Large Scale Laboratory Testing in Support of Seismic Bridge Design and Retrofit

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OVERVIEW

- Seismic Bridge Performance and Retrofit Issues
- California Seismic Bridge Retrofit Program
- Research in Support of Seismic Assessment and Retrofit Technology Development
  - Large Scale Testing of Retrofit Concepts
  - New Materials for Seismic Bridge Retrofit
  - Seismic Response Modification
  - New Bridge Design
- Multi Hazards
- Conclusions

Bridge Failures, 71 San Fernando

Bridge Failures, 89 Loma Prieta

Bridge Failures, 94 Northridge

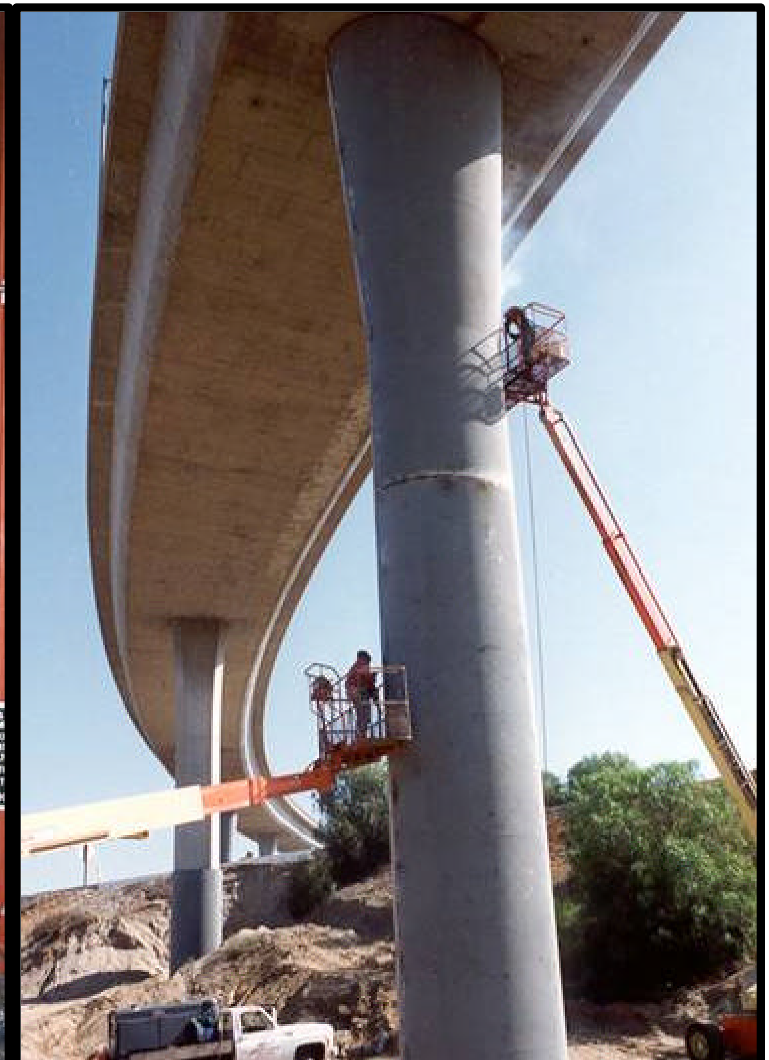
Caltrans Bridge Retrofit Program

Restrainers
Single Column Bents
Multi Column Bents
(Foundations)
Toll Bridges

Example: Single Column Bents

Column Jacketing

a) Research



b) Implementation

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Column Jacket Retrofit

a) Steel Jacketing

b) Carbon Fiber Jacketing

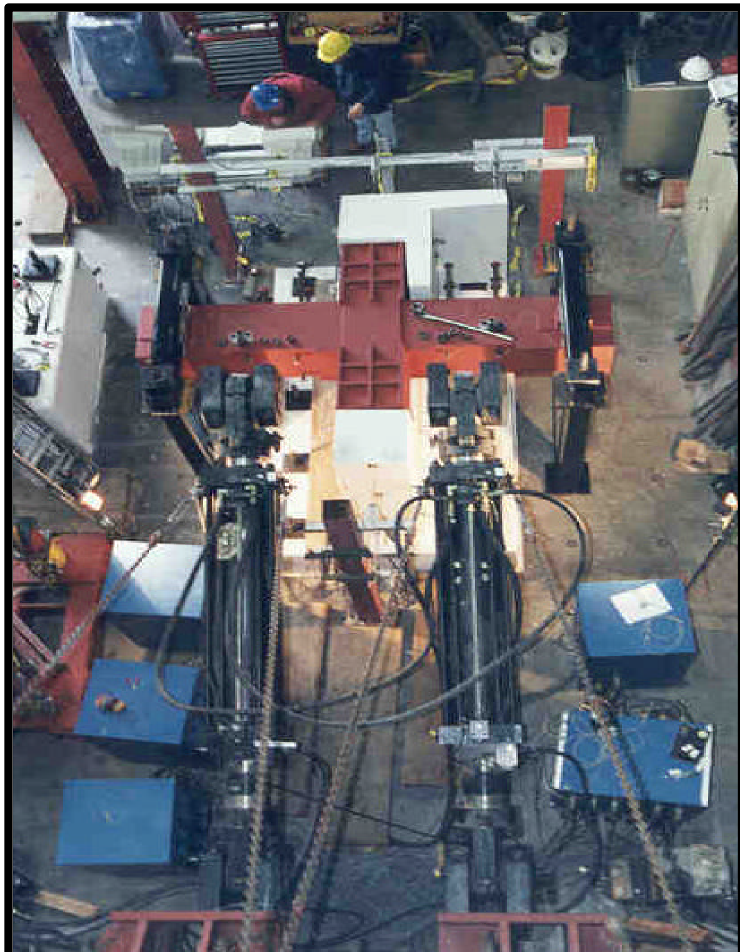
c) Concrete Jacketing

Foundation Retrofit

a) Addition of Piles **b) Reinforced Concrete Footing Overlay**

Abutment Response, I-5/SR-14 Northridge 94

External Abutment Shear Key Testing



a) Test Setup

b) Shear Key Failure Modes

MAIN CAUSES FOR SEISMIC PERFORMANCE PROBLEMS IN BRIDGES

- Reinforcement Design and Detailing
  - Confinement
  - Force Transfer, Strength
  - Development Length

- Bridge Systems Response
  - SFSI
  - Stiffness/Capacity Unbalance
  - Dynamic Inelastic Systems Response

RESEARCH ON BRIDGE ASSESSMENT AND RETROFIT

- Analytical Simulations
  - Demand Assessment
  - Capacity/Performance Assessment
- Large Scale Experimental Testing
  - Component Tests
  - System Tests

LARGE SCALE EXPERIMENTAL TESTING

- Controlled laboratory environment for quality data
- Large or full-scale to exhibit representative damage patterns and failure modes
- Performed under realistic earthquake simulations, test protocols which represent actual demands

EXAMPLES OF SEISMIC BRIDGE PERFORMANCE AND RETROFIT RESEARCH

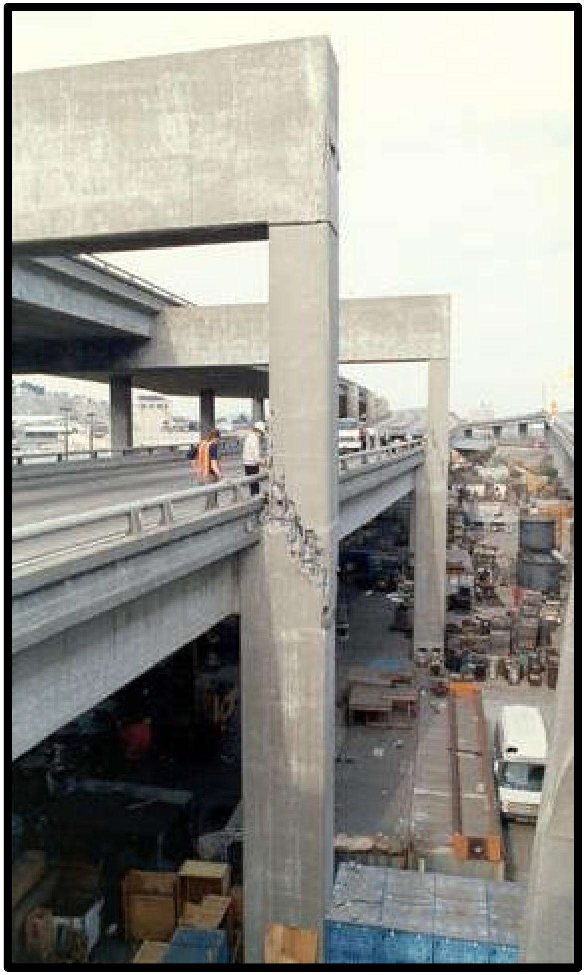
1. San Francisco Double Deck Viaduct
2. Seismic Response Modification
3. SFOBB East Span Replacement

SAN FRANCISCO DOUBLE DECK VIADUCT

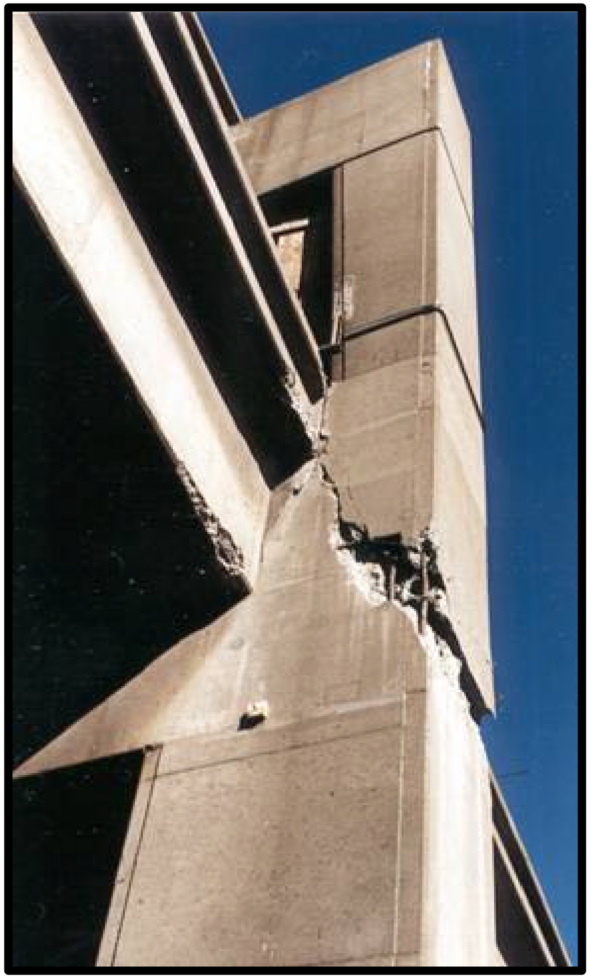
- Column Capacities
- Joint Shear Force Transfer
- Cap Beam Capacities
- Longitudinal Seismic Response


KSFO

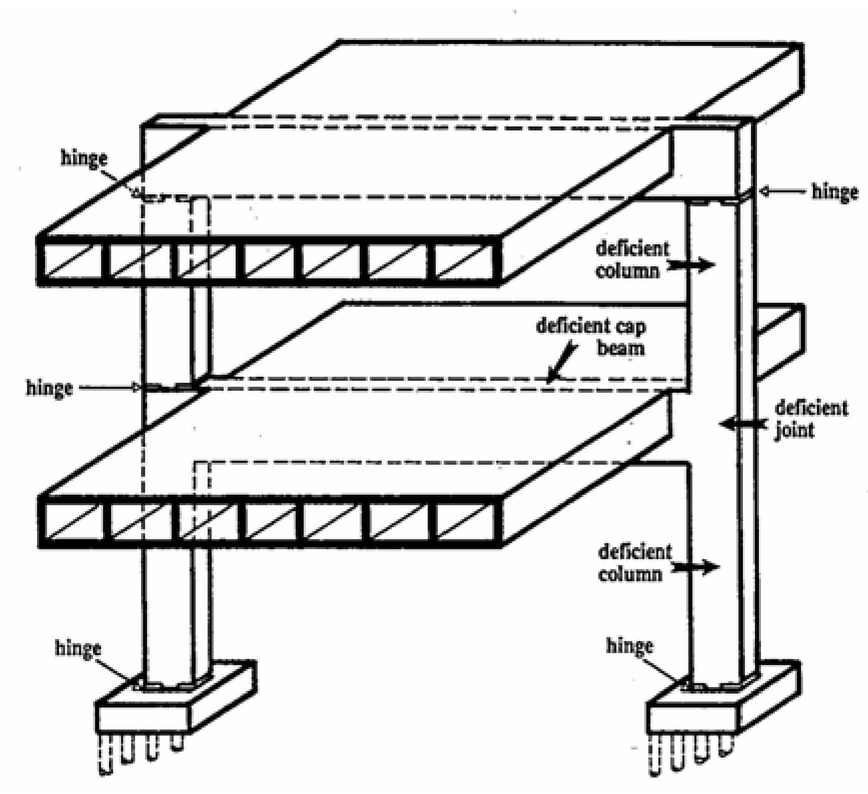
Joint Failures, Loma Prieta, 1989



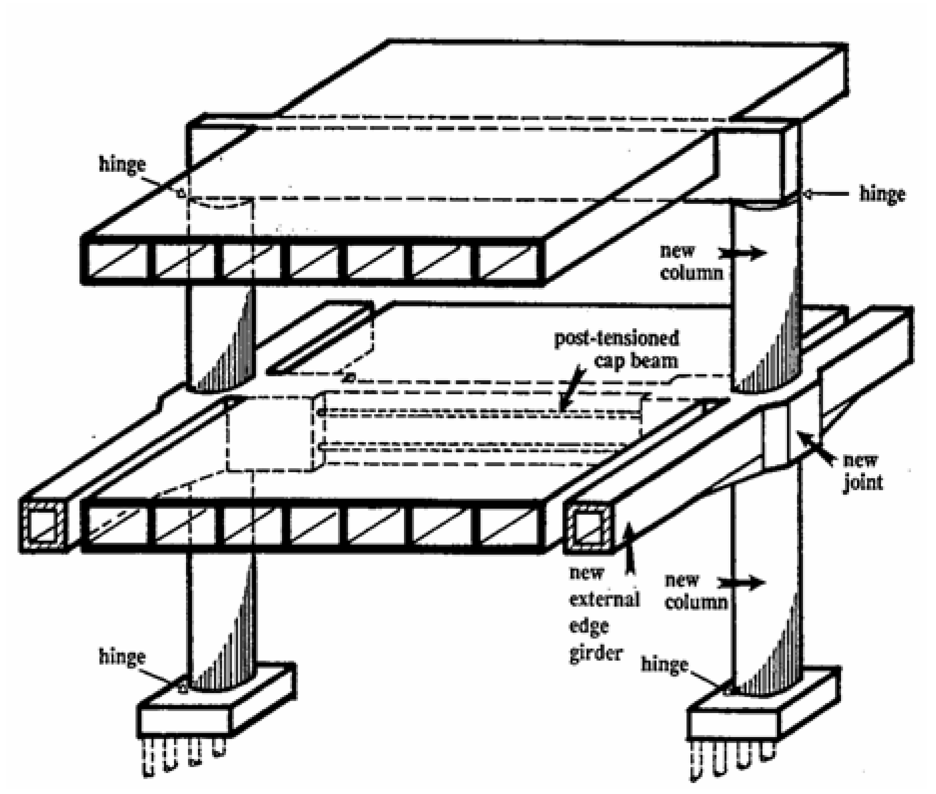
a) I-280 Viaduct



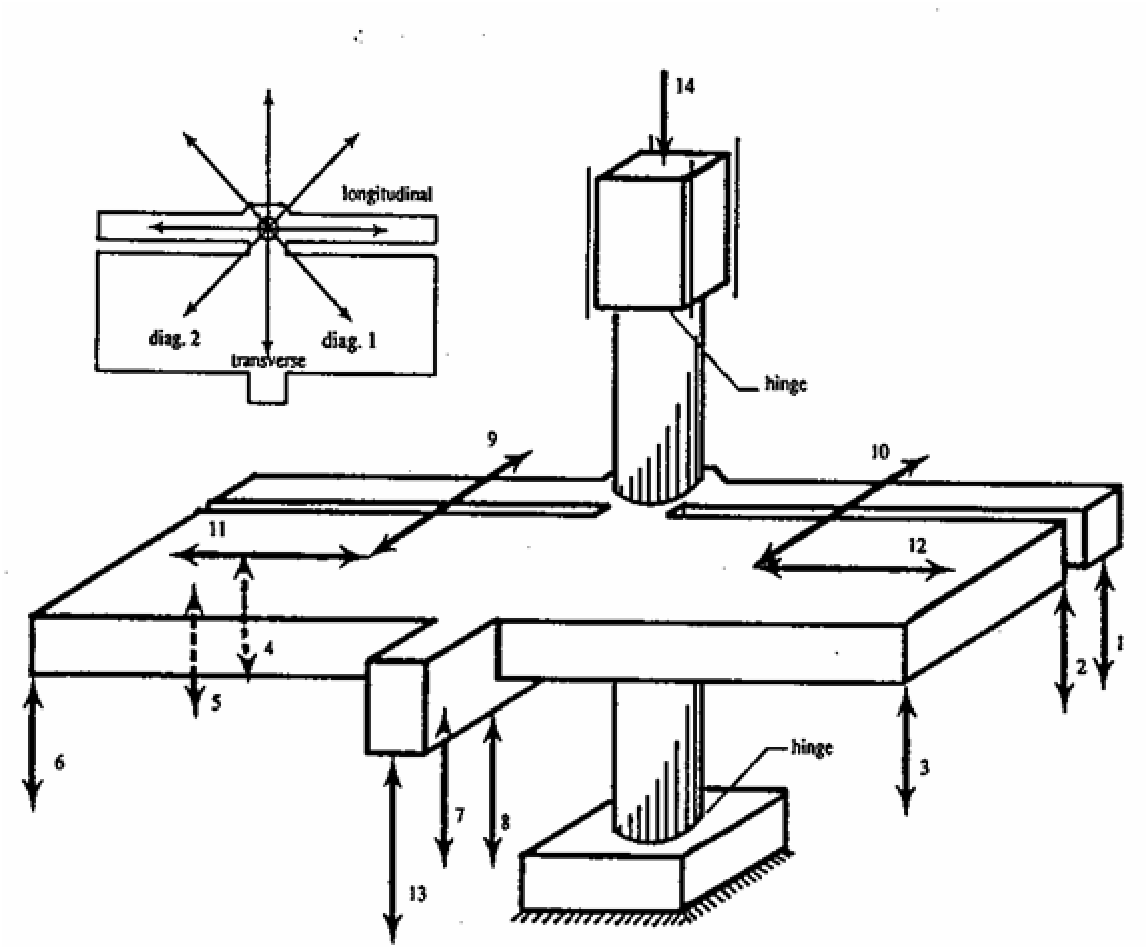
b) I-880 Cypress Viaduct



As-Built Double Deck Viaduct



Retrofit Scheme for Double Deck Viaduct



Prooftest Setup with 14 Servo-Controlled Actuators

Half-Scale Proof-Test Model

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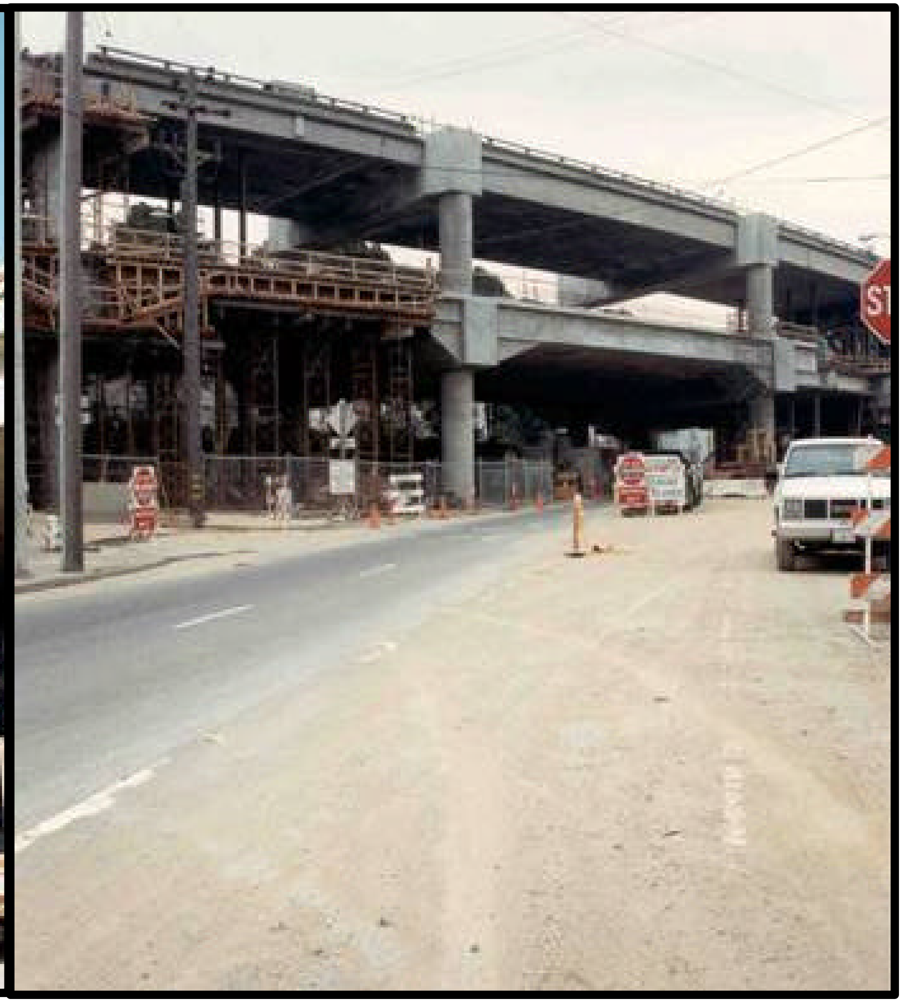
Large Scale Test on Retrofitted Joint Region

