Large-Scale Seismic Simulation
NHERI@UC San Diego

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Natural Hazards Engineering Research Infrastructure

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UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

Large High Performance Outdoor Shake Table

- Designed to permit accurate simulation of severe earthquake ground motions and, particularly, strong near-source ground motions.
- Lack of height limitation allows testing of full- or very large-scale structural specimens.
- Table designed in 2001-2002, built in 2002-2004, and commissioned on October 1, 2004, as part of the NSF NEES Network.
- 27 major tests were performed in 12 years of operation:
  - Reinforced concrete buildings and bridge column
  - Precast concrete parking structure
  - Unreinforced and reinforced masonry building structures
  - Metal building structures
  - Woodframe dwellings and buildings
  - Wind turbine
  - Soil retaining walls
  - Underground structures (deep and shallow)

Objectives of the NHERI@UCSD Site

- The **vision for the NHERI@UCSD Shake Table experimental facility** is rooted on **three critical needs** for advancing the science, technology, and practice in earthquake disaster mitigation and prevention:
  - Fundamental knowledge for understanding the **system-level behavior** of buildings, critical facilities, bridges, and geo-structures during earthquakes, from the initiation of damage to the onset of collapse.
  - Experimental data to support the **development, calibration and validation of high-fidelity physics-based computational models** of structural/geotechnical/soil-foundation-structural systems that will progressively shift the current reliance on physical testing to model-based simulation for the seismic design and performance assessment of civil infrastructure systems.
  - **Proof of concept, benchmark and validation/verification tests** for seismic retrofit methods, protective systems, and the use of new materials, components, systems, and construction methods that can protect civil infrastructure systems against earthquakes.

Mission Statement

- Maintain the shake table for safe, efficient, and accurate operation.
- Assist users with experiment planning, proposal preparation, specimen construction, instrumentation, data acquisition, test performance, demolition and removal.
- Keep NHERI@UCSD at the forefront of experimental shake table technology.
- Enhance the synergy between the NHERI facilities
- Engage the community in education and outreach efforts that will contribute to the realization of sustainable and natural disaster-resilient communities.

Supporting Grand Challenges

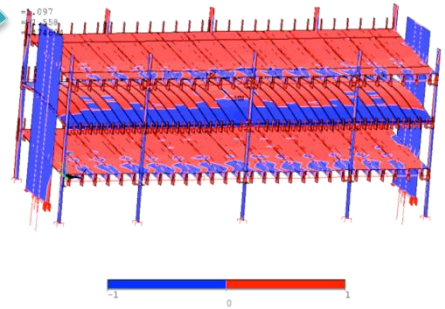
Experimental Research:
NEES@Lehigh
NEES@UCSD

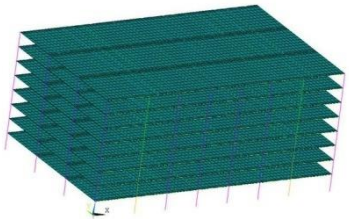
Design Provisions and Assessment Methods

