Bridge PBEE and Resilience

Marc O. Eberhard

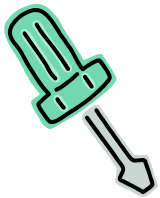
University of Washington

2011 PEER Annual Meeting

Berkeley, California

PEER's Mission

- "Advance and apply performance-based earthquake engineering tools to meet the needs of various stakeholders"



PEER

What's the Point?

- PBEE Provides framework and tools to:
  - Allow stakeholders to make informed decisions
  - Balance competing objectives
  - Consider variety of performance levels
  - Evaluate/develop new materials and systems

PEER

Transportation System Objectives

- Economical
  - Construction (include disruption?)
  - Maintenance and inspection
  - Repair
  - Disposal

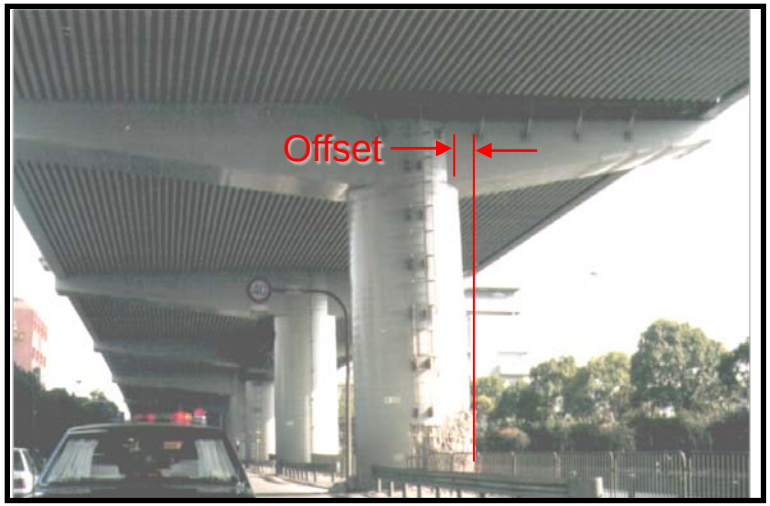
Transportation System Objectives

- "Safe"
  - Very low likelihood of loss of life
  - Very, very low likelihood of collapse

PEER

Transportation System Objectives

- Disaster Resilient
  - Minimize disruption to **community**
  - Available soon/immediately to aid recovery
  - Minimal inspection and repair costs/time
  - Minimal loss of revenue (fares, tolls, contracts)



PEER

Transportation System Objectives

- Sustainable
  - Durability
  - Environmental impact
    - Embodied carbon
      - Construction
      - Use
      - Destruction
    - Construction noise
    - Construction traffic congestion
    - Fish migration

PEER

How is Bridge PBEE Doing??

- Soft Implementation
  - Language/concepts
  - Major bridges
  - Education

- Hard Implementation (AAHSTO Guide Spec.)
  - Displacement-based design
  - Discussion of hazard and performance criteria
  - Displacement capacity of RC columns (4.8.1)

PEER

TSRP Projects

- Enabling Technologies: Overcoming Implementation Barriers/Complexities
  - Ground-motion selection (Baker)
  - Ground-motion stochastic modeling (Der Kiureghian)
  - Long-duration motions (Deierlein, Kramer)
  - OpenSEES tools for uncertainty analysis (Scott, Mackie, Conte)
  - Software platform for PBEE of Bridge Systems (Elgamal)
  - Size effects in bridge columns (Mosalam)
  - PBEE of Humboldt Bridge (Conte)

PEER

TSRP Projects

- Developing New Resilient/Sustainable Systems
  - High-performance fiber-RC (Ostertag, Billington)
  - Post-tensioned CIP Columns (Mahin)
  - Dual-shell steel columns (Restrepo)
  - Precast, pre-tensioned bridge bents (Stanton)
  - Rocking foundations (Kutter, Panagiotou)
  - Isolation of bridge segments (Mahin)

PEER

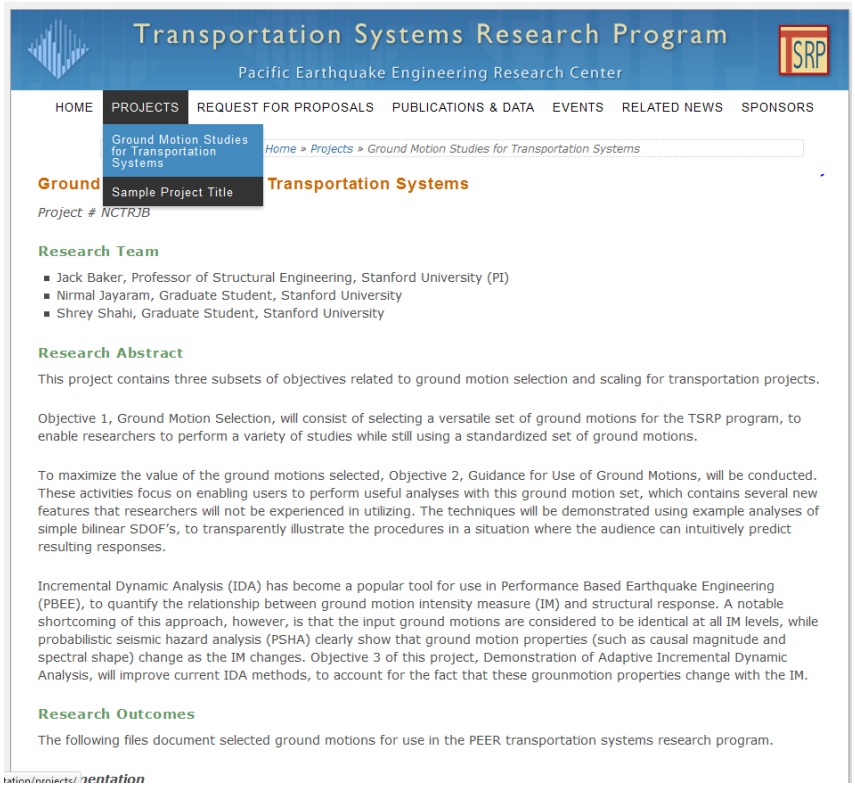
TSRP Projects

http://peer.berkeley.edu/transportation/projects/

PEER

Enabling Technologies

The product: several standardized ground motion sets



Transportation Systems Research Program

Pacific Earthquake Engineering Research Center

HOME | PROJECTS | REQUEST FOR PROPOSALS | PUBLICATIONS & DATA | EVENTS | RELATED NEWS | SPONSORS

Ground Motion Studies for Transportation Systems

Sample Project Title

Home » Projects » Ground Motion Studies for Transportation Systems

Ground Transportation Systems

Project # NCTRJB

Research Team

- Jack Baker, Professor of Structural Engineering, Stanford University (PI)
- Nirmal Jayaram, Graduate Student, Stanford University
- Shrey Shahi, Graduate Student, Stanford University

Research Abstract

This project contains three subsets of objectives related to ground motion selection and scaling for transportation projects.

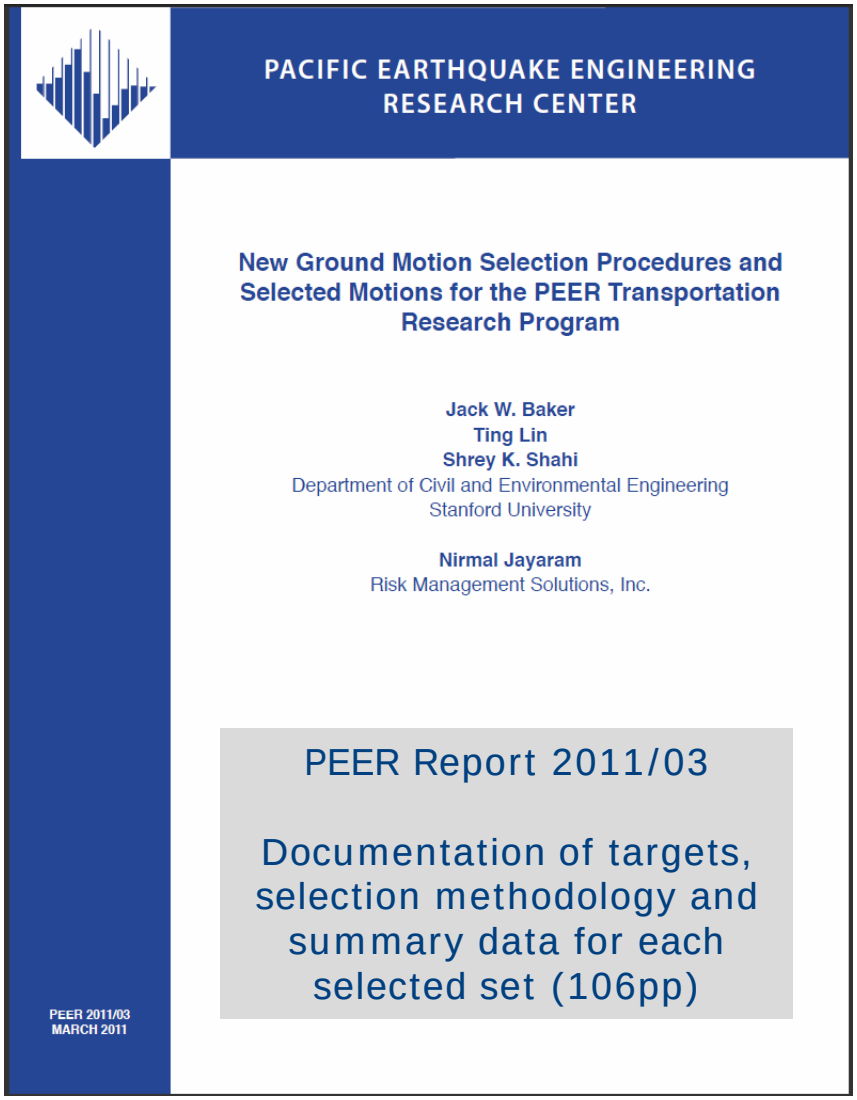
Objective 1, Ground Motion Selection, will consist of selecting a versatile set of ground motions for the TSRP program, to enable researchers to perform a variety of studies while still using a standardized set of ground motions.

