Pilot PBEE Studies for Next Generation Bridges

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Next Generation Bridge

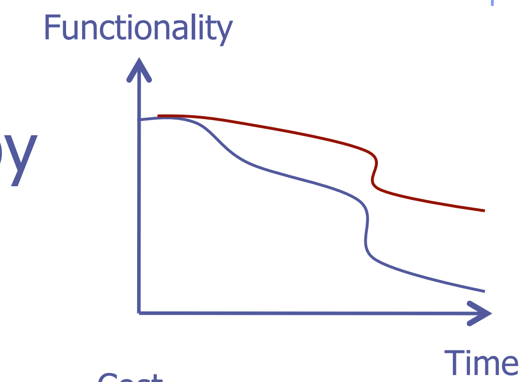
- "Bridges of the future"
  - Longer service life (100 years)
  - Accelerated construction
  - Easily widened or adapted
  - Reduced life-cycle costs
  - Reduced vulnerability to extreme hazards
  - Reduced cost
- From Caltrans perspective
  - Equal or less vulnerable than current design
  - Inclusive of large portion of bridge inventory

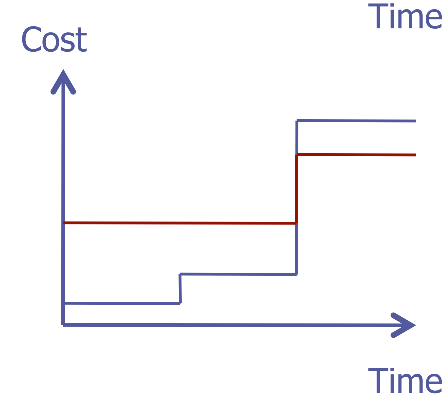
Next Generation Bridge Workshops

- May 20, 2009 with Caltrans engineers
- Aug. 24, 2009 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) Ruminating 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



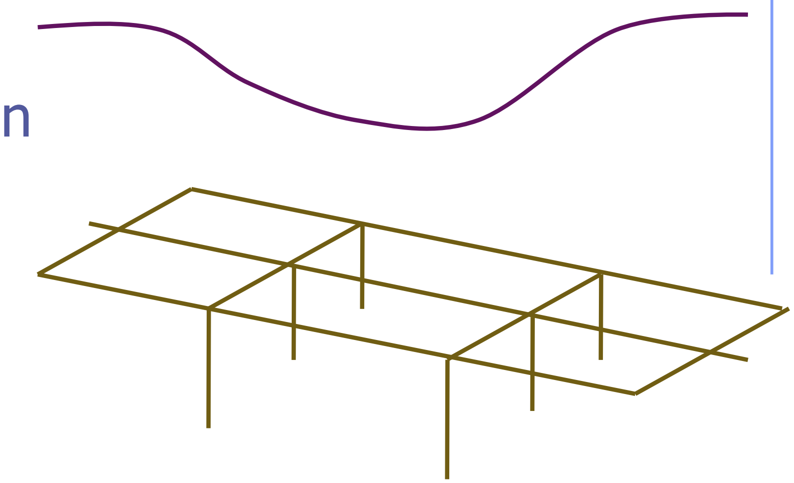


2: NextGen bridge systems

- Focus on system approach
  - Hazards + Structural + Geotechnical + Life-Cycle
  - Foundation performance tied to structural performance objectives
- Techniques and systems
  - Modular, precast
  - Rocking
  - Base isolation
  - Rocking + modular
  - FRC, ECC, composites, & other materials

3: NextGen testbed(s)

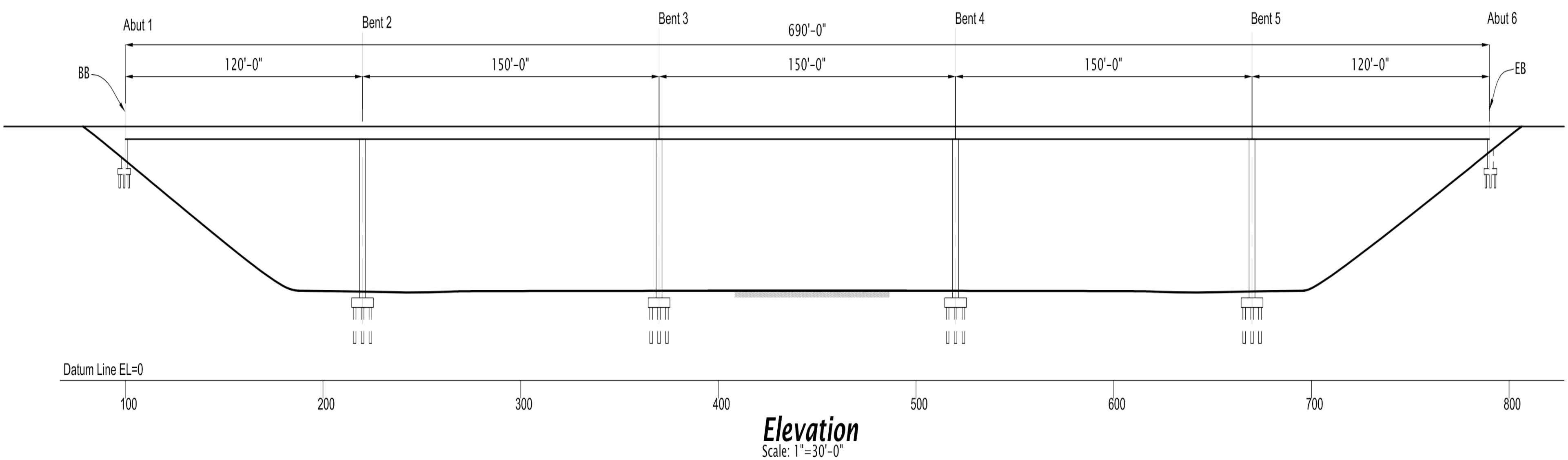
- Boza's blank box
  - No specified technology or design
  - Just cross a valley



