PBEE Assessment and Design of Bridges

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PEER Summative Meeting – June 13, 2007

PBEE Assessment and Design of Bridges

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Ross Boulanger, Yue-Yue Fan -- UC Davis
Scott Brandenberg -- UC Los Angeles
Scott Ashford -- UC San Diego
Pedro Arduino & Steve Kramer, Mark Eberhard, Dawn Lehman & John Stanton -- Univ. of Washington, Seattle
Geoffrey Martin -- USC
Kevin Mackie, FCU
BIP: Fadel Alameddine (Caltrans);
Mark Ketchum (OPAC)

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TA II – Bridge and Transportation Systems

Integrated 3-year plan

	Years 1 - 6	7	8	9	10

Integration Milestones

- performance assessment framework
- RC comp. database & models
- bridge EDP-DM-DV relations
- Ground deformation failure models
- ssfi models
- Ground motion simulation & selection
- design framework
- earthquake risk decision making
- regulatory & societal impl.
- enhanced perf. applications & models

Demonstration Benchmarking

- I-880 Testbed
- Humboldt Bridge Testbed

Years 7–10: Detailed PBEE procedure report; PBEE demo – Baseline bridge; PBEE demo – Bridge with liquefaction hazard

Geotechnical & Hazard Issues

- Probabilistic liquefaction assessment
- Liquefaction effects on foundations
- IM's and ground motion selection

Years 7–10: SSFI models including liquefaction effects; IM's & motion selection; Bridge abutment modeling; Liquefaction SSFI workshop

Pier Performance

- RC component database & fragility models
- Reliability & simulation tools
- Cumulative damage modeling
- Performance enhanced pier concepts

Years 7–10: PBEE demo – Bridge with performance enhanced columns; Enhanced performance bridge piers

Bridge Fragilities & Highway Systems

- Tri-center initiative on highway systems
- Traffic delay and loss modeling
- Decision variable metrics

Years 7–10: Highway systems; Bridge EDP-DM-DV & fragility relations; Cumulative damage modeling

Major Past Accomplishments

- Experiments to characterize major bridge components

- PEER Structural Performance Database


PEER
STRUCTURAL PERFORMANCE DATABASE
SPD
HOME SEARCH ABOUT

Introduction

This site provides the results of over 400 cyclic, lateral-load tests of reinforced concrete columns. The database describes tests of:

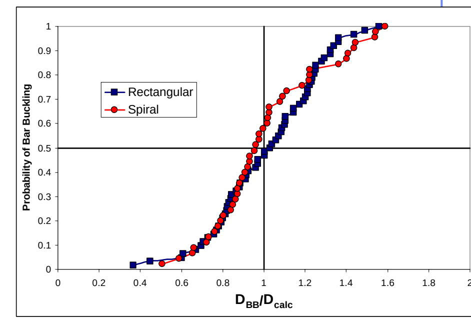
- spiral or circular hoop-reinforced columns (with circular, octagonal or rectangular cross-sections)
- rectangular reinforced columns
- columns with or without splices

For each test where the information is available, the database provides the:

- column geometry
- column material properties
- column reinforcing details
- test configuration (including P-delta configuration)
- axial load
- digital force-displacement history at the top of the column
- top displacement that preceded various damage observations
- key drawings and images (where available)
- comments (e.g., unusual characteristics)
- references and links for further information

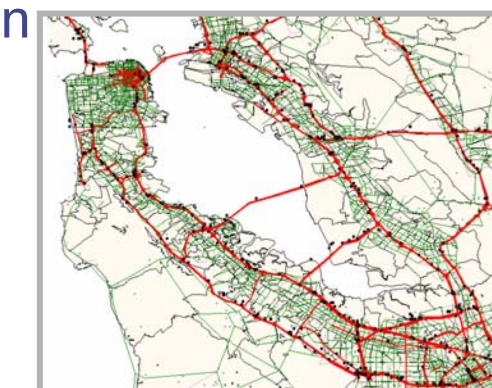
- Development (in concert with TA IV) of improved computational models to represent:
  - Soils and SFSI
  - RC components

- Studies to understand sensitivity of response
- Initial studies characterizing EDP→DM



- Detailed Testbed Exercises

- Transportation Network Analysis

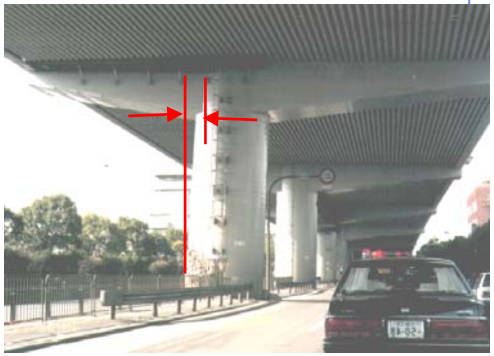


Two high-priority issues for owners

- 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



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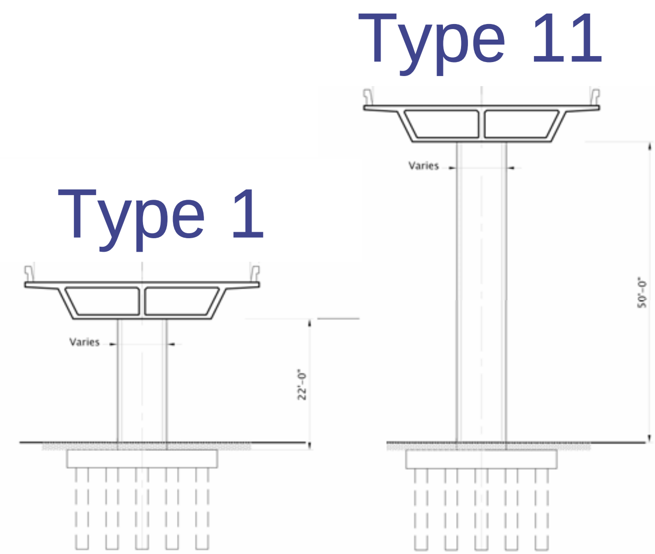
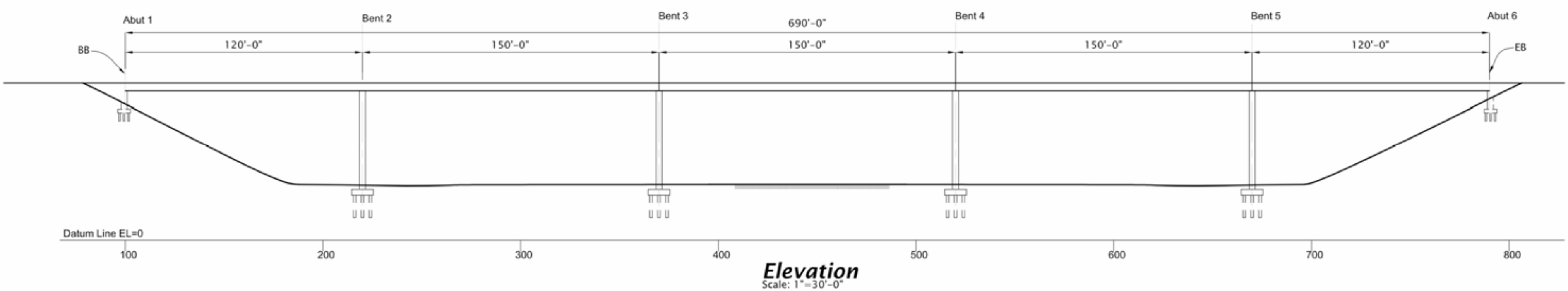
Enhanced Testbeds