- Development
- Verification through numerical simulation

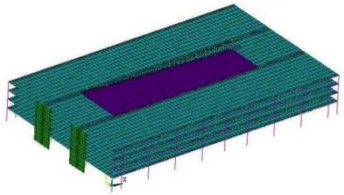
Computational Simulation

- Model development
- Model calibration
- Model validation





8-STORY OFFICE BUILDING



4-STORY PARKING STRUCTURE

AMERICAN SOCIETY OF CIVIL ENGINEERS

ASCE 7-16 SSC MAIN COMMITTEE BALLOT 5

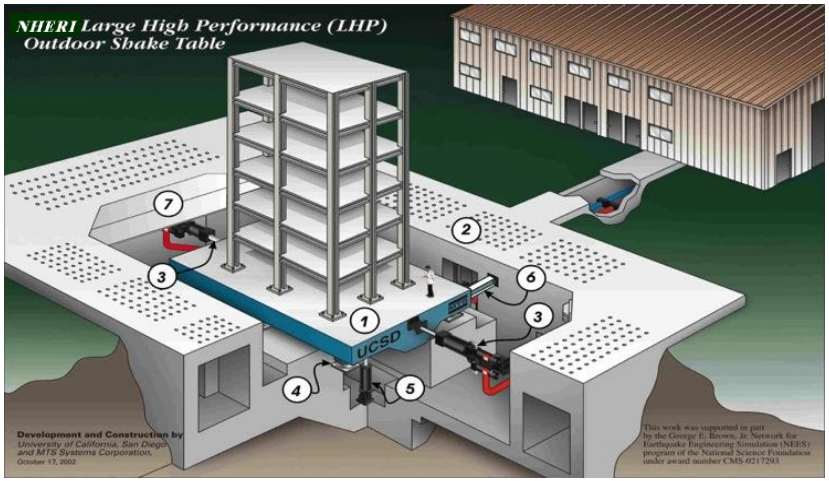
VOTERS COMMENTS - VOTING MEMBERS

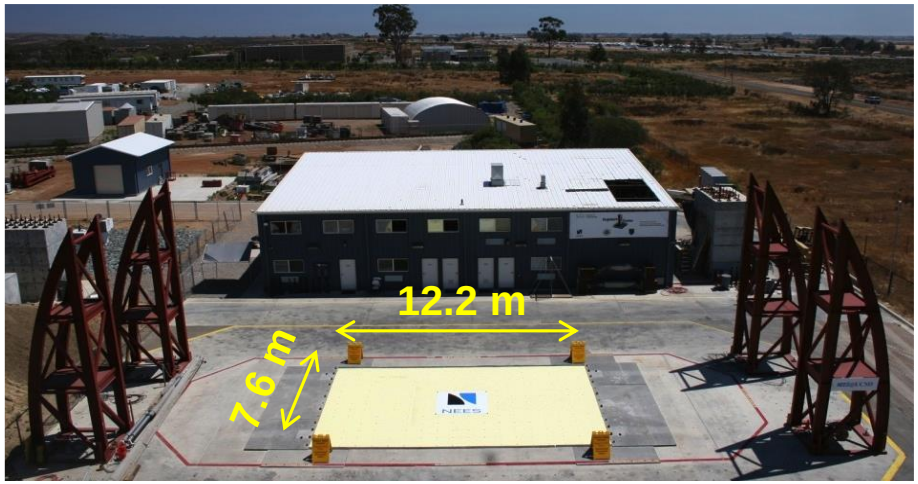
BALLOT CLOSING: MARCH 2015

BALLOT ITEM 4
APPROVE NEW PROPOSAL TC-02 CH12-036R01 BY GHOSH

EARTHQUAKE RESILIENT INFRASTRUCTURE

Large High-Performance Outdoor Shake Table



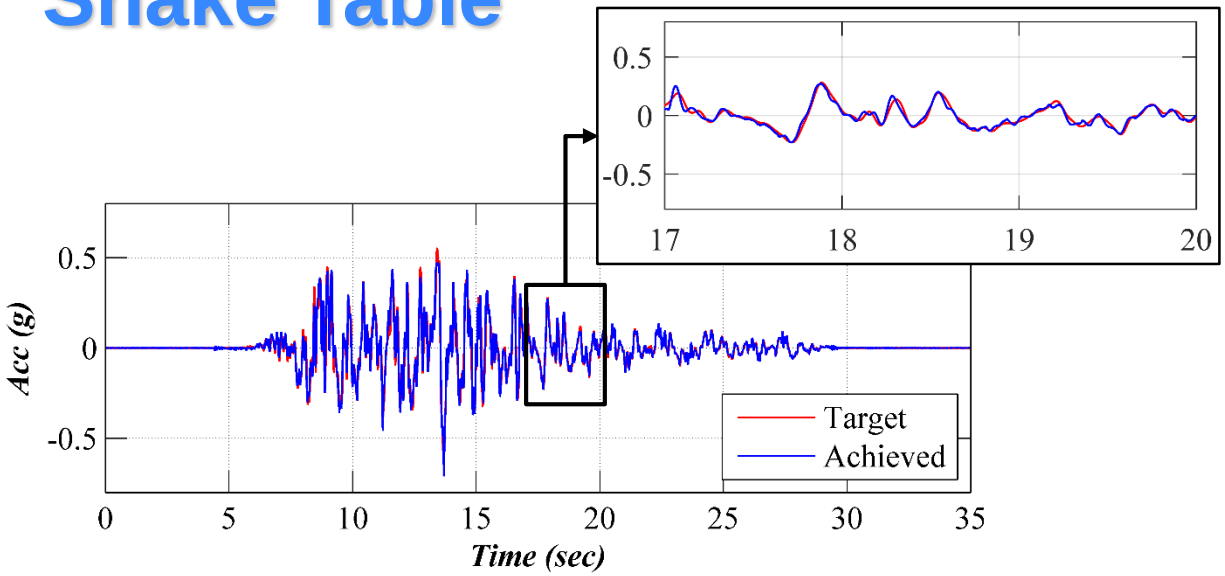


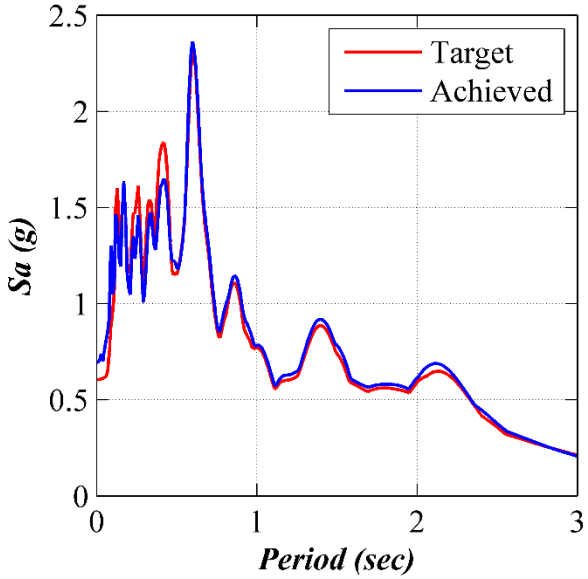
Performance Characteristics in Current 1-DOF Configuration	
Designed as a 6-DOF shake table, but built as a 1-DOF system to accommodate funding available	
Stroke	±0.75m
Platen Size	40 ft × 25 ft (12.2 m × 7.6 m)
Peak Velocity	**1.8 m/sec**
Peak Acceleration	4.7g (bare table condition); 1.2g (4.0MN/400 tons rigid payload)
Frequency Bandwidth	0-33 Hz
Horizontal Actuators Force Capacity	**6.8 MN (680 tons)**
Vertical Payload Capacity	**20 MN (2,000 tons)**
Overturning Moment Capacity	50 MN-m (5,000 ton-m)

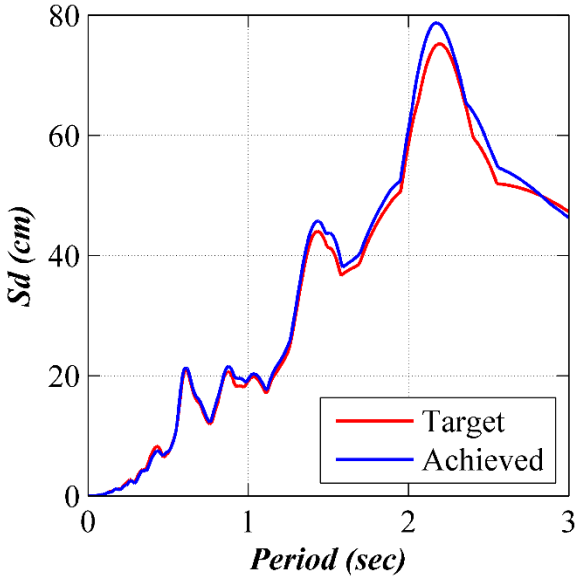
Capabilities/Provisions of NHERI@UCSD Site

- **Simulation of near-source earthquake ground motions** which involve large acceleration, velocity and displacement pulses.
- Seismic testing of **extensively instrumented large/full-scale structural specimens** under extreme earthquake loads at near real-world conditions.
- Seismic testing of **extensively instrumented large-scale geotechnical and soil-foundation-structural systems** by using the shake table in combination with large soil boxes.
- Basic capabilities for **hybrid shake-table testing**.
- **Education** of graduate, undergraduate, and K-12 students, as well as news media, policy makers, infrastructure owners, insurance and the general public, **about natural disasters** and the national need to develop effective technologies and policies to prevent these natural hazard events from becoming societal disasters.

Tracking Performance of NHERI@UCSD Shake Table







1994 Northridge Earthquake
Canoga Park (comp. 196)
Amplitude scaling: 1.55

Use of LHPOST in Combination with Large Soil Boxes

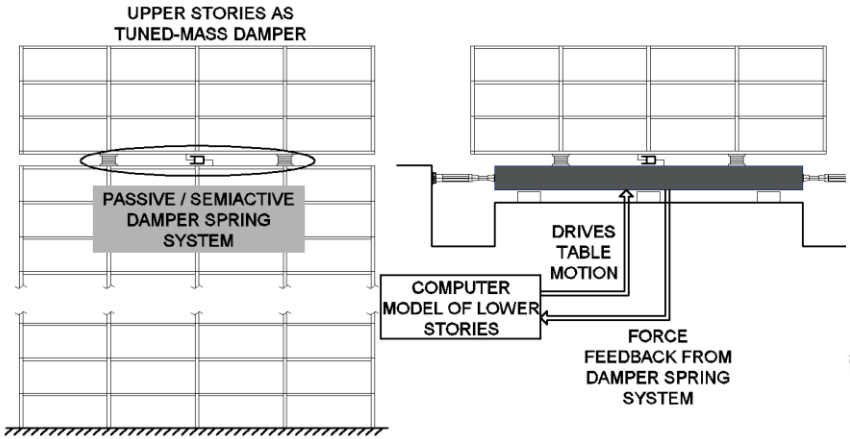
Laminar soil shear box:
6.7m (L) × 3.0m (W) × 4.7m (H)

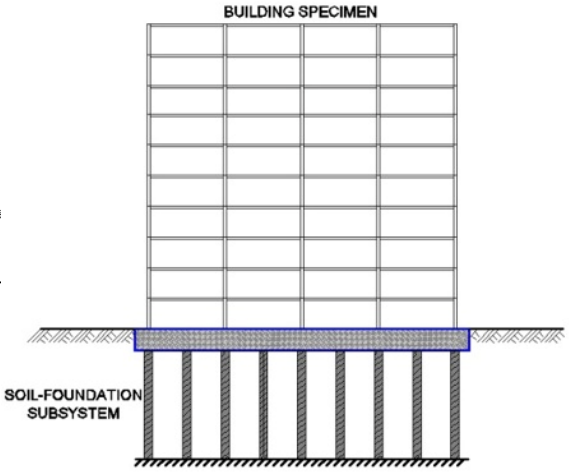
Stiff soil confinement box:
10.0m (L) × 4.6 or 5.8m (W) × 7.6m (H)

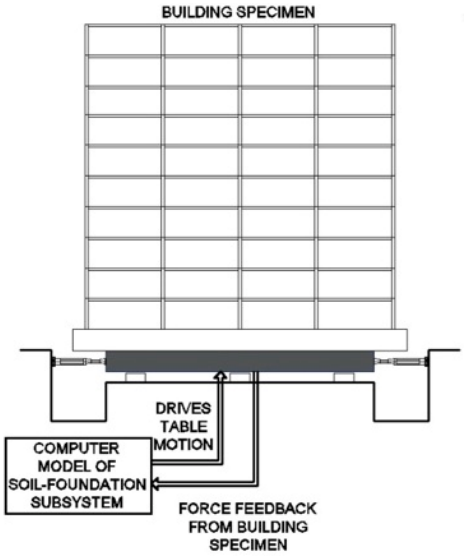
- To investigate the seismic response of soil-foundation-structural systems
- To complement centrifuge tests in order to validate computational models
- To study the performance of underground structures, bridge abutments, earth retaining walls and slope stability in hillside construction
- To investigate soil liquefaction and its effect on the seismic response of soil-foundation-structural systems

