SEISMIC CONNECTIONS IN PREFABRICATED SUPERSTRUCTURES

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Caltrans-PCMAC Precast Bridge Workshop

Outline

- Scope
- Use of I-girders with Inverted-tee bent Cap
- Prototype bridge
- Experimental investigation
- Conclusions

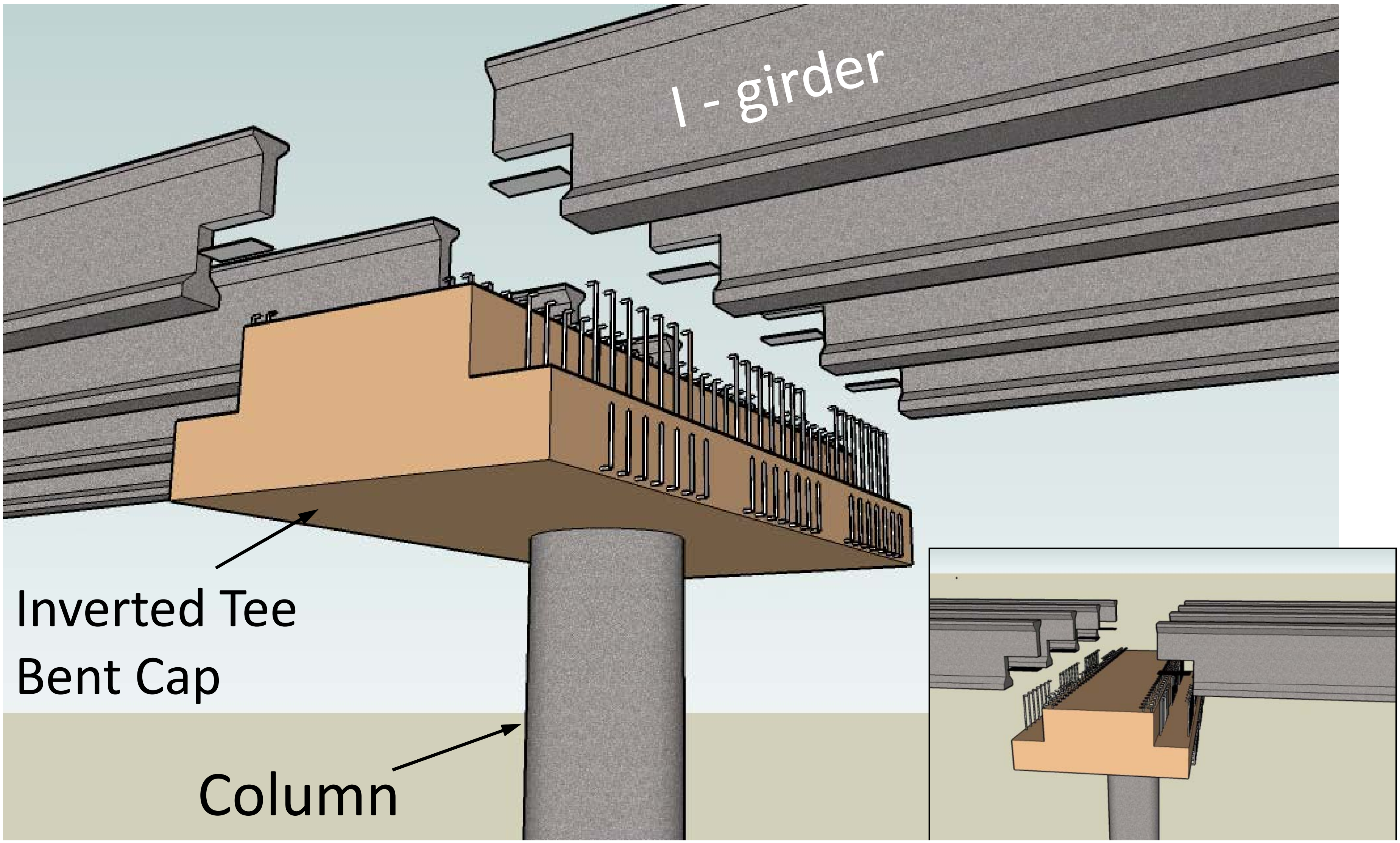
Scope

- To understand the true seismic behavior of inverted tee cap-to-girder connections as currently used and the impact of such connections on the system response using both analytical and experimental means
- To mitigate the potential seismic hazard associated with these bridges

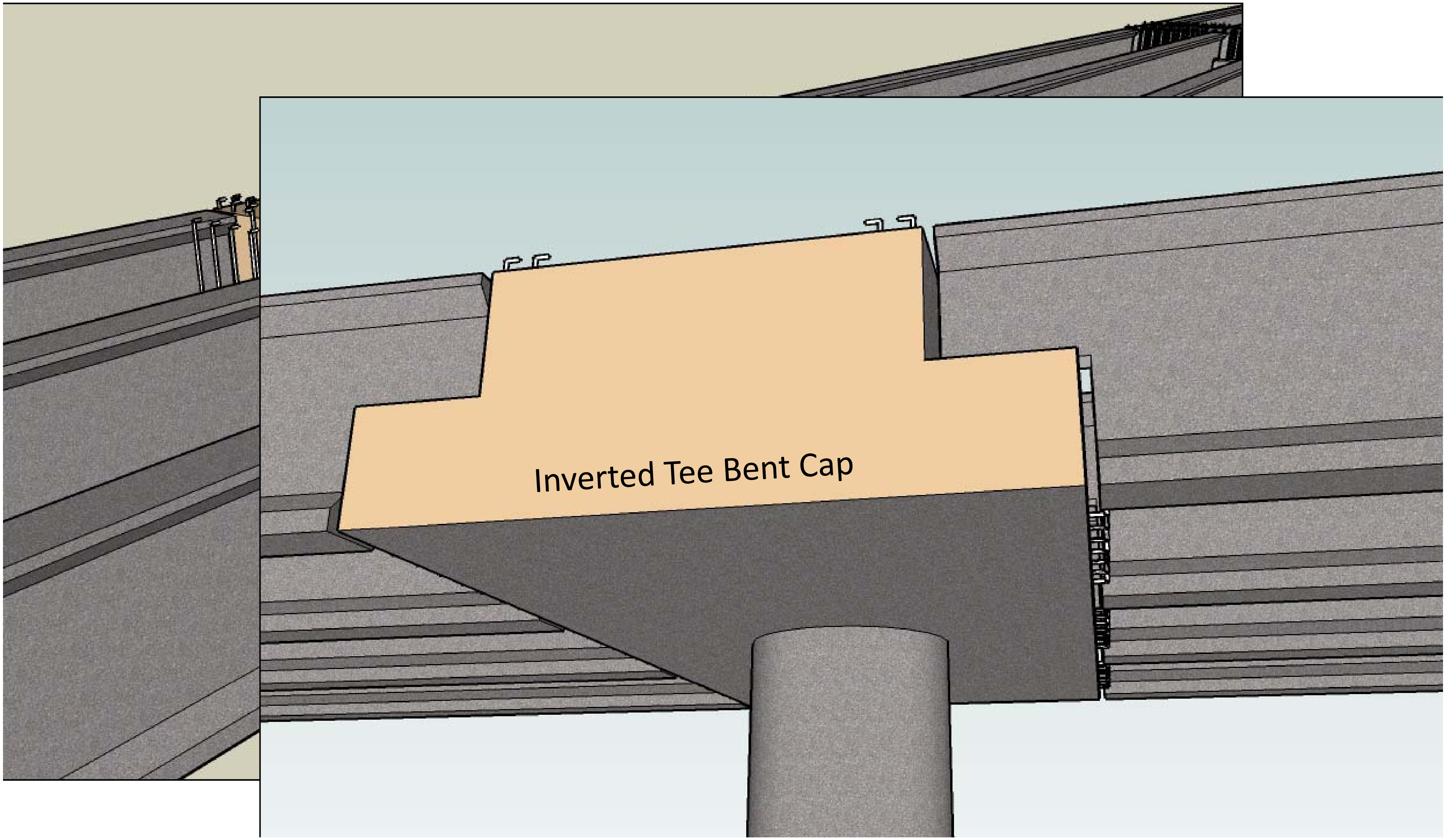
Precast concrete girders in seismic regions

