

Evaluation of Bridge Post-Earthquake Traffic Load Carrying Capacity using Hybrid Simulation

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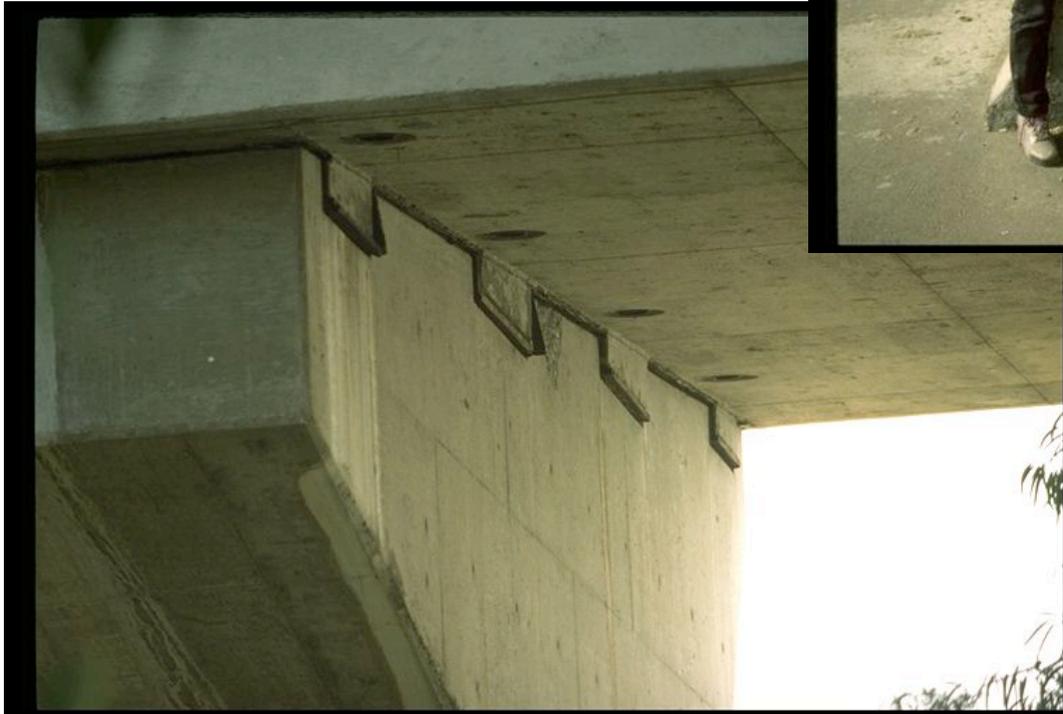
Bozidar Stojadinovic, Professor

University of California Berkeley

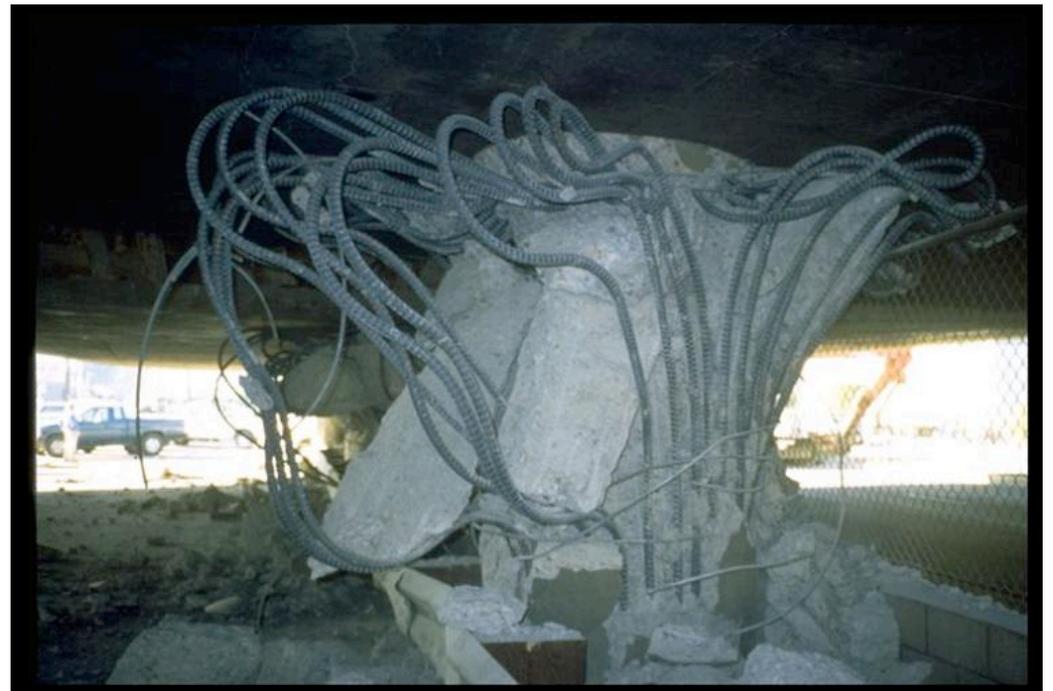
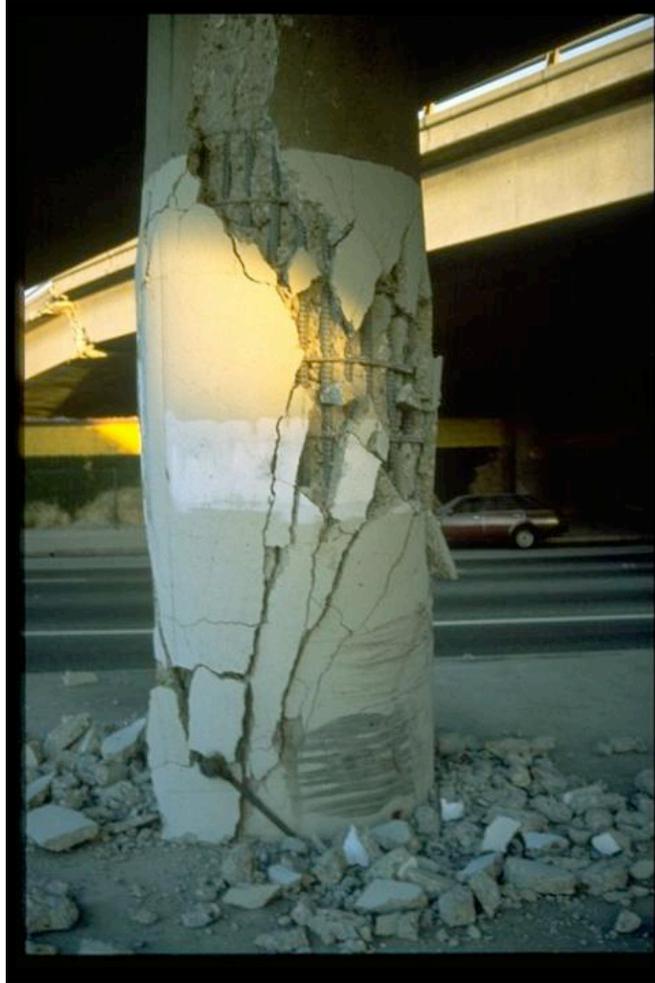


Bridge Performance is...

◆ 1994 Northridge



Bridge Performance is...



Bridge Performance is...

◆ I5-US14 interchange



Bridge Performance is...



Bridge Performance in California Urban Traffic Networks

- ◆ Can a bridge (designed following 2004 Caltrans SDC) safely carry design traffic loads after a design-basis earthquake event?
- ◆ How about emergency loads?

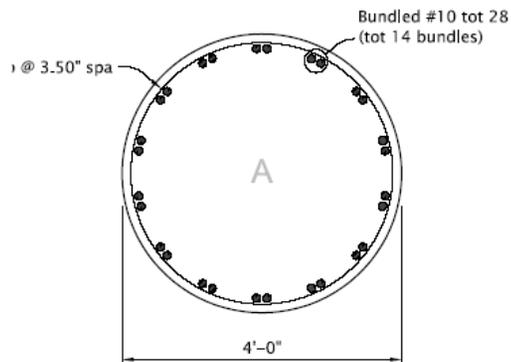
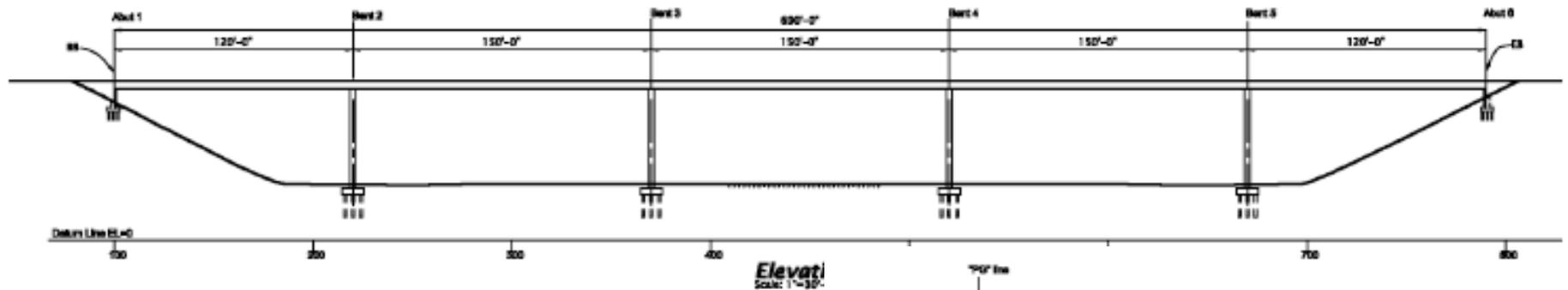


Comprehensive Approach

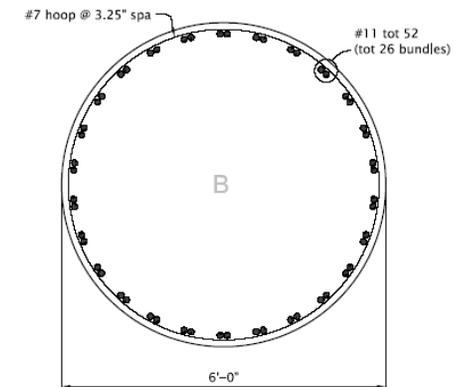
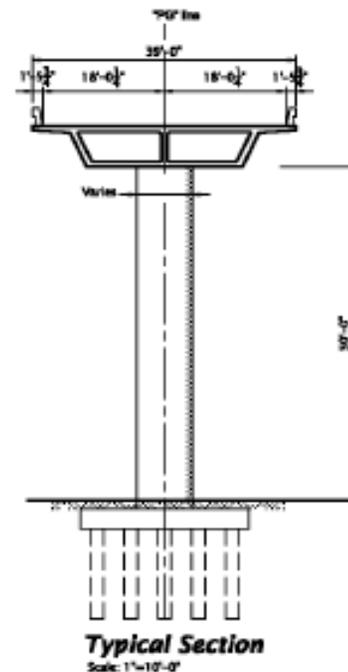
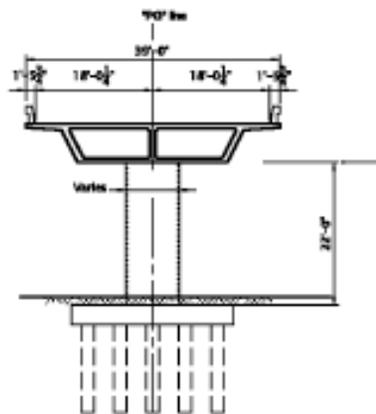
- ◆ Experiments on columns:
 - Lateral quasi-static cyclic tests to a displacement ductility level followed by an axial strength test
- ◆ Calibration of an OpenSees column model
- ◆ Hybrid simulation of bridge response
- ◆ Development of a design model:
 - Vertical load vs. deformation demand capacity degradation curves

PEER Testbed Bridges

5-span RC overpasses (Ketchum, 2004)



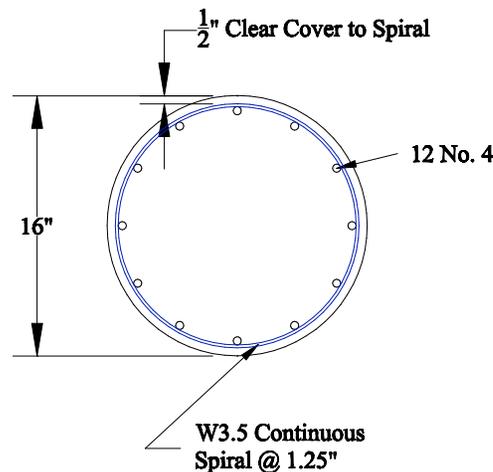
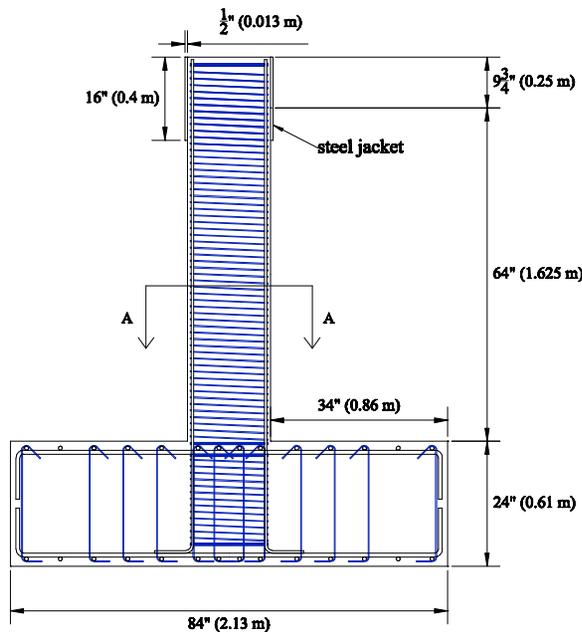
Type 1