- Developed Best Practices White Paper on Basic Approach to PBEE for Bridges (Stojadinovic) -- Common framework and tools
- Demonstrating PBEE methodology for variations on the testbed structure
  - Conventional baseline bridge on competent soils (Stojadinovic)
  - Soils susceptible to spreading and liquefaction
    - Practical design-oriented methods (Bray and Martin)
    - Advanced OpenSees modeling for liquefaction effects (Kramer and Arduino)
  - Assessment of new technology
    - Self-centering, enhanced performance columns (Billington)
- Demonstrating PBEE methodology for transportation & distributed systems
  - Improved direct and indirect system loss estimates based on improved bridge-specific fragility data (Kiremidjian, Brandenberg)
  - Planning issues related to emergency response and system recovery (Fan)
  - Participation in Tri-Center Collaboration (Moehle)

Basic Testbed Bridge Configurations





- Designs by professional engineers (Ketchum)
- Cost and duration of construction and repairs by practitioners (Ketchum) and Caltrans -- Stojadinovic, Eberhard, Ketchum

Common Testbed Model in OpenSees

- Modular design developed
  (Stojadinovic/Mackie)

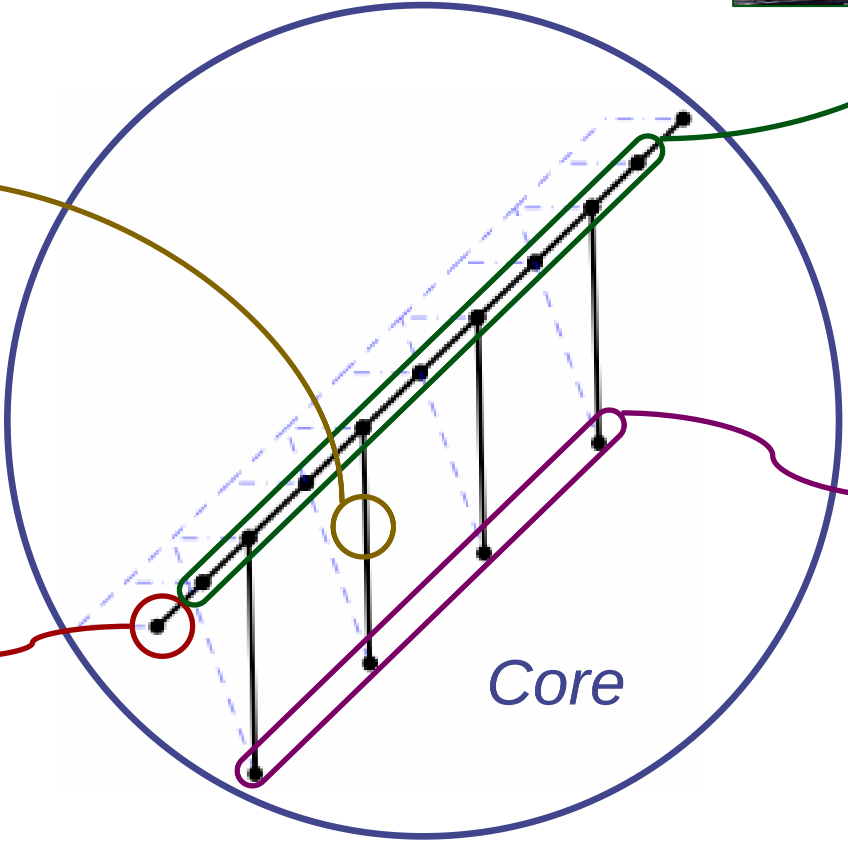
Deck

Columns

Billington, Eberhard, Lehman, Mahin plus Kunnath

Abutment

Ashford



Foundation

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

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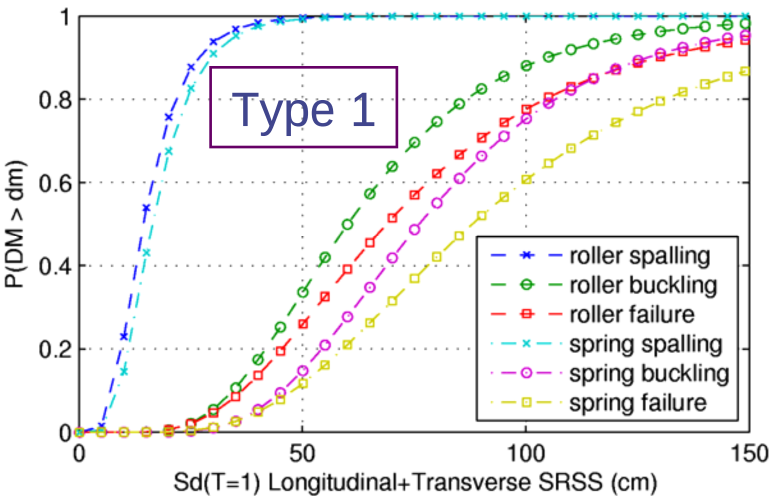
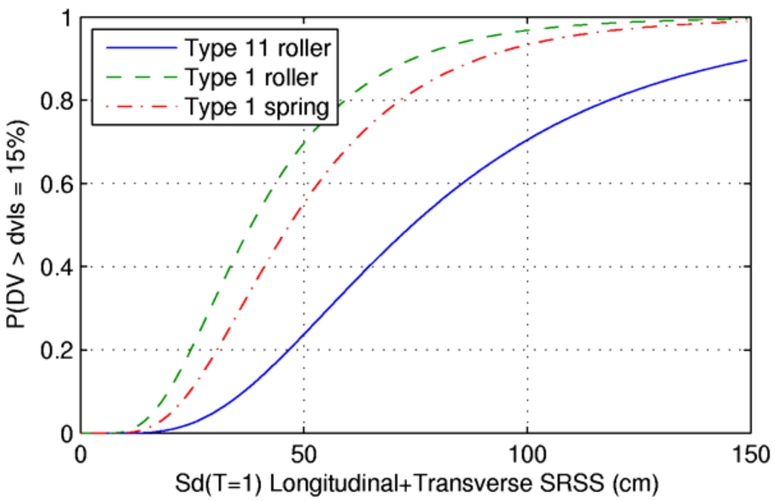
Damage and Loss Fragility Curves