Real-time Hybrid Shake Table Testing

- Basic hardware and software in place for real-time hybrid shake-table testing:
  - Multi-channel MTS FlexTest controller
  - SCRAMNet ring for real-time communication and synchronization of data flow between shake-table controller, FlexTest controller, and real-time target PC running the Matlab/SIMULINK Real-time Workshop and xPC Target software
  - Integration of OpenSees/OpenFresco open-source software framework for advanced computational modeling
  - 500 kN capacity -12 in. stroke dynamic actuator

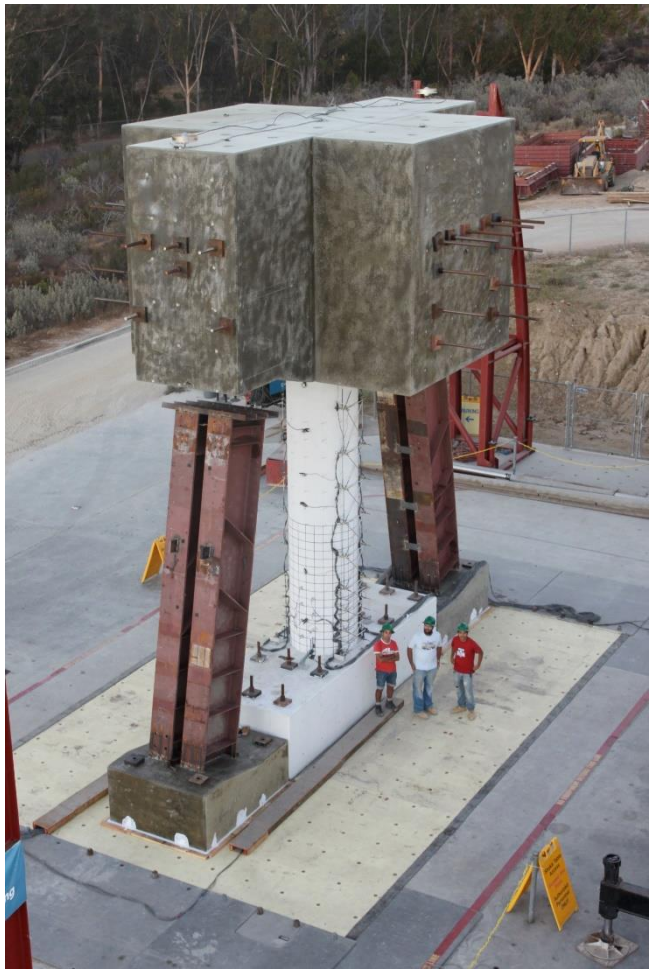






Component test
Large Bridge Column

- Objectives
- Evaluate current Caltrans seismic design criteria with dynamic testing.
- Flow of crushed core concrete?
- Carry on testing to incipient collapse
- Evaluate model uncertainty by means of a blind prediction of the column's response



I-5 @ I-805 interchange (San Diego, CA)

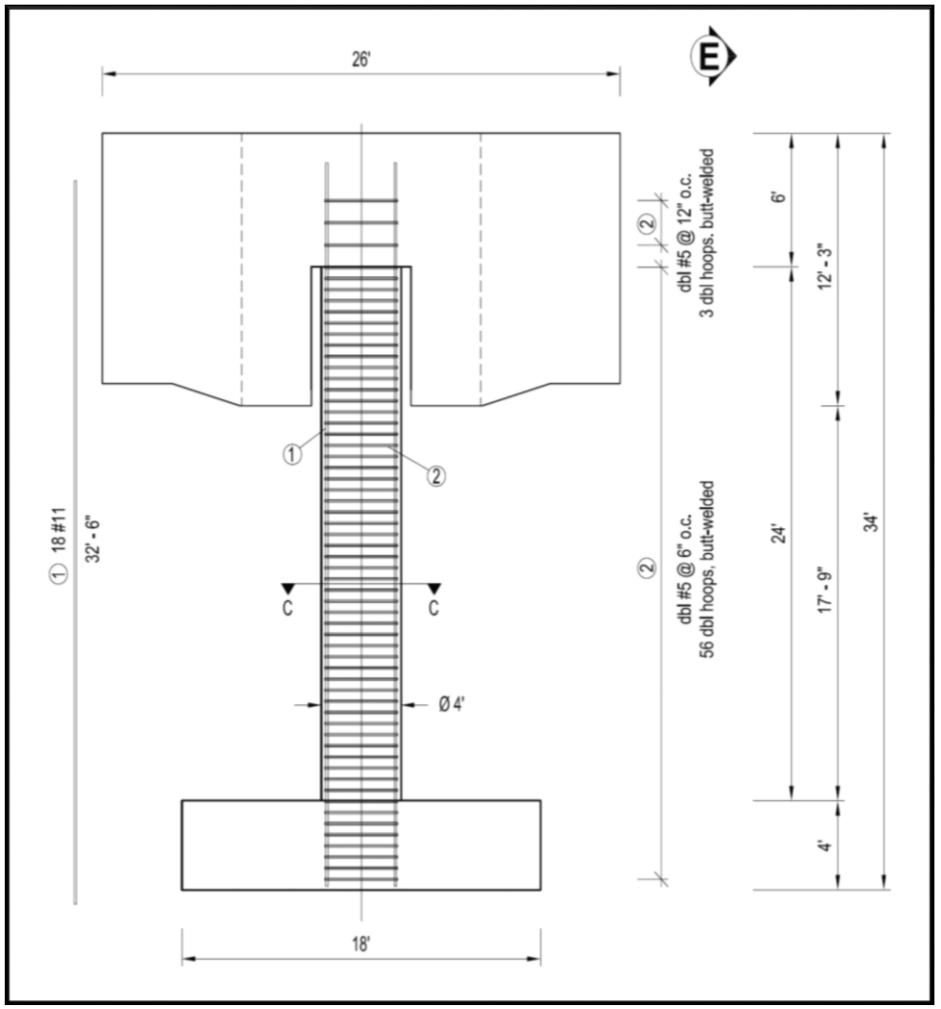
(from Google Earth)

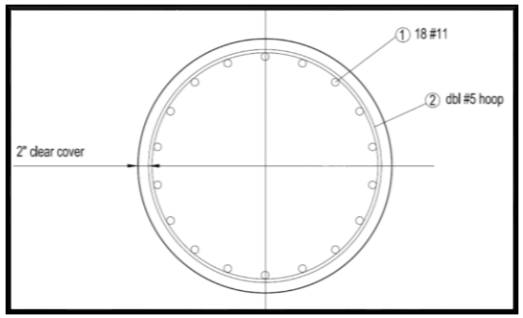
Main Project Sponsors, Donors and Collaborating Institutions

University of Nevada, Reno

Component test
Large Bridge Column

- Geometry:
- 1.2 m diameter
- 7.2 m high cantilevered column
- Reinforcement provided:
- Eighteen #11 (35 mm) longitudinal
- Butt-welded, double #5 (16 mm) hoops at 150 mm o.c..
- Design considerations:
- Longitudinal reinforcement ratio of 1.55%
- Volumetric confining ratio of 0.95%
- Axial load ratio of 5.3%
- Top mass of 250 Tons
- Target period: 1-1.2 sec