Type 11

Calibration Tests

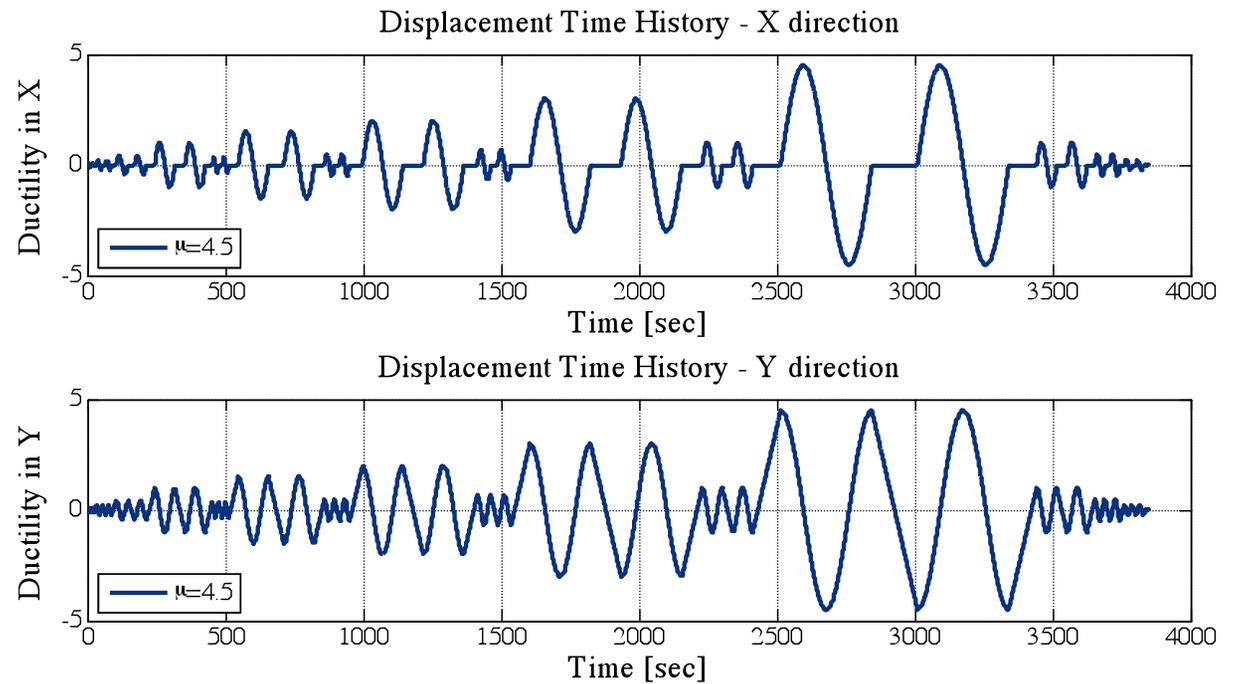
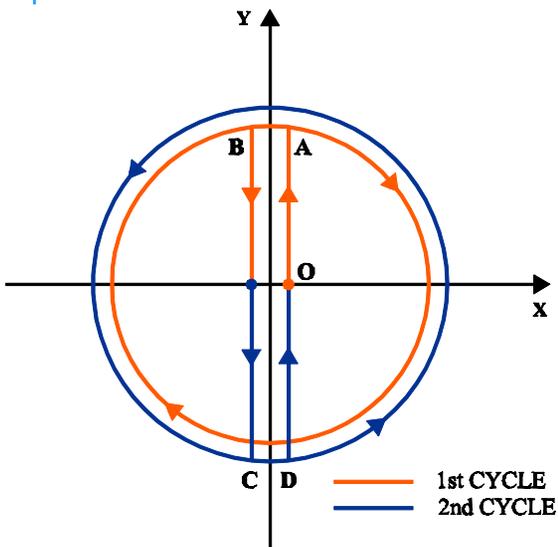
- ◆ Five column specimens (1/3.5 scale):
 - Four Type 11 columns
 - One Type 1 (shear-critical) column



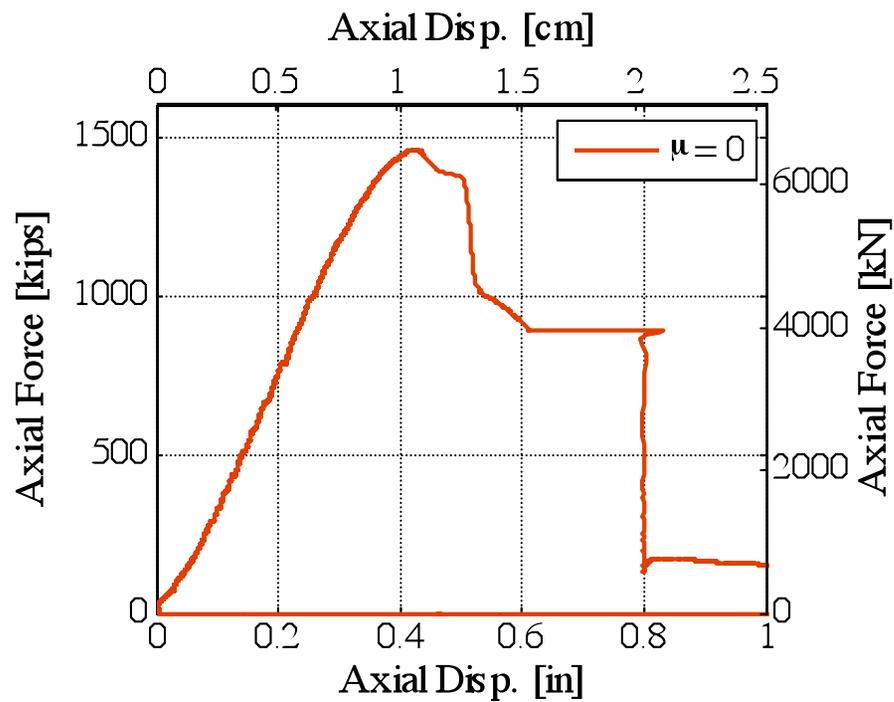
Diameter	16" (40 cm)
Longitudinal reinforcement	12#4 Gr60 ($\rho_l = 1.2\%$)
Transverse reinforcement	W3.5@1.25 in ($\rho_t = 0.75\%$)
Concrete	$f_c = 5$ ksi (34.5 MPa)

Loading Protocol

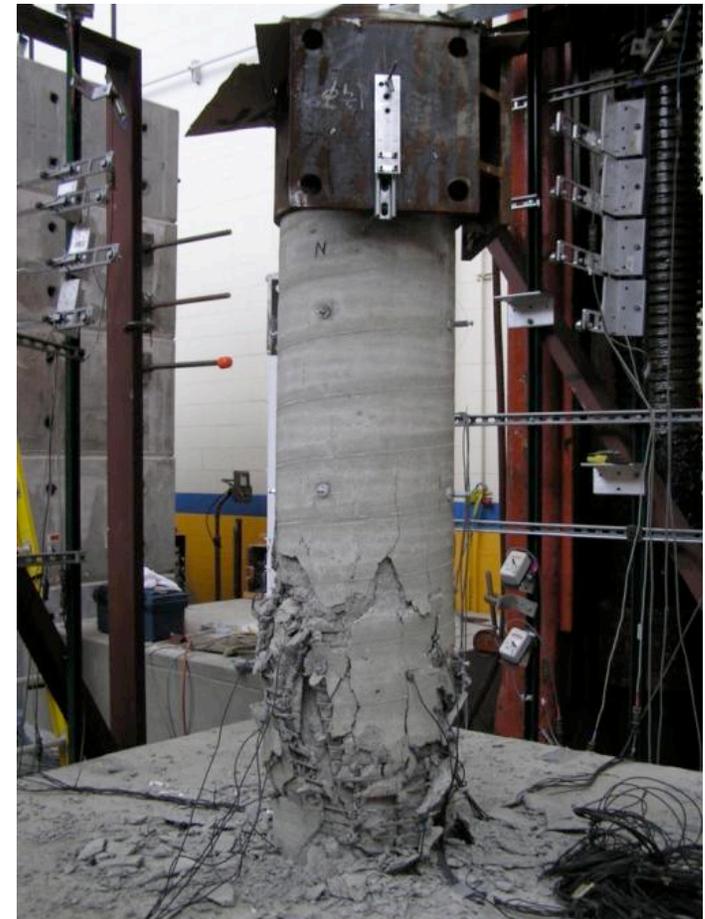
- ◆ 10% ($f'_c A_g$) axial load
- ◆ Bi-directional lateral load



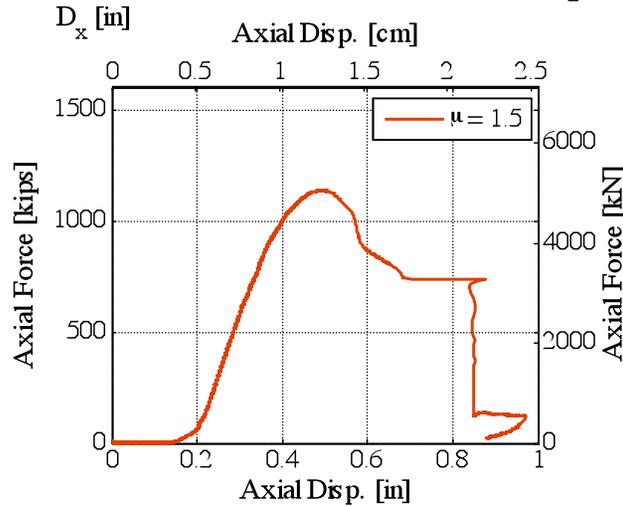
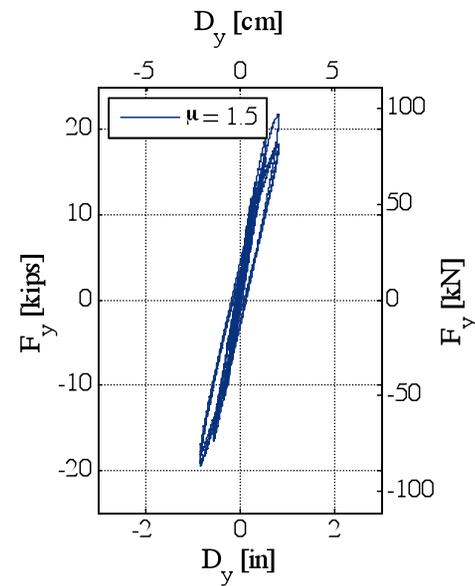
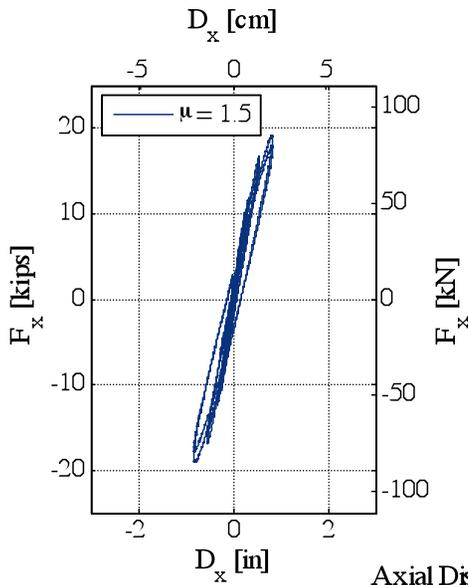
Test: Base0



$$P_0 = 1460 \text{ kips}$$



Test: Base15

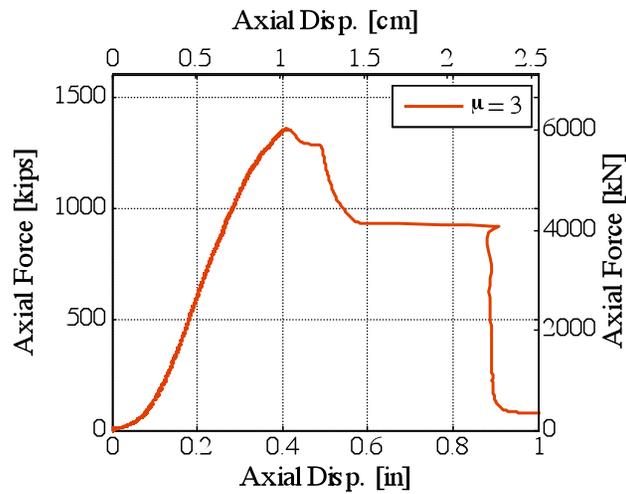
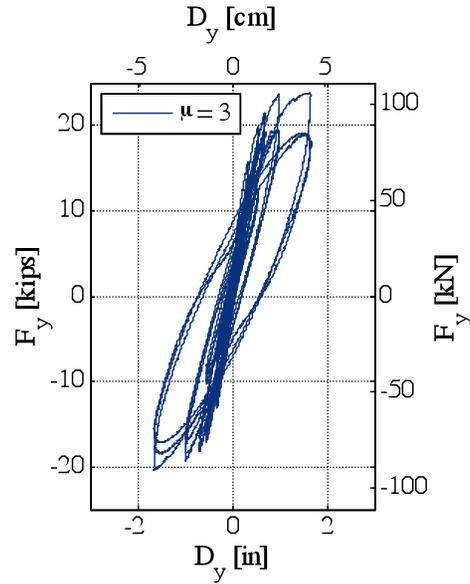
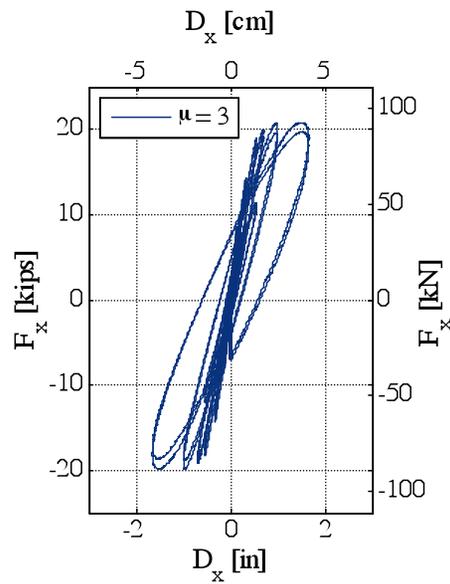