- New modular or BI design
- Modification to existing Ketchum testbed
  - Increase column R factor
  - Add in-span hinge and/or longer span(s)
  - Different column heights
  - Precast components
  - Base isolation
  - Rocking (foundations or joints)
  - Multi-column bents

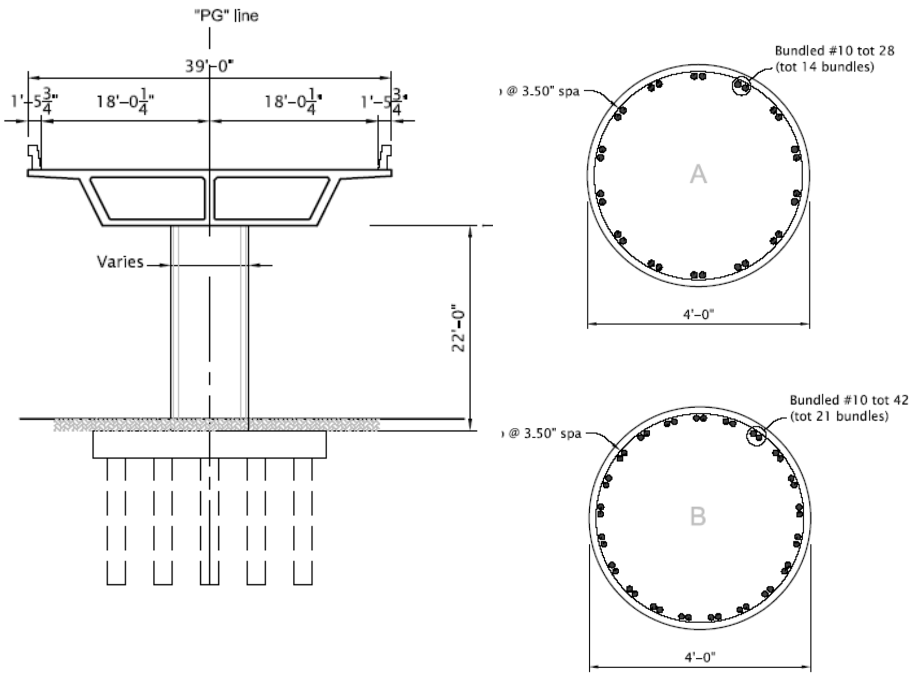
Previous Overpass Testbed