Component test
Large Bridge Column

Component test
Large Bridge Column

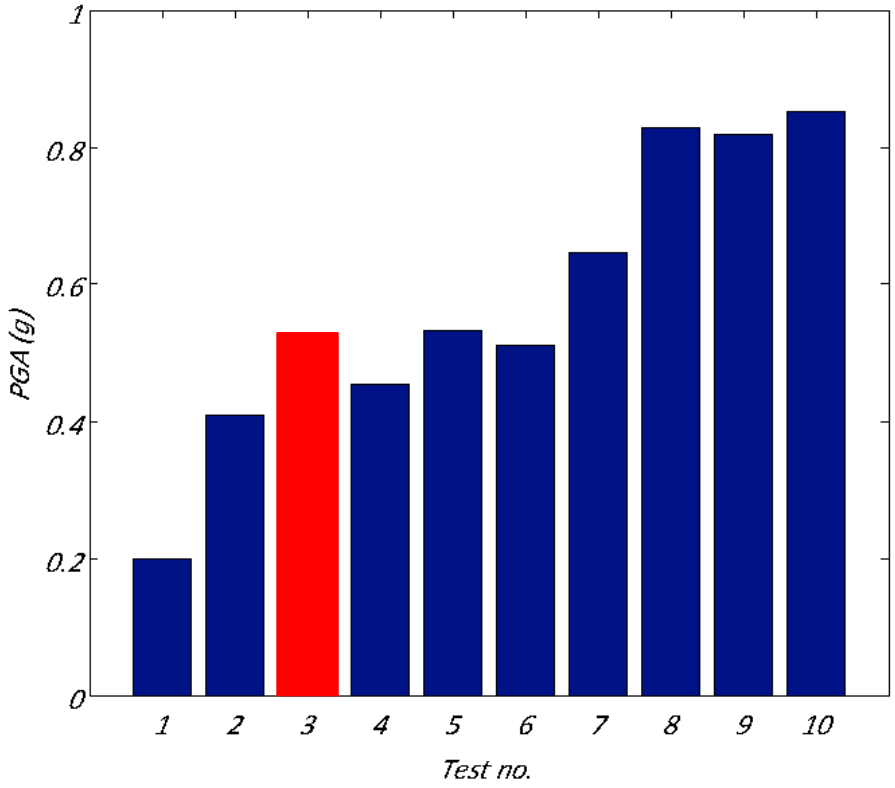
Ground-Motion Selection

- Seismic demand for a site in San Francisco.
- 6 records from historical earthquakes with strike-slip fault mechanism.
- Ground-motion selection based on ability to impose target displacements.
- White-noise excitation between records, for system characterization.

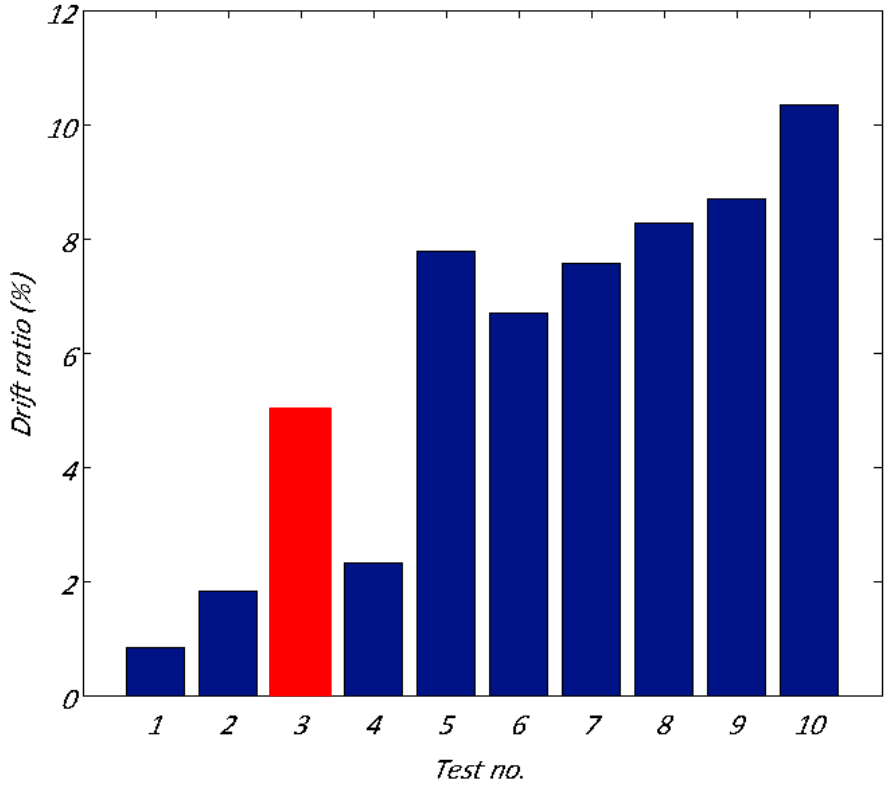
Test	Earthquake	Date	Moment magnitude	Station	Target displacement ductility	Scale factor	Table PGA (g)
EQ1	Loma Prieta	10/18/1989	6.9	Agnew State Hospital	1.0	1.0	-0.199
EQ2	Loma Prieta	10/18/1989	6.9	Corralitos	2.0	1.0	0.409
EQ3	Loma Prieta	10/18/1989	6.9	LGPC	4.0	1.0	0.526
EQ4	Loma Prieta	10/18/1989	6.9	Corralitos	2.0	1.0	0.454
EQ5	Kobe	01/16/1995	6.9	Takatori	8.0	-0.8	-0.533
EQ6	Loma Prieta	10/18/1989	6.9	LGPC	4.0	1.0	-0.512
EQ7	Kobe	01/16/1995	6.9	Takatori	Not applicable	1.0	0.646
EQ8	Kobe	01/16/1995	6.9	Takatori	Not applicable	-1.2	-0.829
EQ9	Kobe	01/16/1995	6.9	Takatori	Not applicable	1.2	0.819
EQ10	Kobe	01/16/1995	6.9	Takatori	Not applicable	1.2	0.851