To maximize the value of the ground motions selected, Objective 2, Guidance for Use of Ground Motions, will be conducted. These activities focus on enabling users to perform useful analyses with this ground motion set, which contains several new features that researchers will not be experienced in utilizing. The techniques will be demonstrated using example analyses of simple bilinear SDOF's, to transparently illustrate the procedures in a situation where the audience can intuitively predict resulting responses.

Incremental Dynamic Analysis (IDA) has become a popular tool for use in Performance Based Earthquake Engineering (PBEE), to quantify the relationship between ground motion intensity measure (IM) and structural response. A notable shortcoming of this approach, however, is that the input ground motions are considered to be identical at all IM levels, while probabilistic seismic hazard analysis (PSHA) clearly show that ground motion properties (such as causal magnitude and spectral shape) change as the IM changes. Objective 3 of this project, Demonstration of Adaptive Incremental Dynamic Analysis, will improve current IDA methods, to account for the fact that these grounmotion properties change with the IM.

Research Outcomes

The following files document selected ground motions for use in the PEER transportation systems research program.



PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

New Ground Motion Selection Procedures and Selected Motions for the PEER Transportation Research Program

Jack W. Baker
Ting Lin
Shrey K. Shahi
Department of Civil and Environmental Engineering
Stanford University

Nirmal Jayaram
Risk Management Solutions, Inc.

PEER Report 2011/03

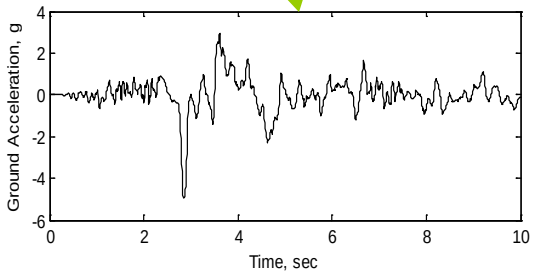
Documentation of targets, selection methodology and summary data for each selected set (106pp)

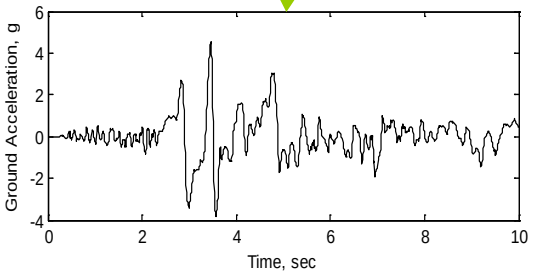
PEER 2011/03
MARCH 2011

Stochastic dynamic analysis of bridges subjected to spatially varying ground motions

Katerina Konakli
and Armen DerKiureghian
University of California, Berkeley

Motivation





PEER

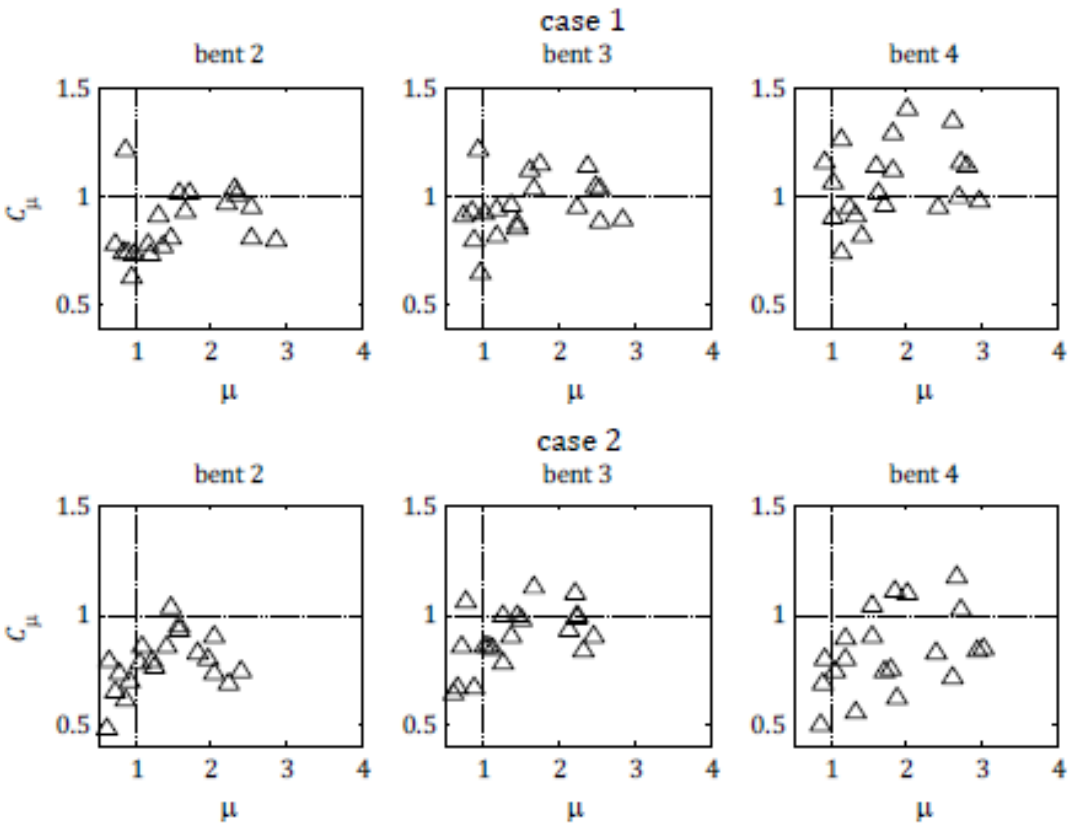
Use of RHA for investigation of "equal displacement" rule

Cμ: ratio of nonlinear to linear response (pier drifts)

μ: ductility ratio

case 1:
uniform support motions

case 2:
variable support motions

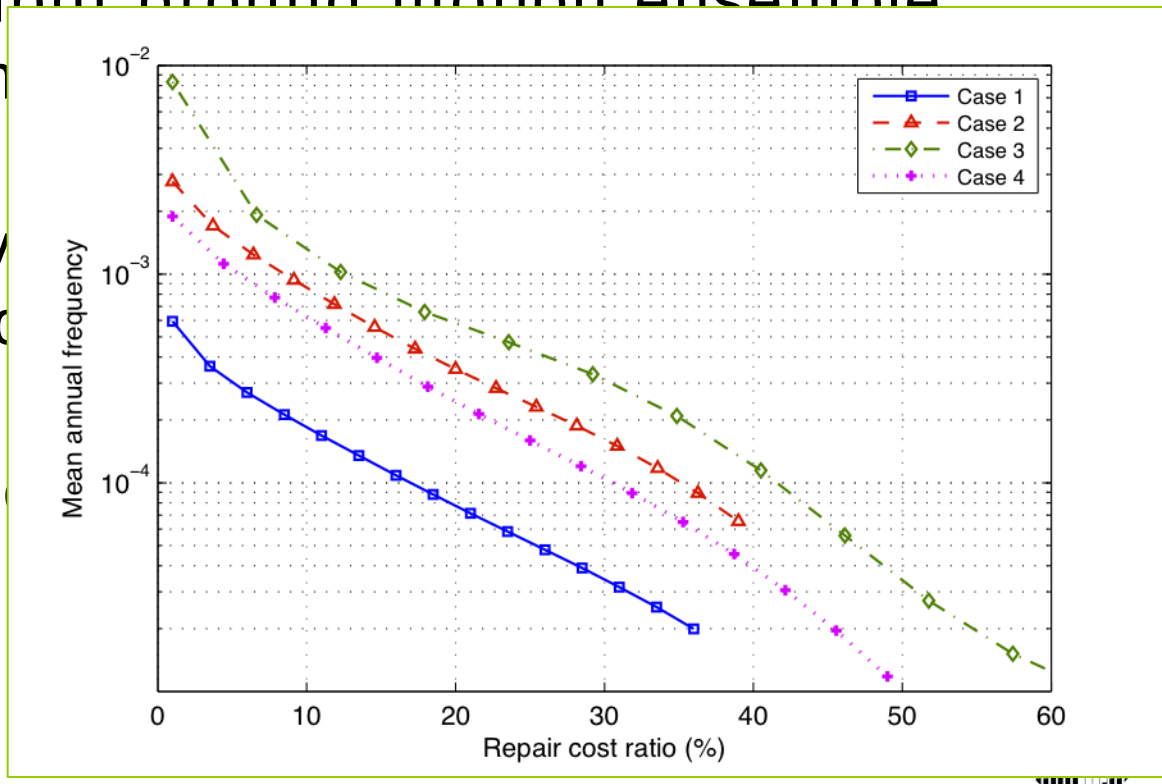


PEER

BridgePBEE

Mackie / Elgamal

- Graphical interface for integrated PBEE
  - Handle the input ground motion ensemble and computin measures
  - Automatically ground FE mo
  - Post-processi response ens outcomes



