

Lessons from Biaxial Shake Table Studies of A Two-span ABC Bridge System with Pocket and Socket Connections

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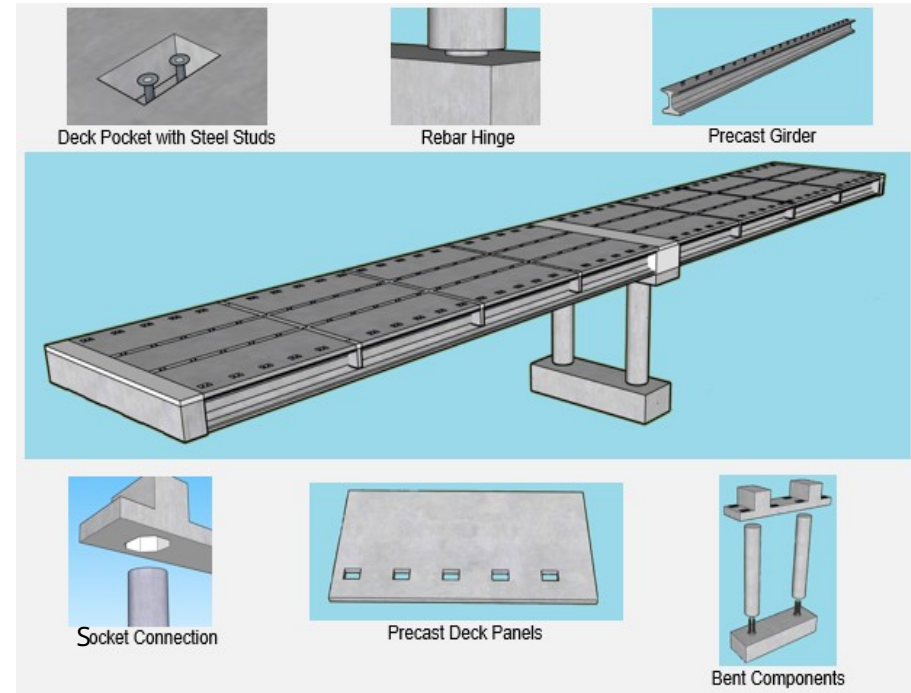
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Integrating Six ABC Connections in Three Bridge System Models

Today's Presentation: Bridge with Socket and Pocket Column Connections

Selection of ABC Connections

- Six ABC connection types were incorporated in this study joining...
 1. Columns to footing socket type
 2. Columns to cap beam pocket type
 3. Girders to cap beam
 4. Deck panels over pier
 5. Deck panels and girders
 6. Deck panels to deck panels
- Utilized information from past research on individual connection types



OBJECTIVES

Investigate the seismic response of a large-scale bridge system that integrates six ABC connection types that individually have performed well according to past research

Method of testing: Earthquake simulated on shake tables

Type of motions: Bidirectional, horizontal

Materials: Conventional concrete, mild steel, and ultra high-performance concrete (UHPC)

Capacity Protected (**Green**) vs Energy Dissipating (**Red**) Bridge Elements

Capacity Protected – No inelastic deformation allowed
Energy Dissipating– Plastic hinging is expected and desired

All connections

Column (bases) to footing socket type

Column (tops) to cap beam pocket type

Girders to cap beam

Deck panels over pier

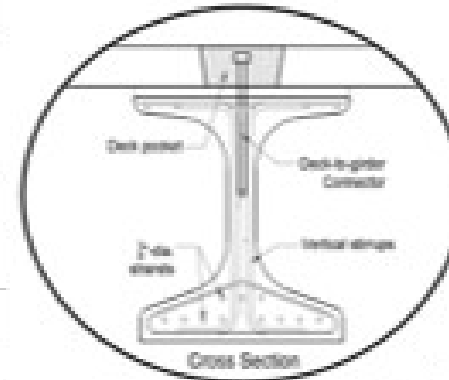
Deck panels and girders

Deck panels to deck panels

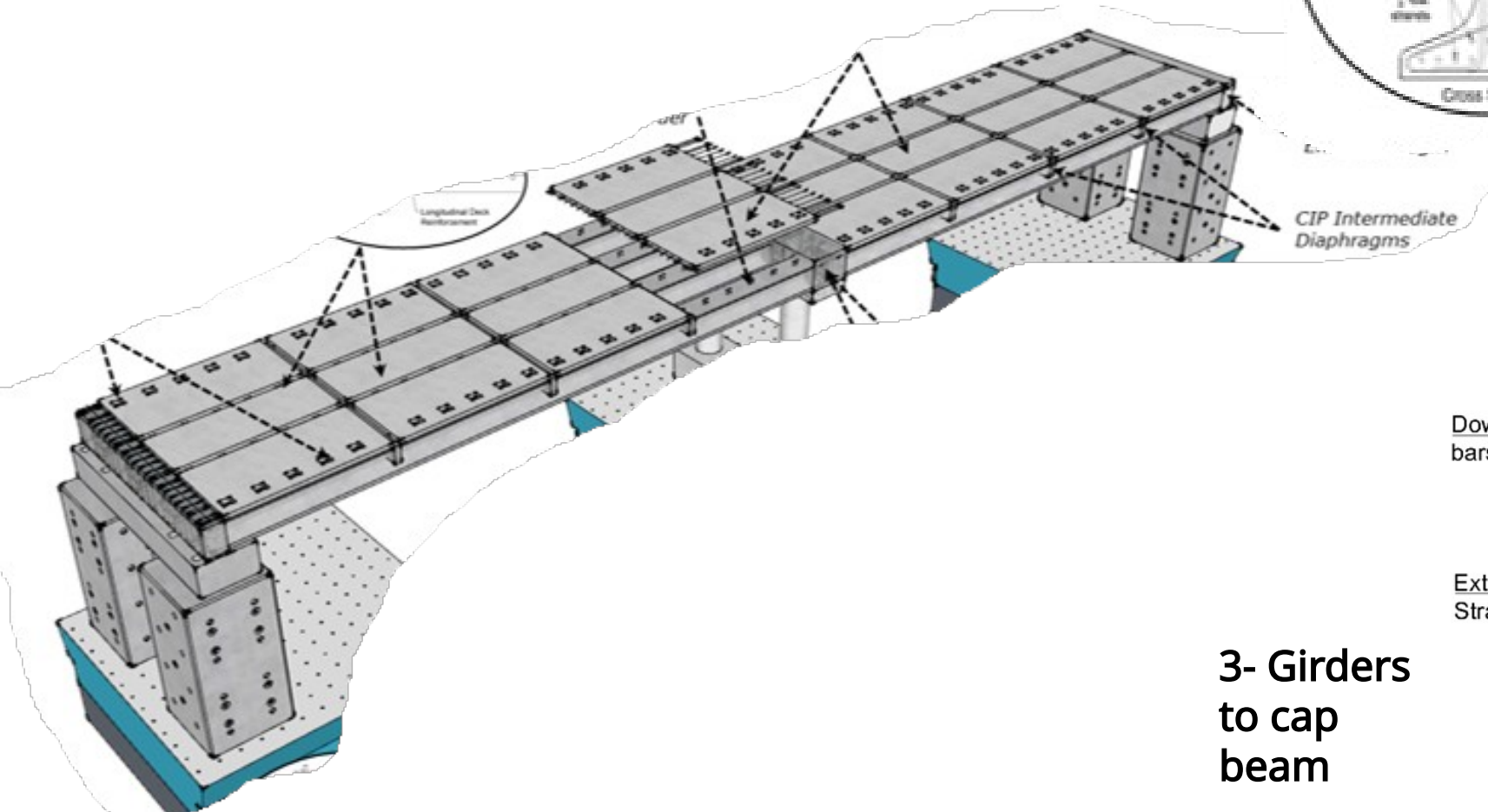
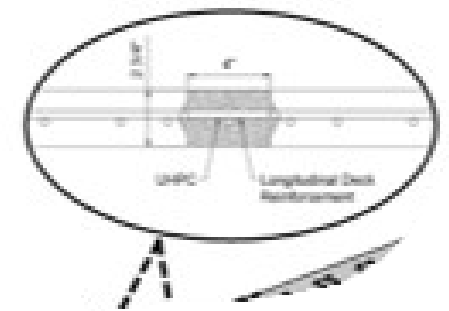
Capacity Protected Bridge Elements

- 1- Deck panels and girders
- 2- Deck panels to deck panels
- 3- Girders to cap beam
- 4- Deck panels over pier