- Advantages of precast concrete
  - Shop construction (improved quality, reduced cost)
  - ABC (reduced field time, reduced traffic divergence, reduced noise and air pollution)
- However, not widely used in seismic regions
  - Lack of a proven design methodology
  - Lack of experimental validation of structural details/connections
  - I-girder/Inverted tee system is not cost effective

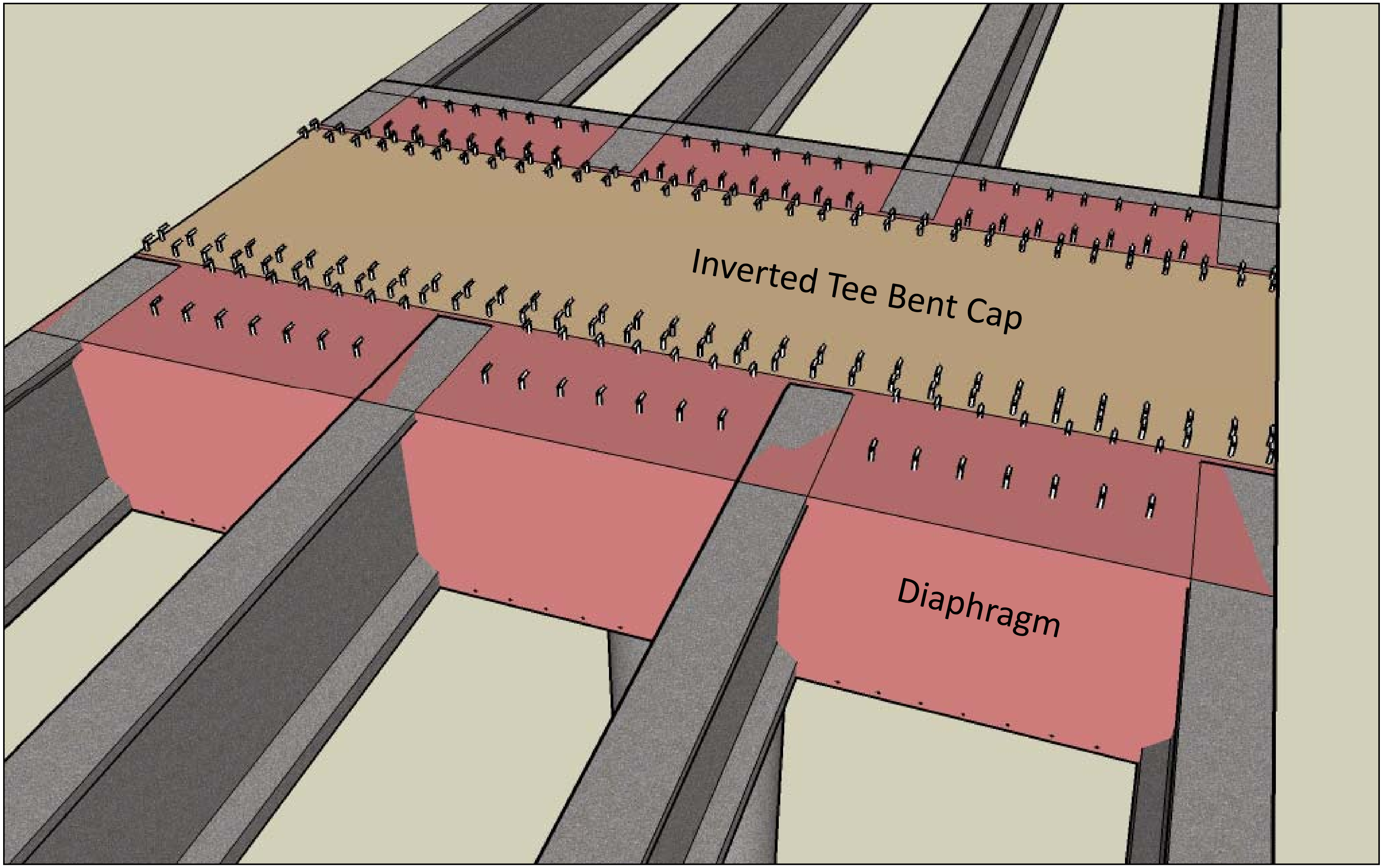
I-girder with inverted-tee bent cap



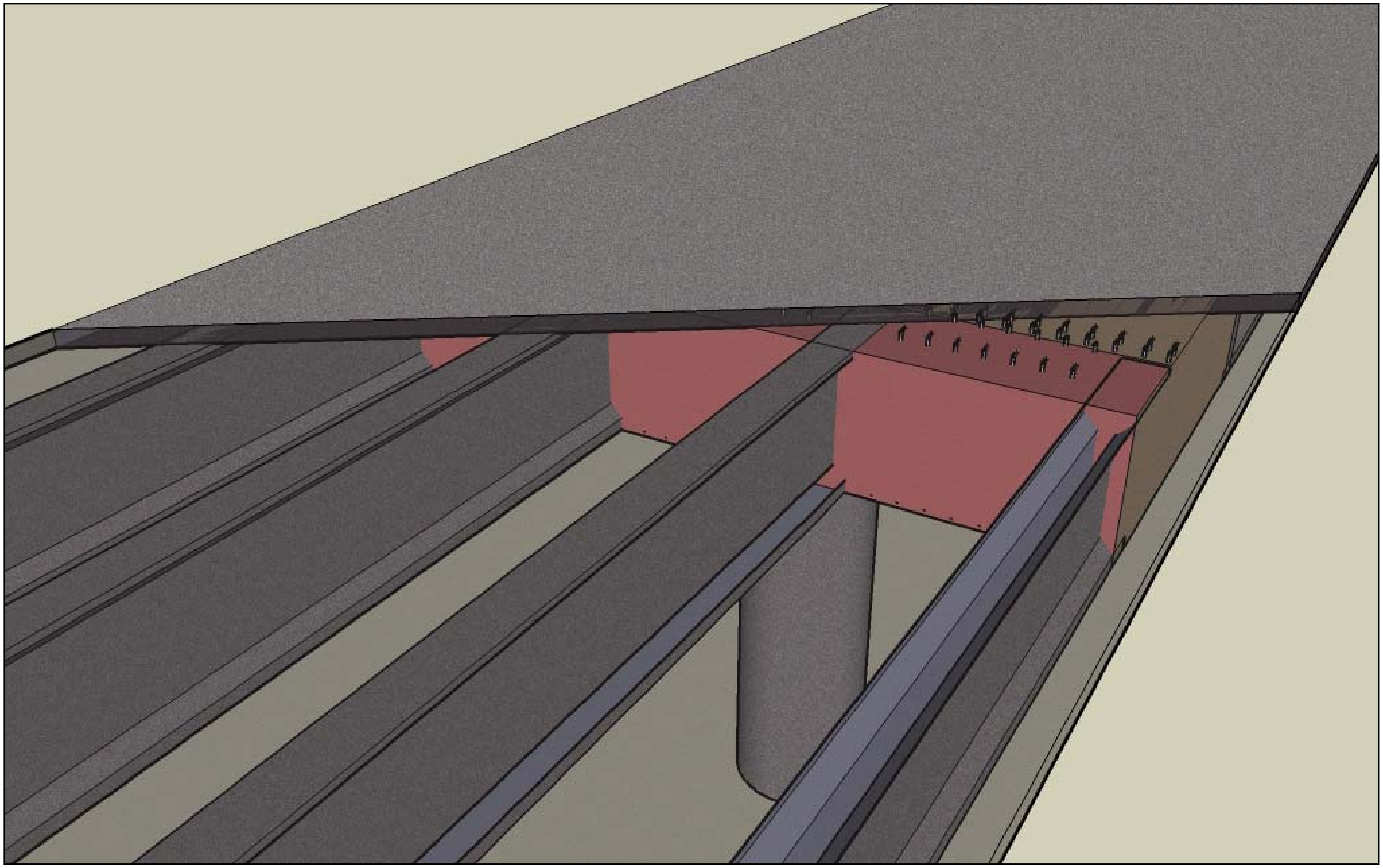
Connection Details



Diaphragms Added



Deck Added



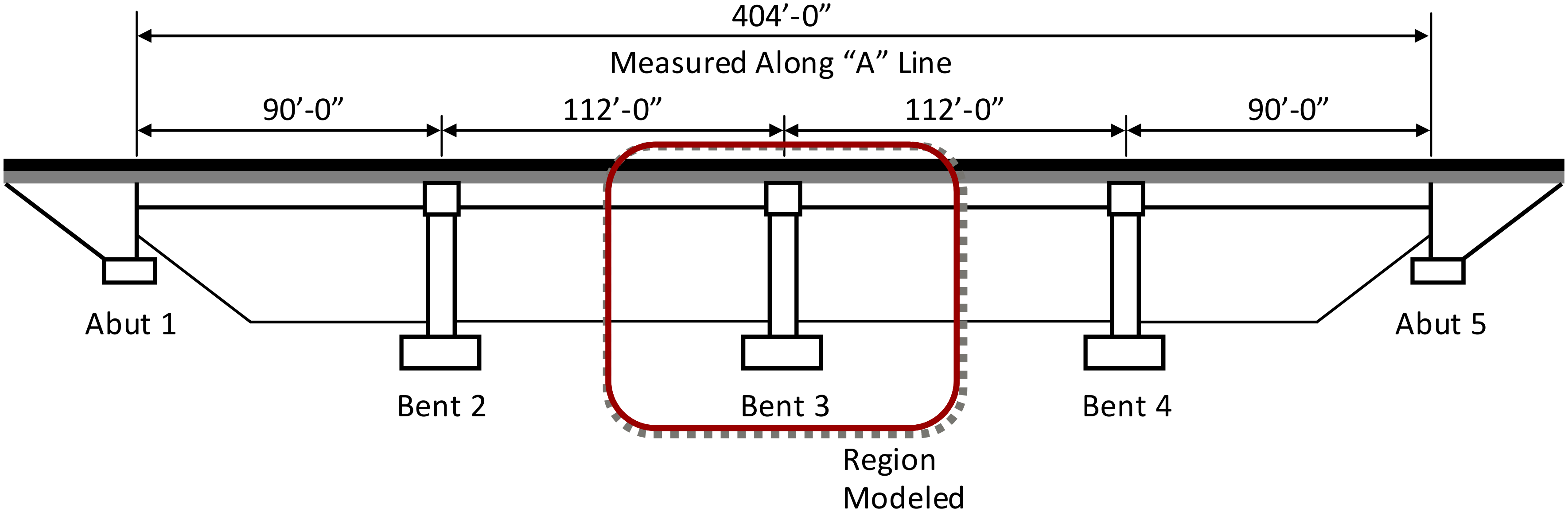
I-Girder/Inverted Tee Connection

- As-built condition
  - Assumed to degrade to a pin connection (due to lack of positive moment connection between the cap and girders)
  - A plastic hinge at the column top is not expected
