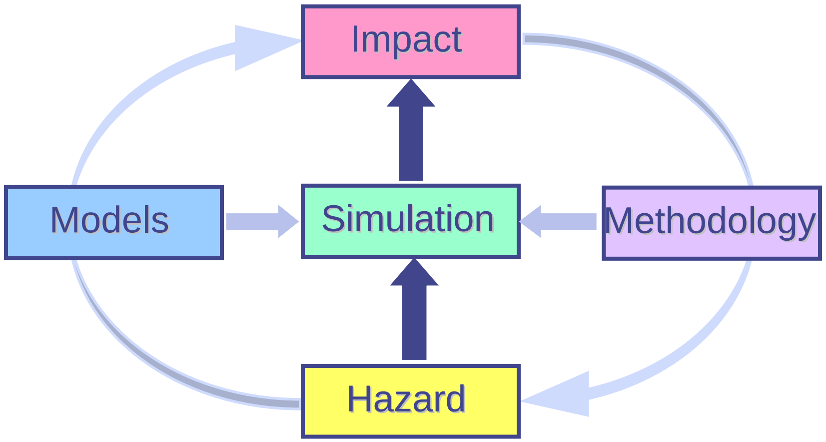
REF: Yang, Conte, Elgamal (UCSD)



REF: Boulanger (UCDavis)

PEER's Research Projects & Products

- PBEE Methodology
- Technologies & Data
- Illustrative Examples
- Guidelines



transitions

Year 1 **Year 5** **Year 10**

Methodology: *Development ---- Application/Packaging*

Data/Model: *Creation ---- Implementation/Validation*

Demonstrations: *Evaluate/Synthesize ---- Impact of PBEE*

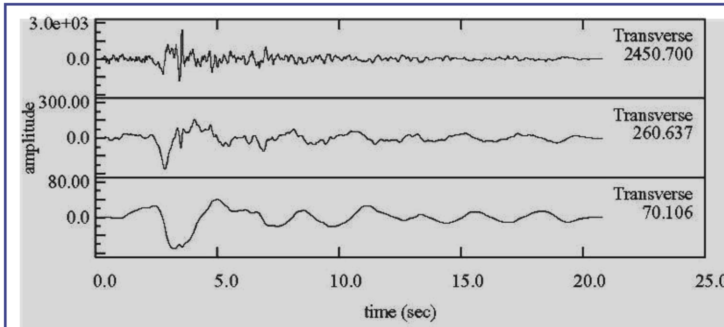
Performance-Based Framework: Buildings

- Collapse & Casualties
- Direct Financial Loss
- Downtime

Decision Variable

Damage Measure

Engineering Demand Parameter

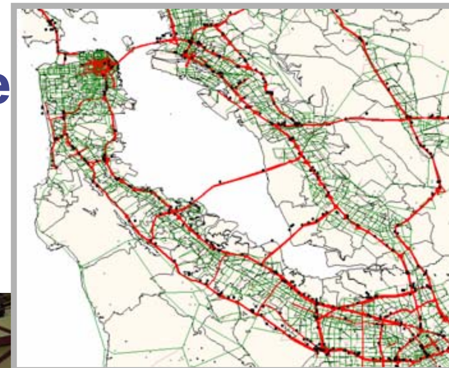


Intensity Measure

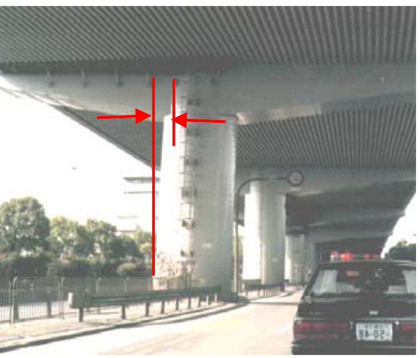
Bridge and Transportation Systems

Quality of Network Service

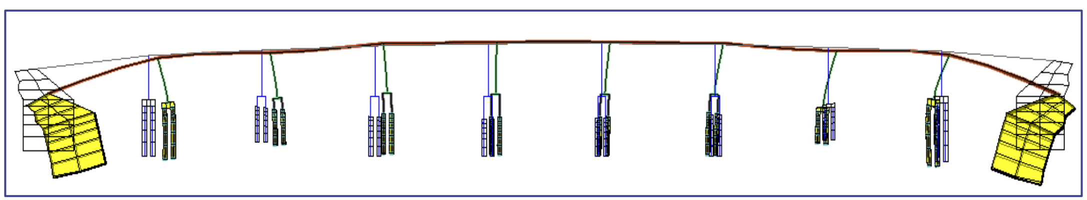
Restoration ($ and Time)



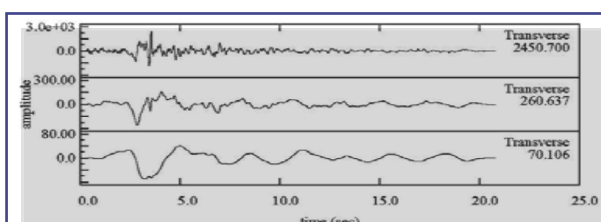
Decision Variable (DV)



Damage Measure (DM)



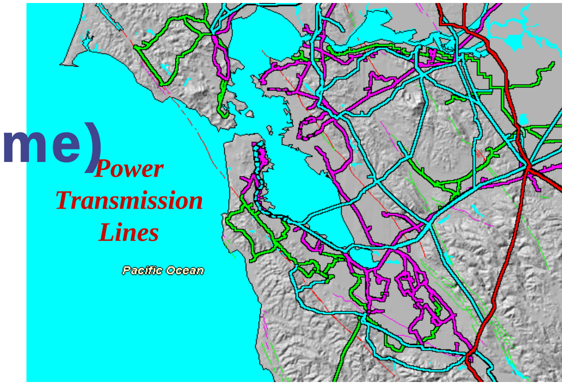
Engineering Demand Parameter (EDP)



Intensity Measure

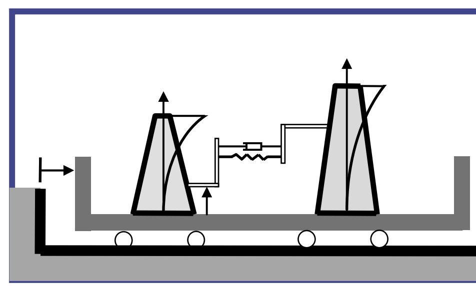
Electric Utility Lifeline Systems

Quality of Service
Restoration ($ and Time)

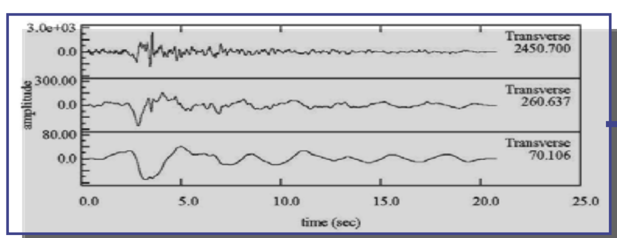


Decision Variable (DV)

Damage Measure (DM)

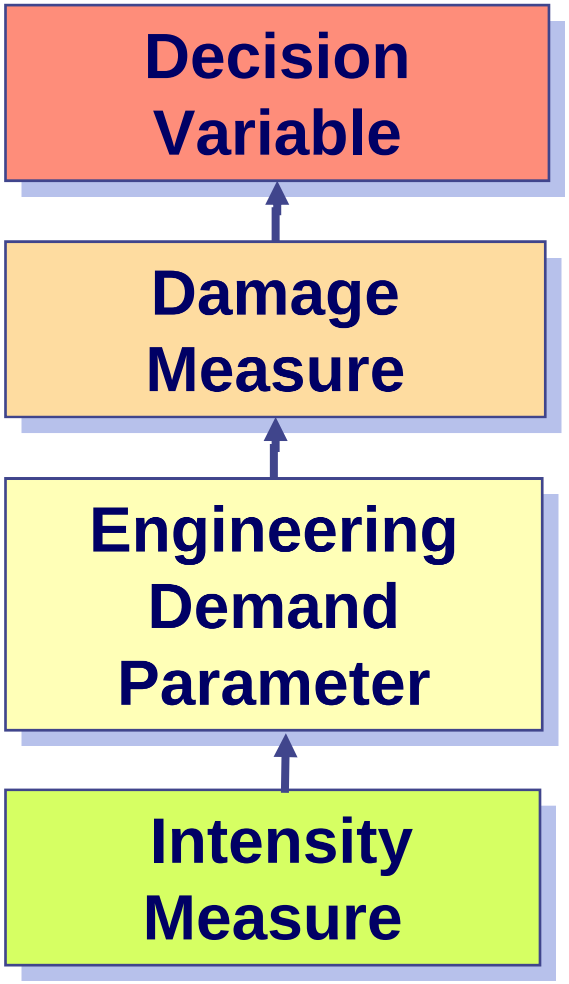


Engineering Demand Parameter (EDP)



Intensity Measure

Performance Assessment Components



Relating Performance to Risk Decision Making

Quantifying Damage Measures

Simulation of System Response

Earthquake Hazard Characterization

PBEE – Probability Framework Equation

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

Impact | **Performance (Loss) Models and Simulation** | **Hazard**

IM – Intensity Measure

EDP – Engineering Demand Parameter

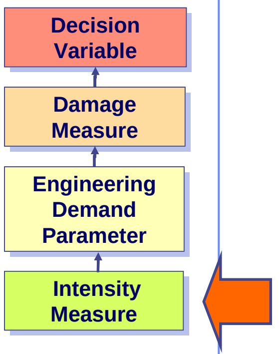
DM – Damage Measure

DV – Decision Variable

ν(DV) – Probabilistic Description of Decision Variable

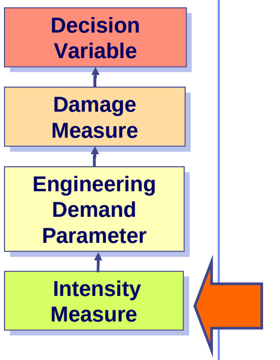
(e.g., Mean Annual Probability $ Loss > 50% Replacement Cost)