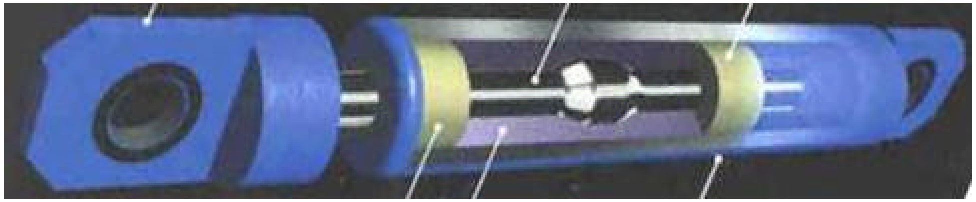
SF DOUBLE DECK VIADUCT RETROFIT



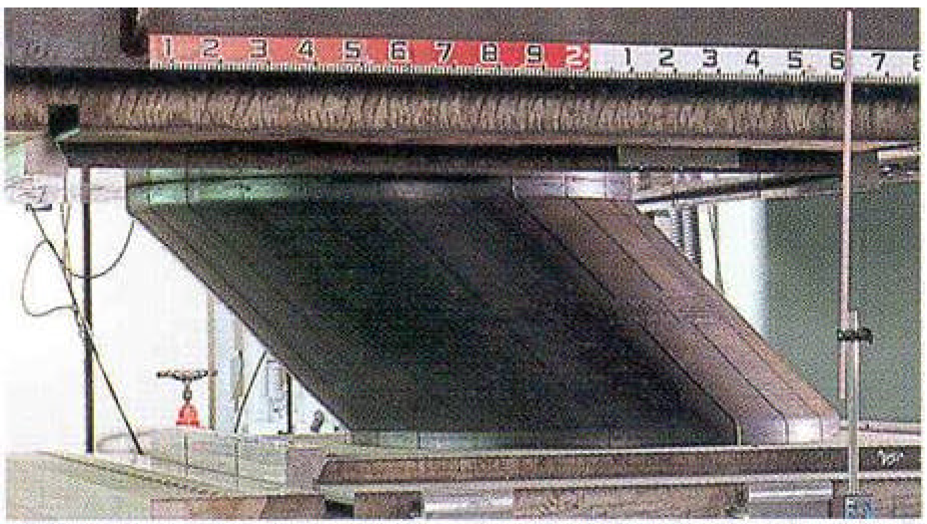
SEISMIC RESPONSE MODIFICATION

- SRMDs (Isolation Bearings, Dampers, Lock-up Devices)
- Displacement/Deformation Control
- Force Limiting Mechanisms

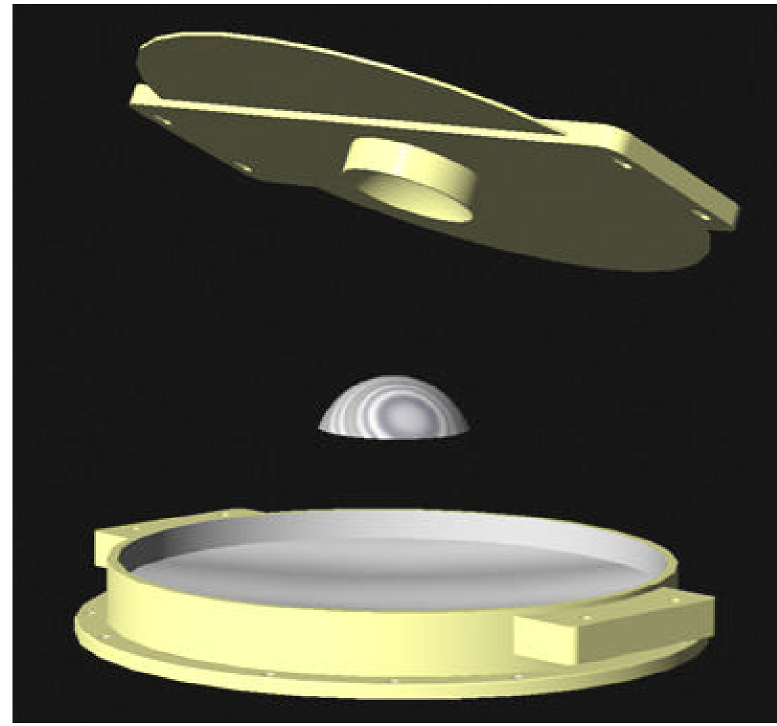
Various SRMD Examples

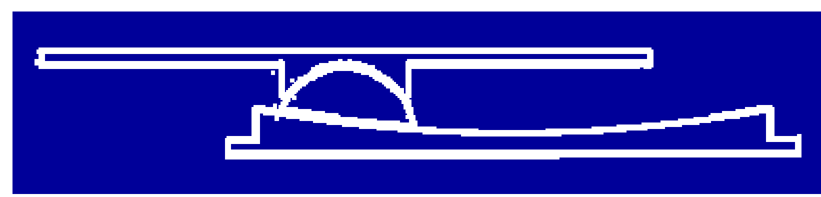


Dampers

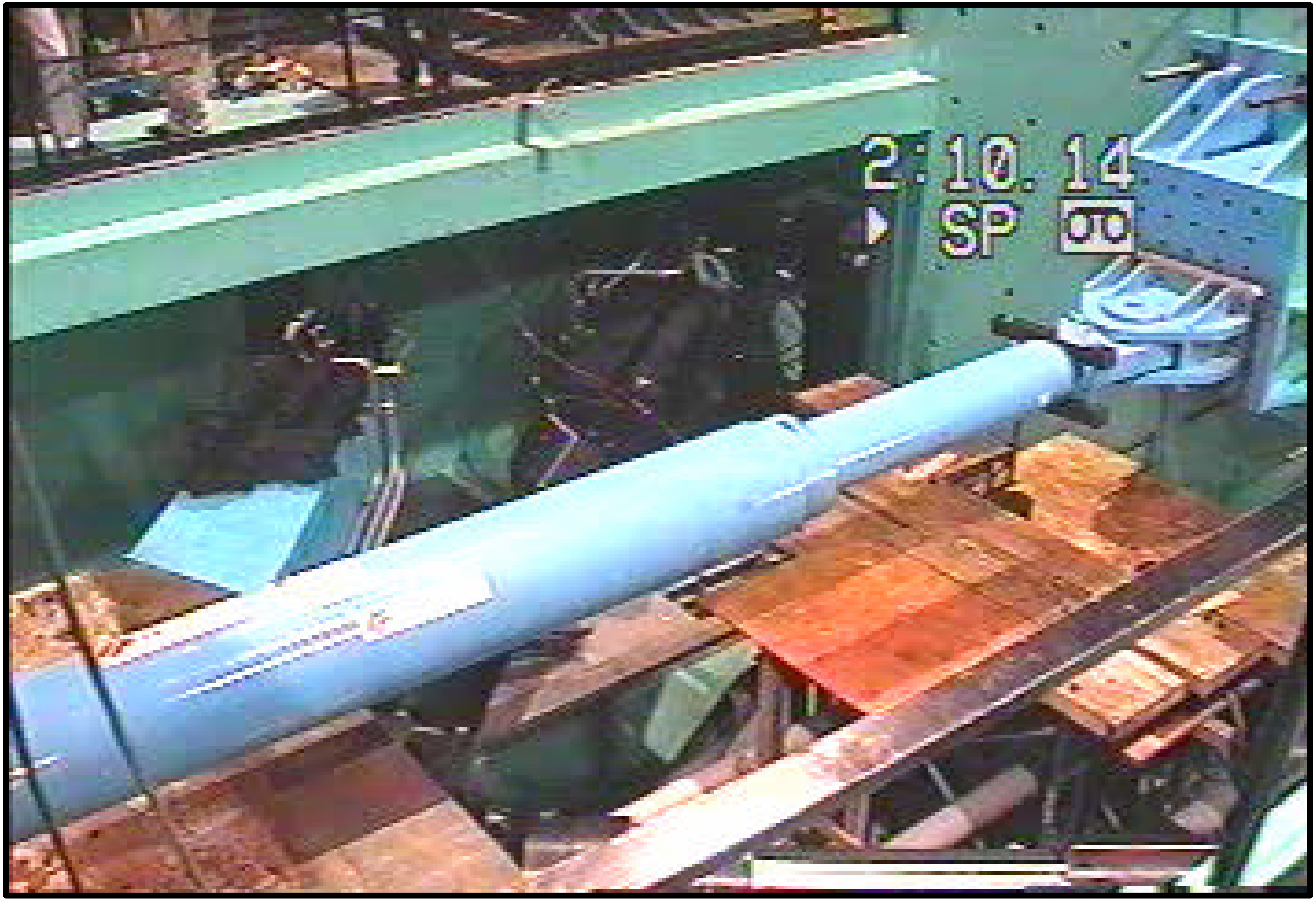


Elastomeric Bearings





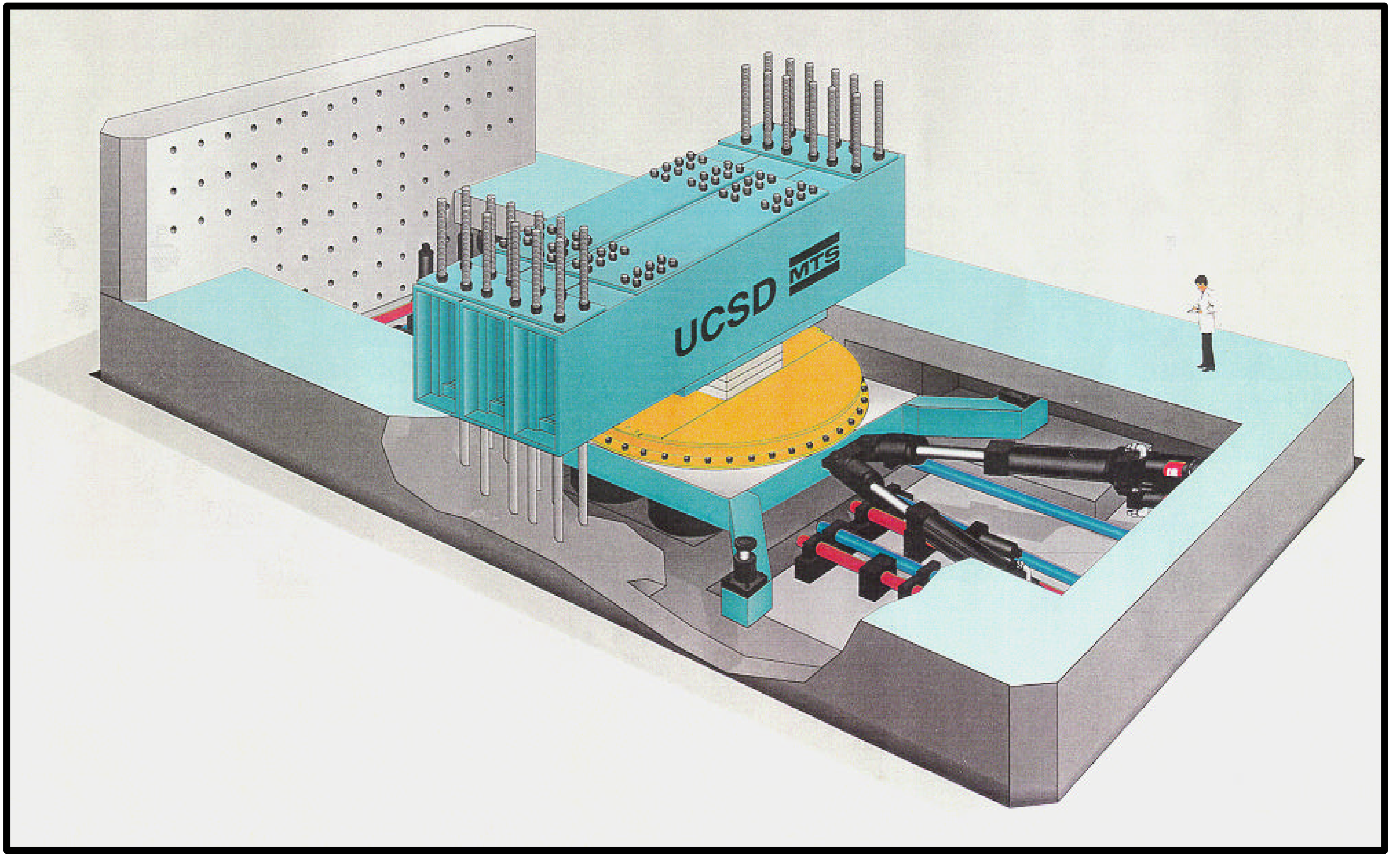
Friction Pendulum Bearings


2:10.14
SP

BENICIA-MARTINEZ BRIDGE

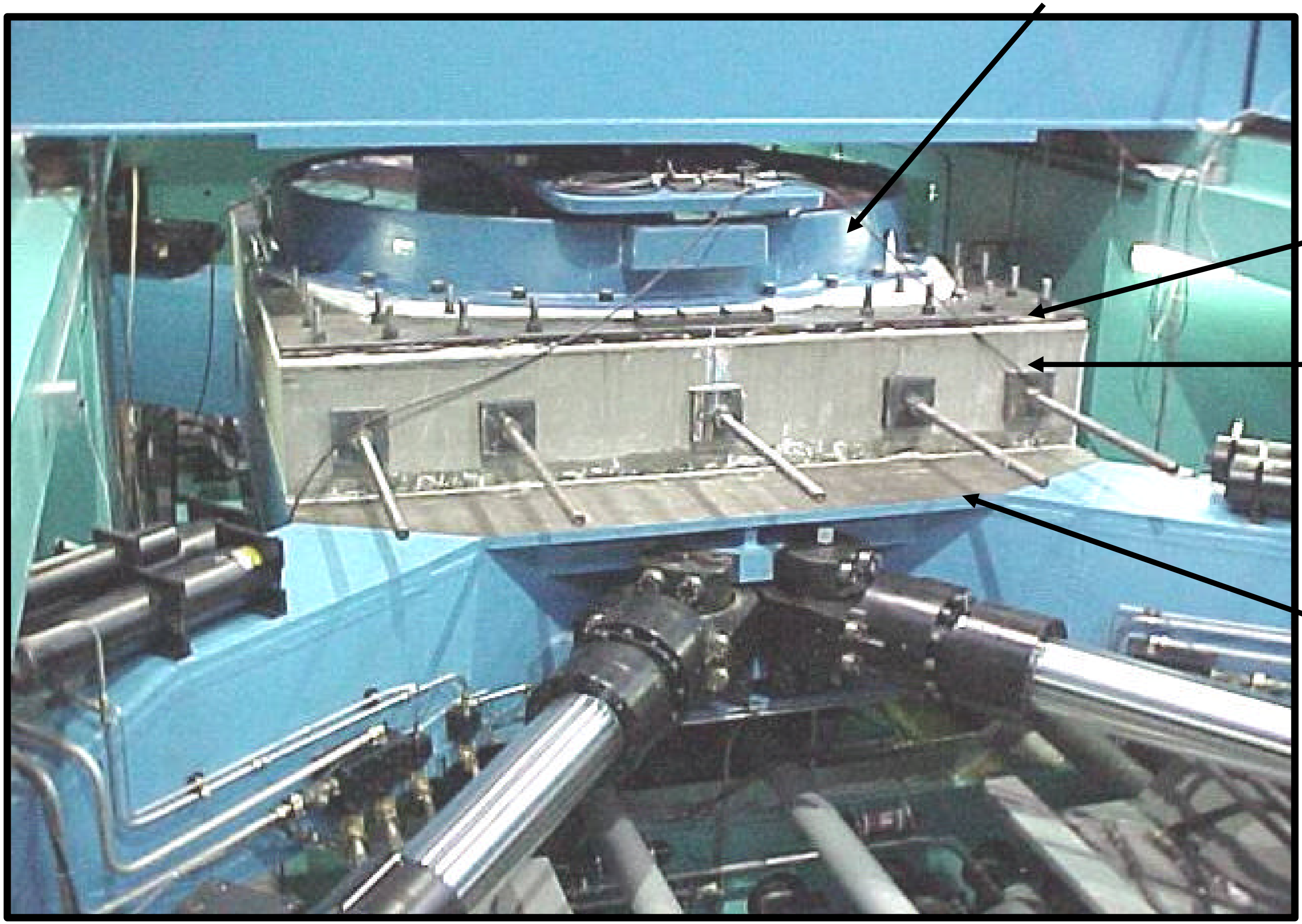

SHEEDY

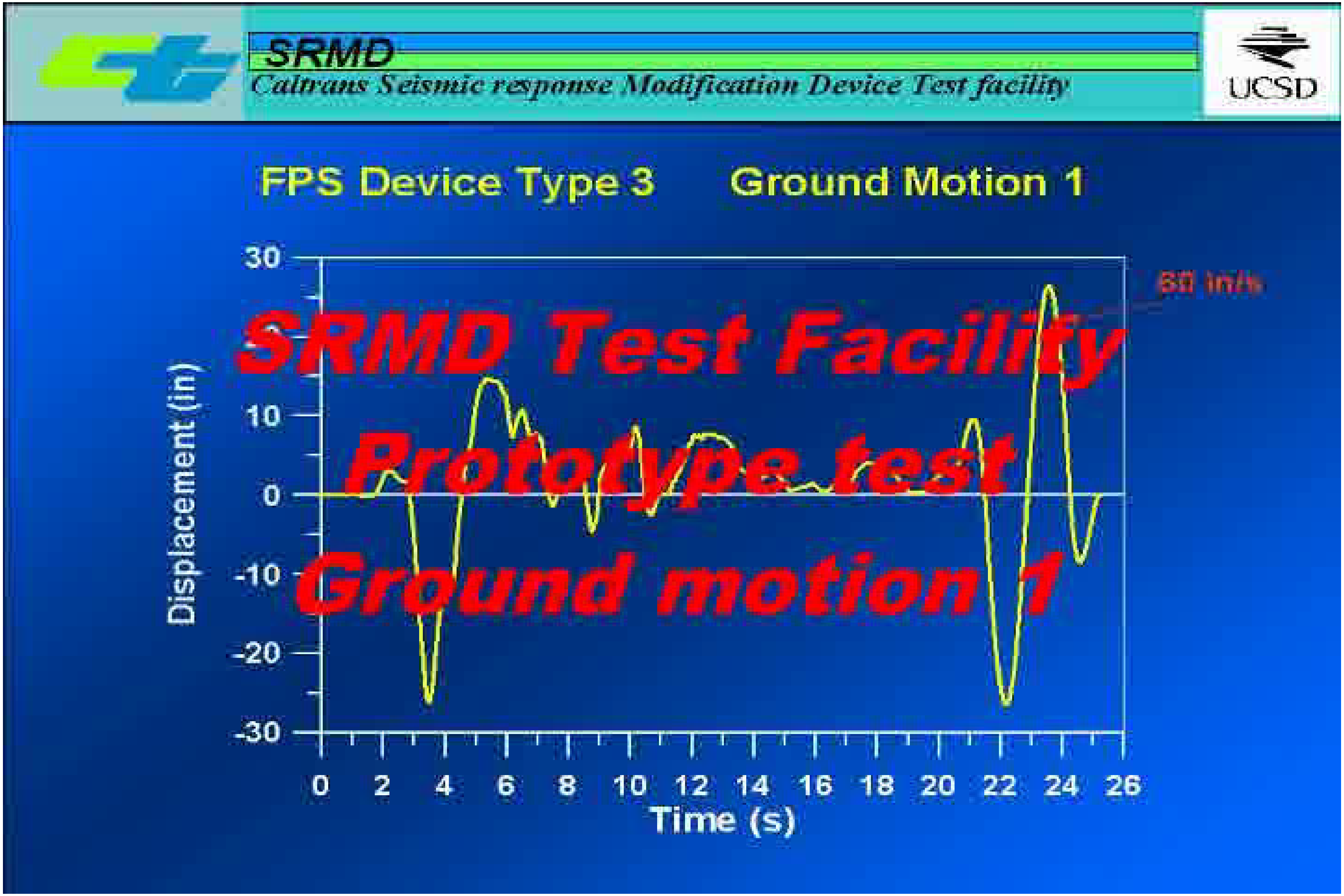
Schematic of SRMD Test System



SRMD Technical Specifications

	Vertical	*Longitudinal*	*Transverse*
Force	53,400 kN (12,000 kips)	8,900 kN (2,000 kips)	4,450 kN (1,000 kips)
Displacement	± 0.127 m (5 in.)	± 1.22 m (48 in.)	± 0.61 m (24 in.)
Velocity	± 254 mm/s (10 in./s)	± 1778 mm/s (70 in./sec)	± 762 mm/s (30 in./sec)
Clearance	Up to 1.52 m (5 ft)		~ 4 m (13 ft)
Relative rotation	± 2°	± 2°	± 2°


Bearing Specimen (Type 1)
Adapting Plate
Concrete Spacer Block
Platen


SRMD
Caltrans Seismic response Modification Device Test facility
UCSD
FPS Device Type 3
Ground Motion 1
SRMD Test Facility
Prototype test
Ground motion 1
Displacement (in)
30
10
0
-10
-20
-30
0 2 4 6 8 10 12 14 16 18 20 22 24 26
Time (s)

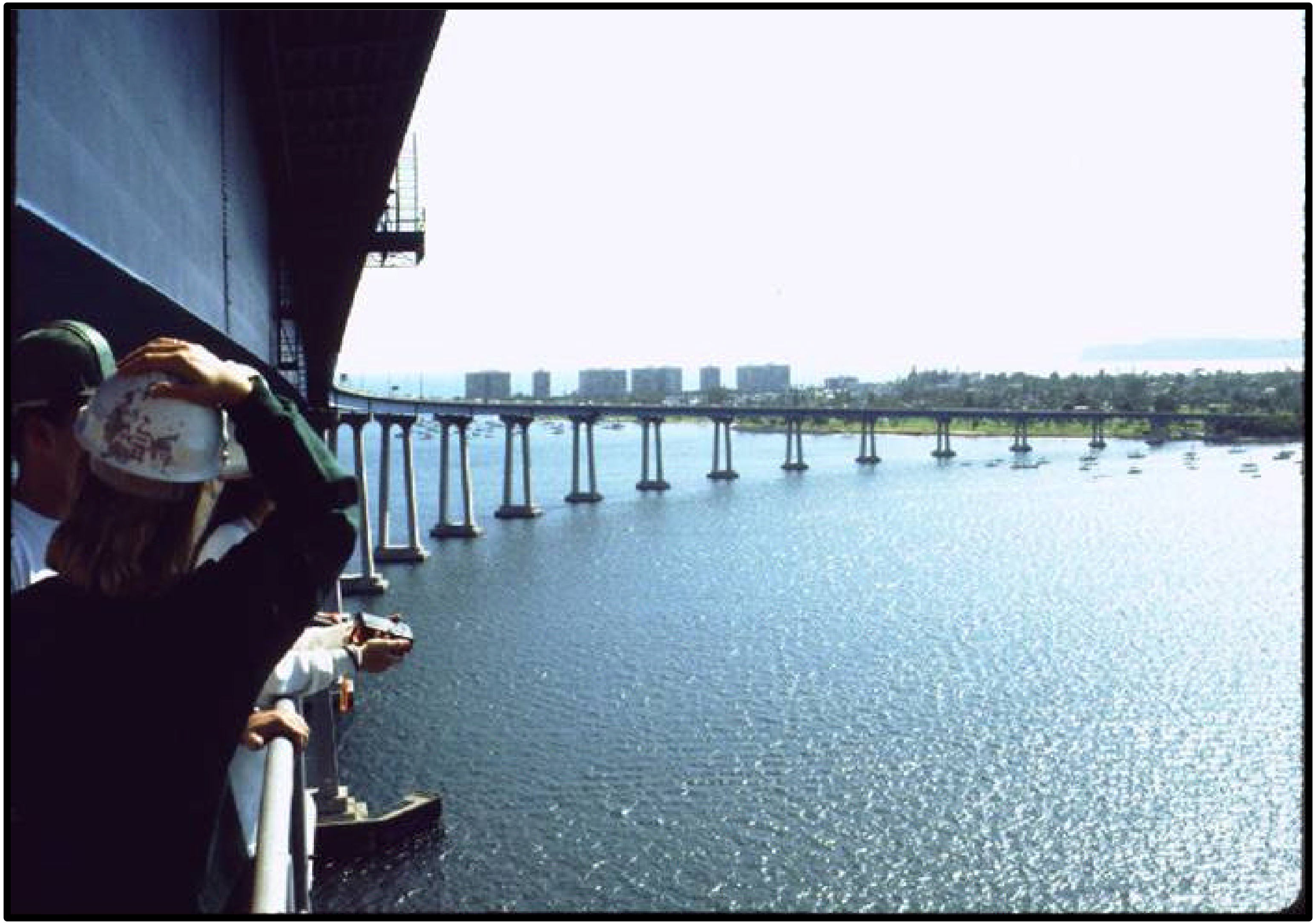
Isolation Bearing Test: Friction Pendulum Bearing

