Bridge PBEE Overview & Pilot Next Generation Bridge Studies

Kevin Mackie – Central Florida

BozidarStojadinovic – UC Berkeley

AdyAviram – UC Berkeley

PEER Annual Meeting
San Francisco, CA
2009/10/15

Next Generation Bridges

- “Bridges of the future” -- FHWA
  - Longer service life (100 years)
  - Accelerated construction
  - Easily widened or adapted
  - Reduced life-cycle costs
  - Reduced vulnerability to extreme hazards
  - Constructability and maintenance important in design considerations
- From Caltrans perspective
  - Equal or less vulnerable than current design
  - Inclusive of large portion of bridge inventory

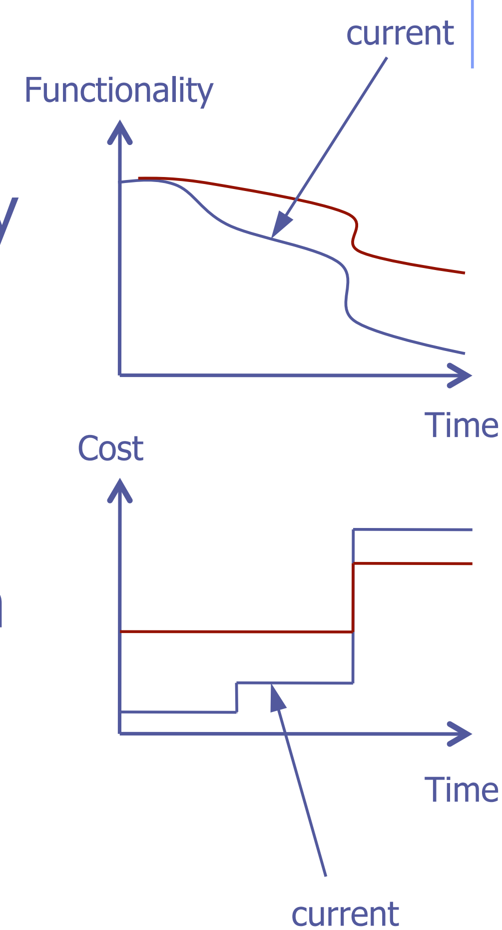
Next Generation Bridge Workshop

- Held Aug. 24 with PEER researchers
- Review of major topics:

1) Performance goals and objectives for next generation of bridges
2) Characteristics of next generation systems (materials, technologies, etc.)
3) Rumination on next generation testbed(s)

1: Performance objectives

- Current approach: monolithic, CIP, RC or PT bridges
  - Damage assessed in terms of deformations
  - Construction and repair constrained by existing approaches
- Need new measures of resilience
  - Functionality
  - Direct (repair) and indirect cost (down time)
  - Carbon footprint, design speed, etc.
- Measuring new system with old PO -> only incremental gains

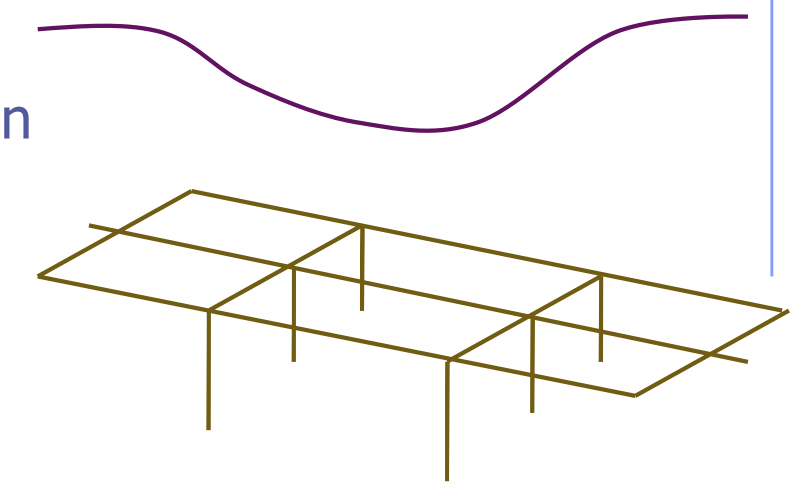


2: NextGen bridge systems

- Focus on common design cases
  - System approach to design (structural + geotechnical)
  - Foundation performance tied to structural performance objectives
  - Ground improvement to attain foundation performance
- Techniques and systems
  - Modular, precast
  - Rocking
  - Base isolation
  - Rocking + modular
  - FRC, ECC, composites, & other materials

3: NextGentestbed(s)

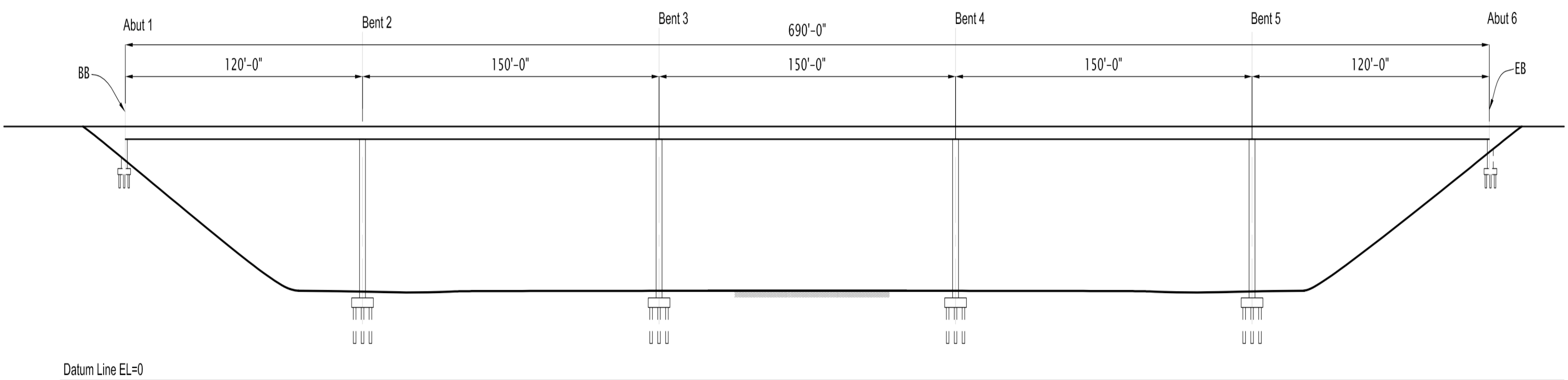
- Boza’s blank box
  - No specified technology or design



- Southern CA permutations
  - Canyon multi-column bent PT
- New modular or base isolated design
- Modification to existing Ketchum testbed
  - Increase column R factor
  - Add in-span hinge and/or longer span(s)
  - Differential column heights
  - Addition of precast components or BI

Previous Overpass Testbed

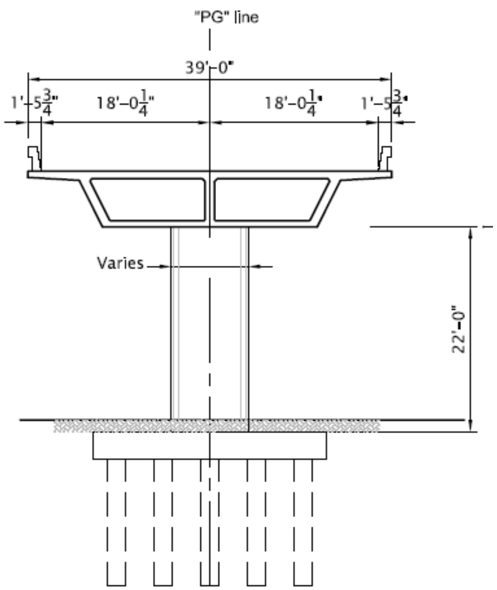
- Bridge characteristics (ala Ketchum)
  - CIP, post-tensioned box girder (Caltrans like)
  - Deck 39 ft wide, 6 ft deep
  - Single column bents
  - Span lengths 120-150x3-120 ft

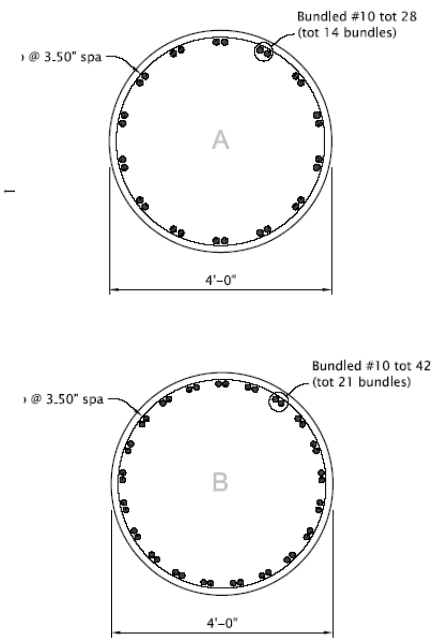


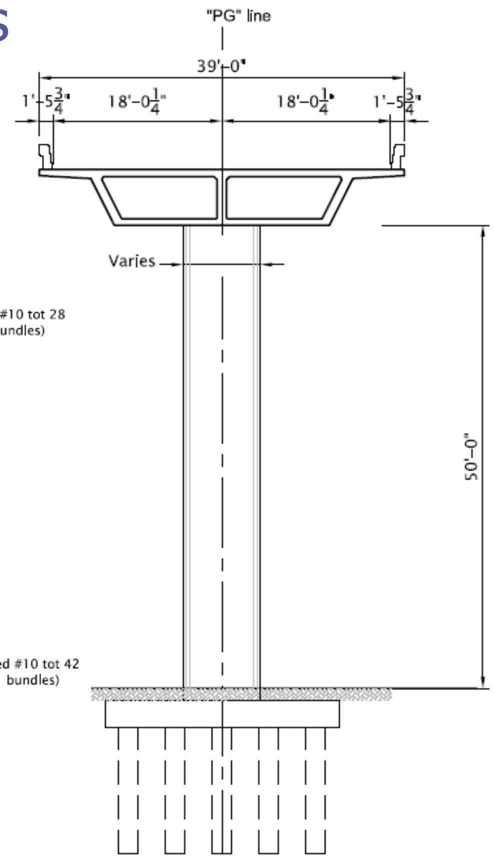
Elevation
Scale: 1"=30'-0"