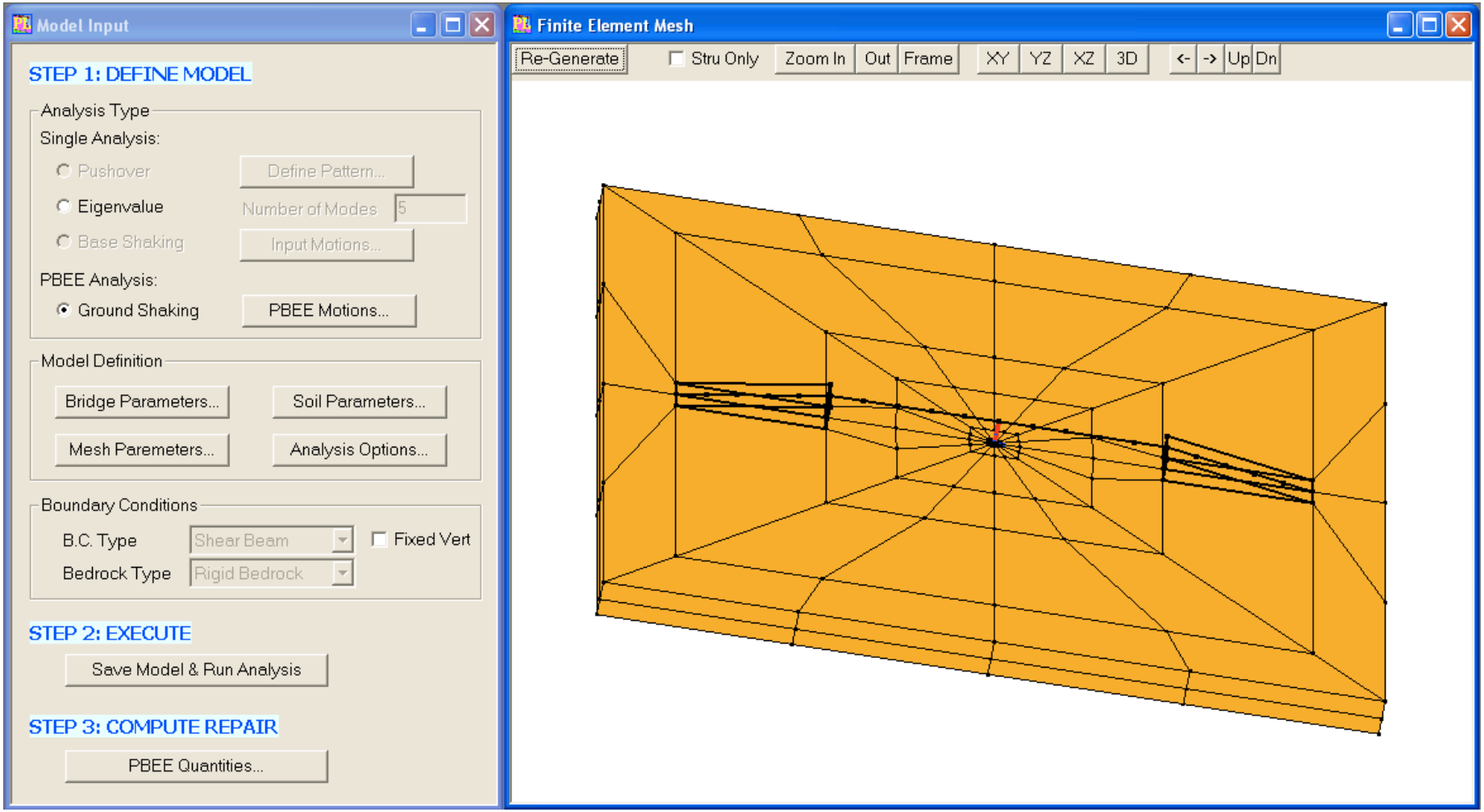
PBEE outcomes: repair costs, repair times (loss models, fragility, or hazard)

PEER

BridgePBEE

Mackie / Elgamal

- Graphical interface for integrated PBEE



Performance-Based Earthquake Engineering Analysis of Humboldt Bay Middle Channel Bridge