$$P_{15} = 1137 \text{ kips}$$

$$P_{15}/P_0 = 0.78$$



Test: Base30



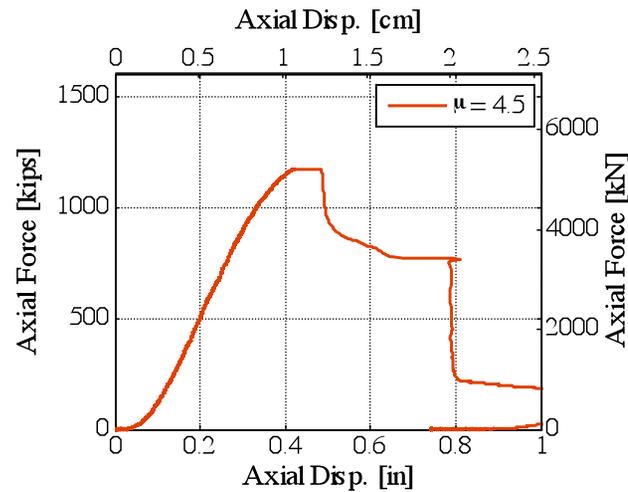
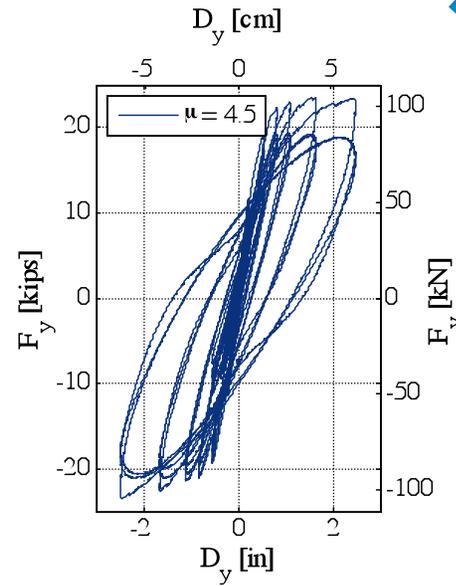
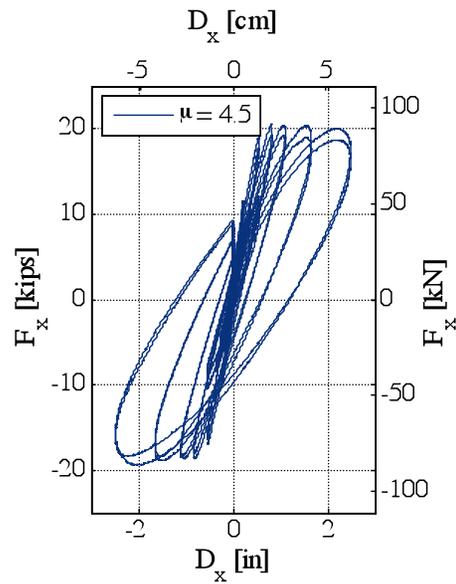
$$P_{30} = 1355 \text{ kips}$$

$$P_{30}/P_0 = 0.93$$



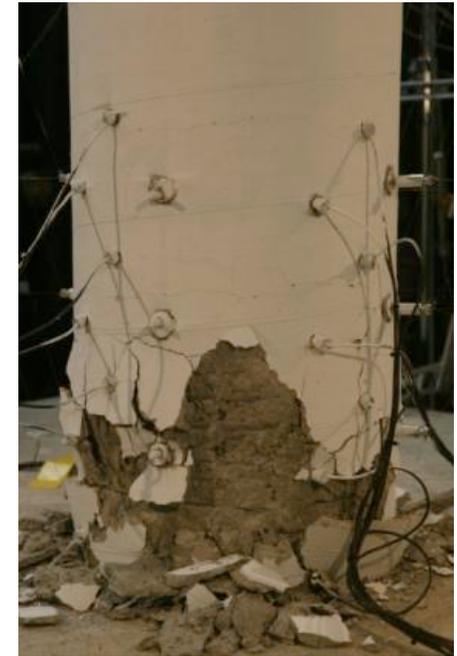
Test: Base45

No hoop or rebar fracture

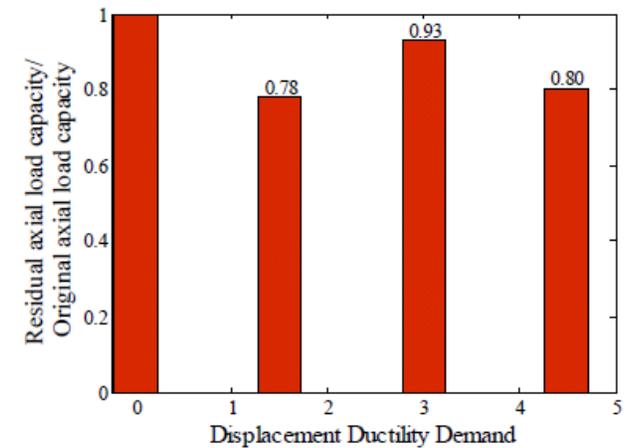
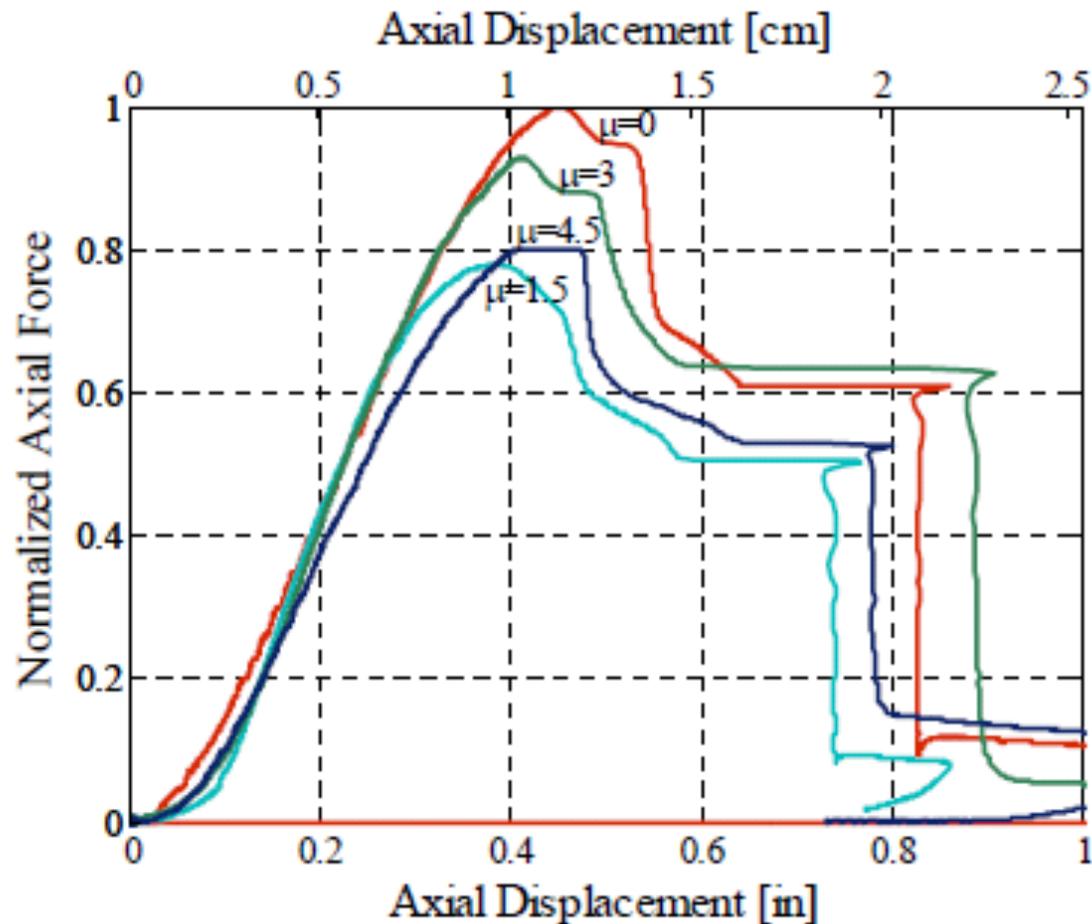


$$P_{45} = 1170 \text{ kips}$$

$$P_{45}/P_0 = 0.80$$



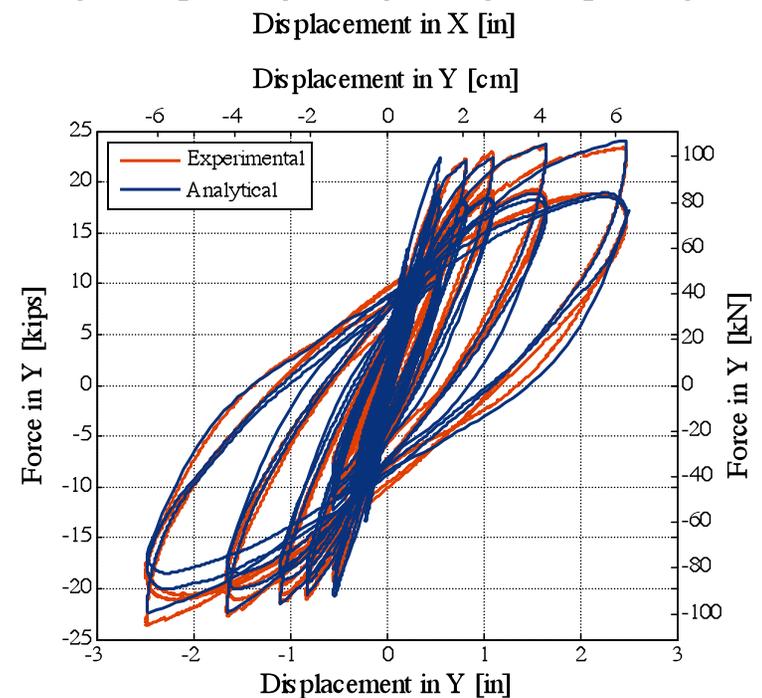
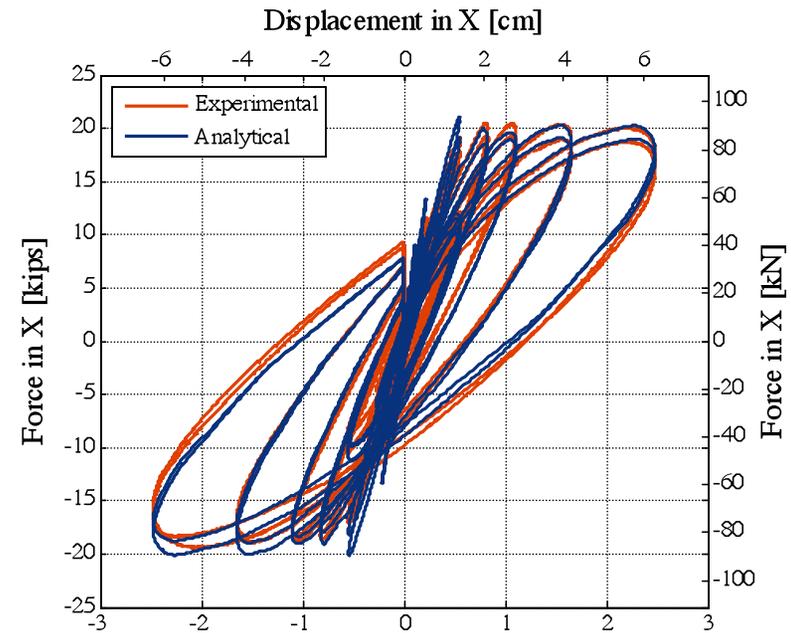
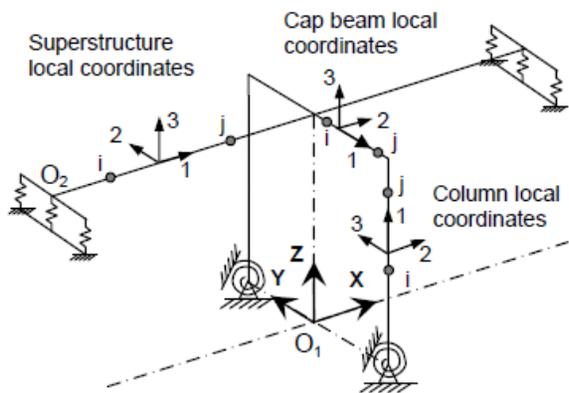
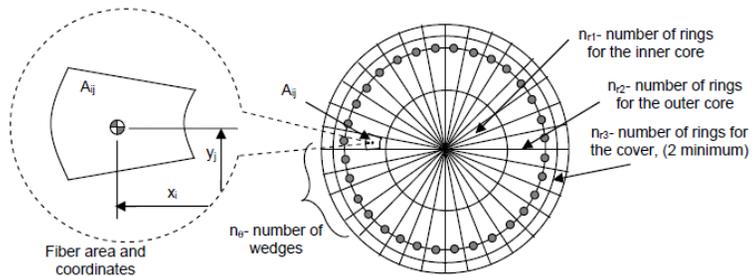
Degradation of Axial Load Capacity



