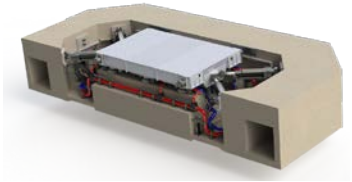
National Science Foundation

University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

Highlights of Recent Projects

José I. Restrepo, Professor of Structural Engineering, UC San Diego

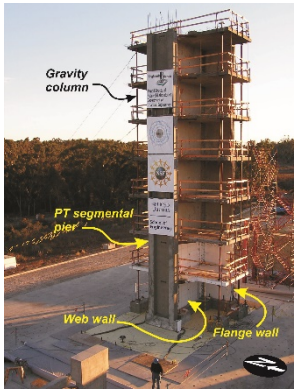


Joint Academia-Industry NHERI Workshop
NHERI@UC San Diego

September 21-22, 2020
University of California, San Diego

Presentation Overview

- **Presentation focused on experiment design, design for safety, and broader impacts of three landmark tests conducted at the NHERI@UCSD LHPOST**



7-story building slice

2004

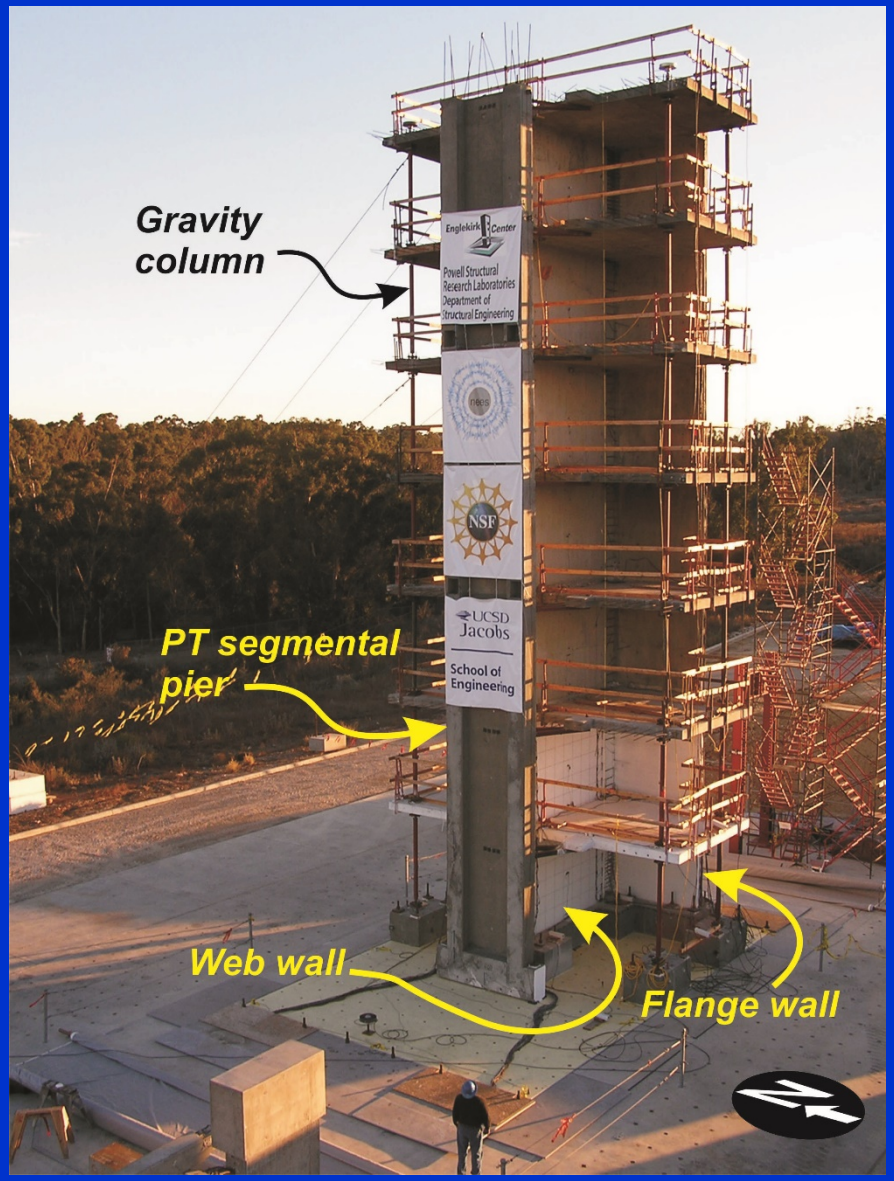
PCI Parking Building

2008

PEER-FHWA Large Bridge Column

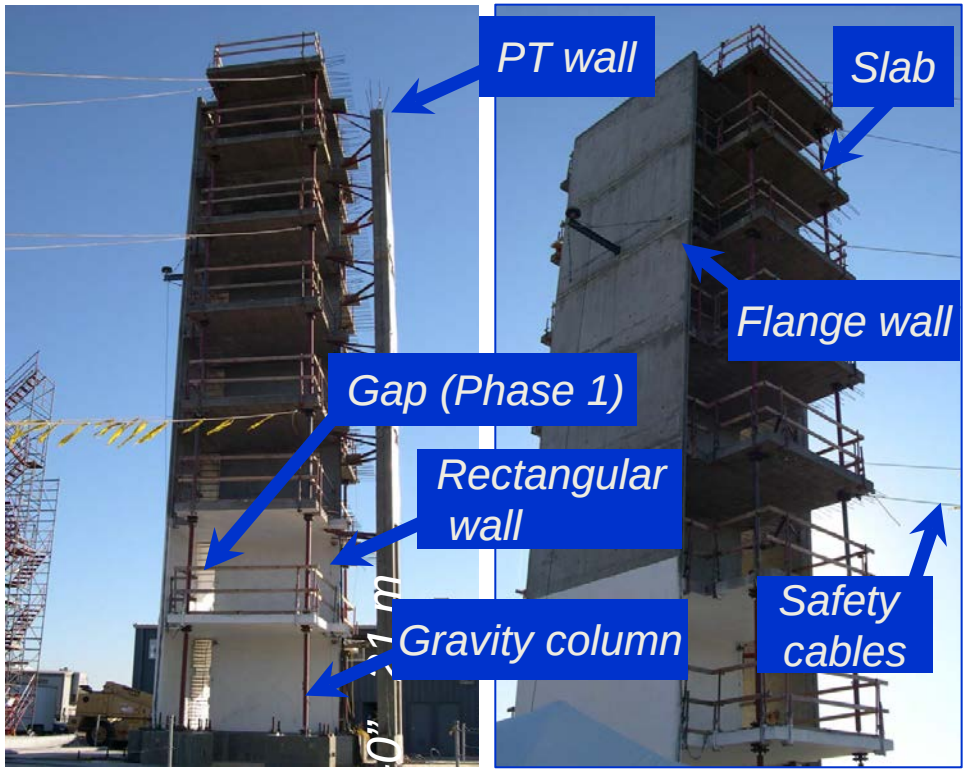
2010

1. 7-STORY BUILDING SLICE



Motivation

- Verify the seismic performance of medium rise reinforced concrete wall building designed for lateral forces that are significantly smaller than those currently specified in building codes in United States
- Full-scale testing and two phases of testing (Rectangular wall and T-wall)



- 7-story building slice with cantilever wall as the lateral force resisting system
- Tallest building structure ever tested on a shaking table then
- Single axis of input ground motion in the plane of the wall

- Phase 1 Testing:

  12 ft. long rectangular wall
- Phase 2 Testing

  14 ft. 7 in. long T-wall

Design For Safety

Threats

