NHERI@UC San Diego

2ND USERS TRAINING WORKSHOP

Objectives

- ➢ Familiarize prospective users of the NHERI@UCSD shake table with its simulation capabilities, performance characteristics and limitations.
- ➢ Introduce prospective users to the basics of large-scale shake table testing, including recommendations for how to plan for and execute successful large-scale shake table projects:
  - Pros and cons of shake table experiments
  - Experiment design and execution
  - Project management
  - Data acquisition, storage, retrieval, and interpretation
- ➢ Provide prospective users with the knowledge necessary to prepare NSF research proposals utilizing the NHERI Experimental Facility at UC San Diego.
- ➢ Provide workshop participants with thoughts on the Grand Challenges in Earthquake Engineering and how NHERI@UCSD can be used to contribute to solving these Grand Challenges.

Workshop Program – Monday Morning

7:45 - 8:00am	Registration
8:00 - 8:15am	Welcome, Introduction & Workshop Schedule (Prof. J. Conte, UCSD)
8:15 - 9:15am	NHERI@UCSD: Facility Description and Capabilities (Prof. J. Conte, UCSD)
9:15 - 9:30am	DesignSafe: user tools & support (Prof. E. Rathje, UT-Austin)
9:30 - 10:15am	Nuts & Bolts: Instrumentation/DAQ, Cameras, IT Resources & Cybersecurity (D. Radulescu and R. Beckley, UCSD)
10:15 - 10:30am	Break
10:30 - 11:00am	Journey through a Project (Structural) (Prof. B. Shing, UCSD)
11:00 - 11:30am	Journey through a Project (Geotechnical) (T. Shantz, Caltrans, and Prof. J. Restrepo, UCSD)
11:30 - 11:45am	SimCenter (Dr. A. Schellenberg, UCB)
11:45 - 1:00pm	Lunch

Workshop Program – Monday Afternoon

1:00 - 2:30pm	Facility Tour (bus to site)
2:30 - 3:00pm	Research Planning in a Nutshell (Prof. T. Hutchinson, UCSD)
3:00 - 4:00pm	Innovative Characteristics and Opportunities at NHERI@UCSD Experimental Facility (Prof. G. Mosqueda, UCSD)
4:00 - 4:30pm	Questions & Answers
6:00pm	Dinner (next door at Chin's Seafood and Grill)

Workshop Program – Tuesday Morning

9:00 - 9:10am	Welcome & Goals for the Day (Prof. J. Conte, UCSD)
9:10-10:20am	Grand Challenges in Earthquake Engineering • Structural Systems (Prof. J. Van de Lindt, CSU) • Geotechnical Systems (Prof. Y. Hashash, UIUC) • New Technologies (Protective Systems & Hybrid Simulation) (Prof. J. Ricles, Lehigh)
10:20 - 10:30am	Recap of NHERI@UCSD Science Plan Instructions for breakout sessions (Prof. J. Conte, UCSD)
10:30 - 12:00pm	Breakout Sessions 1. Building/Bridge/Nonstructural Systems 2. Geotechnical Systems 3. New Technologies
12:00 - 1:00pm	Working Lunch – Outcomes from the Breakout Sessions (Session Leads)

Tuesday Afternoon - Community Workshop to Develop a Large-Scale Testbed Structure

1:00 - 2:00pm	Vision for Testbed Structure: Needs & Preliminary Design (Prof. G. Mosqueda, UCSD, Prof. R. Christenson and Prof. A. Zaghi, U-Connecticut)
2:00 - 4:00pm	Breakout Session to Identify Needs (Damping Devices, Isolation, Hybrid Testing)
4:00 - 5:00pm	Breakout Report and Summary of Needs for Testbed Structure Design (Session Leads)

Presenters

- Robert Beckley, UC San Diego
- Richard Christenson, Univ. of Connecticut
- Joel Conte, UC San Diego
- Youssef Hashash, University of Illinois at Urbana Champaign
- Tara Hutchinson, UC San Diego
- Gilberto Mosqueda, UC San Diego
- Dan Radulescu, UC San Diego
- Ellen Rathje, UT Austin
- Jose Restrepo, UC San Diego
- Jim Ricles, Lehigh
- Andreas Schellenberg, UC Berkeley
- Tom Shantz, Caltrans
- Benson Shing, UC San Diego
- John Van de Lindt, Colorado State University
- Arash Zaghi, Univ. of Connecticut