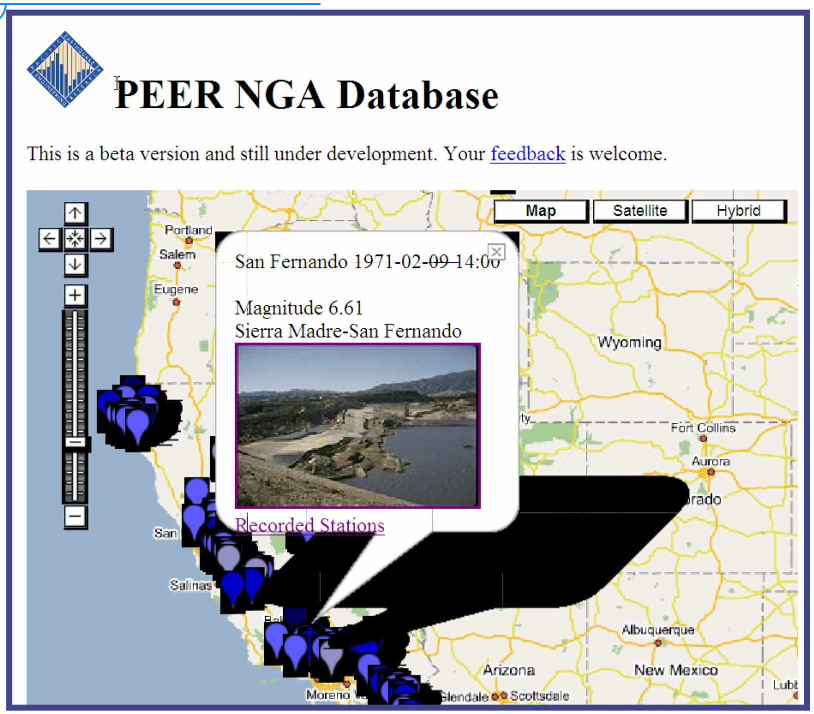
Hazard Characterization



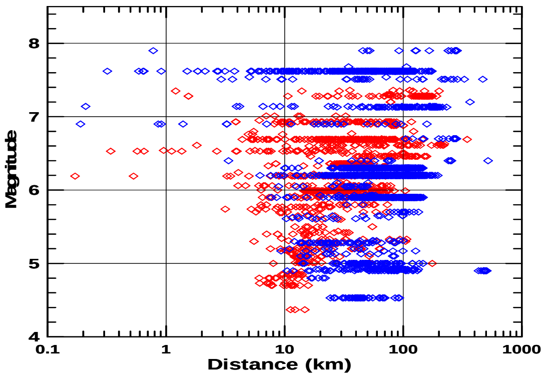
- PEER Ground Motion Database
- Next Generation Attenuation Functions
  - Hazard Mapping
- Geotechnical Data Center
- Selection & Scaling of Ground Motions
- Spatial Hazard & Correlations (scenario)
- Site Response and Effects
- Utilization of GM Shaking Data

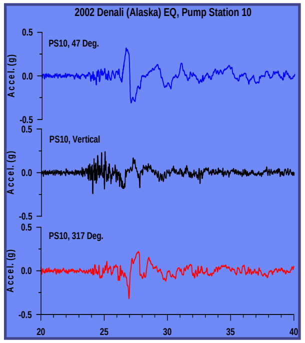
PEER Ground Motion Database

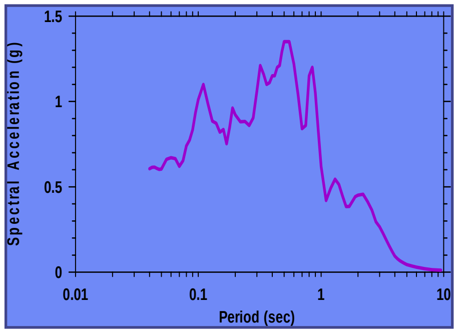




- Over 10,000 records
- Uniformly Processed
- Available On-Line
- “Google Inspired”
  - Ground motions
  - Maps
  - Damage Photos







New Data **Previous Data**

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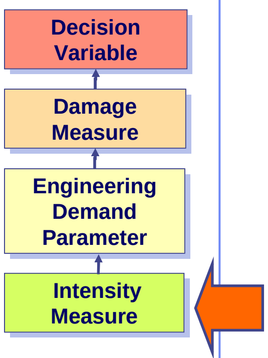
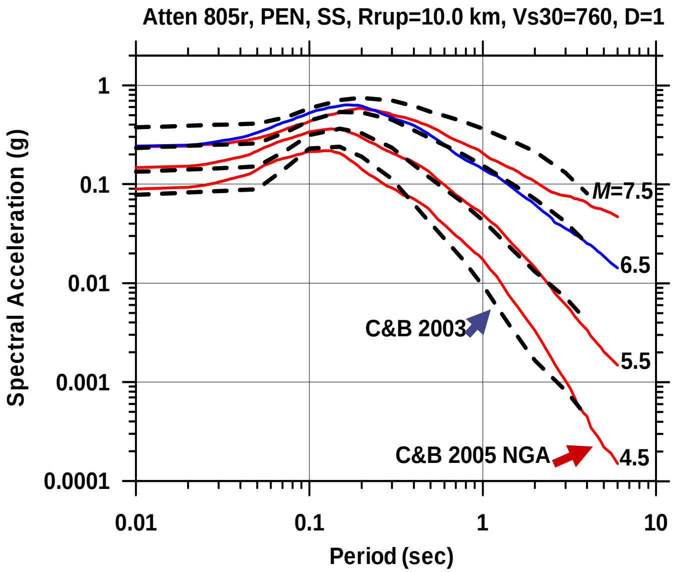
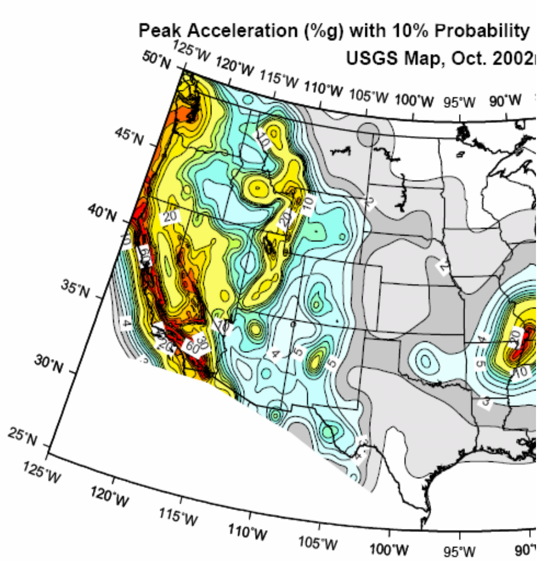
Attenuation Functions & Hazard Maps

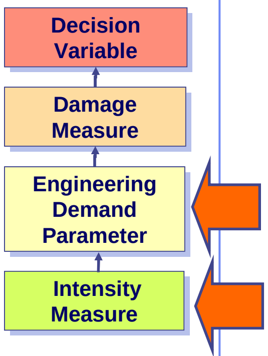


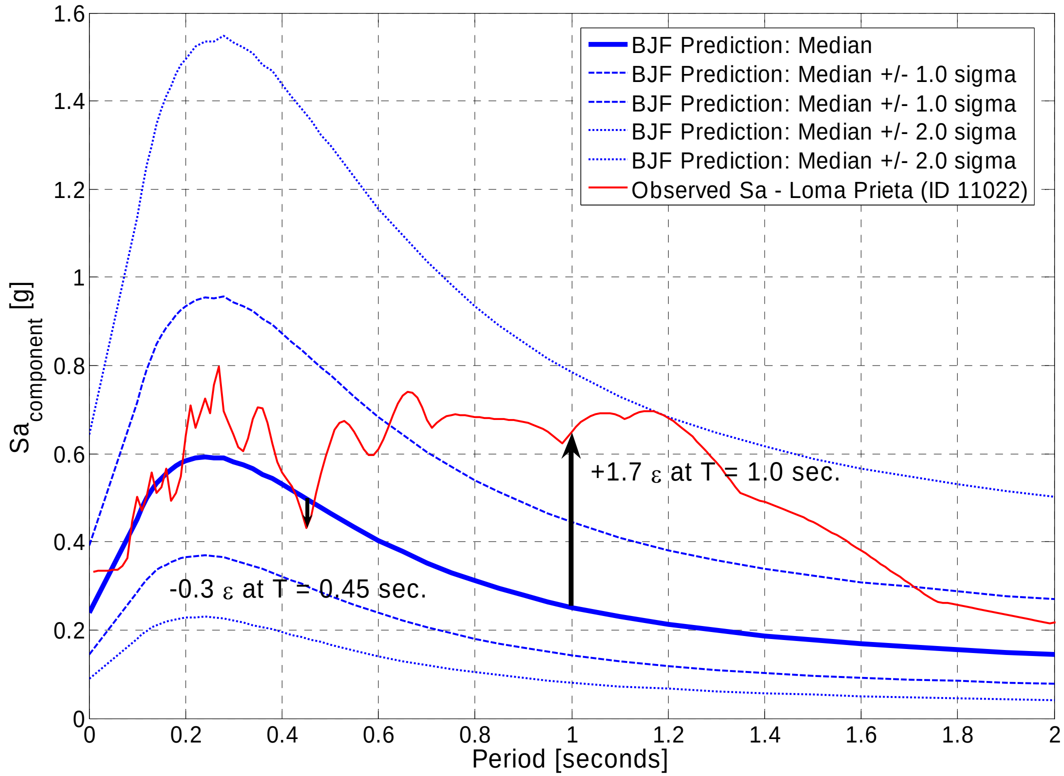




- NGA Attributes
  - Long Period (0 to 10 sec.)
  - Magnitude Range (5.0 to 8.5)
  - Distance Range (0 to 200 km)
  - Fault Mechanisms (SS, R, N)
- More Accurate
  - Lower intensity in many places
- Improved Understanding
  - Spectral shape
  - Spatial correlations
- Influencing US national seismic hazard maps