Joel P. Conte, Ahmed Elgamal, Yuyi Zhang, and Zhaohui Yang

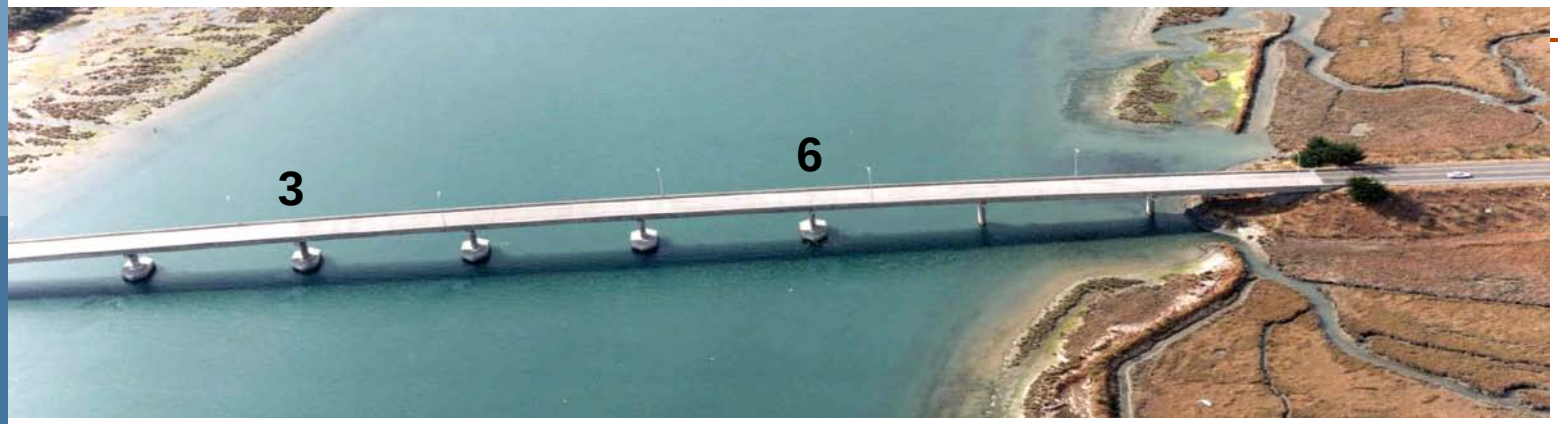
Dept. of Structural Engineering

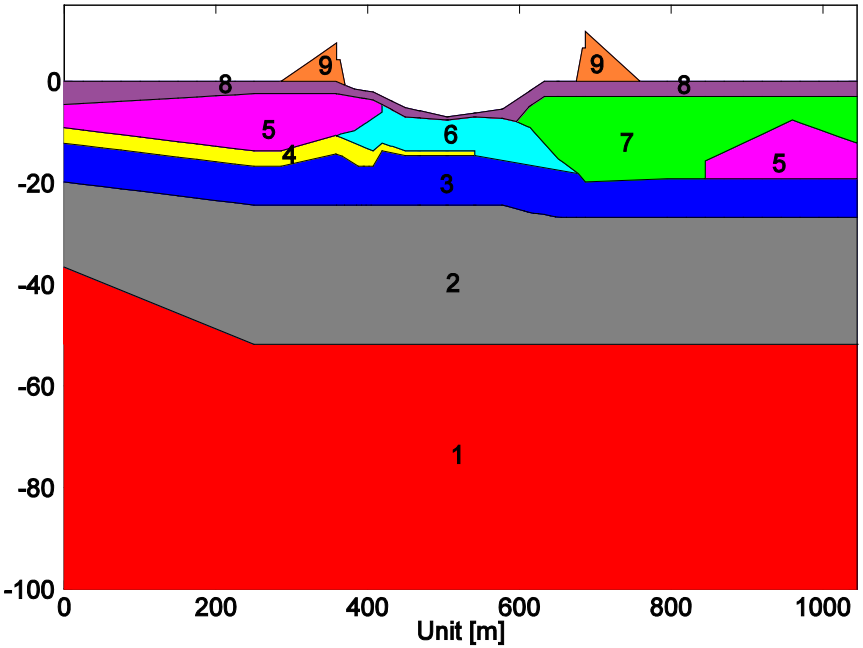
University of California, San Diego

PEER
Pacific Earthquake Engineering Research Center

UCSD Jacobs | Structural Engineering

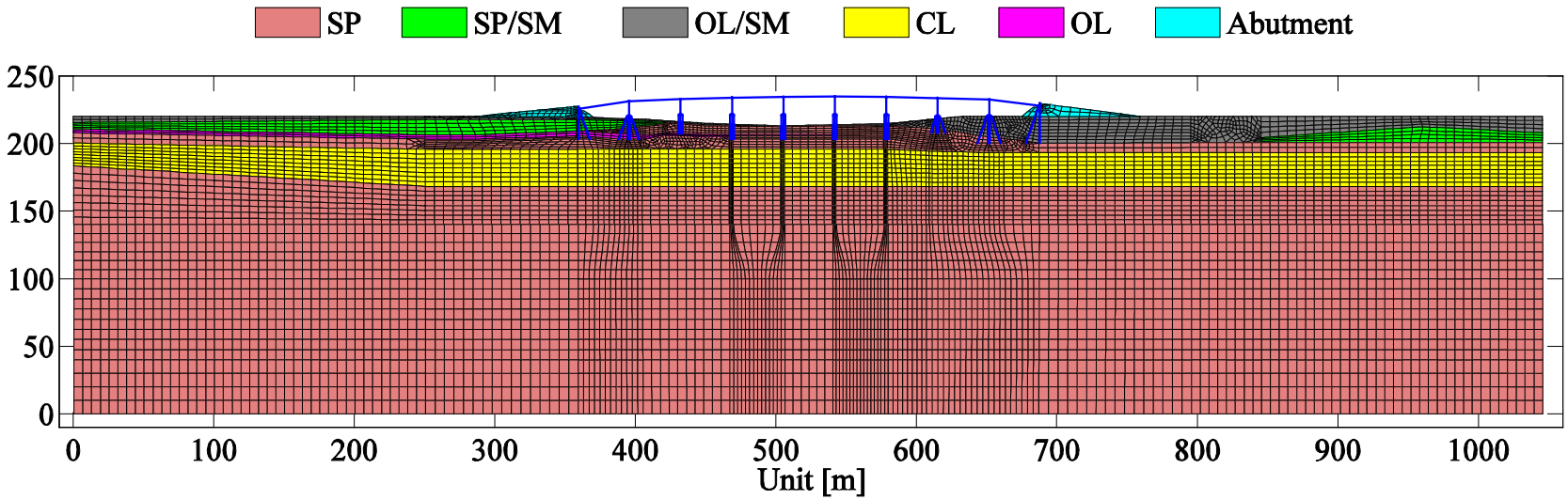
Humboldt Bay Bridge Testbed





PEER

OpenSEES Finite Element Model



- 10,889 nodes, 10,600 elements and 20,686 degrees of freedom
- Size of the soil dom $1050 \times 220m$, plane strain condition
- Thickness of the soil domain: 6.10 m, thickness of the abutments: 10.4 m
- Four-noded, bilinear, isoparametric finite elements with four integration points
- The maximum size of the soil elements is controlled to accurately propagate seismic waves up to 15*Hz*

Potential Failure Mechanisms and Associated EDPs

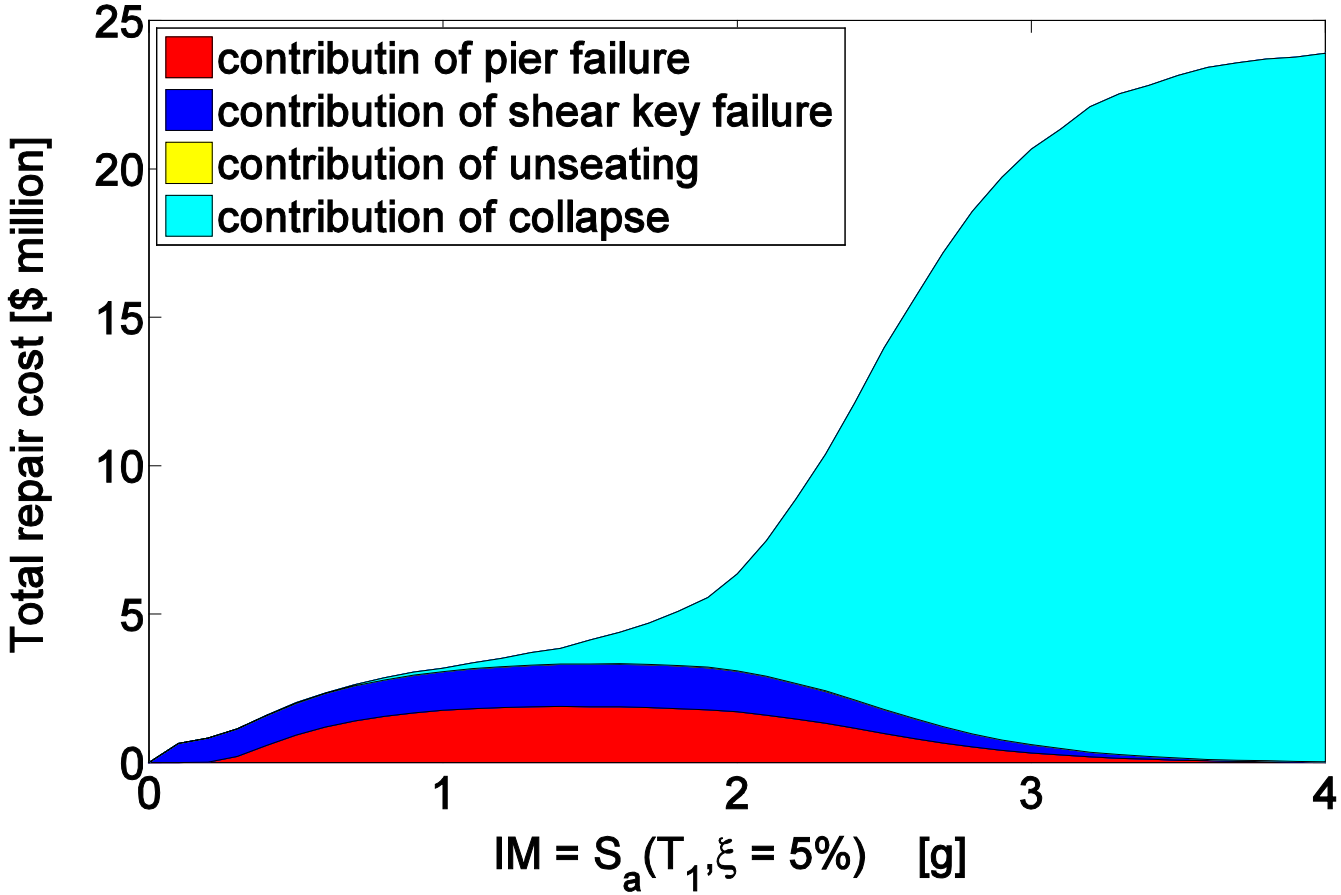
- **Pier flexural failure (EDP: peak pier lateral drift)**
- **Shear key failure (EDP: peak shear key deformation)**
- **Unseating (EDP: peak unseating displacement)**

Pier flexural failure

Shear key failure

Unseating failure

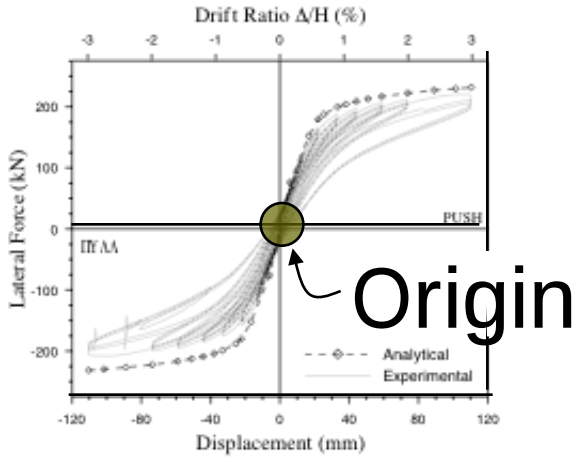
Seismic Loss Hazard Analysis Results

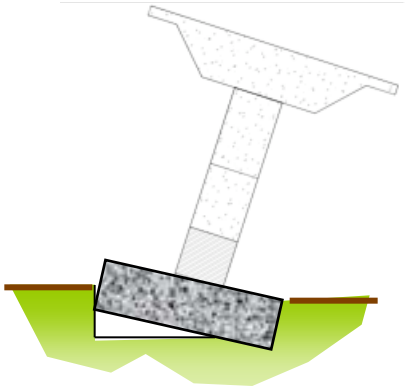


Developing New Systems

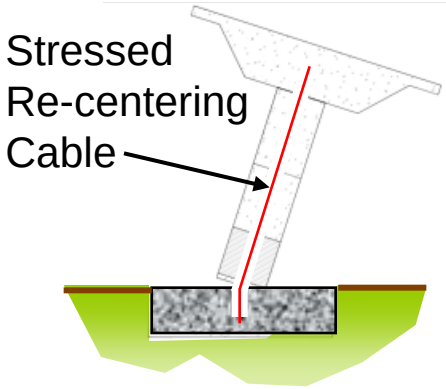
Resilient Designs Options

- Origin-oriented hysteretic loops
  - Partially prestressed RC columns
  - Rocking of foundations