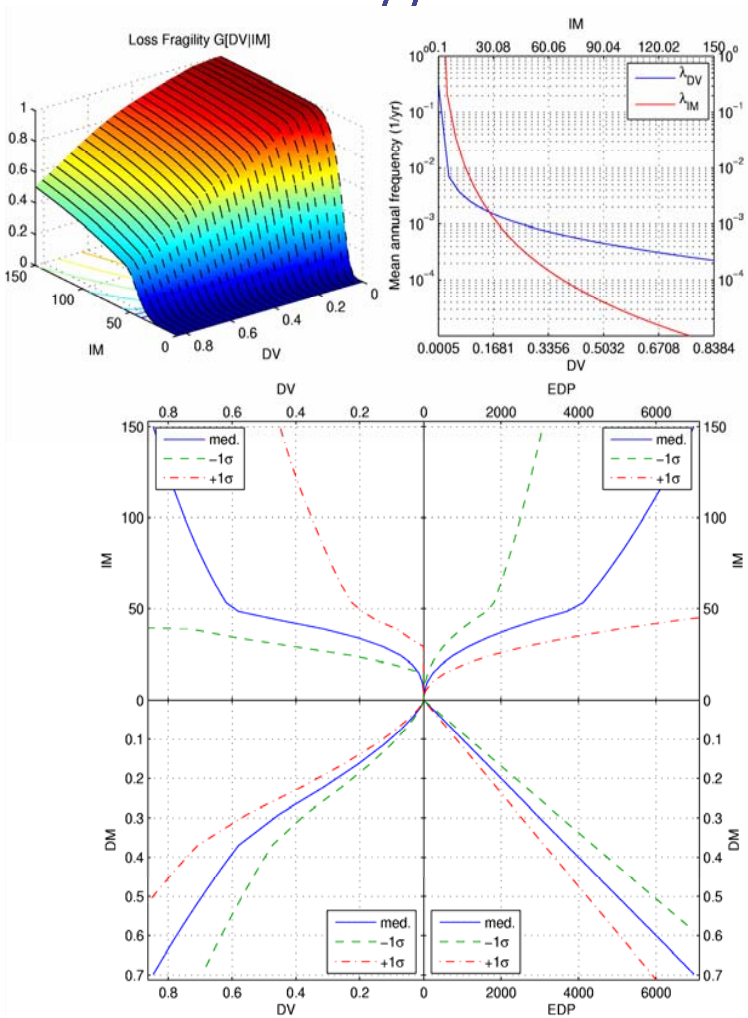
- Probability of exceeding damage limit states, or loss level given earthquake intensity
- Column damage from relations developed using PEER structural performance database
- Costs (DVs) from cost consultants and Caltrans

PI: Stojadinovic

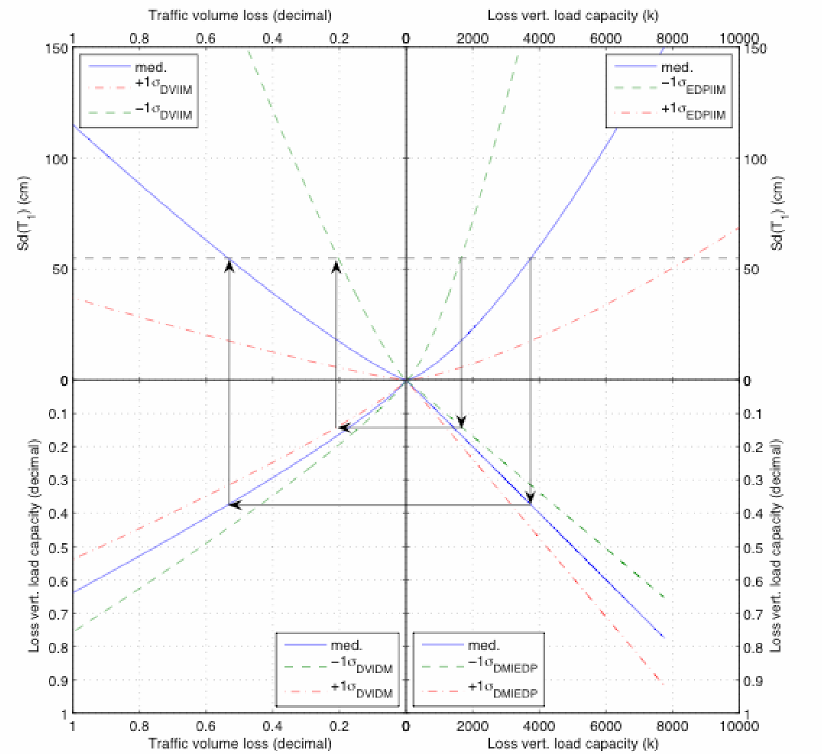
PBEE Application Tools

Given demand, damage and loss models (with uncertainties)