Selection & Scaling of Ground Motions

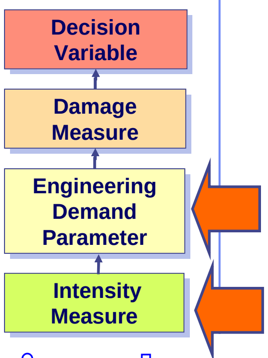


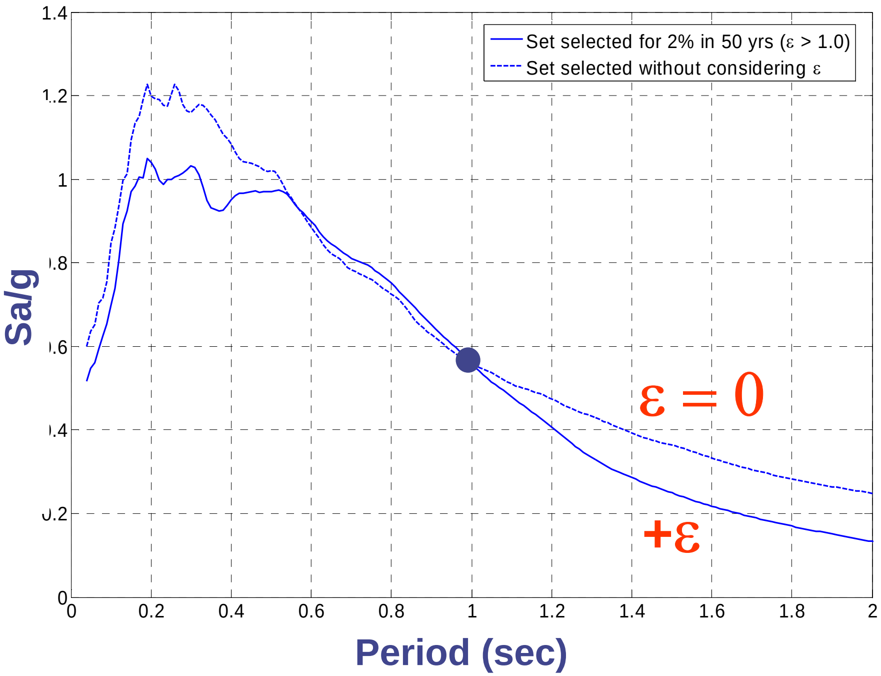


the *"+ε effect"*

- Spectral Shape of Extreme (Rare) Ground Motions
- Collapse Assessment at the MCE

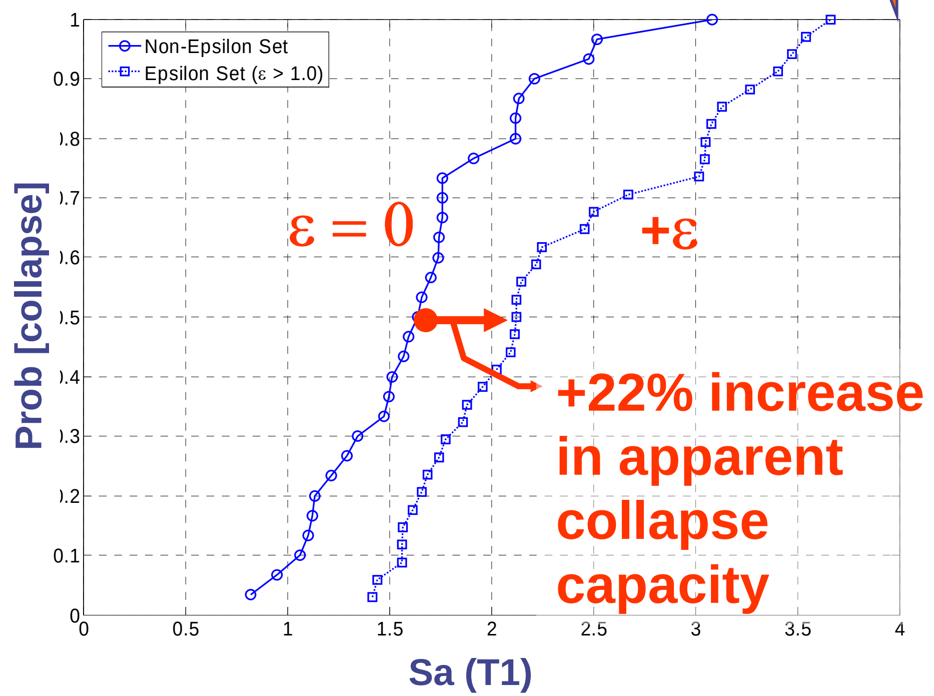
Significance of +ε (SSF) effect





Average Response Spectra

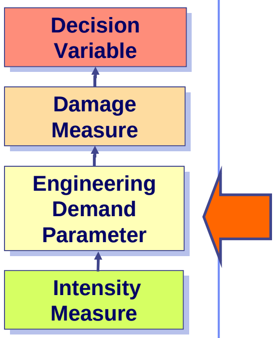
(from bins of +ε and epsilon neutral records)



Building Collapse Fragility

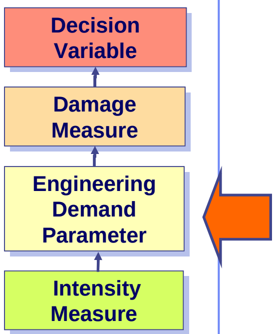
(case study 4-story building from NL dynamic analyses)

Structural & Geotechnical Simulation

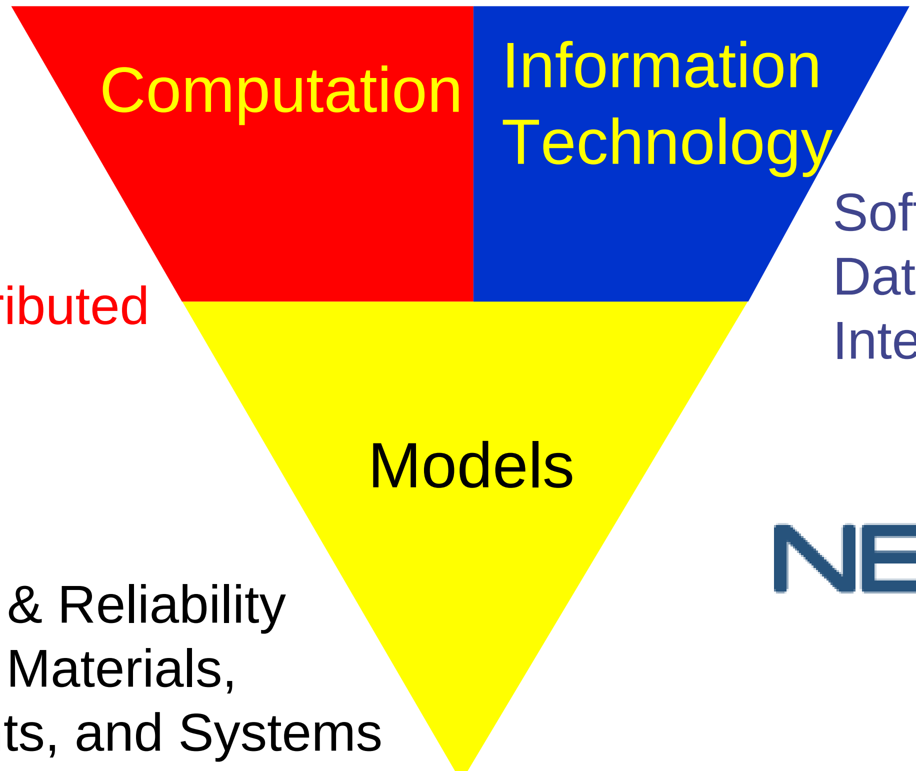


- Reinforced Concrete Structural Modeling
  - Cyclic degradation and shear needed for assessing damage and collapse potential
- Continuum Soil Models
  - Large ground deformations & Liquefaction
- Soil-Foundation-Structure Interaction
  - Site response, foundation interaction necessary for system performance
- Computational Reliability
  - Consistent tracking of uncertainty from hazard to model uncertainty
- Advanced Computing and Simulation
  - Integrating with NEESit and cyberinfrastructure