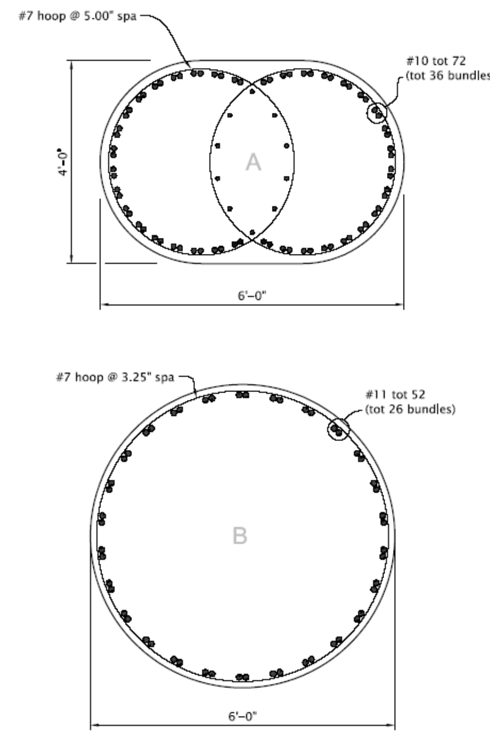
Testbed Bents

- Type 1 (22’) and Type 11 (50’) column height
- Different cross section options









- Type 1
- Type 11

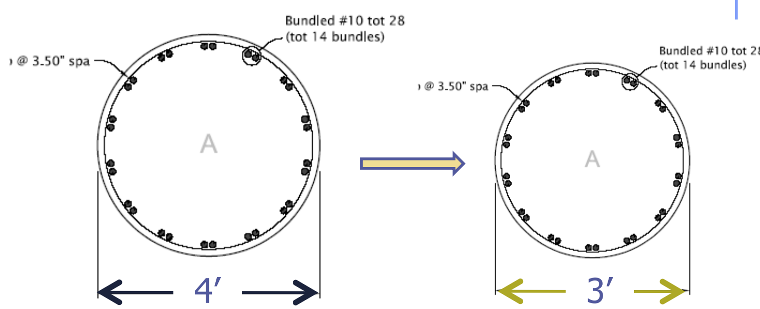
PEER

Pilot Studies on Bridge Systems

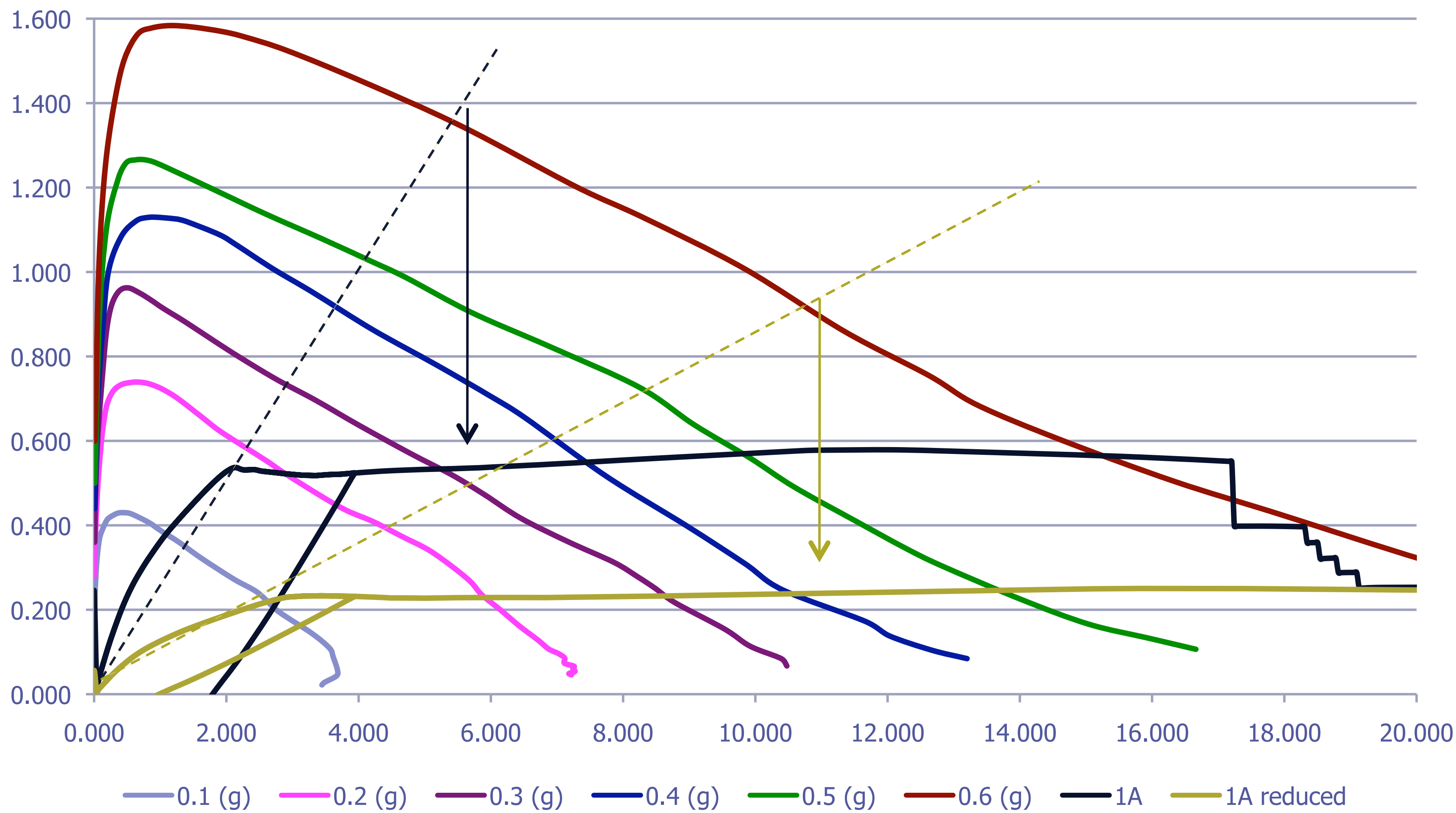
- **Conventionally reinforced concrete (RC) bridge**
  - RC1: Based on Type 1A (Ketchum *et al.* 2004)
  - RC2: Column redesign of RC1
- **Fiber-reinforced concrete (FRC) bridge**
  - Fiber-reinforced bridge pier to replace Type 1A
  - Special reinforcement details in the plastic hinge zone
  - Relaxed transverse reinforcement
- **Seismically isolated (BI) bridge**
  - Lead rubber bearings beneath superstructure
  - BI1: isolators designed -> elastic column behavior
  - BI2: isolators stiffer -> potential inelastic column behavior
- **Modular columns and bent frames**
  - Dry joints, pre-cast column segments
  - Post-tensioned

Modified TestbedBents

- Type 1A and 1A reduced



ARS Soil profile D, M=7.25±0.25



Fiber Reinforced Piers

- Fiber-reinforced bridge pier with 1.5% volume fraction V_f of steel fibers (aspect ratio 80)
- Special reinforcement details in the plastic hinge zone: longitudinal dowels to avoid base cracks and rebar debonding to reduce stress concentration and offset rebar fracture
- Relaxed transverse reinforcement
- Analytical model based on predicted FRC behavior
- Improved model calibrated according to experimental results of two ¼- scale FRC cantilever columns tested at UC Berkeley