Matlab Application



Application suitable for hand solution

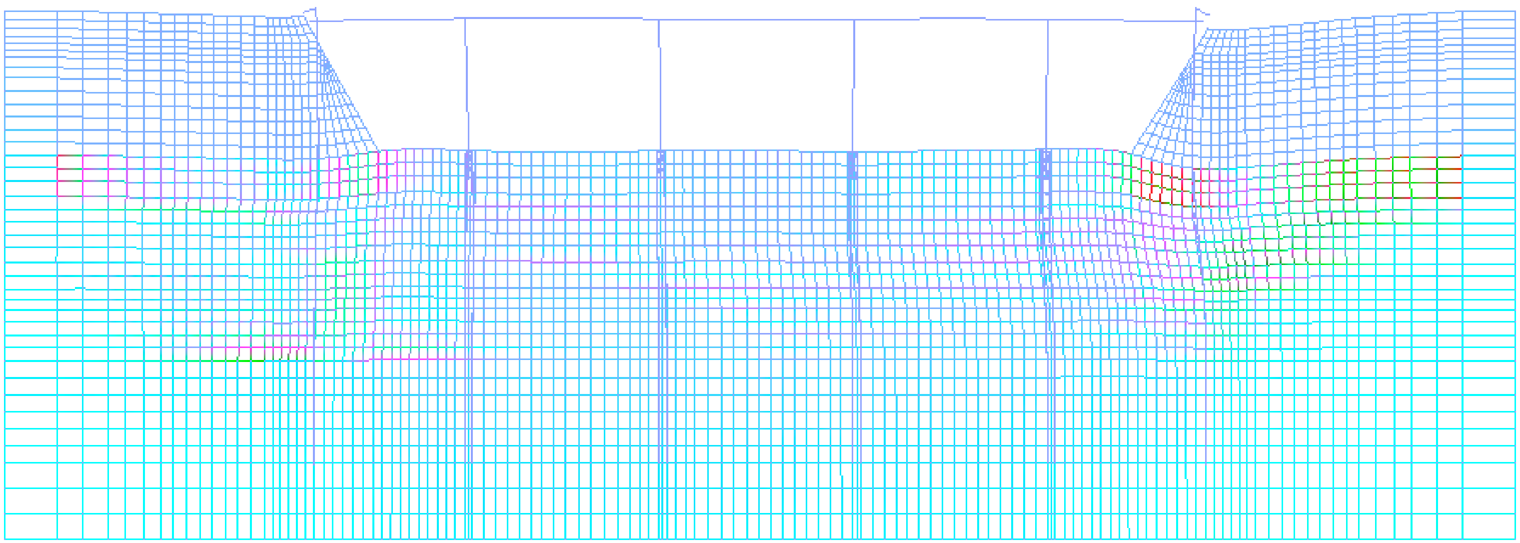


Helps visualize loss hazard and useful tool for assessing design decisions

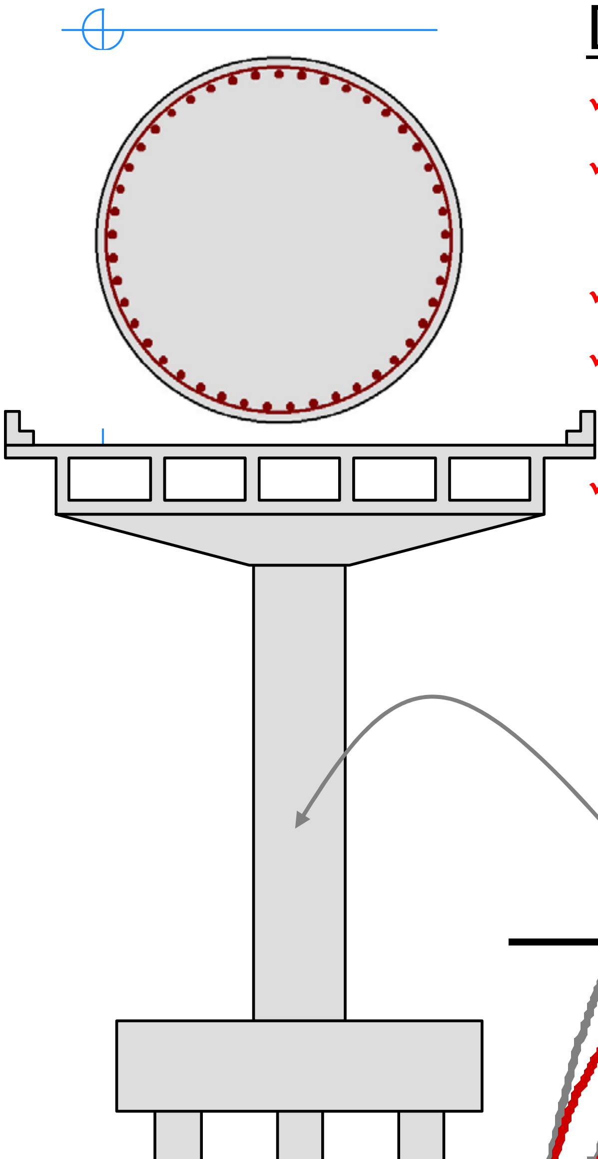
Testbed with lateral spreading / liquefaction

Assessment of current approaches, improve understanding, and identification of benefits of nonlinear analysis in assessment of liquefaction hazards

- Assessment of current design methods and remediation approaches (Bray and Martin)
- Coupled Soil-Pile-Structure Model in OpenSees (Kramer and Arduino)