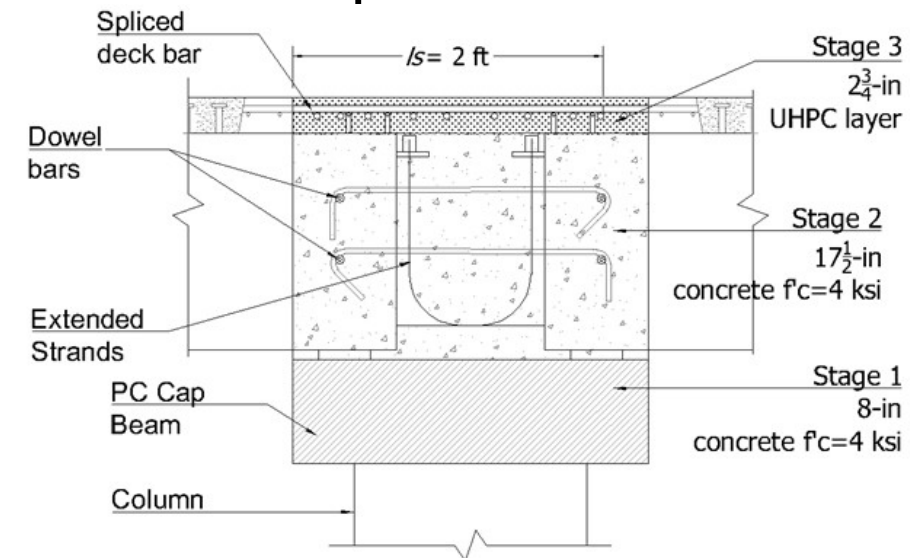
(1) Deck-to-Girder Connection



(2) Deck Panel-to-panel Connection

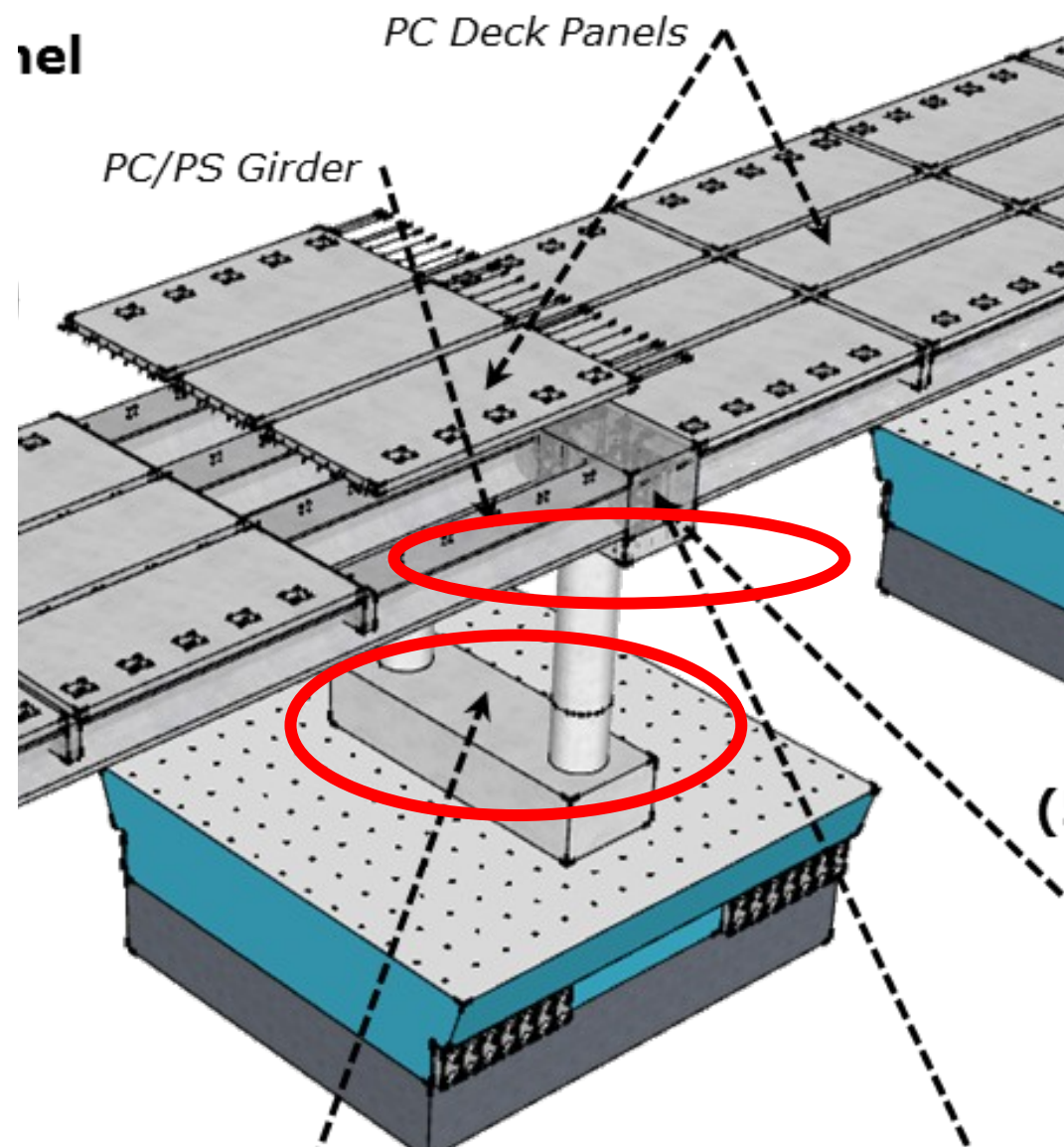


4- Deck panels



3- Girders to cap beam

Energy Dissipating Members



Bridge System

Geometry and dimensions of main elements

Geometry and dimensions of main elements	0.35-scale Two spans, straight, no skew Total Length= 69' – 8" (20.9 m) Span Length= 34' – 3¾" Bridge width= 11' (3.3 m)
Structural scheme	Simple for dead, continuous for live load (SDCL)
Superstructure	Precast prestressed girders with PC full depth panels
Bent	Precast two-column bent
Abutment	Seat-type abutments Abutment backwall and shear keys not included
Materials	- Conventional reinforced concrete members ($f'_c = 4$ ksi, $f_y = 60$ ksi) - Grout - UHPC

Structural scheme

Simple for dead, continuous for live load (SDCL)

Superstructure

Precast prestressed girders with PC full depth panels

Bent

Precast two-column bent

Abutment

Seat-type abutments

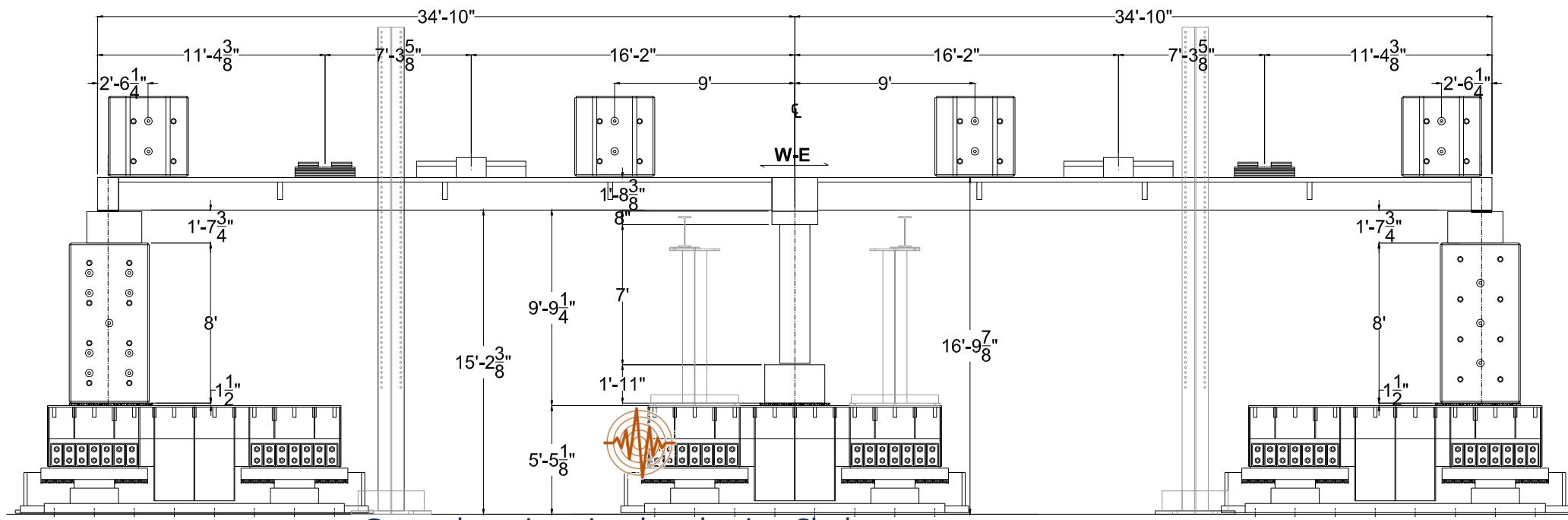
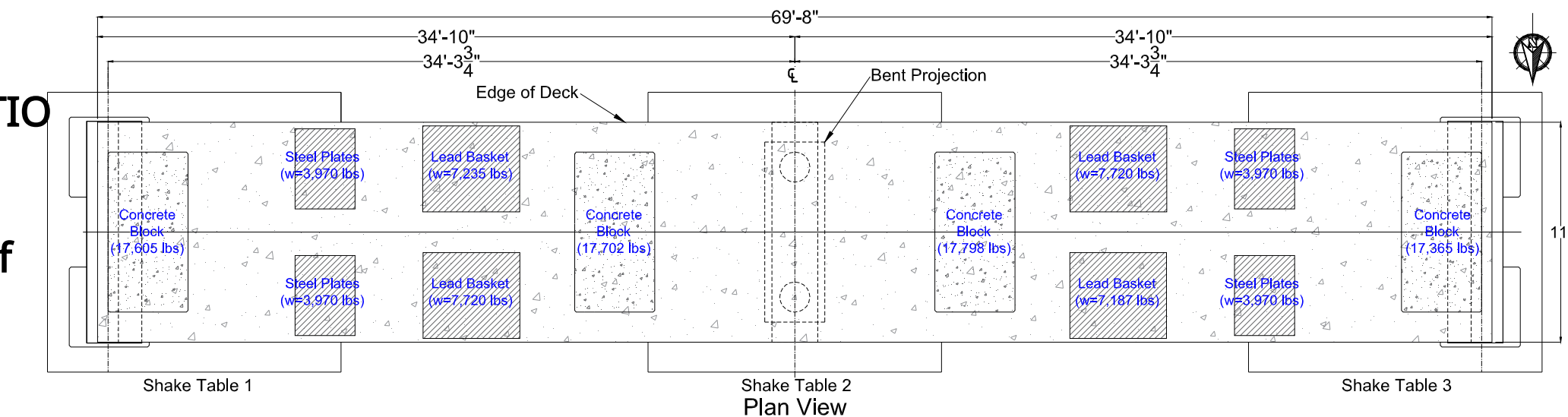
Abutment backwall and shear keys not included