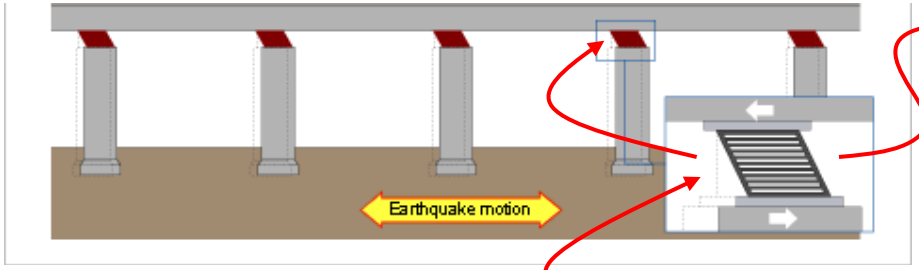


Rocking Foundation

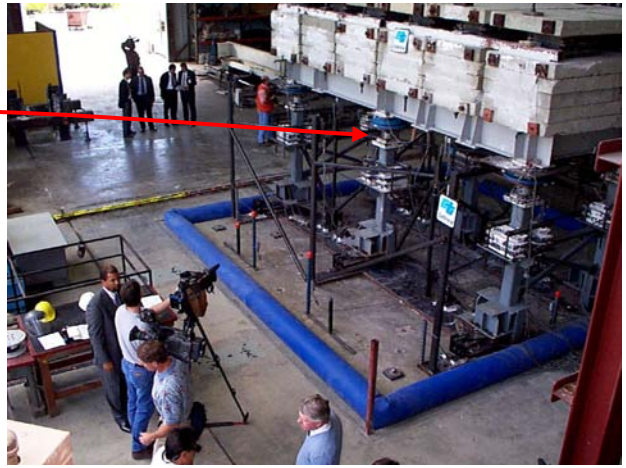


Prestressed column

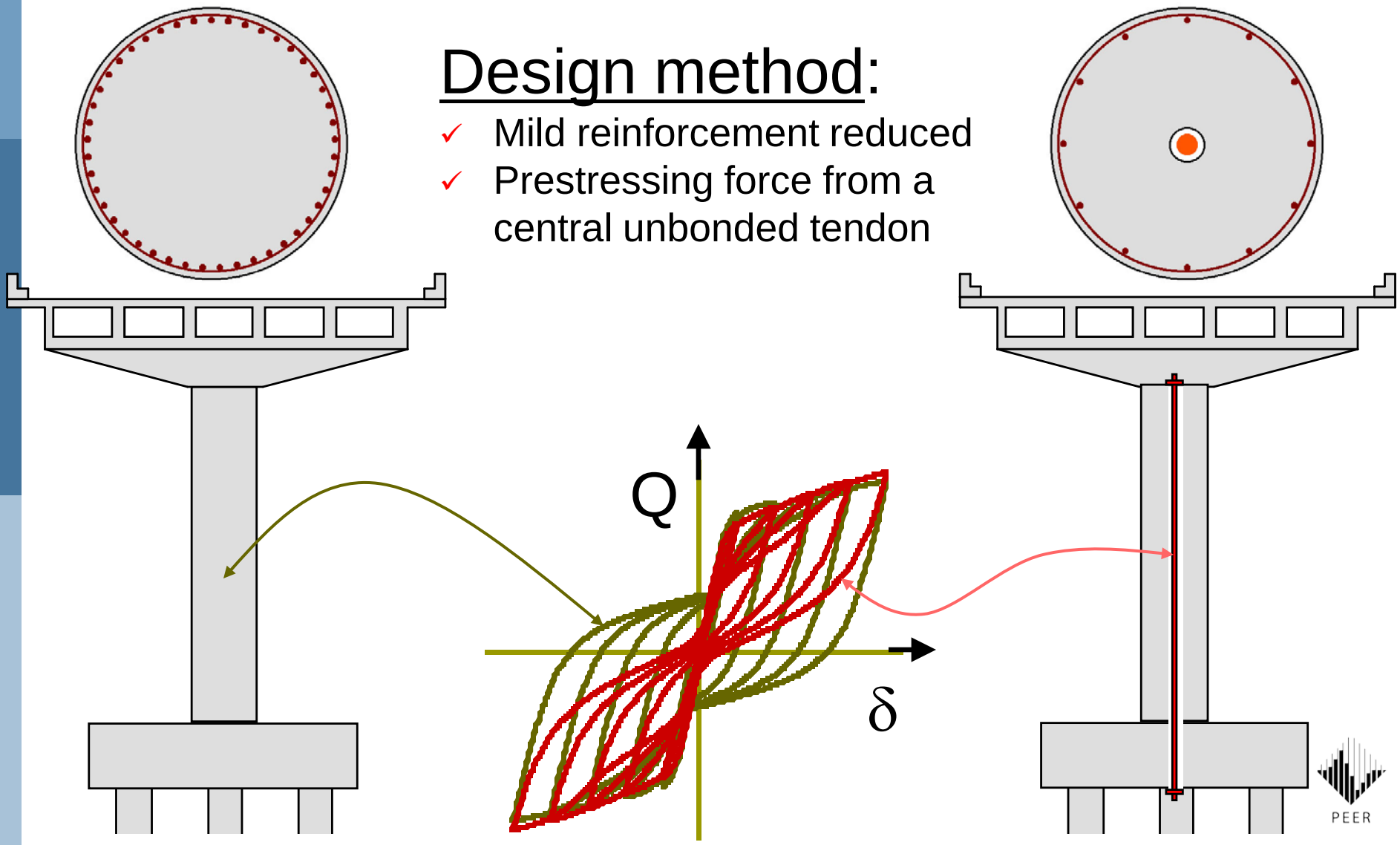
- Seismic Isolation



Seismic Isolators



Partially Prestressed, Reinforced Concrete Self-Centering Column (Mahin)



Design method:

- ✓ Mild reinforcement reduced
- ✓ Prestressing force from a central unbonded tendon

PEER

Ductile Self-Centering Bridge Column

- μ >10, peak displacements within 10%

- Residual displacement < 0.6%

Advanced Precast Concrete Dual-Shell Steel Columns

Gabriele Guerrini
Graduate Student Researcher

Jose' I. Restrepo
Professor, Principal Investigator

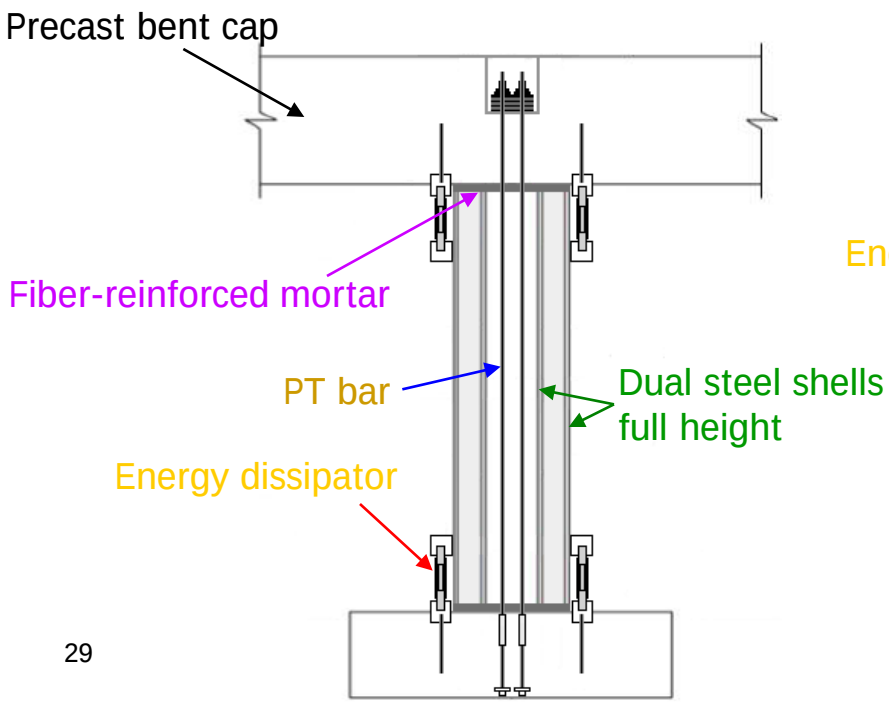
University of California, San Diego
Structural Engineering Department

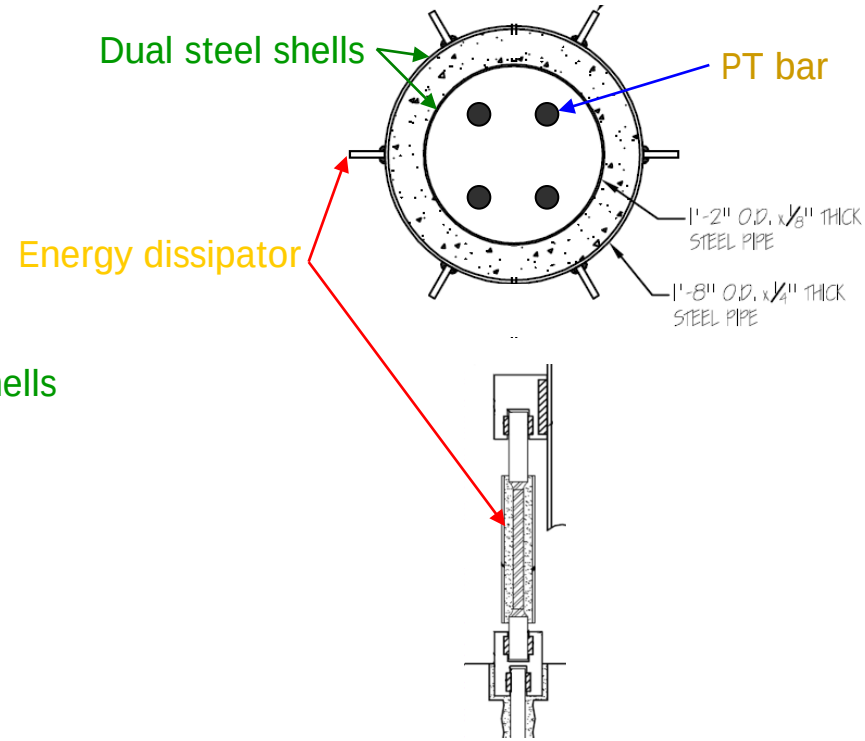
Goals

- Accelerated bridge construction
- Resilient bridge pier seismic performance

Main Features

- Dual steel shells
- Postensioning / recentering
- Energy dissipation
- Fiber-reinforced mortar