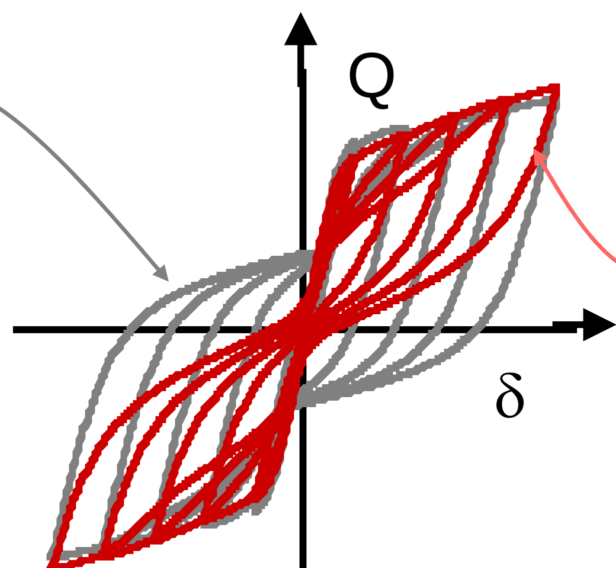


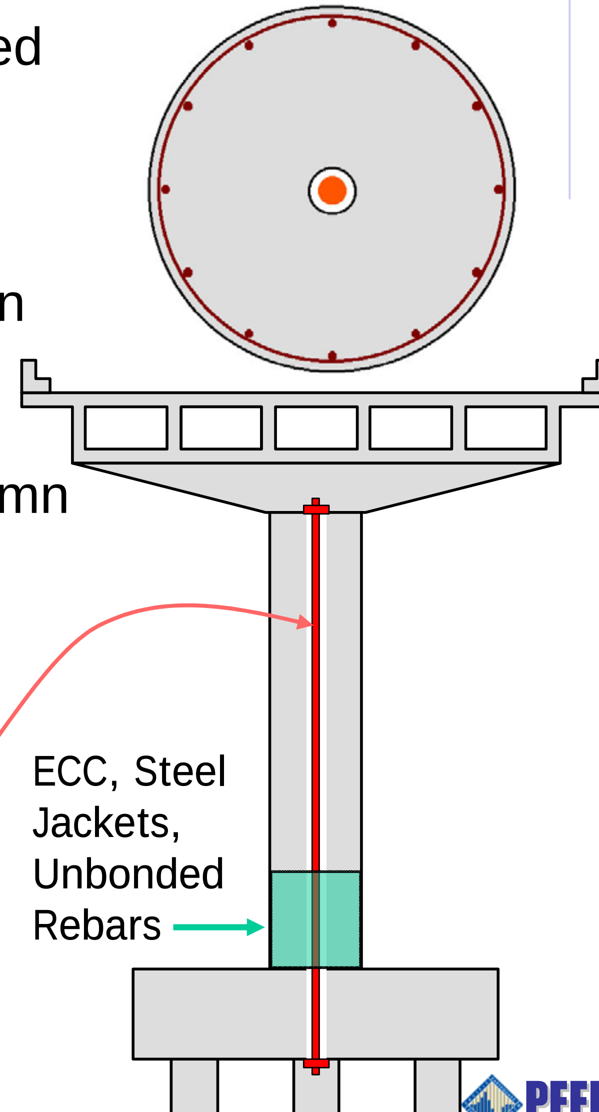
Testbed with Self-Centering Columns



Design method:

- ✓ 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





Response During Maximum Level Tests

100% of Los Gatos

Response Ductility = 13-14

Conventional RC Column

Partially Prestressed RC Column

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

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YUV420 codec decompressor
are needed to see this picture.

PI: Mahin

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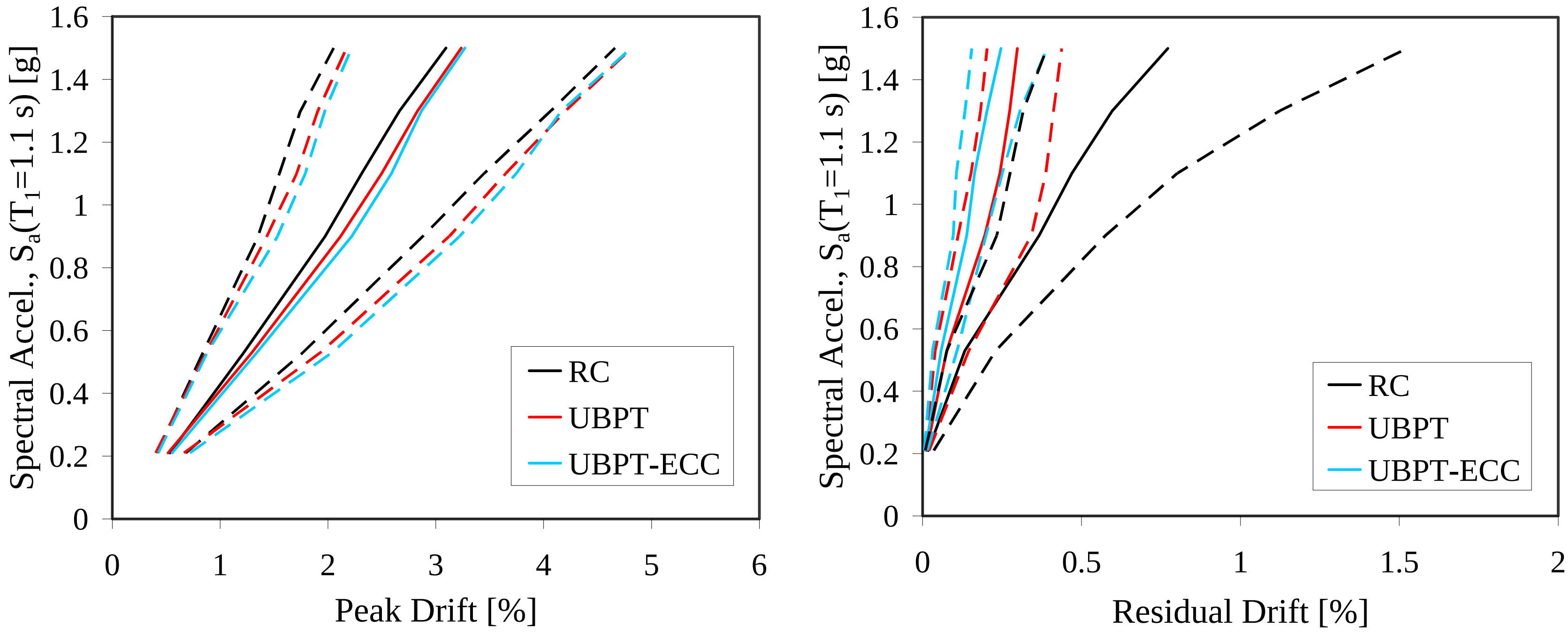
Dynamic Analysis Results