  - Thus requiring a larger diameter columns and large foundations making it less cost effective in comparison to a cast-in-place alternative

I-Girder/Inverted Tee Connection

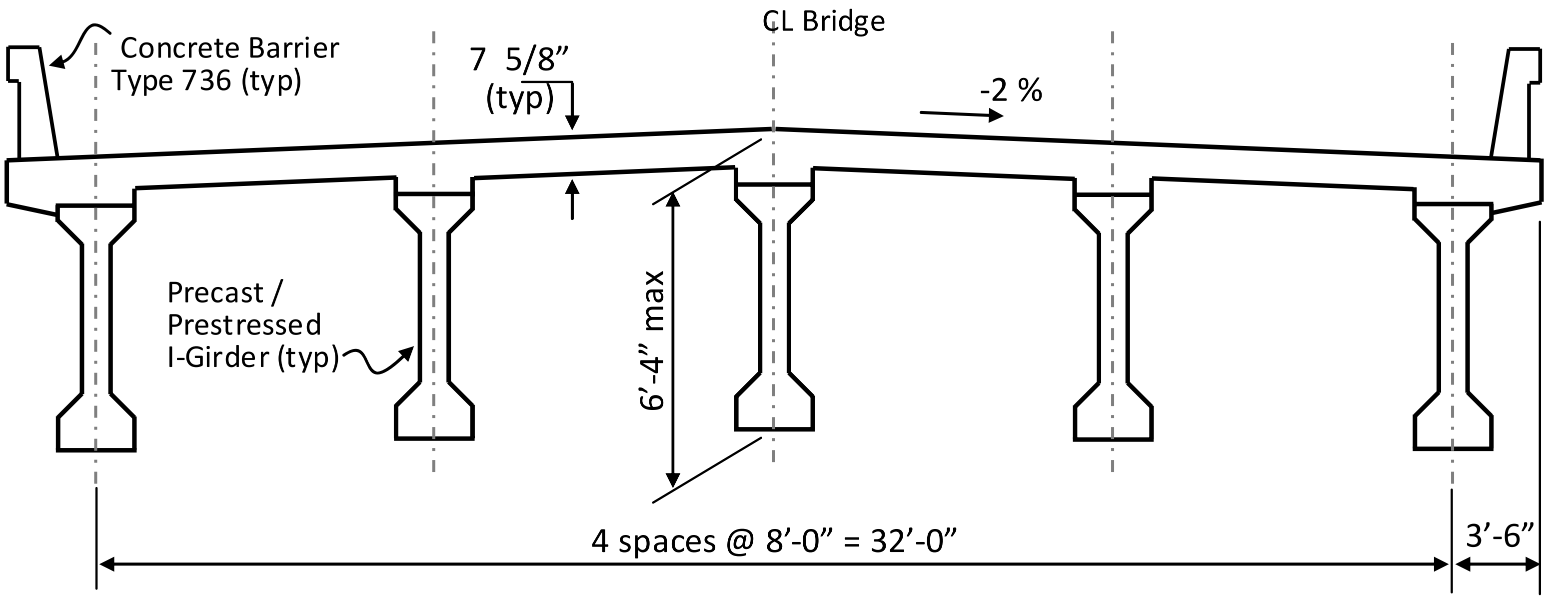
- Contribution of research
  - Analysis shows the as-built connection will act more like a fixed connection due to dowel bars going through the girders and integration of the connection using diaphragm and deck
  - An improved connection detail was explored as a possible detail for future bridge
  - After considering several options, the connection performance was improved by running grouted unstressed tendons in the bottom flange of the girders through the cap for the entire bridge length
  - Make this design option cost effective by allowing formation of a plastic hinge at the column top