- Very slender structure
- No precedent in the world – no structure of that height/ slenderness had ever been tested before under input ground motion in a shaking table
- Quasi-static testing on wall components indicated significant damage could occur after 2% drift ratio
- Test specimen was in very close proximity to the power plant and the control room

Actions Taken

- Move the control room away from the pump building
- Reach out to Experienced Professionals, SEAOC, Senior NEES@UCSD Leadership
- Guy the building to allow it to move but to guide it toward the north in case of loss of stability
- Conduct key tests with no spectators
- Carry out simulations with different models and platforms ahead of time
- Analyze test results before moving to higher intensity input ground motions
- Convene the Advisory Panel and discuss the results, compare results with those predicted by models
- Stop after reaching 2% roof drift ratio, regardless of the test building structural health

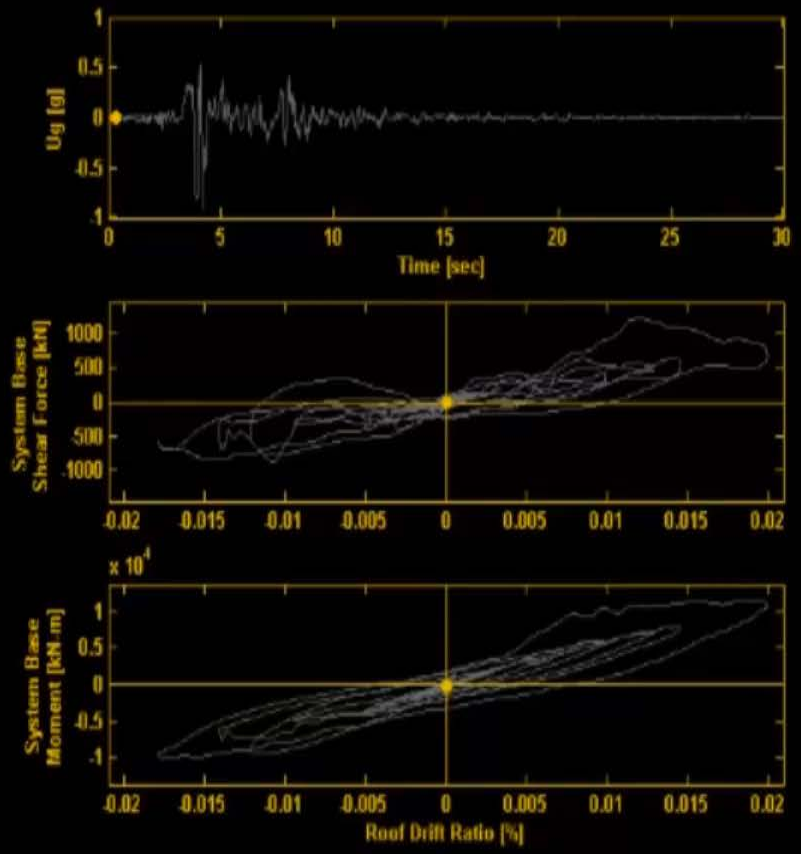
Instrumentation

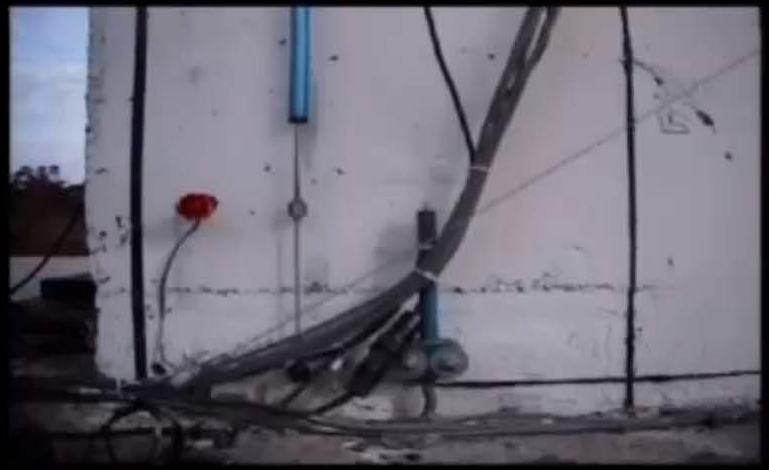
- **600+ sensors deployed on the building, shake table and surrounding soil**
  - DC coupled accelerometers
  - Displacement transducers
  - Strain gauges
  - Load cells
  - Oil pressure transducers
- **First time use of 50Hz, 3 mm resolution, real-time GPS displacement sensors**
- **17 videos feeds streamed through NEESCentral**