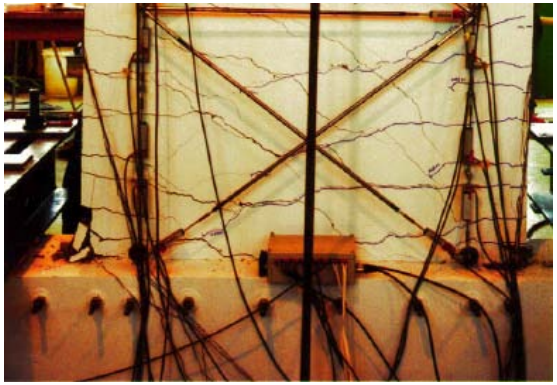


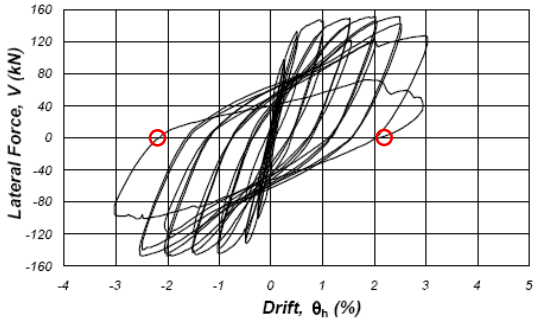


Advantages

- Limited structural damage compared to monolithic systems
- Small residual displacements compared to monolithic case
- Operability right after strong shakes
- Added energy dissipation

Monolithic System

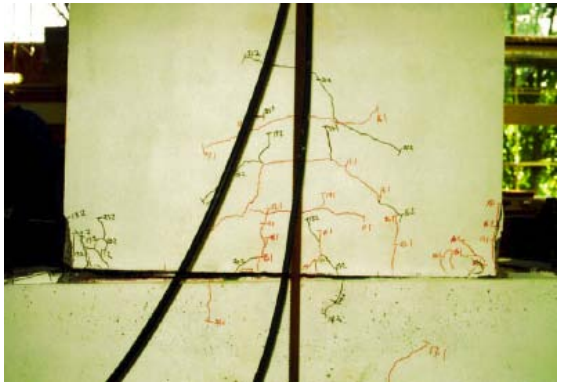


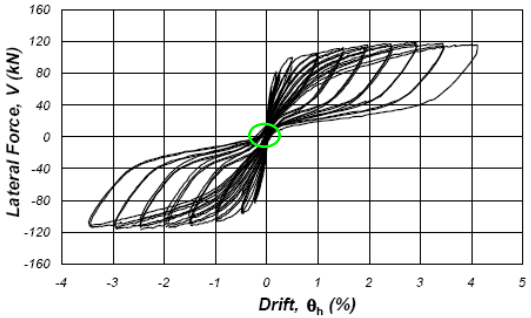


Shear-wall test results

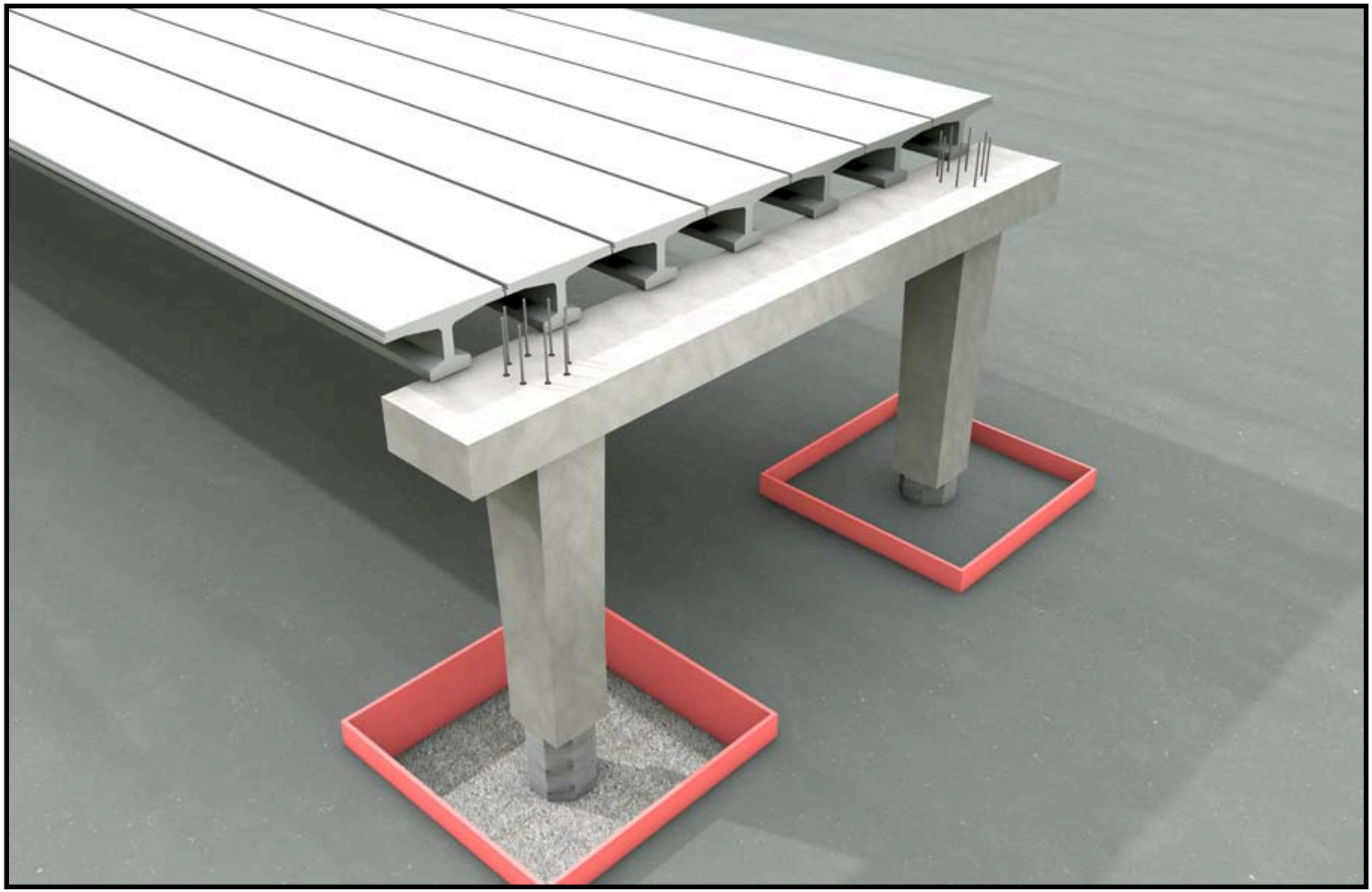
(Restrepo, Mander, Holden)

Self-Centering System



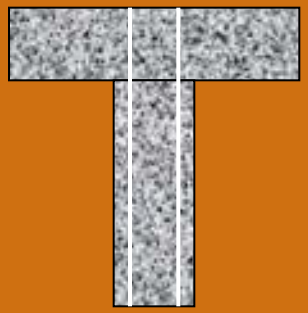
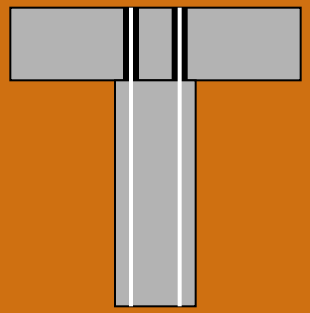
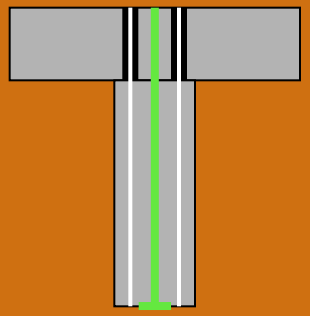
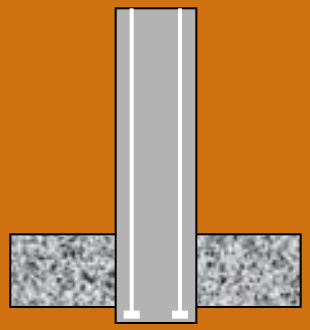
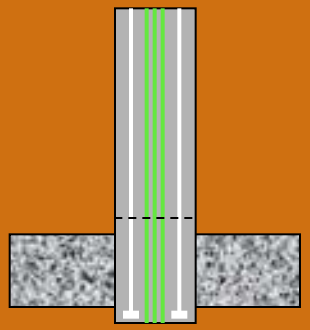
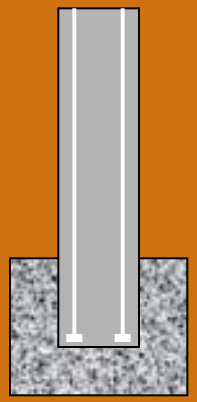


Damage Resilient Precast Structures (Stanton, UW)



PEER

Connection Details

	CIP RC (ref)	Precast RC	Precast Pretensioned
Cap-Beam to Column			
Column to Spread Footing			
Column to Drilled Shaft			