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

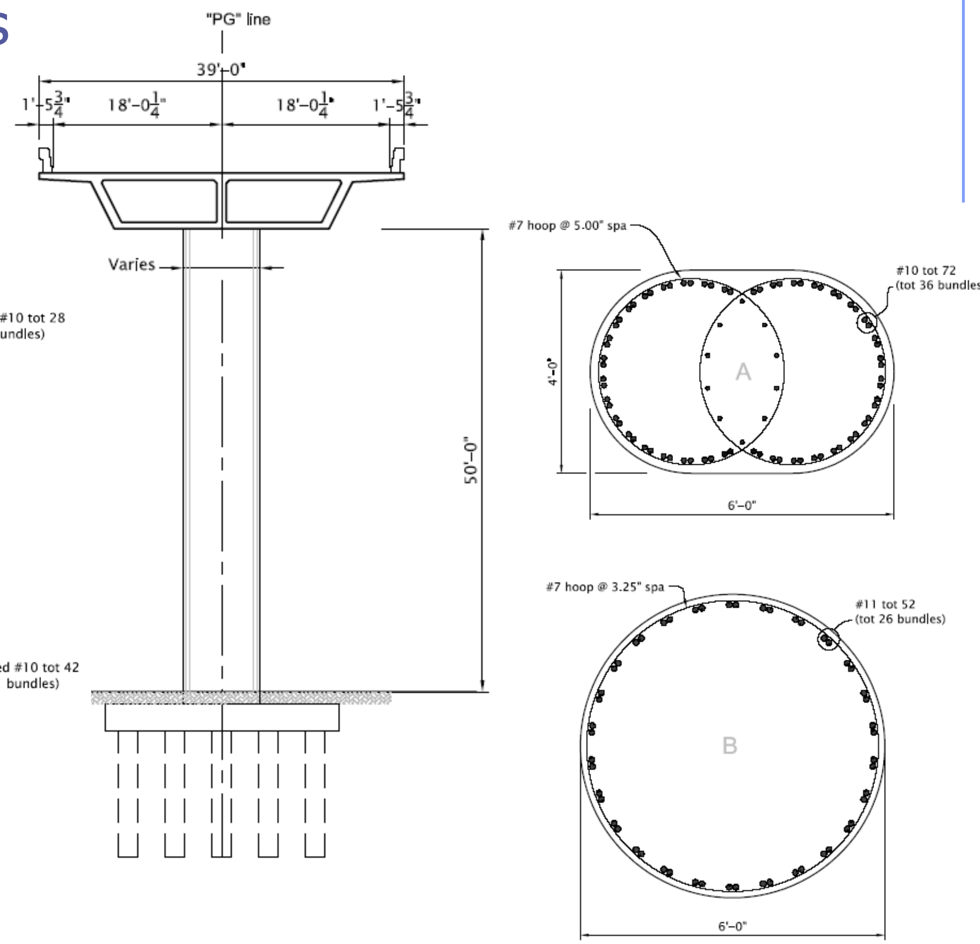


Testbed Bents

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



- Type 1



- Type 11

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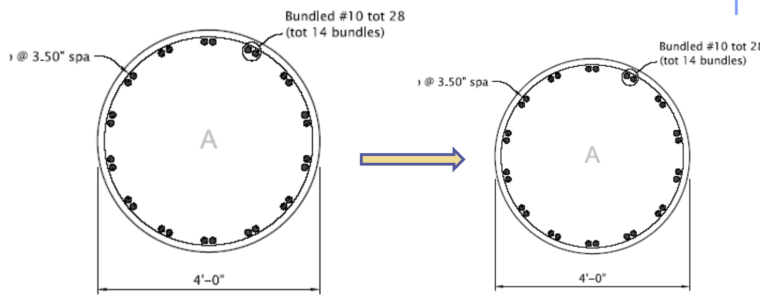
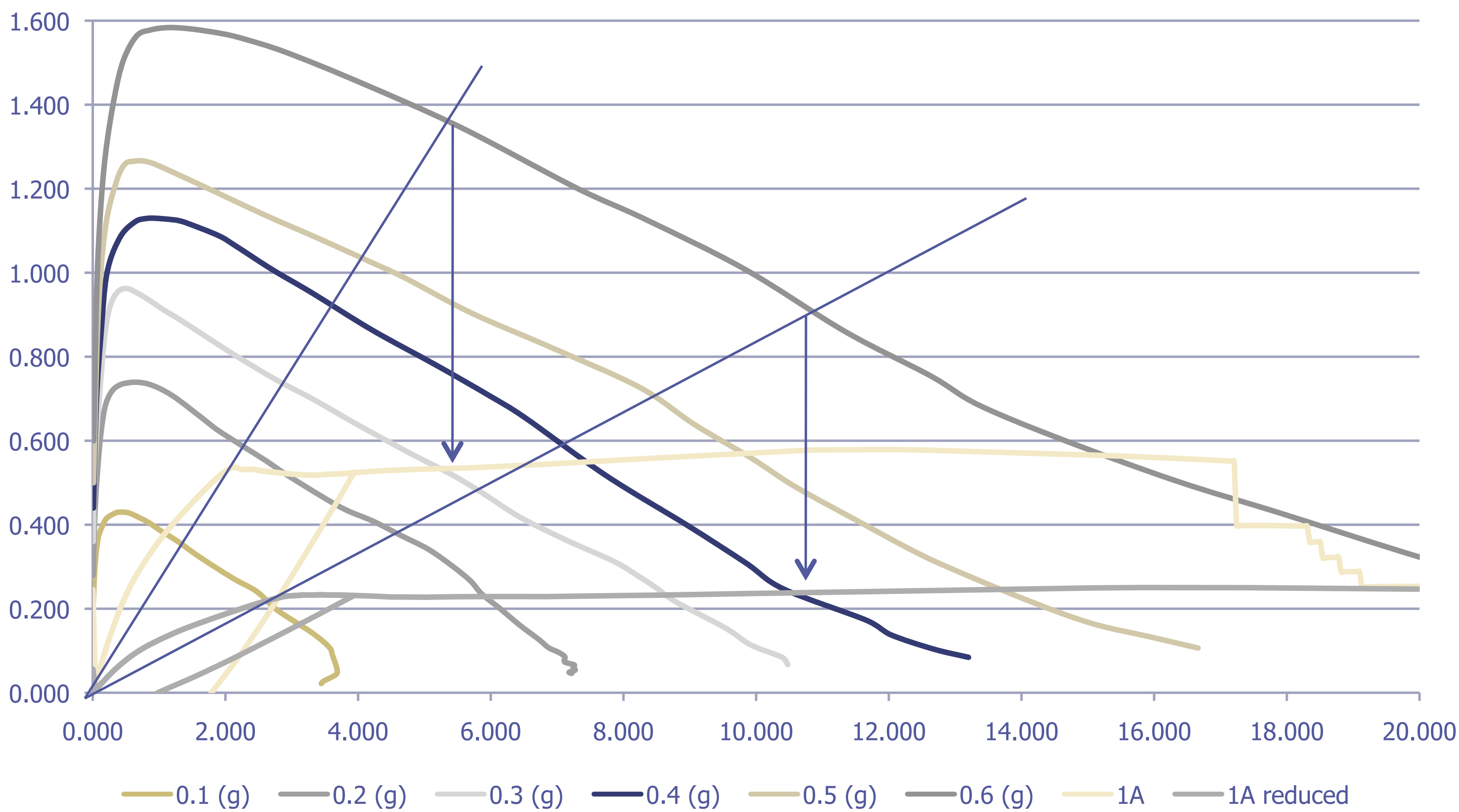
Modified Testbed Bents