Test: EQ4

Northridge Earthquake (1994)

Sylmar Olive View Med 360°





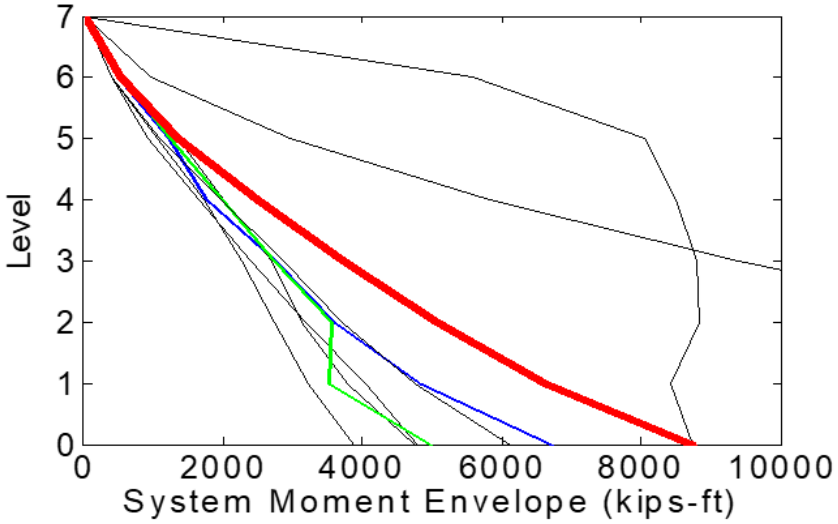
Broader Impacts

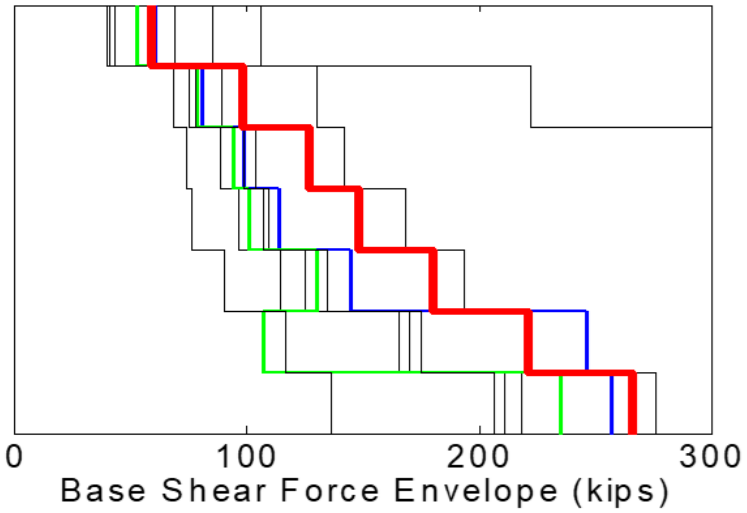
- This project attracted the attention of many professional engineers in California. The complete dataset was uploaded to NEESCentral (today it is archived by DesignSafe CI)

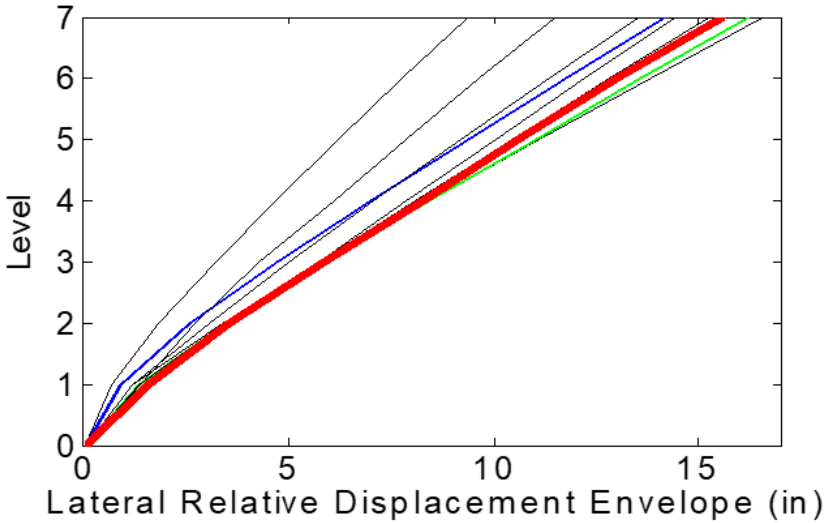
- A small dataset containing key results has been distributed widely among design professionals, student and researchers around the world. A large number of publications by others using the small dataset have appeared over the years. At Design Safe CI, one could upload the entire dataset, but it is wise to also have a folder with key results that others can make immediate use of it.