Materials

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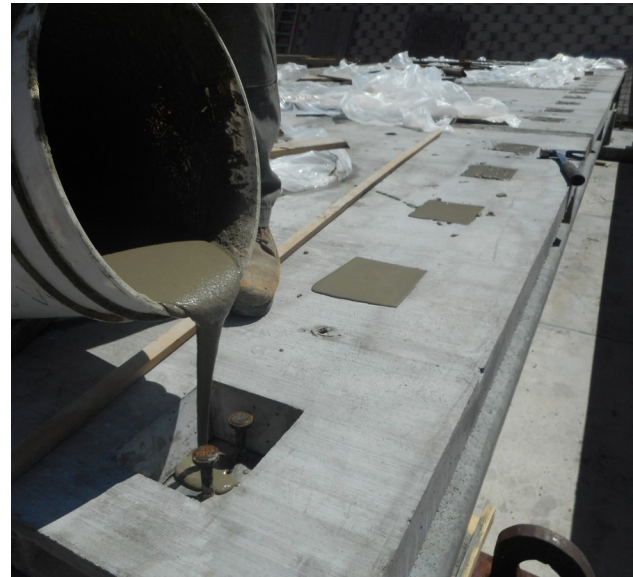
INSTRUMENTATION:

424 Channels of data

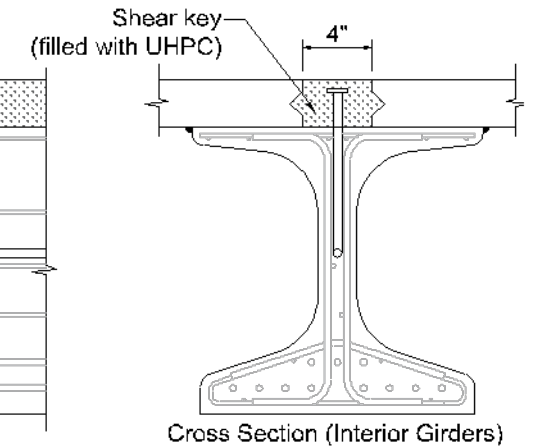
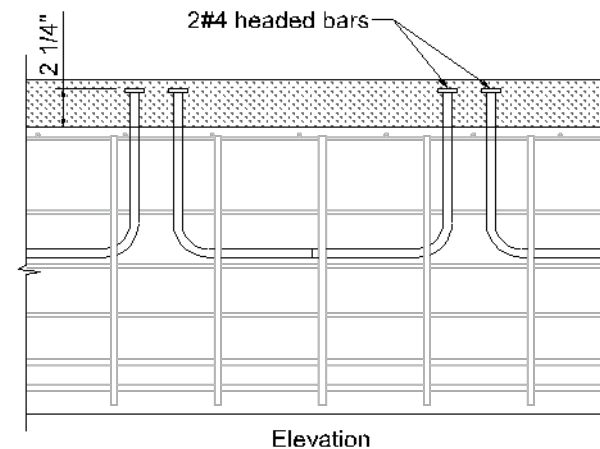
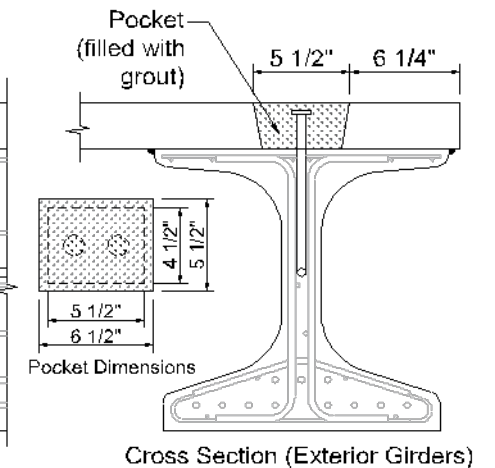
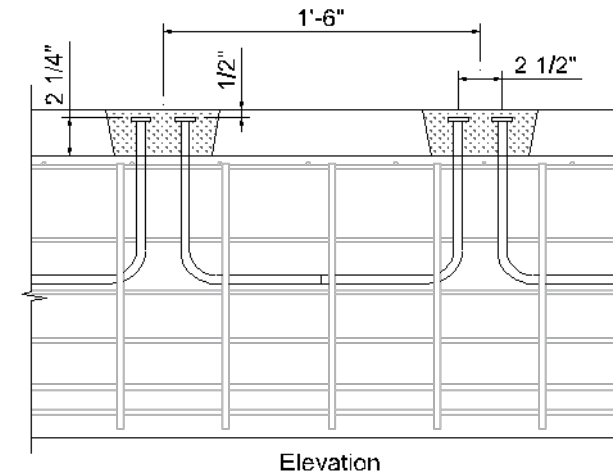


Deck-to-girder Connection

- Previous research: UNR-Caltrans, U. Nebraska-Lincoln
- Reinforced concrete deck panels $t_s = 2\frac{3}{4}"$, 34 – 45" x 95"
- Shear connectors: 2#4 headed bars @18"
- High early strength, non-shrink grout ($\bar{f}_{grout_{28d}} = 10 \text{ ksi}$)

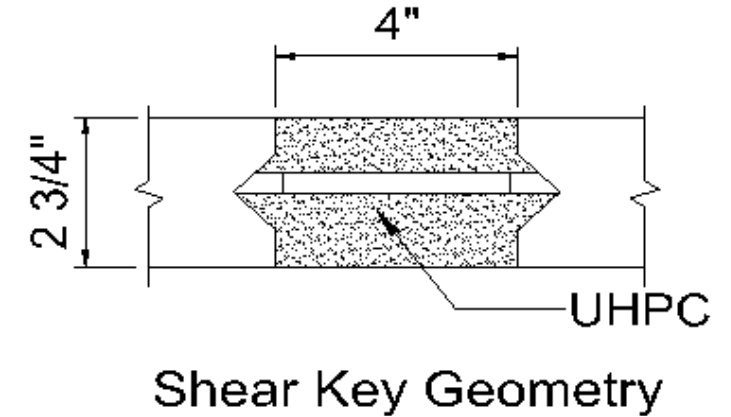


($t_s = 8"$, 8'-10' x 22')
(10#5 -or equivalent area- @ 4')



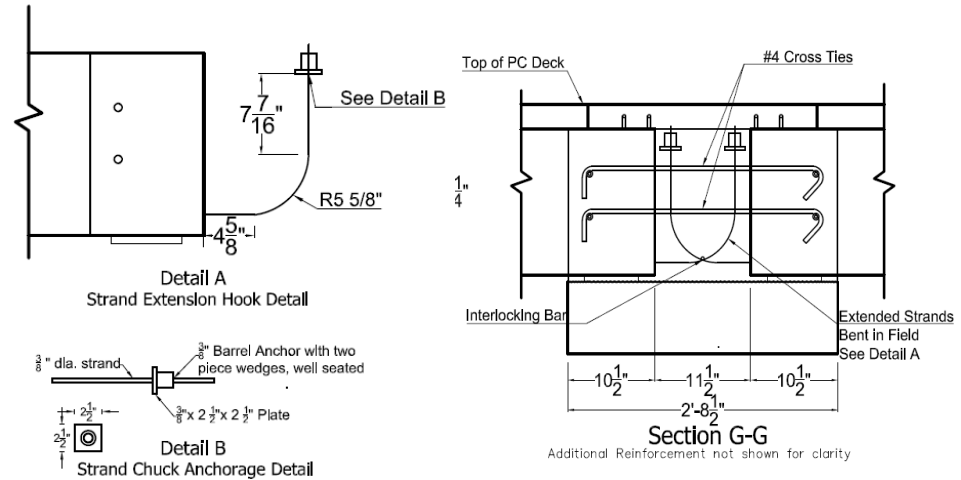
Deck-to-Deck Connection

- Previous research: FHWA, U. at Buffalo shake table tests
- Shear key filled with UHPC ($\bar{f}_{UHPC_{28d}} = 26 \text{ ksi}$)
- CIP intermediate diaphragms used under the transverse joints