NHERI@UC San Diego: Facility Description and Capabilities

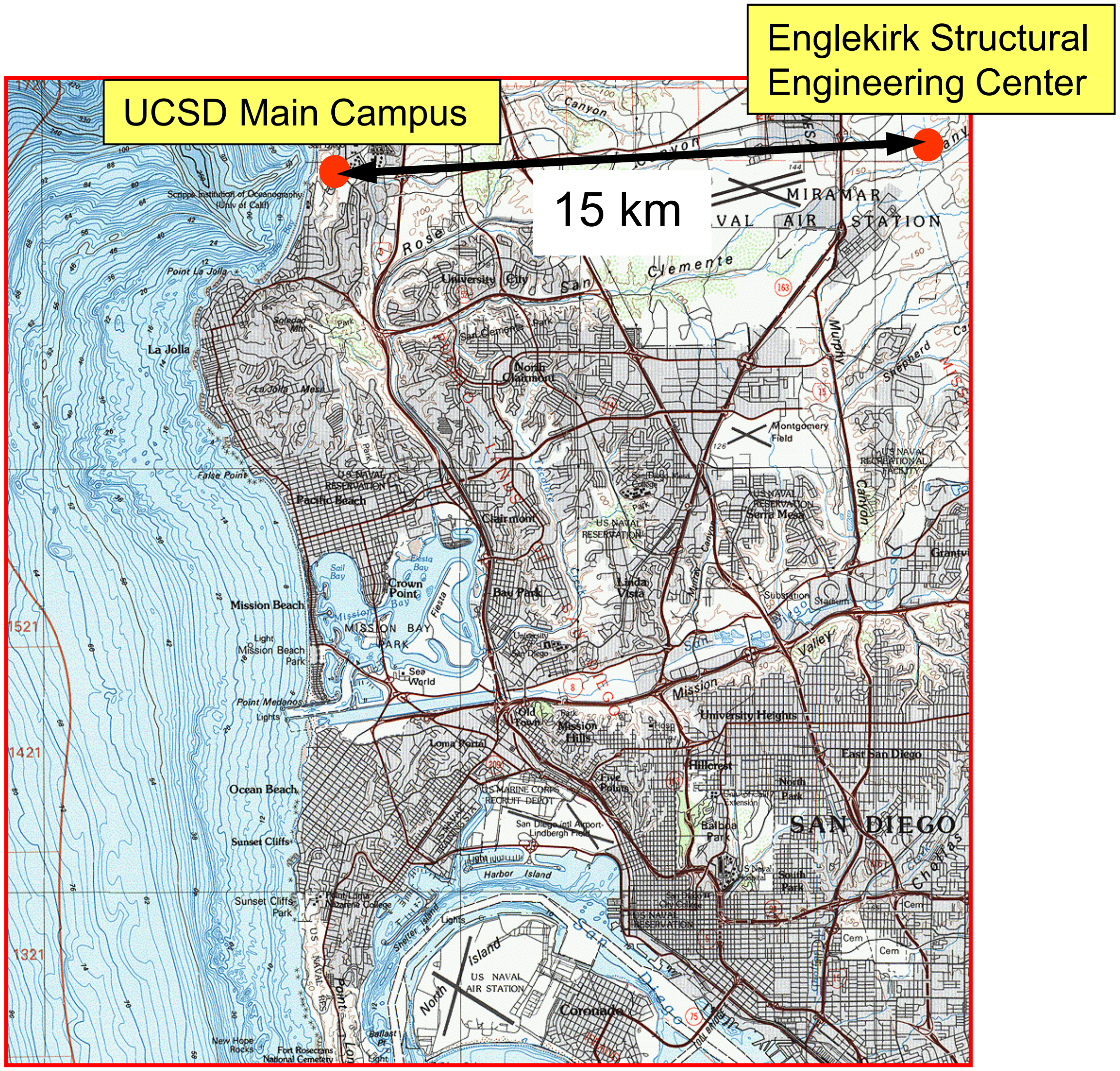
Joel Conte, Professor

University of California, San Diego

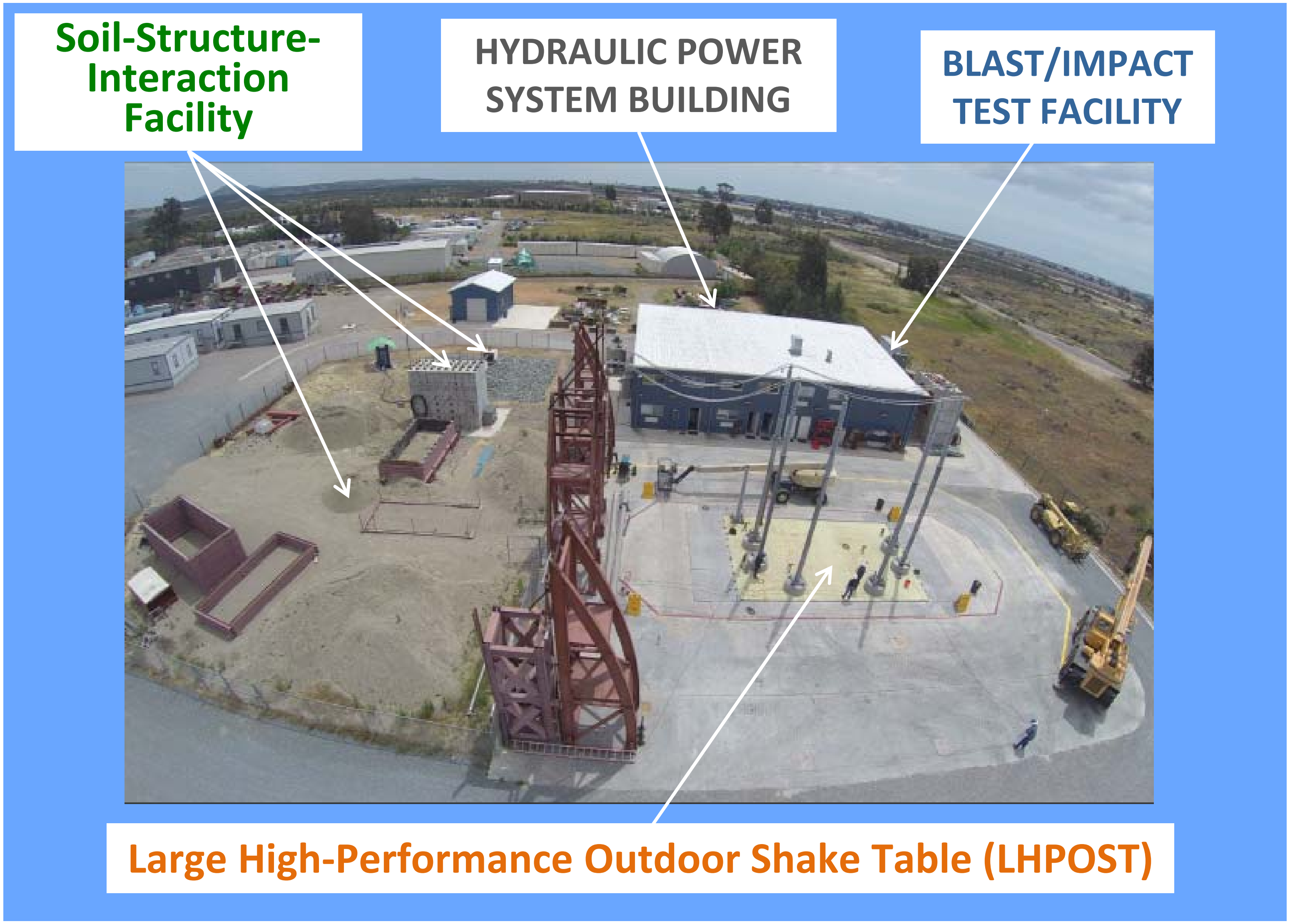
December 12, 2016

Natural Hazards Engineering Research Infrastructure (NHERI) Network

Englekirk Structural Engineering Center



Location of Site and Relation to the Englekirk Structural Engineering Center



IAS Accreditation of ESEC

International Accreditation Service

CERTIFICATE OF ACCREDITATION

This is to signify that

ENGLEKIRK STRUCTURAL ENGINEERING CENTER
10201 POMERADO ROAD
SAN DIEGO, CALIFORNIA 92131

Testing Laboratory TL-356

has met the requirements of the IAS Accreditation Criteria for Testing Laboratories (AC89), has demonstrated compliance with ISO/IEC Standard 17025:2005, *General requirements for the competence of testing and calibration laboratories*, and has been accredited, commencing July 15, 2013, for the test methods listed in the approved scope of accreditation.