- *Cover damage*
- *Some core damage*
- *No column hoop or rebar bar failure*

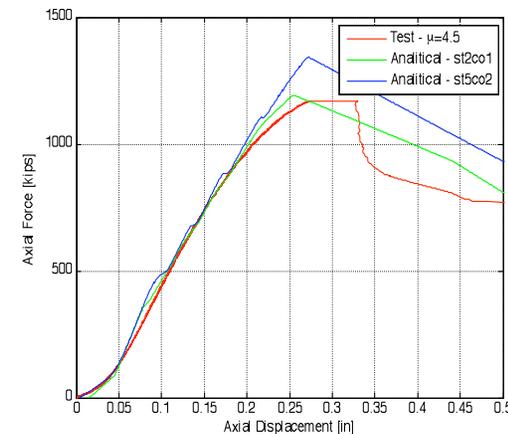
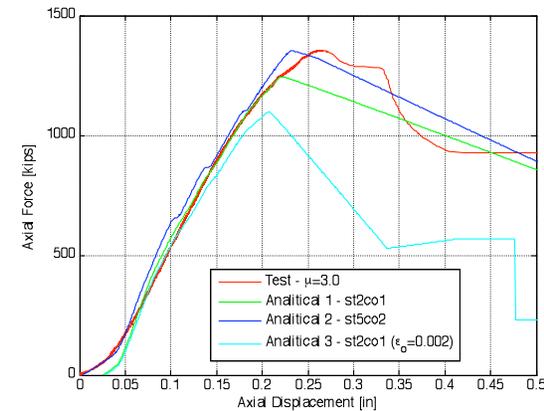
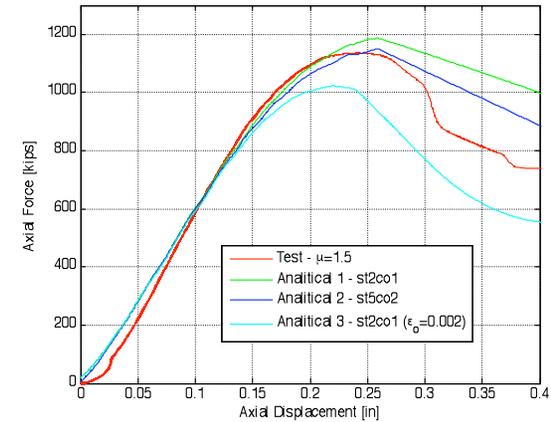
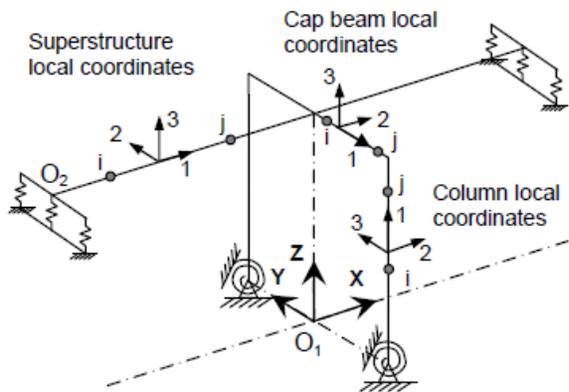
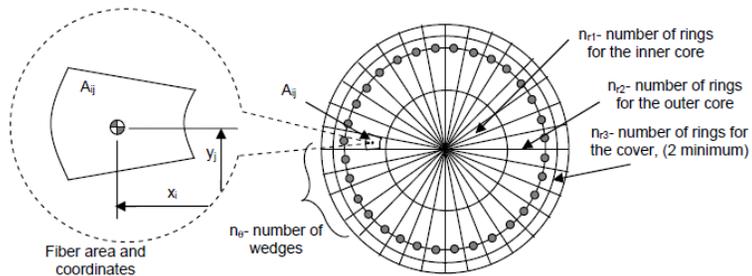
OpenSees Model Calibration: Bending

◆ Beam-column force-based fiber element



OpenSees Model Calibration: Axial

◆ Beam-column force-based fiber element

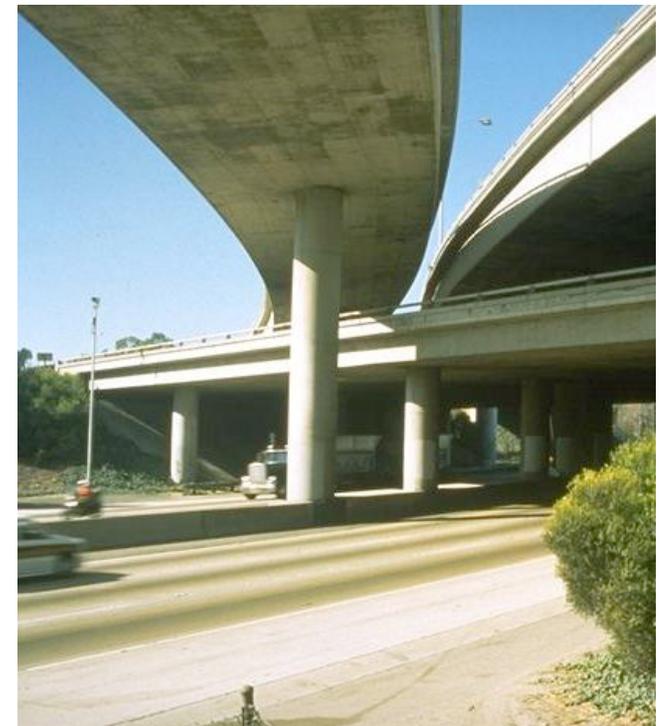
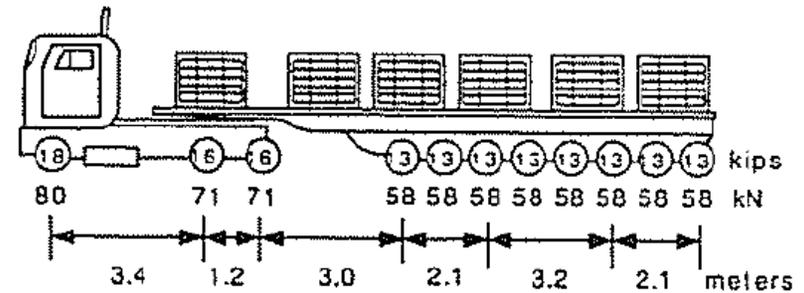


Hybrid Simulations

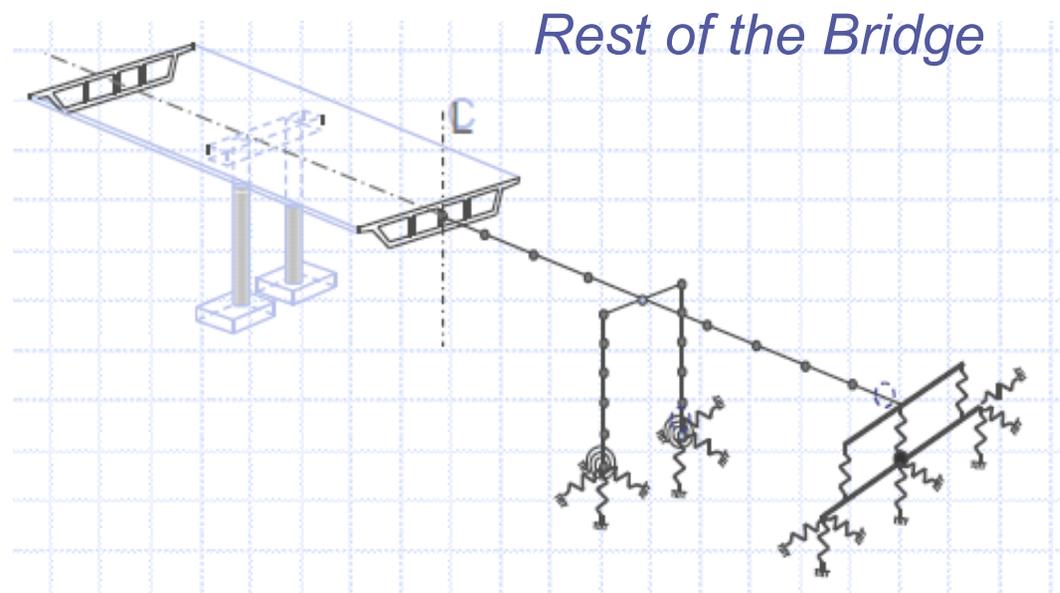
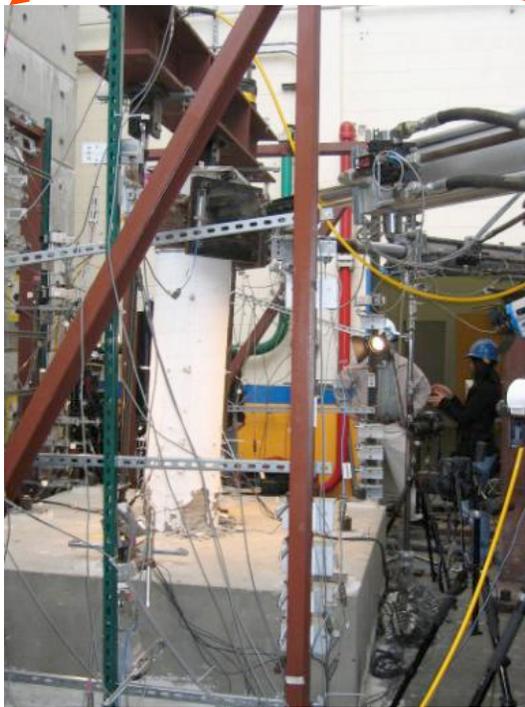
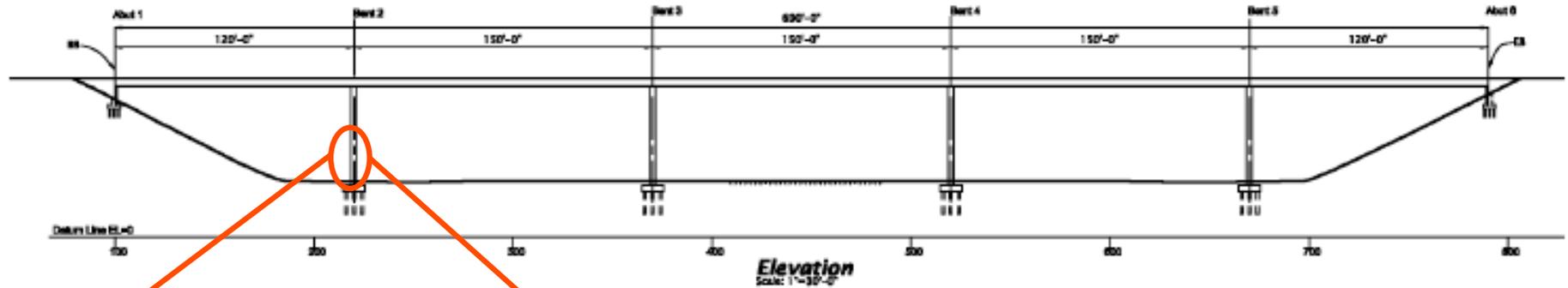
◆ Can a damaged bridge carry heavy truck after an earthquake?