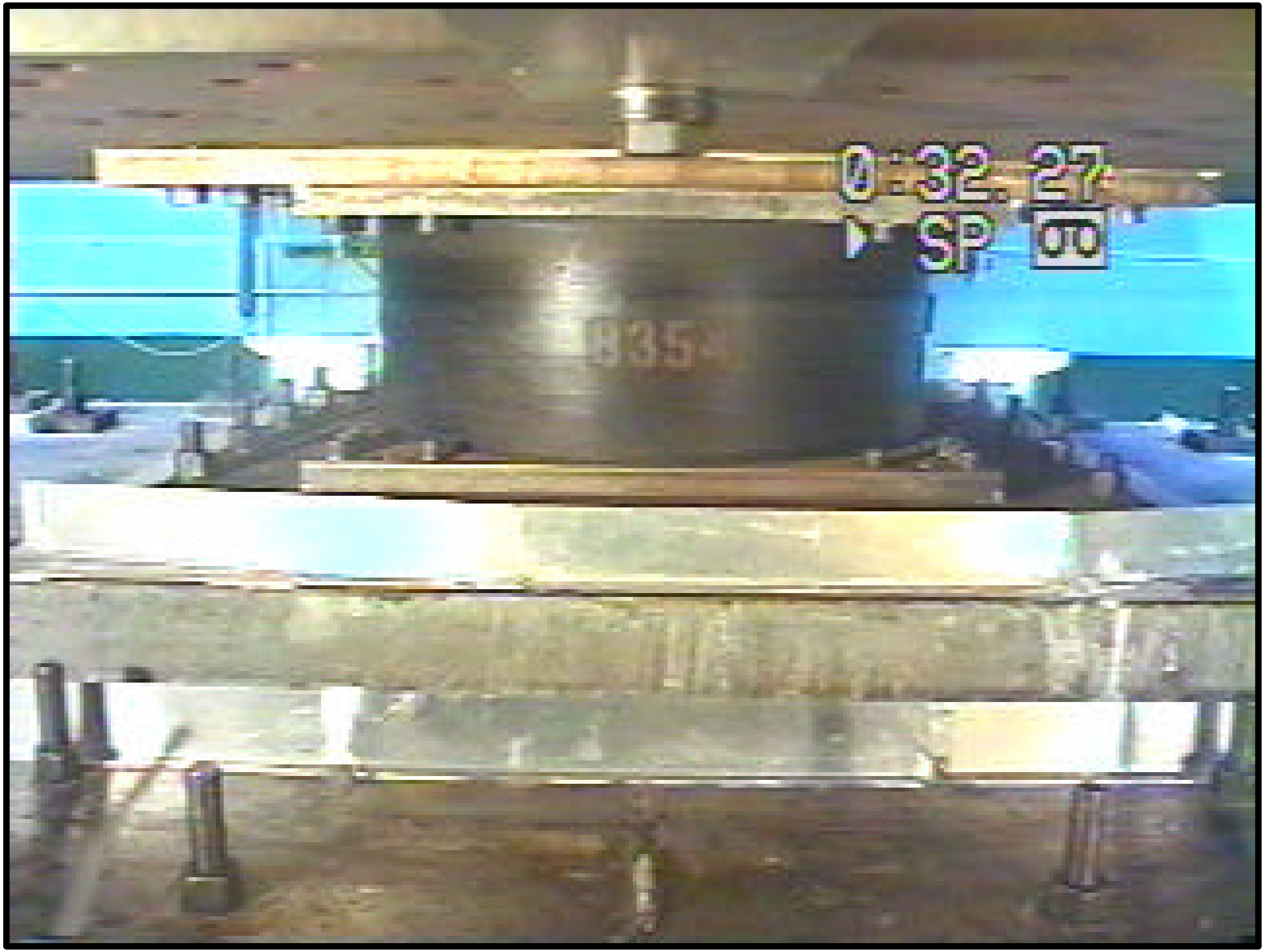
P_z = 6000 kips

D_x= +/- 29 inches

Vel = 60 in./sec.

CORONADO BRIDGE




0:32:27
SP
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The San Francisco – Oakland Bay Area

SFOBB – Existing Bridge

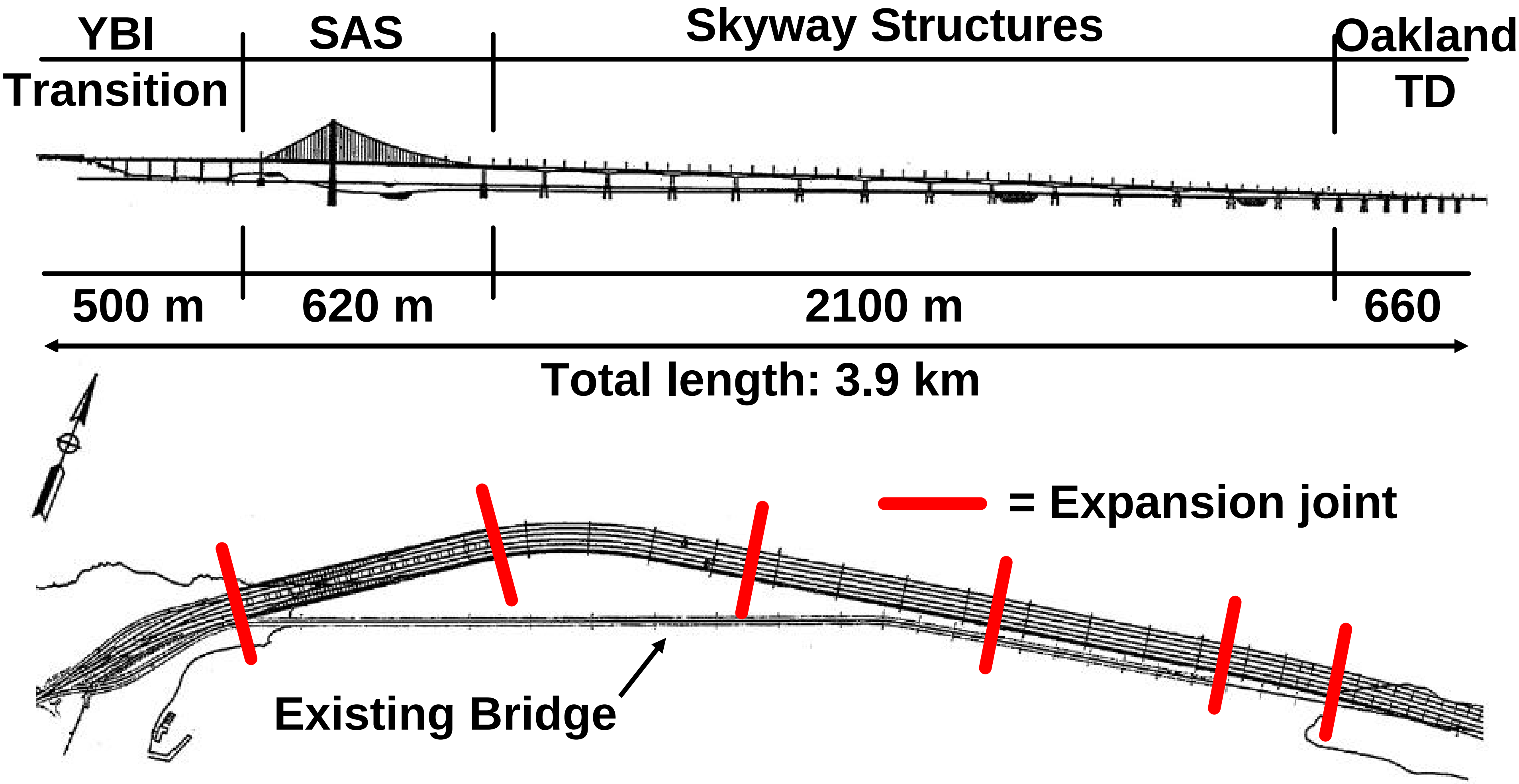
October 17, 1989 – 5:04 PM

Partial collapse of deck roadway above Pier E9 during the Loma Prieta EQ

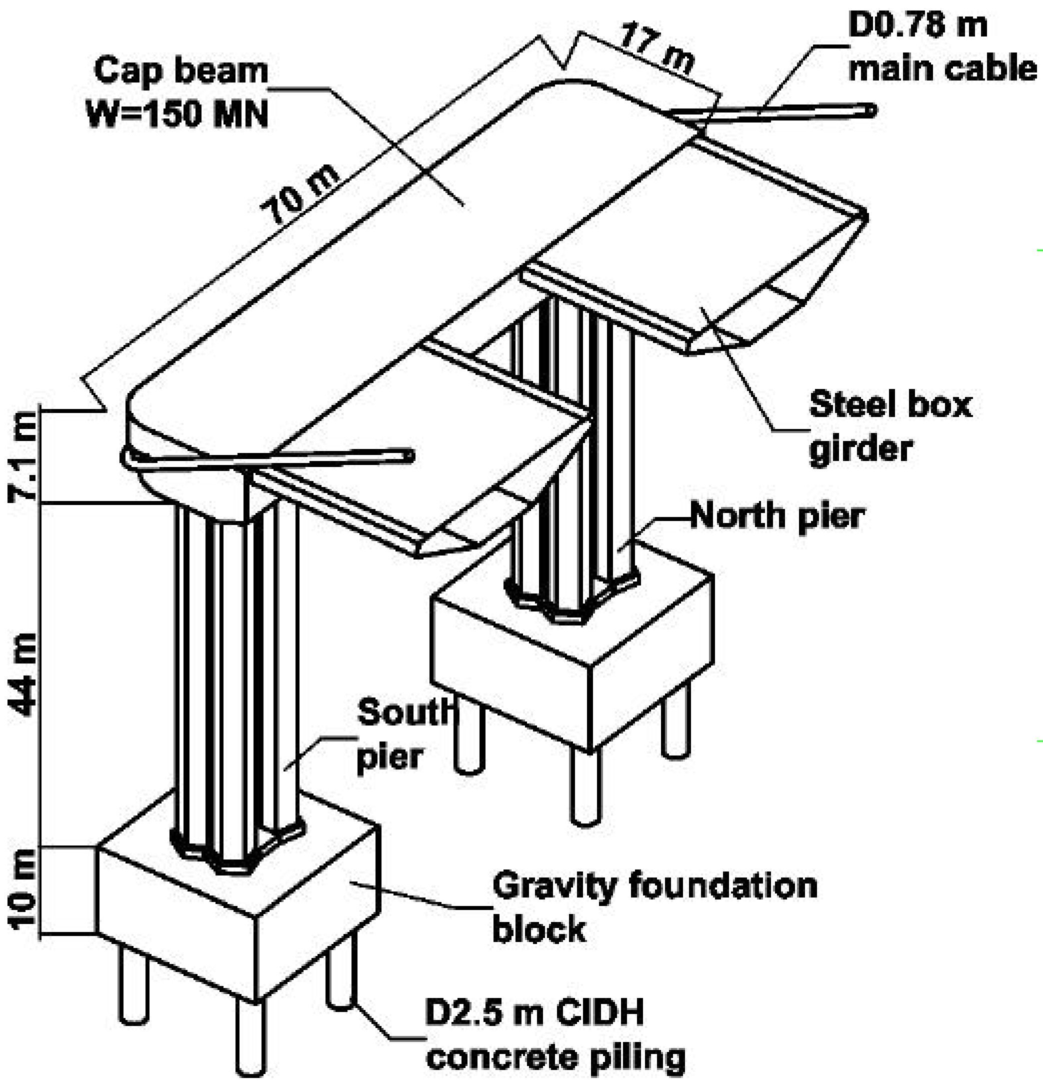
1 casualty
One month bridge closure
Million $$$ in losses