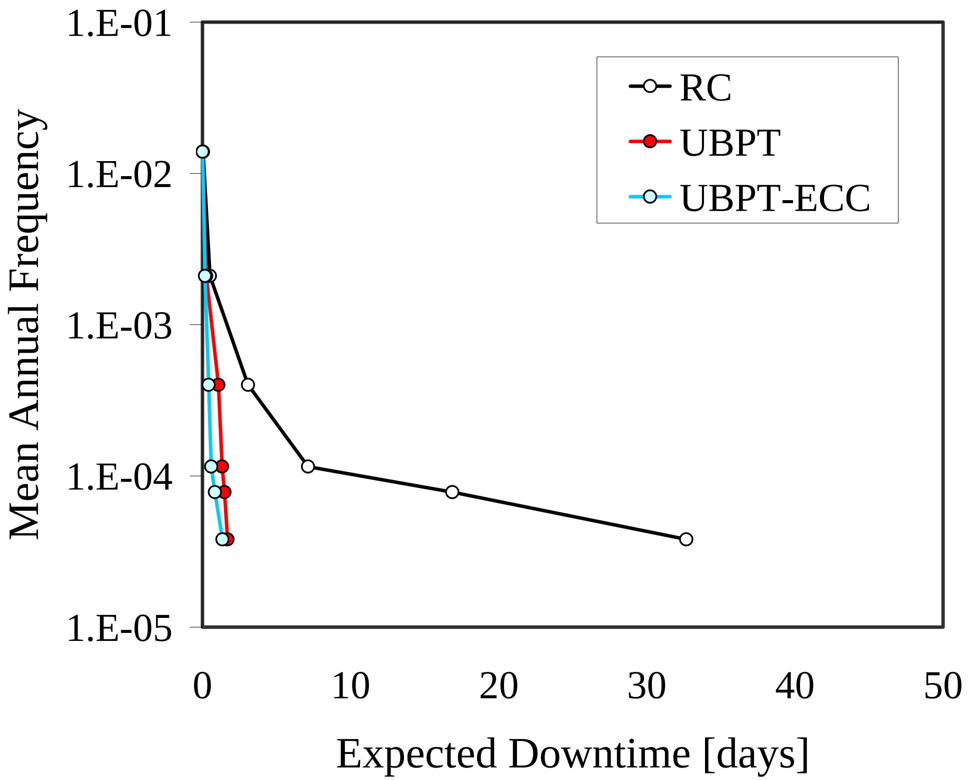
Enhanced performance systems have similar peak drifts as conventional systems, but significantly reduced residual drifts.



Solid lines are mean values and dashed lines are plus/minus one standard deviation (PI: Billington).

Application of the PEER Integral

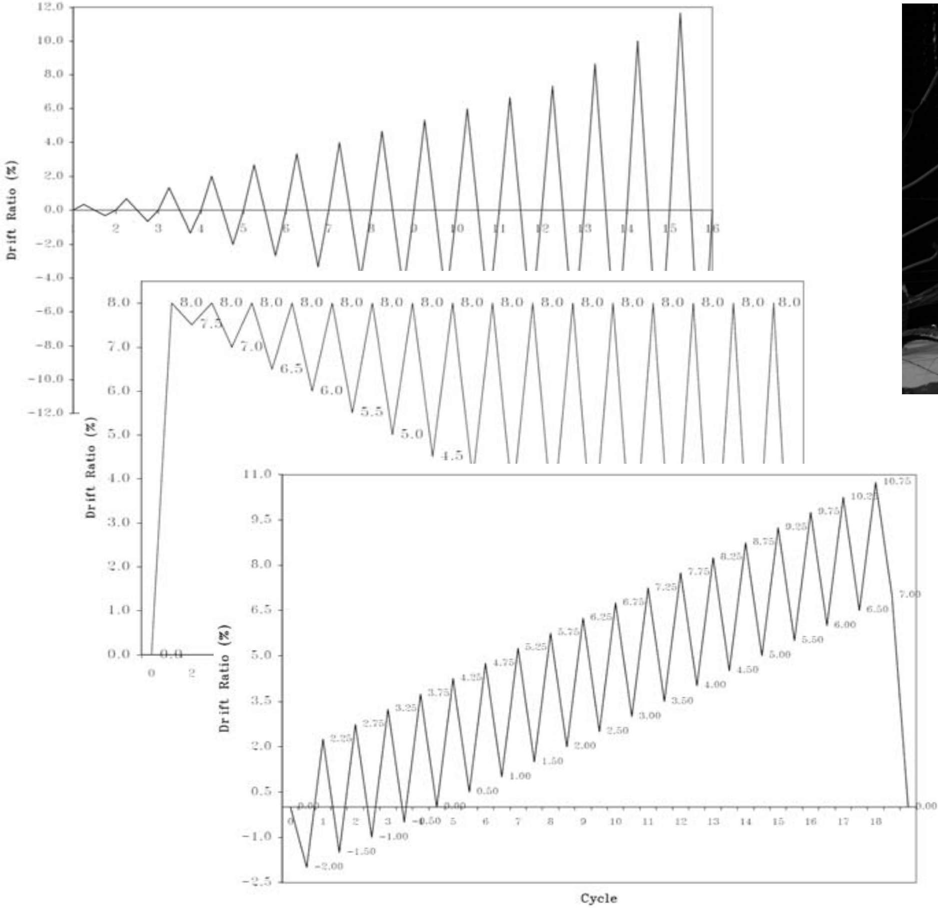
Combining seismic hazard, dynamic analysis, damage modeling, and loss modeling data:



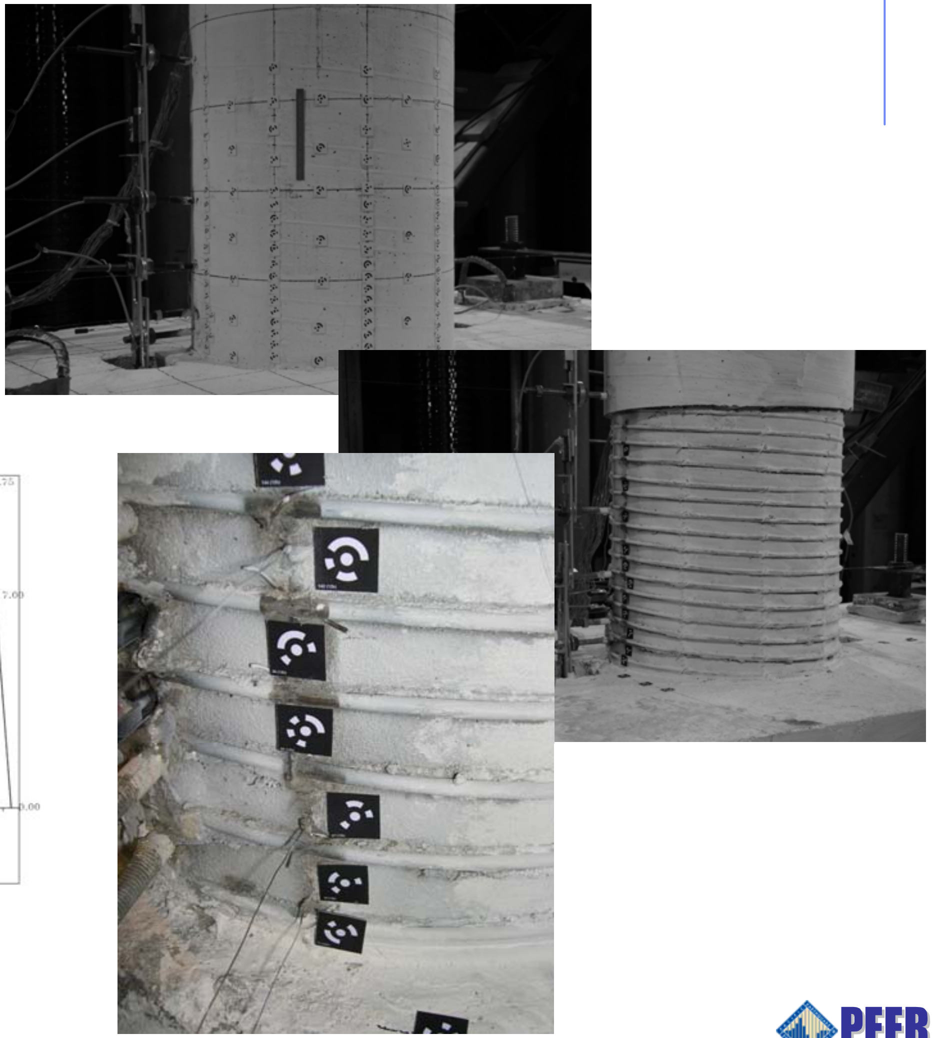
Result: For low mean annual frequency (high intensity) events, expected downtime for bridge due to excessive residual drifts is very large compared to enhanced performance systems *(PI: Billington).*