Integrated Simulation/Assessment Platform



Algorithms,
Solvers,
Parallel/distributed computing

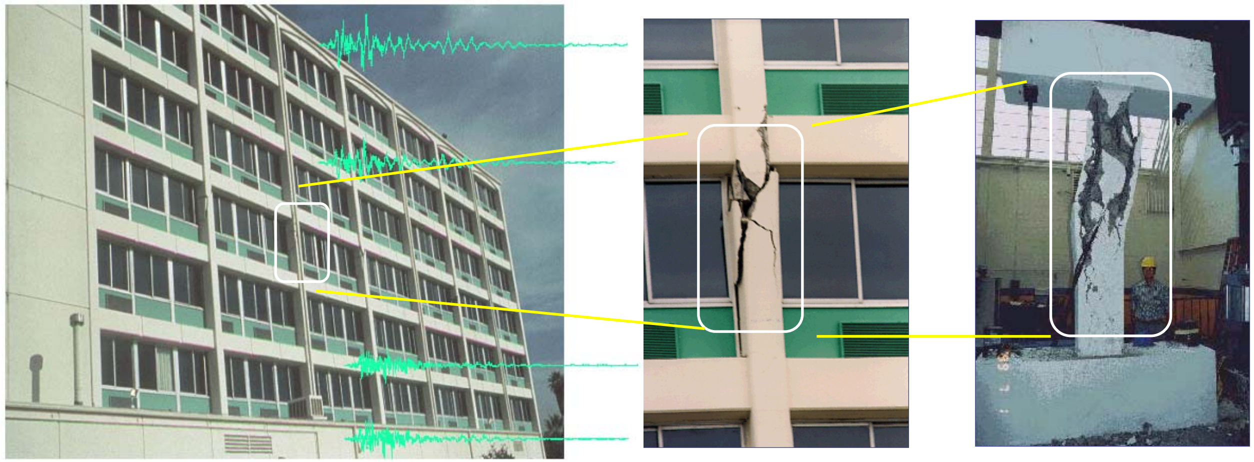


Software framework,
Databases, Visualization,
Internet/grid computation

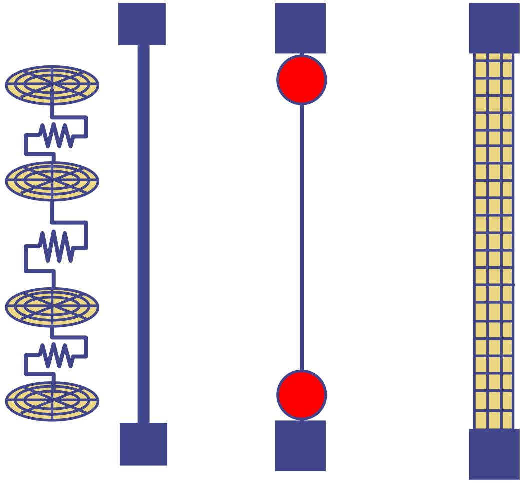
NEESgrid

Simulation & Reliability Models for Materials, Components, and Systems

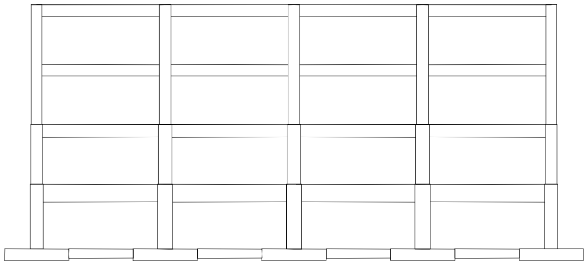
Simulating Non-Ductile RC Columns



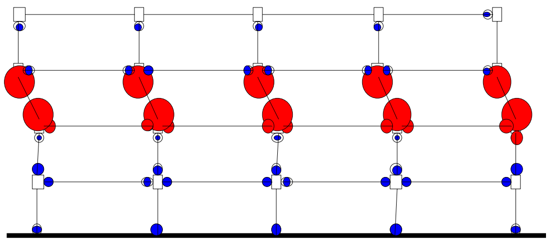
Numerical Models



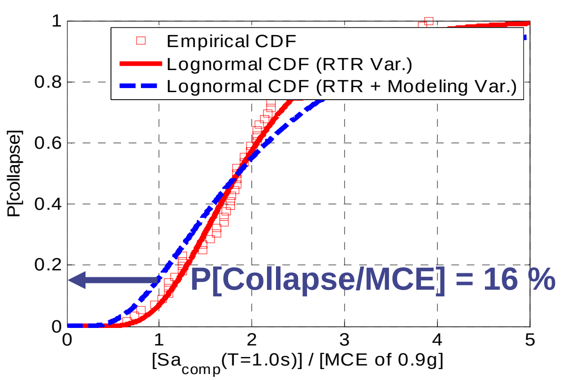
Simulating Collapse of RC Buildings



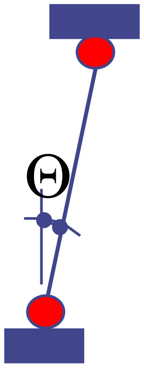
Building Frame Definitions

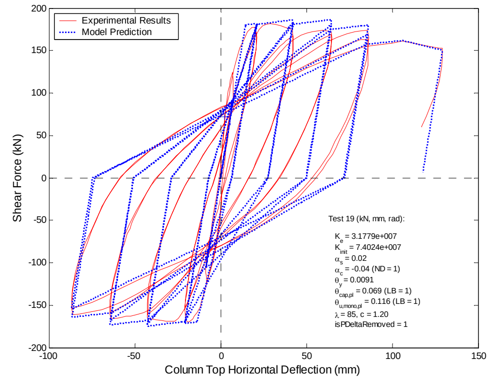


Collapse Mechanisms



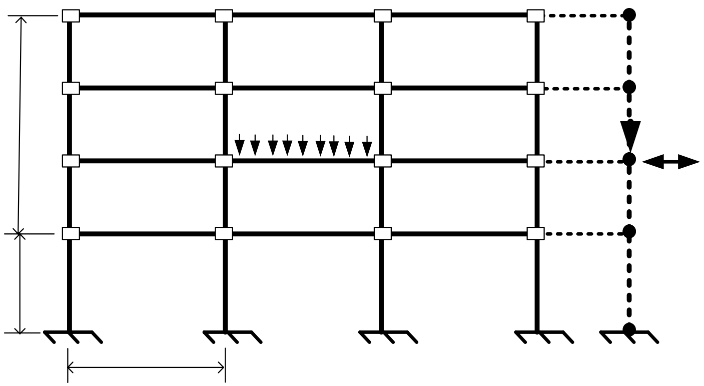
Collapse Fragility Curves





Component Tests & Models

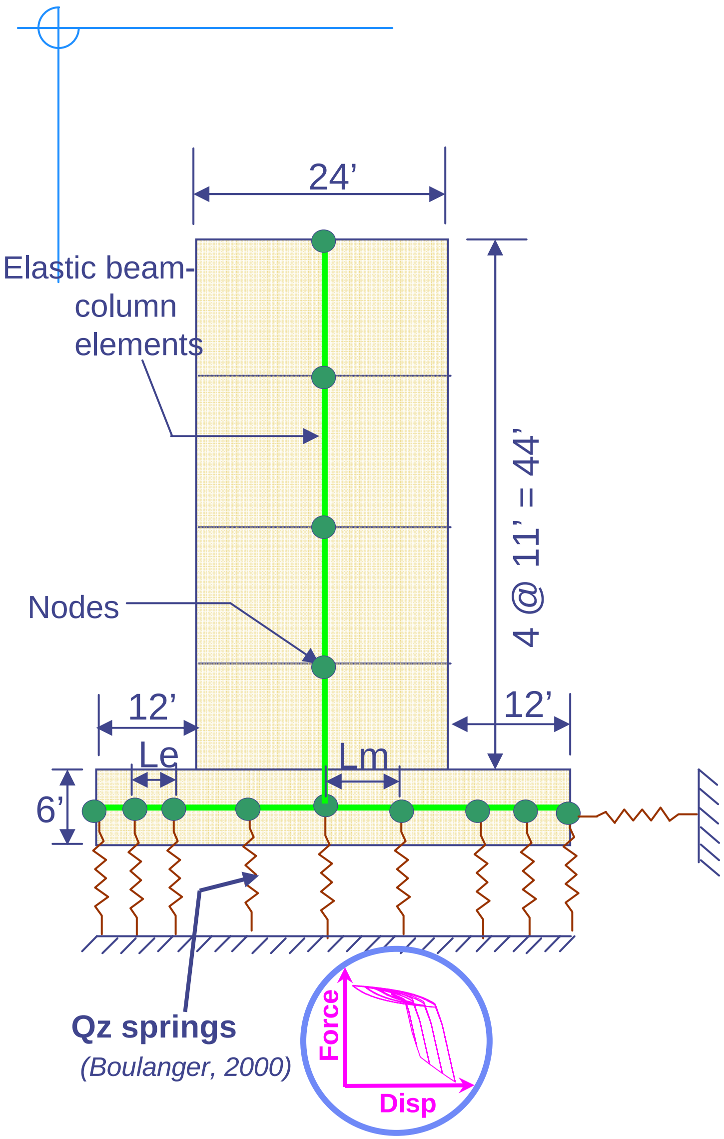
PEER STRUCTURAL PERFORMANCE DATABASE SPD

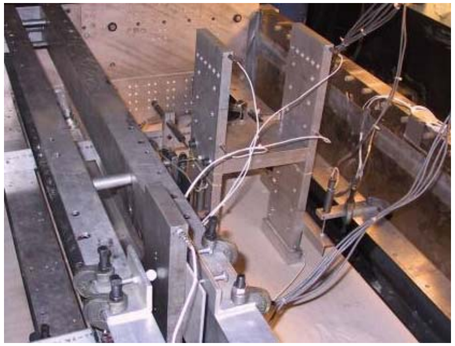


Building System Simulation

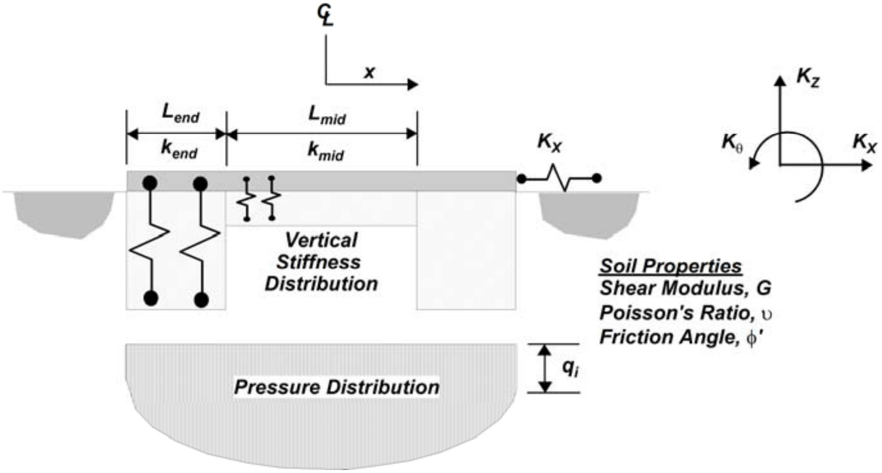
OpenSees

Geotechnical and Soil-Foundation Models



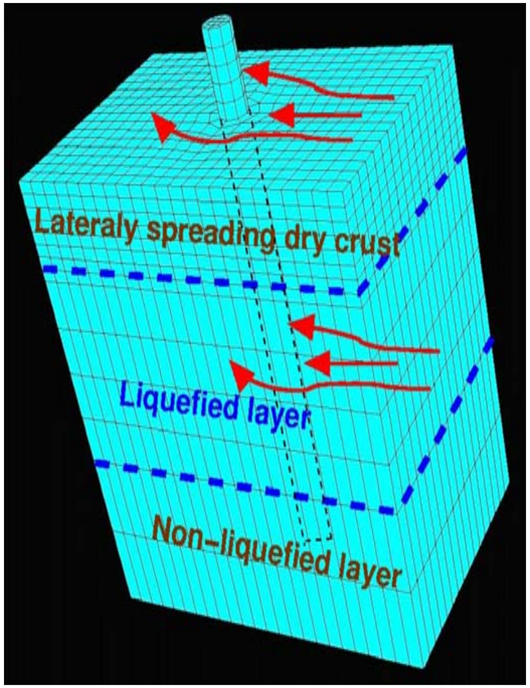


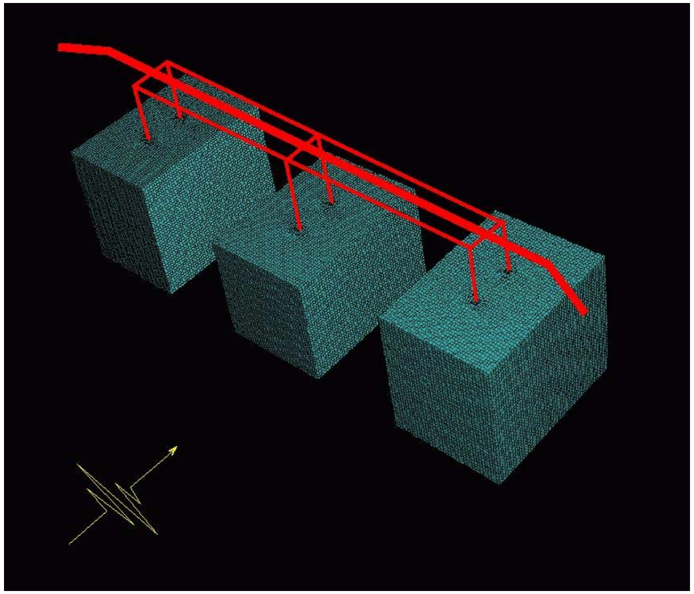
Centrifuge Experiments (NEES-UC Davis)