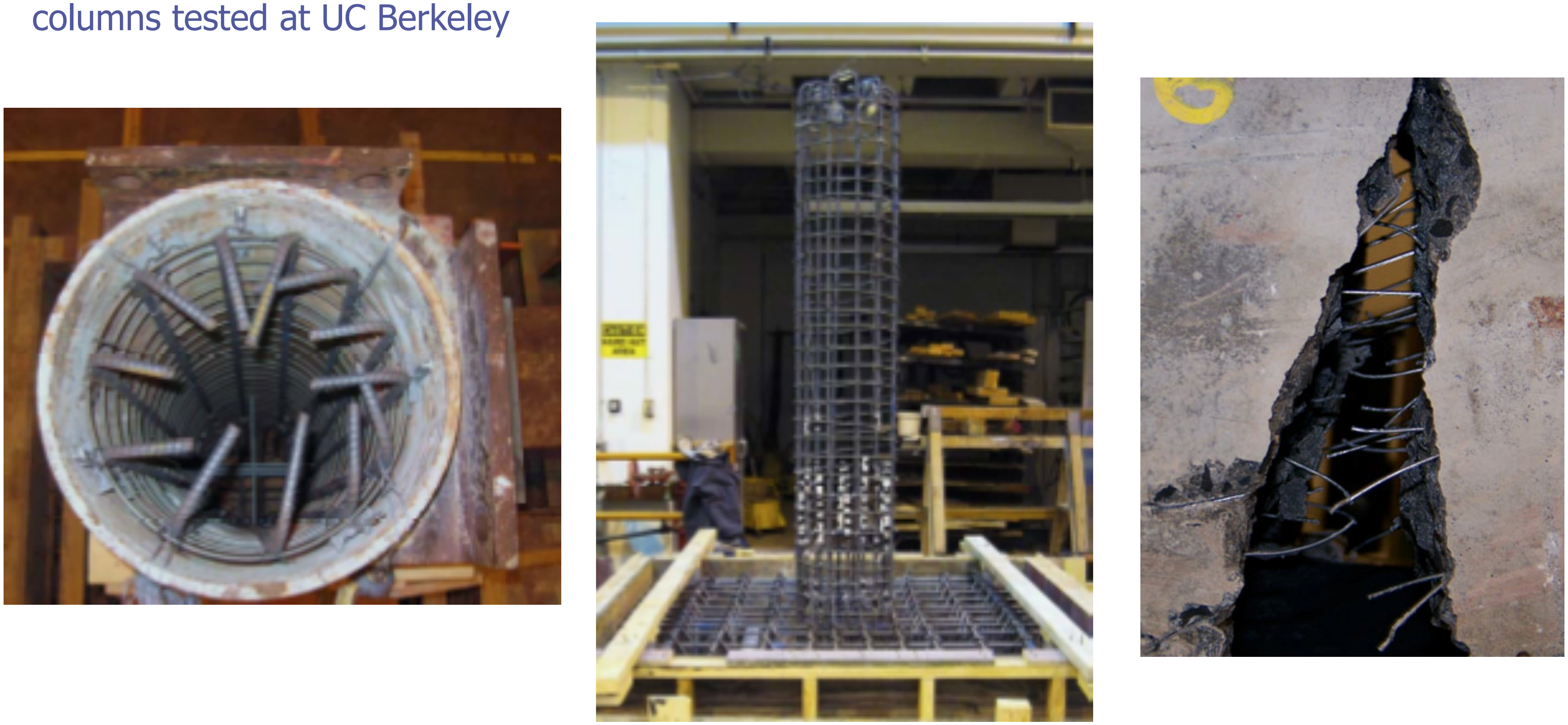


Figure: Details of FRC scale testing cages

Isolated Bridge Systems

- BI1: Elastic column behavior $\mu_d < 1$, $D_c = 5'$, $\rho_l = 3\%$, $\rho_t = 0.16\%$. Isolators: $B_i = 35''$, $H_i = 20''$
- BI2: Inelastic column behavior: $\mu_d < 2$, $D_c = 4.25'$, $\rho_l = 3\%$, $\rho_t = 0.16\%$. Isolators: $B_i = 31.5''$, $H_i = 15''$
- Design based on AASHTO Guide Specifications for Seismic Isolation Design, SDC 2004