Patrick V. McCullen
Vice President

C. P. Ramani, P.E.
President

ilac-MRA

IAS ACCREDITED

(see attached scope of accreditation for fields of testing and accredited test methods)

Print Date: 09/25/2013

Page 1 of 2

This accreditation certificate supersedes any IAS accreditation certificate bearing an earlier date. The certificate becomes invalid upon suspension, cancellation or revocation of accreditation. See the IAS Accreditation Listings on the web at www.iasonline.org for current accreditation information, or contact IAS directly at (562) 364-8201.

Soil-Foundation-Structure Interaction Facility

Bridge Abutment - Soil Interaction
(Caltrans)

Pile – soil interaction
(Port of Los Angeles)

NHERI@UC San Diego
Shake Table Experimental Facility

NHERI@UC San Diego Personnel

Joel Conte
PI

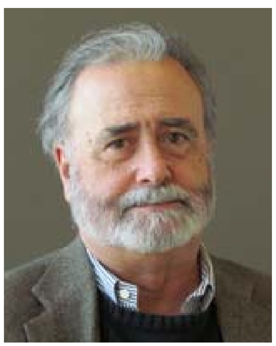
Tara Hutchinson
Co PI

Gilberto Mosqueda
Co PI

Benson Shing
Co PI

Lelli Van Den Einde
Co PI

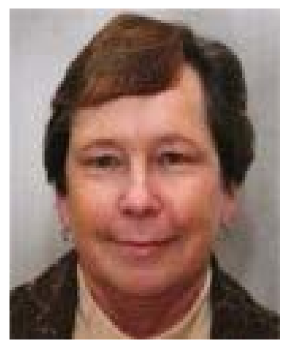
José Restrepo
Senior Personnel



Enrique Luco
Senior Personnel

Dan Radulescu
Operations Manager

Robert Beckley
IT Manager



Linda Johnson
Office Manager

Alex Sherman
Site Foreman

Jeremy Fitcher
Development Technician

Outline

- Overview of NHERI@UCSD Shake Table Experimental Facility
  - Description of Facility
  - Performance Characteristics
  - Capabilities and Limitations
- Shake Table Dynamics and Control
  - Sources of Signal Distortion
  - Shake Table Controller
  - Fidelity in Signal Reproduction
- Select Large-Scale Shake Table Tests Performed on the NHERI@UCSD Shake Table

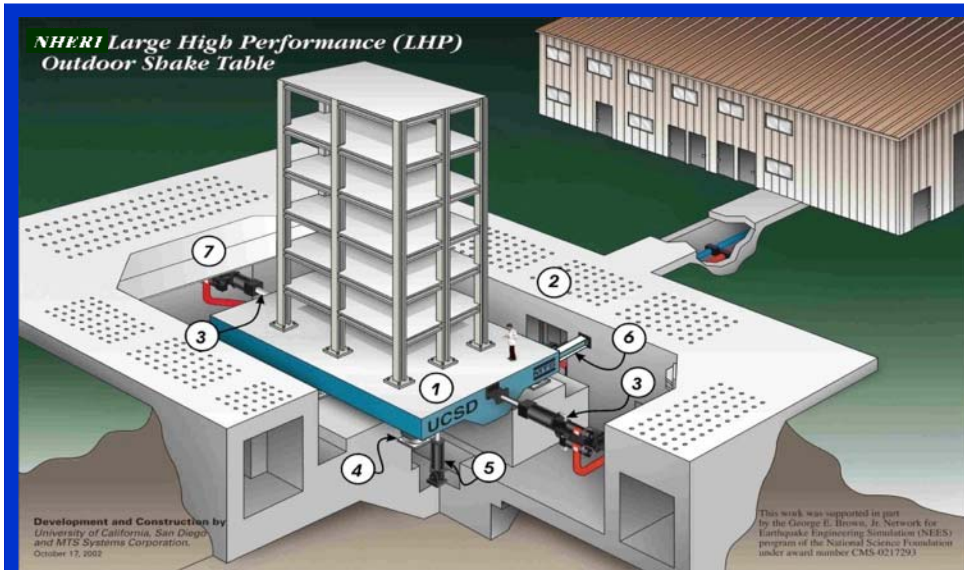
Objectives of the NHERI@UCSD Site

- 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.