Loma Prieta EQ
D = 100 km
M = 7.1

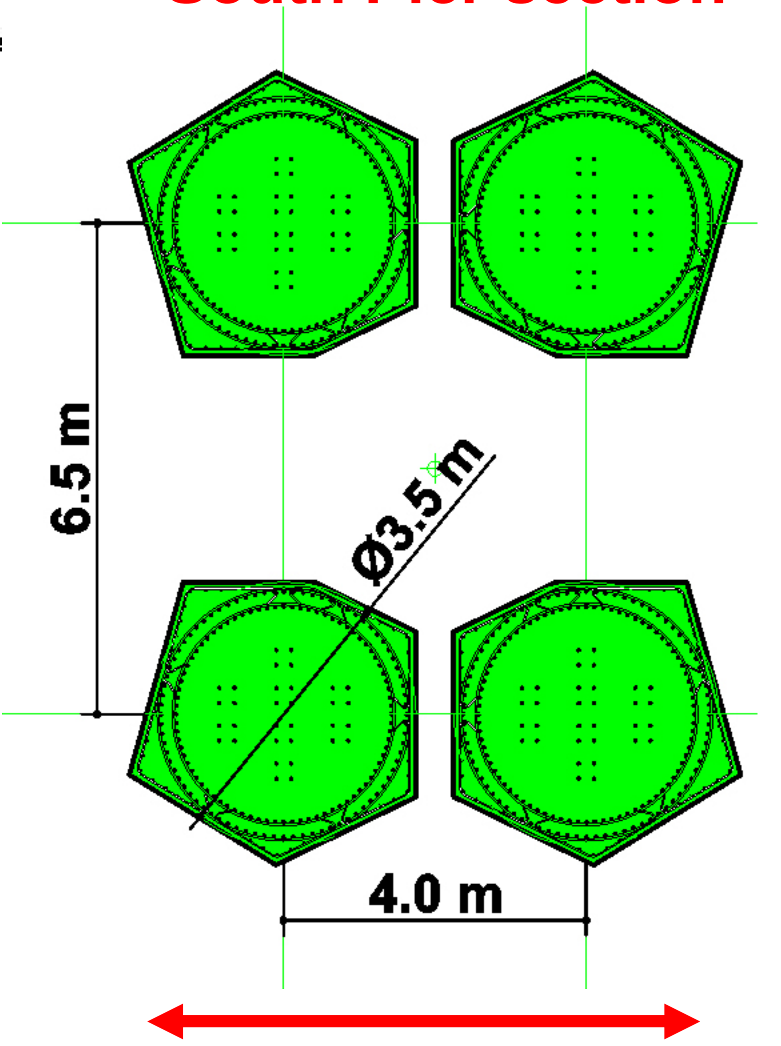
SFOBB East Span Segments



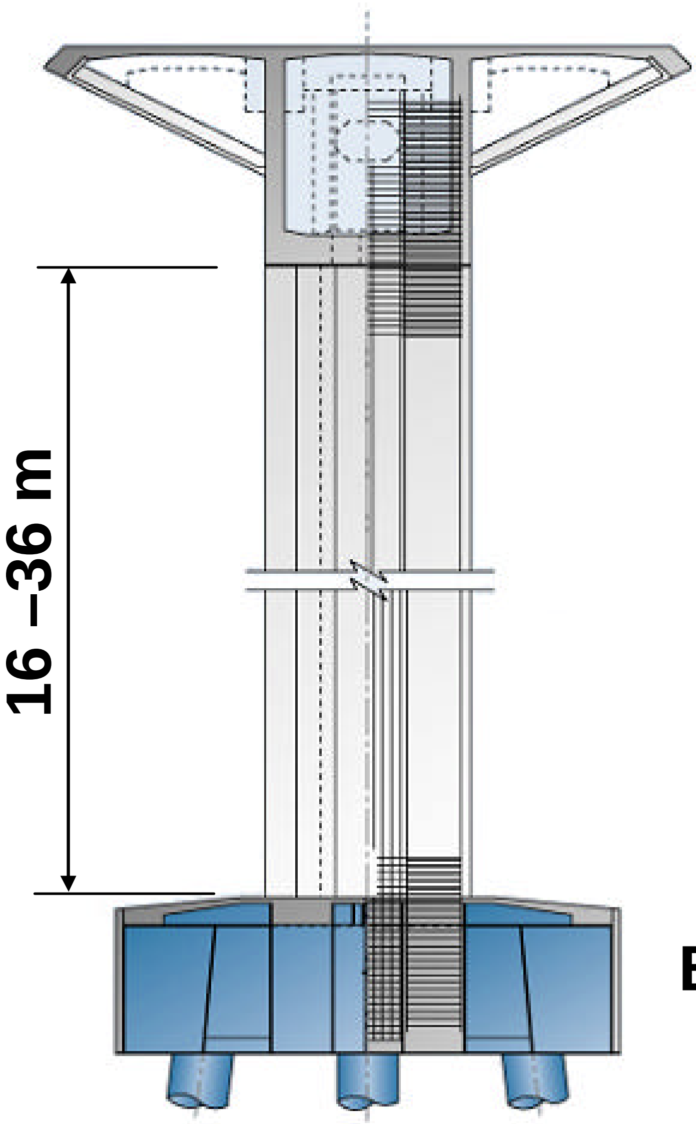
Pier W2

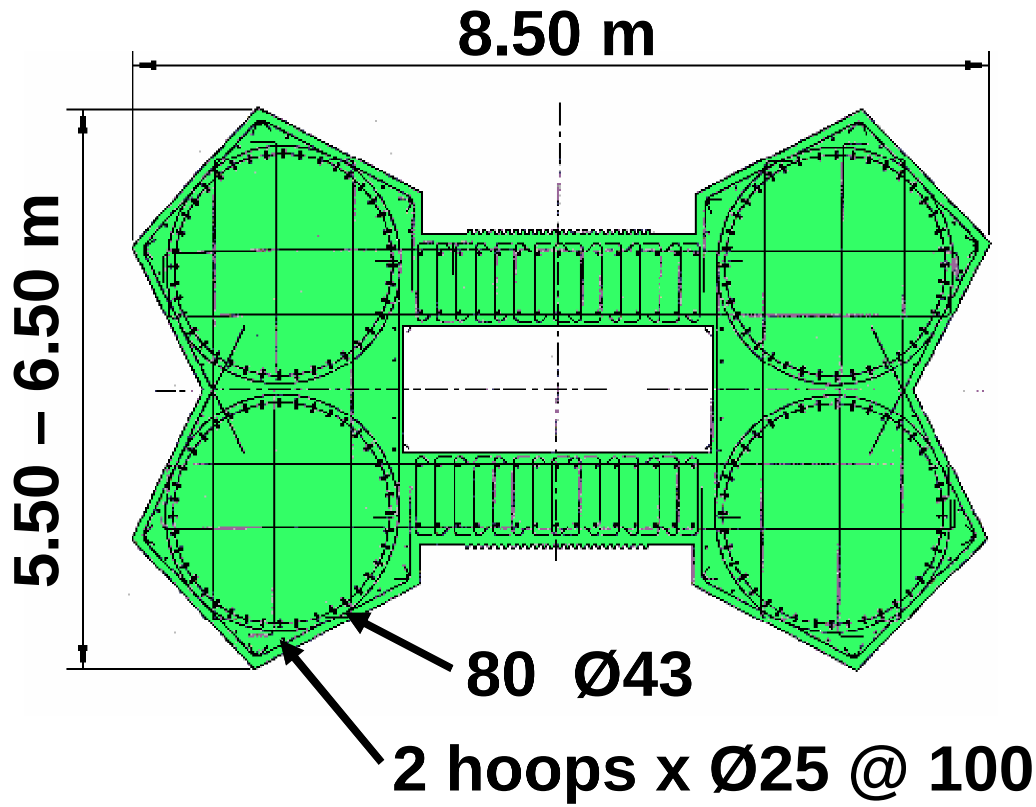


South Pier section



Skyway Structures

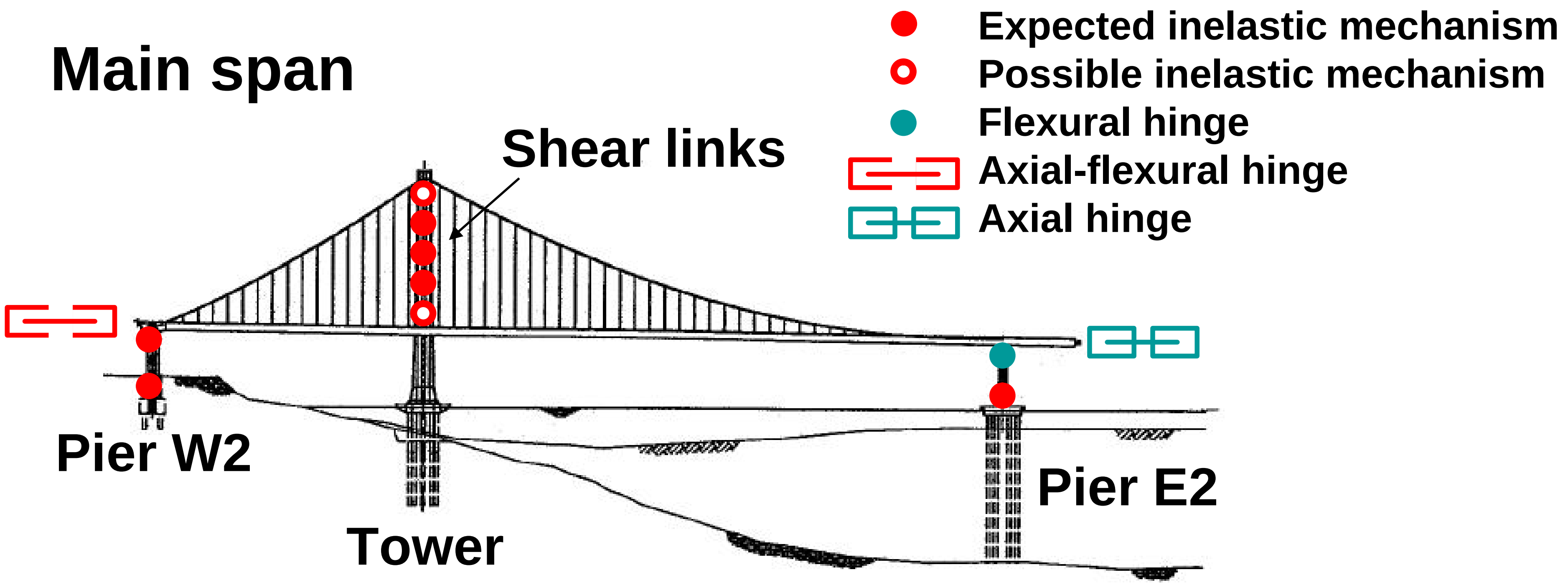




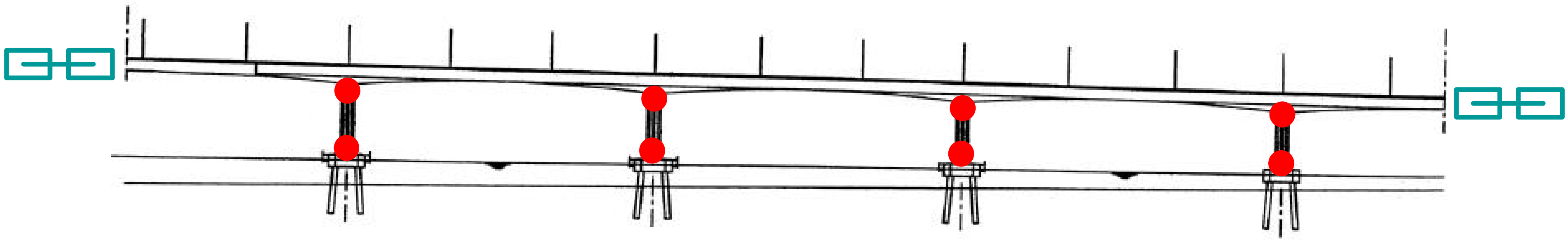
Boundary Elements: r_l=0.020, r_s=0.017

Walls: r_l=0.018, r_t=0.010

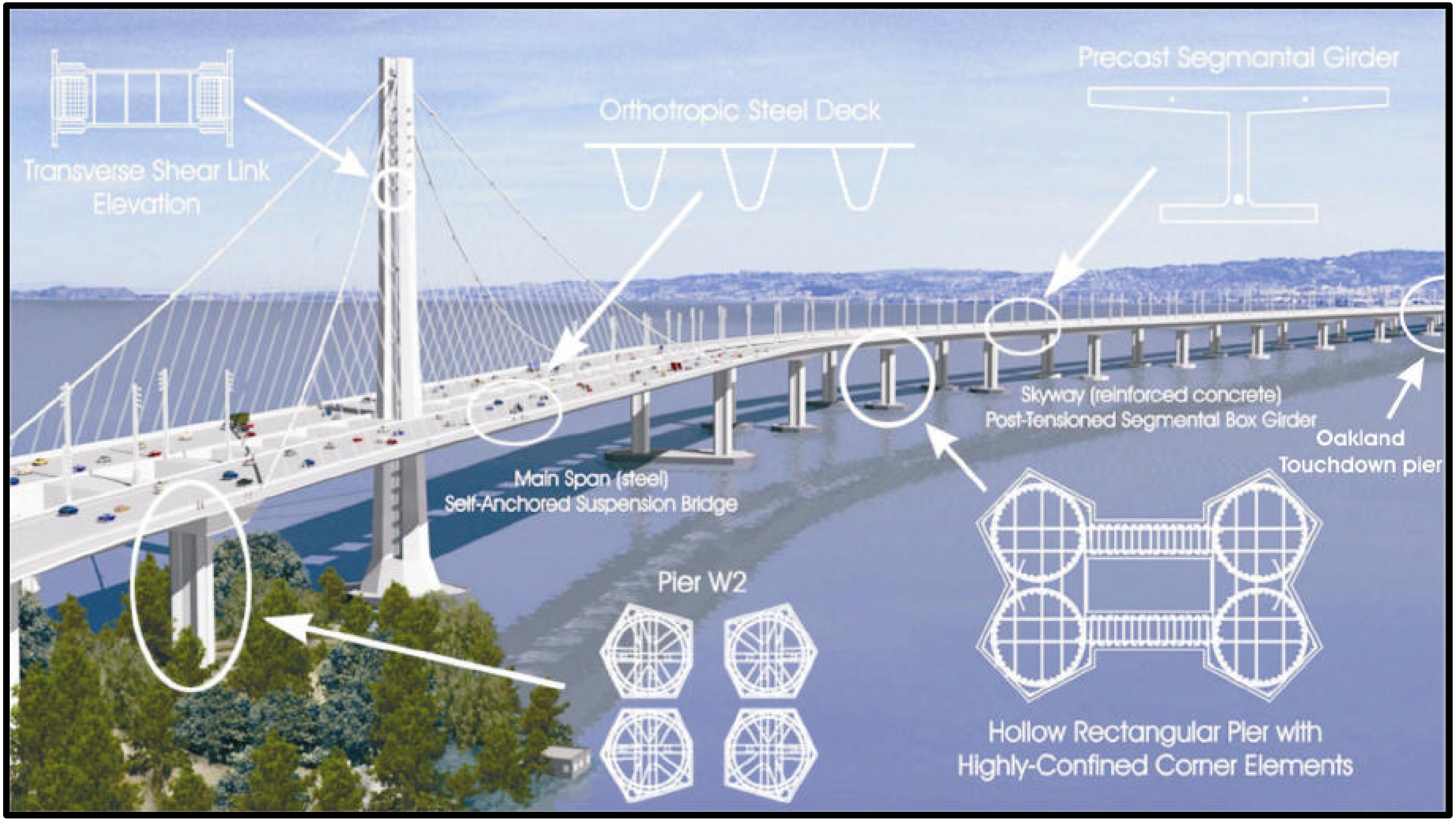
Seismic Response Mechanism



Skyway

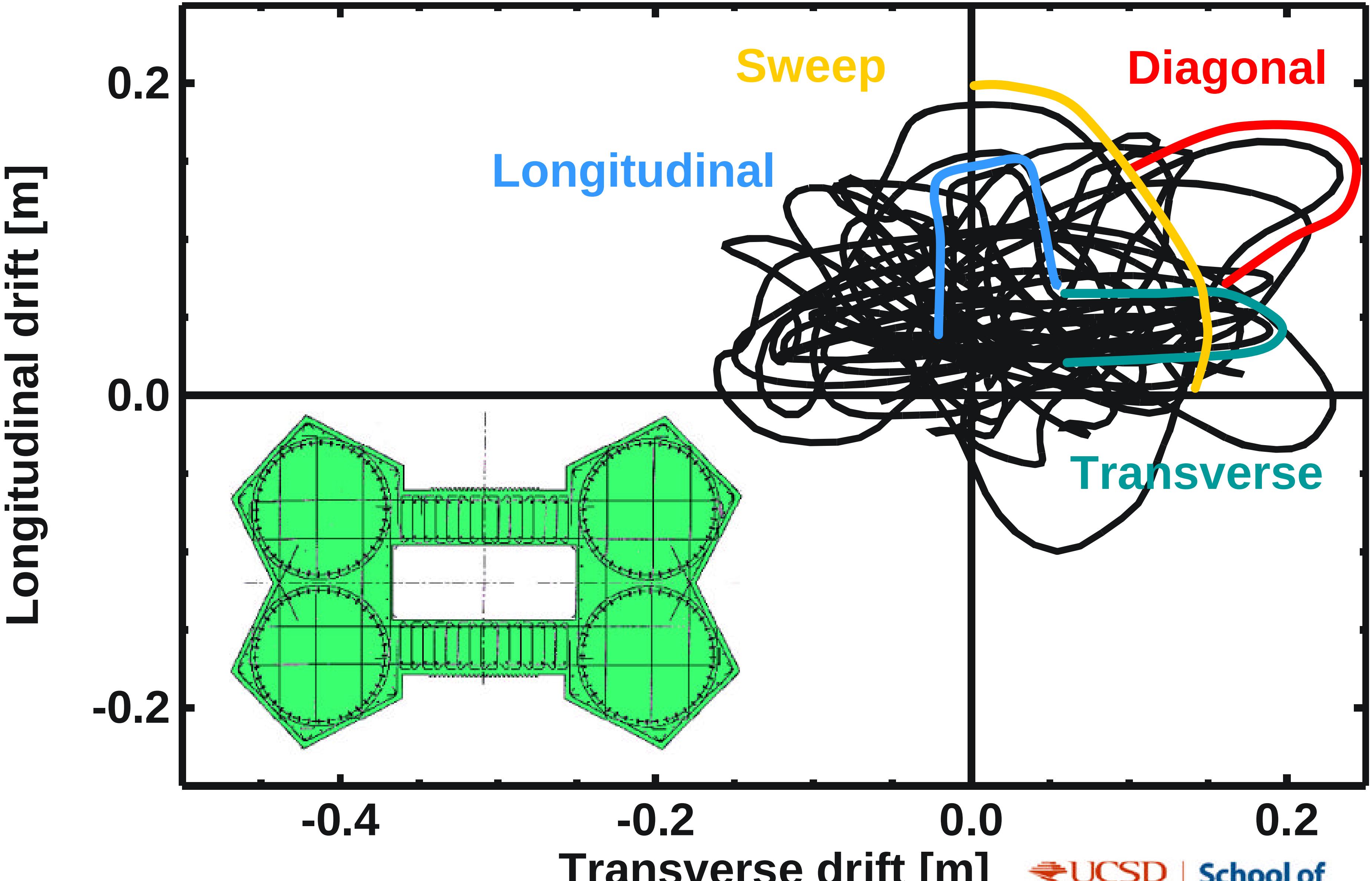


Proof Test Program



Caltrans -- Research Connection -- Thursday, June 17, 2004

Seismic Drift of Skyway Pier E9



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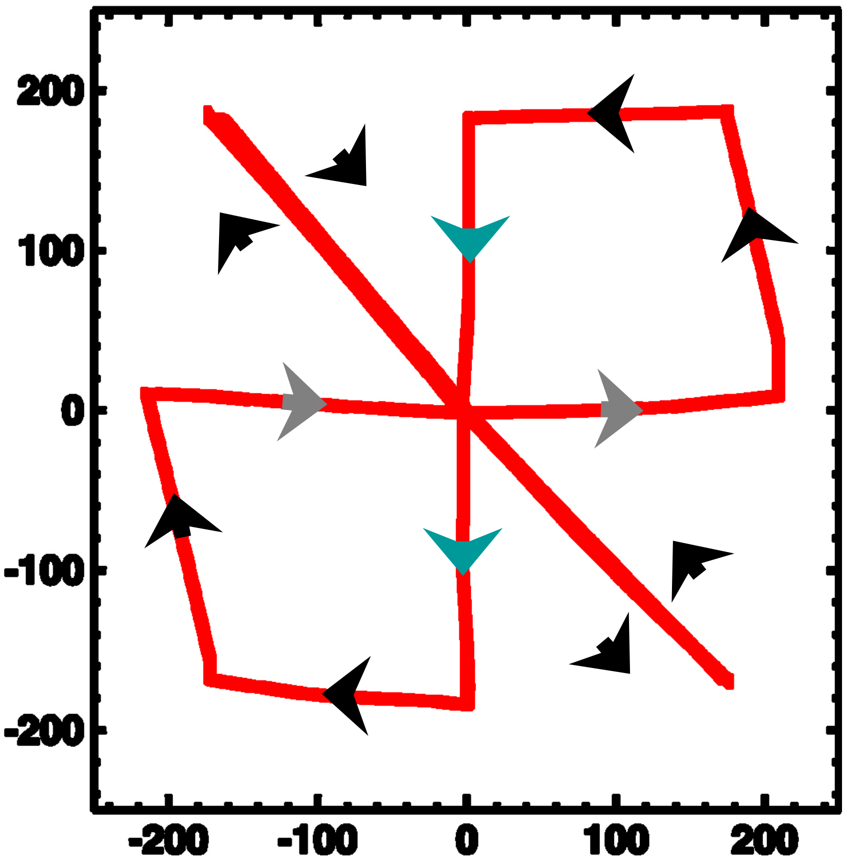
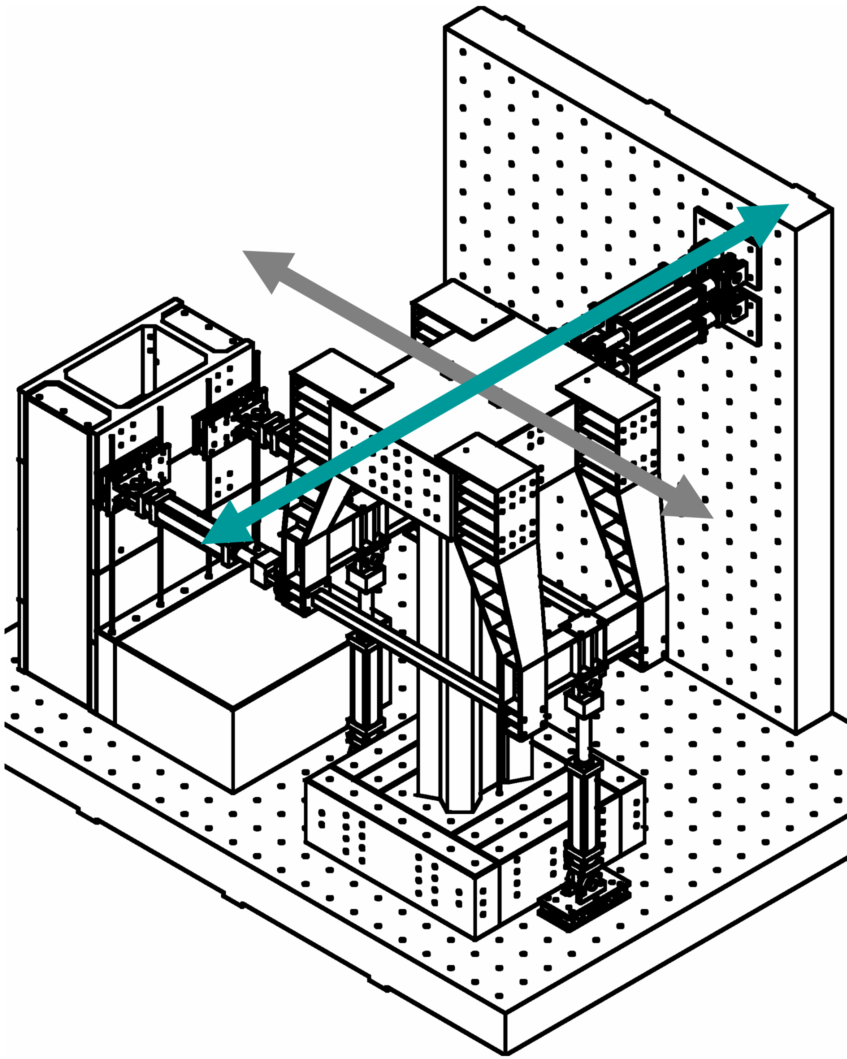
Skyway Pier Test Set UP

Loading History

Transverse Displacement (mm)



Longitudinal Displacement (mm)



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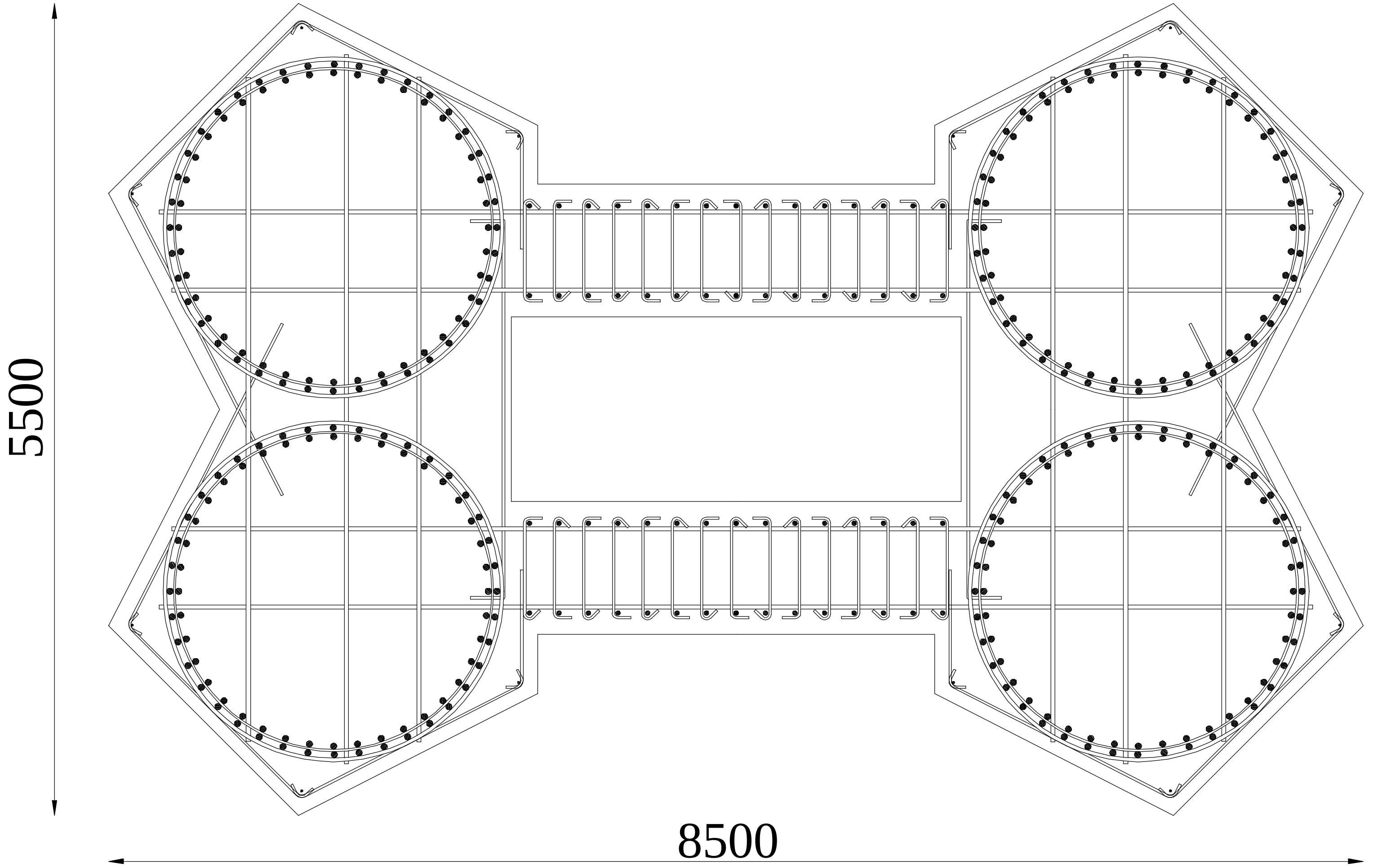
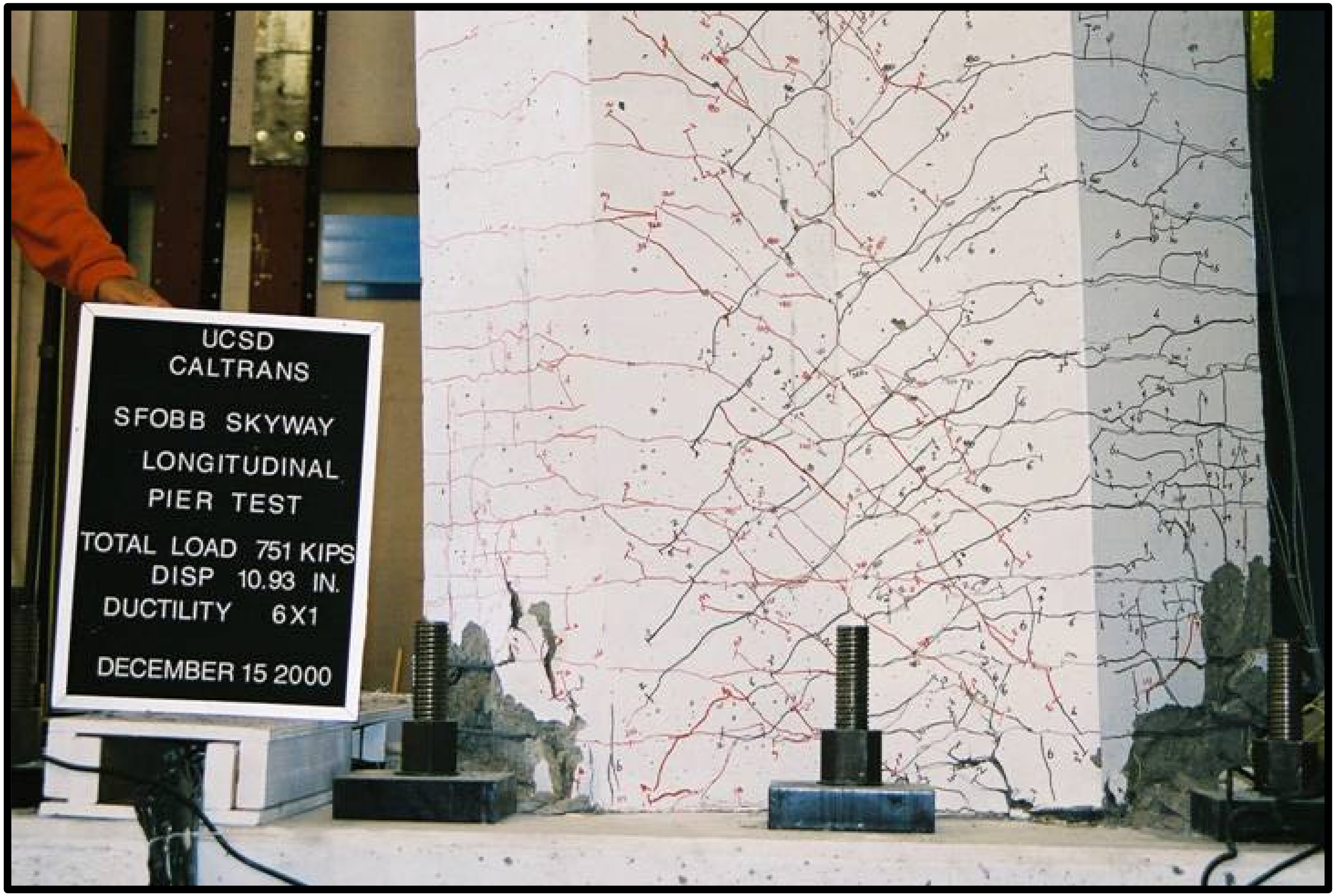
SFOBB Longitudinal Pier Test Setup