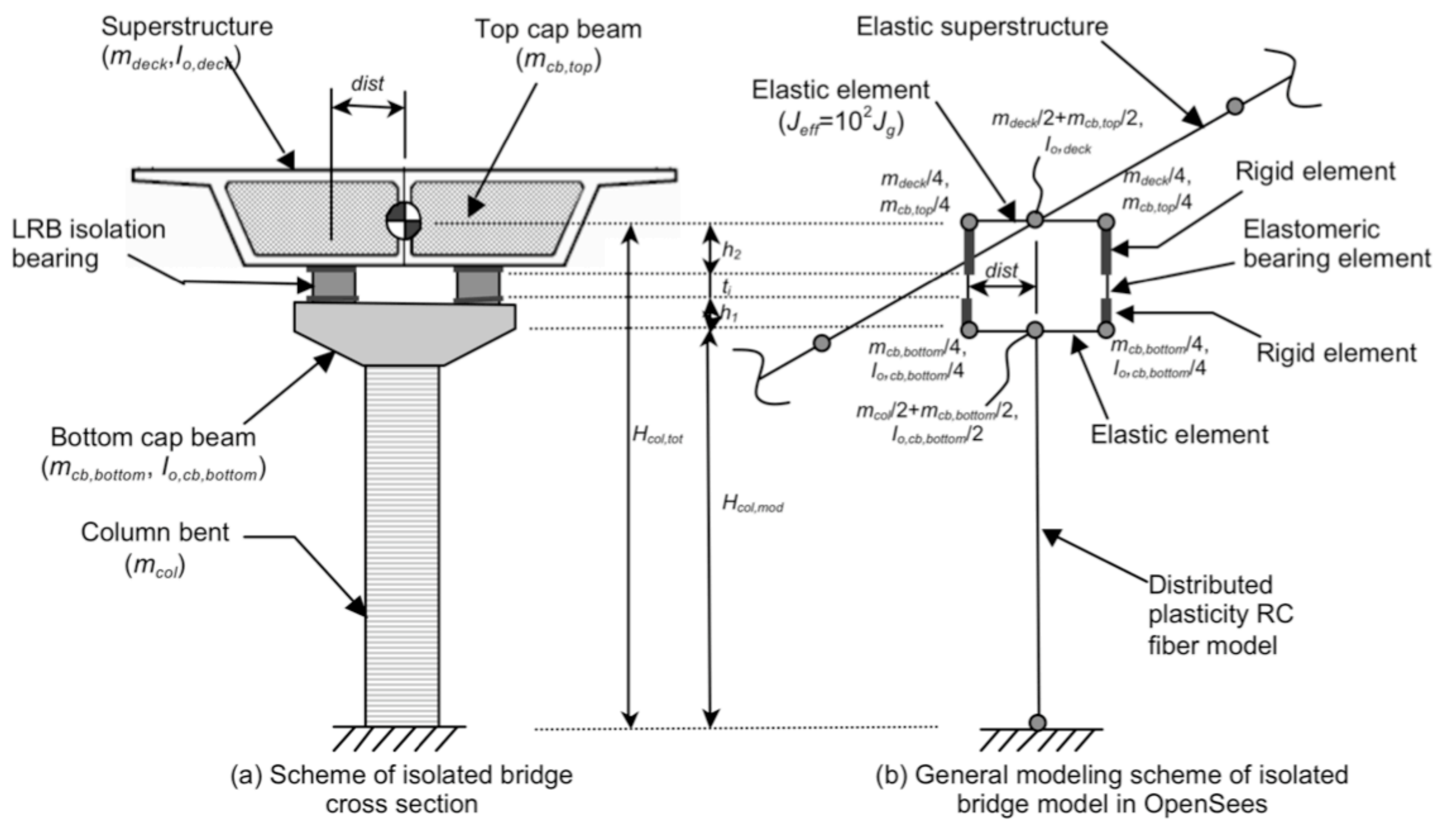


Figure: Details of RC bridge Type 1A with base isolation

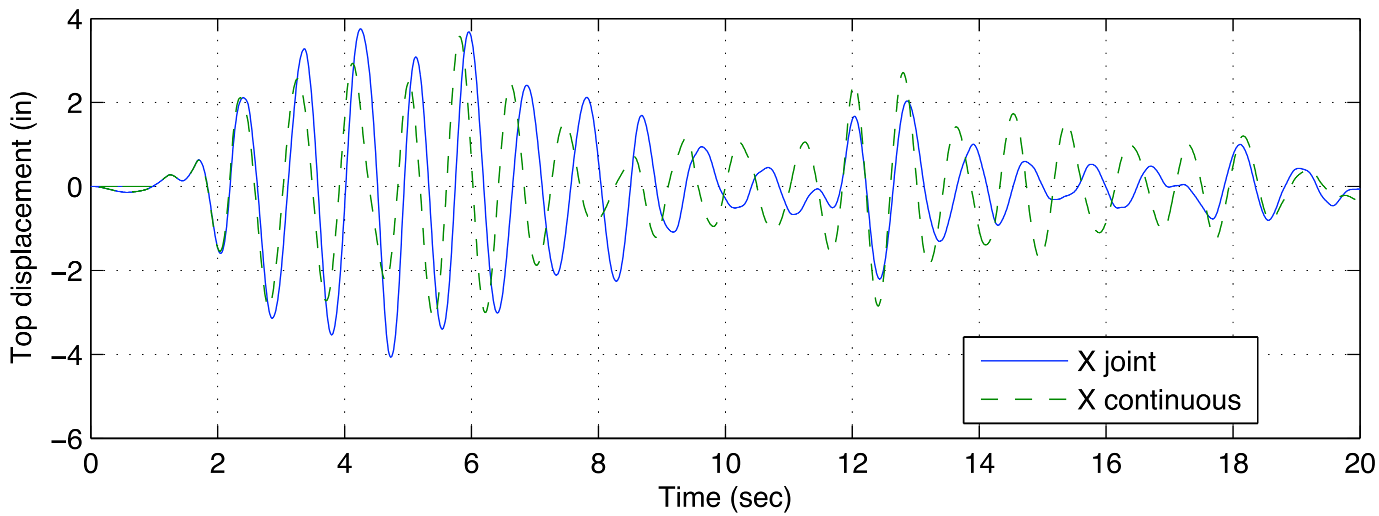
PEER

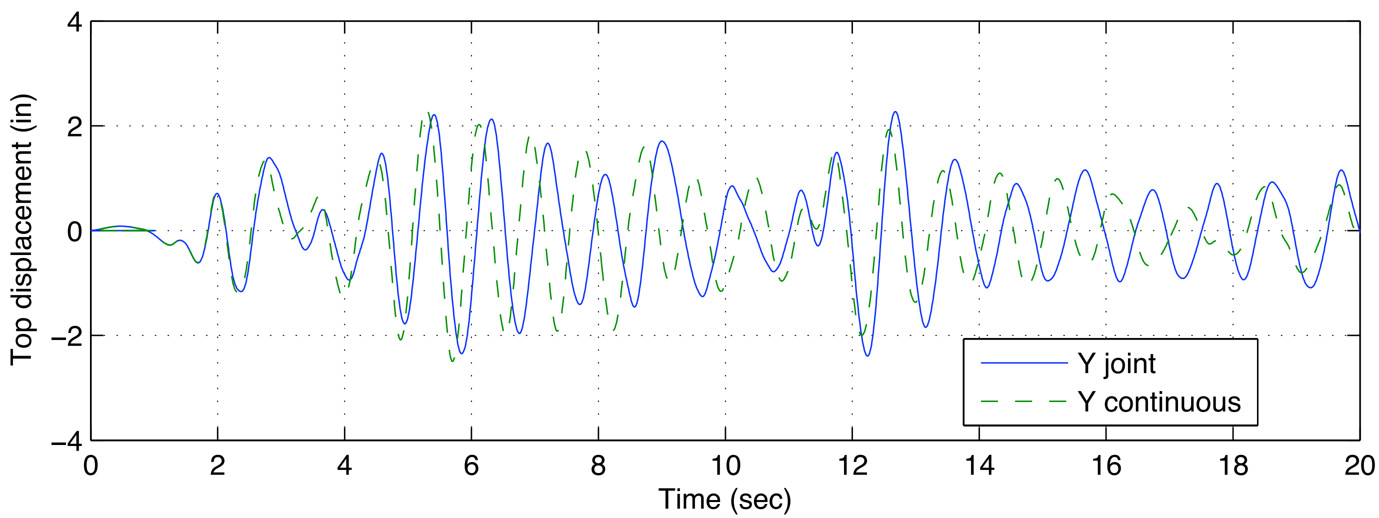
Modular Construction

- Pre-cast segments (column, deck, etc.)
- Dry joints
- Post-tensioning

Modular Construction

- Dry joint vs continuous column comparison





New Construction Costs

Table: New construction costs of RC, RC2, FRC, BI1, and BI2 bridges

Item	Total construction cost 2008Q3				
	RC	RC2	FRC	BI1	BI2
Structure excavation (bridge)	$120,769	$120,769	$120,769	$120,769	$120,769
Structure backfill (bridge)	$89,765	$89,765	$89,765	$89,765	$89,765
Furnish piling (Caltrans Ave. Fdn. Cost)	$104,077	$104,077	$104,077	$104,077	$104,077
Drive piling (Caltrans Ave. Fdn. Cost)	$108,243	$108,243	$108,243	$108,243	$108,243
Prestressed cast-in-place concrete	$294,647	$294,647	$294,647	$294,647	$294,647
Structural concrete, bridge footing	$46,677	$46,677	$46,677	$46,677	$46,677
Structural concrete, bridge	$1,651,188	$1,636,312	$1,651,188	$1,719,376	$1,705,788
Joint seal (type B-MR 2”)	$9,919	$9,919	$9,919	$9,919	$9,919
Bar reinforcing steel	$453,639	$440,608	$450,446	$492,687	$485,649
Concrete barrier (type 732)	$80,517	$80,517	$80,517	$80,517	$80,517
Steel fibers	$0	$0	$17,069	$0	$0
Lead rubber bearing isolators	$0	$0	$0	$449,056	$264,535
Subtotal	**$2,959,441**	**$2,931,534**	**$2,973,316**	**$3,515,733**	**$3,310,586**
Percent increase wrt’ RC bridge (%)	**0**	**-0.9**	**0.5**	**18.8**	**11.9**
Superstructure cost	~$2490k				
Foundation cost	~$259k				
Earthworks	~$210k				

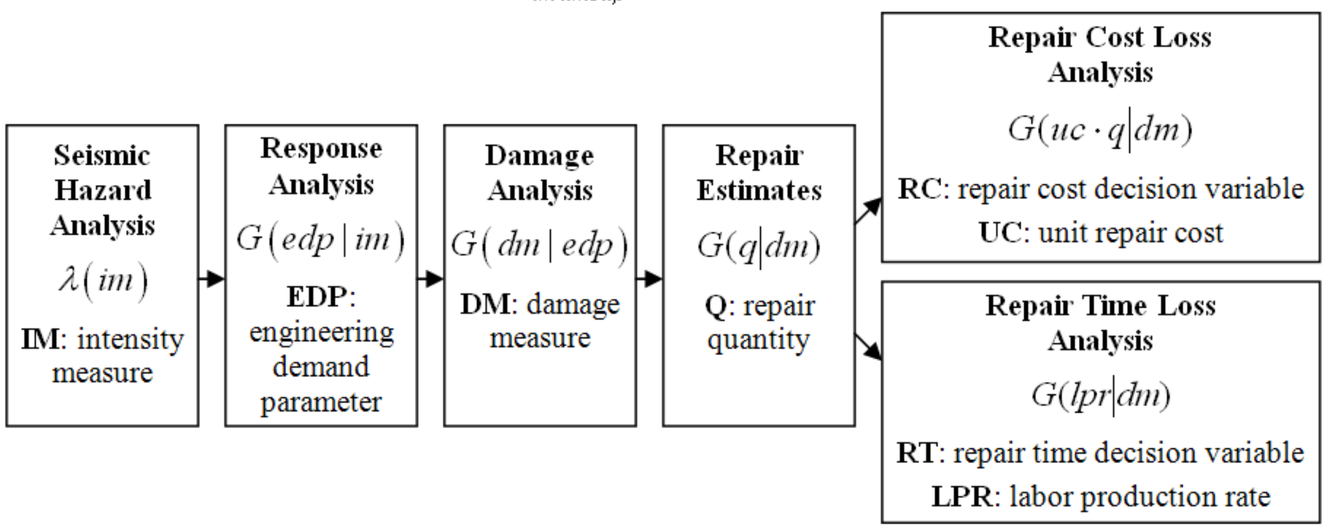
PEER

Post-Earthquake Repair Costs & Time

Figure: Schematic procedure for the LLRCAT methodology

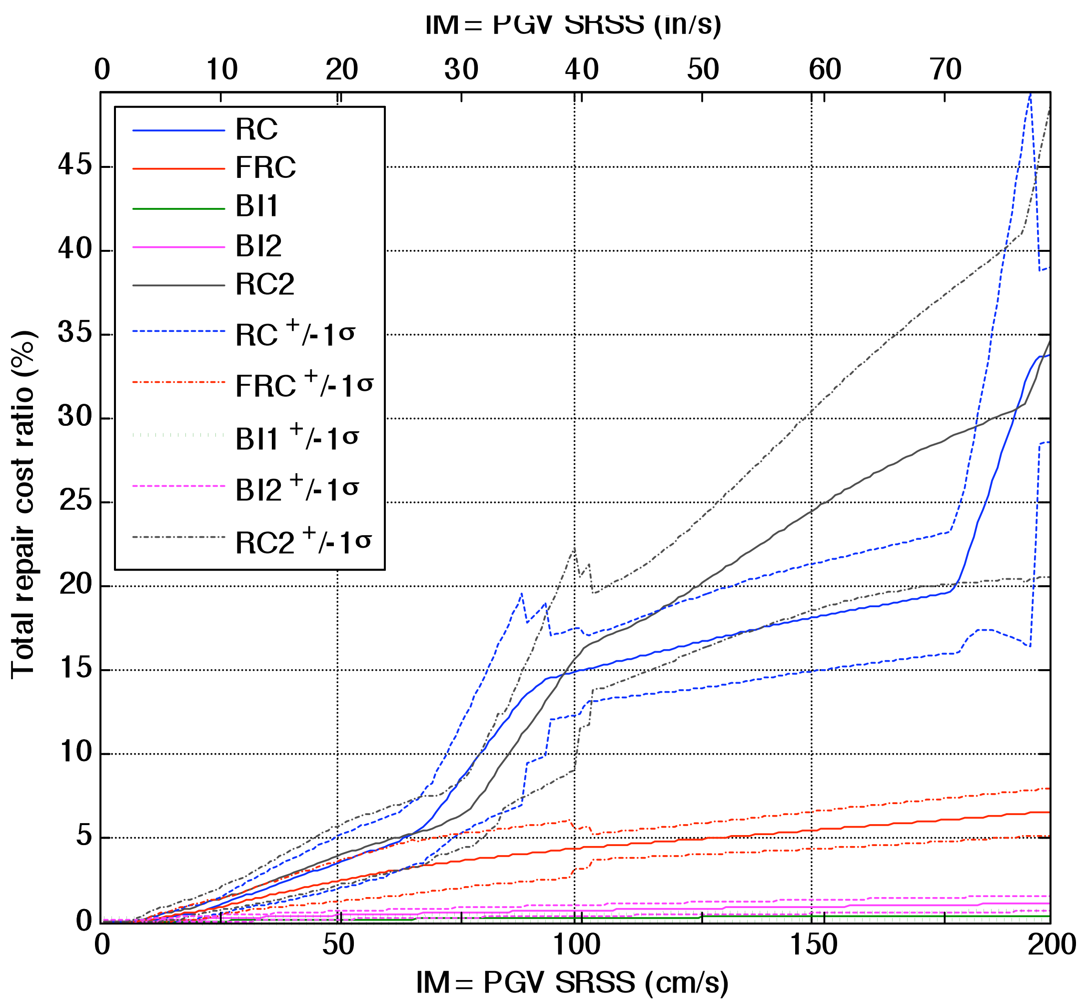
Repair cost: $$\lambda(RC > rc) = \int_{im}\int_{dm}\int_{edp} G(uc \cdot dq|dm)\,dG(dm|edp)\,dG(edp|im)\,|d\lambda(im)|$$