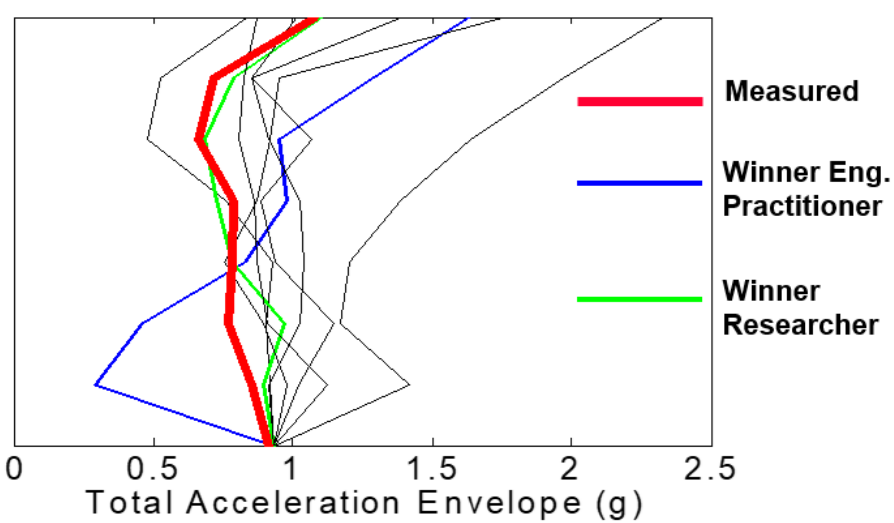
- An international blind prediction contest was organized under the sponsorship of NEES and the Portland Cement Association. Participants submitted their predictions in one of three categories: (i) Researcher, (ii) Practicing engineer, and (iii) Undergraduate student. **These contests are outstanding ways to positively impact the community.**

Blind Prediction Contest – Test EQ4









2. PCI DSDM PROJECT

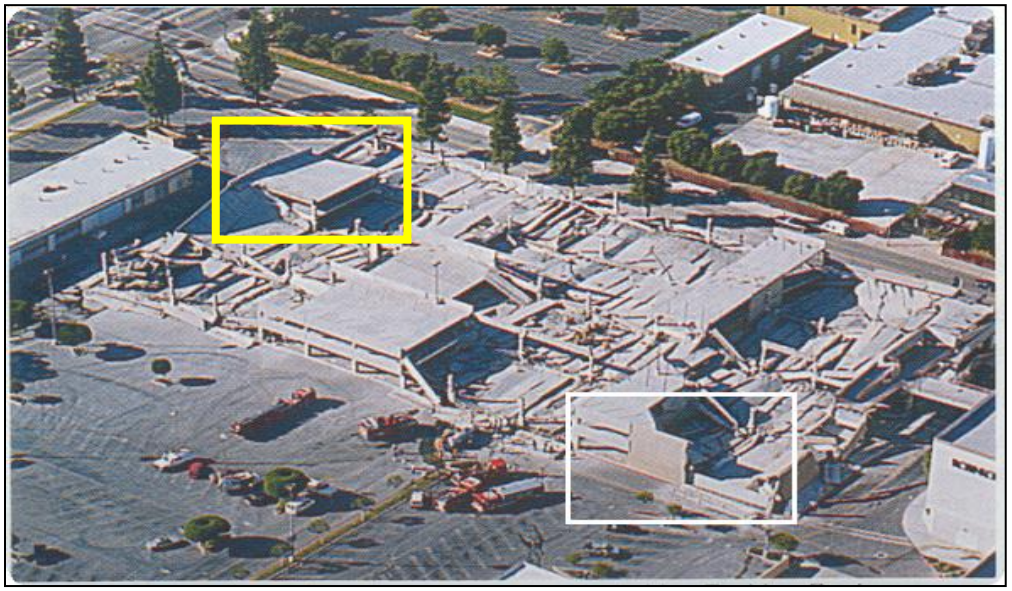
PCI DSDM PROJECT

- Multi-University Research Projects initiated by the Precast/Prestressed Concrete Institute
- U Arizona, Lehigh & UCSD co-PIs and Grad Students
- Full- or Large-Scale Testing
- Strong Simulation Component
- Design Consultant Oversight
- Industry Partners
- General Topic: Floor Diaphragms

Motivation

Diaphragm action carries seismic forces horizontally in the floor slab to walls and frames…

Precast floor diaphragms have shown a vulnerability in past earthquakes…



Research Flow

Structure Level (UCSD)

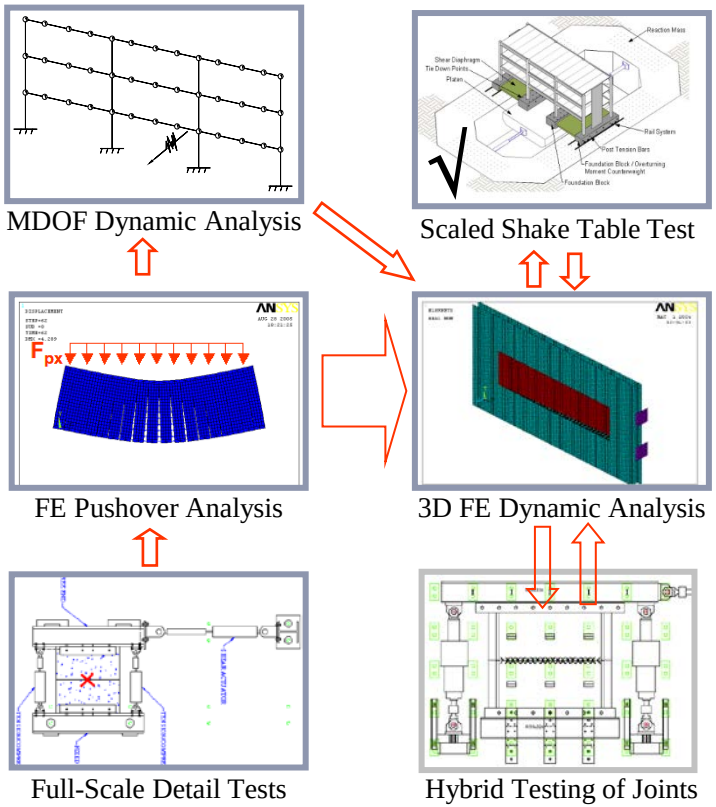
- Diaphragm Inertial Forces
- Flexible Diaphragm Structures

Diaphragm Level (UA)

- Diaphragm Capacity
- Diagram Load Paths & Limit States

Detail Level (LU)