Skyway Pier Test: Front view of the test setup

Prototype section for Longitudinal Pier Test

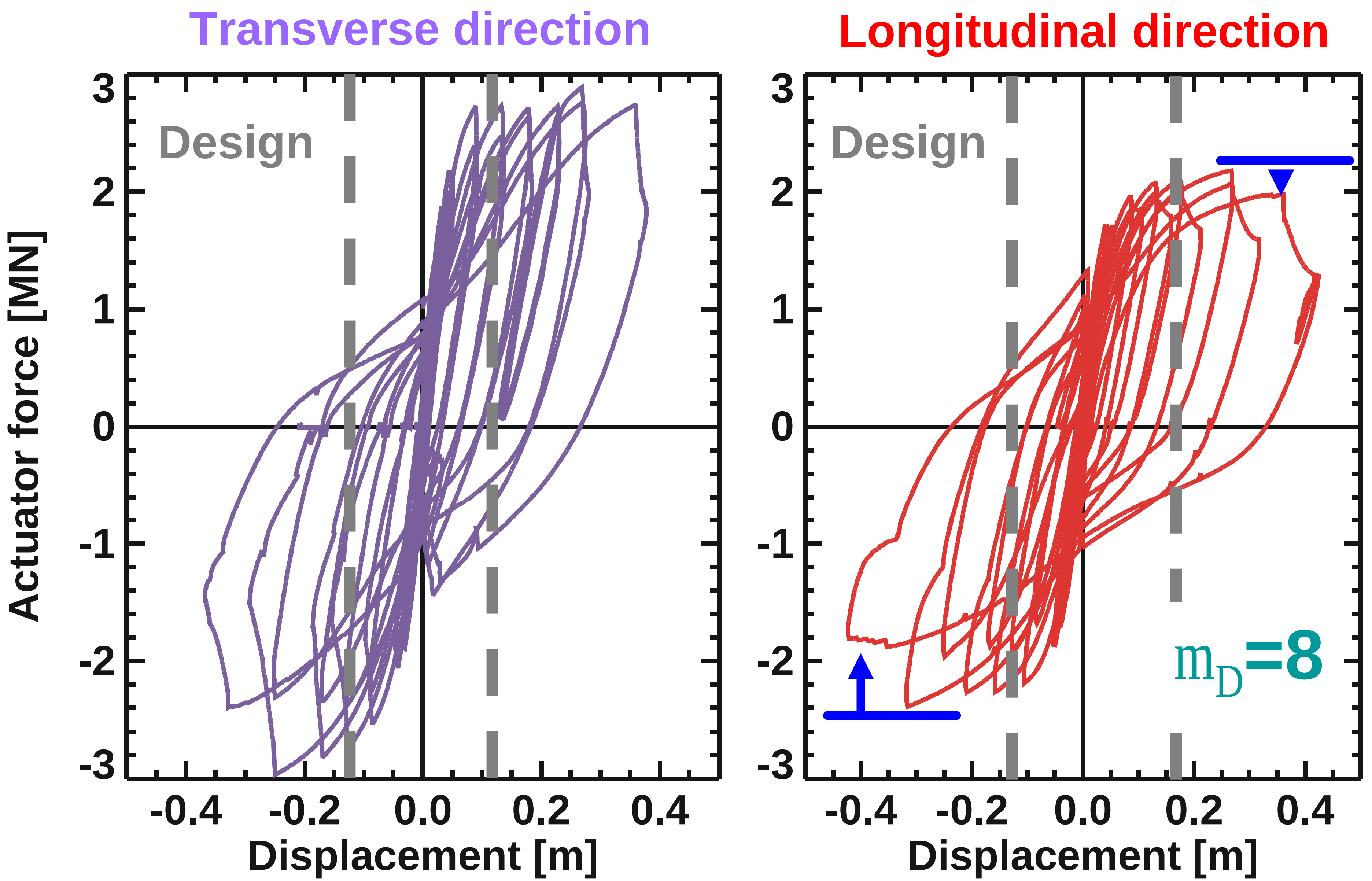




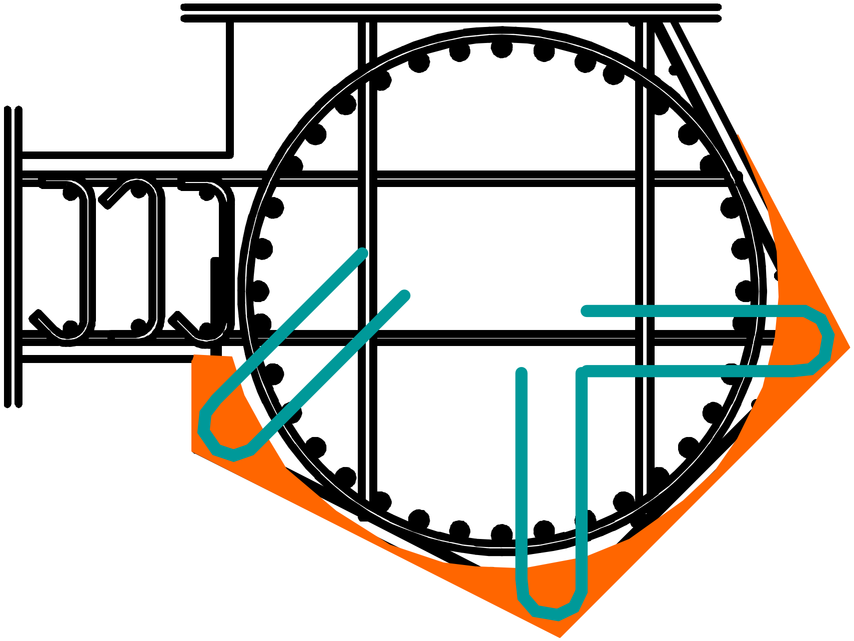
$$\mu_{\Delta} = 6 \times 1$$

$$\mu_{\Delta} = 2 \text{ x } 1$$

Skyway Pier Test: Hysteretic behavior



FEE Performance



m_D=2

Spalling of the architectural concrete

Column Damage

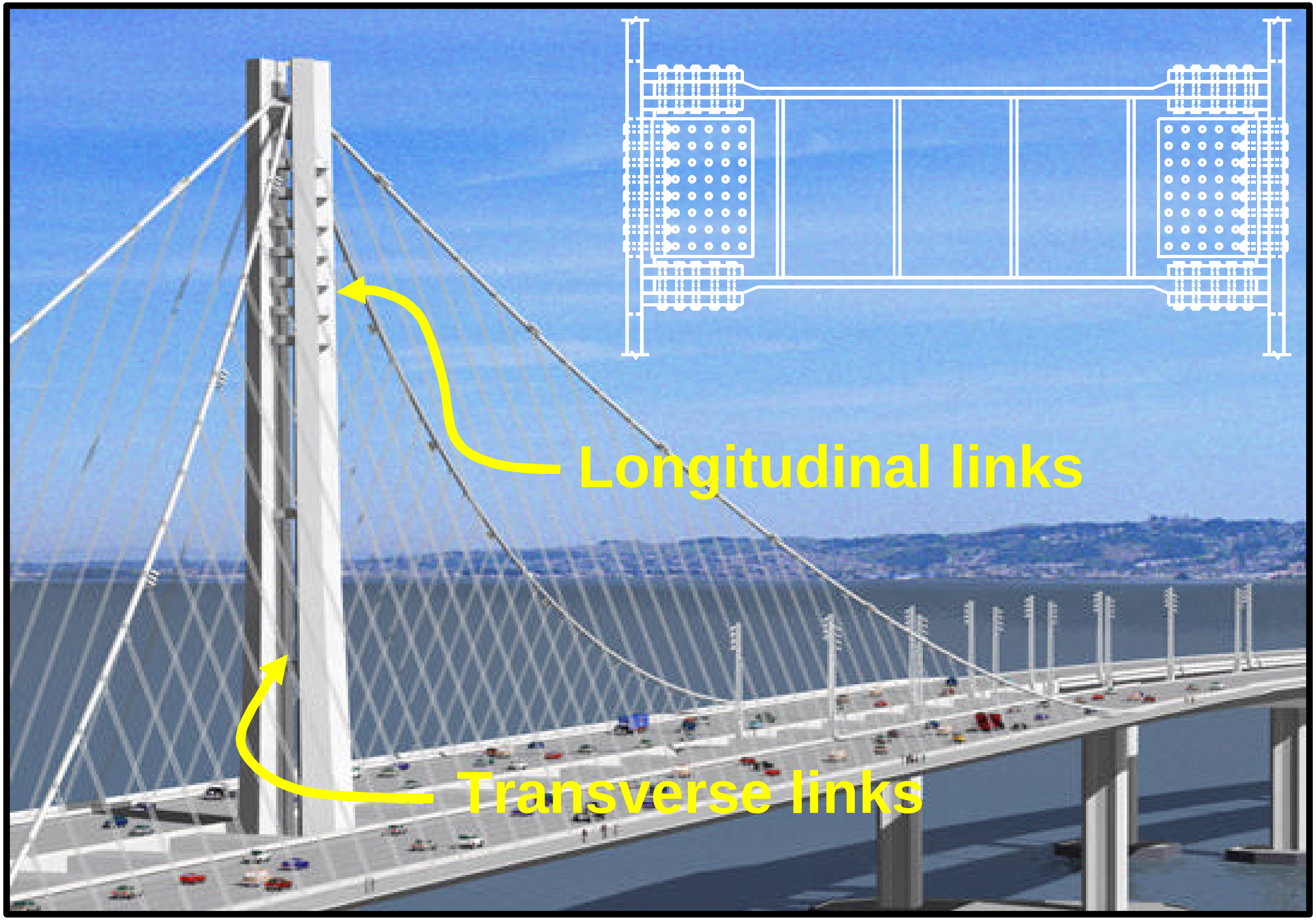
Longitudinal Pier Test

No isolation gaps

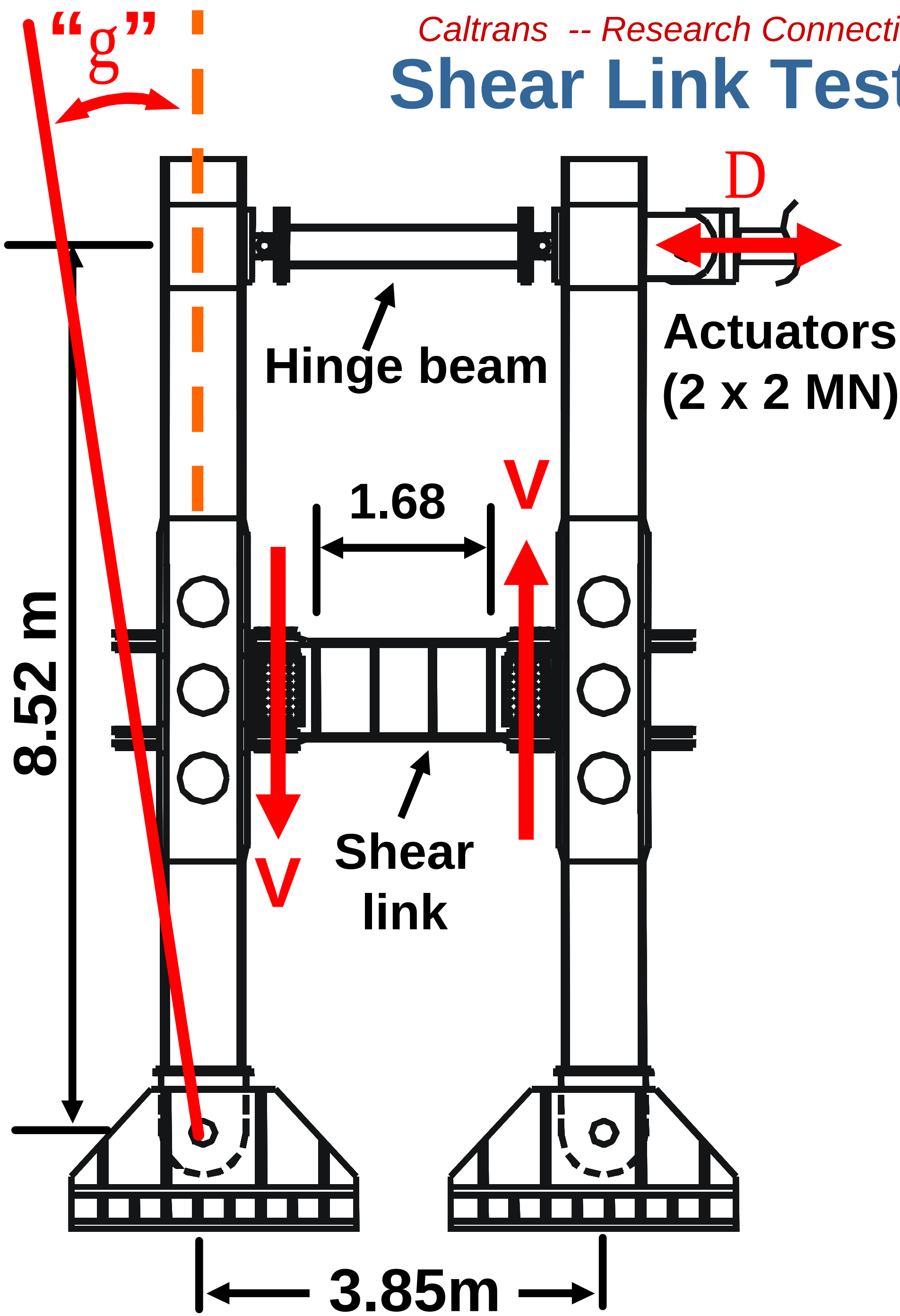
Diagonal Pier Test

With isolation gaps

Shear Link Tests

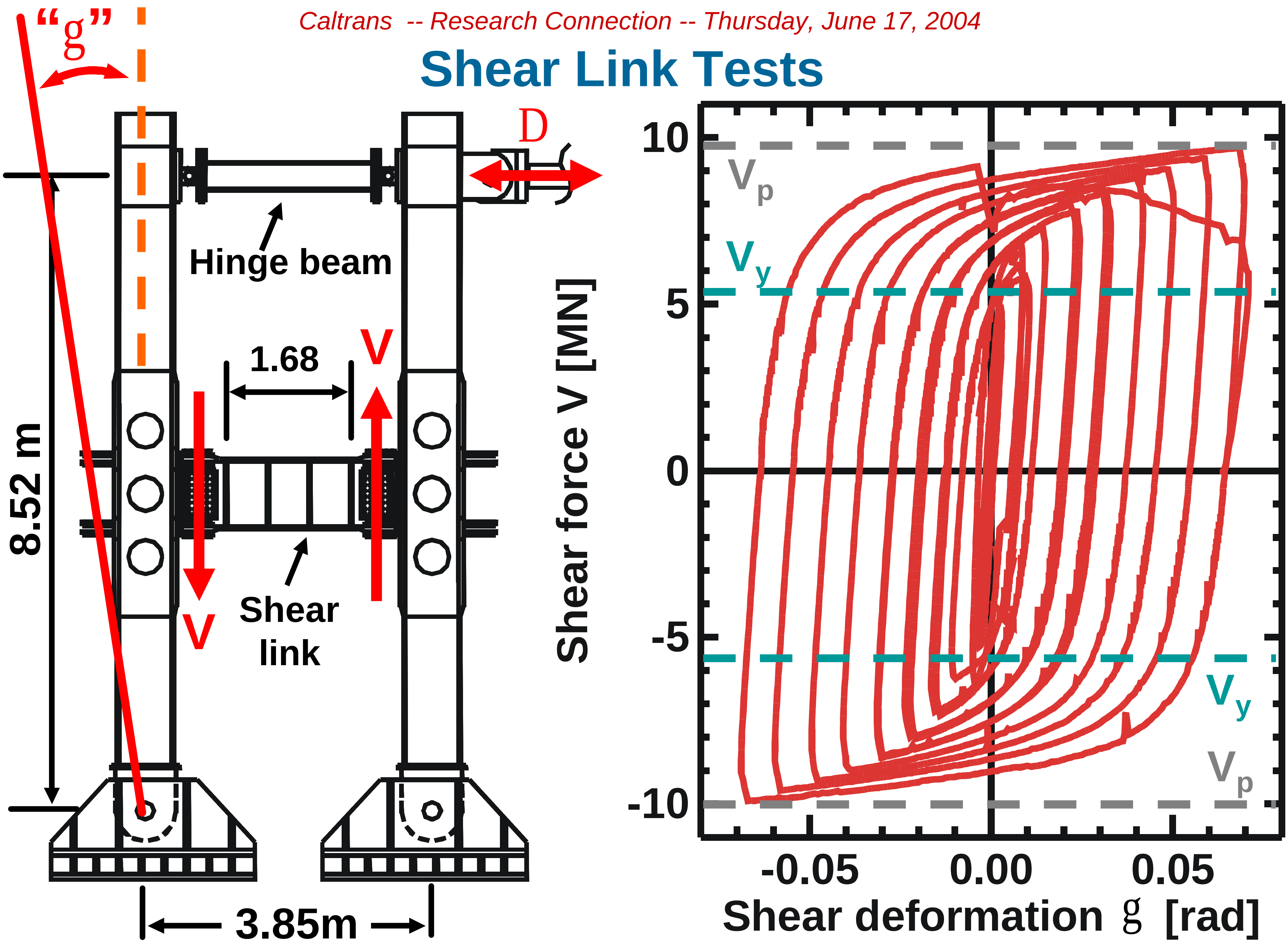


Shear Link Tests: Test setup

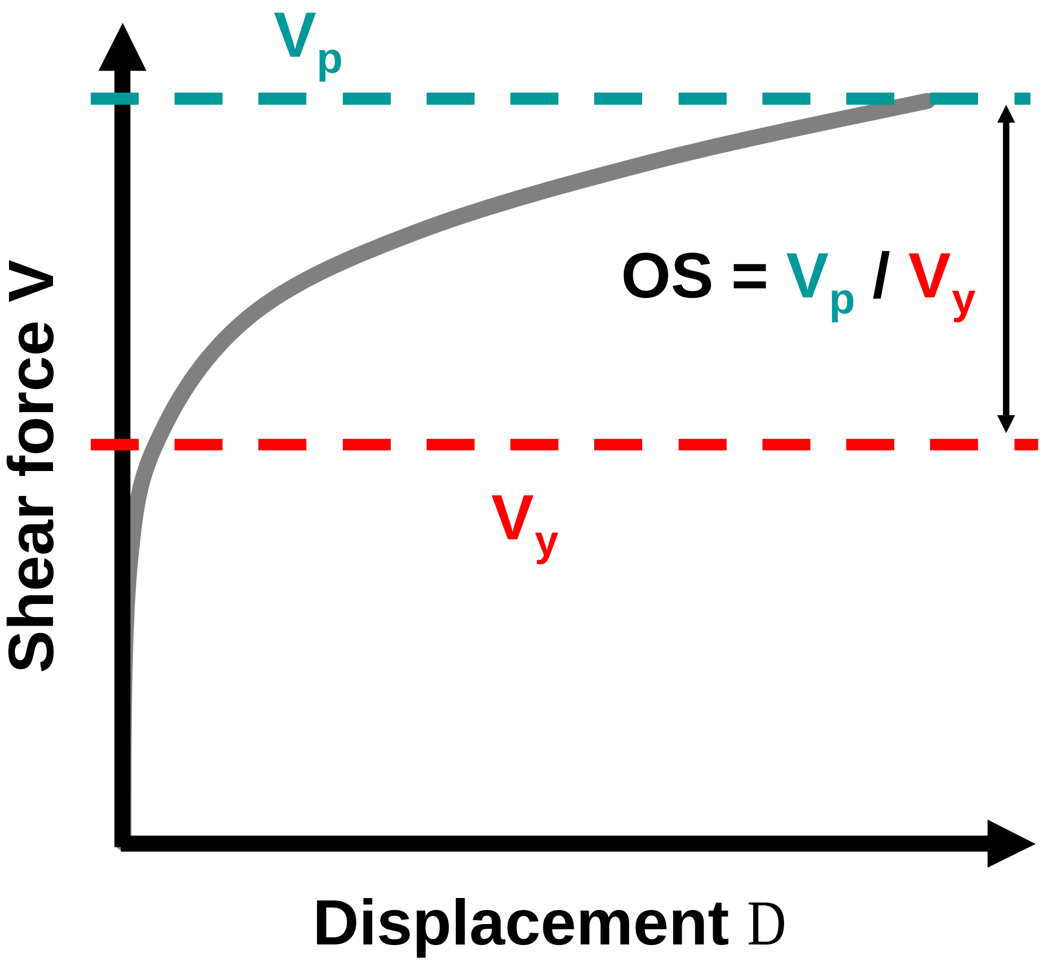


Caltrans -- Research Connection -- Thursday, June 17, 2004

Shear Link Tests



Shear Link Overstrength

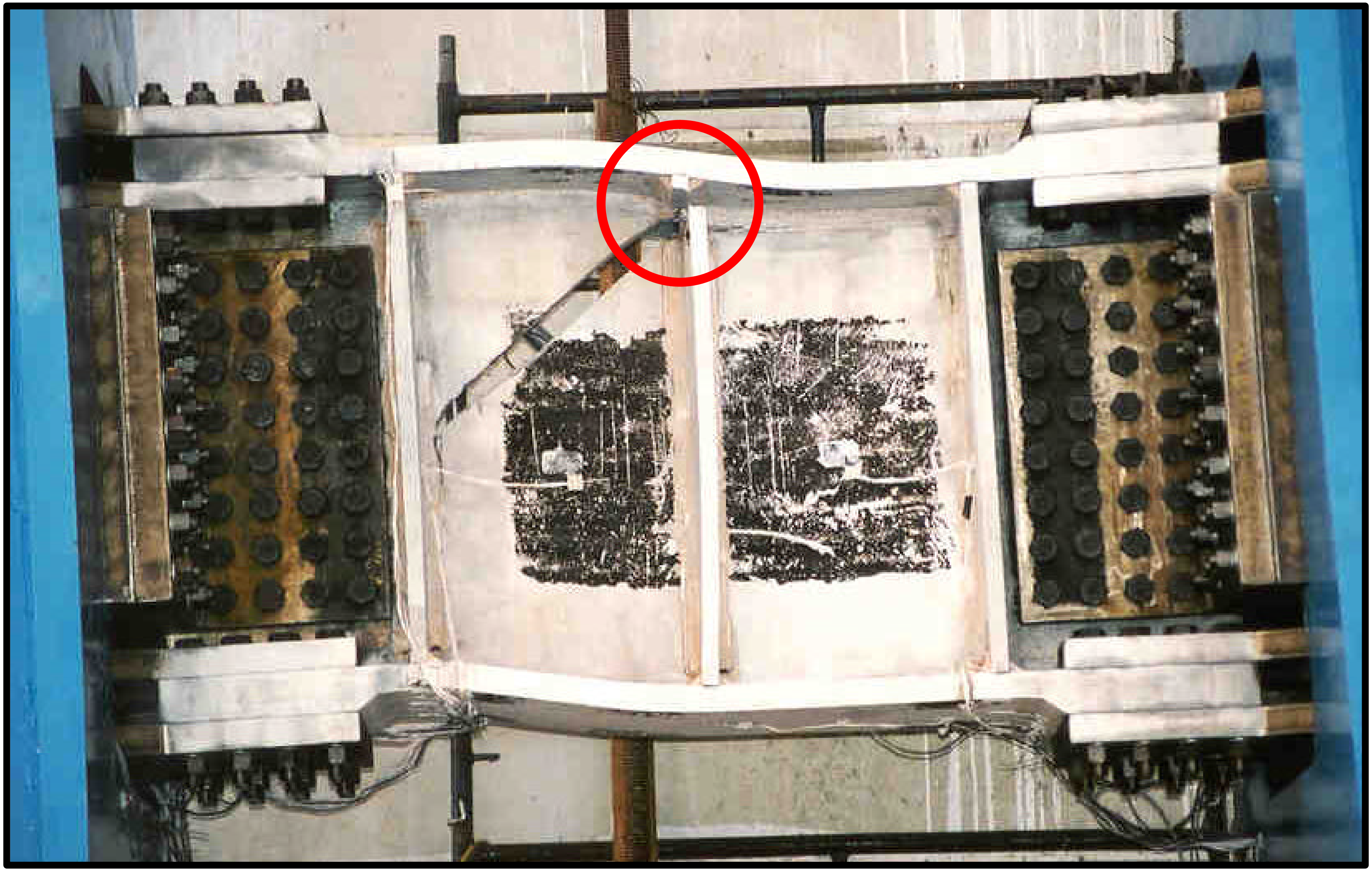


Overstrength

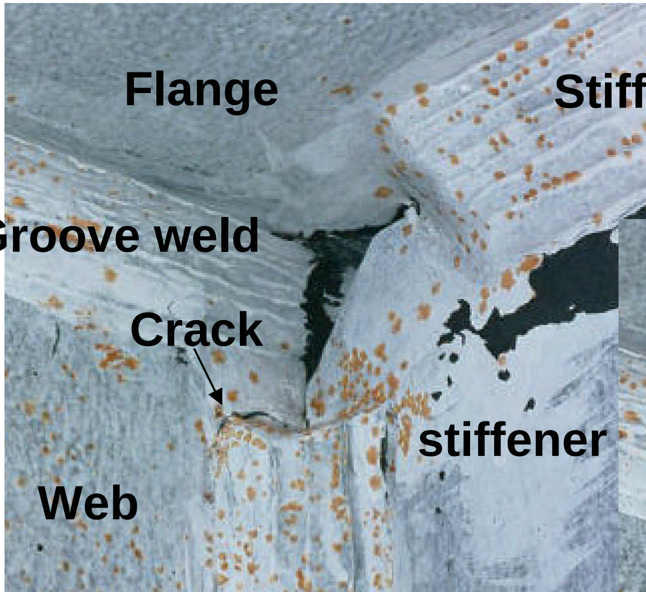
Transverse Link	1.83
Longitudinal Link	1.94
AISC Code	1.25