Component test
Large Bridge Column

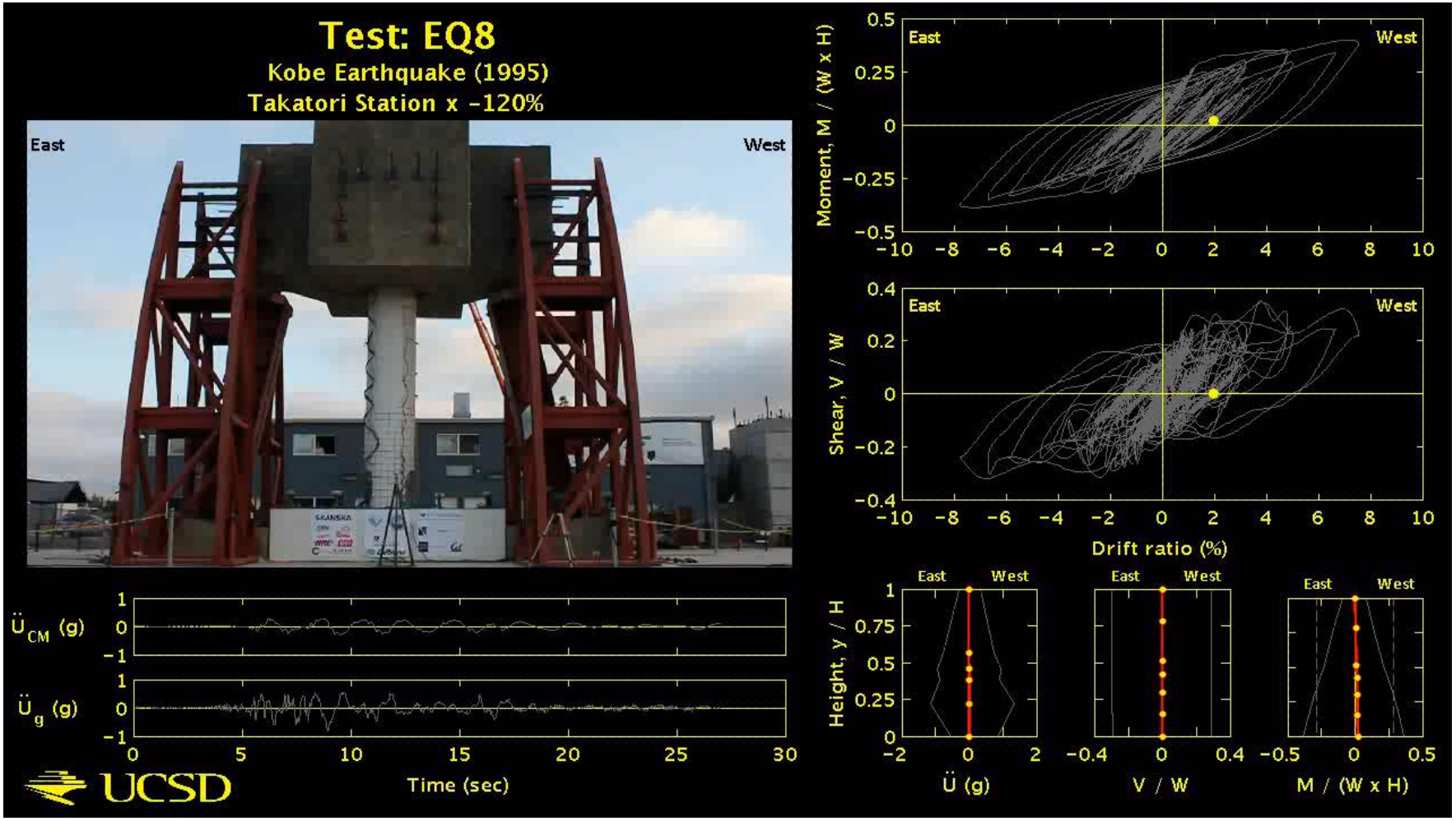
Recorded Table PGA



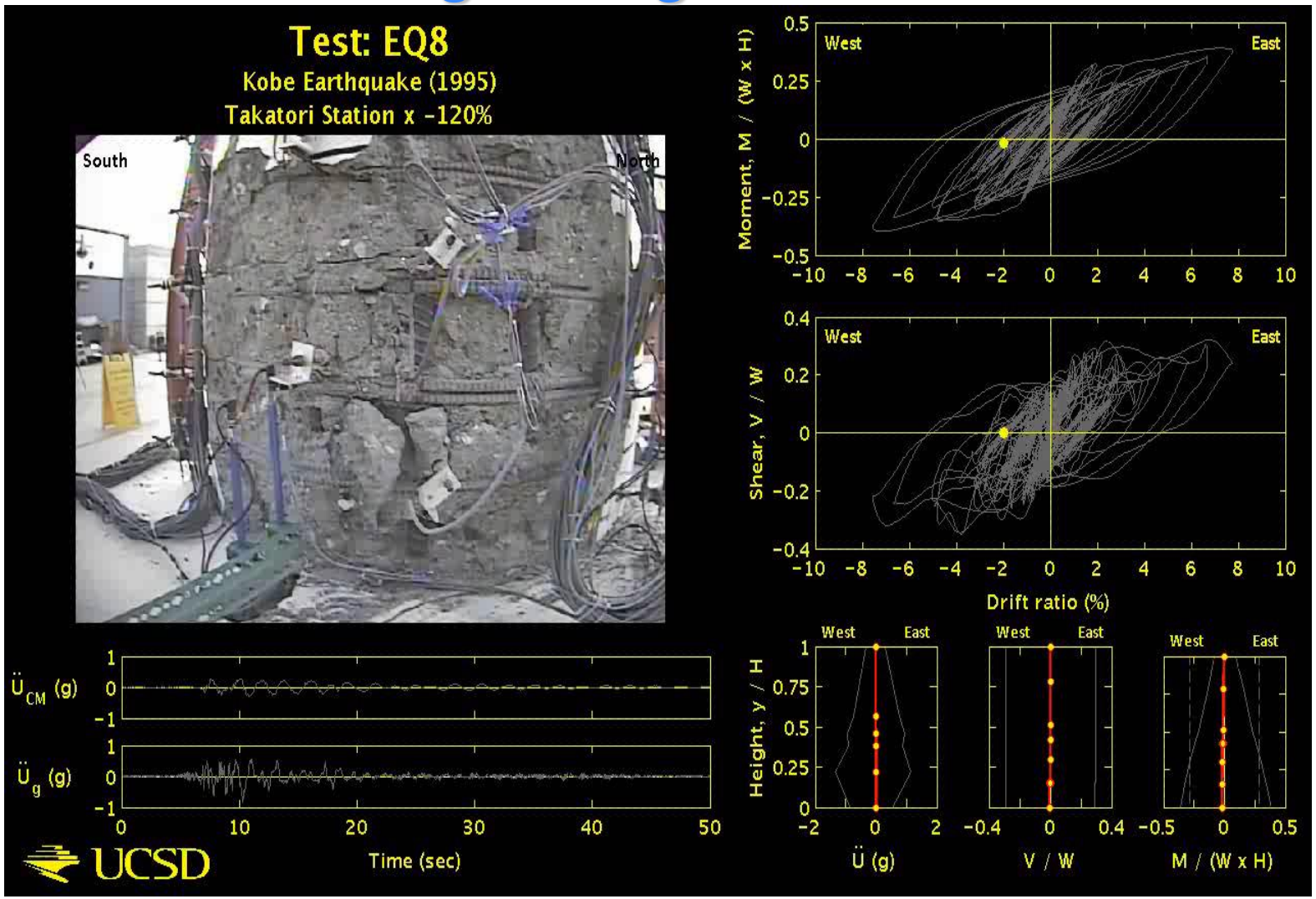
Recorded Column Drift Ratios



Component test
Large Bridge Column

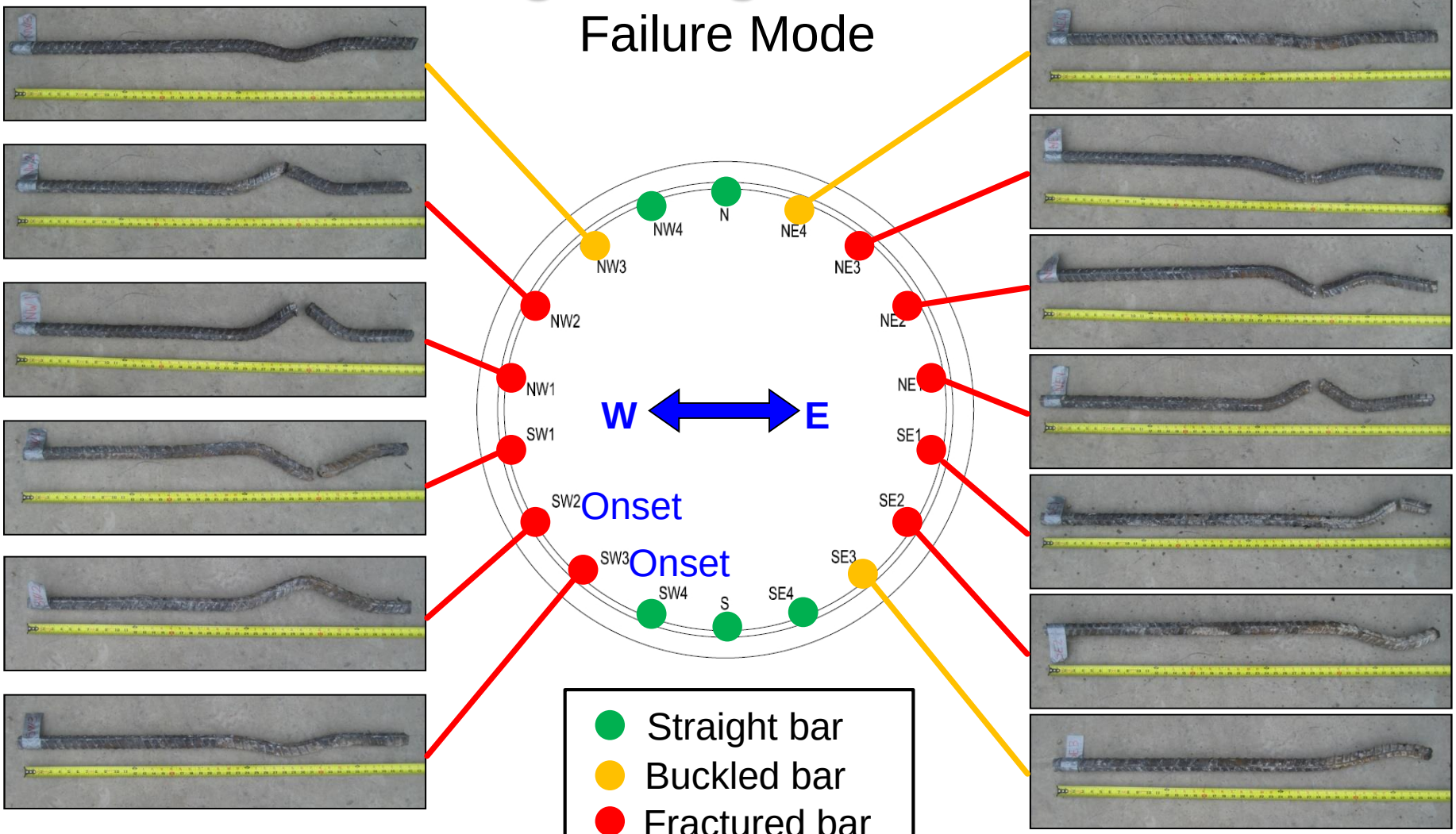


Component test
Large Bridge Column



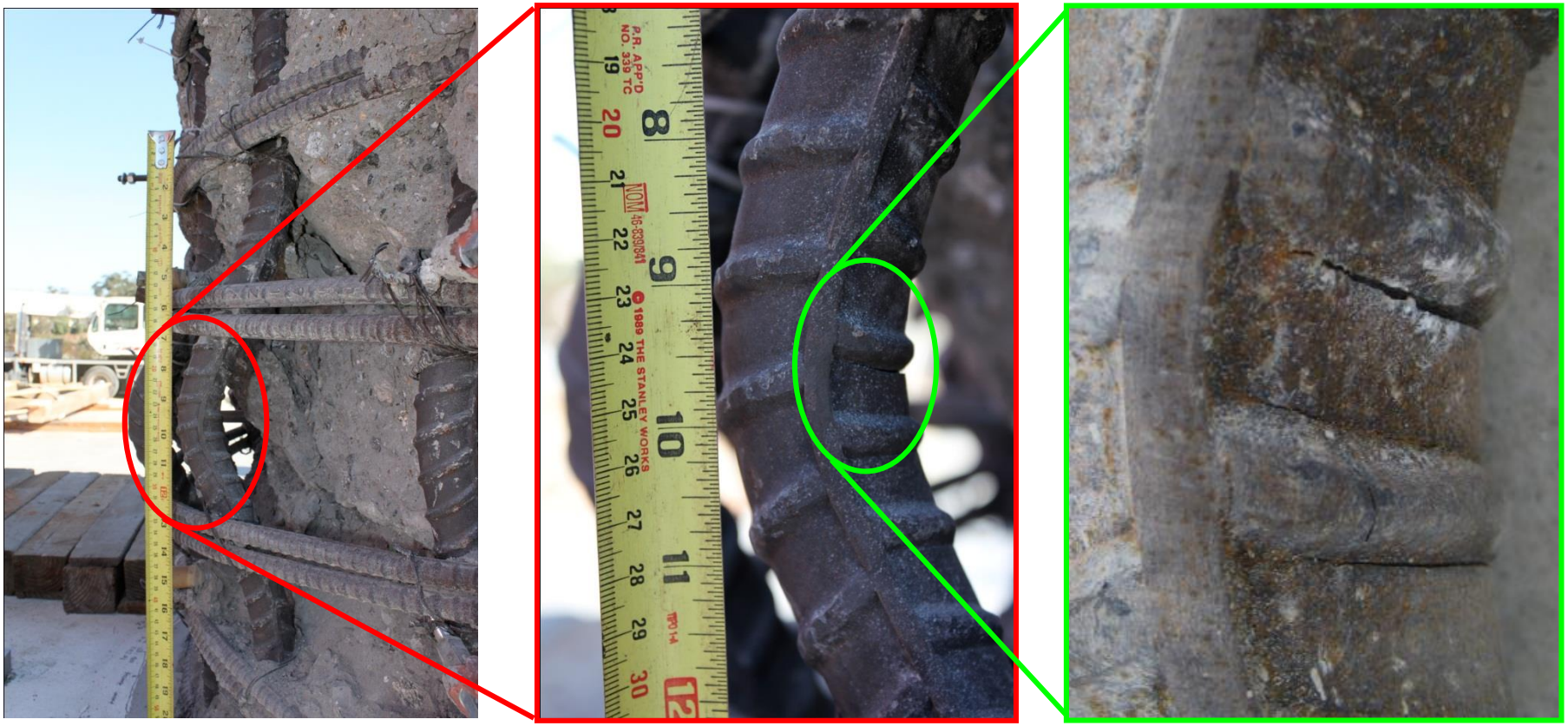