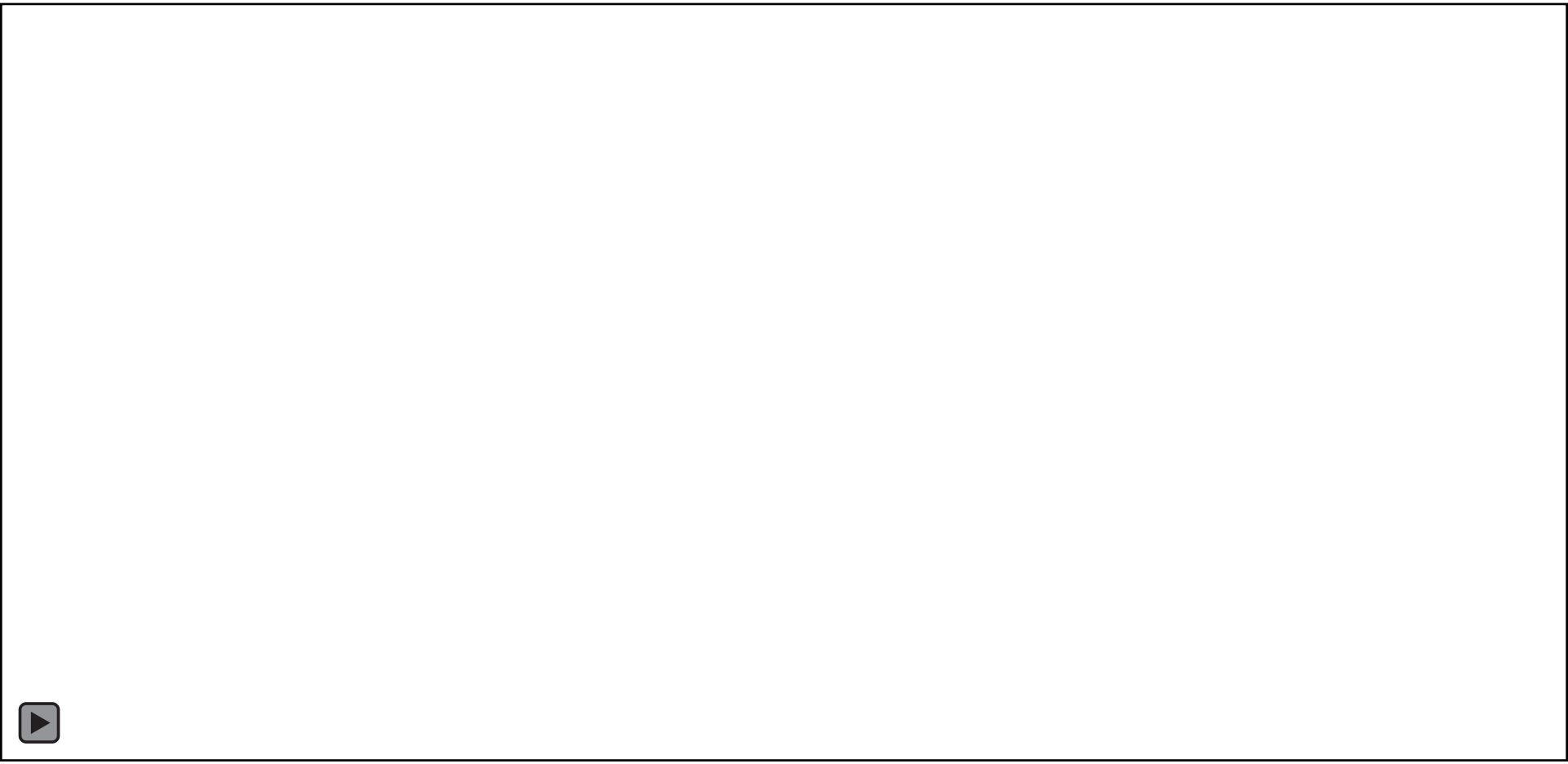
- Connector Properties
- Connector Classification



Design for Safety

- A MCE_R input ground motion had the potential to catastrophically collapse the test building

Capstone Test: 0.4 Scale Three-story Prefabricated Building

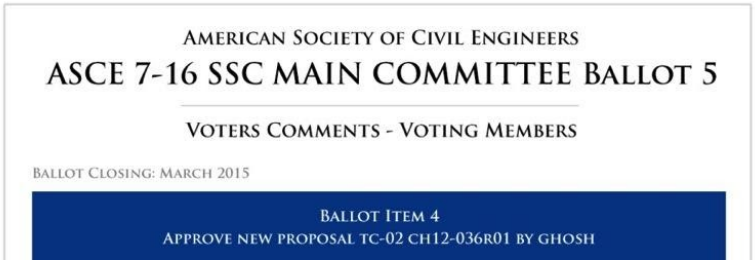


Design for Safety

8x8 timber after impact upon excursion to 4% drift ratio

Broader Impacts

- Significant collaboration with industry continued over a span of seven years, for a total project duration of thirteen years, and culminated with the implementation of prescriptive design provisions for the seismic design of precast concrete diaphragms in ASCE 7-16



AMERICAN SOCIETY OF CIVIL ENGINEERS

ASCE 7-16 SSC MAIN COMMITTEE BALLOT 5

VOTERS COMMENTS - VOTING MEMBERS

BALLOT CLOSING: MARCH 2015

BALLOT ITEM 4

APPROVE NEW PROPOSAL TC-02 CH12-036R01 BY GHOSH

3. LARGE BRIDGE COLUMN

Motivation

- Evaluate current Caltrans seismic design criteria with dynamic testing
- Investigate failure mode: flow of crushed concrete vs. reinforcement fracture
- Evaluate model uncertainty by means of a blind prediction of the column's response
- Testing to collapse