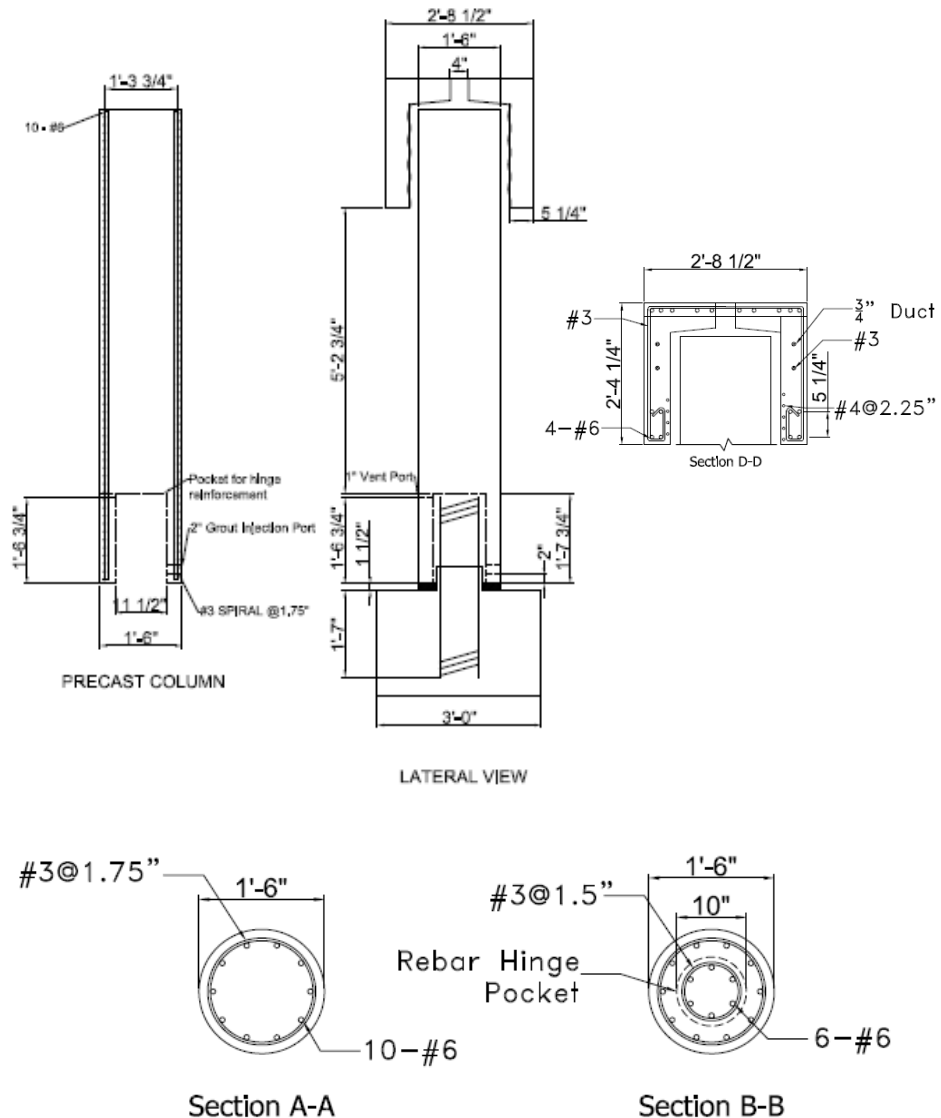
Cap Beam Connections

- Girder-to-cap beam connection
 - Headed bars, crossties, and extended prestress strands
 - Provide positive moment resistance through prestress strands and shear friction
- Deck connection over pier
 - Straight longitudinal reinforcement over pier
 - Long lap spliced connection embedded in ultra-high performance concrete (UHPC)
 - Provide negative moment resistance
 - Lap splices are not allowed in critical bridge regions. Therefore, use UHPC to address this concern



Column End Regions and Connections

- Column-to-footing: Two-way rebar hinge
 - Reduced column section to reduce plastic moment transfer
 - Precast with footing and connected via opening in the column filled with grout
 - This configuration had not been previously studied
- Column-to-cap beam: Socket/pocket connection
 - Columns fit into openings in precast beam and connected with grout
 - Moment connection
 - Plastic hinge forms in columns below cap beam-column interface
 - This configuration had not been studied under biaxial loading or loaded in out-of-plane direction





Column
connections
at top



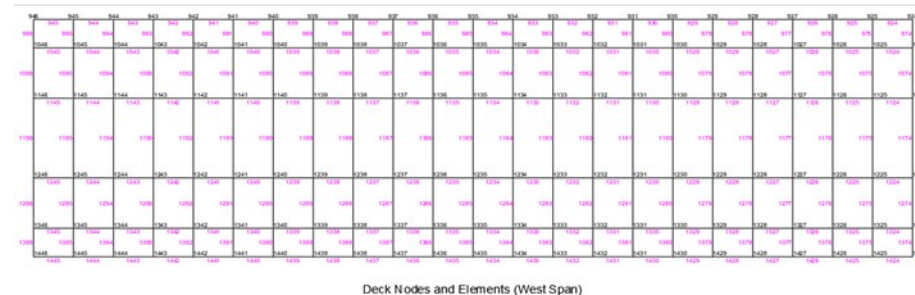
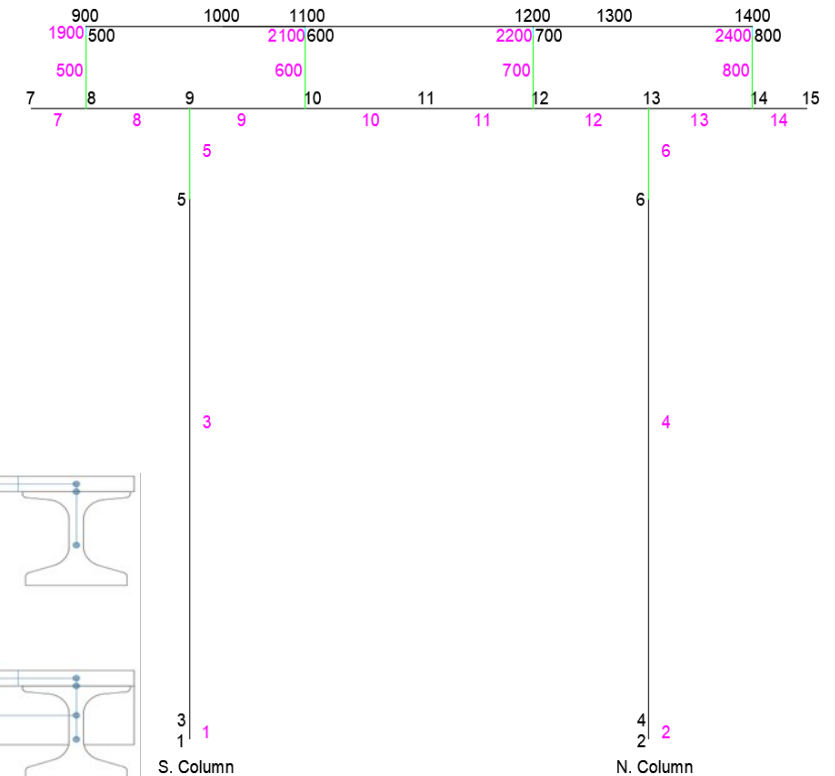
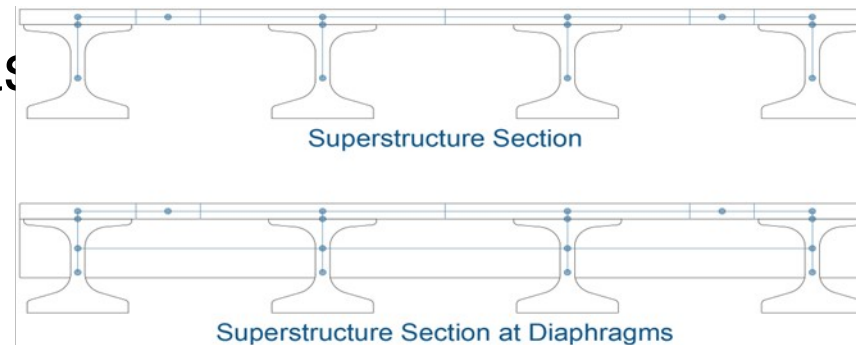
Column
connections
at base

Column End Regions and Connections (Cont'd)



Pretest Analytical Model

- Opensees
- A 3-D grillage model
- Elastic elements for the superstructure
- ForceBeamColumn elements for columns and hinges
- connections modeled as connections