Buckling and Low-Cycle Fatigue

Experiments with different loading histories



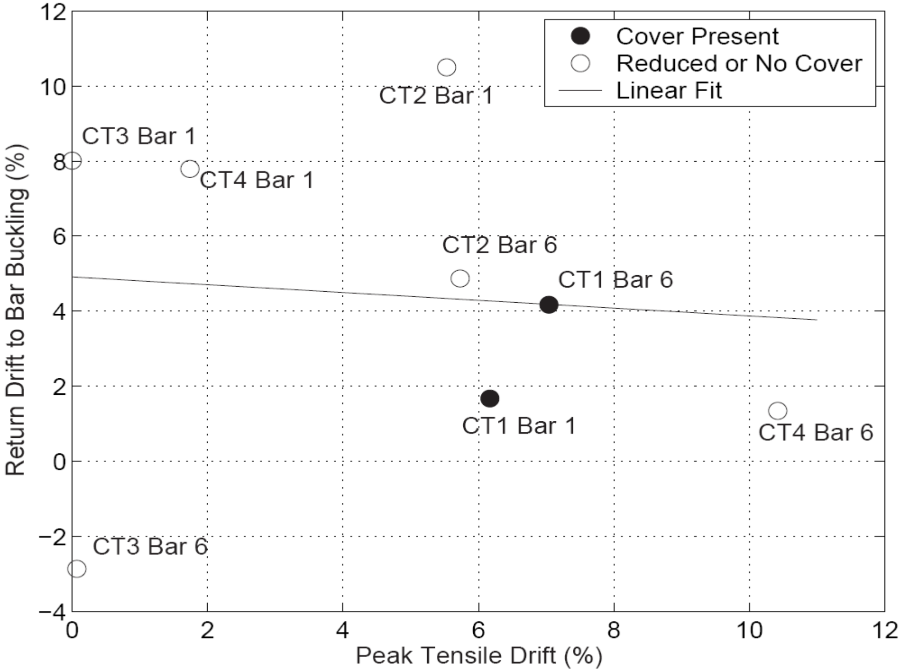
Careful tests to detect and measure bar buckling