Component test
Large Bridge Column

Failure Mode



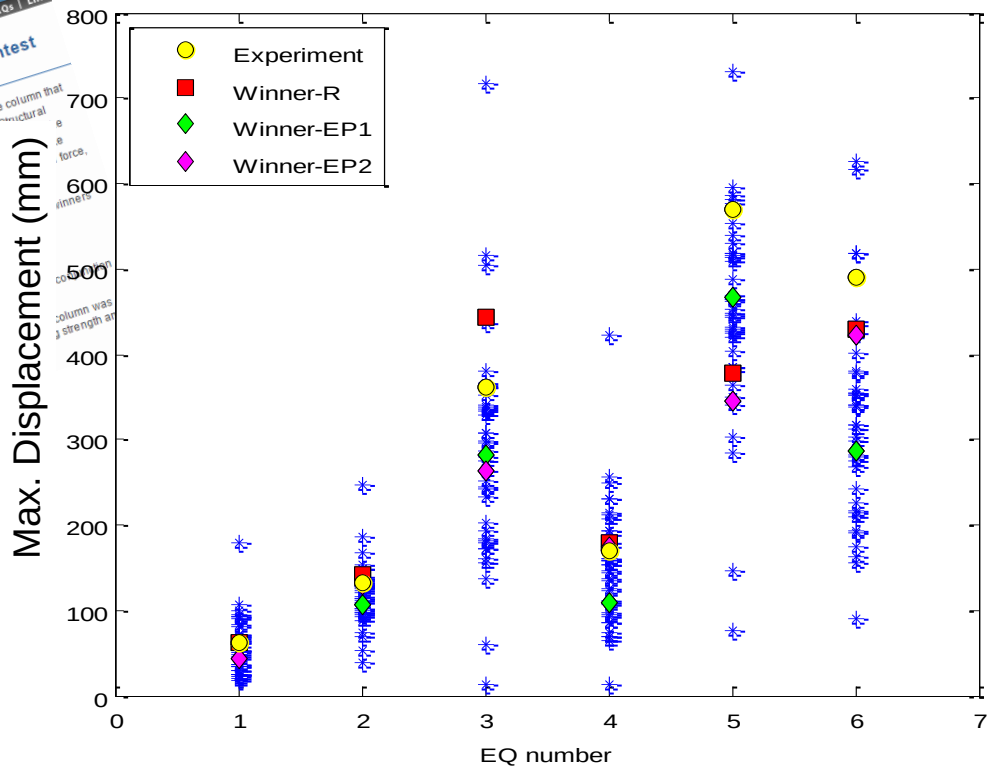
Component test
Large Bridge Column

Failure Mode



Component test
Large Bridge Column

Responses: Max. Displacement



System Test
BNCS Building

Building Nonstructural Components & Systems (BNCS) Project (2011-2015)