Repair time: $$\lambda(RT > rt) = \int_{im}\int_{dm}\int_{edp} G(lpr|dm)\,dG(dm|edp)\,dG(edp|im)\,|d\lambda(im)|$$



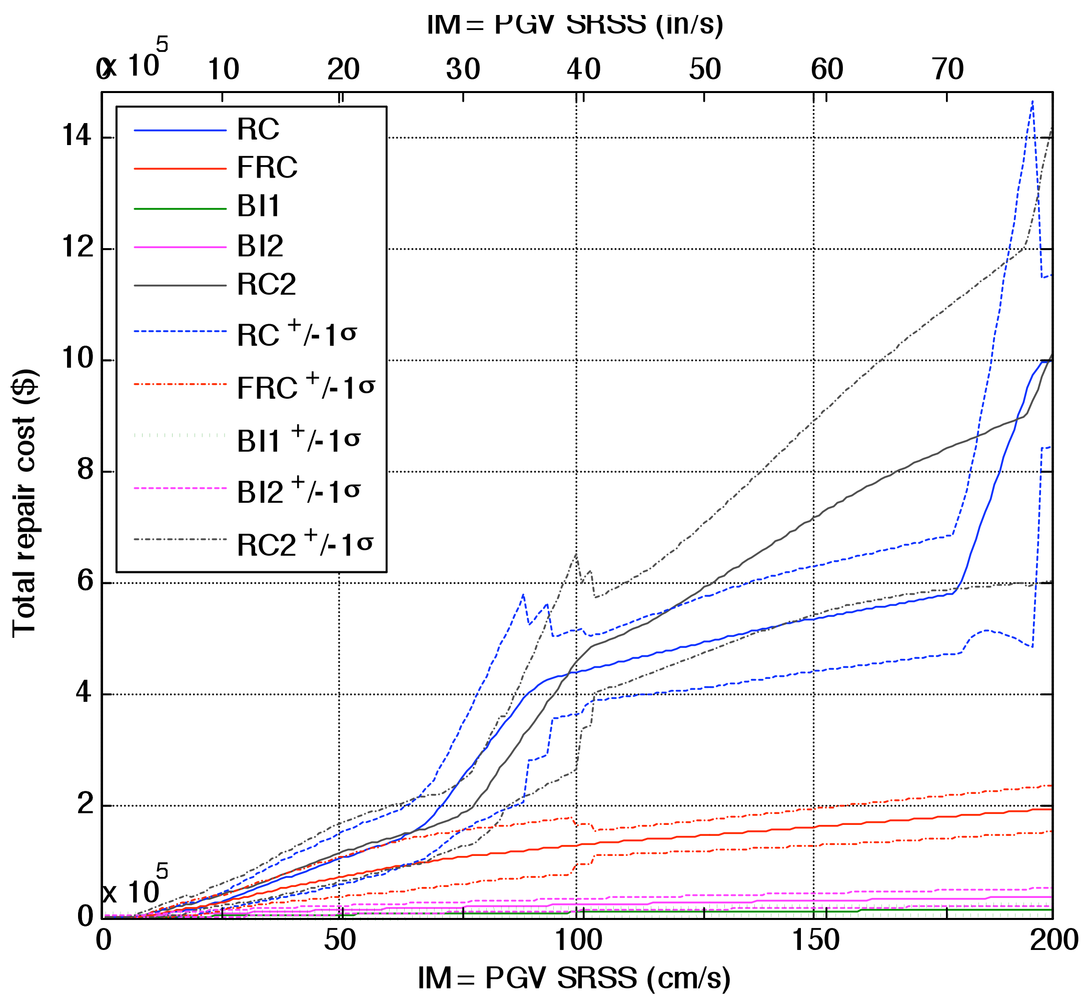
Post-Earthquake Repair Cost Ratio

Figure: Repair cost ratio loss model for different bridge types as a function of earthquake intensity



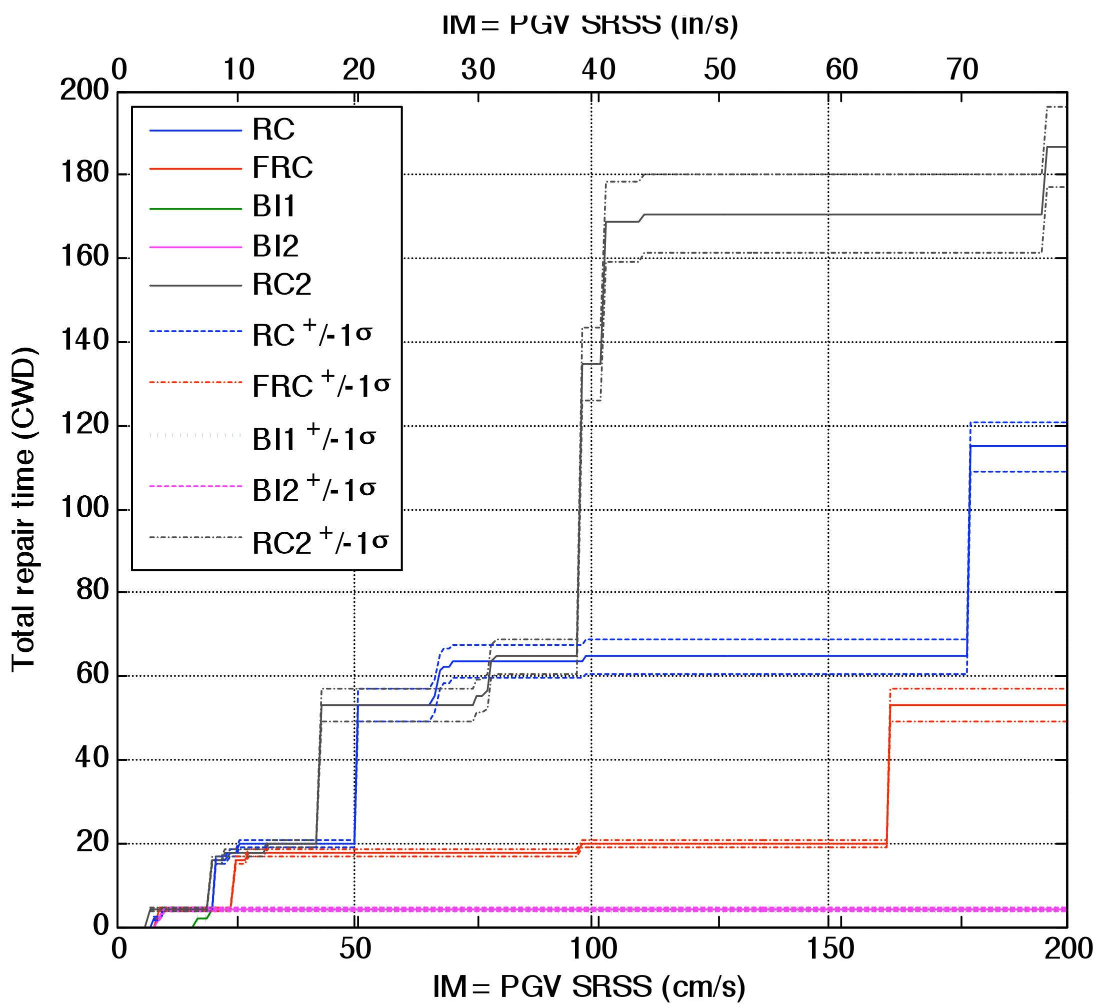
Post-Earthquake Repair Costs

Figure: Total repair cost loss model for different bridge typesas a function of earthquake intensity



Post-Earthquake Repair Time

Figure: Total repair time (effort) loss model for different bridge types as a function of earthquake intensity



Cost-Effectiveness of Bridge Systems

Table: Total cost of different bridge types (discount rate *i*=2-8%, annuity growth rate *g*=3%)