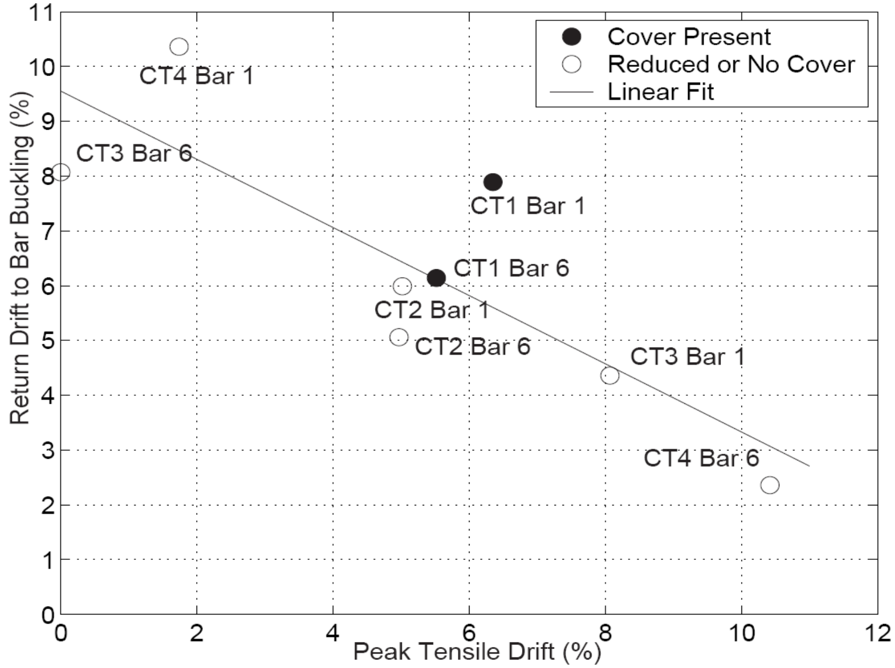
PIs: Lehman and Stanton

Buckling and Low-Cycle Fatigue

"Observed" data



"Measured" data



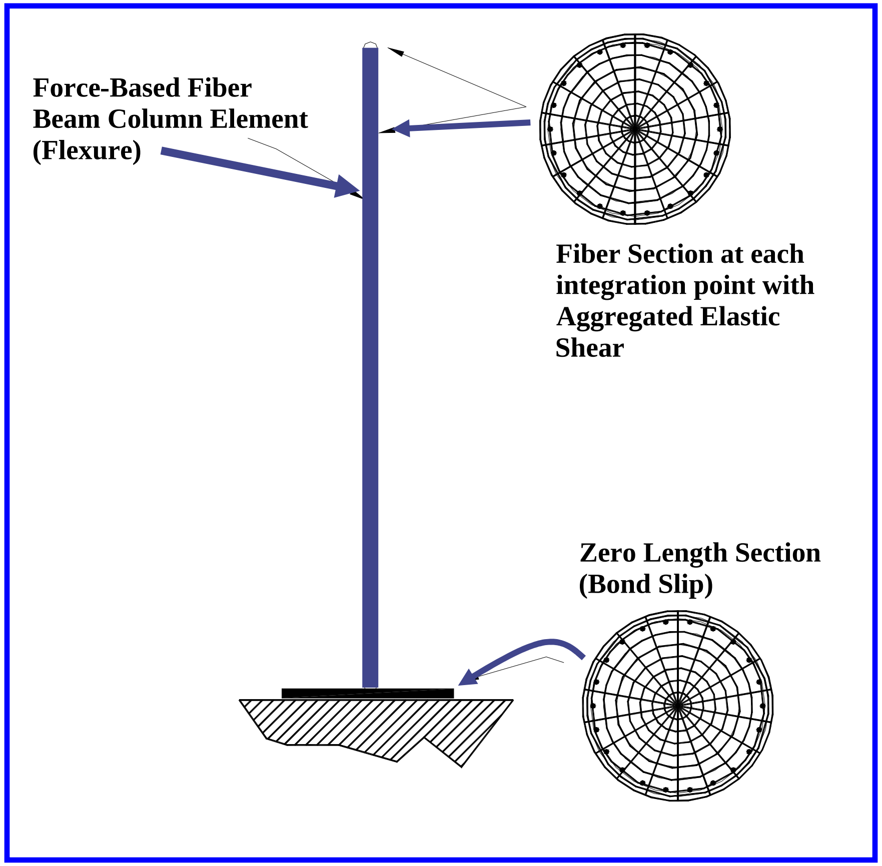
Accurate measurements indicate trends and correlations not previously noted.

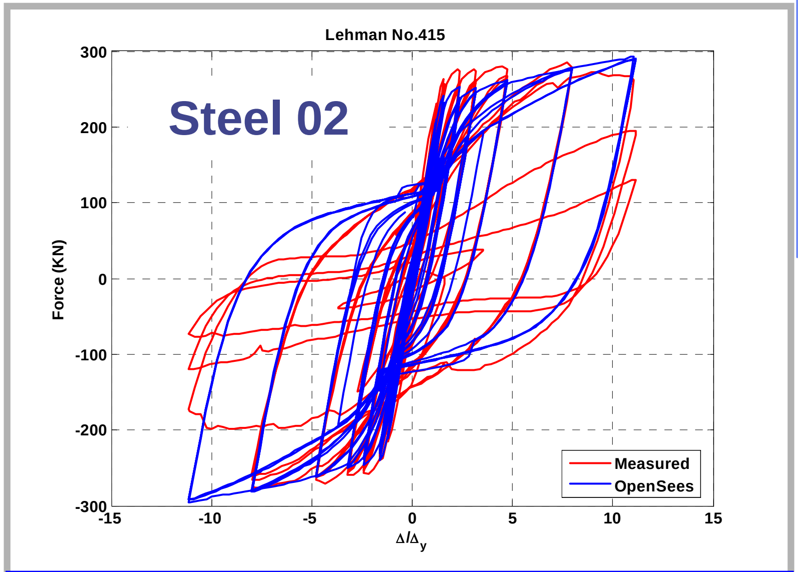
Past data on bar buckling and fracture may not be reliable

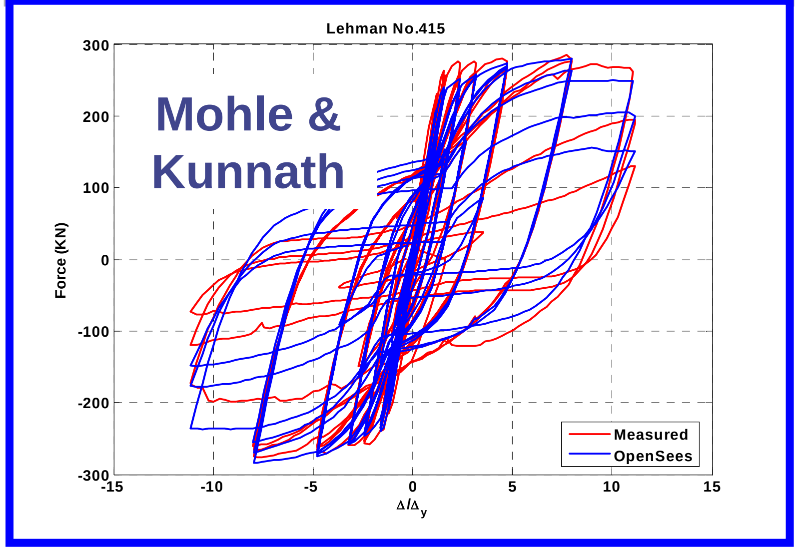
Working with TA IV researchers (Kunnath) to improve reinforcing models

PIs: Lehman and Stanton

Improved Numerical Models and Parameters







Optimum model values determined from test results (integration points, discretization, stiffness parameters, shear and bond parameters, etc).

Expanding model calibration and EDP-DM relations for other components

PI: Eberhard

Transportation Network Studies

- The improved detail and realism of the loss fragilities determined for individual bridges permits improved assessment of the socio-economic impacts of earthquakes on transportation systems (and provides basis for consideration of other geographically distributed systems)
- Team of Anne Kerimedjian (Stanford) and Yue You Fan (UC Davis) are working with Boza Stojadinovic (structural engineering input on fragilities),
  - High level of Tri-Center coordination and participation
  - Great interest by Caltrans and other transportation agencies
- Case study of highway system between Fairfield and Oakland, CA considered
- High potential for liquefaction at several sites explicitly considered (Scott Brandenberg, UCLA)

Transportation Network Studies

Efforts include:

- Quantifying propagation of uncertainty in estimates of total loss probability
- Use of explicit bridge fragility data to compute total risk including bridge losses and impacts such as increased travel times
- From a transportation operations perspective, how to route traffic optimally through a damage transportation system
- From a disaster management and mitigation perspective, how to develop and support effective strategies for recovering and modifying transportation systems to minimize societal disruption.

Bring it all together

- Synthesis report, describing in a clear, step-by-step how PBEE can be used by design professionals, including:
  - Modeling guidelines, including the complexity of modeling needed for a particular application
  - Databases
  - EDP-DM and DM-DV relations
  - Tools for carrying out PBEE
  - Recommendations on the type of information that can be obtained and how to present it.
  - Guidelines related to the complexity of modeling needed