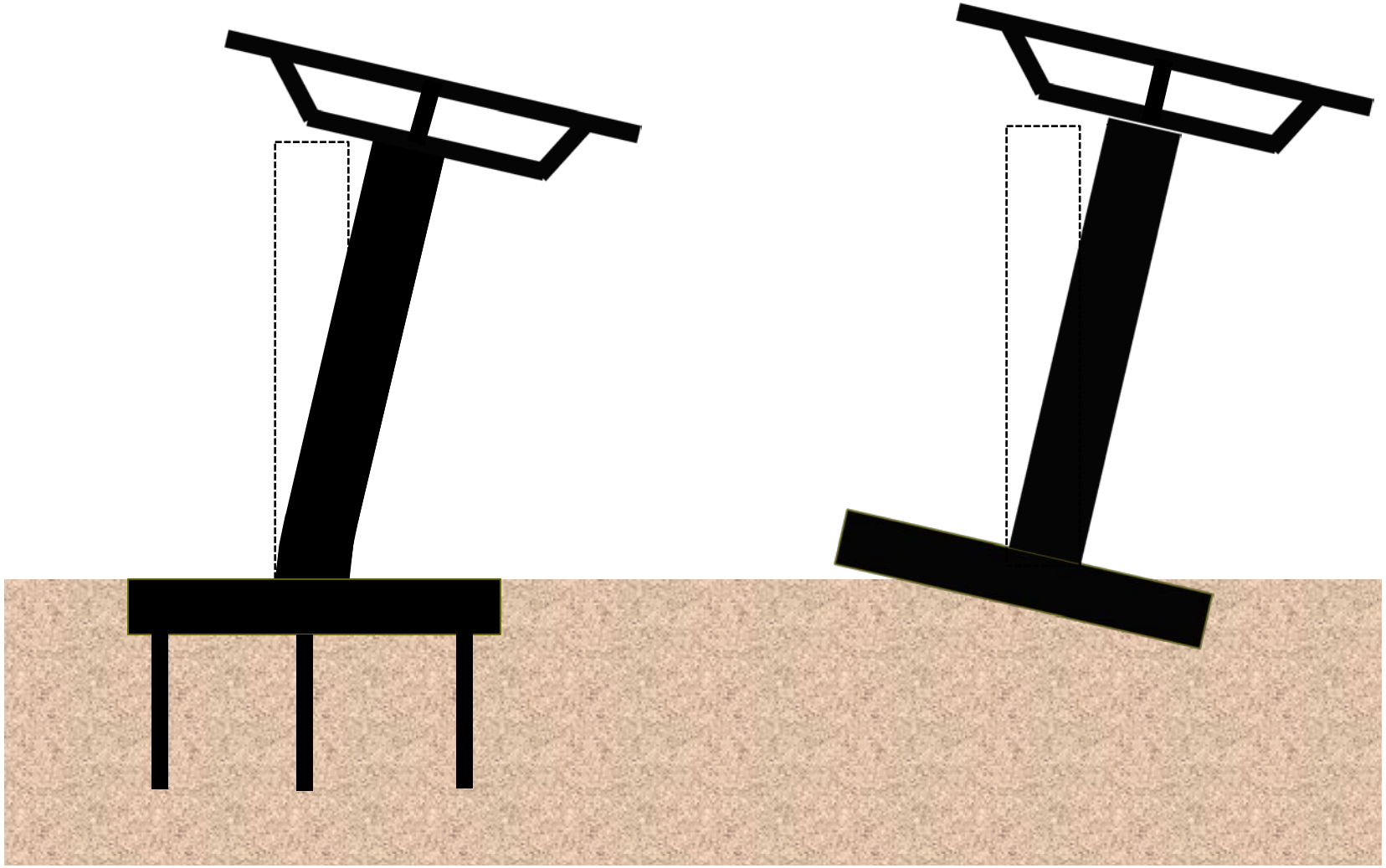
Seismic Performance Evaluation of Bridges with Foundations Designed to Uplift

Grigorios Antonellis
Graduate Student Researcher
University of California, Berkeley

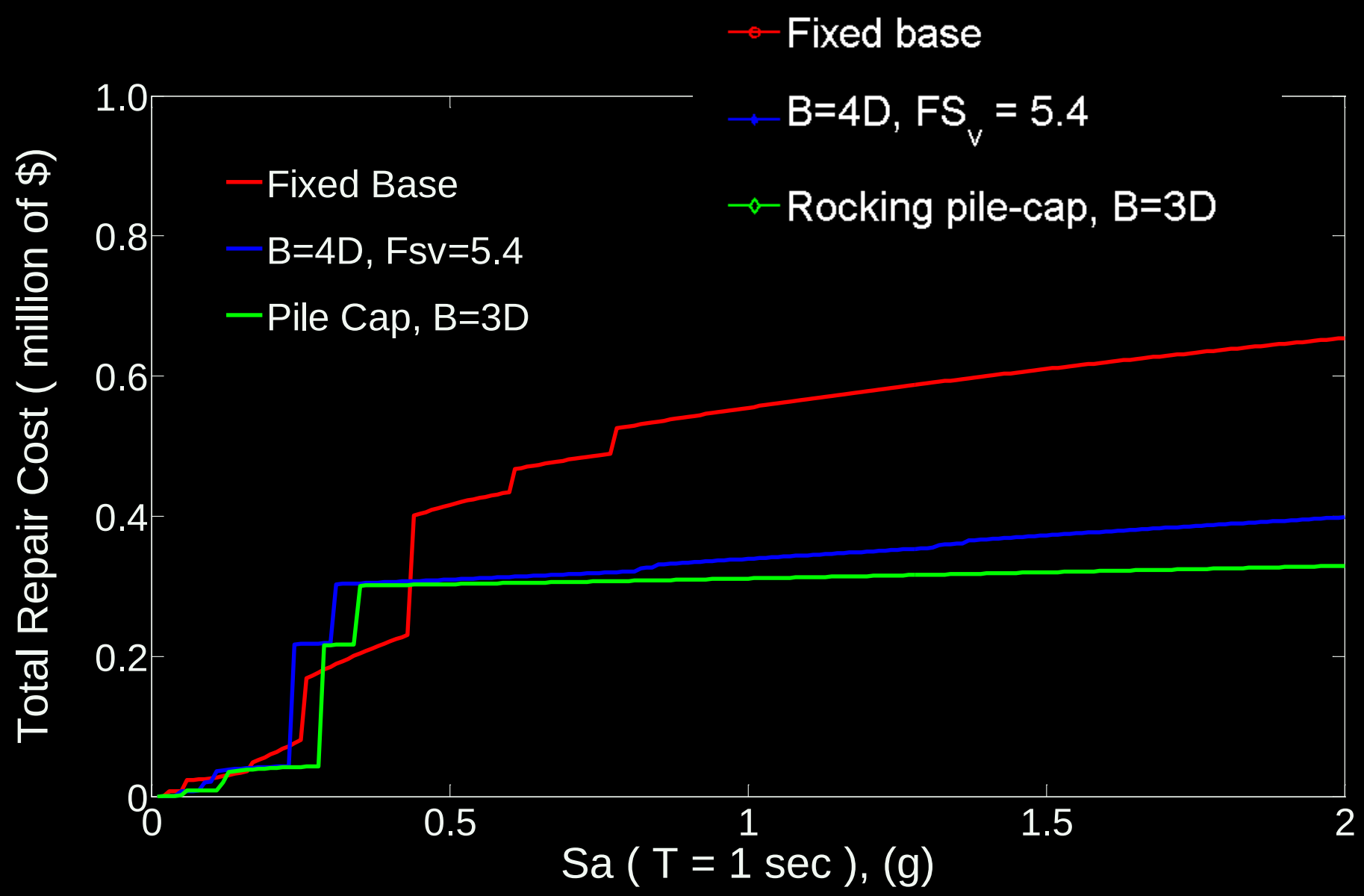
Marios Panagiotou
Assistant Professor,
University of California, Berkeley

"Fixed" base pier

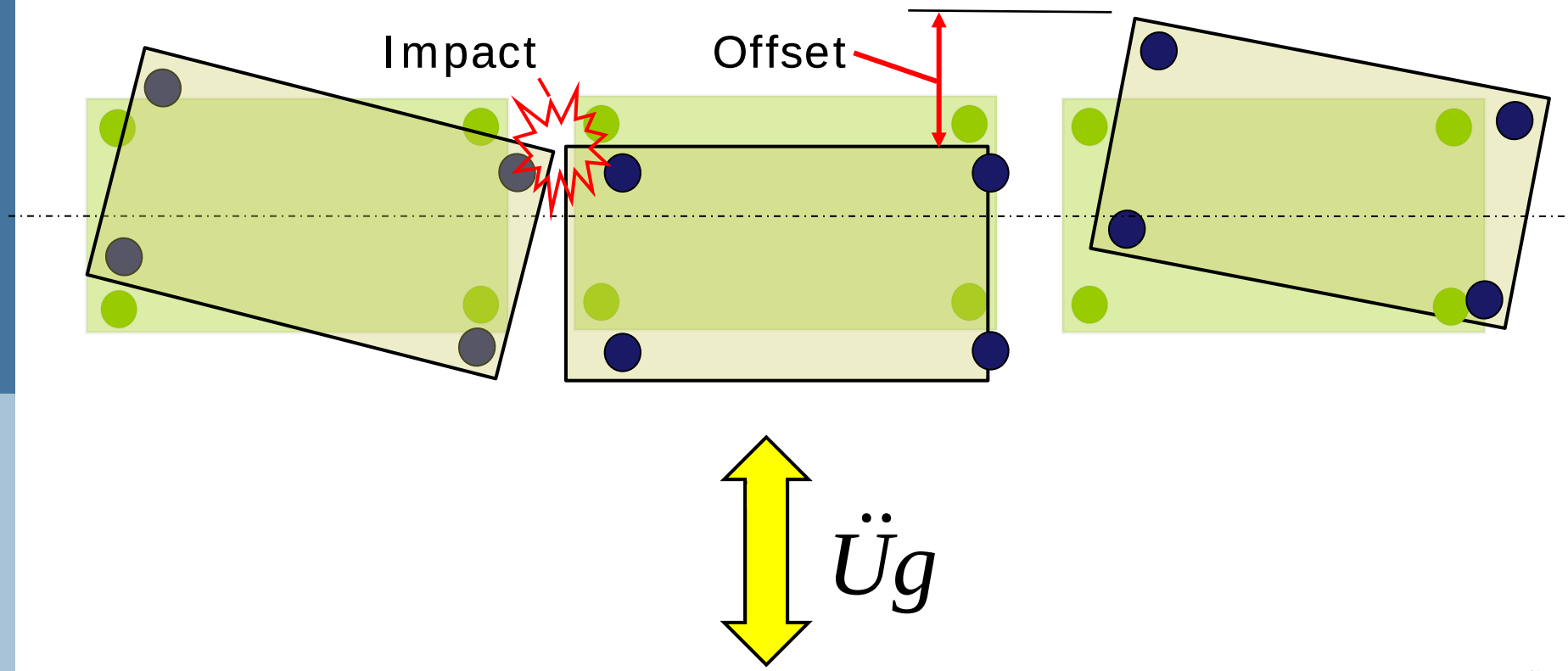
*Pier on **rocking** shallow foundation*