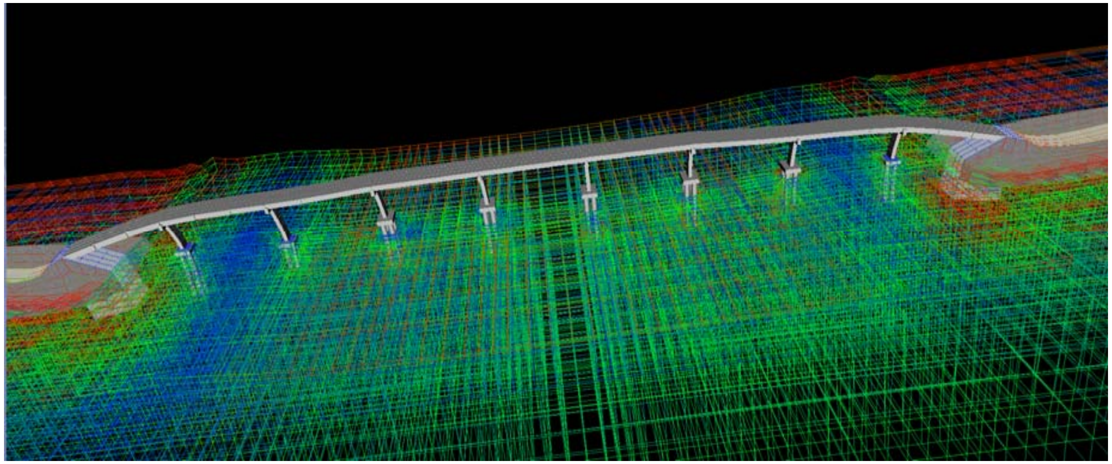
OpenSees Soil-Foundation Model

Soil-Structure-Foundation Interaction



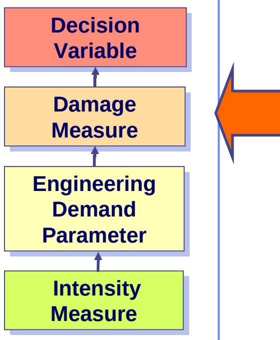


System performance analyses



Behaviour of piles in liquefied soils using coupled fluid-soil models

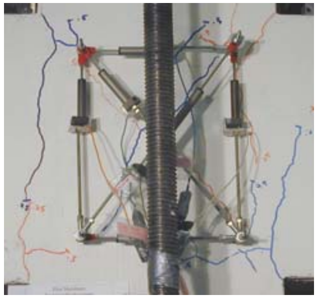
Damage Measures & Fragility Functions



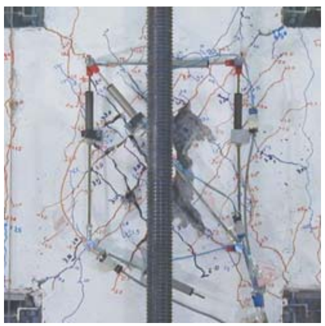
Development of concepts, techniques and data applied to:

- Reinforced Concrete Components
  - columns & beam-column joints
- Nonstructural Components & Contents
  - interior partitions
  - laboratory equipment
  - HVAC facilities
- Electric Utility Equipment

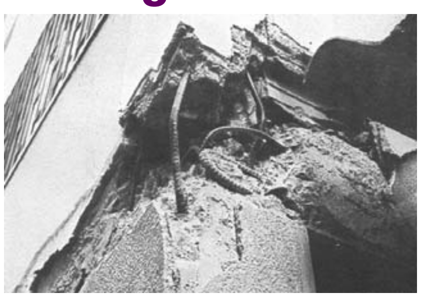
Repair-Specific Damage Functions



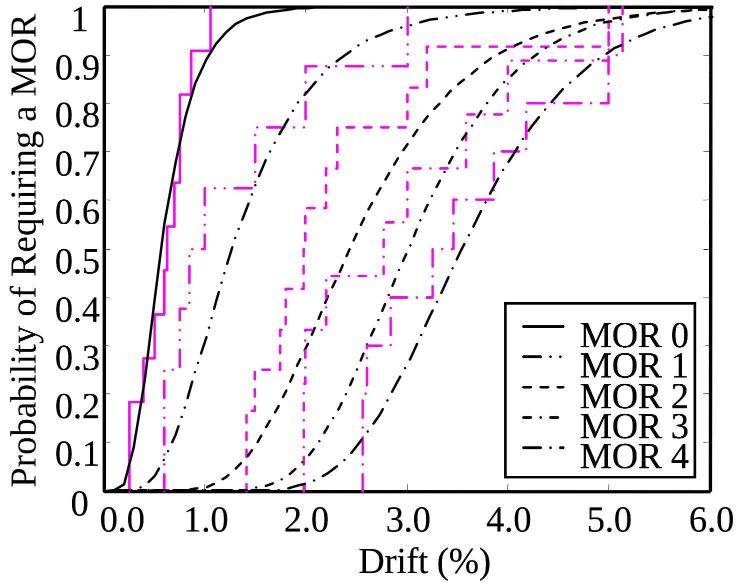
Damage State 0

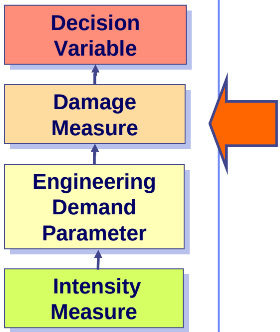


Damage State 2



Damage State 4





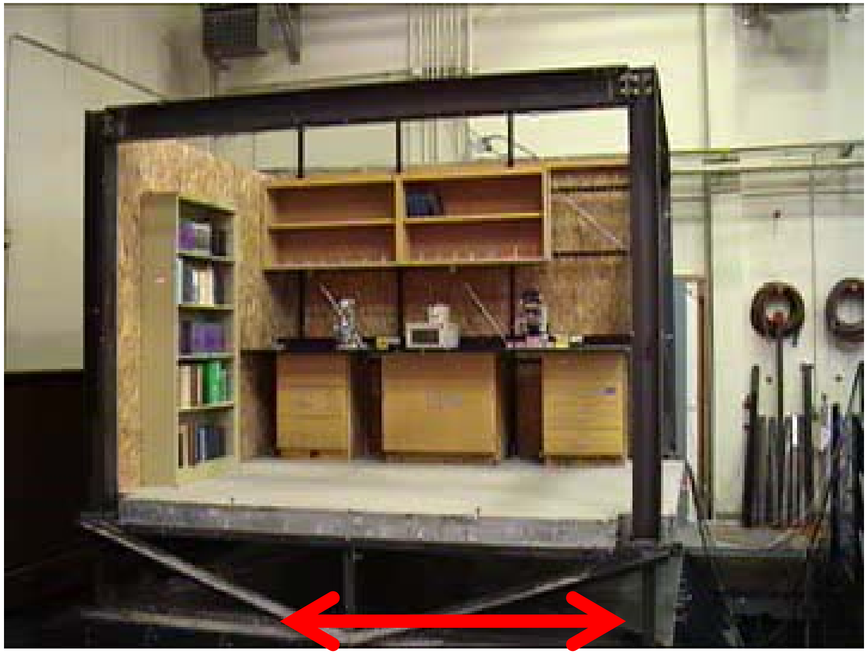
P[DM:EDP]

Components Evaluated:

- RC Beam-Columns, Joints, Walls
- Interior Partitions
- Laboratory Equipment
- Ceiling & MEP Systems
- Electric Utility Components

Testing Nonstructural Components & Equipment

Electric Utility Equipment



Lab Equipment

- Development of Damage (Fragility) Functions
- Design Improvements to Components and Equipment
- Development of Testing Standards
  - FEMA 461: Interim Protocols For Determining Seismic Performance Characteristics of Structural and Nonstructural Components
  - IEEE-693 standard for testing