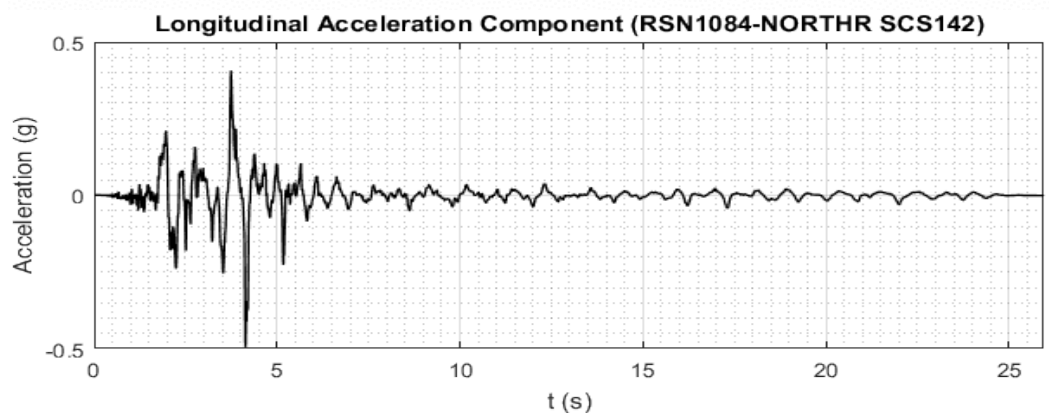
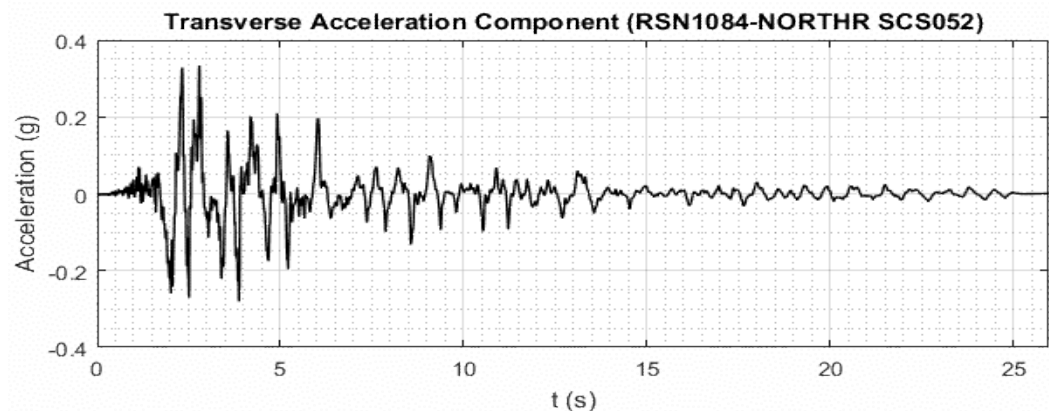


Loading Protocol

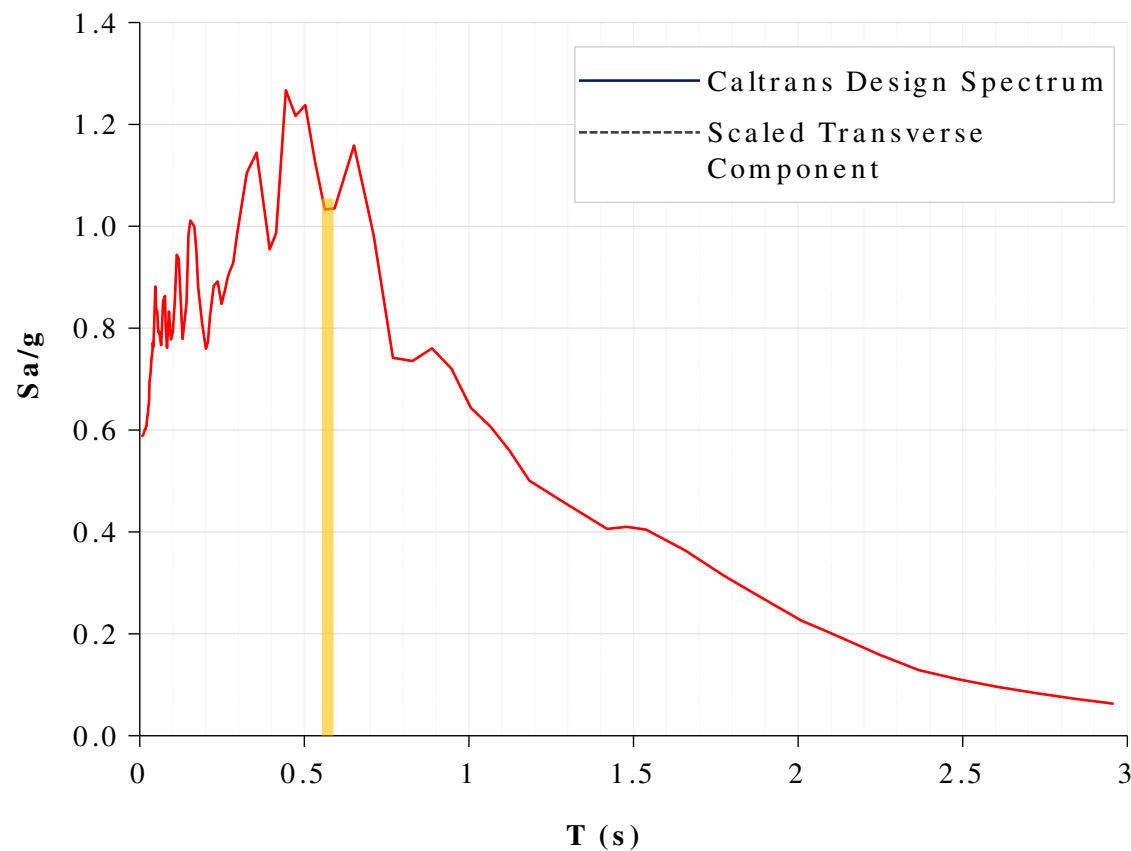
1994 Northridge Earthquake recorded at the Sylmar Converter Station.

Motion replicated in the central shake table.

Resultant displacement demand for design spectrum = 3.59" (100%DE - Run 4)



Time scaled acceleration components
(Compression factor = 0.592)



Time scaled acceleration response spectrum

Shake Table Tests

- White noise tests between earthquake simulations
- 7 biaxial earthquake runs based on pre-test modeling ranging from 30% to 200% of the design level earthquake
- An 8th run corresponding to 225% design EQ was applied but was incomplete due to concern for safety.