◆ It is very difficult to physically model the bridge with the (moving) truck on it

➔ hybrid simulation is the way to go



Hybrid Model of the PEER Testbed Bridge



Interface at Column Mid-Height

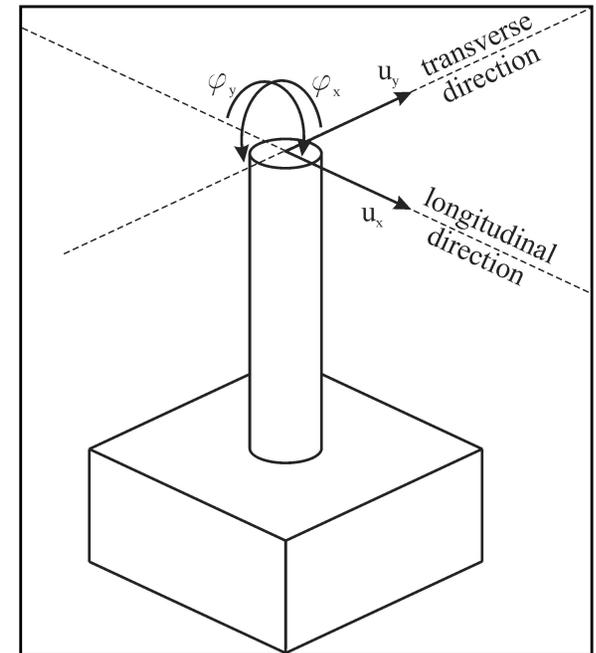
◆ *There are 6 DOFs that could be controlled at the top-of-the-column node:*

- $u_x, u_y, u_z, \phi_x, \phi_y, \phi_z$

◆ *We are controlling 4 DOFs:*

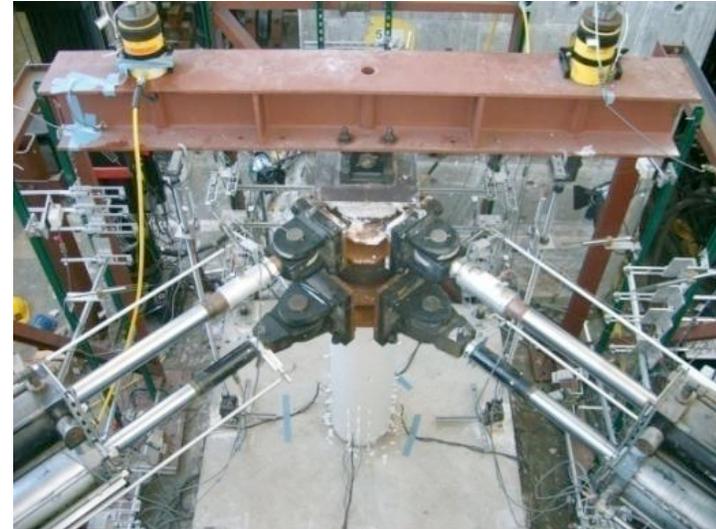
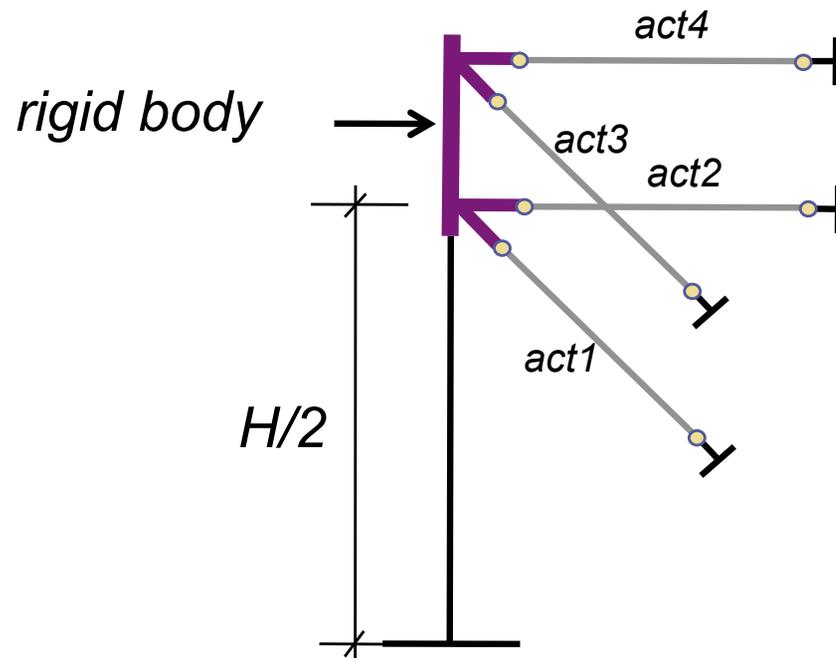
- u_x, u_y, ϕ_x, ϕ_y

- *Assuming that rotation (ϕ_z) and displacement (u_z) are small enough that can be neglected and condensed*

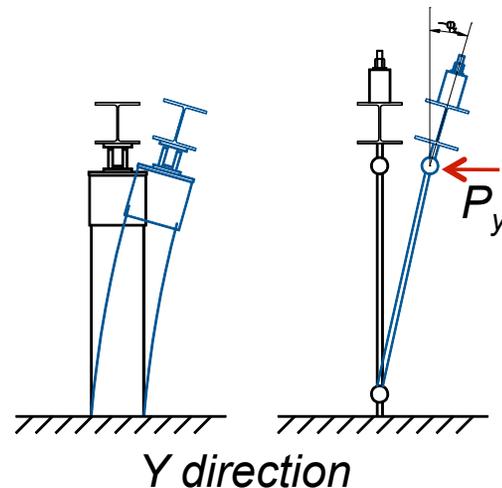
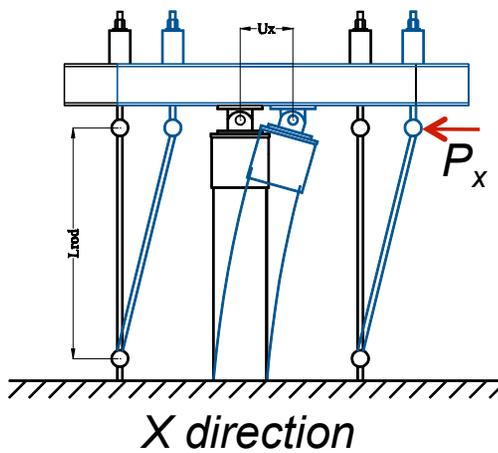
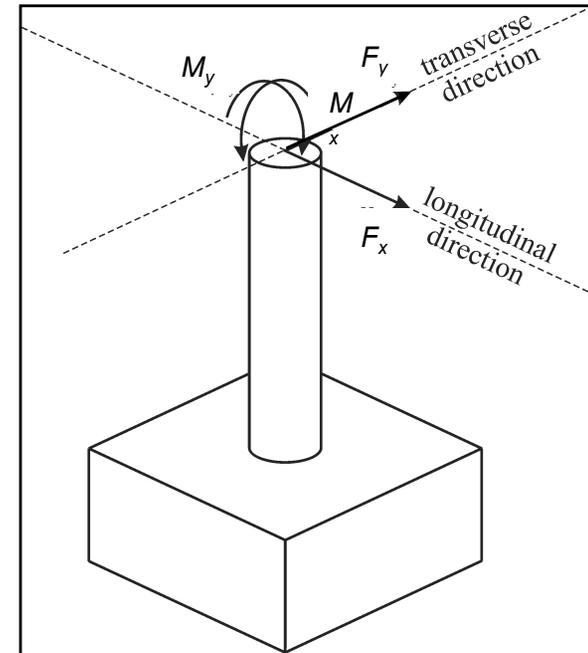
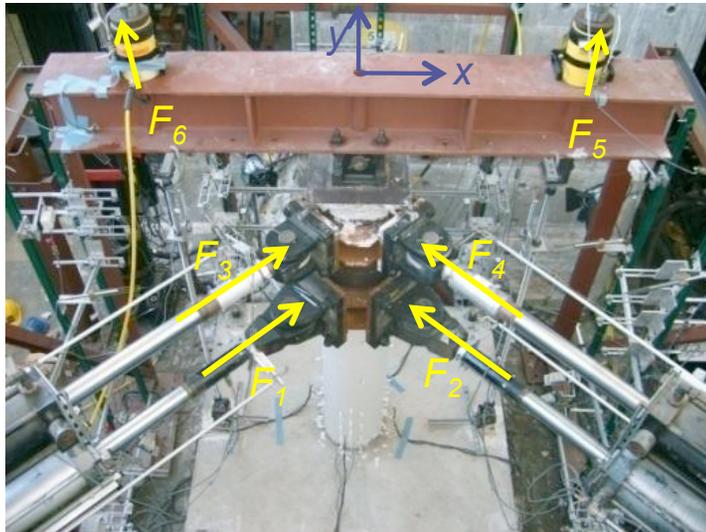


Experimental Setup: Lateral Displacements

- ◆ To control 4 chosen DOFs we will use 4 actuators:
 - Co-rotational formulation



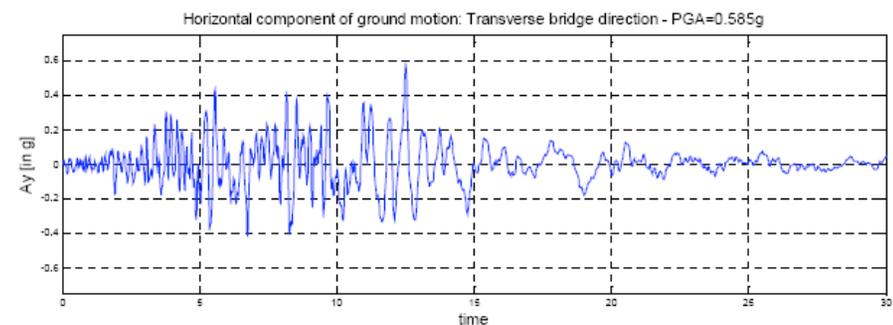
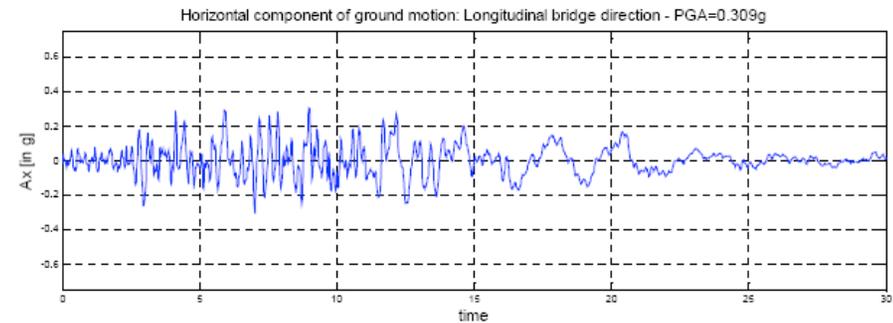
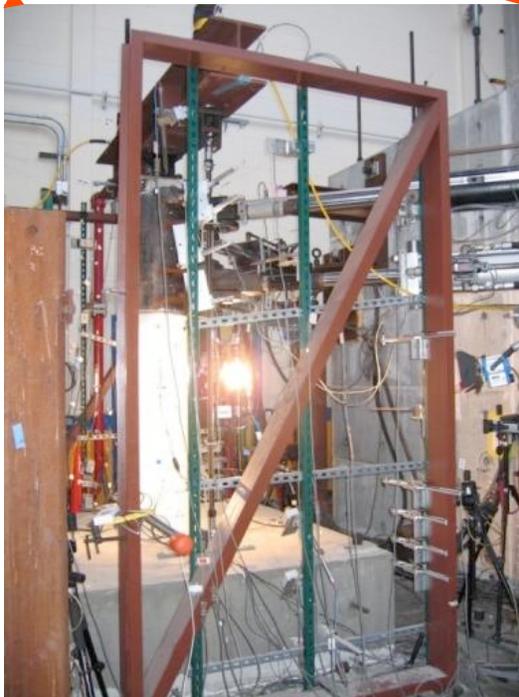
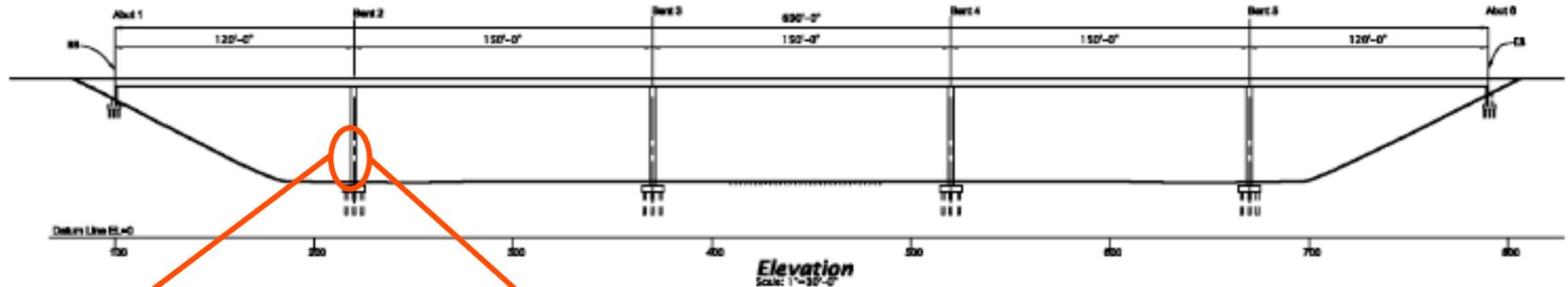
Experimental Setup: Lateral Forces