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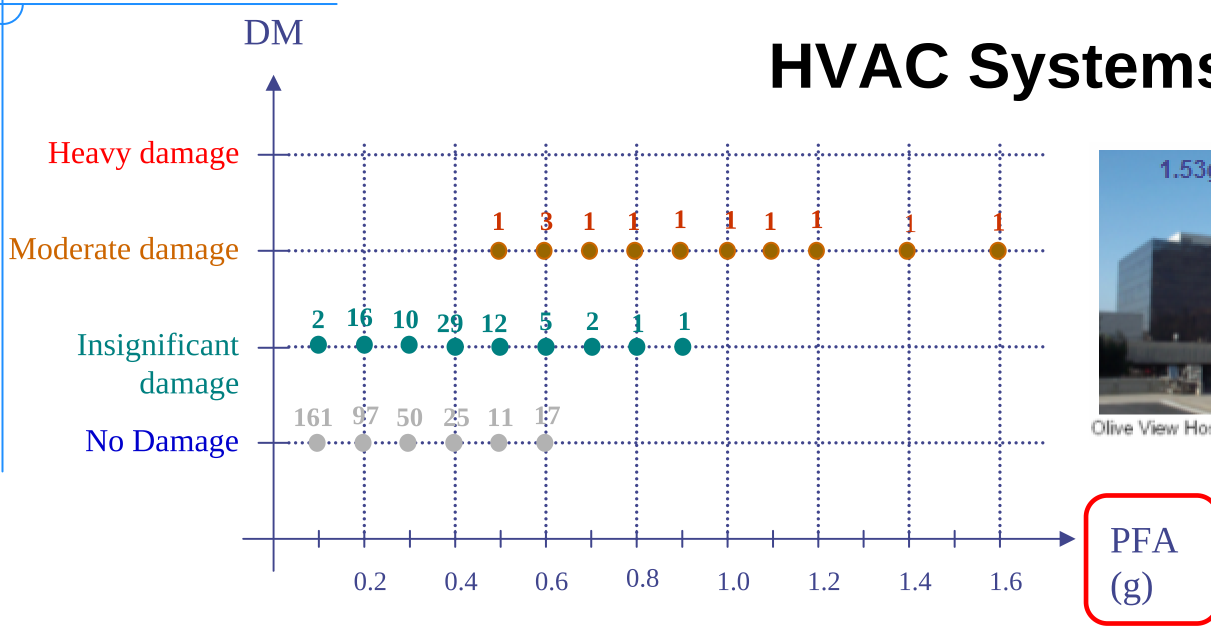
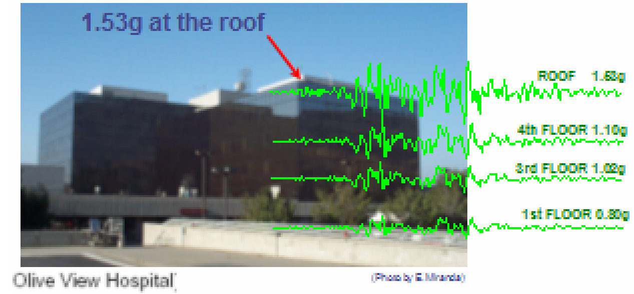
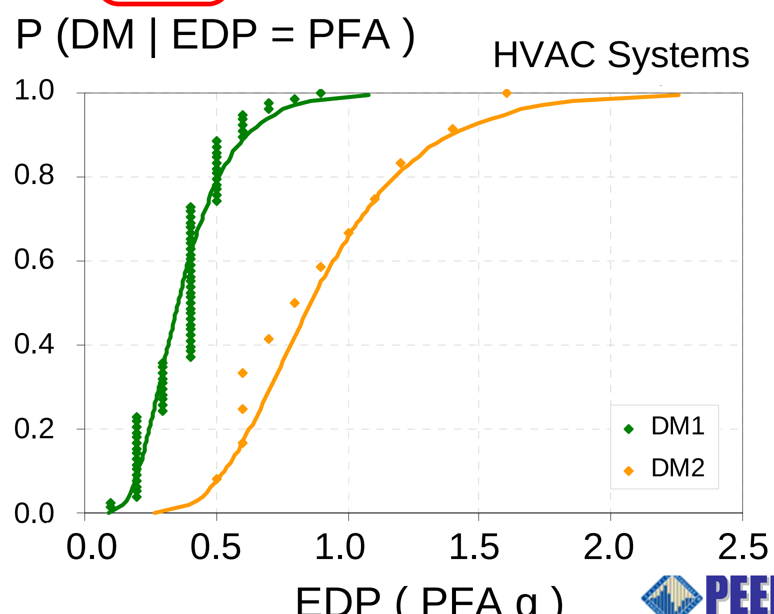
Motion-Damage Pairs from Real Buildings

HVAC Systems





a model for systematically collecting & characterizing data from damaged buildings



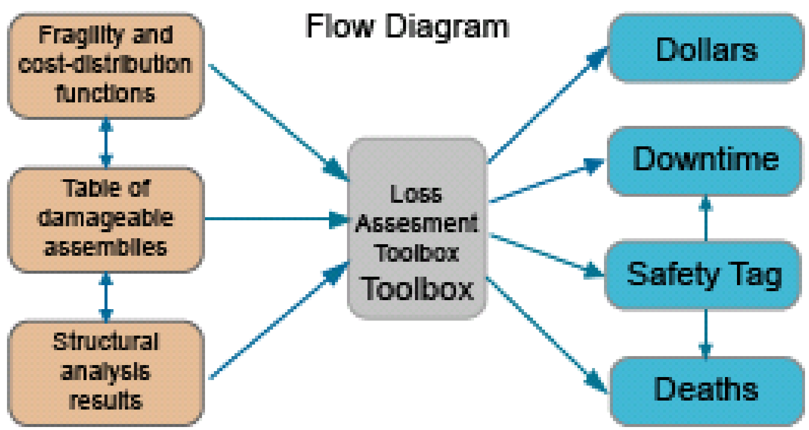
Translating Damage to Decision Variables

Loss Assessment Tools

Component-based and story-based loss assesment toolboxes were developed to integrate response, damage, and performance.

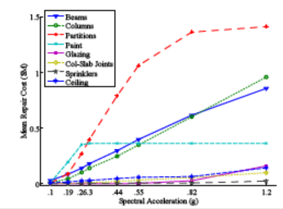
Flow Diagram

Typical inputs of loss assesment toolboxes.

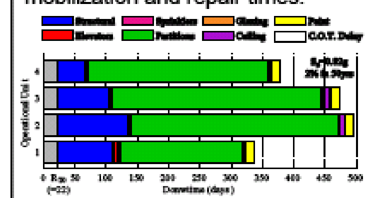


Typical outputs of loss assesment toolboxes.

Dollars: Mean repair losses are calculated for various building components at each hazard level.



Downtime: Total downtime is calculated as the sum of the mobilization and repair times.



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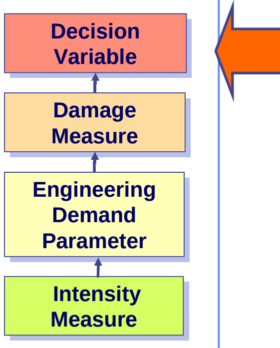
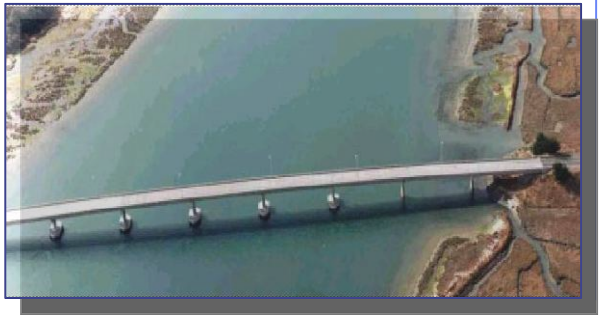
Decision Making and PBEE Applications

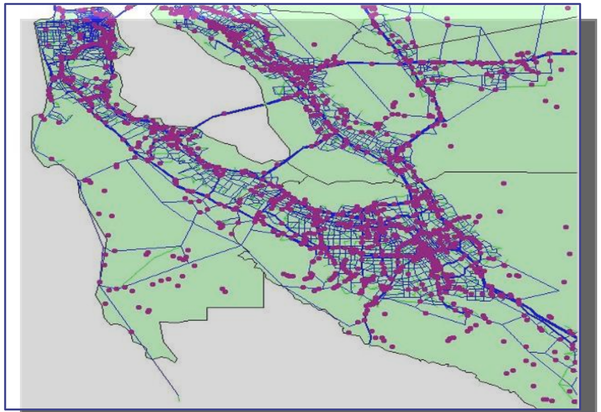


- Tradeoffs in Decision Making
  - quantifying *benefits* and *costs*
- Influencing practice
  - “early adopters”
  - codes and standards
  - implementing new technologies
- Influencing policy
  - benchmarking standards and practice
  - collaborating with stakeholders
  - regulatory models

Integrative Testbeds

- Buildings
  - Van Nuys
  - UC Sciences
- UCB Campus
- Bridges
  - Humboldt Bay
  - I-880 Viaduct
- Bay Area Highway Network





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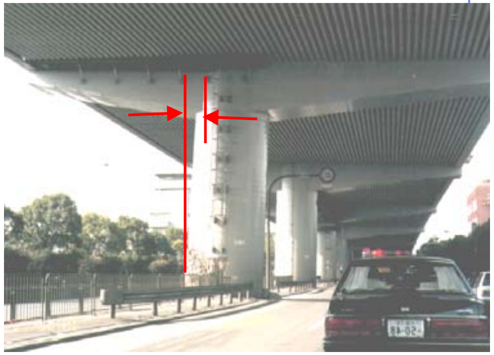
High-priority Issues for Bridges

- Post-earthquake residual displacements are a primary contributor to bridge closure.

- Liquefaction hazards continue to cause widespread damage or drive huge foundation costs.

About 100 columns with more than 1.75% drift were demolished after 1995 Kobe Earthquake although they did not collapse



Bridge Testbed Model in OpenSees

- Modular design developed (Stojadinovic)