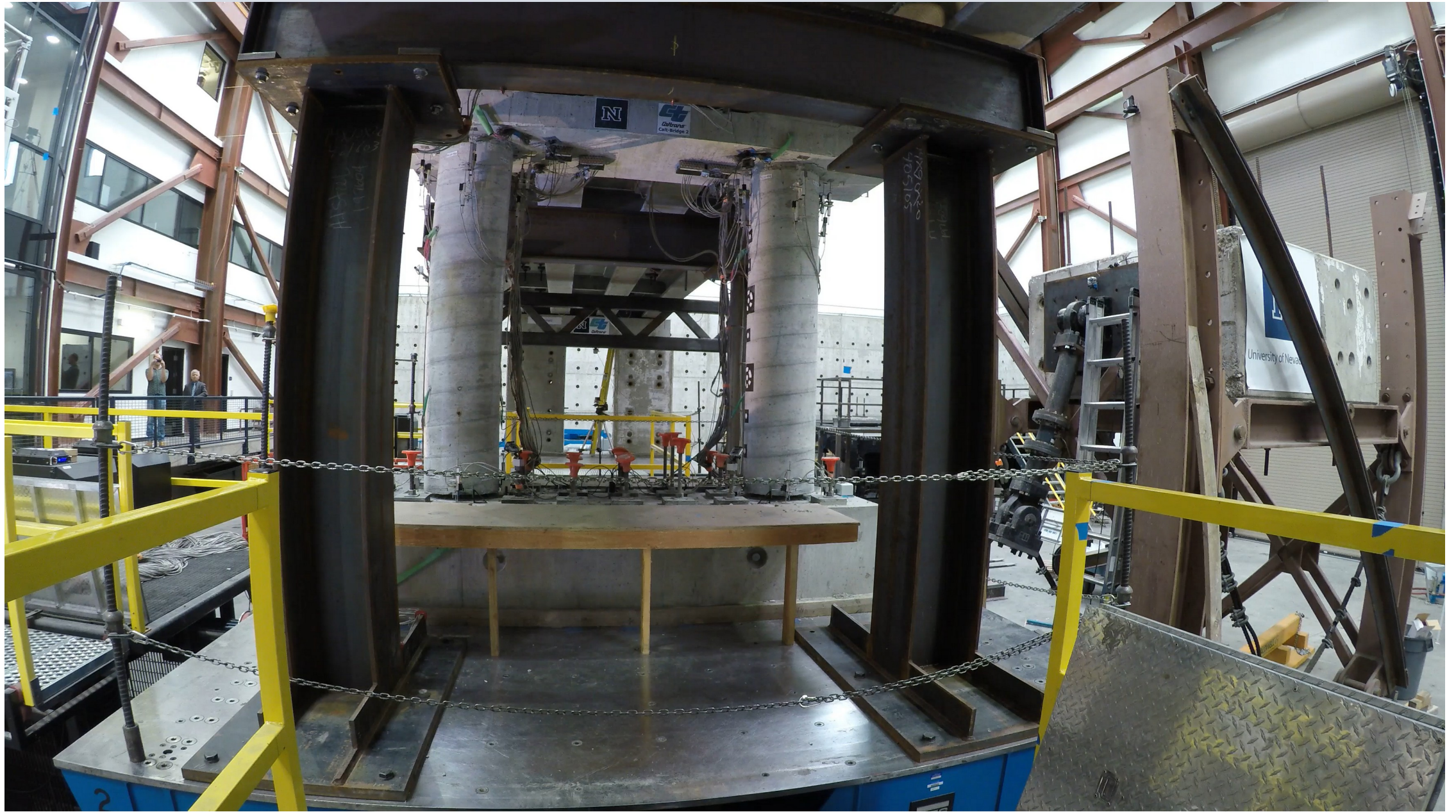
225% Design Earthquake



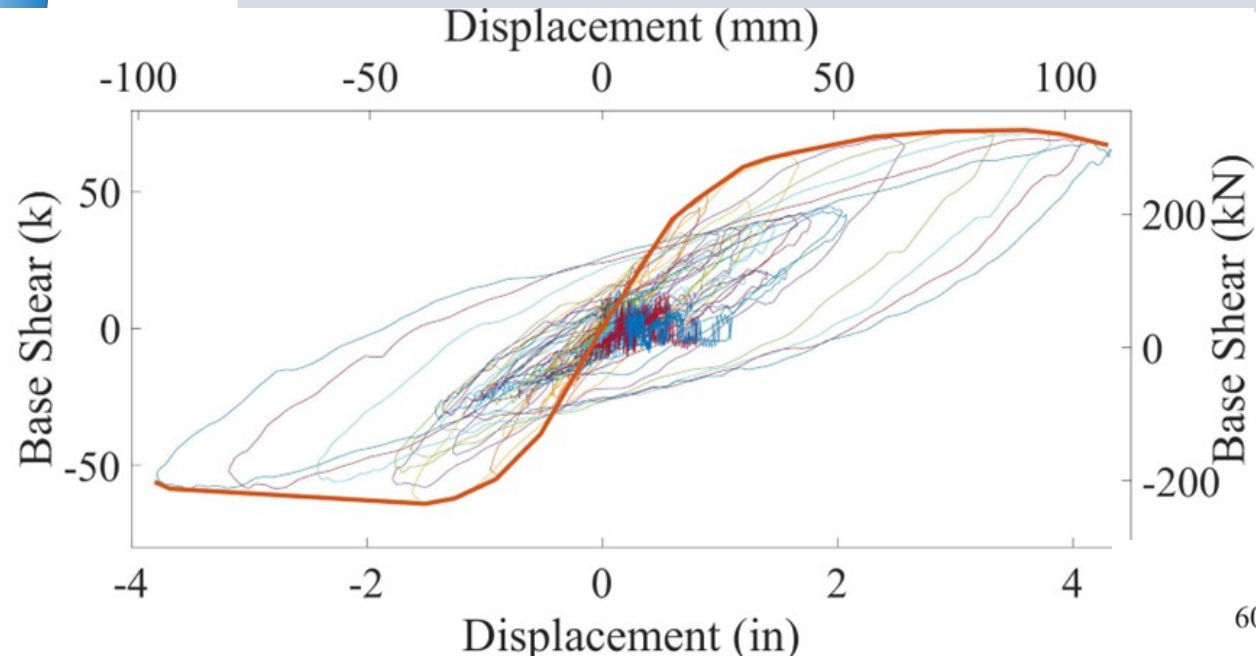
225% Design Earthquake



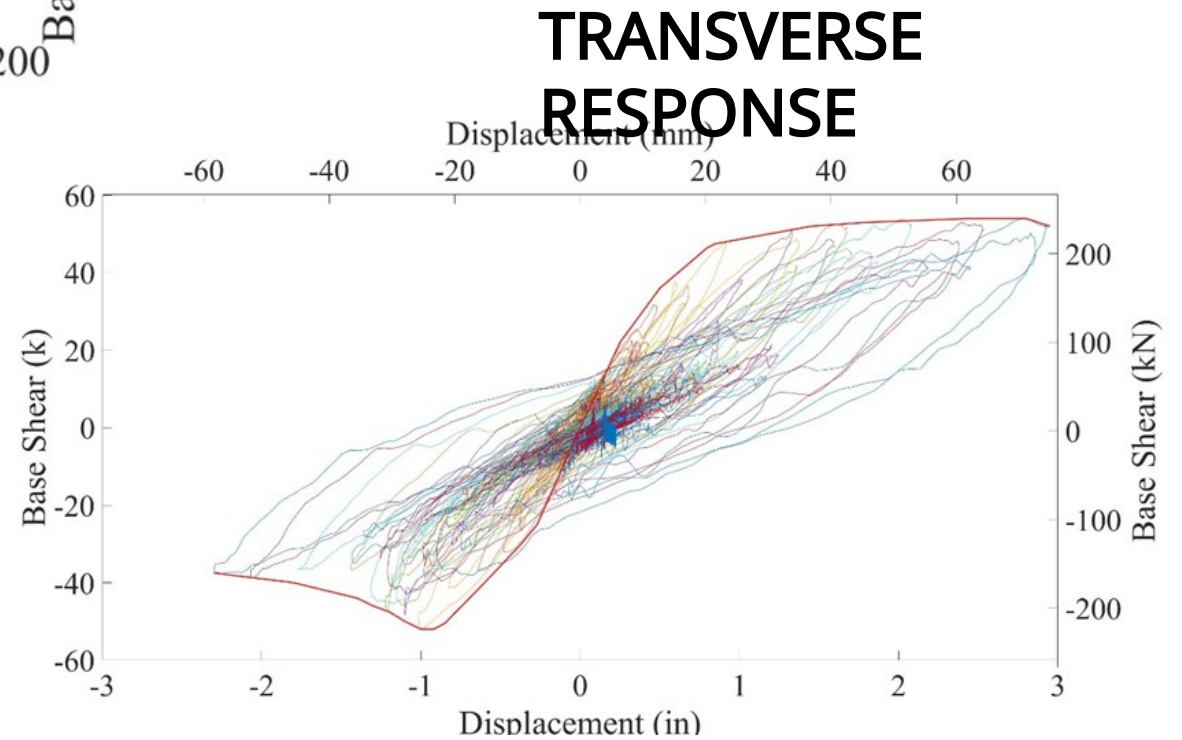
225% Design Earthquake



Measured Force-Displacement Response



**LONGITUDINAL
RESPONSE**



**TRANSVERSE
RESPONSE**

Column Damage State after 200 % Design Earthquake



**BOTTOM PLASTIC
HINGES**



**TOP PLASTIC
HINGES**



Capacity Protected Elements Damage State after 200% Design Earthquake- **Cap Beam**



CAP
BEAM

Capacity Protected Elements Damage State after 200% Design Earthquake- Girder to Cap Beam Connections

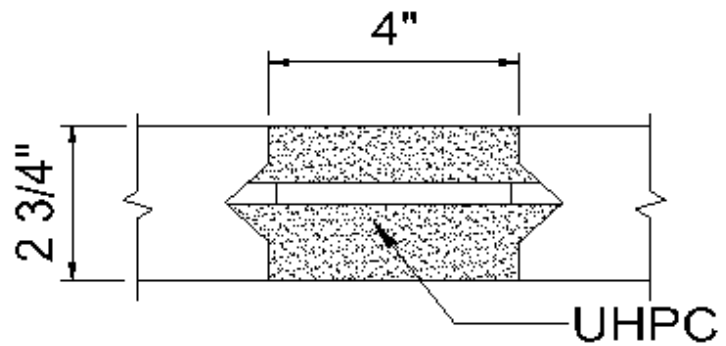


No couplers; but used UHPC

Capacity Protected Elements Damage State after 200% Design Earthquake- Girder Connection to Cap Beam

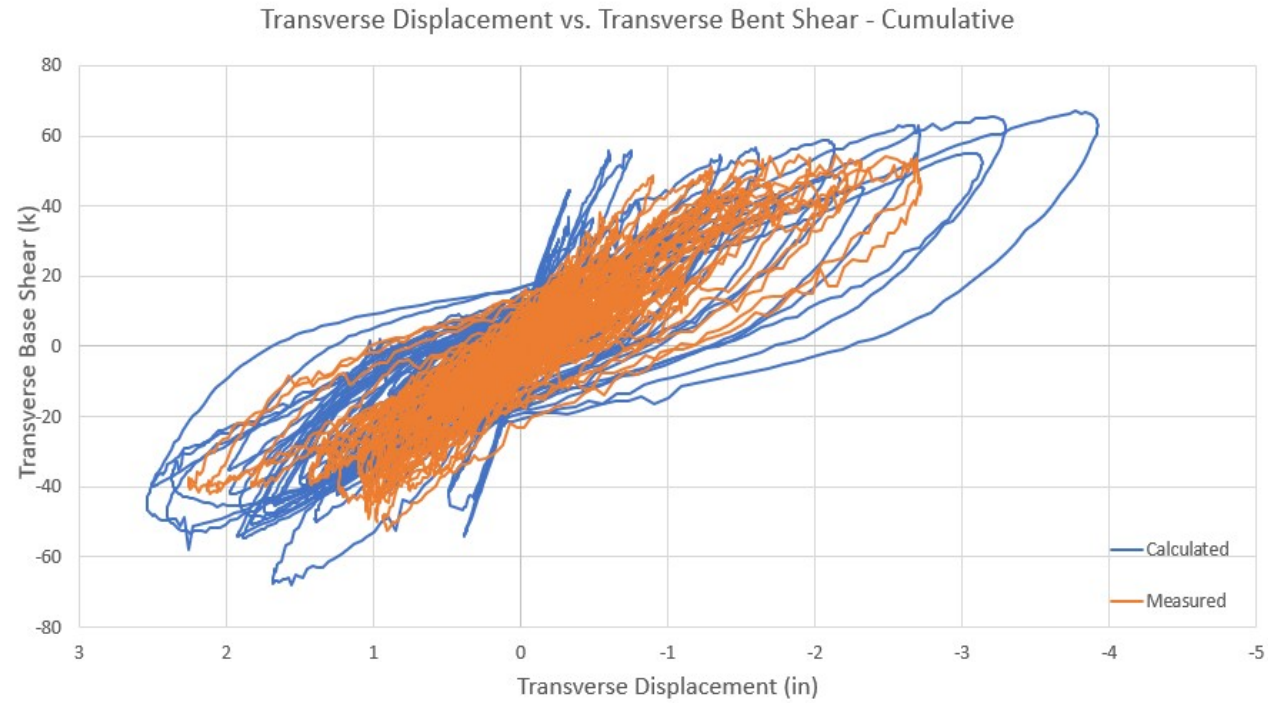


Capacity Protected Elements Damage State after 225% Design Earthquake- Deck Panel Connections