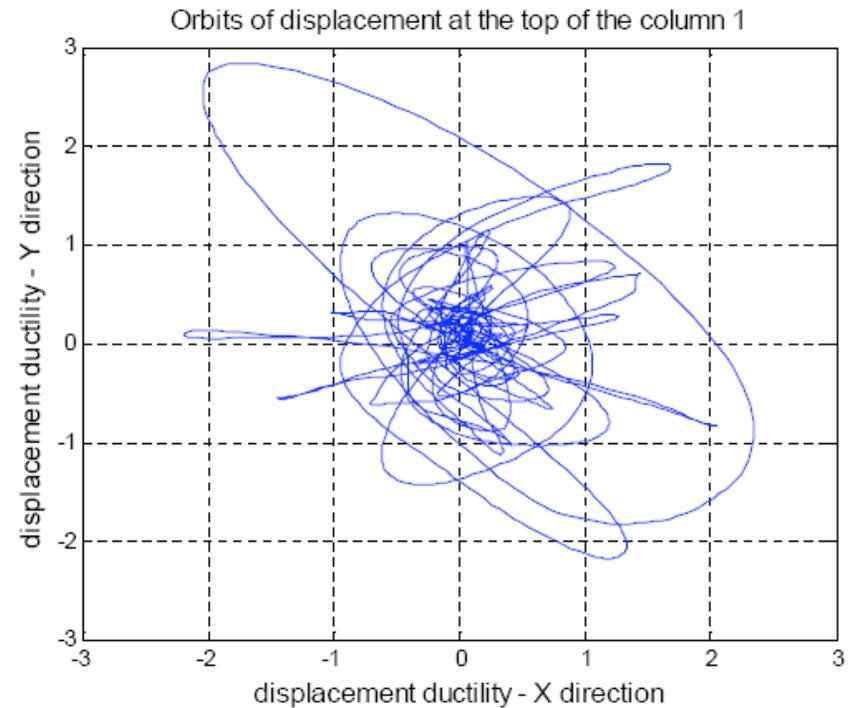
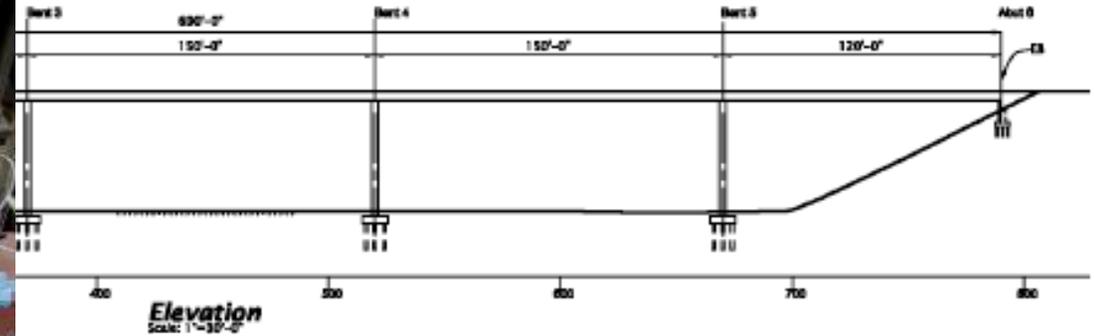
P-Delta Effects

— Deformed configuration
— Initial configuration

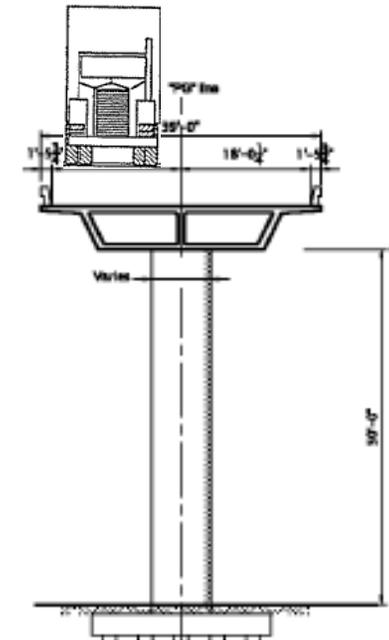
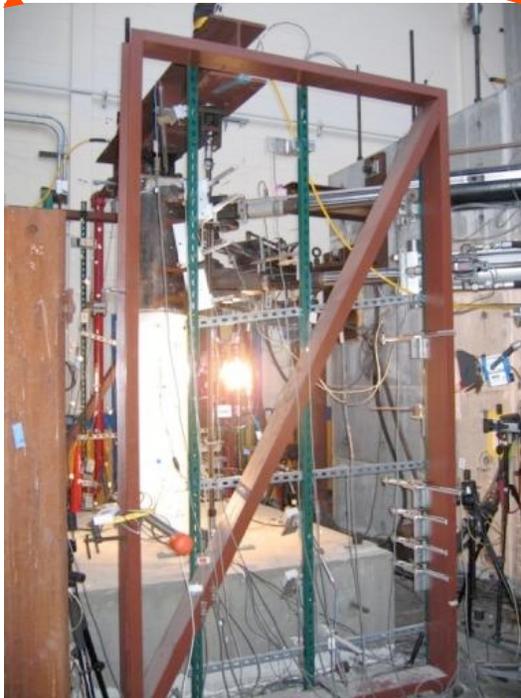
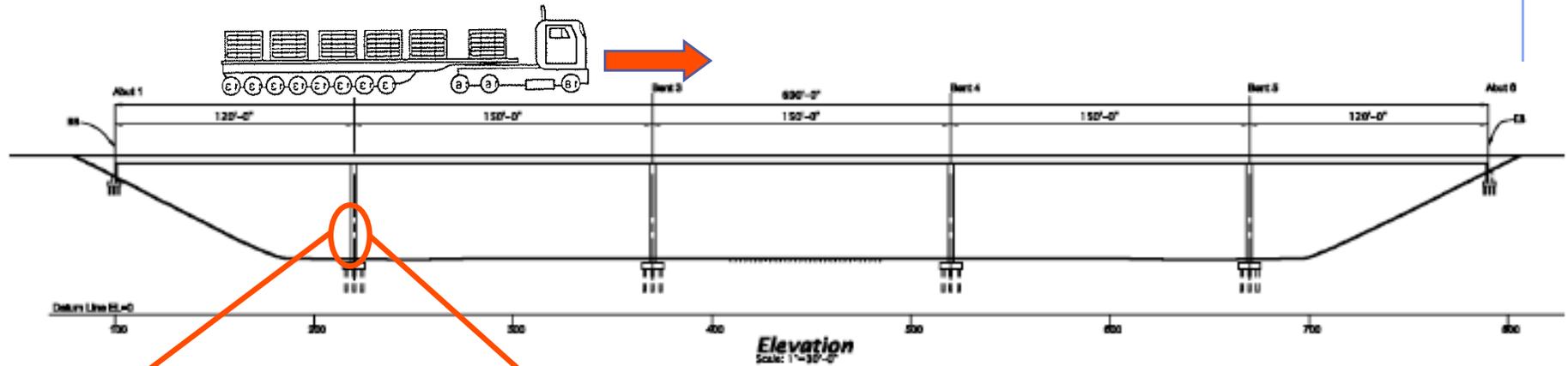
Hybrid Simulation: Gravity First; Then an Earthquake



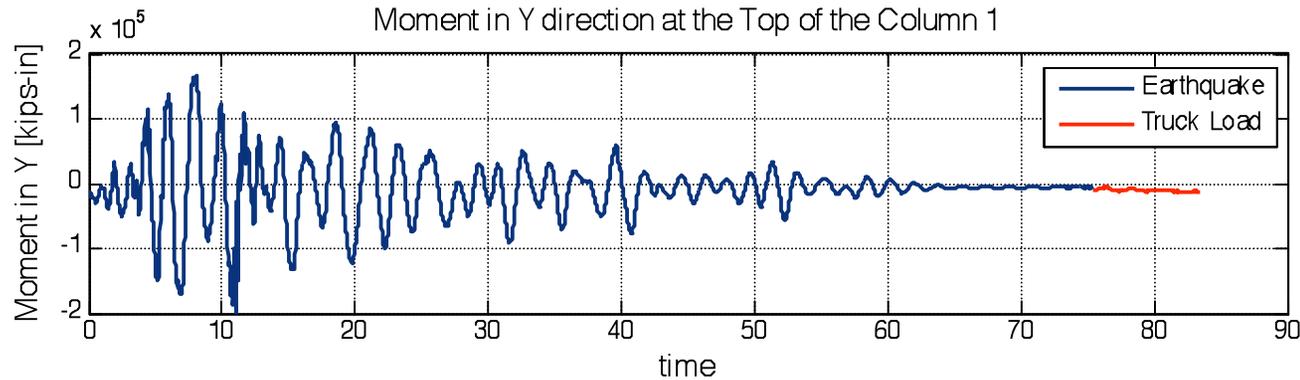
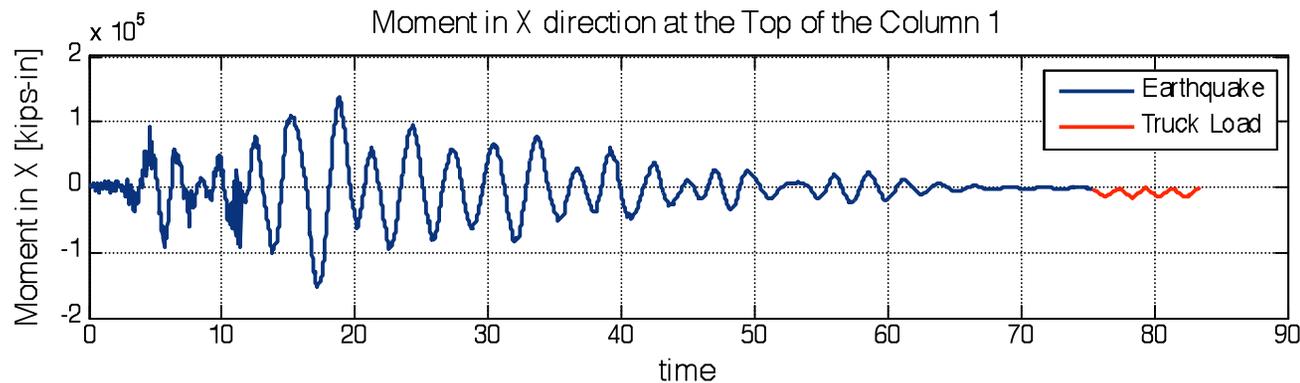
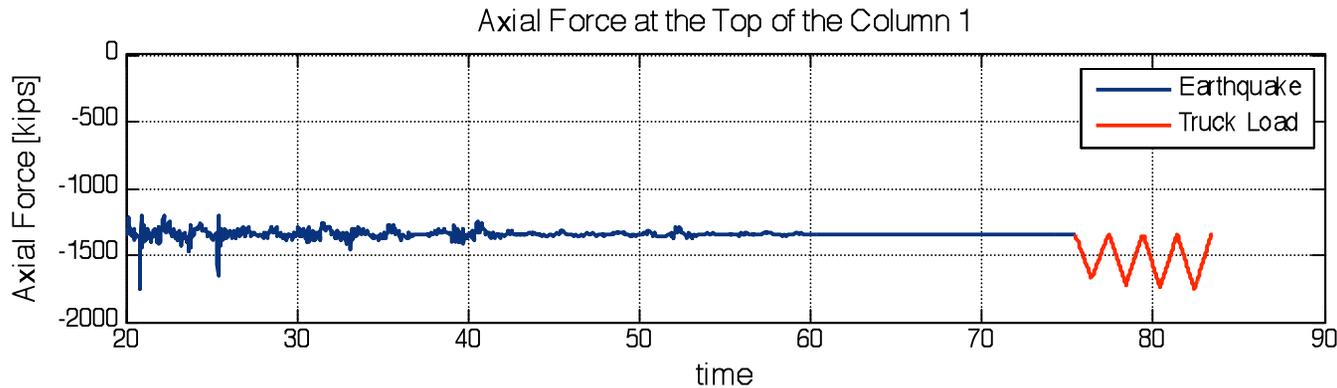
Hybrid Simulation: Earthquake Response