- *Total building system*, focus on performance of nonstructural systems; in a systems setting

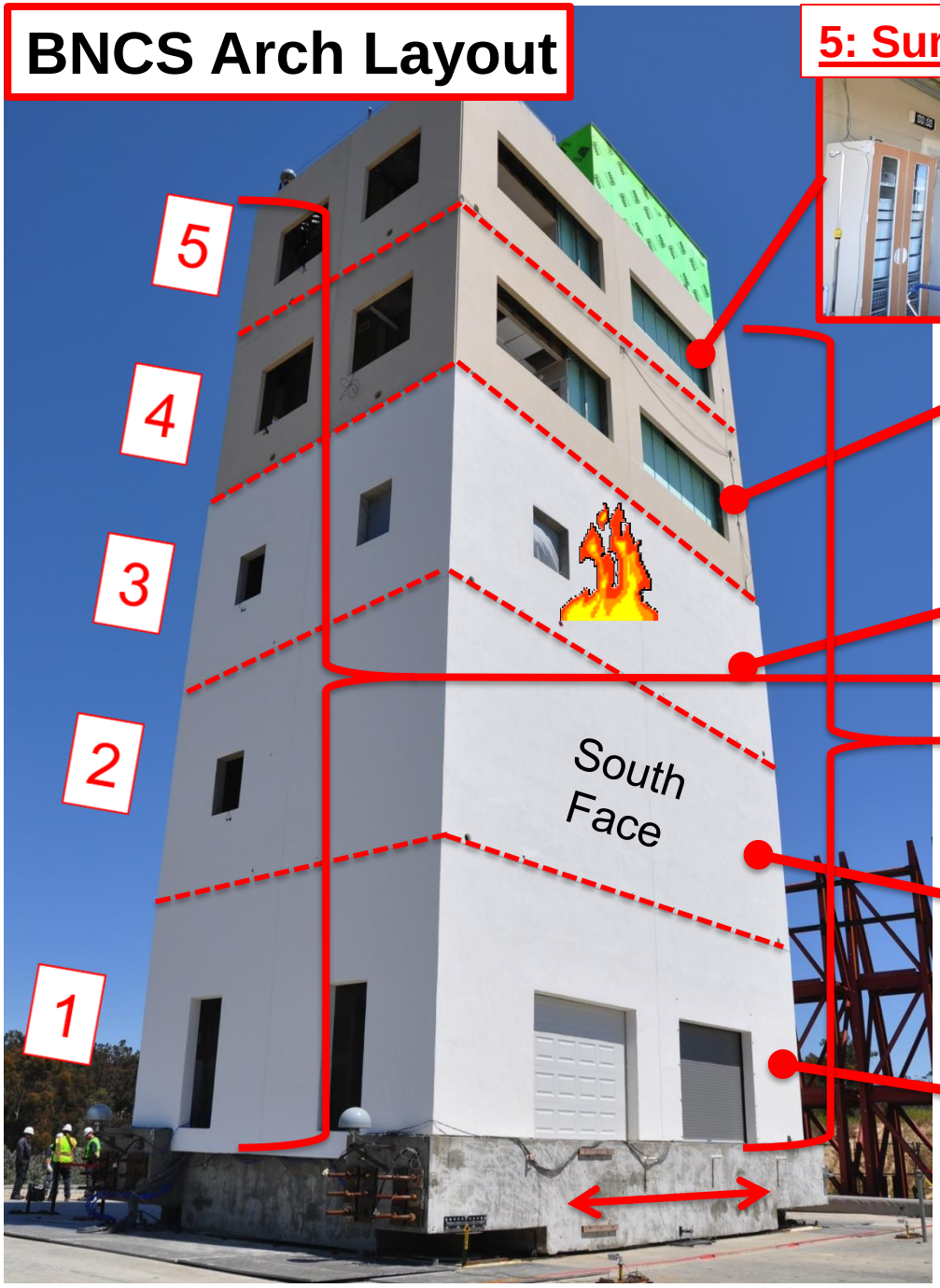
- Complete, full-scale building system
- Landmark test program
- Earthquake & post-earthquake fire scenario
- Two test phases
  - Base isolated
  - Fixed based condition

System Test
BNCS Building

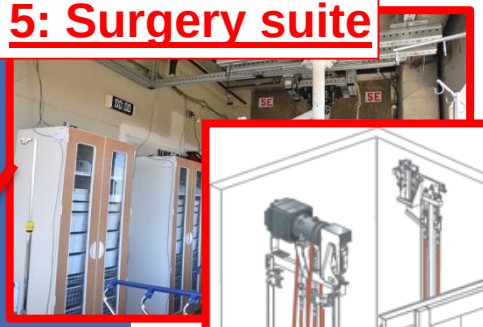
Partners

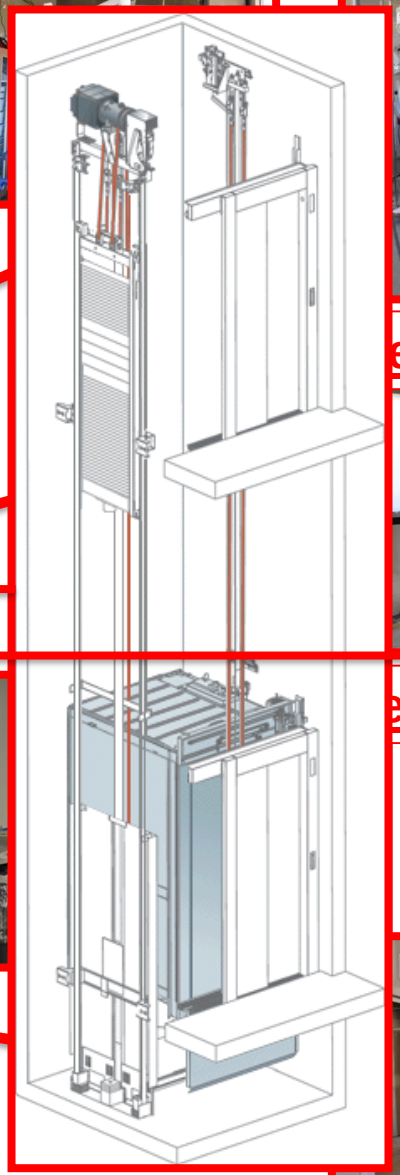
- Academic Partners
  - **University of California, San Diego (UCSD)**
  - Worcester Polytechnic Institute (WPI)
  - San Diego State University (SDSU)
  - Howard University (HU)
- Broad stakeholder participation
  - Industry (>40) and government