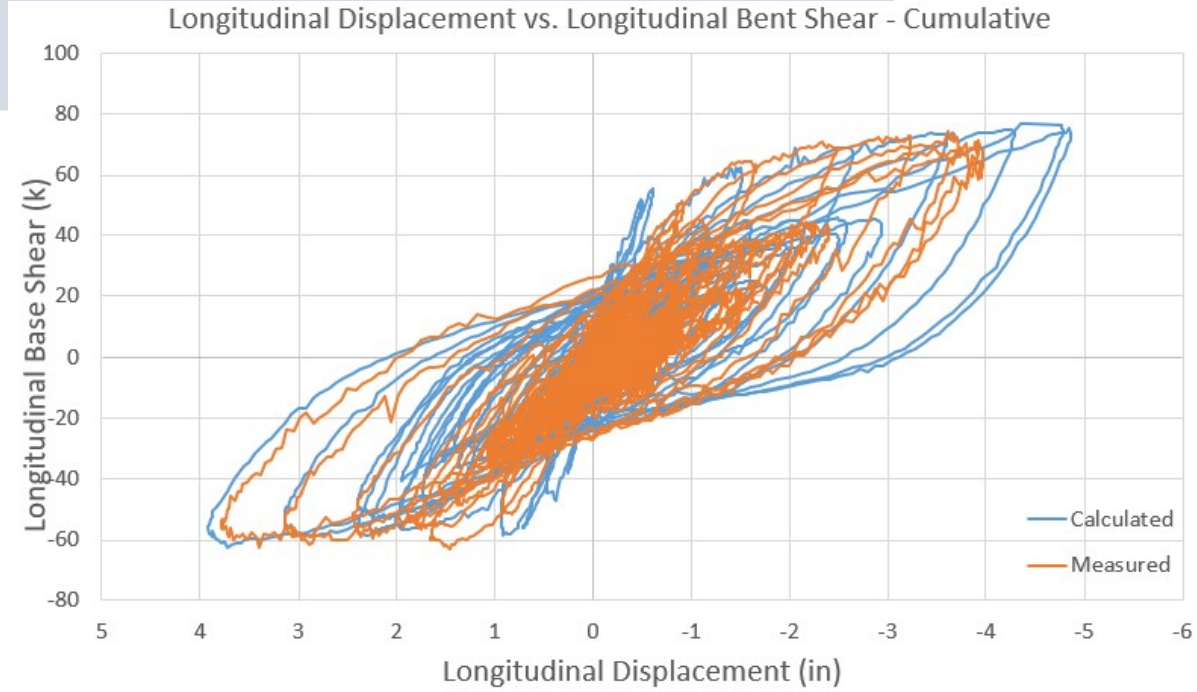


Shear Key Geometry

Post Test Analytical Studies

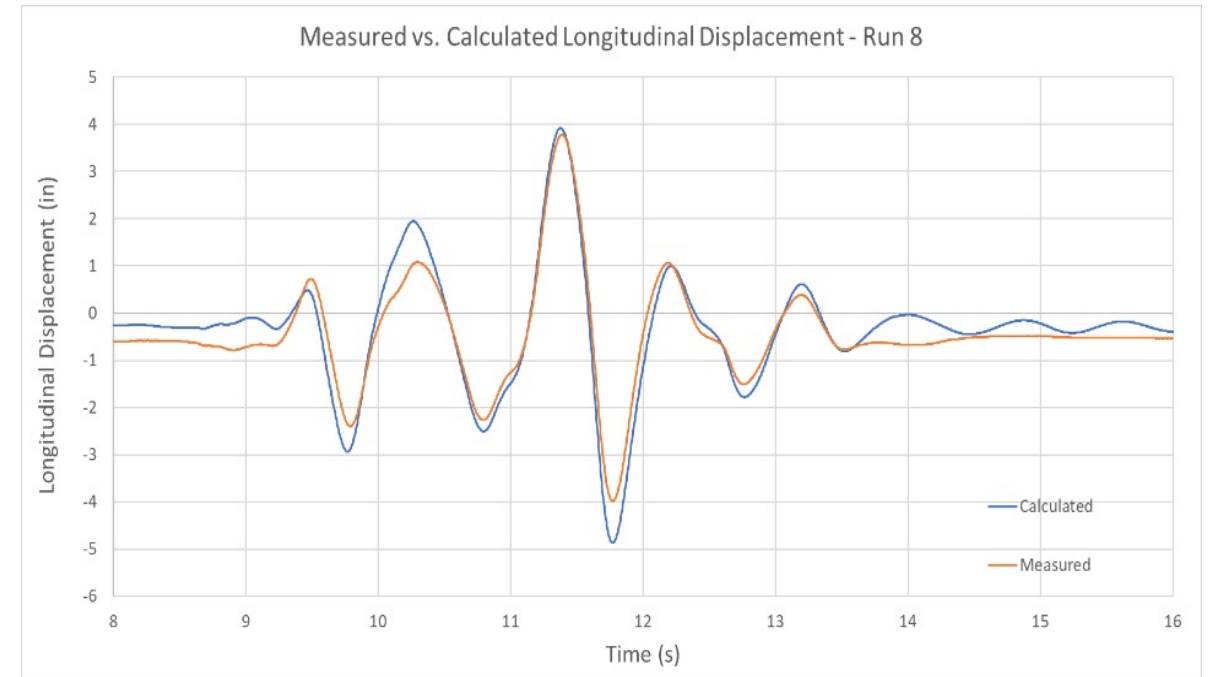
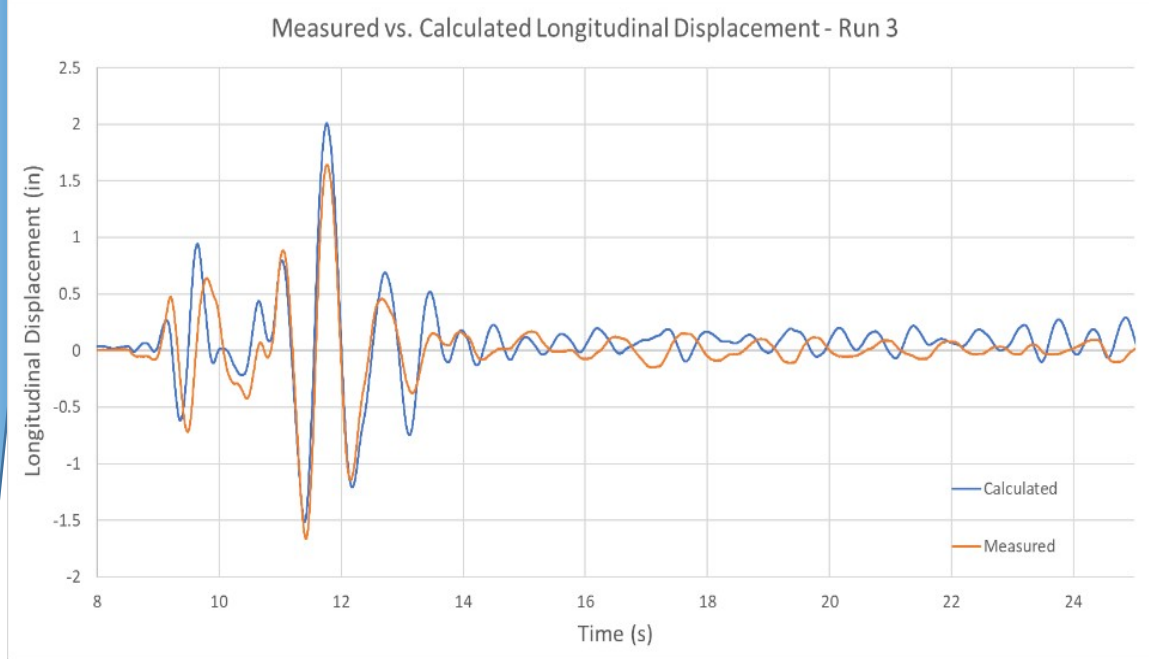