Large High Performance Outdoor Shake Table (LHPOST)

- 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)

Large High-Performance Outdoor Shake Table

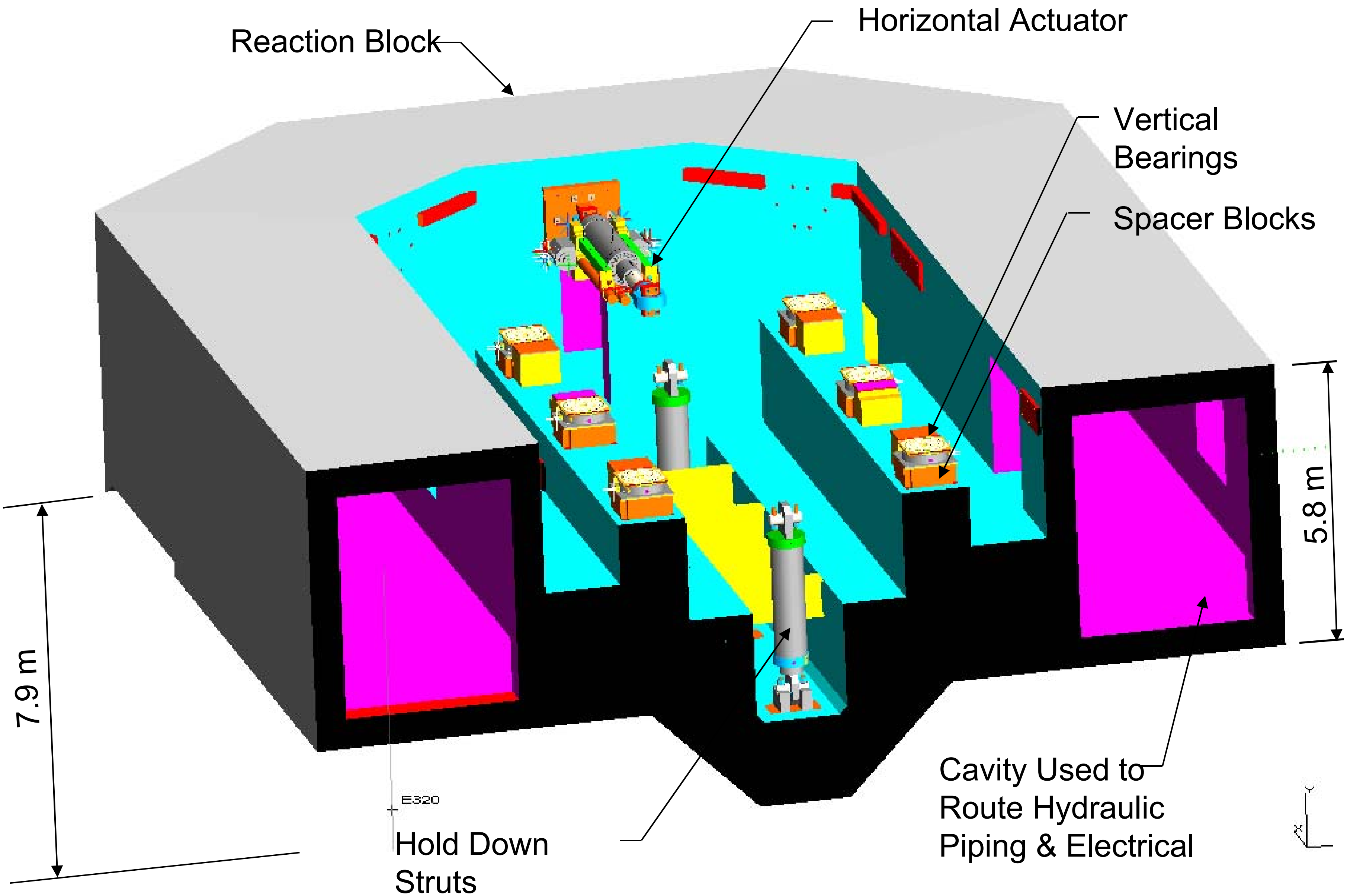


Performance Characteristics in Current 1-DOF Configuration	
Designed as a 6-DOF shake table, but built as a 1-DOF system to accommodate funding available	