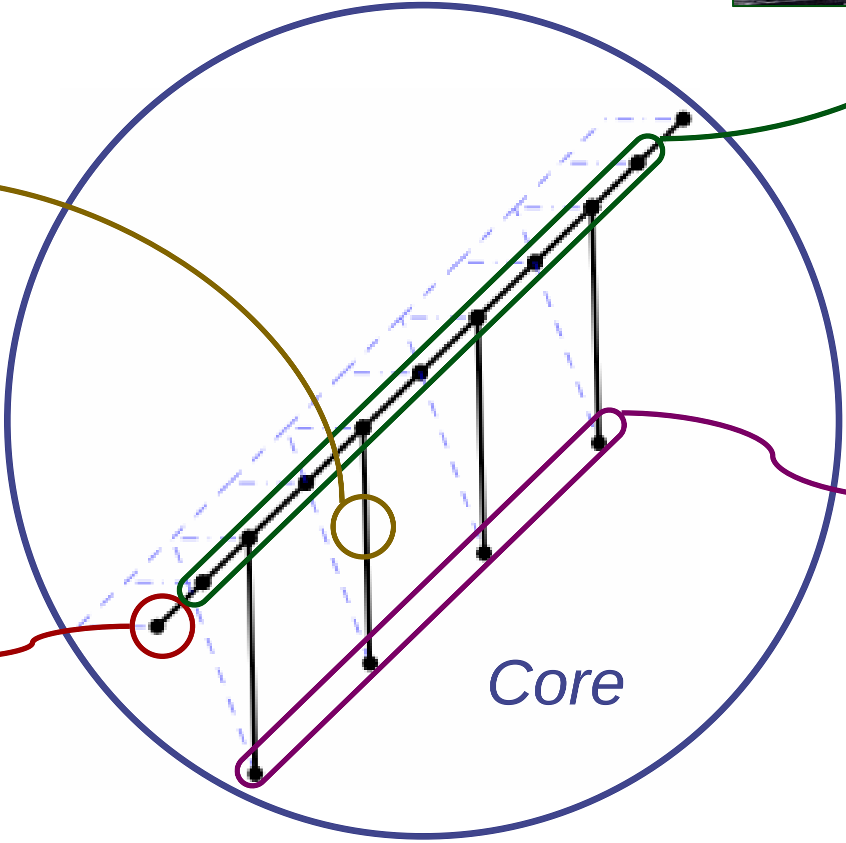
Deck

Columns

Billington, Eberhard, Lehman, Mahin plus Kunnath

Abutment

Ashford



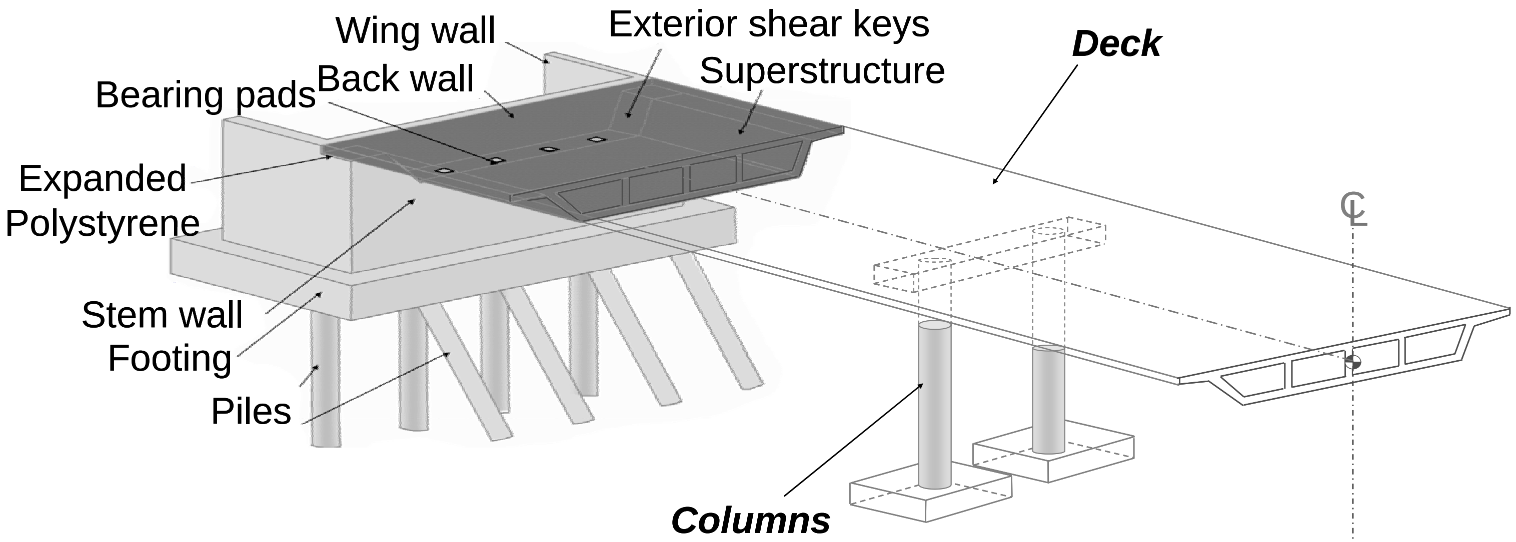
Foundation

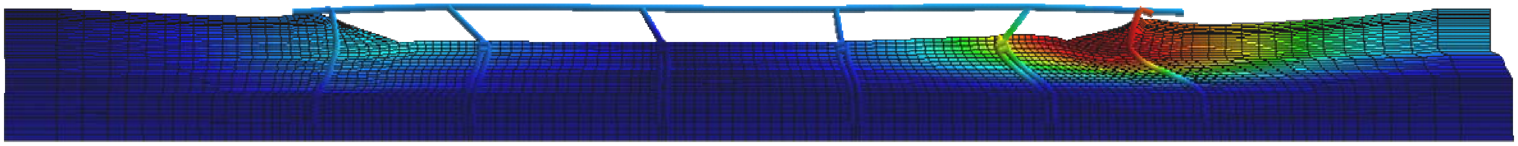
Arduino & Kramer, Boulanger, Brandenberg, Bray, Martin plus Jeremic, Elgamal

Bridges with lateral spreading / liquefaction

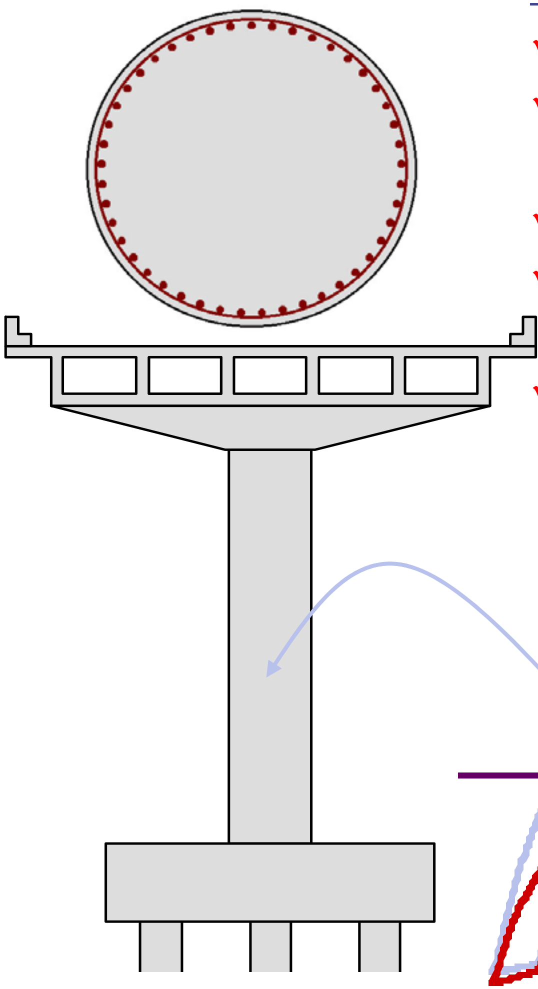
Assessment of current approaches, improve understanding, and identification of benefits of nonlinear analysis:

- Current design and remediation methods, vs.
- coupled soil-pile-structure models in OpenSees



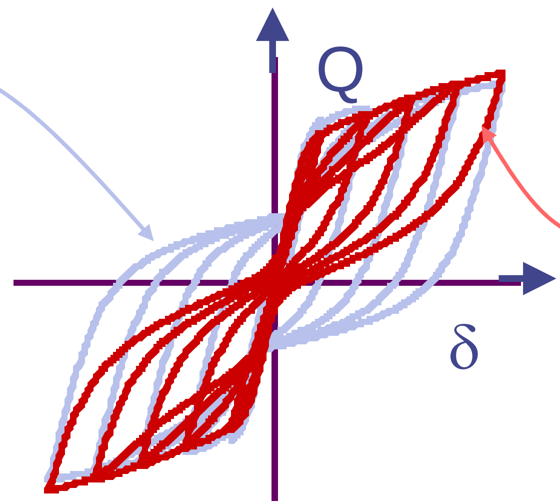


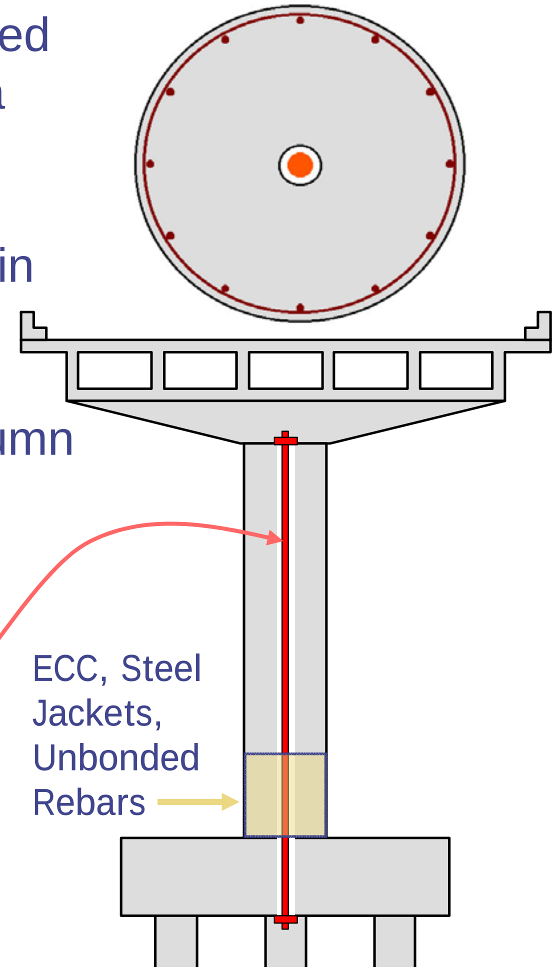
New Technologies: Self-Centering Columns



<u>Design method</u>:

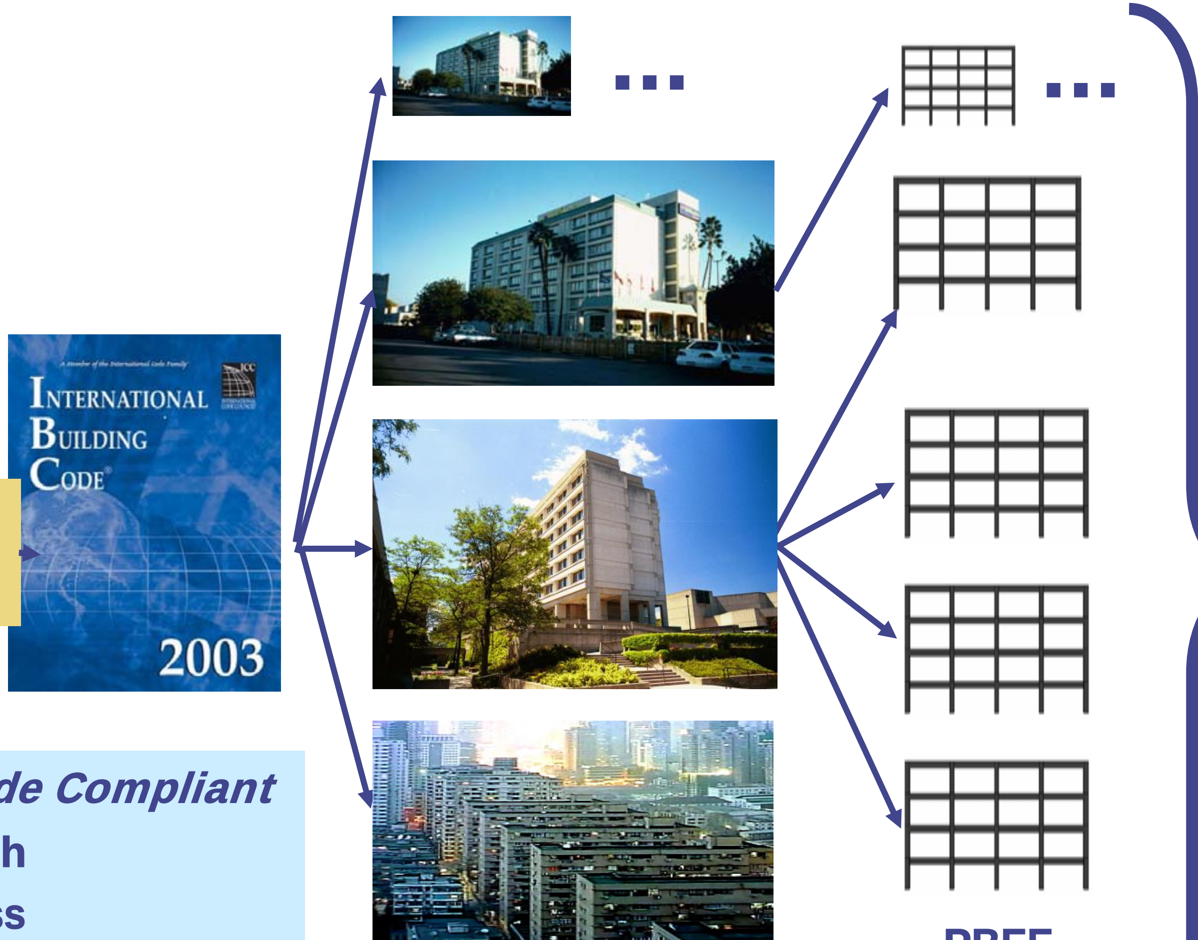
- ✓ Mild reinforcement reduced
- ✓ Prestressing force from a central unbonded tendon
- ✓ Same envelop Q-δ
- ✓ Peak displacements within 10% of RC column
- ✓ Residual displacements less than 20% of RC column





Building Benchmarking Studies

Facility Definition



2003 Code Compliant

- Strength
- Stiffness
- Capacity Design
- Detailing

multiple realizations

"design uncertainty"

PBEE Assessment

IM-EDP-DM-DV

DV's:

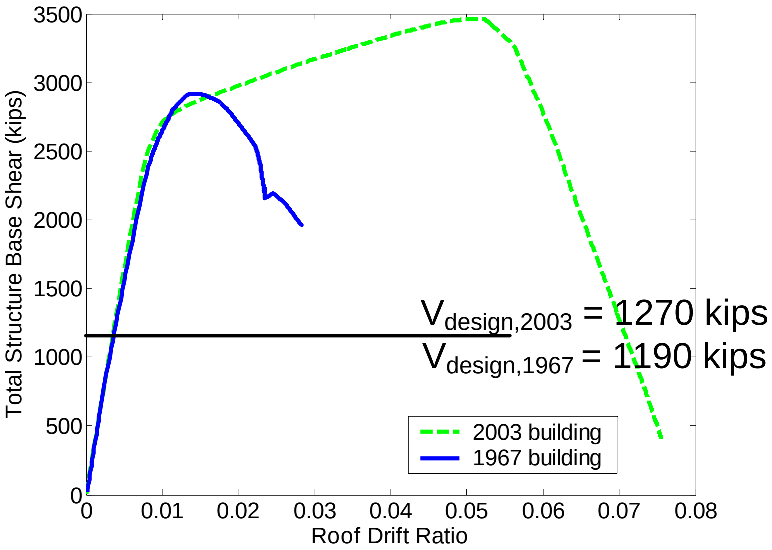
p(collapse)

p($ > X)

p(D.T. > Y)

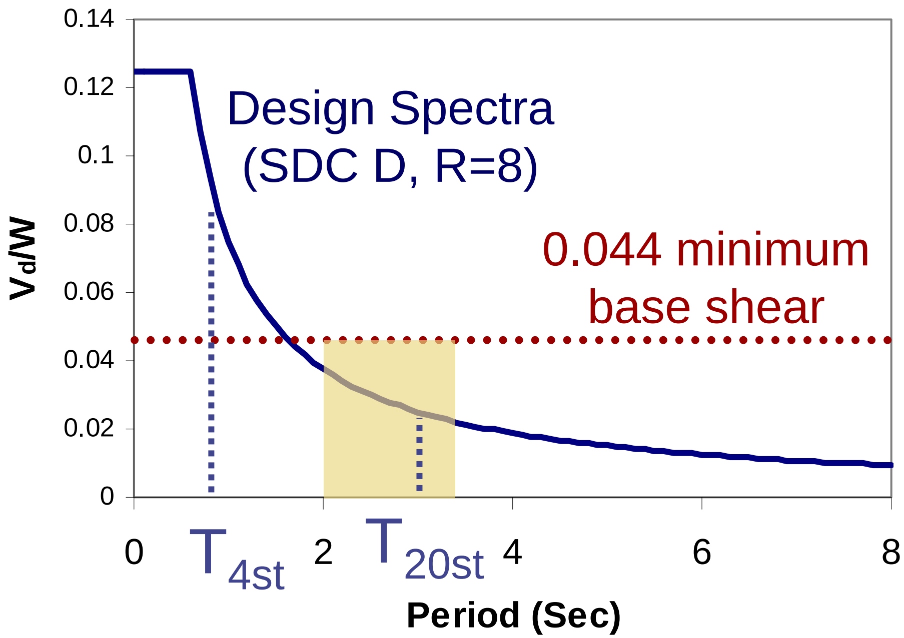
Benchmarking: 1967 vs. 2003 Designs

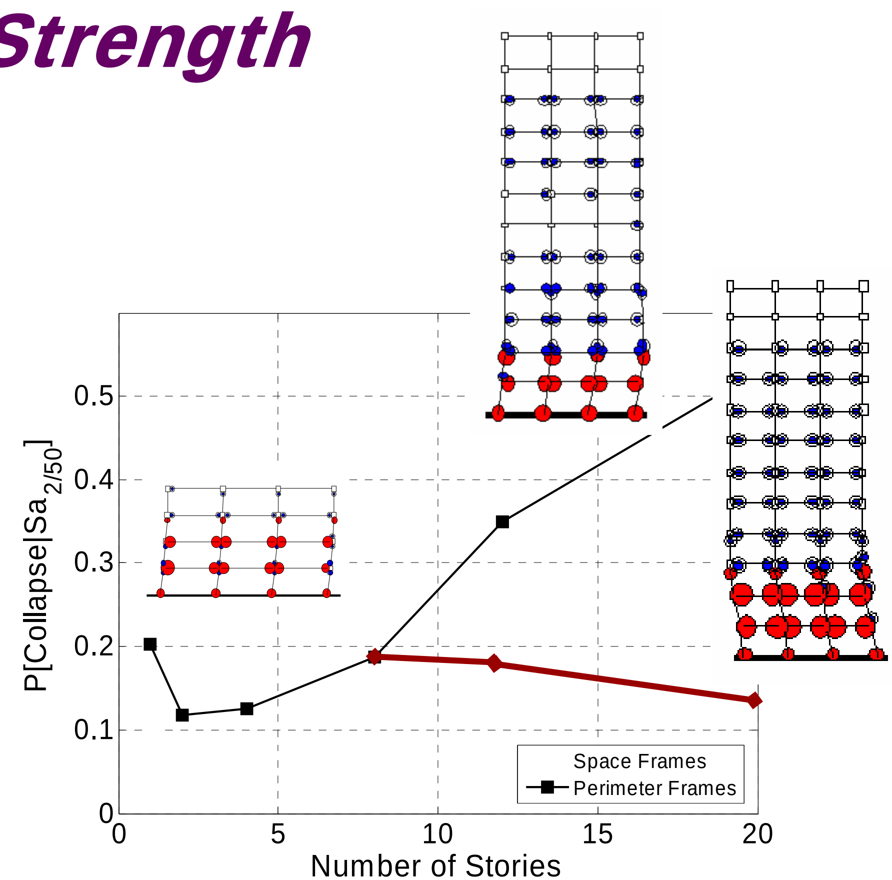
2003 Design Codes



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

Effect of Design Parameters on Performance:
Minimum Base Shear Strength





Issue: What minimum base shear (if any) should be imposed in *ASCE 7 Minimum Design Loads* Standard?

Building code, regulation and policy issues

- Benchmarking building codes
  - Absolute safety and performance
  - Relative safety and performance across:
    - systems/materials
    - building heights/configurations,
    - seismic hazard categories
    - use/occupancy
- Non-ductile RC Building Risks
  - how bad is the problem?
  - technologies to address it cost-effectively
  - policy, incentives and regulation
- Residential High Rise
  - structural systems not envisioned by code
  - tenant & societal performance expectations
- New Innovative structural systems

PEER --- Making an IMPACT

- Tools for decision makers
  - Cost-benefit, financial models
  - Regulatory & implementation issues (IRCC)
- Packaging of PBEE Methodology
  - Specificity & Simplification !
- Demonstrate value/benefits of PBEE
  - Building benchmarking
  - Bridge systems (liquefiable soil, self-centering)
- Dissemination & Outreach Initiatives
  - Research community (NEES researchers)
  - Professional engineers
  - Other design professionals & decision makers
- Implementation Initiatives
  - Buildings - ATC 58, 63, NEHRP, Insurance, ...
  - Bridges – Caltrans, FHWA, ...