BNCS Arch Layout

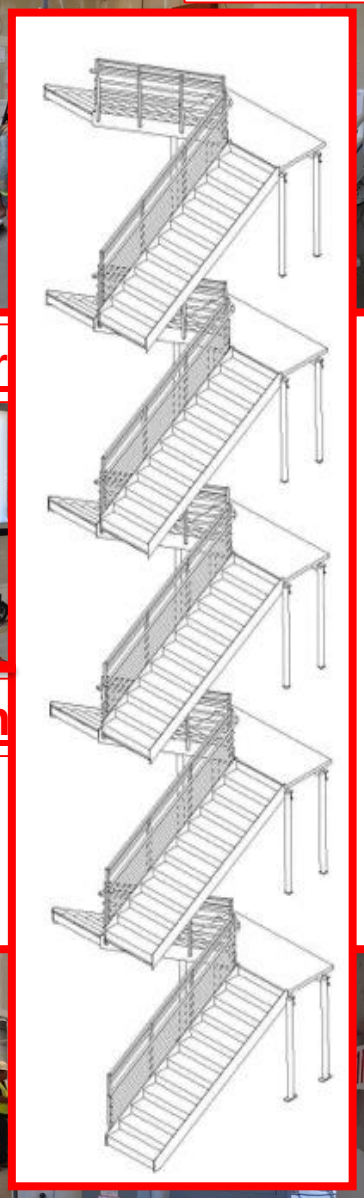


5: Surgery suite



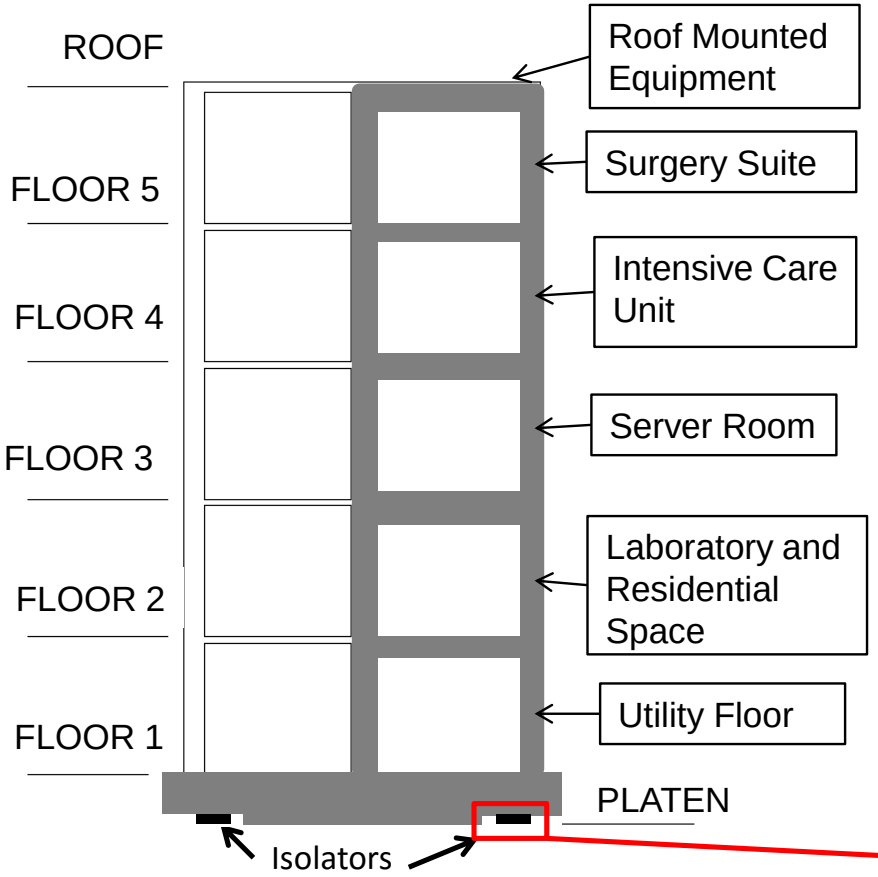


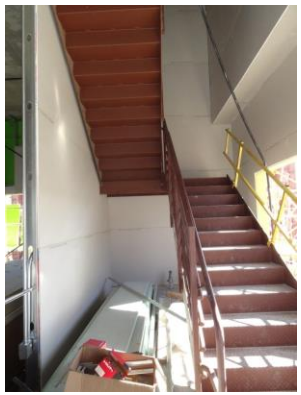
4: ICU



System Test
BNCS Building

87 video cameras & 515 channels of sensors:
~ 2/3 installed on NCSs, ~1/3 on structure





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BNCS Building

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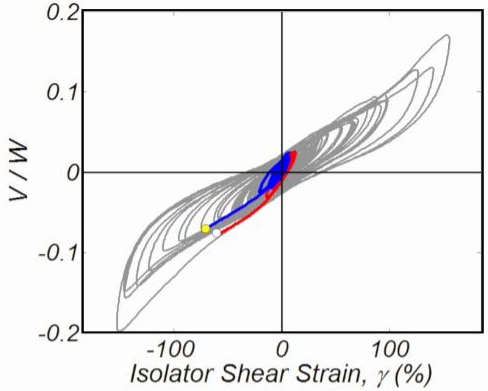

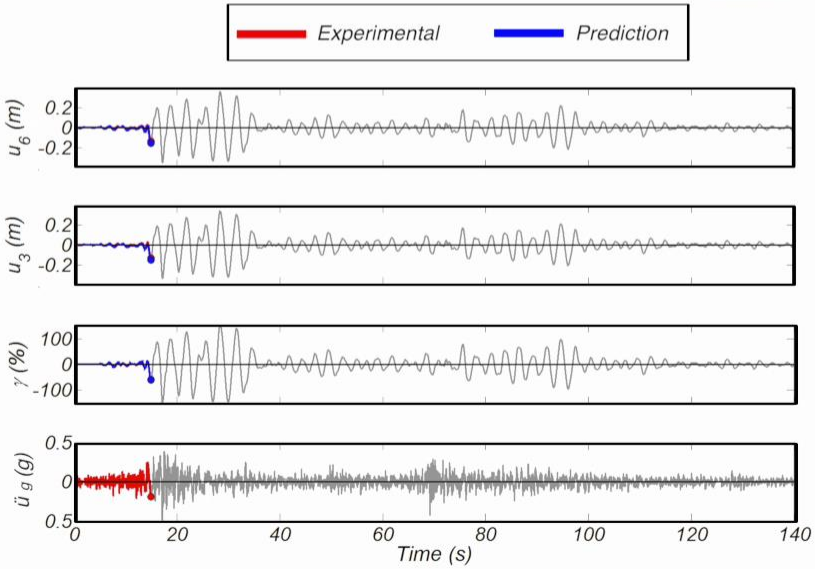

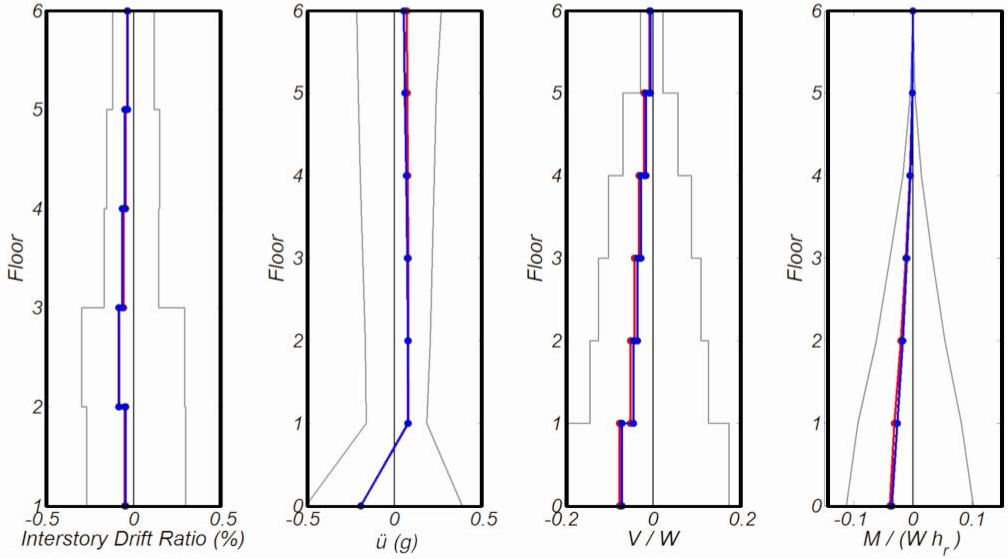

System Test
BNCS Building

Visit http://bncs.ucsd.edu/ for complete project information

Soil-foundation-structure Interaction Test


THANK YOU!
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