Prototype Bridge



- Four spans (no skew)
- Total length = 123 m
- 34 m interior spans
- AASHTO LRFD with CA amendments
- Caltrans SDC
- Caltrans Bridge Design Aids

Prototype Bridge - Section

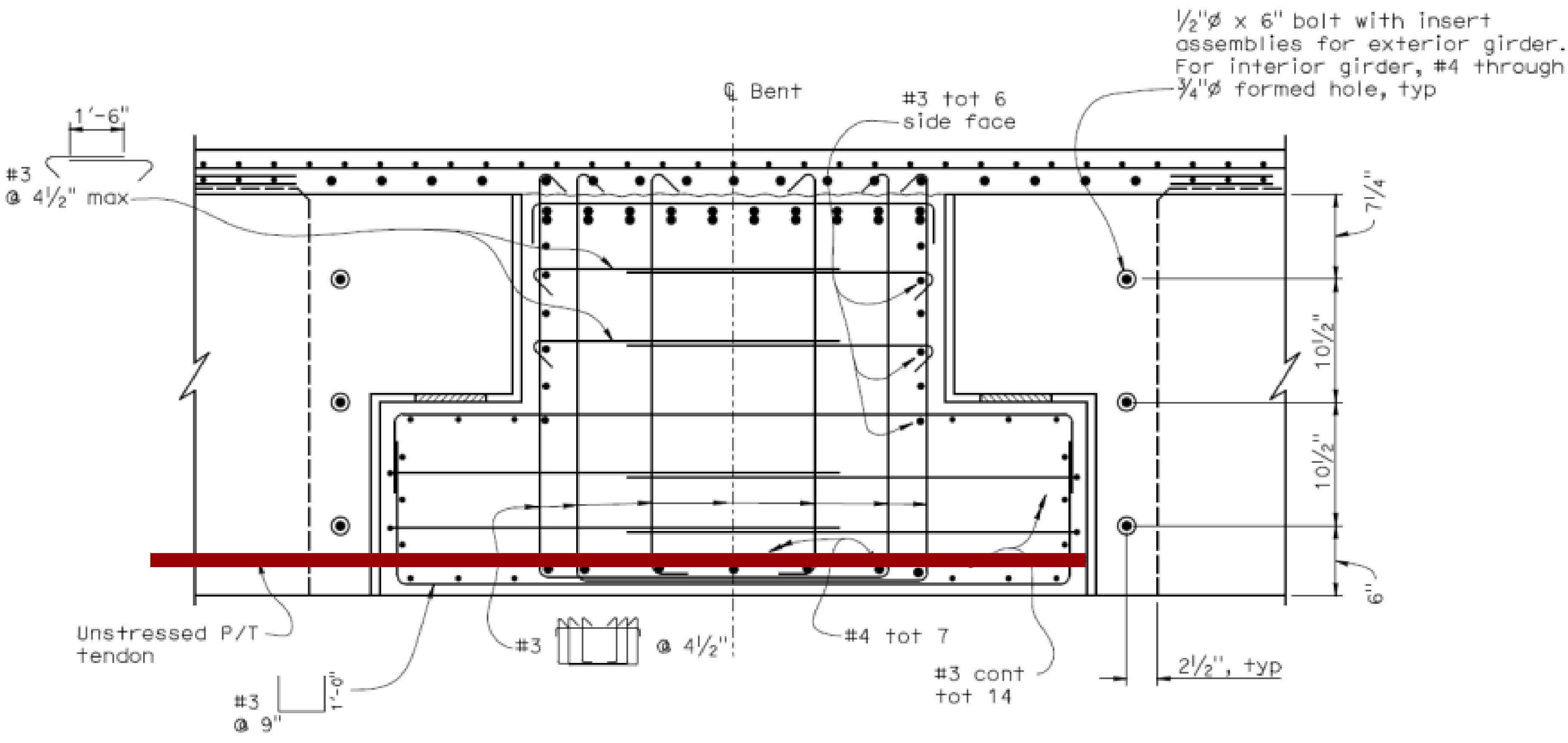


- Designed by PBS&J, verified by ISU
- SS Depth = 1.93 m
- D/S = 0.0565
- 5 precast I-Girders with 1.67 m depth
- CONSPAN for service load analysis/design

Test Unit Configuration

- Center portion of prototype structure
- 50% dimensional scale
- Single column with inverted-tee cap beam
- Superstructure of five I-girders overlaid with deck
- As-built girder-to-cap connection on one side of cap beam and improved connection on other side