Hybrid Simulation: Truck after the Earthquake



Results: Forces



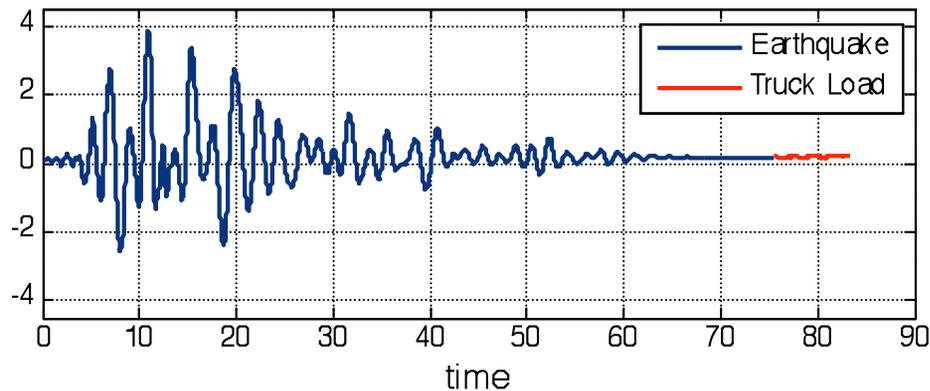
Four truck positions on a bridge

P-13 up to 150% of the weight

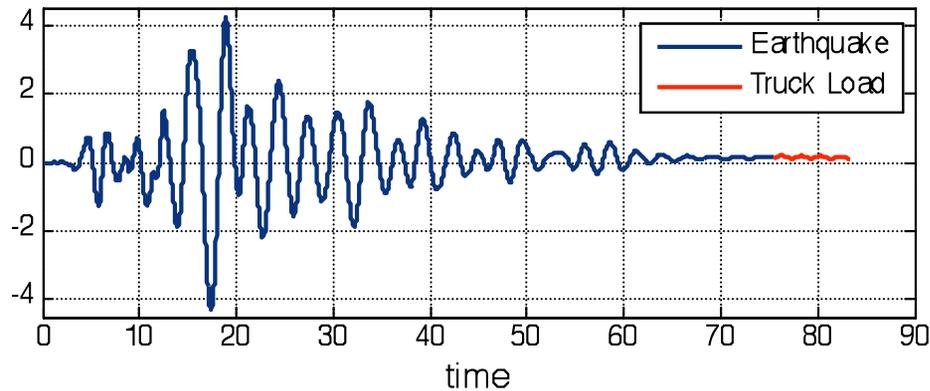
Results: Displacements



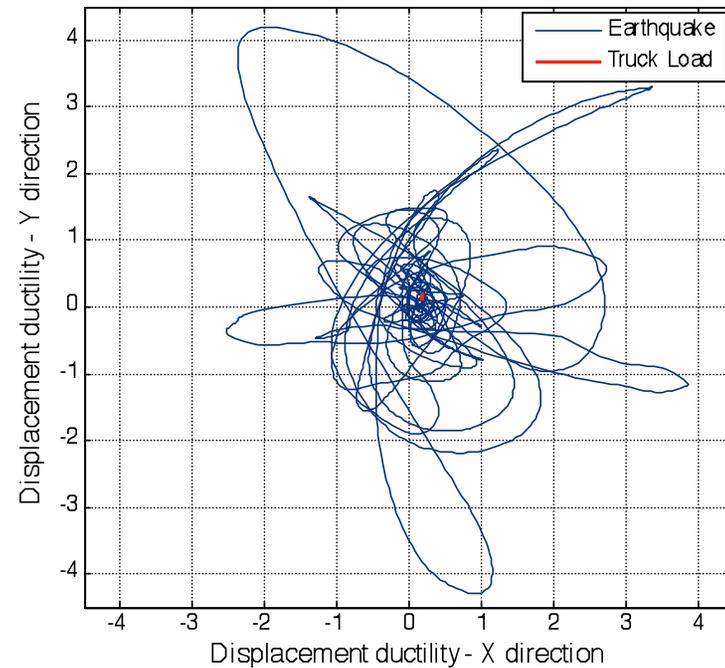
Normalized displacement at the top of the column 1 - X direction



Normalized displacement at the top of the column 1 - Y direction

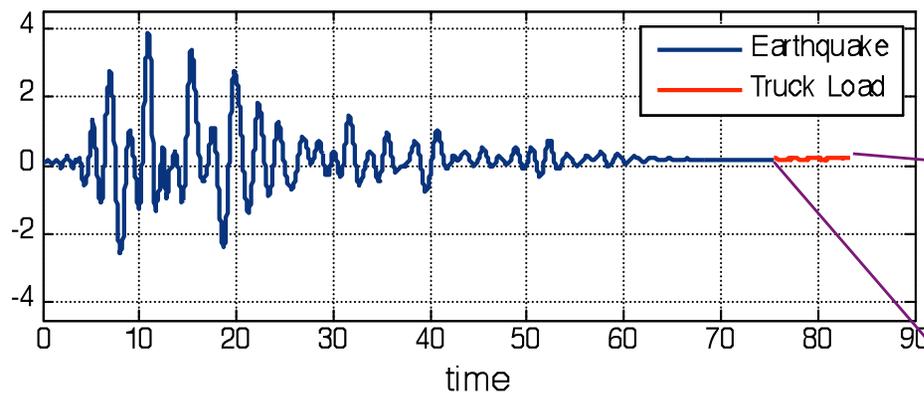


Displacement orbit at the top of the column 1

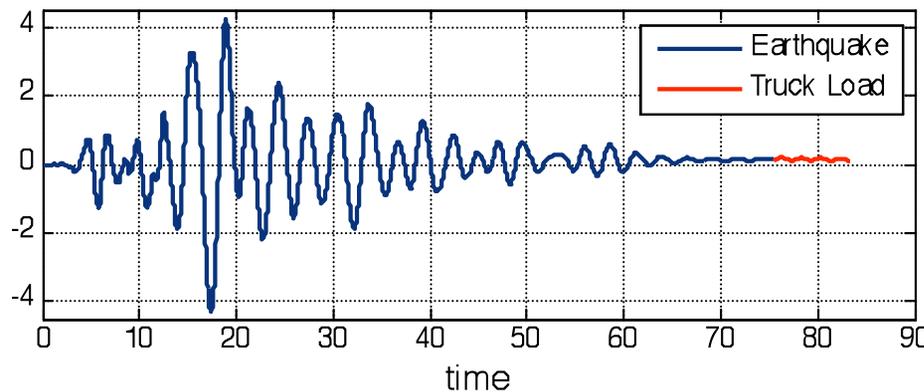


Results: Displacements

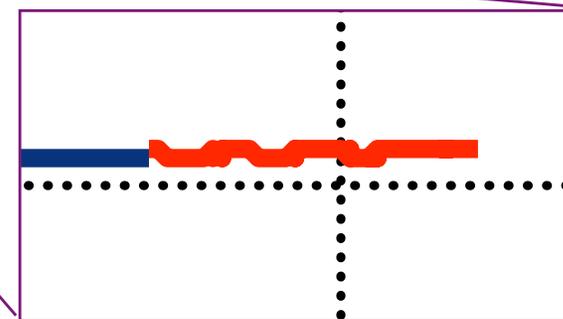
Normalized displacement at the top of the column 1 - X direction



Normalized displacement at the top of the column 1 - Y direction



The bridge holds the truck!



No hoops or bars fractured!

Evaluate Post-Earthquake Traffic Load Capacity

- ◆ Use the calibrated OpenSees model
- ◆ Method:
 - Run an earthquake (3 displ. components)
 - Record max. transverse drift
 - Push bridge sideways to a lesser residual drift (unless it is already there)
 - Place an HS-20 truck and increase its weight until bridge collapses
 - Repeat for the next earthquake

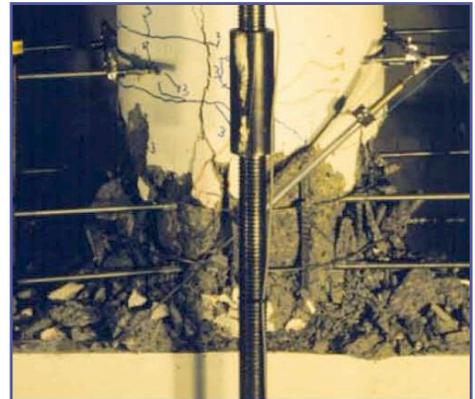
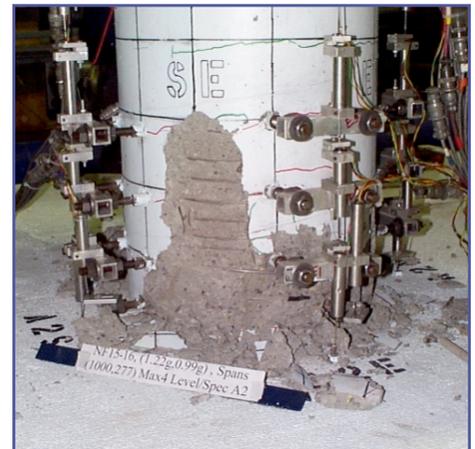
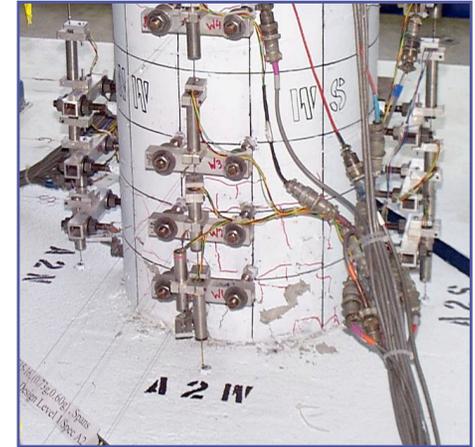
Post-Earthquake Truck Load Capacity

◆ Outcome depends on the state of the column after the earthquake:

1. No hoop or rebar failure in any of the columns

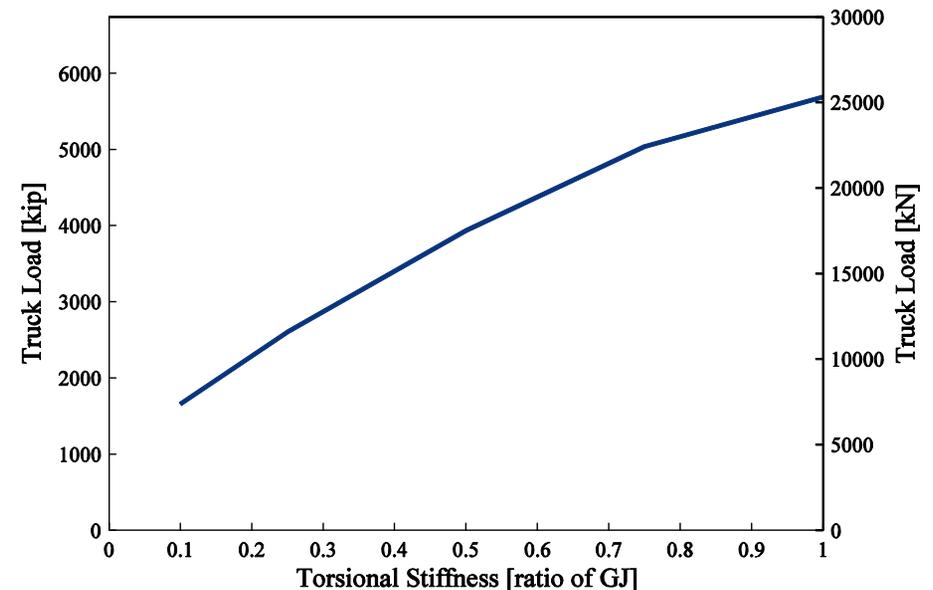
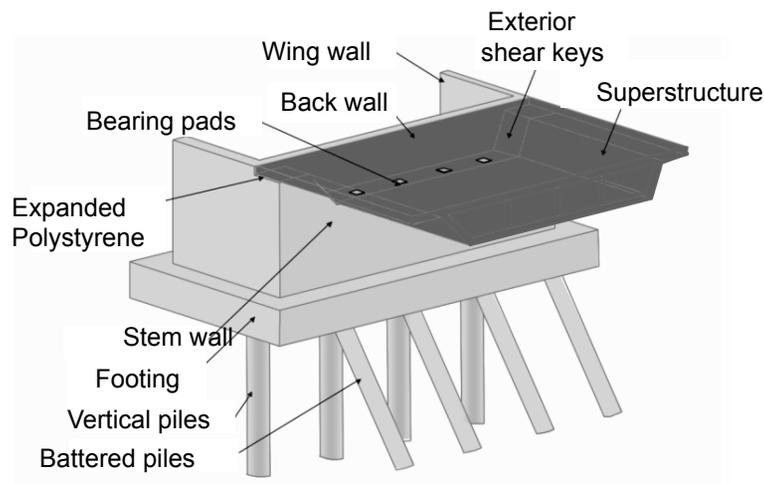
or