PEER

Caltrans

FHWA

NEES

CRSI Concrete Reinforcing Steel Institute

SKANSKA

AGC CALIFORNIA

HRC

DSI

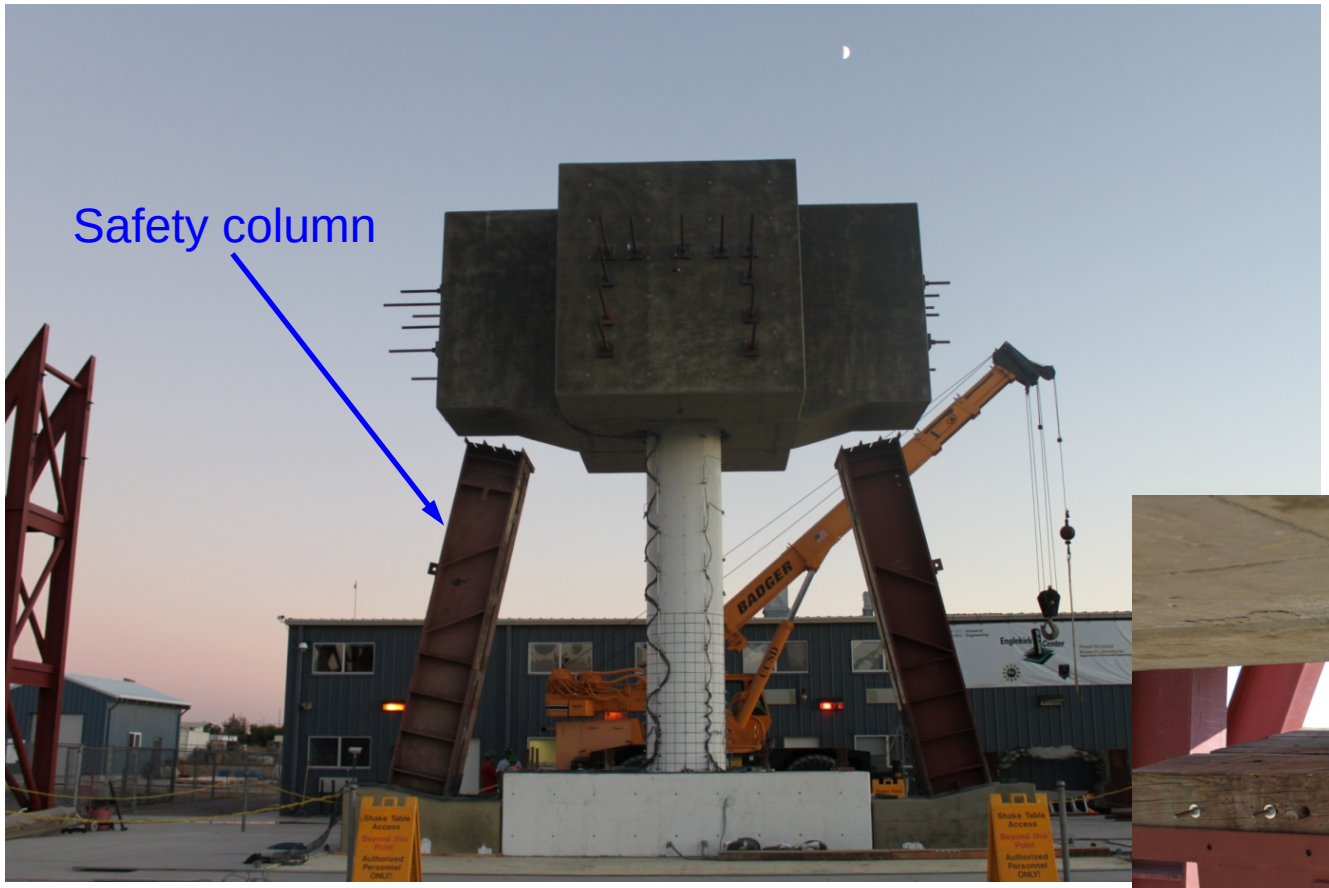
CONCO

MAYER SURVEYING, Inc

University of Nevada, Reno

Cal

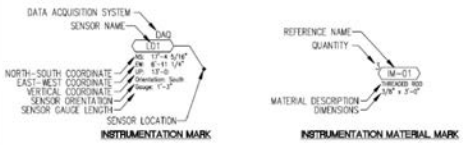
Design for Safety



Instrumentation Plan

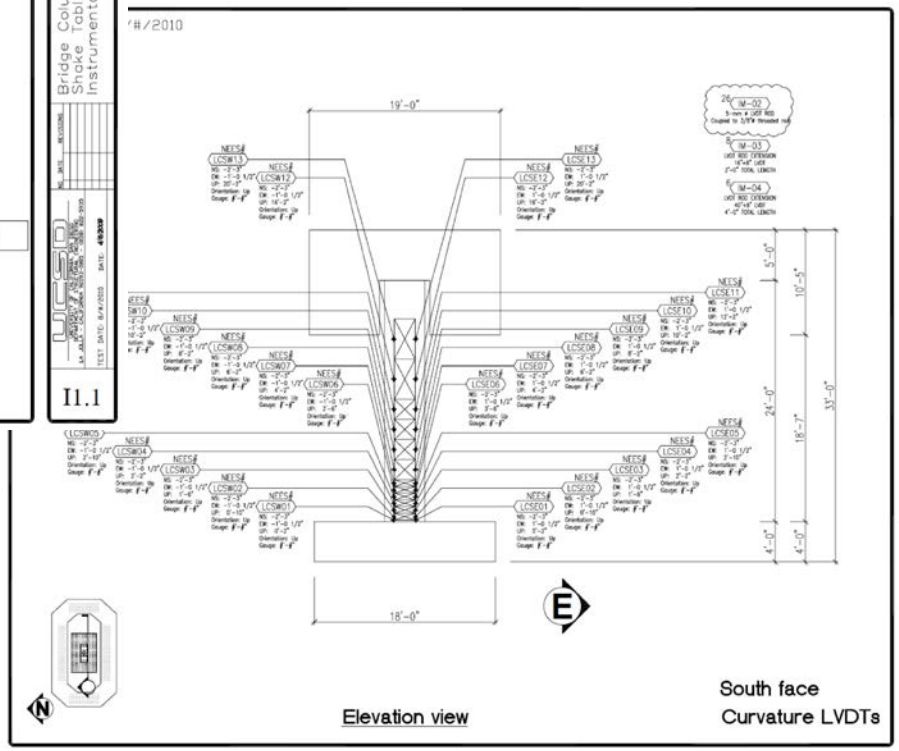
TEST DATE: 8/#/2010

INSTRUMENTATION									
SHEET	DESCRIPTION	10g ACCEL.	1" LVDT	2" LVDT	S.G.	20" S. POT	30" S. POT	GPS	
I2.1	Foundation accel.	6					1	1	
I3.1	South curvature LVDTs		2	24					
I3.2	North curvature LVDTs		2	24					
I3.3	South shear LVDTs			24					
I3.4	North shear LVDTs			24					
I3.5	South dilation LVDTs			13					
I3.6	North dilation LVDTs			13					
I4.1	East long. straing gauges				28				
I4.2	West long. strain gauges				28				
I4.3	Transverse strain gauges				14				
I5.1	Dilation LVDTs			24					
I5.2	North and South curvature LVDTs			12					
I6.1	Column and superstructure accelerometers	20							
I7.1	Displacement string pots.					2	2	1	
	TOTAL	26	4	158	70	2	2	2	262



Bridge Column Project
Shake Table Test
Instrumentation Layout

I1.1



Bridge Column Project
Shake Table Test
Instrumentation Layout

I3.1

Project Execution: Pre-Test Checks

- Temporary lateral stability: Guy wires anchored to reaction mass.
- Site safety procedures reviewed with researchers.
- Safe viewing locations established (see PEER bridge column Safety Map.pdf).
- Site visitors sign in and review emergency plan and procedures (see UCSD Safety Test Pamphlet Sep20.pdf).
- Lateral restraint mechanism: Safety columns for in-plane restraint (10% drift limit), safety towers for out of plane restraint (1/4 inch clearance).
- Collapse prevention mechanism: Safety columns located beneath superstructure mass.
- One minute warning to start cameras and enter safe viewing areas over loudspeaker.
- Visual check by NEES staff for people outside of viewing areas prior to test commencement.
- Ten second countdown over loudspeaker.
- Emergency stop button: Control room.

Project Execution: In Between Test Checks

- **Lateral restraint mechanism: Safety columns for in-plane restraint (10% drift limit), safety towers for out of plane restraint (1/4 inch clearance).**
- **Collapse prevention mechanism: Safety columns located beneath superstructure mass.**
- **Test complete announced over loudspeaker after test.**
- **Hydraulic pressure indication announced over loudspeaker (High pressure/Low pressure/Zero pressure, all clear, safe to approach specimen).**
- **Specimen stability and safety assessed:**
  - Impact with restraints: Assess column and restraint mechanisms for safety
  - Excessive drift