- Type 1A and 1A reduced

ARS Soil profile D, M=7.25±0.25



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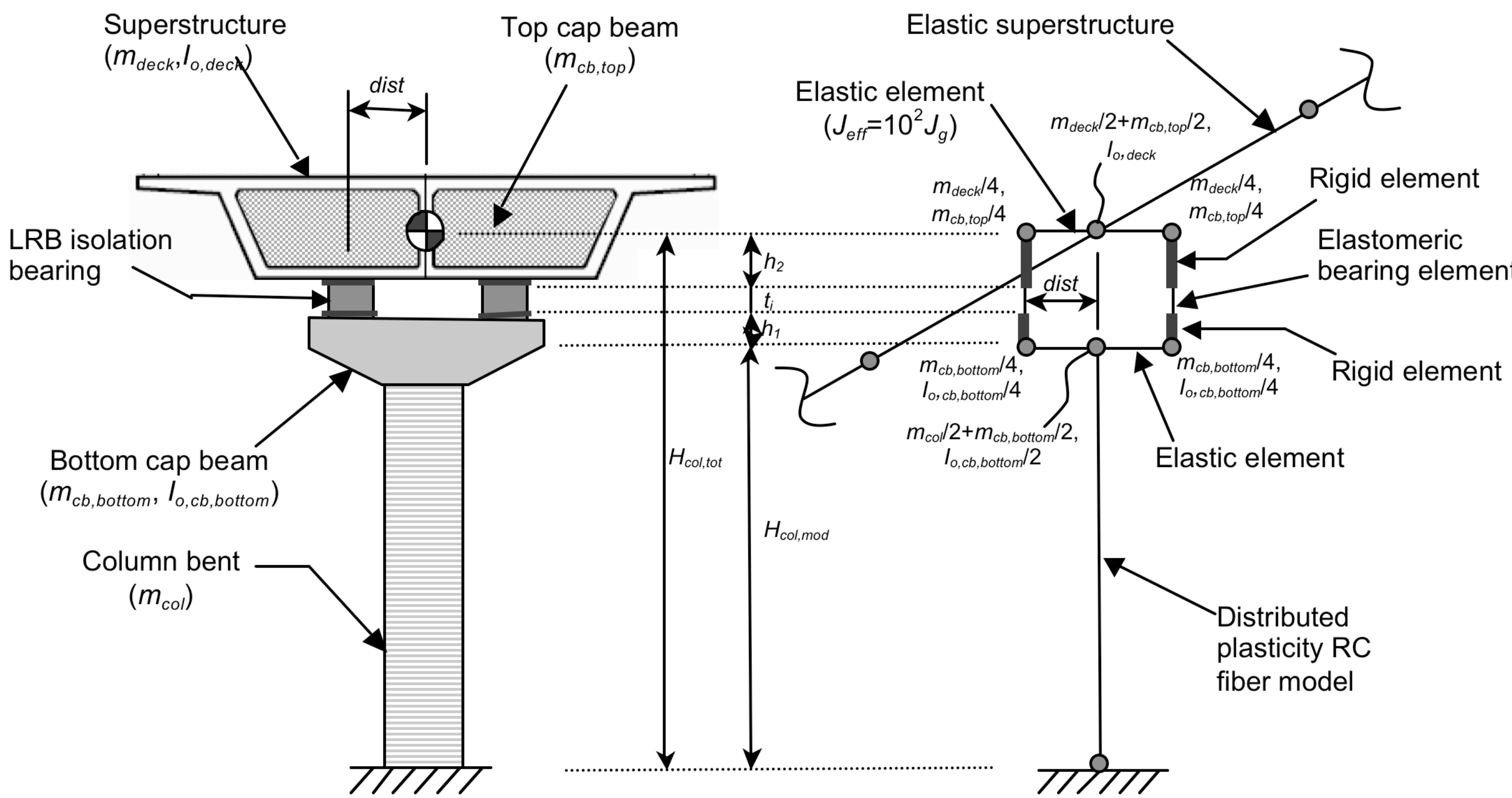
Isolated Bridge Systems