2. At least one column experienced hoop or rebar failure



Post-Earthquake Truck Load Capacity

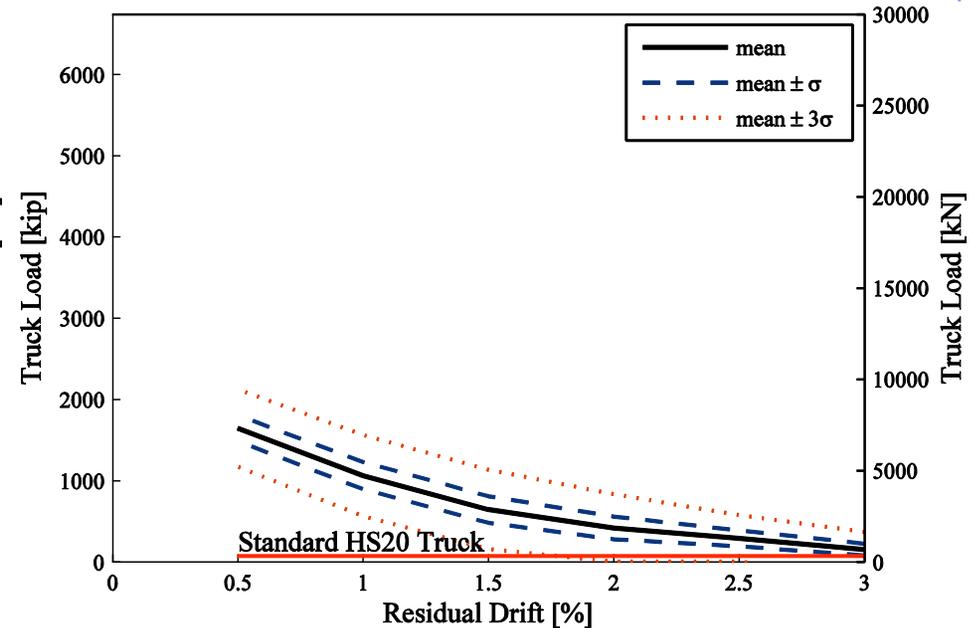
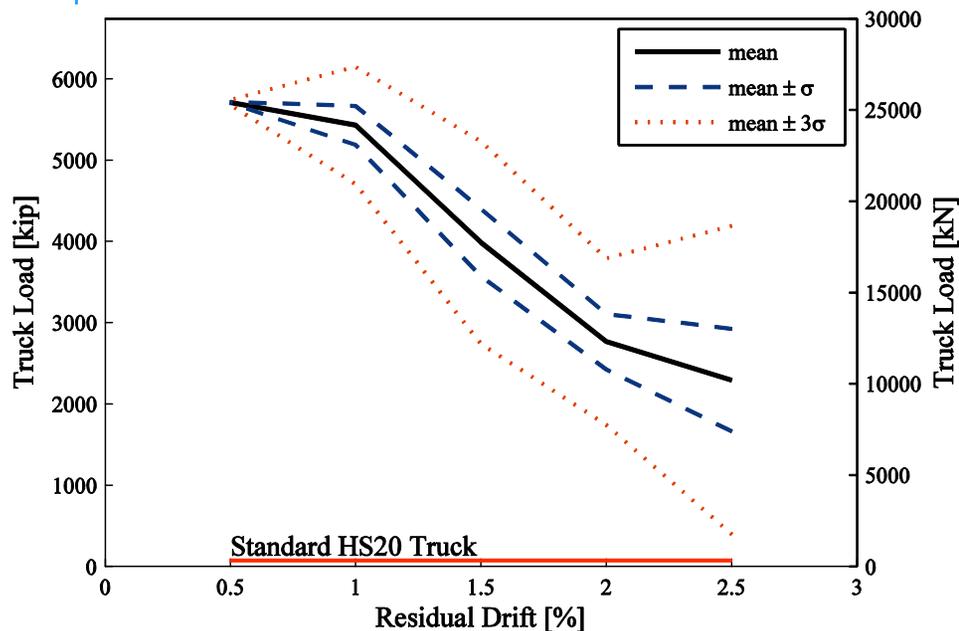
- ◆ Outcome depends on deck torsion restraint at the abutments:
 - No restraint: deck is free to twist
 - Fully restrained: deck cannot twist



No Column Failed

◆ Torsion restrained

◆ Torsion unrestrained

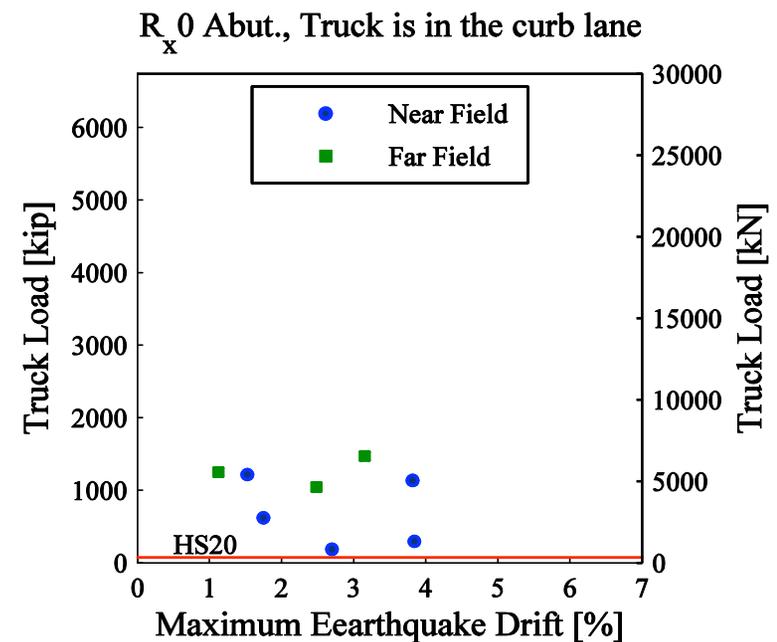
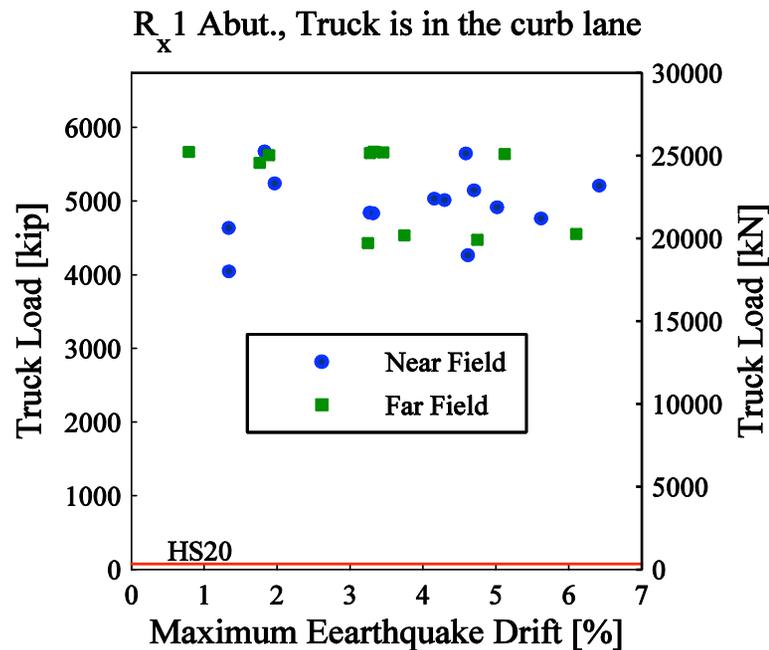


*One and three STD bands
about mean truck load capacity*

At Least One Column Failed

◆ Torsion restrained

◆ Torsion unrestrained

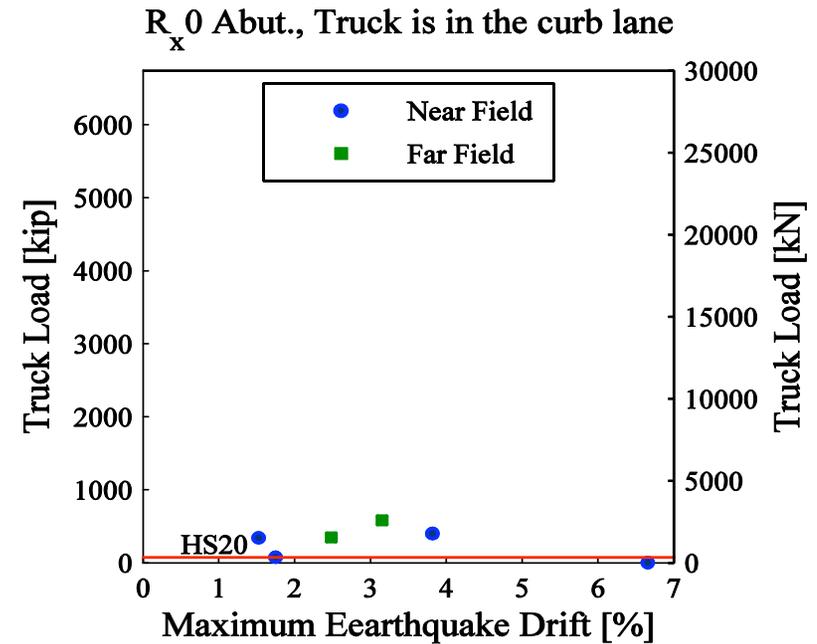
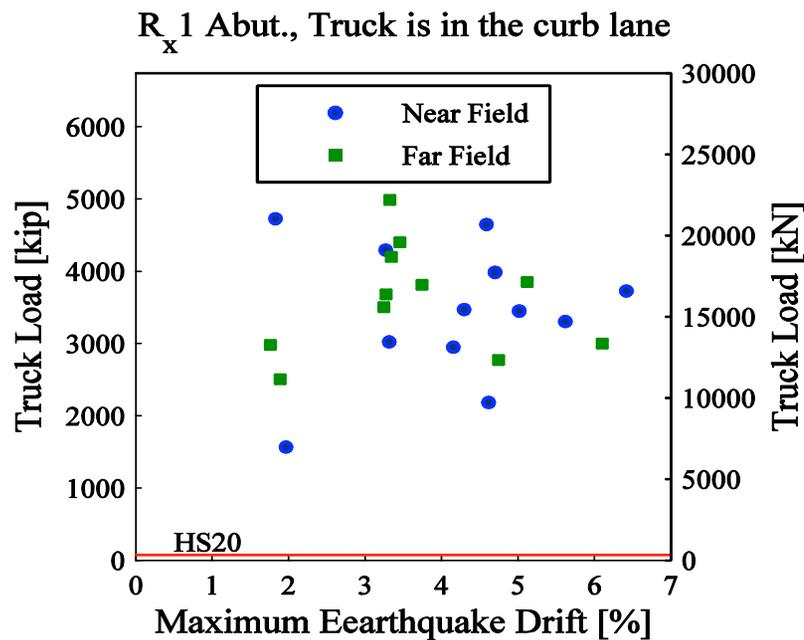


0.5% residual drift

At Least One Column Failed

◆ Torsion restrained

◆ Torsion unrestrained

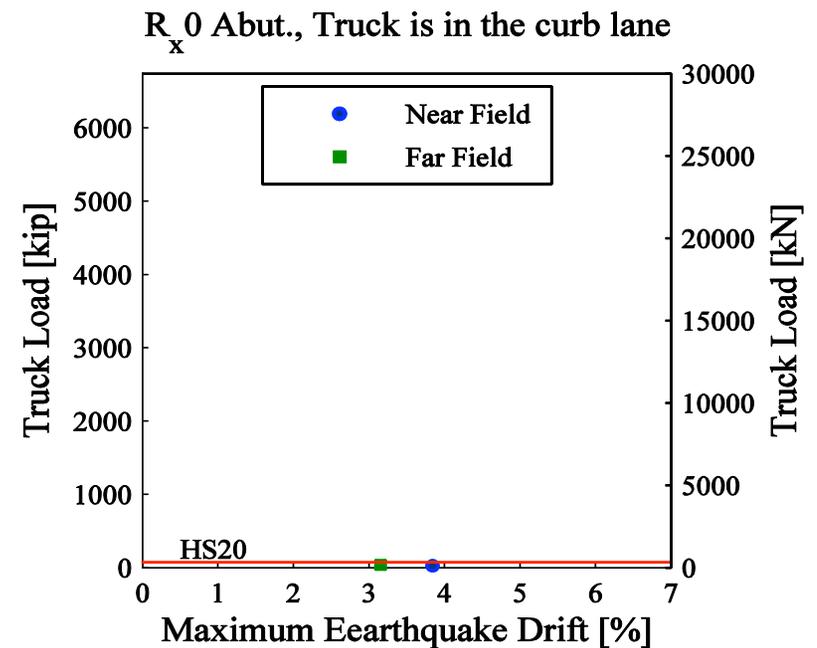
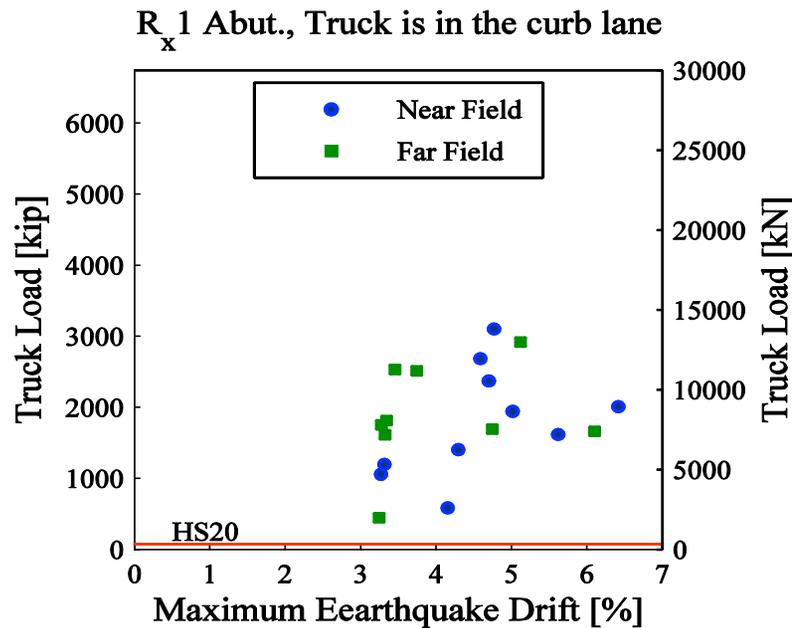


1.5% residual drift

At Least One Column Failed

◆ Torsion restrained

◆ Torsion unrestrained



3.0% residual drift

Findings

- ◆ If no column fails (no hoop or bar fracture is found), the bridge is reasonably safe for post-earthquake traffic loading
- ◆ If at least one column fails:
 - If the abutments:
 - ◆ Restrain deck torsion, the bridge may be used for emergency traffic
 - ◆ Provide no torsion restraint to the deck, the bridge must be closed

Conclusions

- ◆ Modern Caltrans standard ordinary bridges designed following 2004 SDC are reasonably safe for traffic after a design-basis earthquake:
 - Target displacement ductility is 4, no hoop or rebar fracture is expected
- ◆ Inspection should focus on:
 - Hoop and rebar fracture discovery
 - Abutment and deck bearing ability to restrain deck torsion

Thank you!

Caltrans and PEER
sponsored the work behind
this presentation.