Stroke	±0.75m
Platen Size	40 ft × 25 ft (12.2 m × 7.6 m)
Peak Velocity	**1.8 m/sec**
Peak Acceleration	4.7g (bare table condition); 1.2g (4.0MN/400 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)

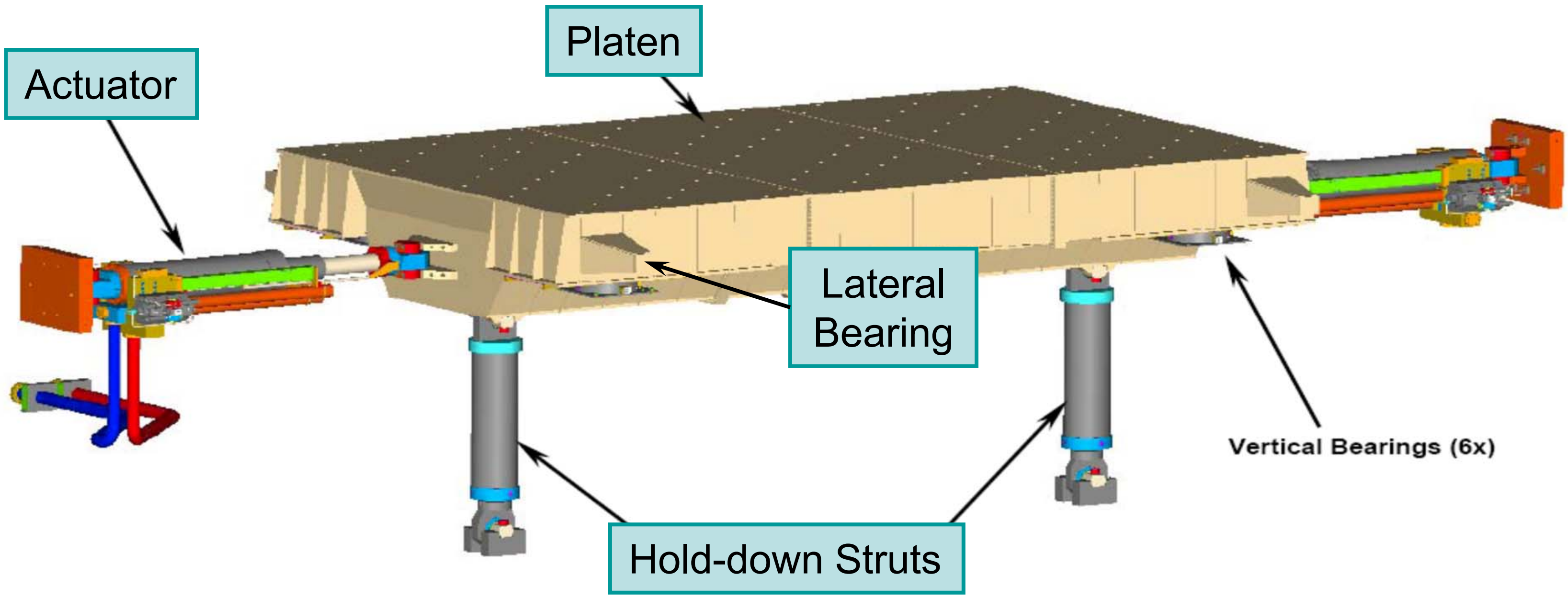
Capabilities/Provisions of NHERI@UCSD Site