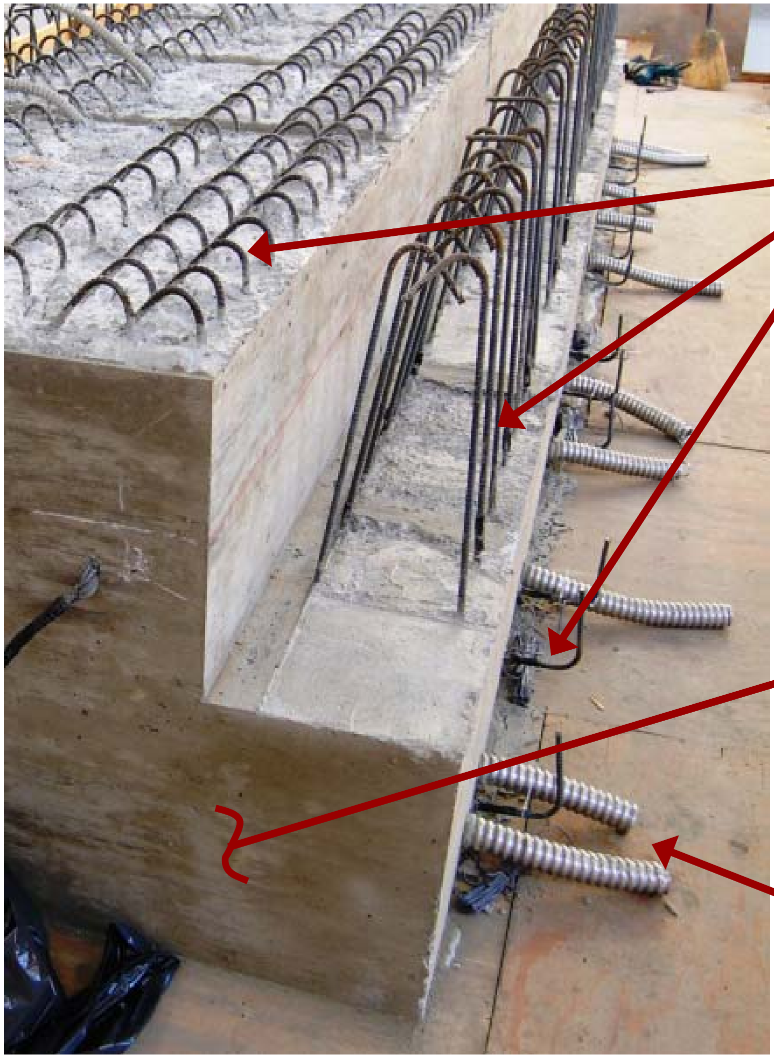
Test Unit - Connection Details



Improved **As-built**

Construction of Girders and Cap

Inverted Tee



Connection reinforcement

Inverted-tee cap beam

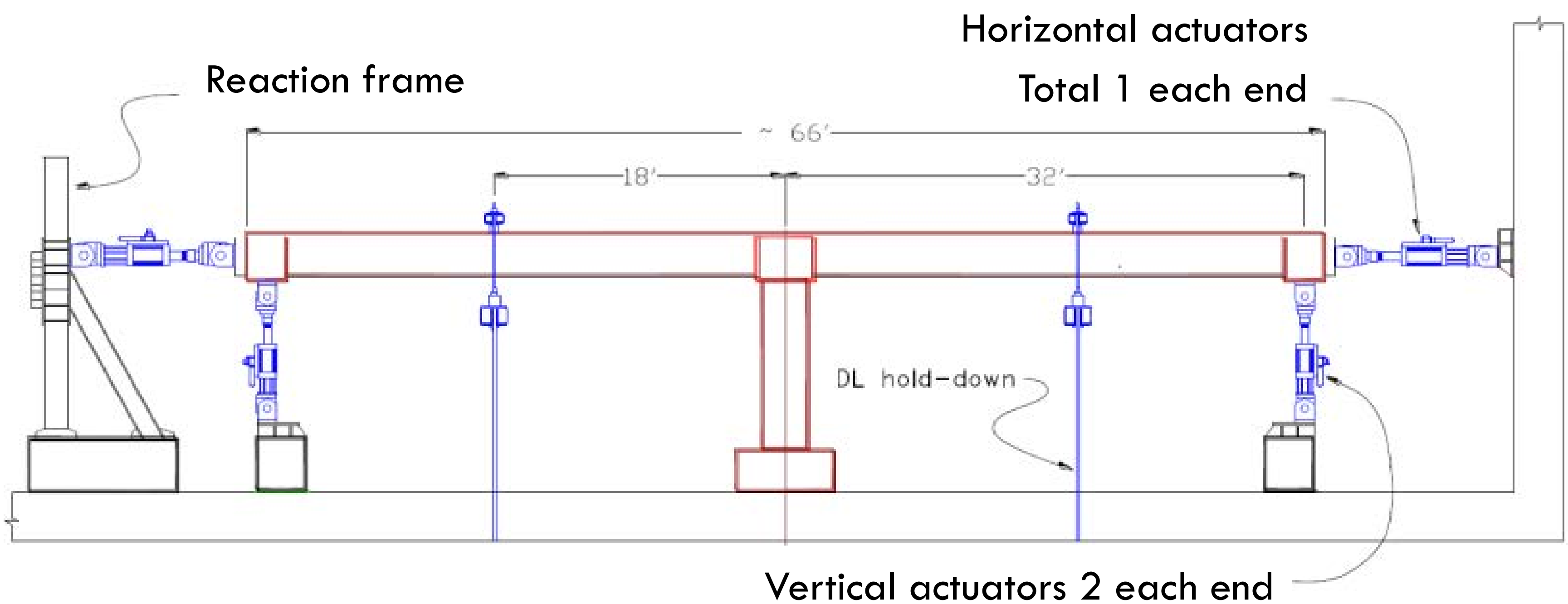
Strand ducts

Construction at UCSD Laboratory

Test Phases

- **Phase I Testing**
  - Horizontal seismic testing
  - Evaluate system performance
  - Verify if both connections are adequate to form a plastic hinge at the column top
- **Phase II Testing**
  - Vertical load/displacement
  - Full exercise the girder-to-cap connections

Phase I Configuration

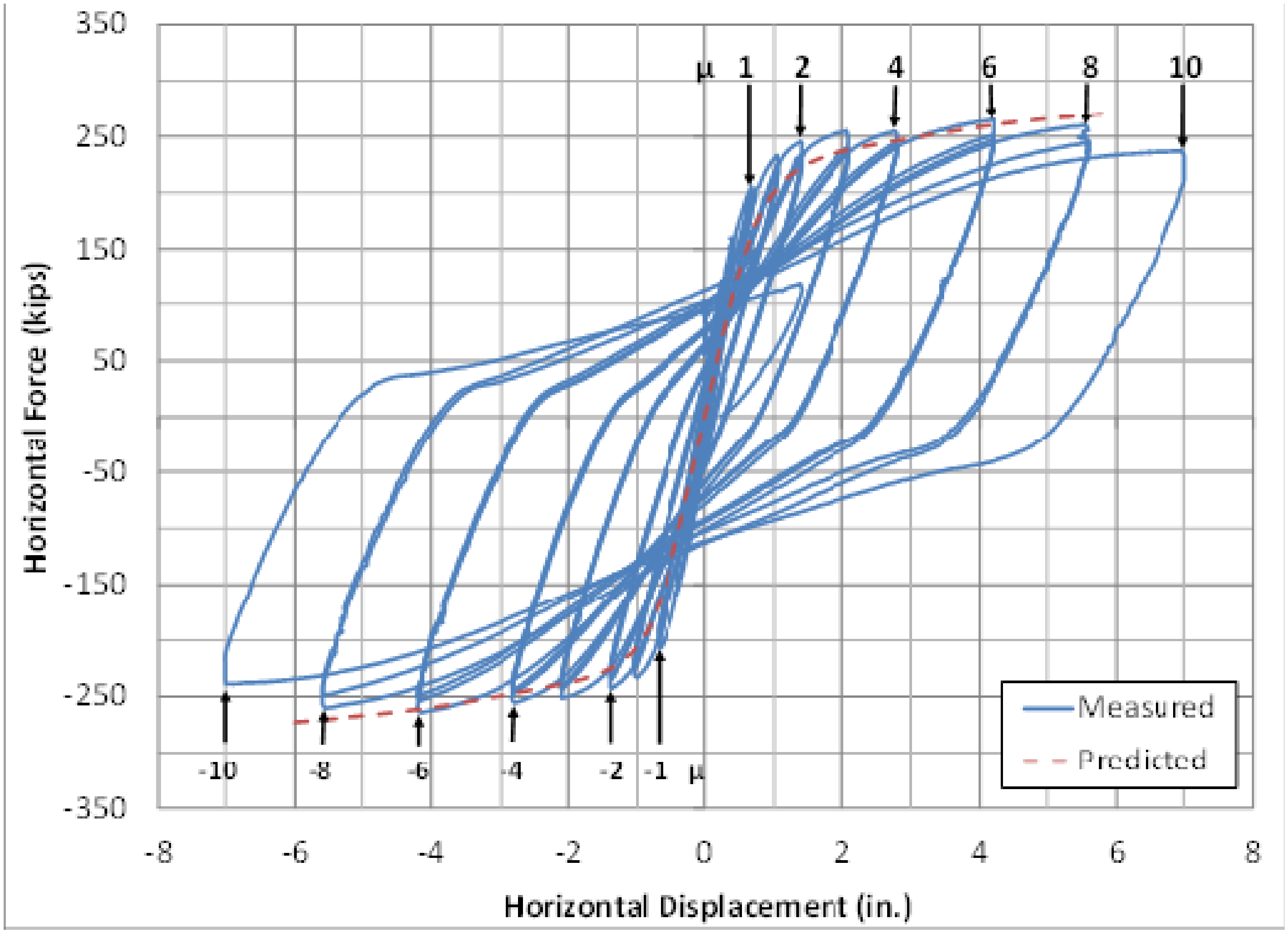


- Length of test unit was 66 ft
- Tie-downs and four vertical actuators simulated gravity effects
- Four horizontal actuators simulated the seismic action