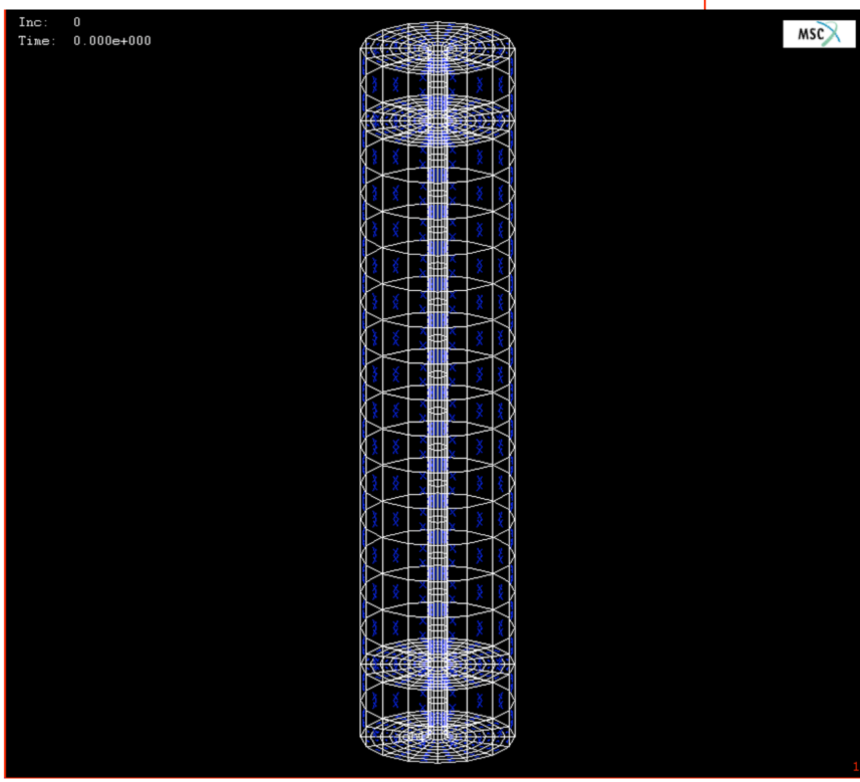
(a) Scheme of isolated bridge cross section

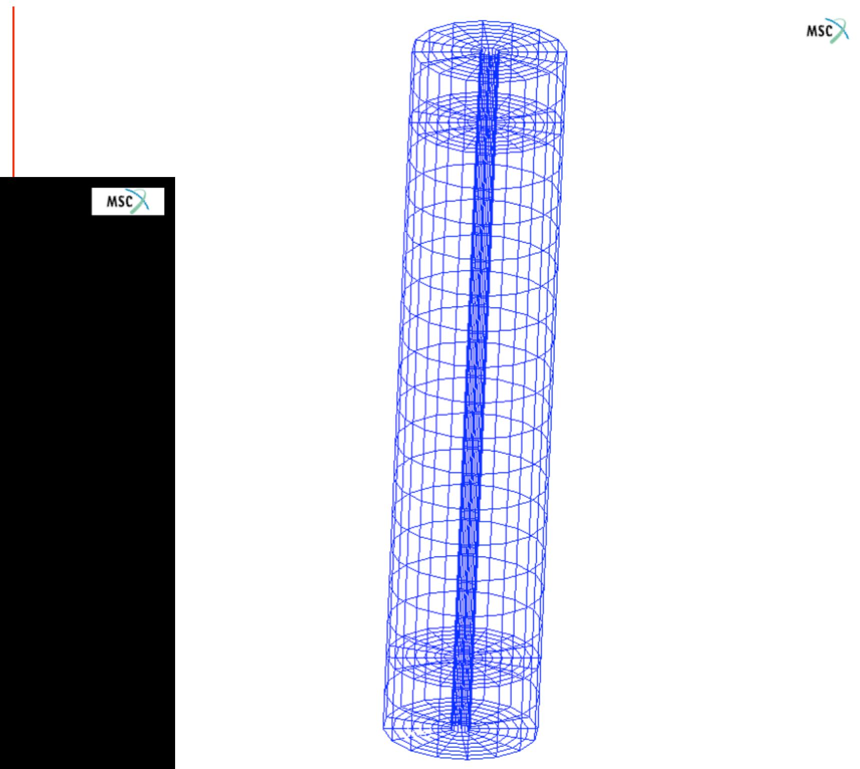
(b) General modeling scheme of isolated bridge model in OpenSees