Transverse



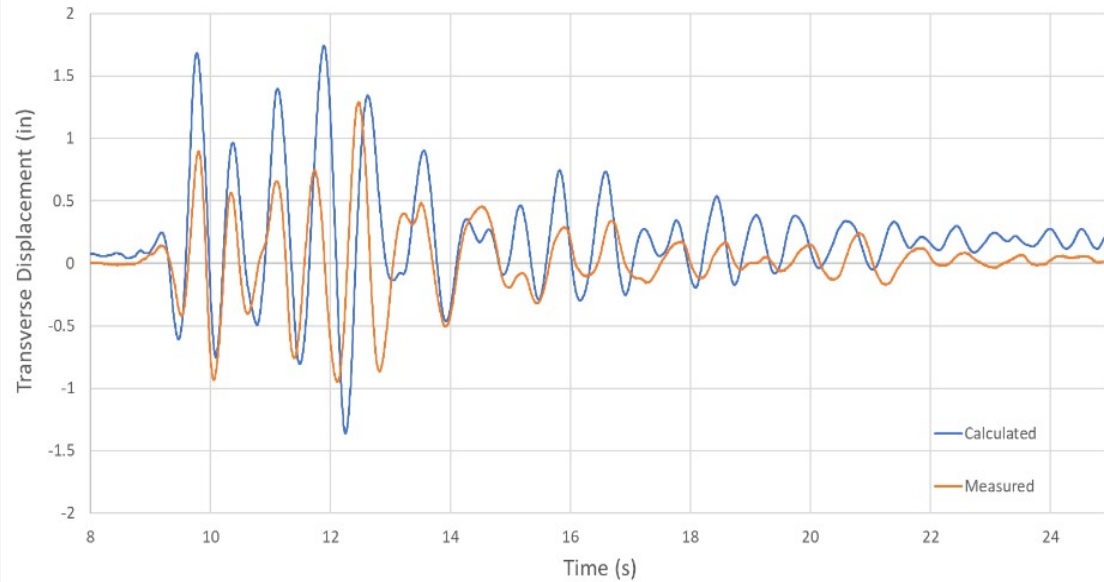
Longitudinal

Post Test Analytical Studies (Cont'd)

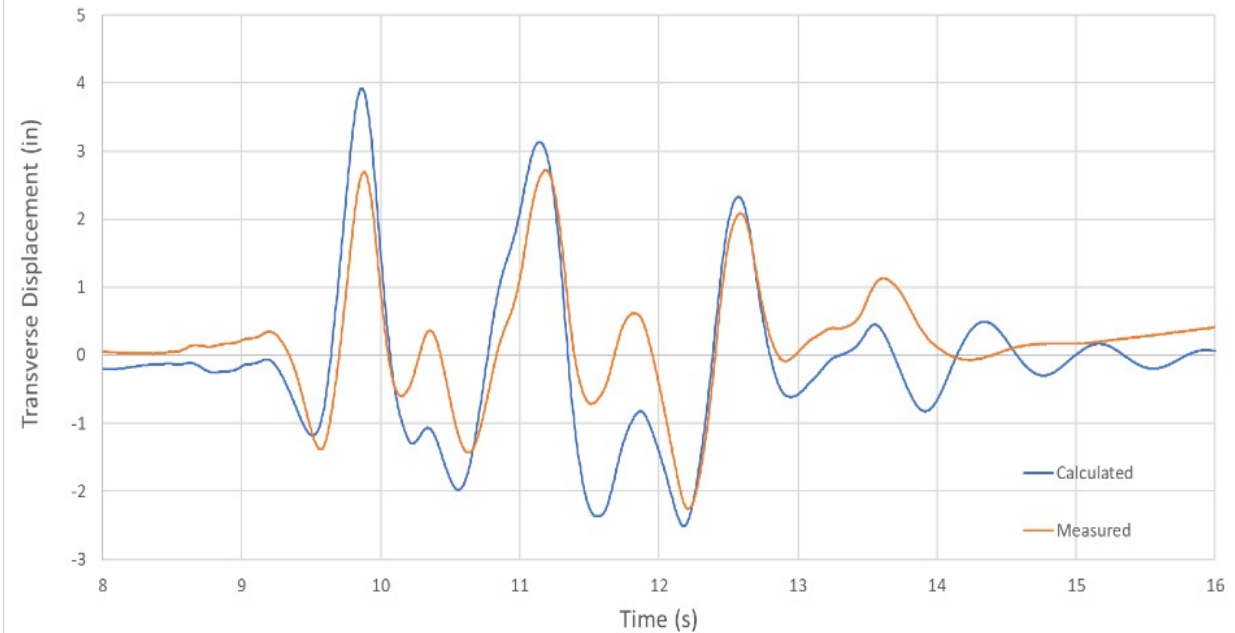


Post Test Analytical Studies (Cont'd)

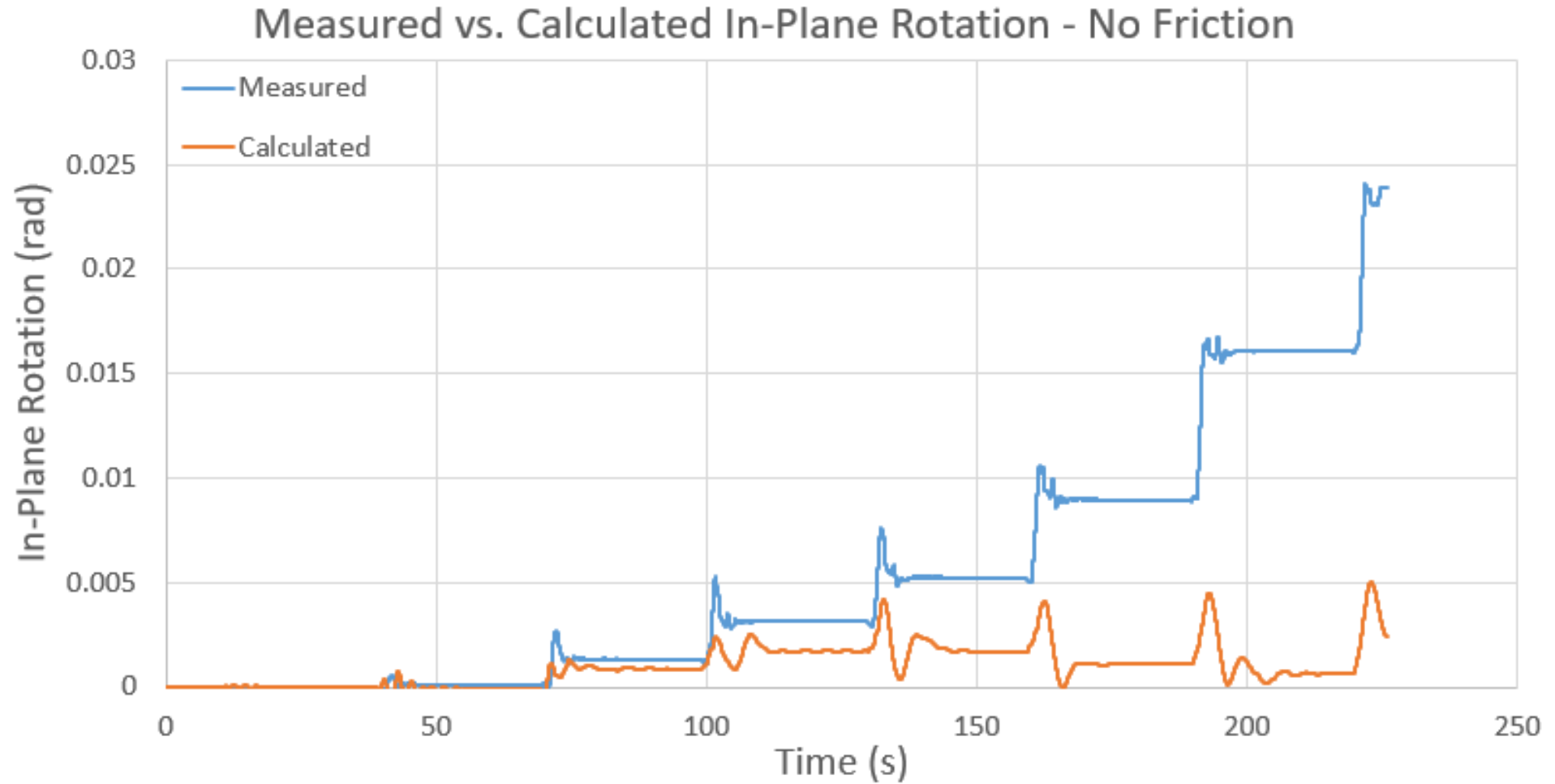
Measured vs. Calculated Transverse Displacement - Run 3



Measured vs. Calculated Transverse Displacement - Run 8



In-plane Superstructure Rotation



Conclusions

- Design, construction and testing of a two-span, 0.35-scale bridge model incorporating ABC connections was successful.
- A bridge system incorporating precast elements and ABC connections can emulate the response of cast-in-place bridges: Ductile behavior and maintain integrity under large deformations.
- The six integrated ABC connections performed well even under earthquakes with more than twice the amplitude of the design level.

Conclusions- (Cont'd)

- The capacity protected elements remained elastic or essentially elastic while the plastic hinges were formed at the top and base of the columns.
- The ABC connections at the superstructure remained damage-free.
- The satisfactory shake table performance of this (and two other ABC bridges) provided confidence on the part of bridge designers to adopt ABC methods in practice.