Phase I Configuration

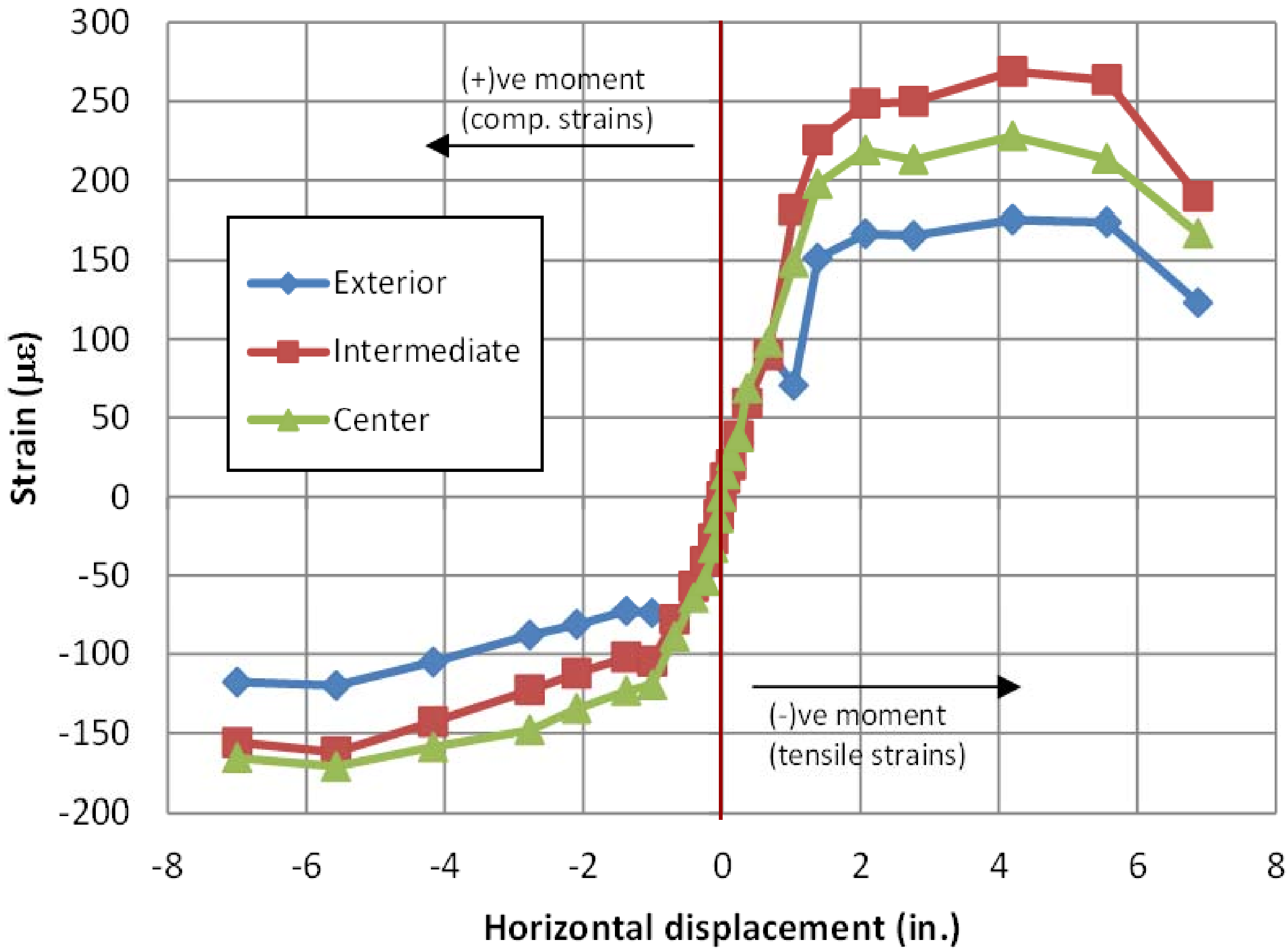
"Caltrans" "inverted tee"

Force-Displacement Response



- Good comparison with SAP analysis
- Results converge as structure softens through cracking and yielding
- Similar behavior in both directions

Girder Load Distribution (Improved Connection side)



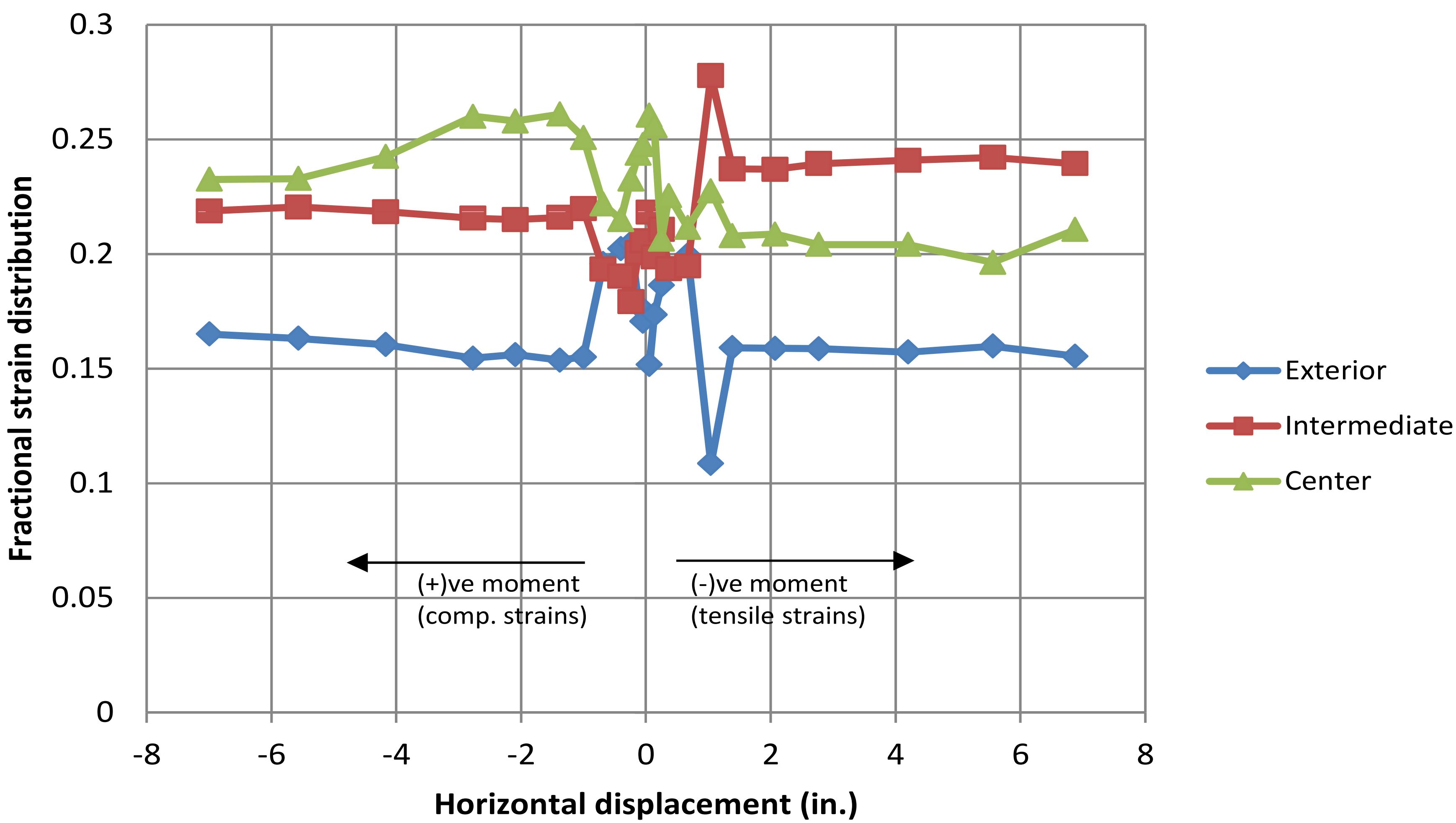
- Center: 20%
- Intermediate: 25%
- Exterior: 15%
- Compare to analysis:

  22.8%

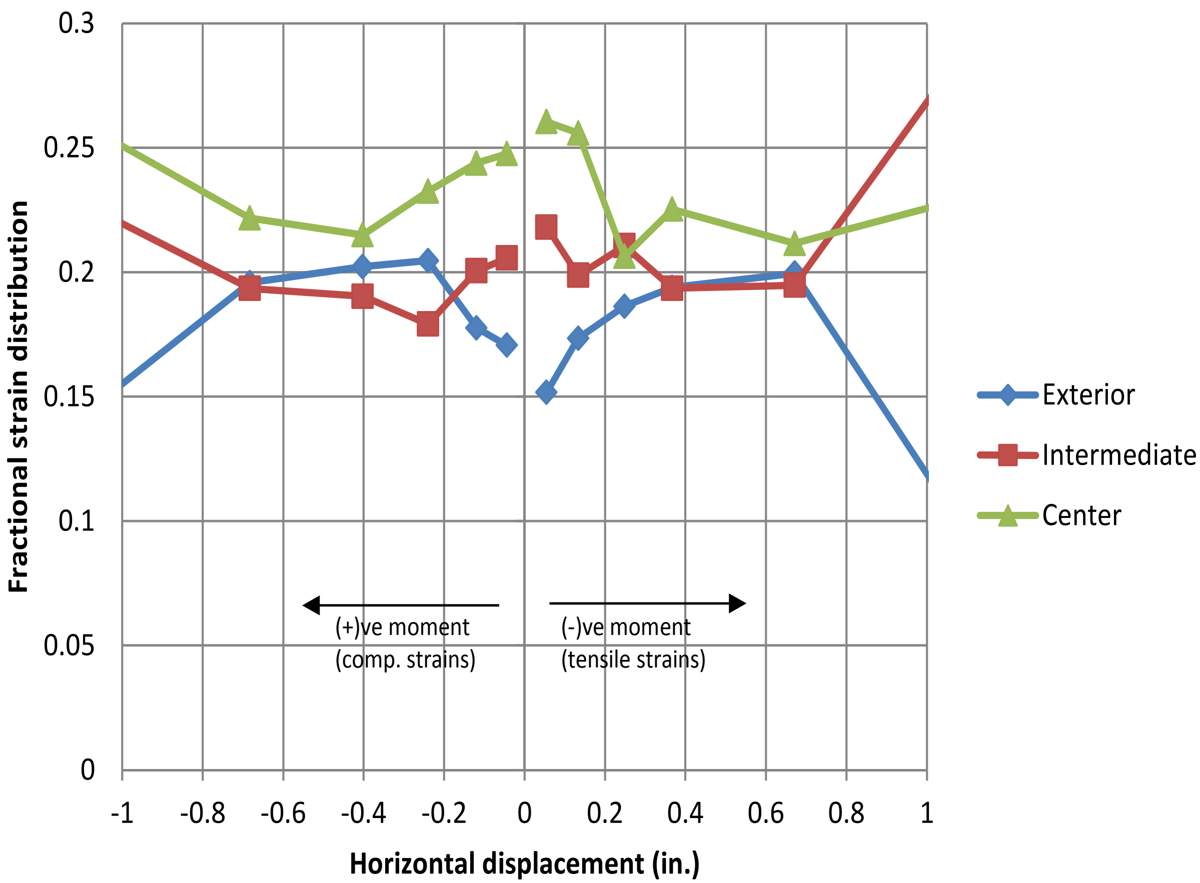
  21.2%

  17.4%

Girder load distribution



Girder load distribution (Low load levels)

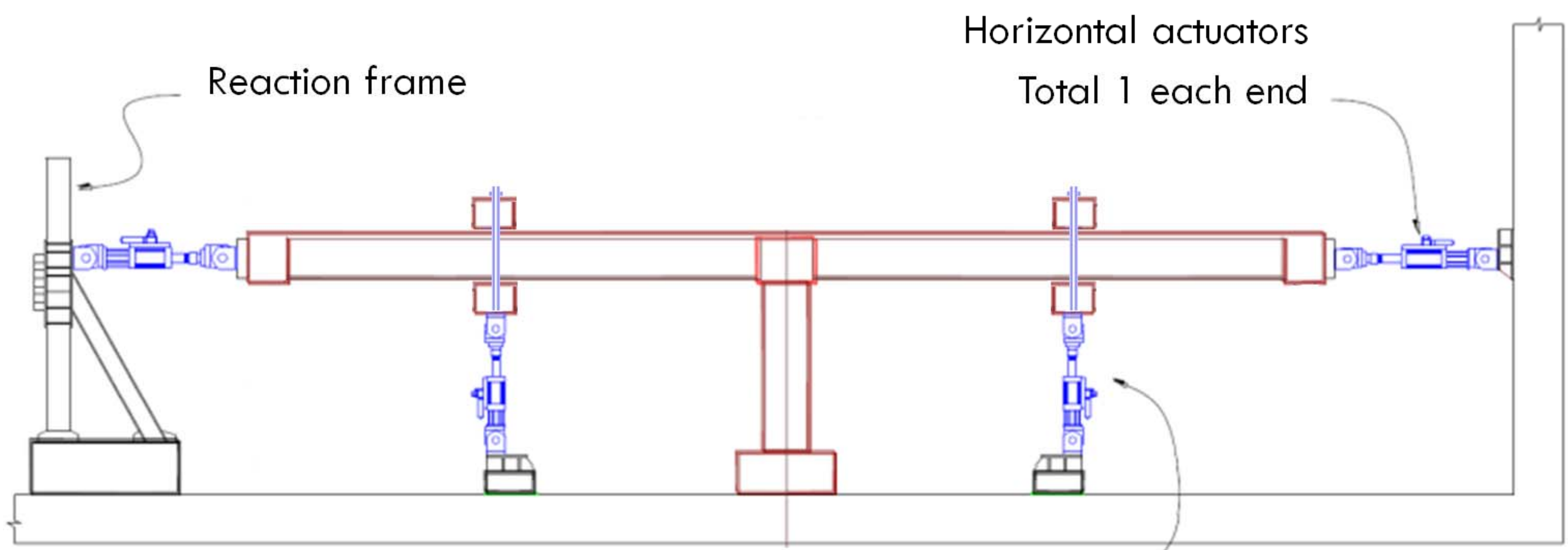


- First step to right of zero corresponds to +0.25 Fy
- Already significant load distribution occurring at this point
  - Cen: 26.0%
  - Int: 21.8%
  - Ext: 15.1%

Phase I General Performance

- Excellent overall performance for system and both as-built and improved connections
- Displacement ductility of 10 ($\Delta_h = \pm 7$ in.)
- Little degradation of positive as-built connection (contrary to current design guides)
- Very little degradation to improved connection
- As-built connection: behaved as fixed; Minimal measures required to ensure satisfactory performance of existing inverted-tee – I-girder bridges

Phase II Test Configuration



- Vertical load/displacement
- Full exercising of girder-to-cap connections
- Horizontal actuators – used for stability purposes

Phase II Testing


0E
Caltrans
1858 150 2008
IOWA STATE
UNIVERSITY
UCSD
Jacobs
Structural
Engineering
PBS&J