Details of RC bridge- type 1A with base isolation

Modular construction

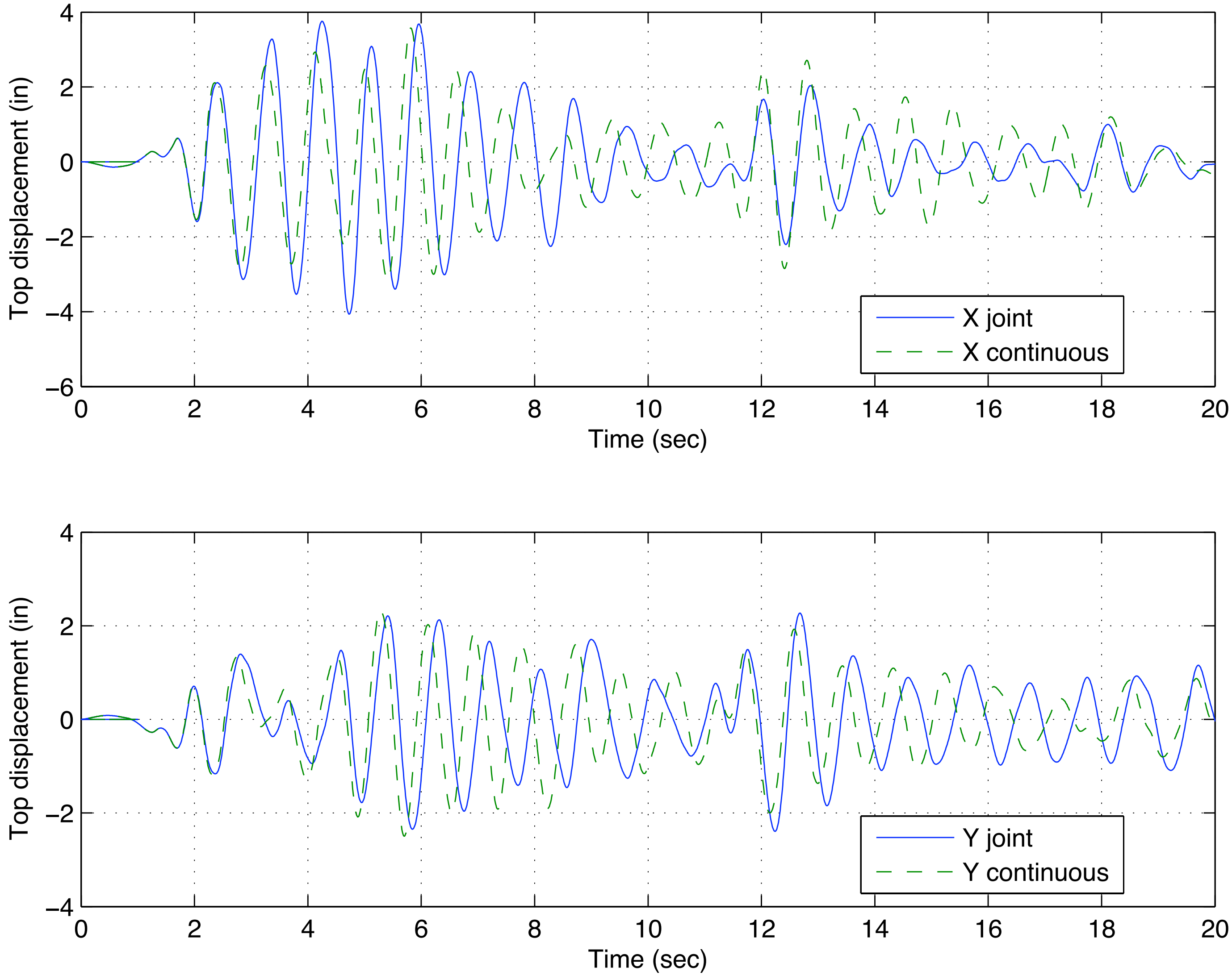
- Pre-cast segments (column, deck, etc.)
- Dry joints
- Post-tensioning





Modular construction

- Dry joint vs continuous column comparison



Pilot Studies on Bridge Systems

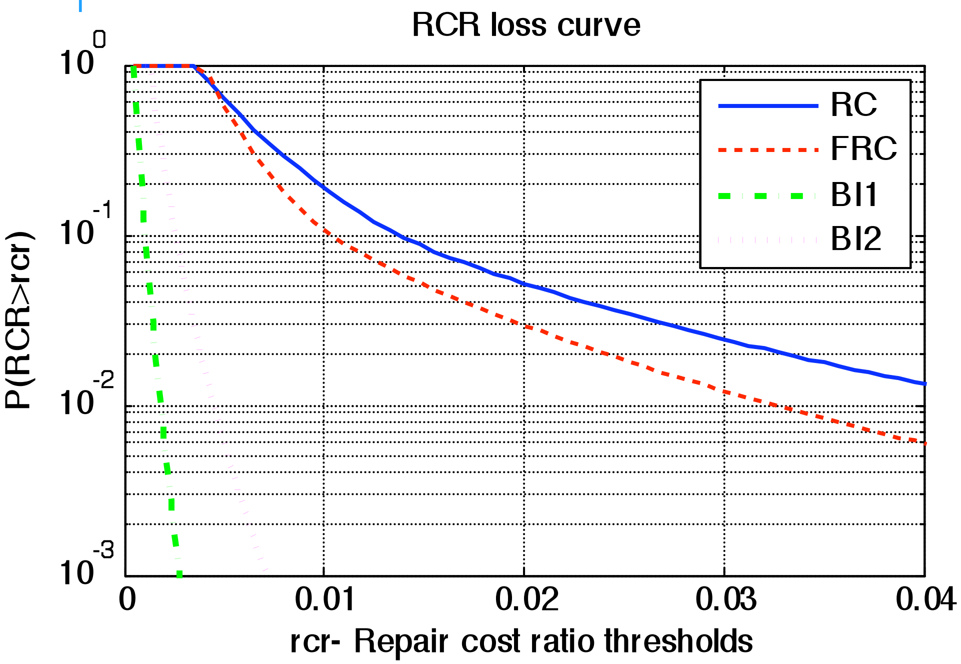
- **Conventionally reinforced concrete (RC) bridge: Type 1A (Ketchum *et al.* 2004)**
  - Inelastic column behavior $\mu_d < 4.5$, $D_c = 4'$, $\rho_l = 2\%$, $\rho_t = 0.16\%$.
- **Fiber-reinforced concrete (FRC) bridge:**
  - Fiber-reinforced bridge pier with 1.5% volume fraction V_f of steel fibers.
  - Fiber aspect ratio L_f/ϕ_f of 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 in Davis Hall, UC Berkeley is pending.
- **Seismically isolated (BI) bridges:**
  - Lead rubber bearings underneath superstructure.
  - 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