  - Reinforcing bar fractures
  - Hoop fractures
  - Unanticipated response

Project Execution: Pre-test Sensor Checks

- **Pre-test**
- **Review sensor plan with NEES personnel.**
- **Review installed sensors with NEES personnel.**
- **Location measurements taken**
  - Three dimensional coordinates of each sensor's position or end points
  - Three dimensional coordinates of test specimen: Key points defining geometry, and shake table.
  - Three dimensional autocad drawing created from sensor locations and specimen.
- **Photographic documentation of each sensor**
- **Sensor check:**
  - Low amplitude white noise test for sensor check: 0.03g RMS
  - Visual inspection of each channel's response through Matlab Dataviewer
  - Corrective measures for bad channels:
    - ✓ Check sensor
    - ✓ Check cable connection
    - ✓ Check cable
    - ✓ Check DAQ connection

Project Execution: In Between Tests Sensor Checks

- **Post-test**
- **Visual inspection of sensors.**
- **Sensor check:**
  - Visual inspection of each channel's response through Matlab Dataviewer.
  - Corrective measures for bad channels:
    - ✓ Check sensor
    - ✓ Replace (Update DAQ configuration files) or remove bad sensors

Project Execution: Test Specific Safety Requirement Pamphlet

UCSD Jacobs School of Engineering

UC San Diego
9500 Gilman Drive, MC 0826
La Jolla, CA 92093-0826

Englekirk Center

University of California, San Diego - Department of Structural Engineering
Englekirk Structural Engineering Center

September 20, 2010

'LARGE BRIDGE COLUMN TEST'
LARGE HIGH PERFORMANCE OUTDOOR SHAKE TABLE
NEES @ UCSD
Professor José Restrepo & Matthew Schoettler

CAUTION

SAFETY INFO:

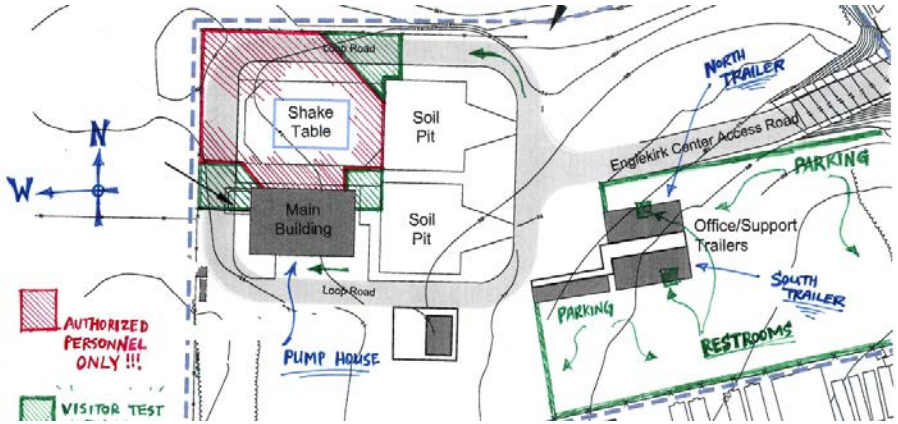
- Wear your hard hat at ALL times. Hard Hats are located between the North and South Trailers.
- Closed toed shoes are necessary to access all shake table areas (i.e. no sandals, no high heels, etc.).
- **Stay behind 'red tape barriers' at all times.**
- Do NOT enter immediate shake table area, please stay with in the red barriers; **Authorized Personnel ONLY!**
- Pump house bathroom is closed due to proximity to shake table.
  - Please use either North or South Double Wide Trailer Bathrooms (refer to map)
- Do NOT enter pump house: Authorized Personnel ONLY.
- Watch out for moving equipment, stay out of brush areas due to snake hazards and always be aware – this is a HAZARDOUS testing area!
- Pay attention and heed the warnings of the announcements made on the PA system.
- If in doubt – ASK! Englekirk Center Staff wear blue hard hats – Professors wear red hard hats - Students wear green hard hats – Researchers wear yellow hard hats.