Code significantly underestimates the overstrength

Shear Link Tests: Failure



Shear Link Test: Failure development

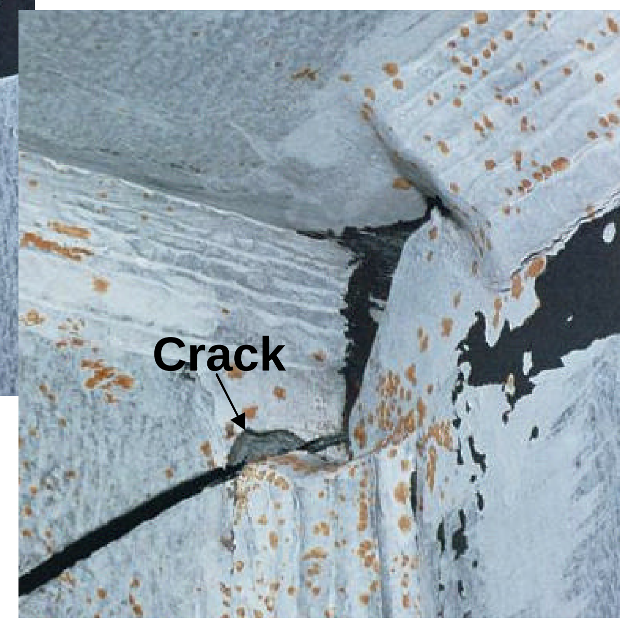


Stiffener / web
fillet weld

g = 0.04 rad

g = 0.05 rad

On the way to
g = 0.069 rad



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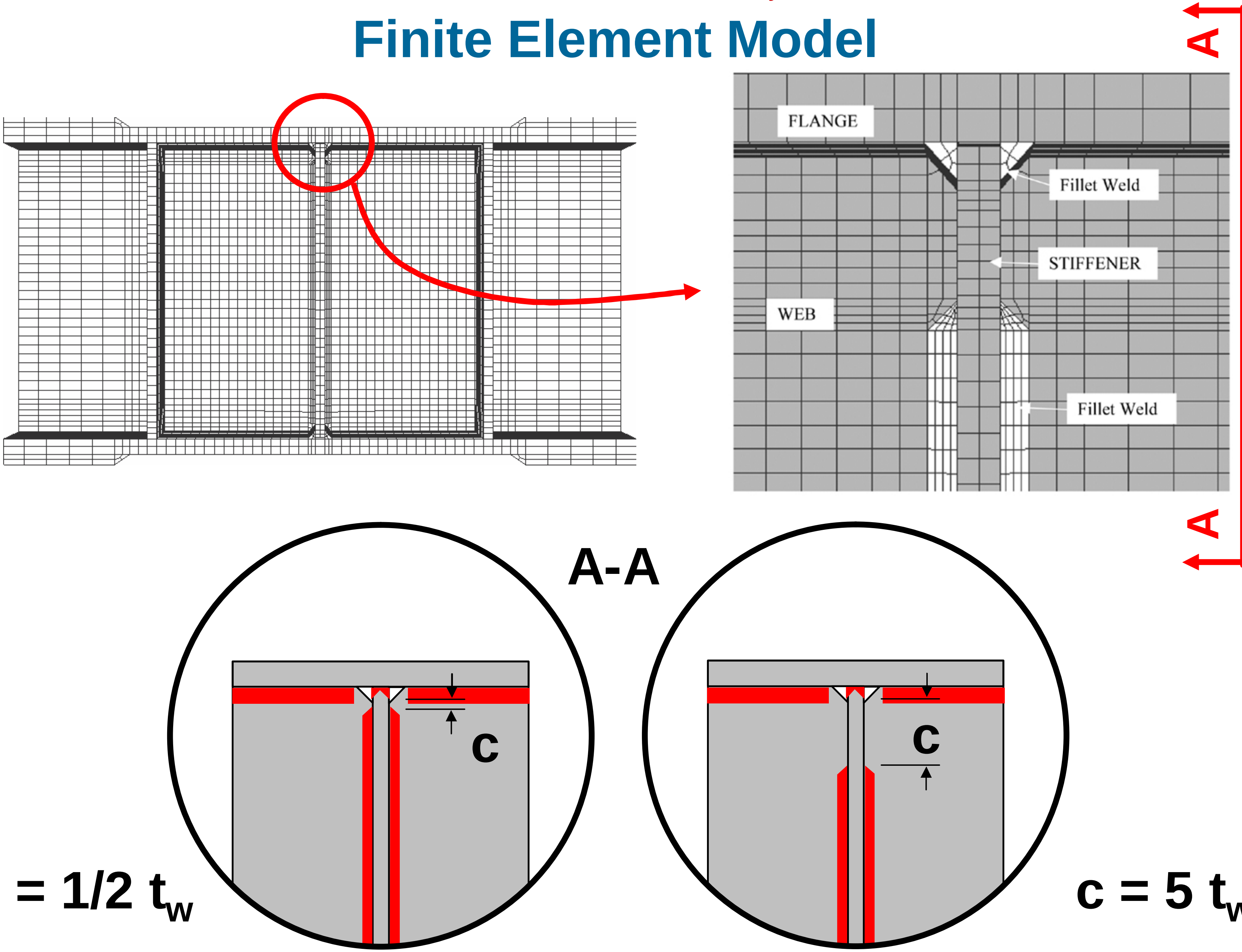
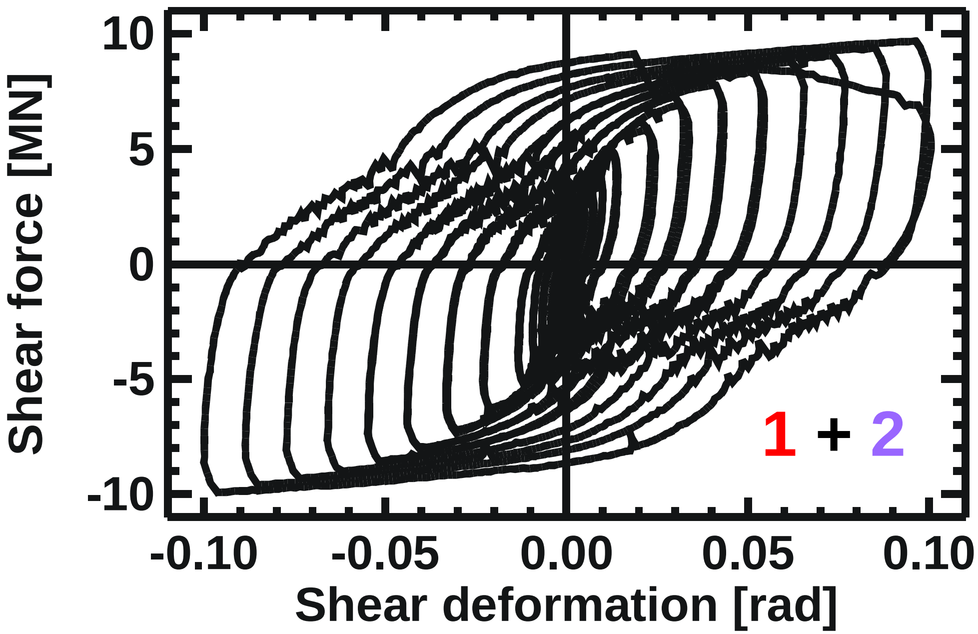
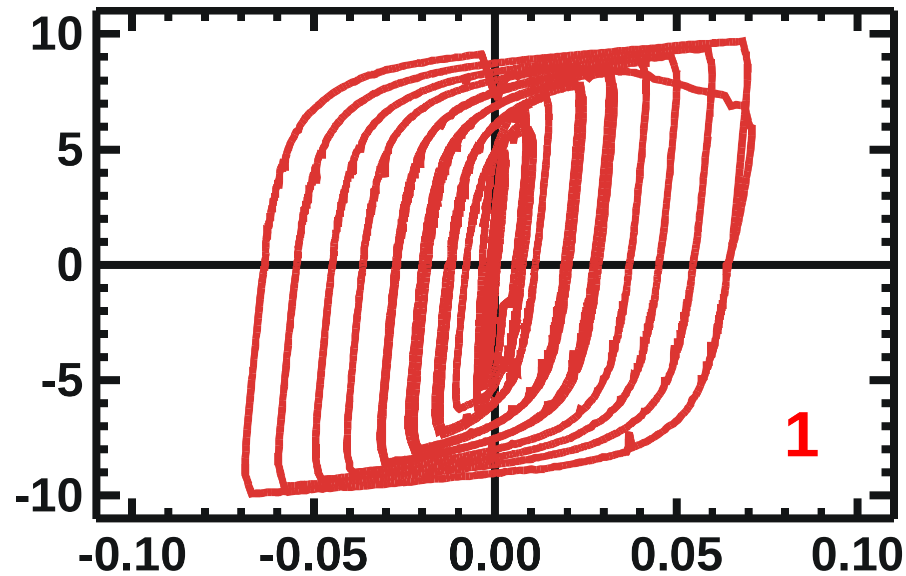
Finite Element Model

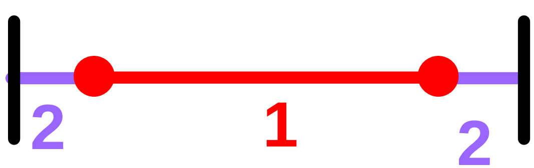


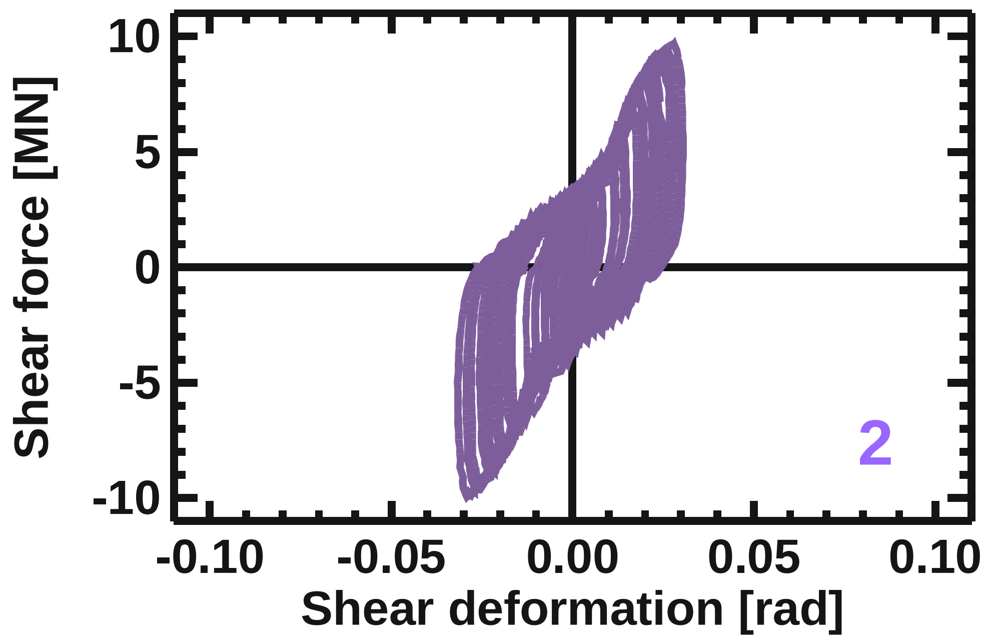
Global Bridge Analysis





Shear link model





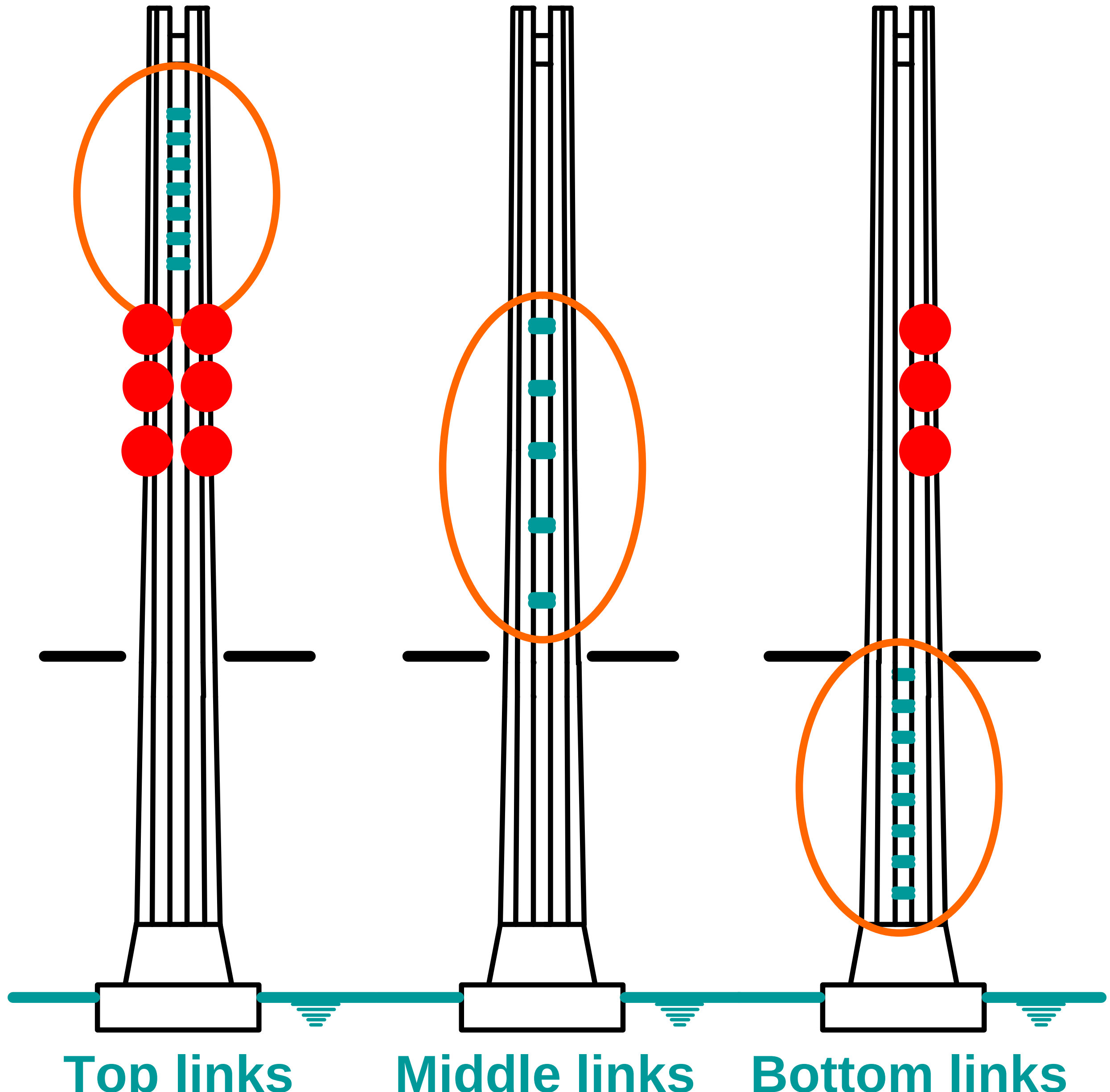
Time History Analyses: Parameter Study

- Influence of tower link stiffness
  - vary size of the tower links
- Influence of tower link location
  - vary link location along tower height
- Influence of tower link inelastic behavior
  - vary link hysteretic characteristics

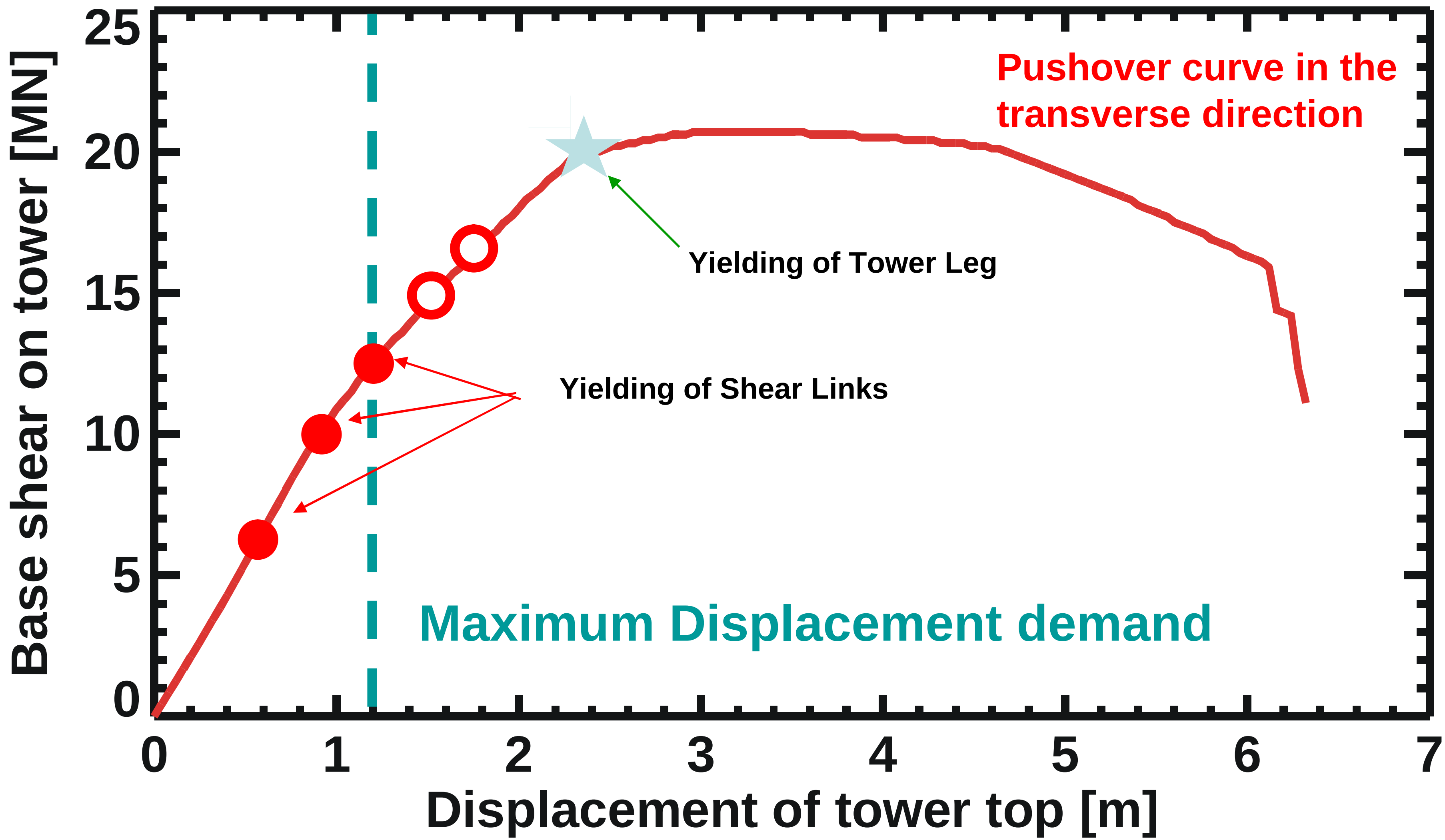
Influence of Tower Link Location

Yielding of the tower shaft during SEE

Tune strength, stiffness and location of the links to achieve the optimum design



Tower Displacement Capacity/Demand



SFOBB East Bay Replacement

State of US Infrastructure

ASCE American Society of Civil Engineers

2003 Report Card for America's Infrastructure

Roads	D+
Bridges	C
Transit	C-

Aviation	D
Schools	D-
Drinking Water	D

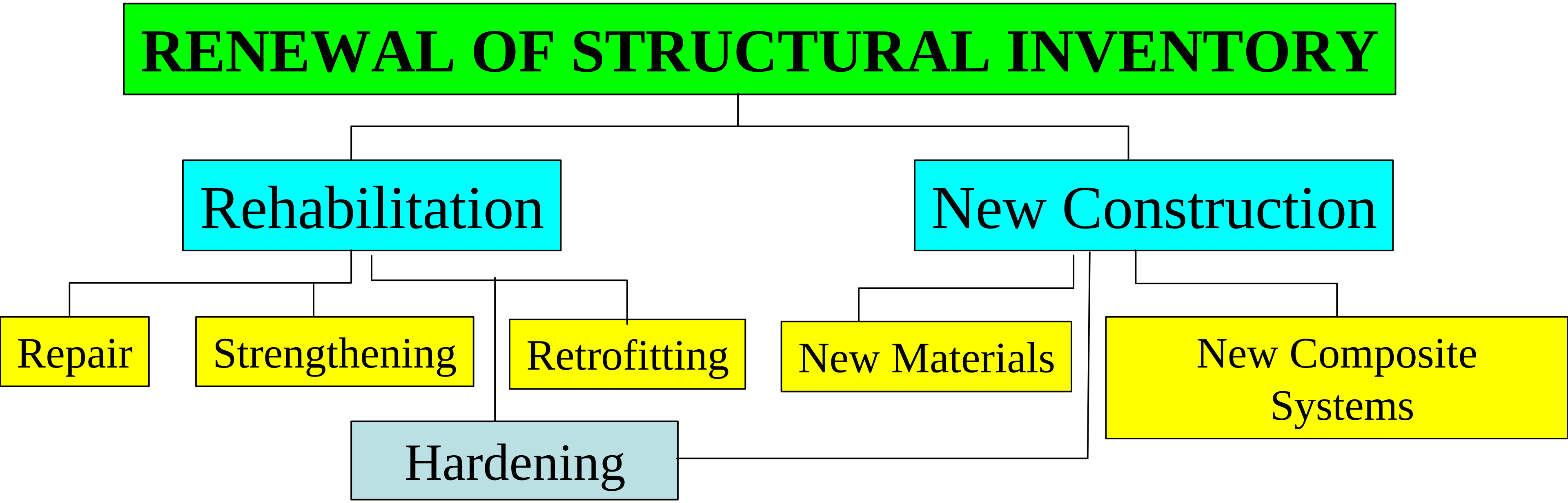
America's Infrastructure G.P.A. = D+ **Total Investment Needs = $ 1.6 Trillion** *(estimated 5-year need)*	**A** = Exceptional **B** = Good **C** = Fair **D** = Poor **F** = Inadequate	Each category was evaluated on the basis of condition and performance, capacity vs. need, and funding vs. need.