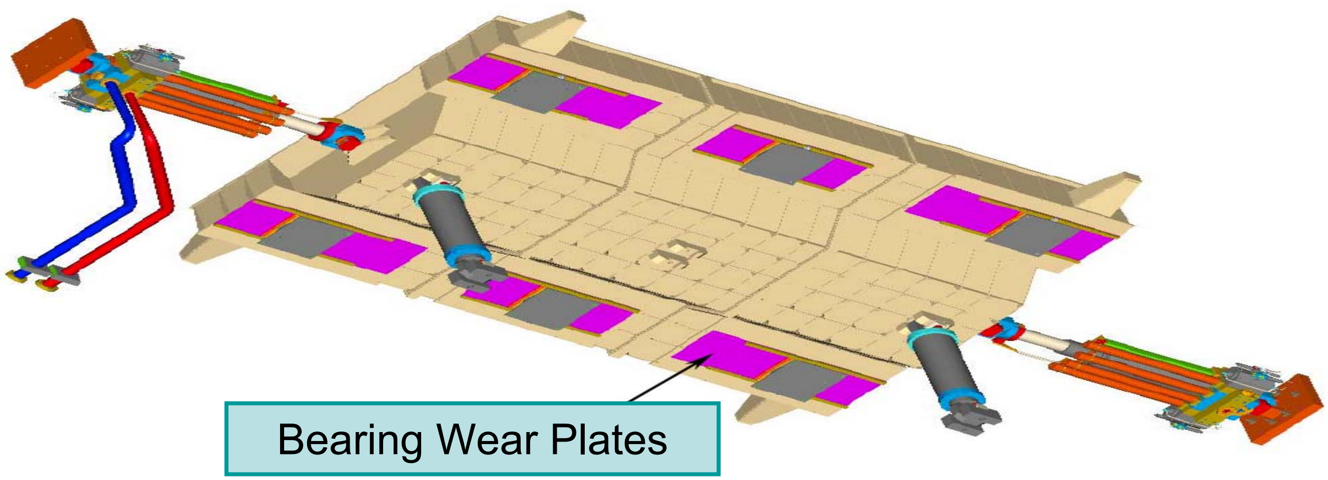
- **Simulation of near-source earthquake ground motions** which involve large acceleration, velocity and displacement pulses.
- Seismic testing of **extensively instrumented large/full-scale structural specimens** under extreme earthquake loads at near real-world conditions.
- Seismic testing of **extensively 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.

Connection of Platen to Reaction Block



Mechanical and Servo-Hydraulic Components

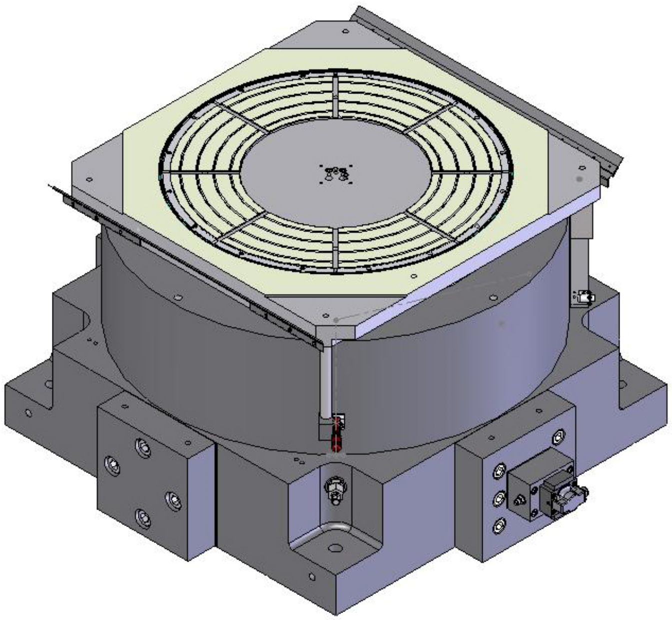




Vertical Actuators

VERTICAL ACTUATORS SPECIFICATION		
	Bi-Axial Configuration	**4 or 6 DOF Configuration**
Piston Diameter	0.81 m	0.81 m
Piston Stroke	± 0.006 m	± 0.127 m
Piston Tilt	N/A	± 2°
Force Rating	20.7 MPa	20.7 MPa
Compression	10.0 MN	10.0 MN
Valve Flow	56.8 lit/min	18,927 lit/min