**Please refer to attachment map for access areas and all other info. Remember, call 911 or (858)534-HELP in case of an emergency.

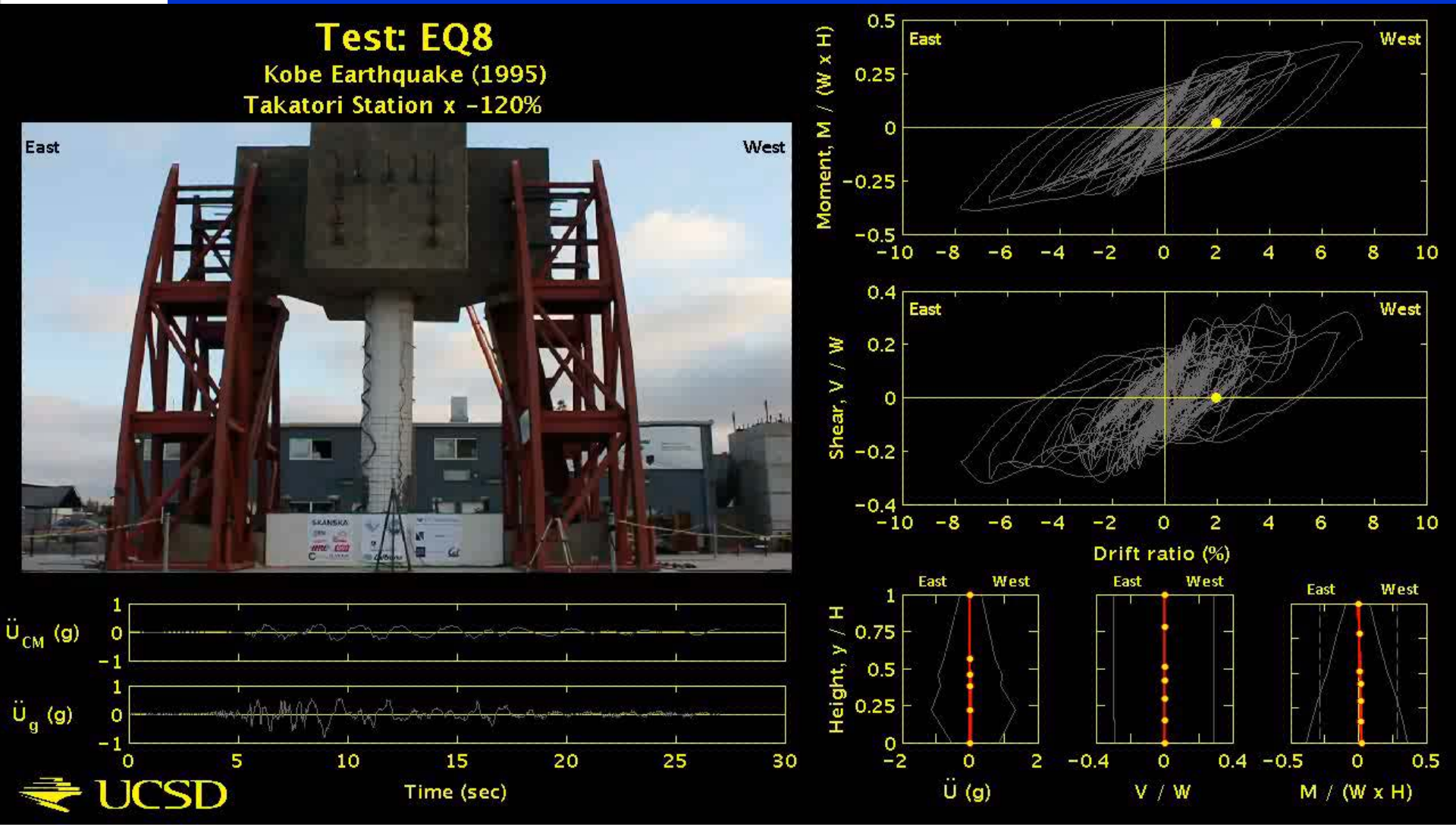
We THANK YOU for your participation and please assist us in keeping the shake table area and site SAFE for all!

Sincerely,

ESEC Faculty, Staff and Students



Test Video


Test: EQ8
Kobe Earthquake (1995)
Takatori Station x -120%
East
West
Moment, M / (W x H)
Shear, V / W
Drift ratio (%)
Height, y / H
Ü (g)
V / W
M / (W x H)
Time (sec)
UCSD

Summary

- This unique facility enables users to design and test structural components and systems at full-scale or large-scale

- Testing at the NHERI@UC San Diego facility can be used as the culmination of a large research project combining extensive simulations, testing at other facilities to observe the performance of structural systems designed and built in accordance to existing codes or guidelines, test new seismic retrofit strategies, and to test new and innovative systems

- The experience gained from large scale testing by UC San Diego personnel and by personnel from other Universities who have tested in the facility is available to support those researchers who have no experience and can help you developing a research, instrumentation, test execution and safety plans

https://spectrumcenter.umich.edu/article/thank-you-our-friends-and-partners