Condition of Constructed Facilities




Structural Health Monitoring
Damage Prognosis
Life Cycle Prediction
Renewal Engineering

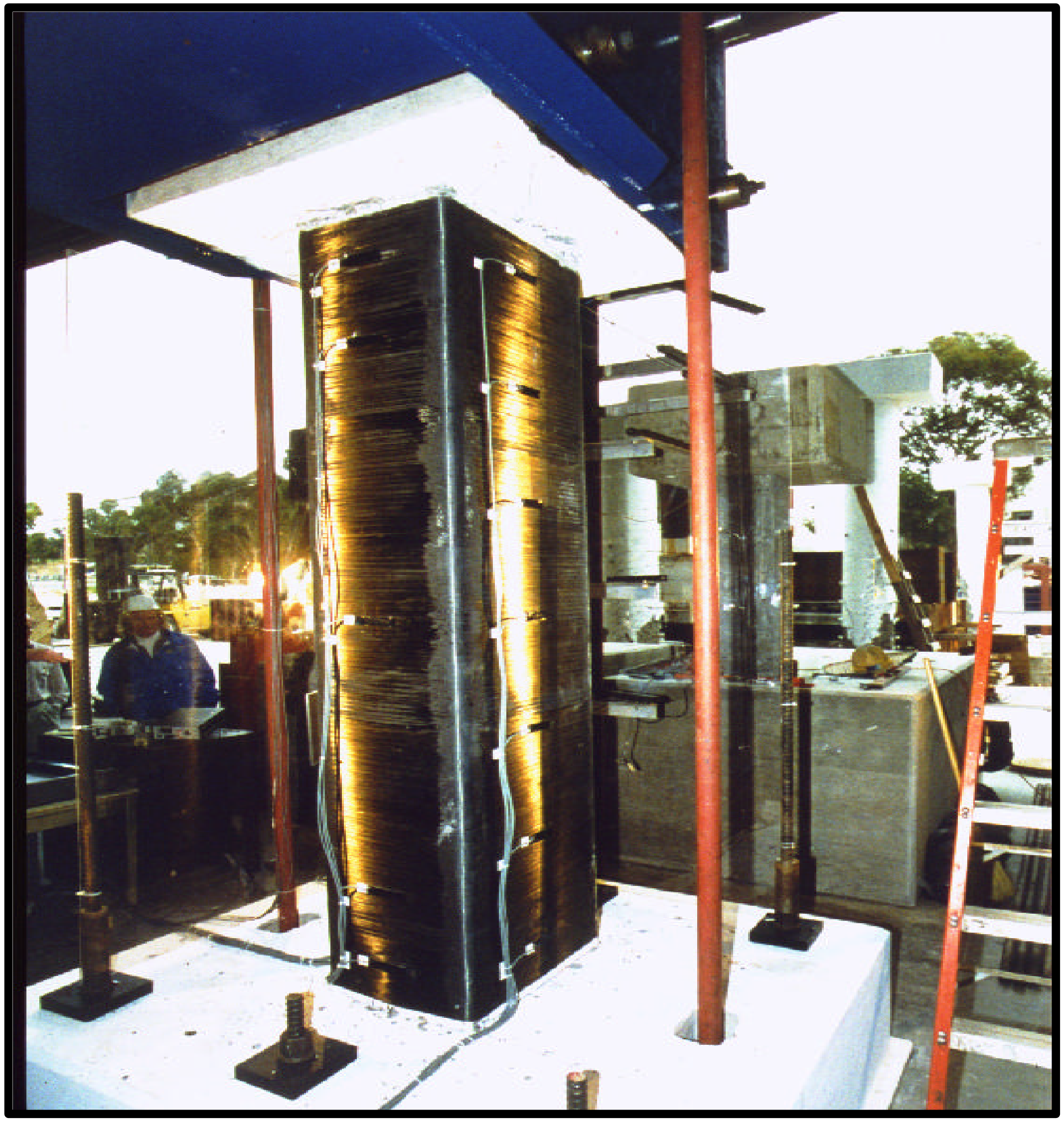
New Materials
New Application/Construction Processes
New Design Concepts
New Infrastructure Management



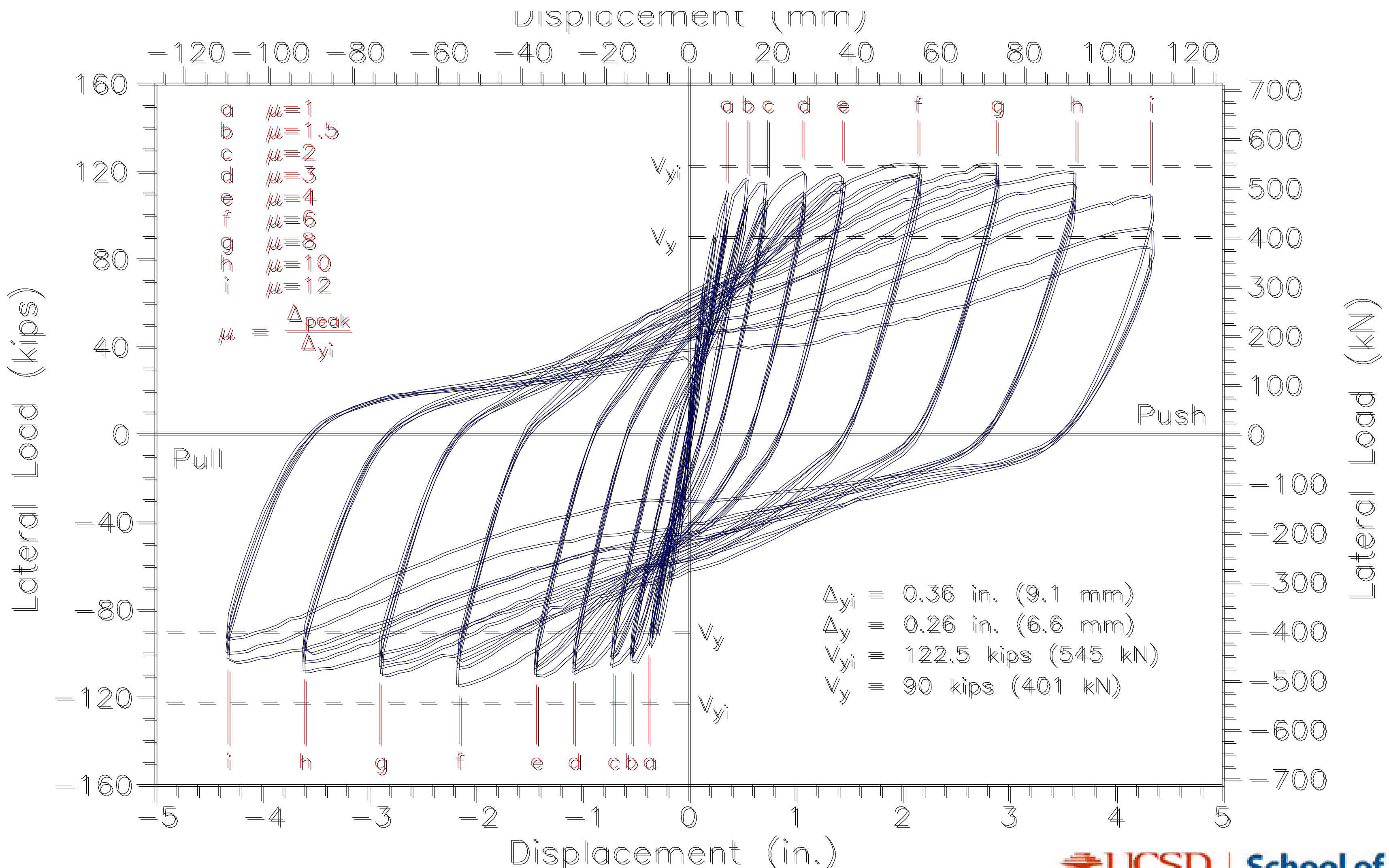
Distributed Sensors/Networks
Wireless Instrumentation/Data
Instantaneous Access/Processing
Data Archiving, etc.

Example of Composite Retrofit of Column

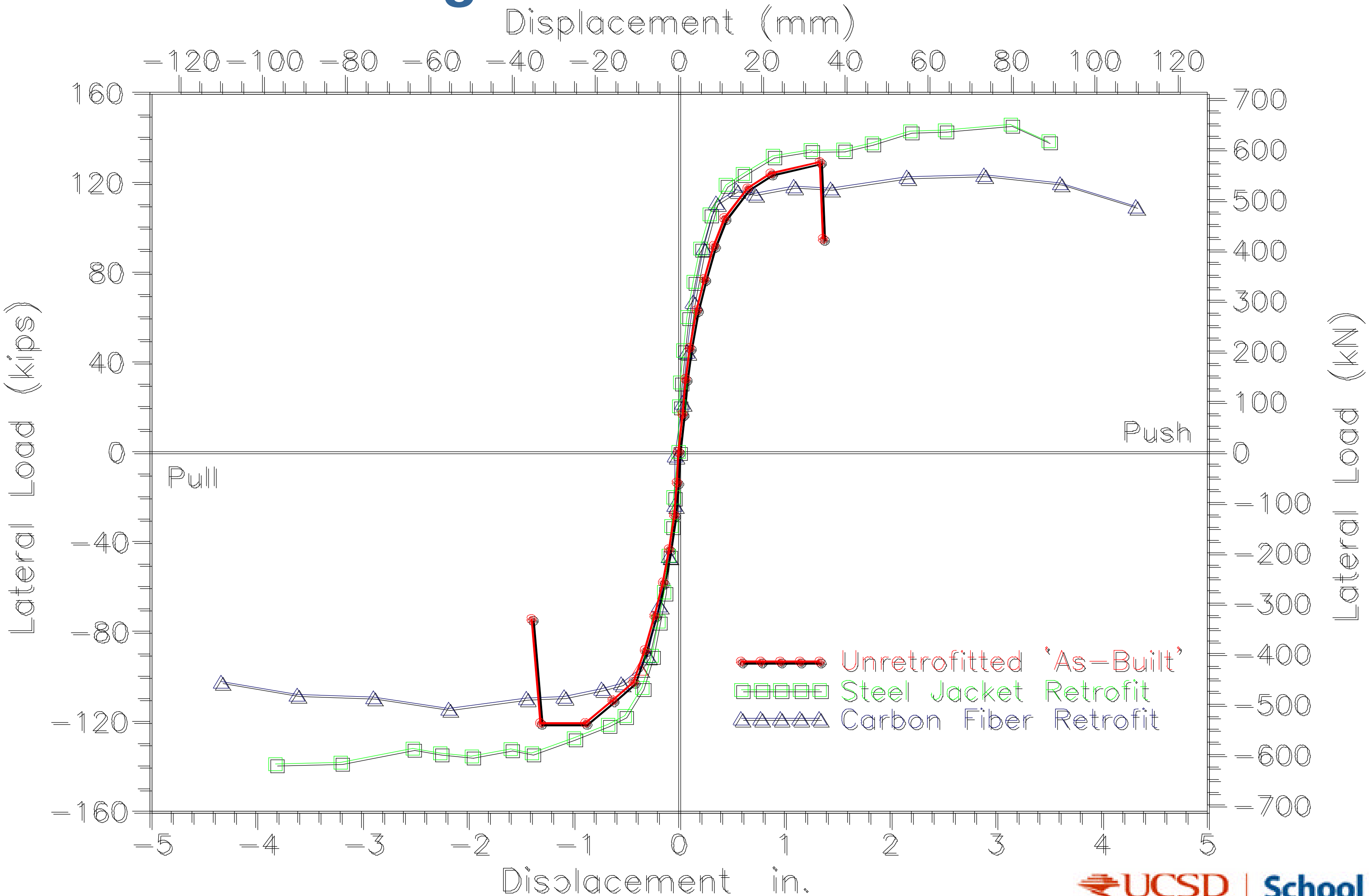
Rectangular
Column
CFRP Retrofit



Load-Displacement Curve for Fiber Retrofitted Column - Rectangular Shear Column 2.5%

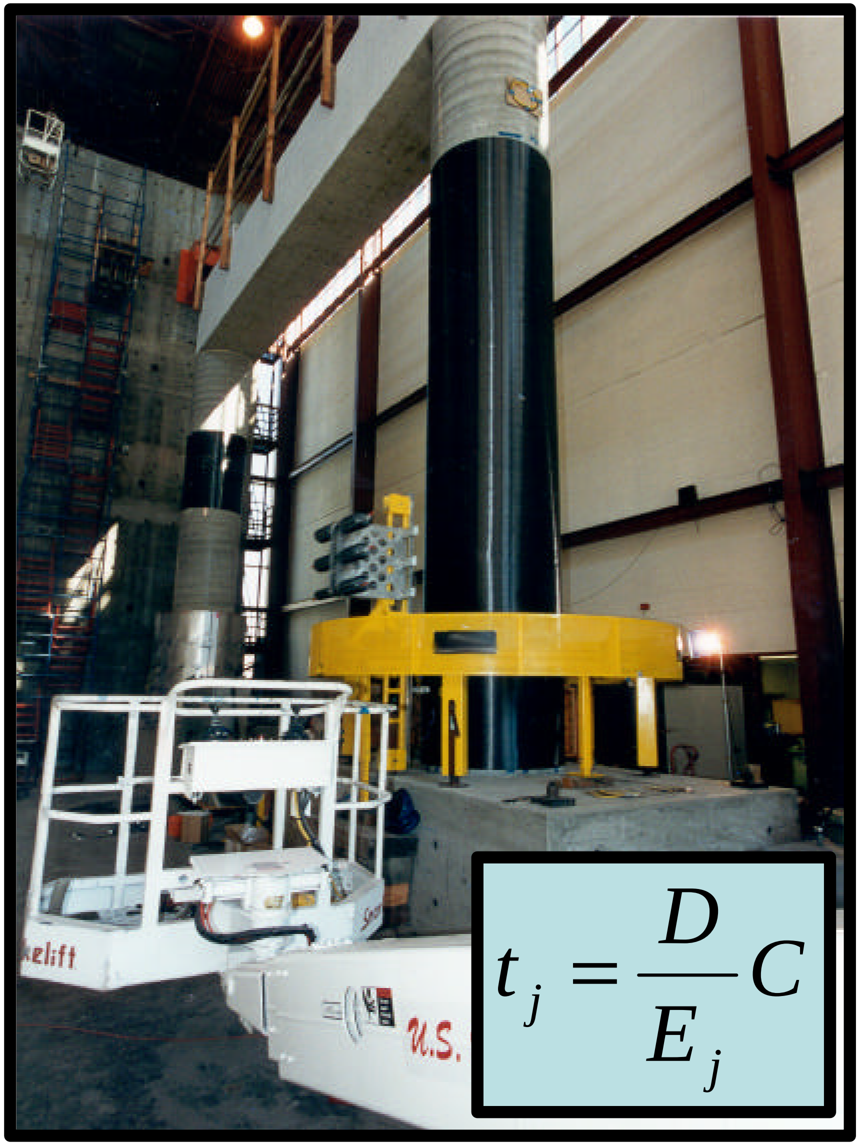


Comparison of Load-Displacement Envelopes Rectangular Shear Column 2.5%



Installation of FRP Jacket, I-10 Santa Monica Viaduct

Full Scale Prooftest



$$t_j = \frac{D}{E_j} C$$

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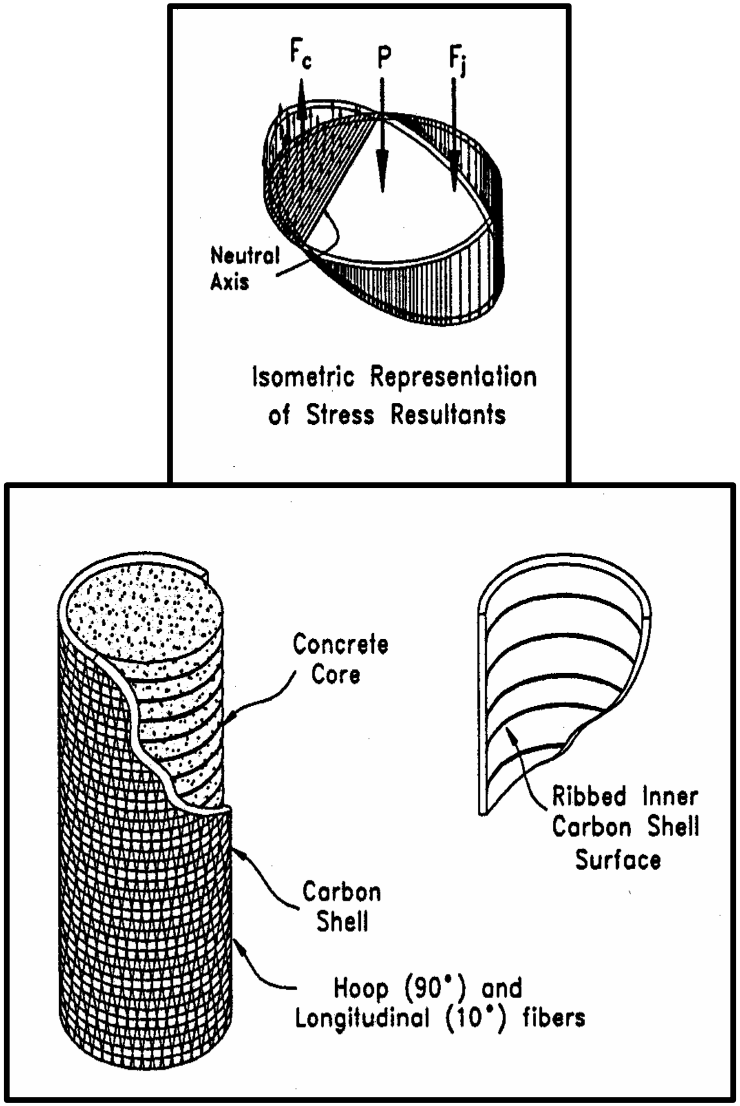
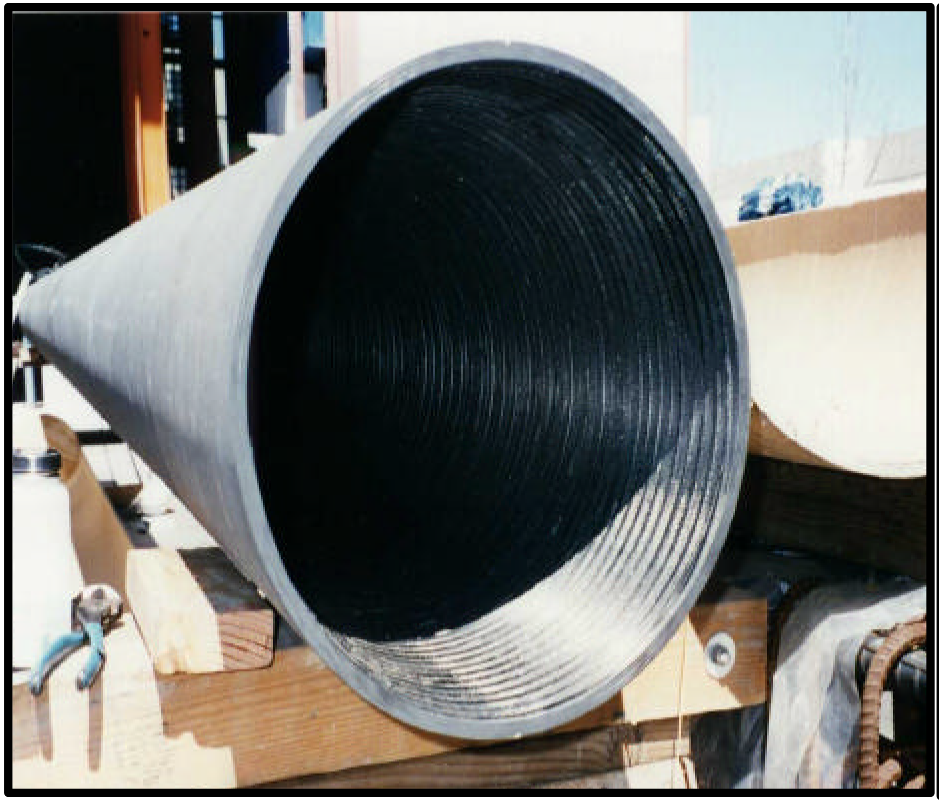
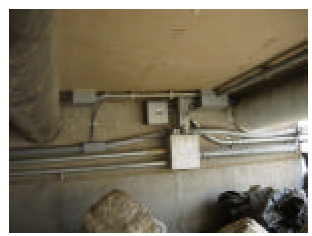
Concrete Filled Carbon Shell System

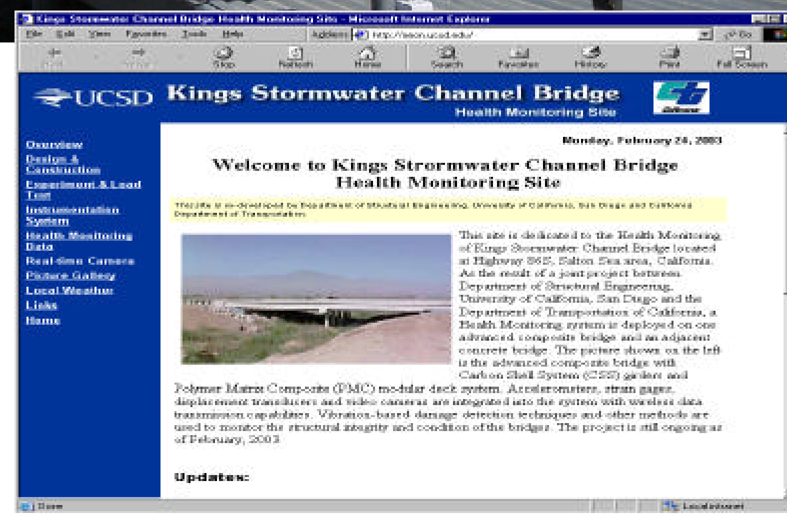


Concrete Filled Carbon Shell System



UCSD Advanced Composites Bridge
Imperial County (near Palm Springs)