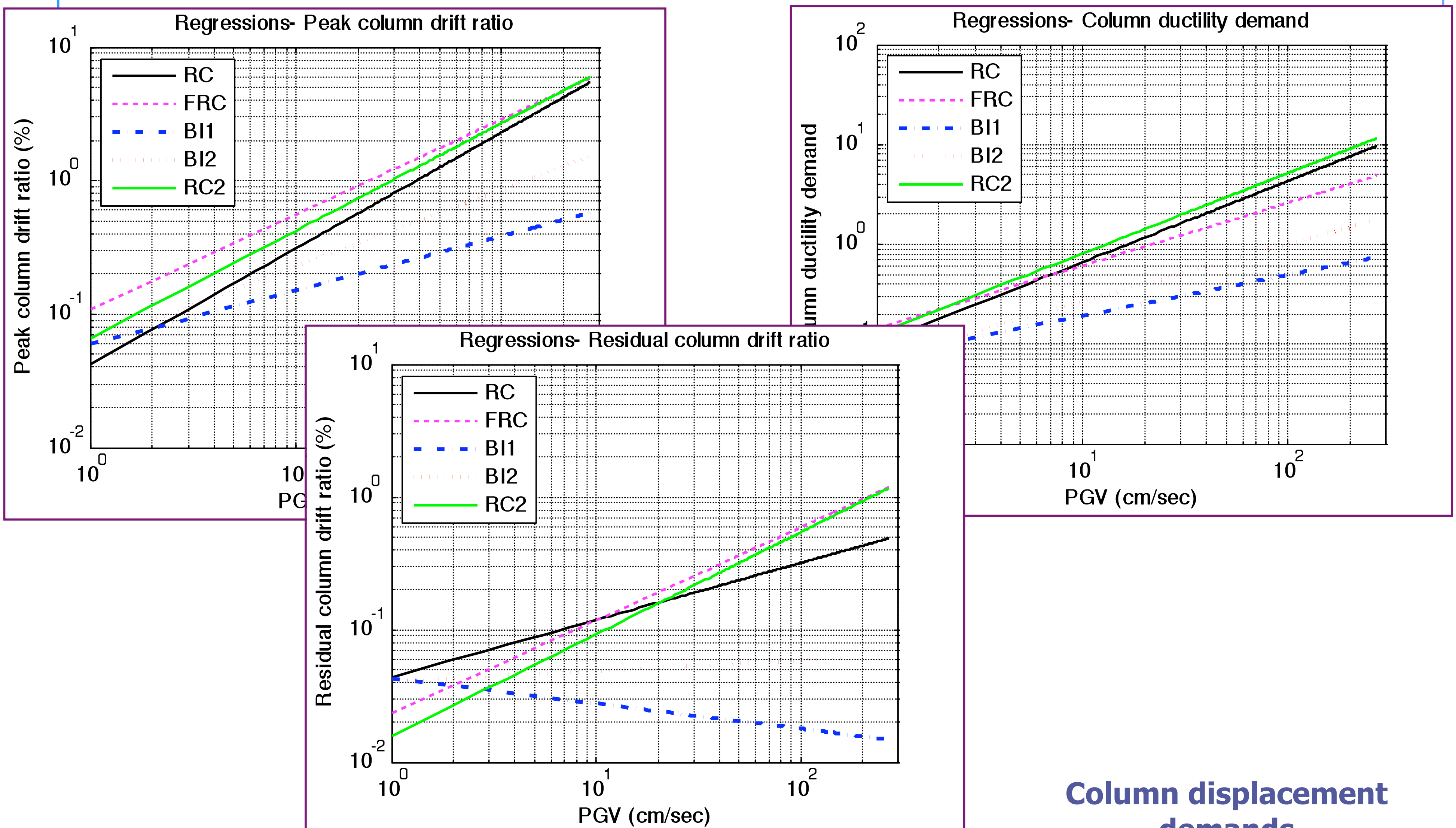
Cost	Bridge type				
	RC	RC2	FRC	BI1	BI2
New construction	$2,959,441	$2,931,354	$2,973,316	$3,515,733	$3,310,586
Post-EQ Repair (1 yr)	$17,154	$24,816	$15,739	$989	$4,388
Total EQ-repair, *i*=2%, *g*=3%	$1,850,297	$2,676,749	$1,697,669	$106,677	$473,307
Total EQ-repair, *i*=8%, *g*=3%	$333,276	$482,137	$305,785	$19,215	$85,252
Total (75 years), *i*=2%, *g*=3%	$4,809,738	$5,608,103	$4,670,985	$3,622,410	$3,783,893
Total (75 years), *i*=8%, *g*=3%	$3,292,717	$3,413,491	$3,279,101	$3,534,948	$3,395,838
Δ- Difference wrt' RC, *i*=2%, *g*=3%	**0%**	**16.6%**	**-2.9%**	**-24.7%**	**-21.3%**
Δ- Difference wrt' RC, *i*=8%, *g*=3%	**0%**	**3.7%**	**-0.4%**	**7.4%**	**3.1%**

Further analysis of total cost-effectiveness and repair efforts of these bridge systems using varying time intervals, discount rates, and growth rates is pending.

Table: Repair time of different bridge types

Time	Bridge type				
	RC	RC2	FRC	BI1	BI2
Repair time (1 yr)	9	10	7	2	4
Repair time (75 yr)	46	61	19	4	4