Median Total Repair Cost

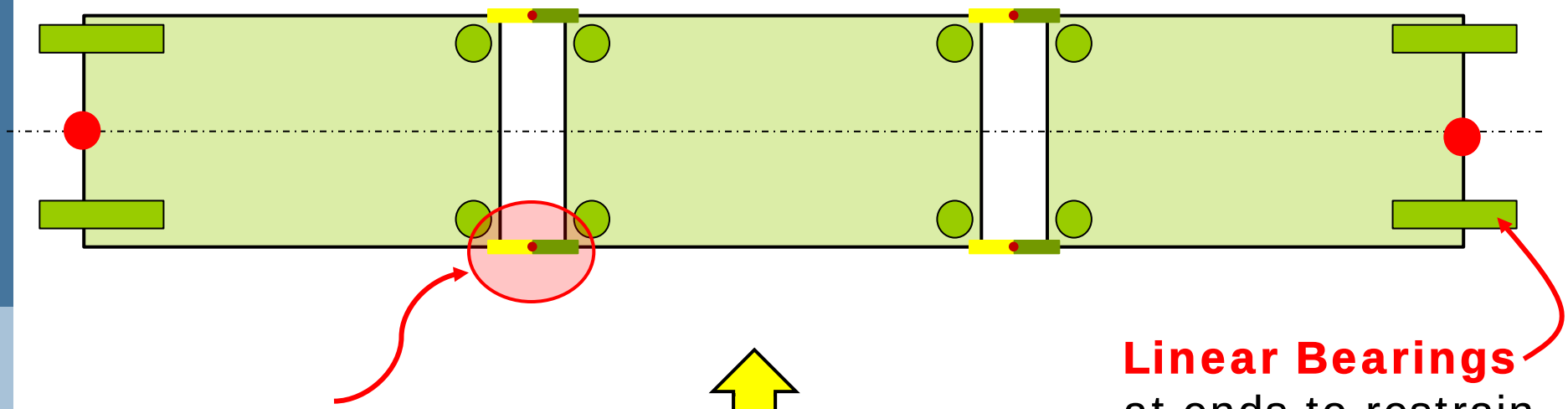


Isolation of Segmented Bridges



PLAN VIEW

Segmental Displacement Control



Lock-Up Guides to retrain relative transverse displacement of segments

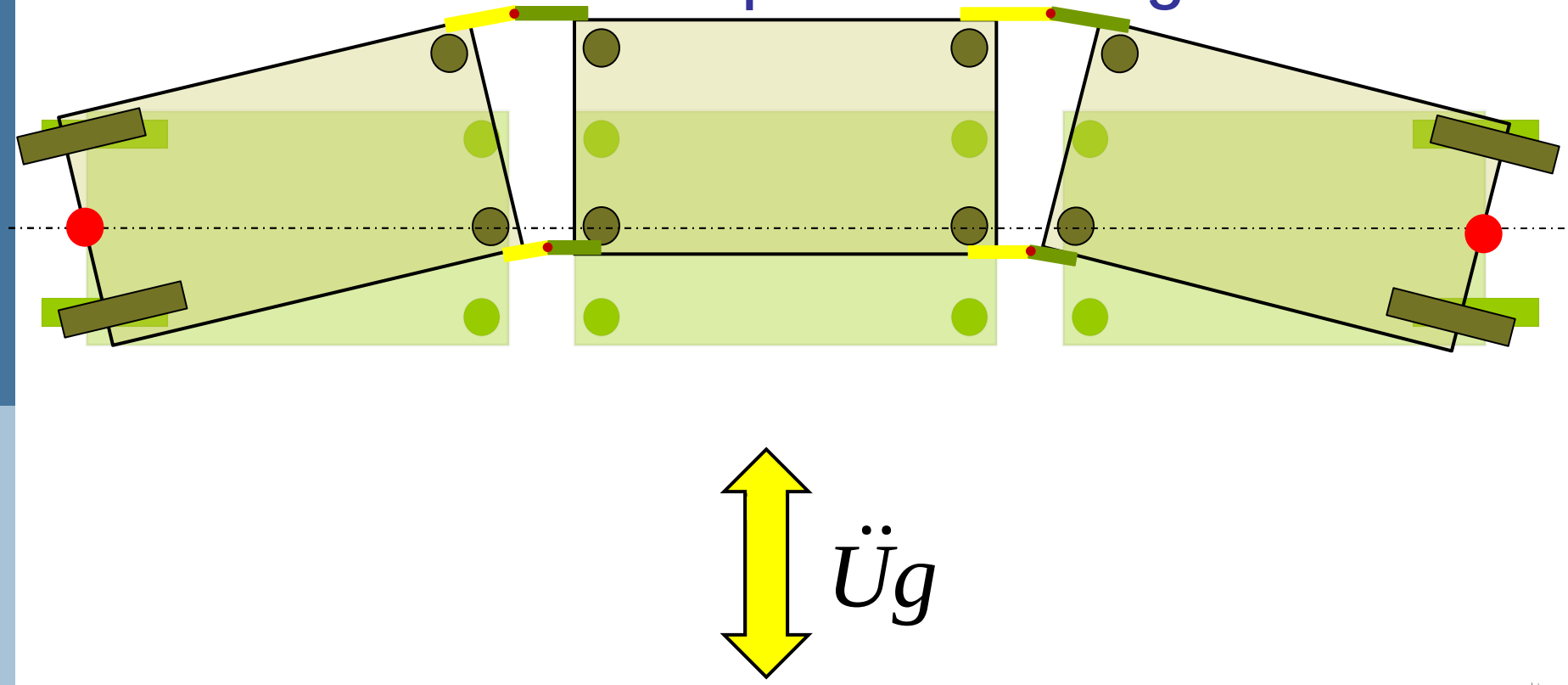
$\ddot{U}g$

Linear Bearings at ends to restrain transverse displacement at abutments

PLAN VIEW

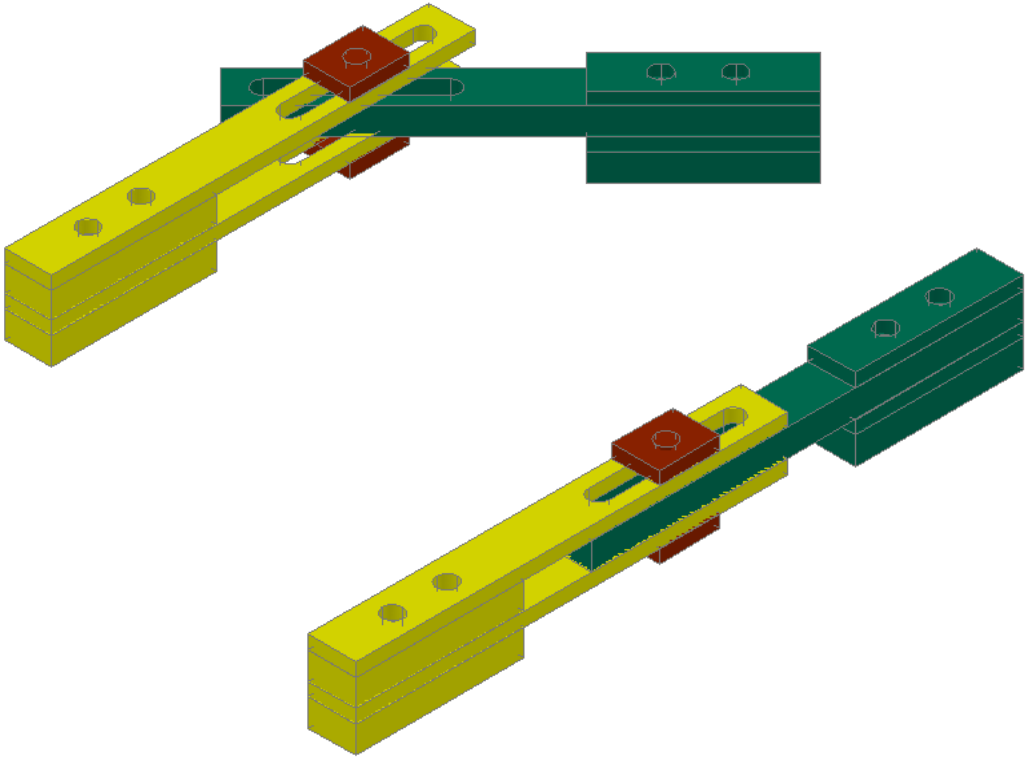
Segmental Displacement Control

- Isolated bridge with relative lateral restraint of independent segments



Segmental Displacement Control

- Lock-Up Guide



Test Observations

PEER

Concluding Remarks

- PBEE has transformed bridge engineering culture.
- In process of transforming standard practice
- Transportation System Research Program (TSRP) focused on developing/validating
  - Enabling Technologies
  - New resilient and sustainable systems.
- PLEASE PARTICIPATE IN TSRP SESSIONS TOMORROW.

PEER