100 accelerometers, strain gages, and video link

Bridge ⟶ Toro Peak ⟶ Mt Soledad ⟶ Anywhere worldwide

Continuous Wireless Monitoring http://hpwren.ucsd.edu/

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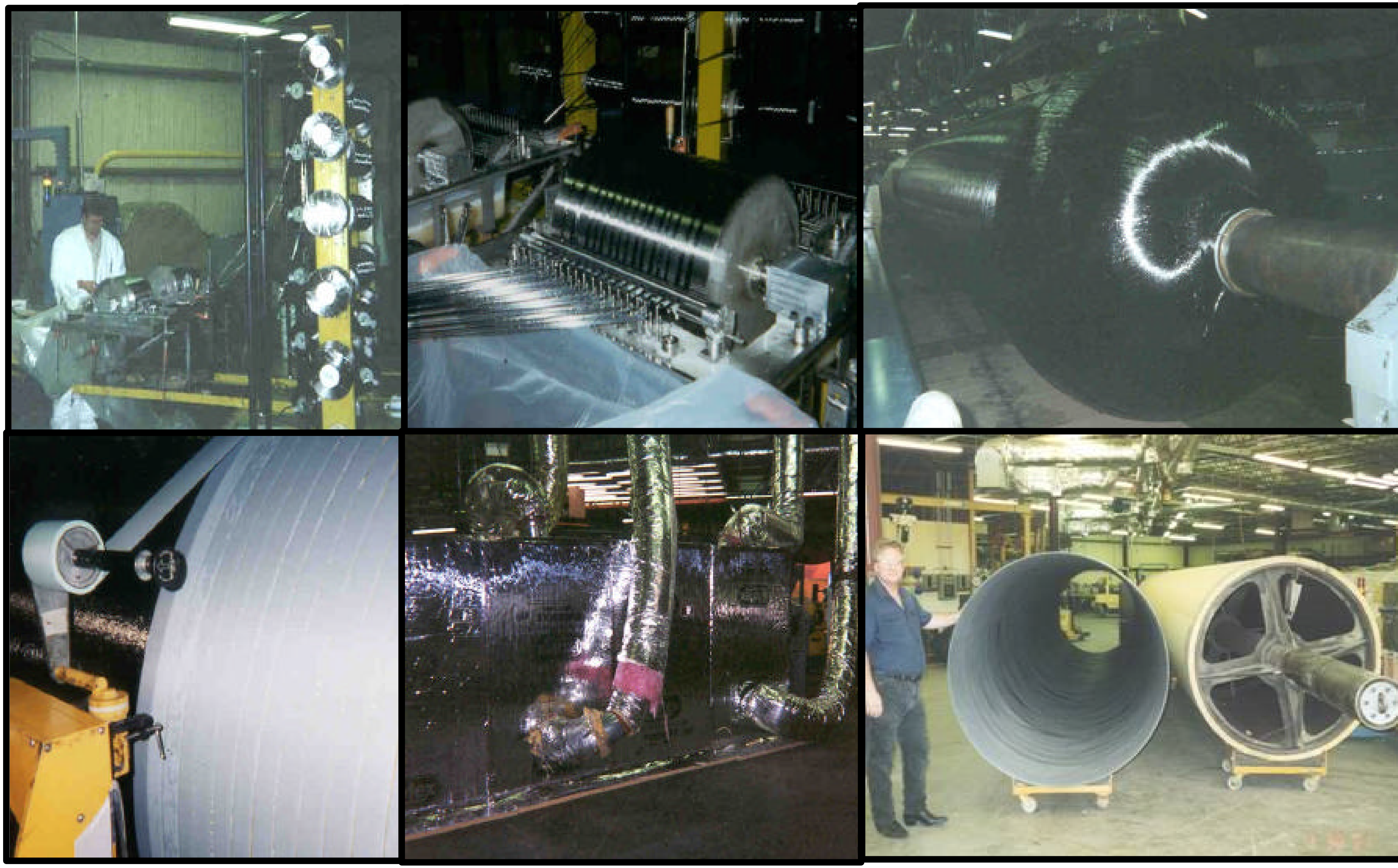
Pylon Shell *(1.5m Diameter, 9mm thick)*

Pylon Manufacturing



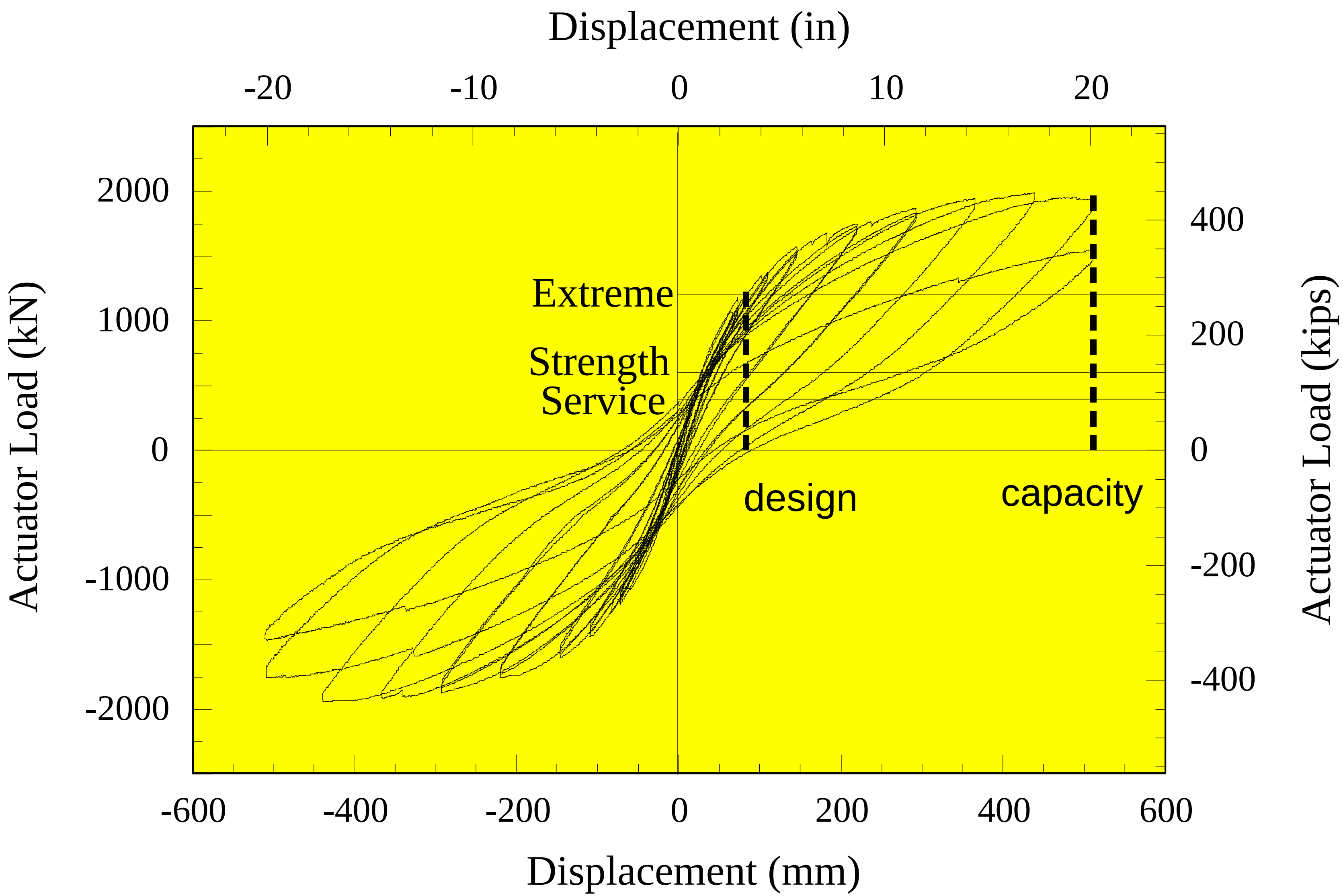
Extreme drift at displacement ductility 7

Ruptured bars at end of test

(15 out of 30 bars ruptured w/minimal strength degradation)

a) Push side of footing

b) Pull side of footing



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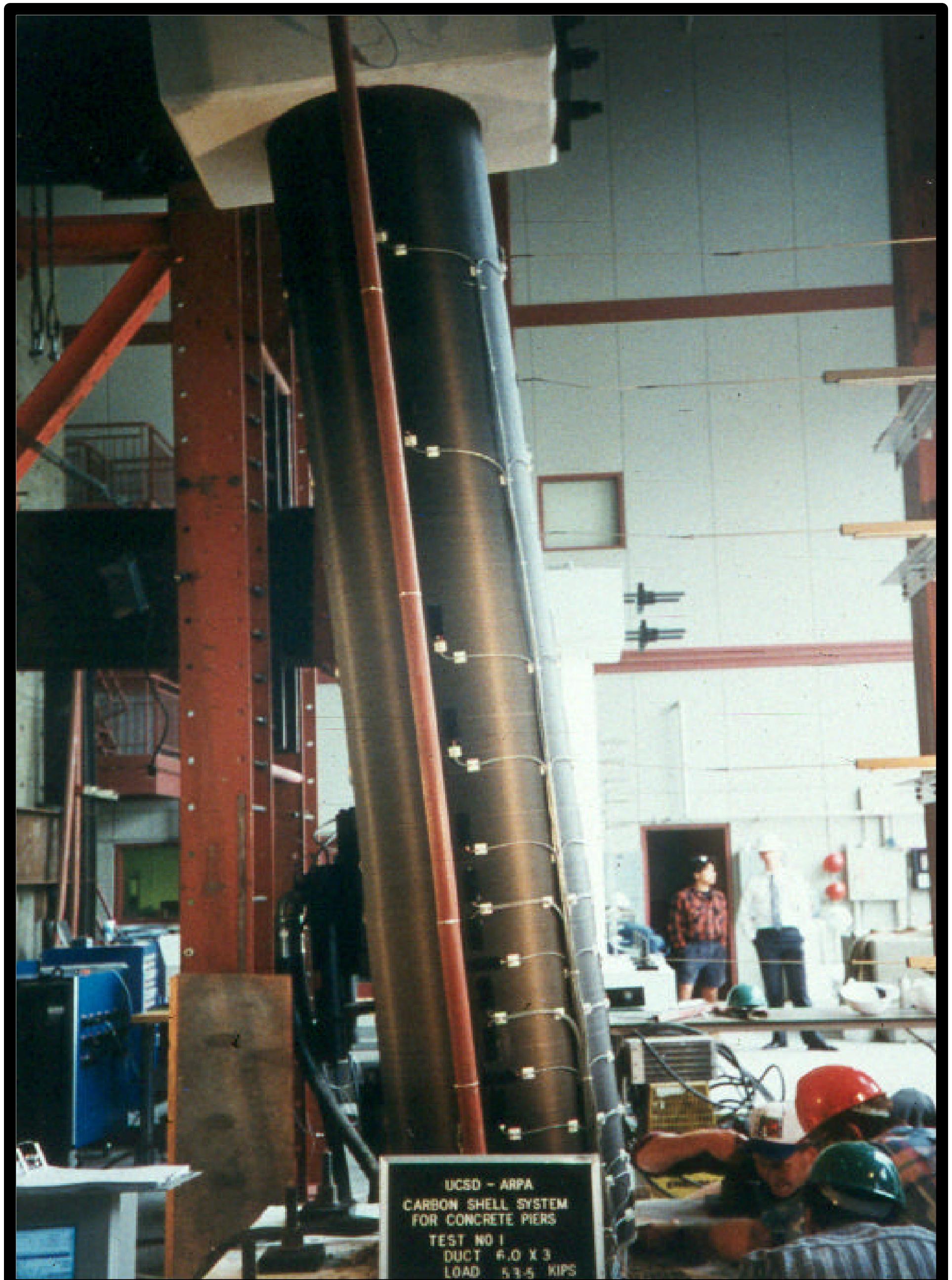

Applications of CSS

- ***Modular Construction***
- ***Light-weight***
- ***Stay-in-place Forms***
- ***Reinforcement***
- ***Seismic – Confinement***

- ***Blast Resistance***

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Caltrans -- Research Connection -- Thursday, June 17, 2004

Blast Mitigation of Critical Structures

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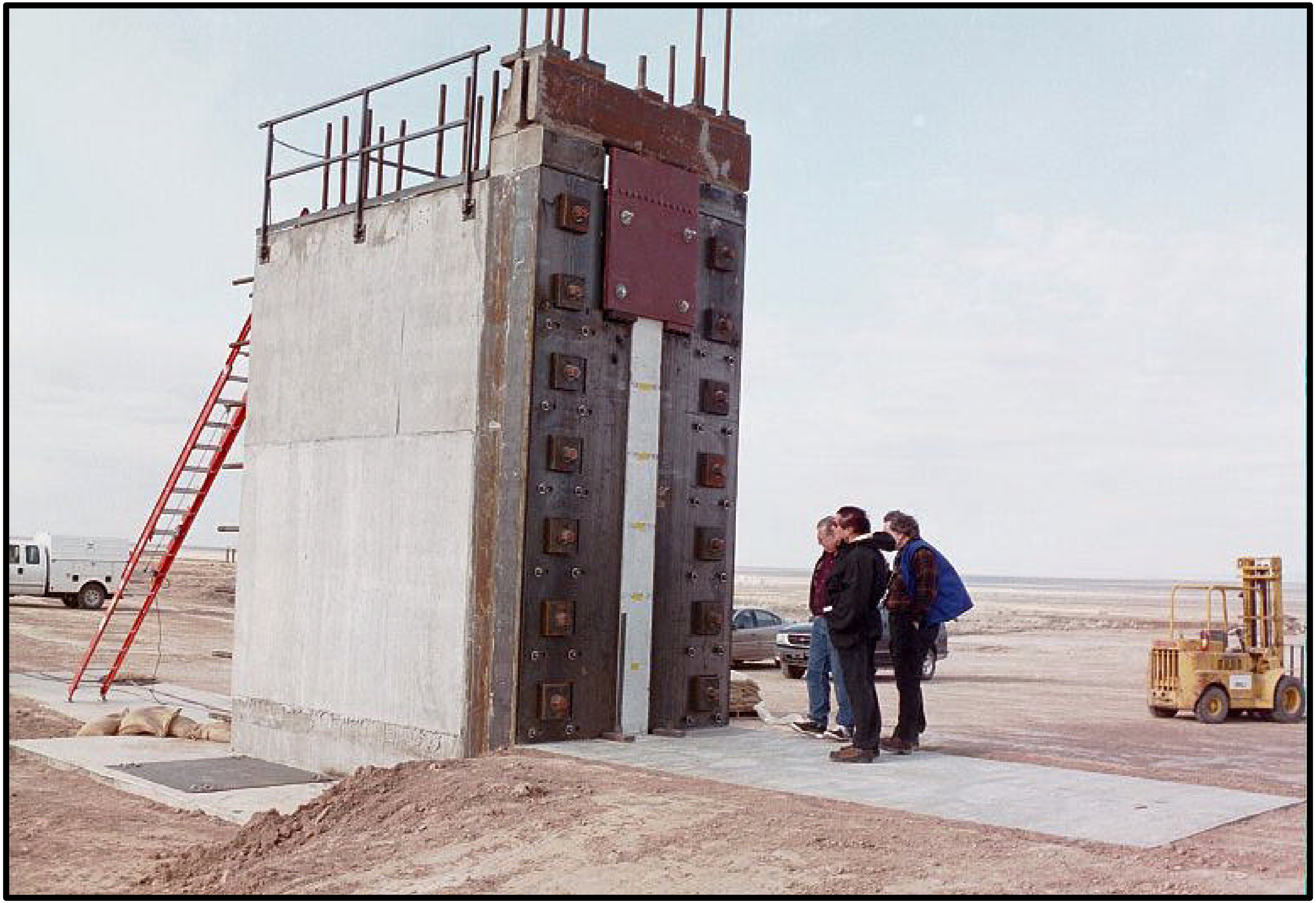
What the threat may look like!

Blast Retrofit of Buildings

Blast Damage to Unretrofitted and Retrofitted Reinforced Concrete Column (CTS-1 Structure)



DB-20 High Speed Photography

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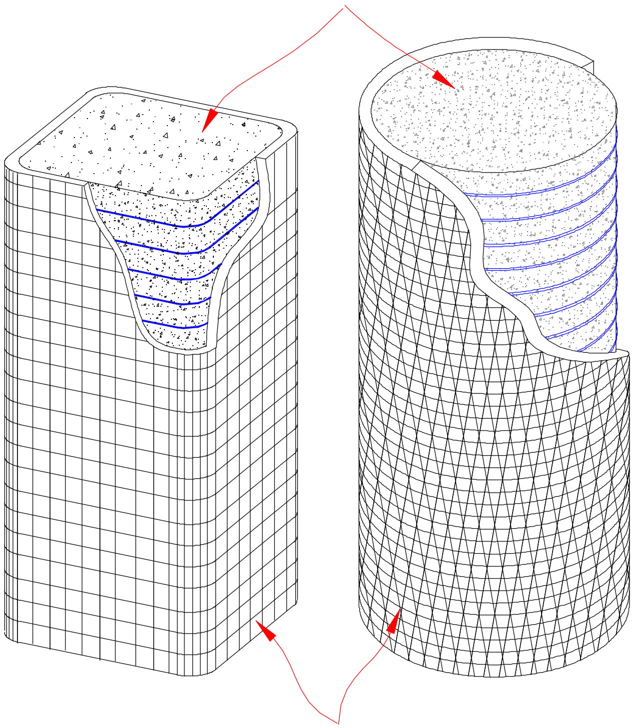
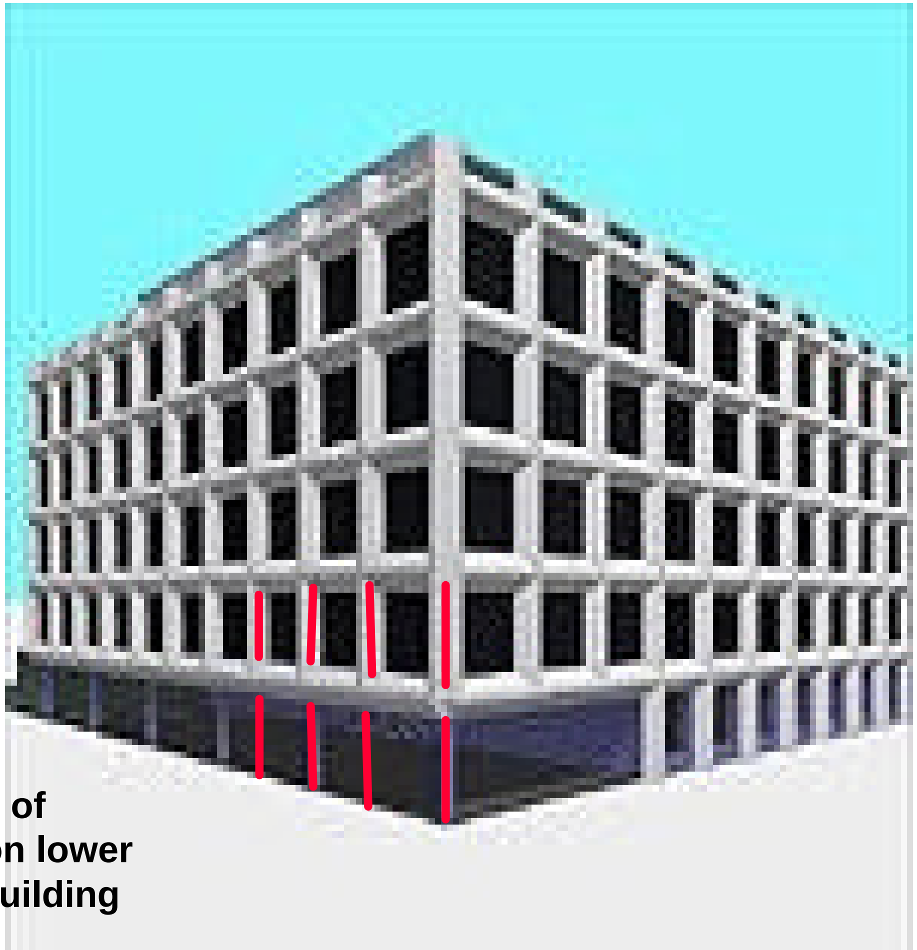
Column Protection For New Critical Facilities

Concrete core



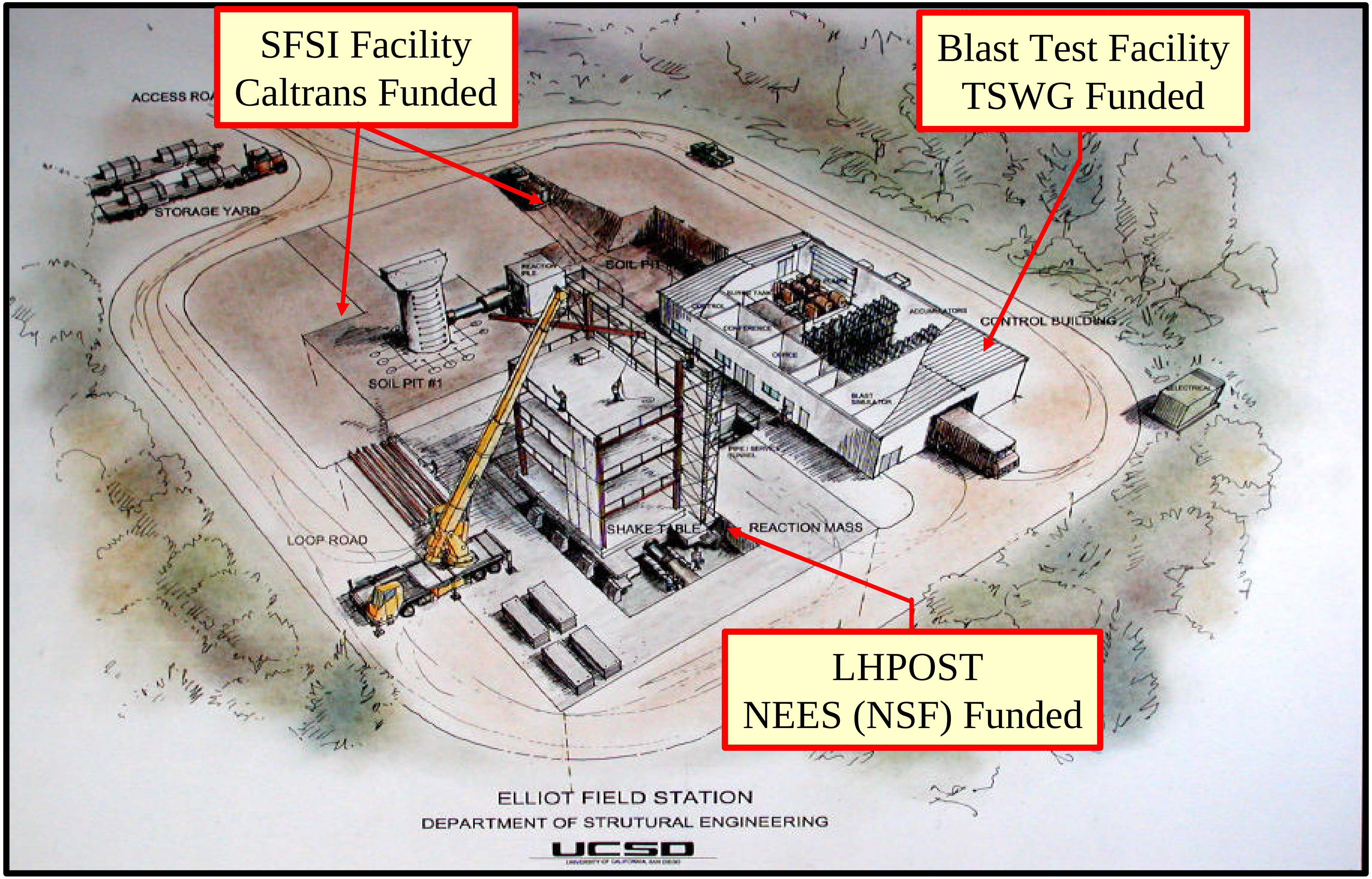
Carbon composite shell with transverse and longitudinal fibers



Protection of columns on lower levels of building

Four 27-strand DSI tendons looped through footing for a total applied axial load of approximately 2000 tons

Camp Elliott Development Project



CONCLUSIONS

Research on Seismic Bridge Response leads to

1. Better Simulation Tools for Seismic Response Assessment
2. Retrofit Technology Development to Correct Local Detailing Deficiencies
3. Proof of Concept Testing to Validate Retrofit Measures and New Design Concepts