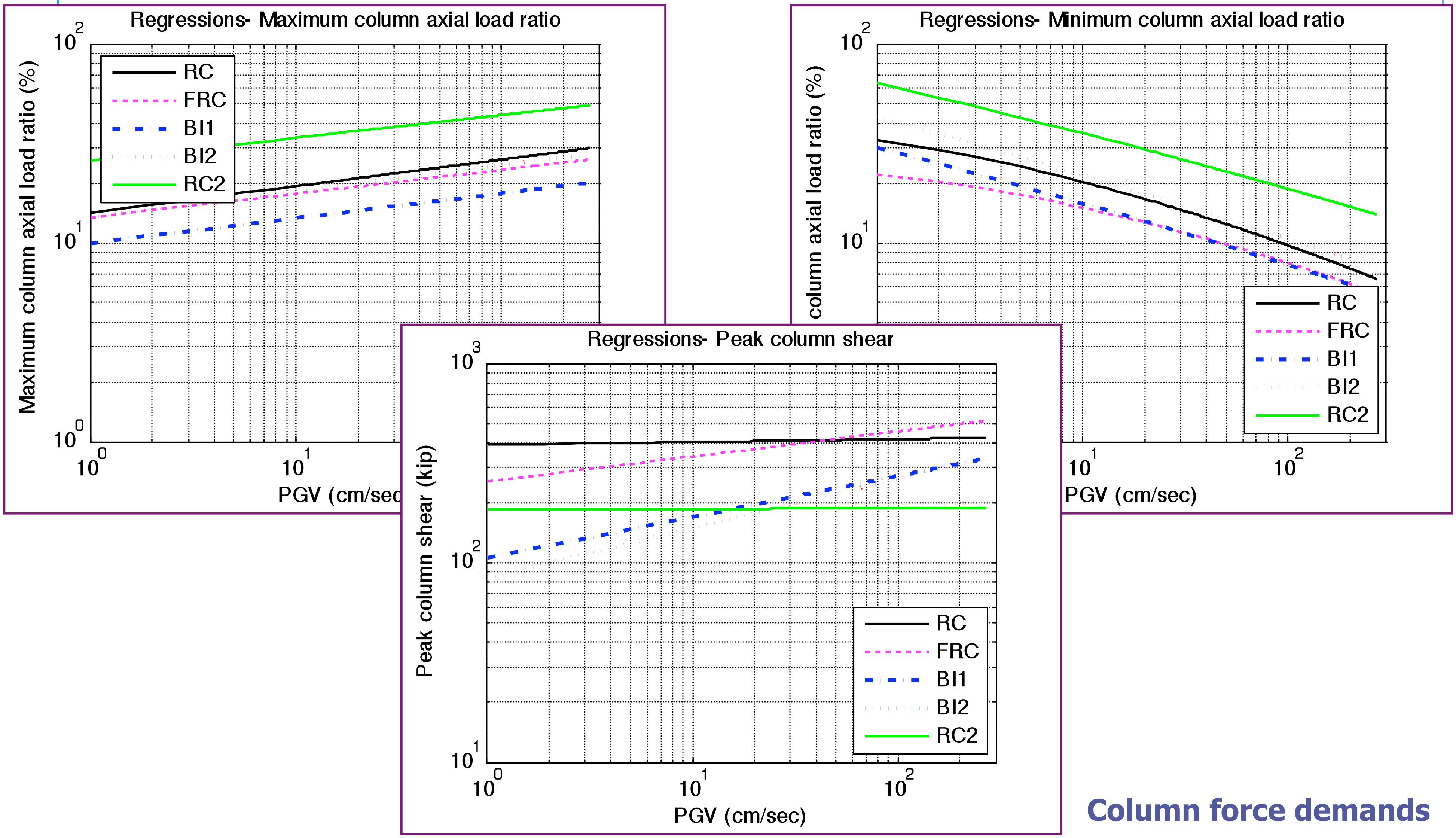
Important EDPs for Bridge Systems



Column displacement demands

PEER

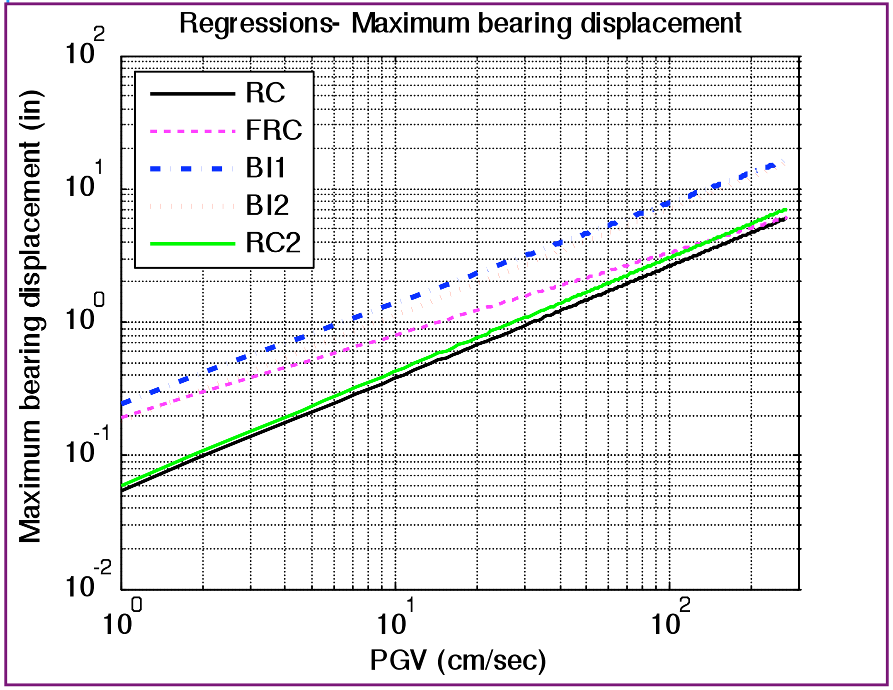
Important EDPs for Bridge Systems

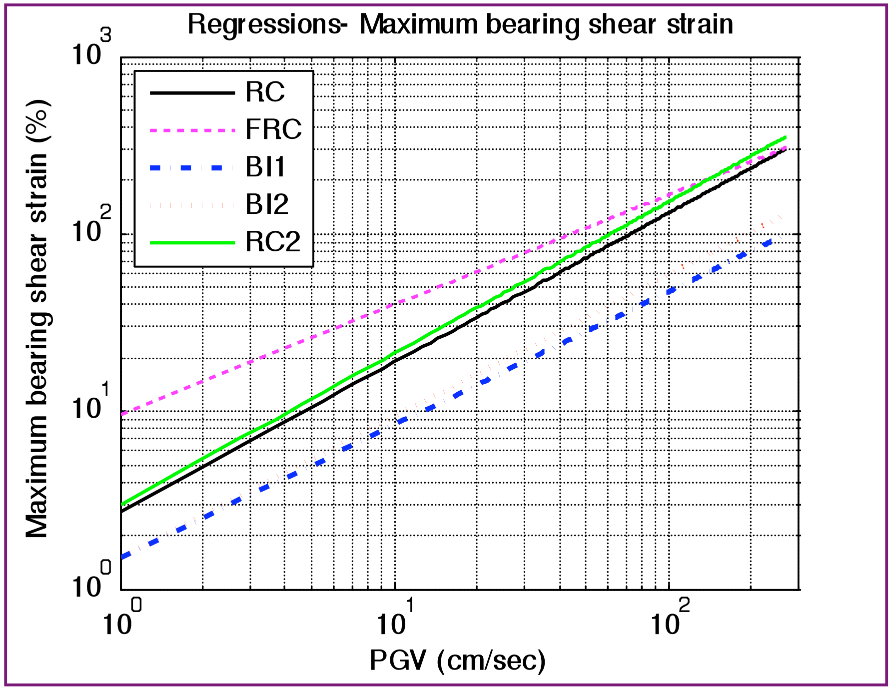


Column force demands

Important EDPs for Bridge Systems

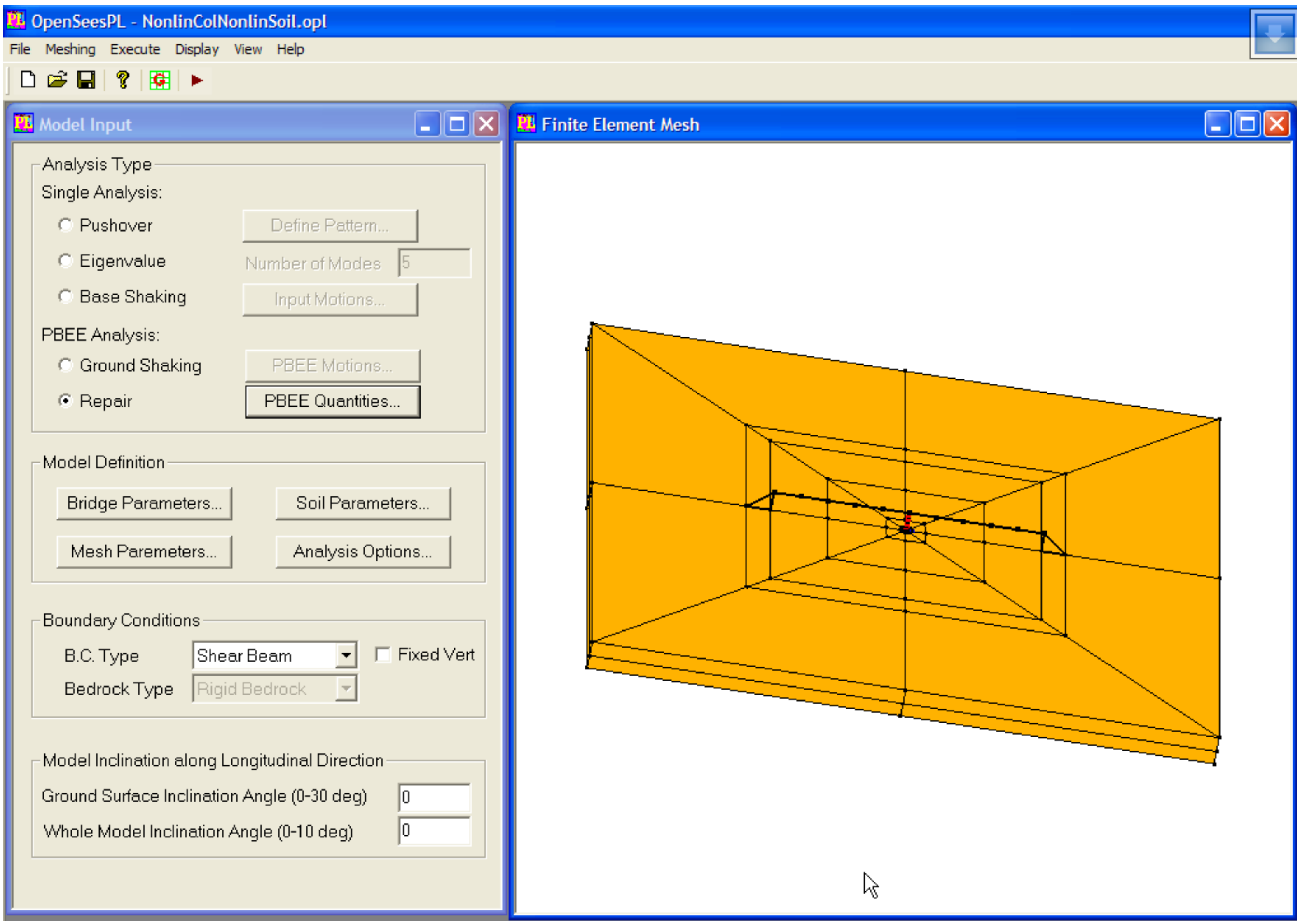
Bearing displacement and shear strain demand