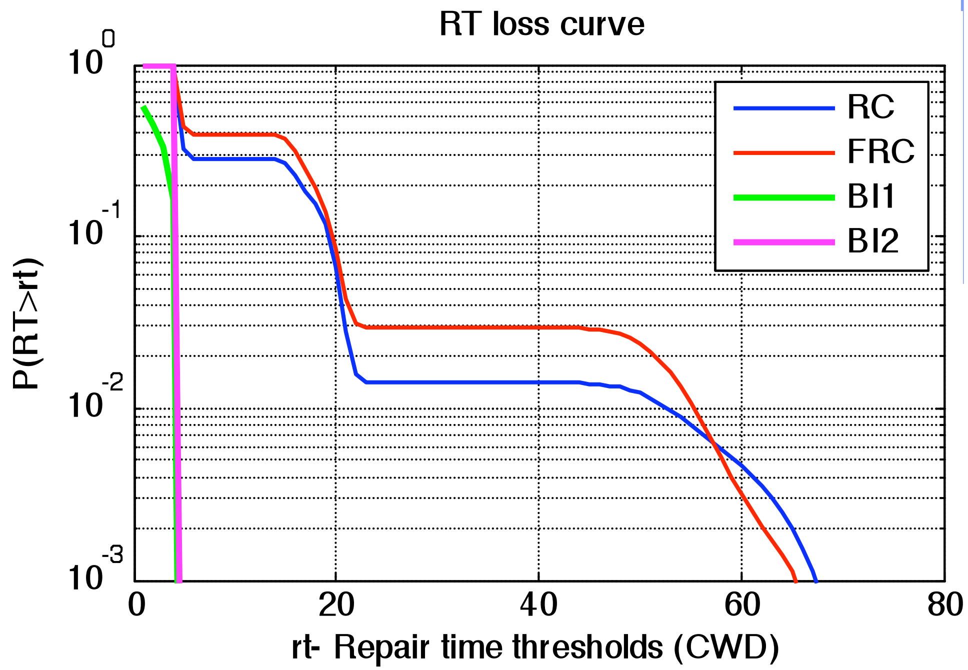
New Construction Costs

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

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

Post-Earthquake Repair Costs and Time





RCR and RT MAF or loss curves for different bridge types

Construction costs, annual repair cost and repair time for different bridge types

Parameter	RC bridge	FRC bridge	BI1 bridge	BI2 bridge
NC- Cost of new construction	$2,959,441	$2,973,316	$3,515,733	$3,310,586
A_{RCR}- Mean annual RCR	**0.80%**	**0.65%**	**0.02%**	**0.13%**
A- Mean annual repair cost	$23,530	$19,433	$989	$4,388
A_{RT}- Mean annual repair time	**8 CWD**	**10 CWD**	**1 CWD**	**4 CWD**

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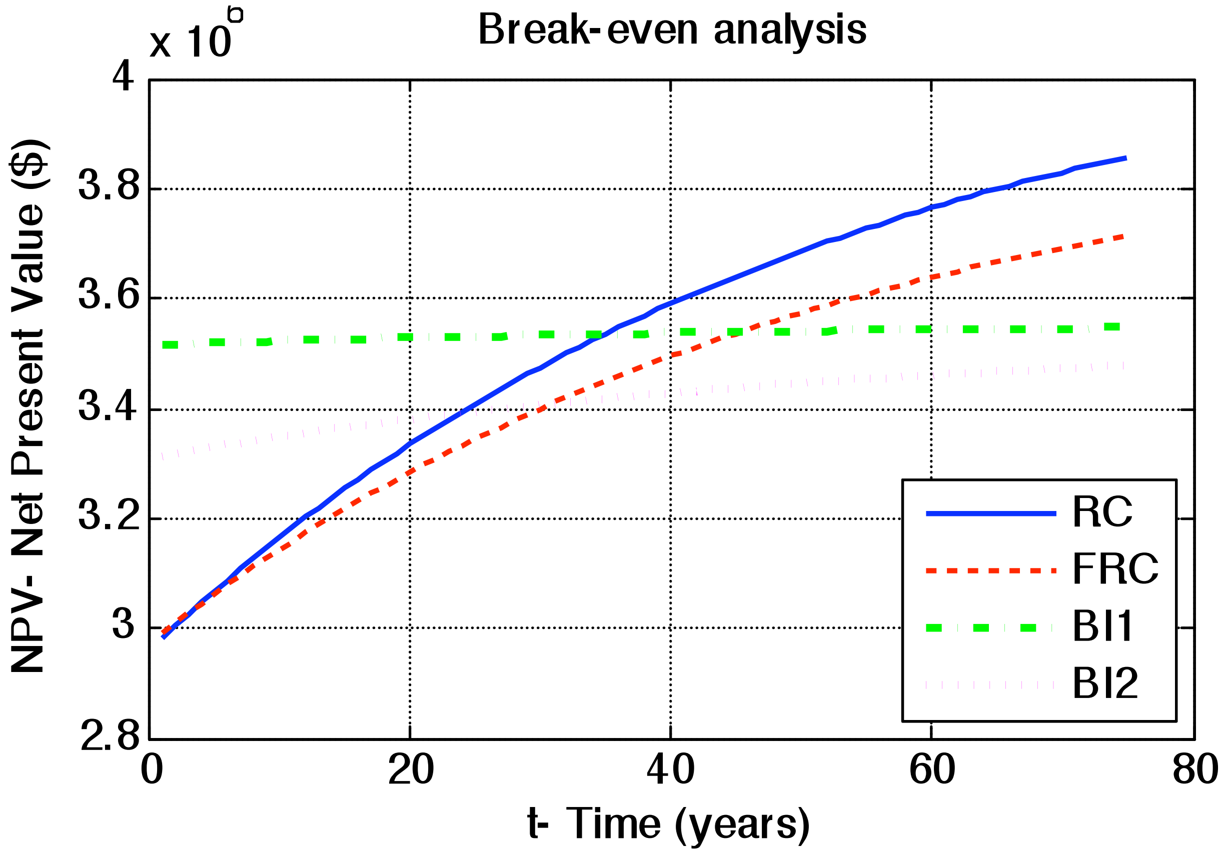
Cost-Effectiveness of Bridge Systems