Phase II General Observations

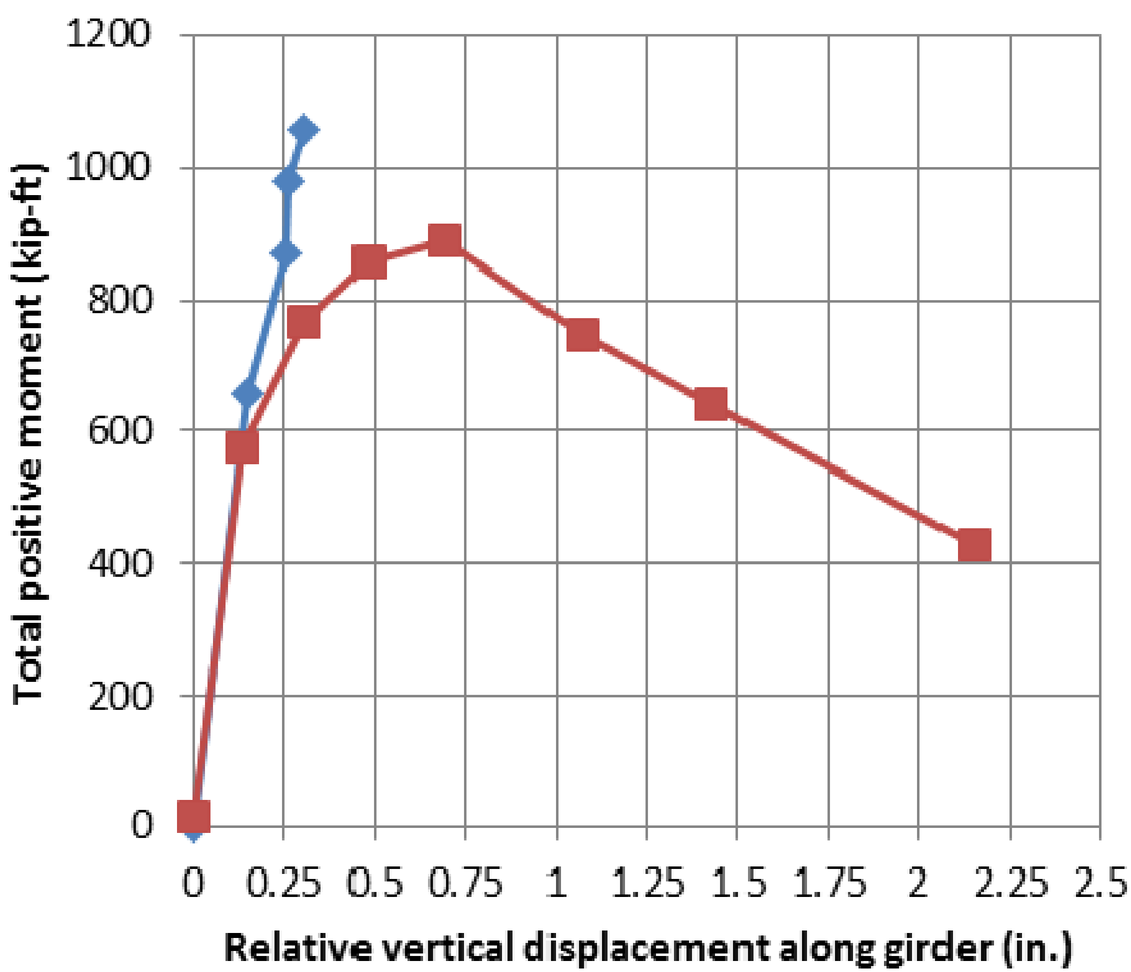
- Maximum displacements:
  - Positive = 3 in. (upward)
  - Negative = 6 in. (downward)
- As-built connections exercised to full capacity
- Did not achieve full quantification of improved connection due to failure of the as-built connection and column hinges

Phase II – As-built Connection Region

Opening up of as-built connection under positive-moment loading

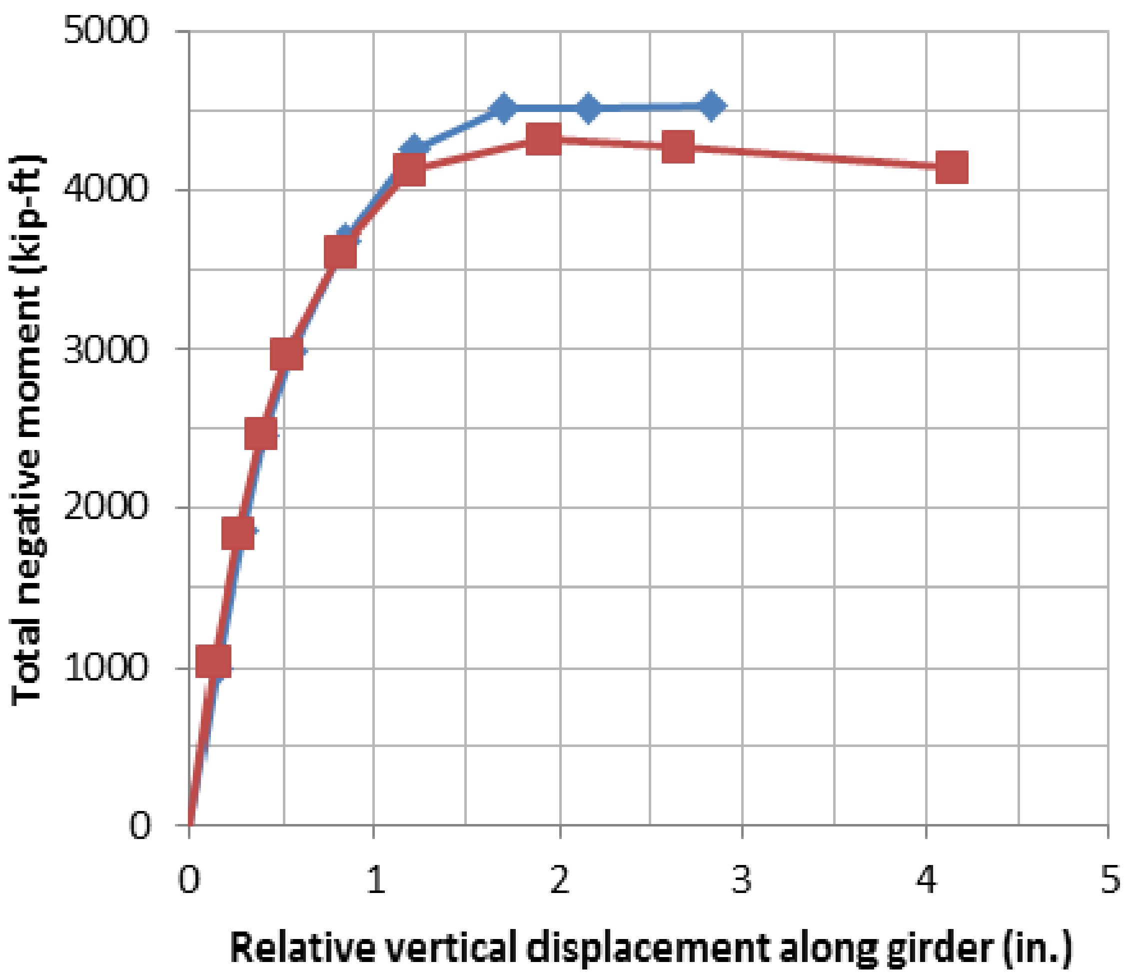
End of test

Phase II
Positive moment vs. displacement



- Noticeable difference between improved and as-built
- Improved: elastic and higher moment
- Similar stiffness in elastic region

Phase II
Negative moment vs. displacement



- Difference more subtle
- Decrease in strength on as-built side
- Larger displacements for as-built side reflect the observed deterioration

Conclusions

- As-built connection behaved as a fully continuous connection during horizontal seismic testing, but this detail is not recommended for new bridges
- Only tops of columns in as-built bridges require retrofitting to prevent premature column damage, but note that
  - column shear demand will be increased
- Improved connection provided
  - dependable behavior under both positive and negative moments
  - an integral connection design to develop a plastic hinge in the top of the column
  - a means to promote ABC of bridges in seismic regions

Thank You!

Acknowledgements

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