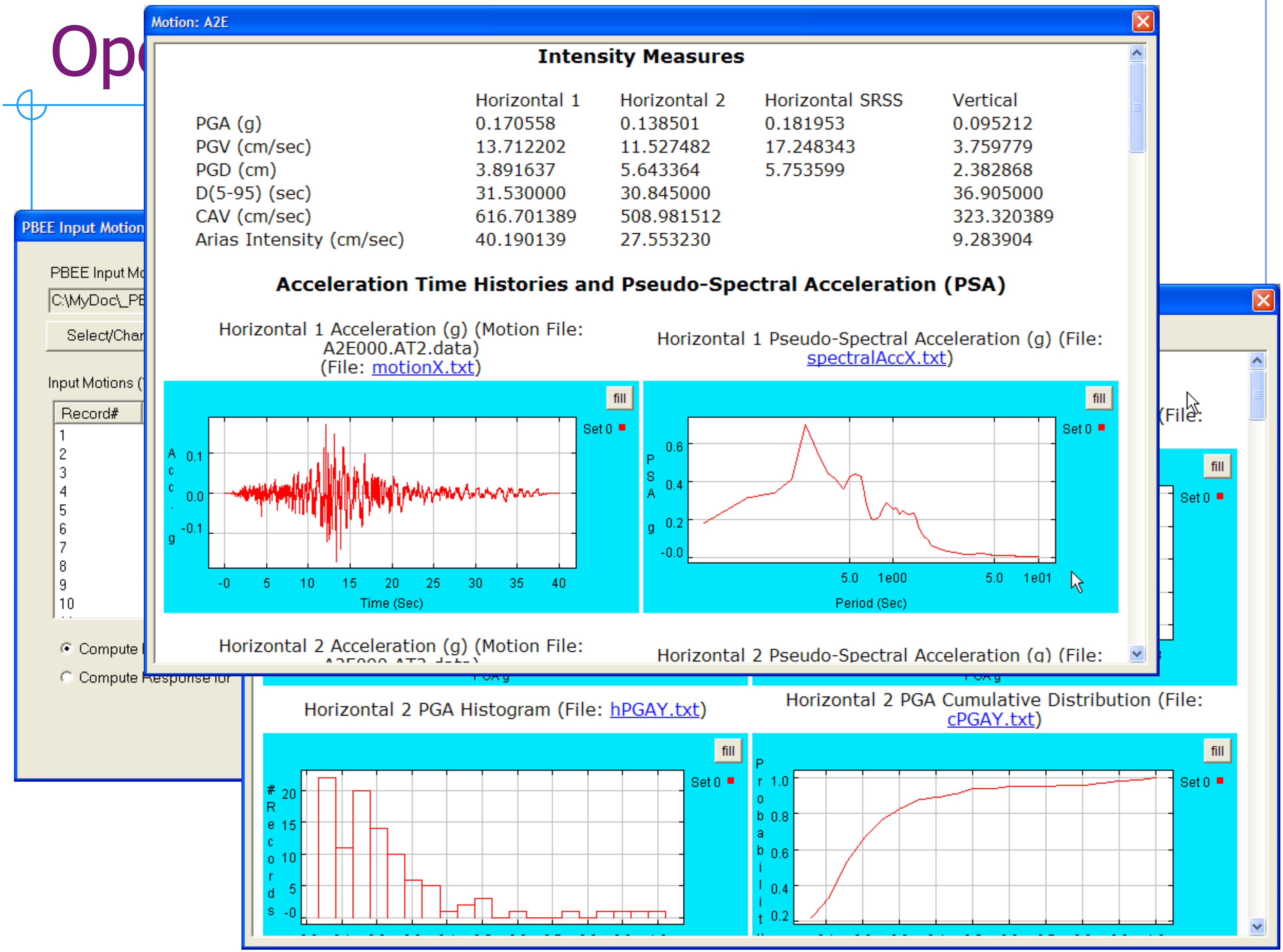


OpenSeesPL*PBEE*

A graphical user interface to bridge PBEE



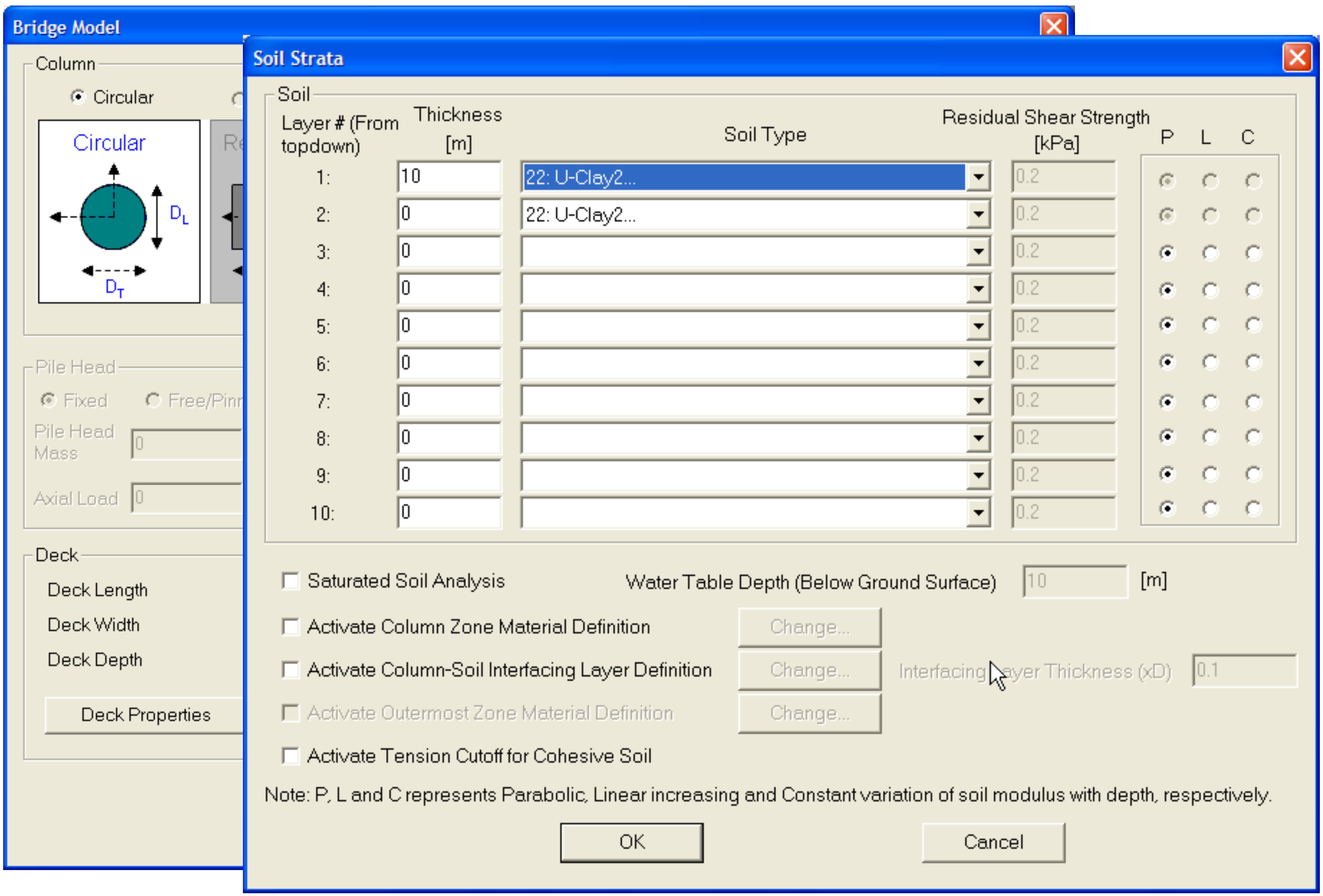
Op



Motion: A2E
Intensity Measures
Horizontal 1 | Horizontal 2 | Horizontal SRSS | Vertical
PGA (g) 0.170558 0.138501 0.181953 0.095212
PGV (cm/sec) 13.712202 11.527482 17.248343 3.759779
PGD (cm) 3.891637 5.643364 5.753599 2.382868
D(5-95) (sec) 31.530000 30.845000 36.905000
CAV (cm/sec) 616.701389 508.981512 323.320389
Arias Intensity (cm/sec) 40.190139 27.553230 9.283904
Acceleration Time Histories and Pseudo-Spectral Acceleration (PSA)
Horizontal 1 Acceleration (g) (Motion File: A2E000.AT2.data) (File: motionX.txt)
Horizontal 1 Pseudo-Spectral Acceleration (g) (File: spectralAccX.txt)
fill
Set 0
Time (Sec)
Period (Sec)
Horizontal 2 Acceleration (g) (Motion File:
Horizontal 2 Pseudo-Spectral Acceleration (g) (File:
PBEE Input Motion
C:\MyDoc_PE
Select/Char
Input Motions (
Record#
Compute
Compute Response for
Horizontal 2 PGA Histogram (File: hPGAY.txt)
Horizontal 2 PGA Cumulative Distribution (File: cPGAY.txt)
Records
Probability

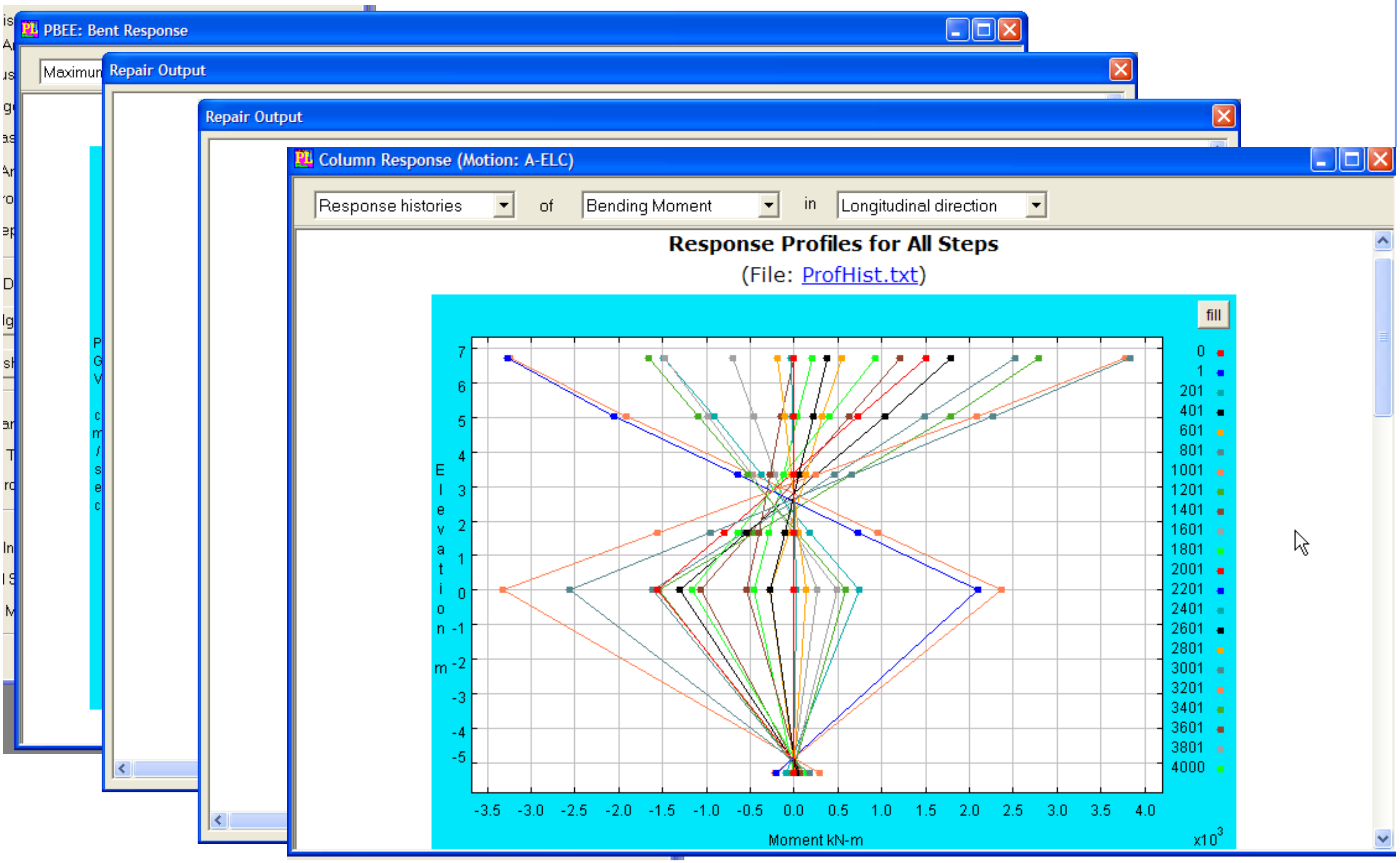
OpenSeesPL*PBEE*

Graphically change bridge and soil properties



OpenSeesPL*PBEE*

Compute and plot demands <u>and</u> losses



PEER

Thank You!

- Please contact:
  - Kevin Mackie: kmackie@mail.ucf.edu
  - BozaStojadinovic: boza@ce.berkeley.edu