Break-even analysis for 5% discount rate and mean annual repair cost ratio (c.o.v.=0).



Cost-Effectiveness of Bridge Systems

Net Present Value with varying discount rate, *i* and c.o.v. for the repair cost annuity, *A*.

Confidence Intervals	RC bridge, Discount rate, *i* (%) 2	4	6	8	FRC bridge, Discount rate, *i* (%) 2	4	6	8
μ-σ, c.o.v.=0.4	4,482,288	3,687,240	3,375,409	3,233,737	4,230,997	3,574,387	3,316,853	3,199,850
μ-σ, c.o.v.=0.3	4,736,096	3,808,539	3,444,737	3,279,453	4,440,611	3,674,565	3,374,110	3,237,606
μ-σ, c.o.v.=0.2	4,989,903	3,929,839	3,514,065	3,325,168	4,650,224	3,774,744	3,431,366	3,275,361
μ-σ, c.o.v.=0.1	5,243,711	4,051,139	3,583,392	3,370,884	4,859,838	3,874,922	3,488,622	3,313,117
μ- Mean	**5,497,519**	**4,172,439**	**3,652,720**	**3,416,600**	**5,069,451**	**3,975,101**	**3,545,878**	**3,350,873**
μ+σ, c.o.v.=0.1	5,751,327	4,293,738	3,722,048	3,462,316	5,279,065	4,075,279	3,603,134	3,388,628
μ+σ, c.o.v.=0.2	6,005,134	4,415,038	3,791,376	3,508,032	5,488,679	4,175,457	3,660,391	3,426,384
μ+σ, c.o.v.=0.3	6,258,942	4,536,338	3,860,704	3,553,748	5,698,292	4,275,636	3,717,647	3,464,139
μ+σ, c.o.v.=0.4	6,512,750	4,657,638	3,930,032	3,599,464	5,907,906	4,375,814	3,774,903	3,501,895

Confidence Intervals	BI1 bridge, Discount rate, *i* (%) 2	4	6	8	BI2 bridge, Discount rate, *i* (%) 2	4	6	8
μ-σ, c.o.v.=0.4	3,568,620	3,541,009	3,530,179	3,525,259	3,593,951	3,446,012	3,387,988	3,361,626
μ-σ, c.o.v.=0.3	3,577,434	3,545,221	3,532,587	3,526,847	3,641,179	3,468,583	3,400,888	3,370,132
μ-σ, c.o.v.=0.2	3,586,249	3,549,434	3,534,995	3,528,434	3,688,406	3,491,154	3,413,788	3,378,639
μ-σ, c.o.v.=0.1	3,595,063	3,553,647	3,537,402	3,530,022	3,735,634	3,513,725	3,426,688	3,387,146
μ- Mean	**3,603,878**	**3,557,859**	**3,539,810**	**3,531,610**	**3,782,862**	**3,536,296**	**3,439,589**	**3,395,652**
μ+σ, c.o.v.=0.1	3,612,692	3,562,072	3,542,218	3,533,197	3,830,089	3,558,867	3,452,489	3,404,159
μ+σ, c.o.v.=0.2	3,621,507	3,566,284	3,544,625	3,534,785	3,877,317	3,581,438	3,465,389	3,412,666
μ+σ, c.o.v.=0.3	3,630,321	3,570,497	3,547,033	3,536,373	3,924,544	3,604,009	3,478,290	3,421,172
μ+σ, c.o.v.=0.4	3,639,136	3,574,710	3,549,441	3,537,960	3,971,772	3,626,580	3,491,190	3,429,679

Project Status

- Writing the final report:
  - Modular and accelerated seismic construction
  - Behavior:
    - Monolithic (with wet joints) with conventional plastic hinges
    - Motion at joints (different at different intensity levels)
    - Isolation or rocking
  - Technologies: modular structures
  - Expect to finish in a couple of months

Challenges and Future Work

- Distribution of the testbed structure:
  - OpenSees modules
- Integration with Caltrans
- Support of new PEER projects:
  - New materials
  - Rocking
  - New elements and joints
  - System behavior (e.g. curved rocking bridge)

Thank You!

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