3-D Rendering of the Vertical Bearing

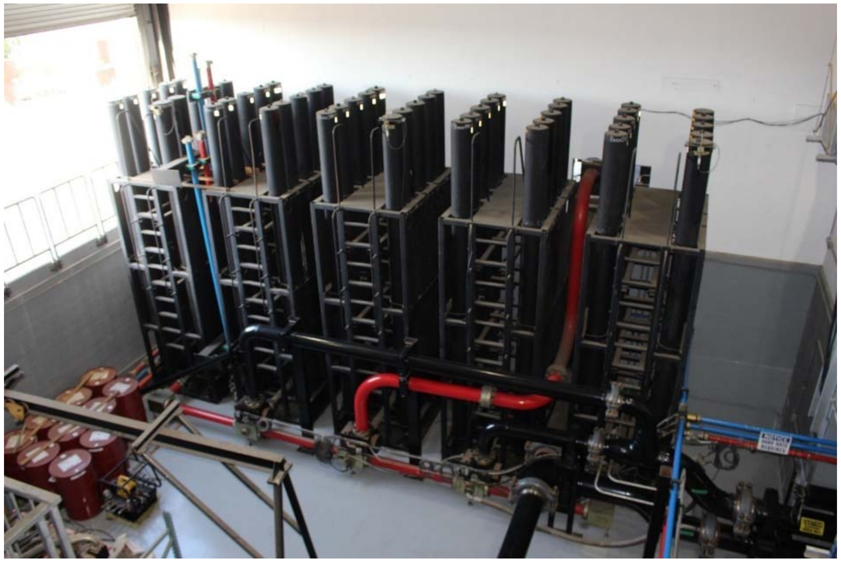


Hydraulic Power System

Pumps

Hydraulic System	
Accumulator swept displacement	7.5 m
Accumulator bank pressure	35 MPa
System pressure	20.7 MPa
Blow-down maximum flow rate	38,000 lt/min
HPU flow rate @ 35 MPa	431 lt/min
HPU flow rate @ 20.7 MPa	718 lt/min
Surge tank capacity	20,000 lt

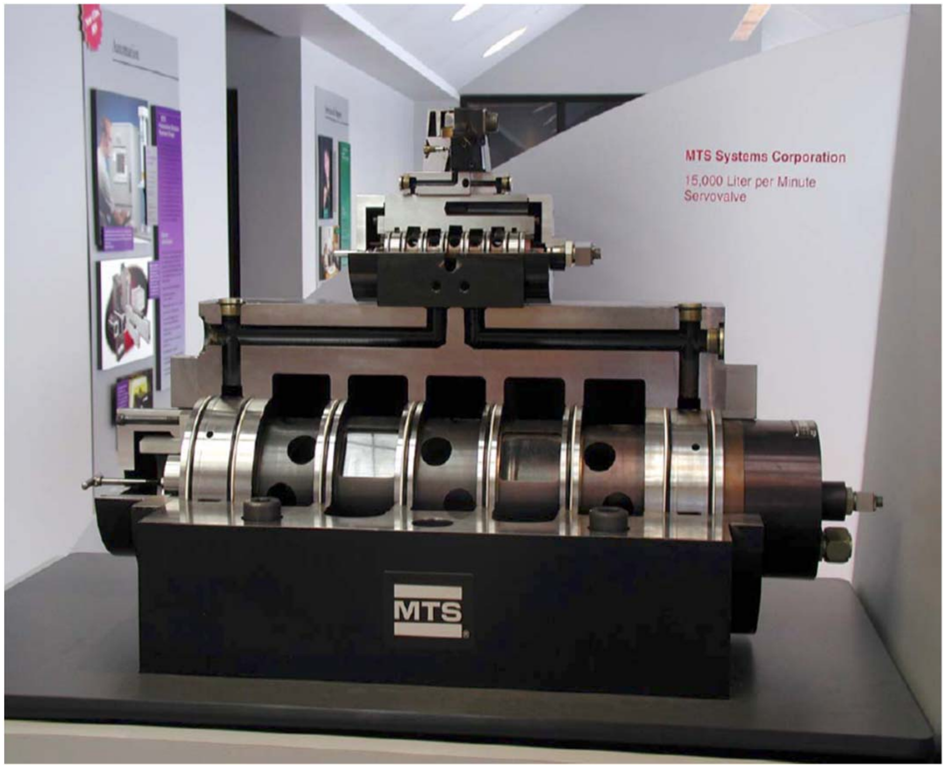
Accumulator bank



Surge tank

Servovalves

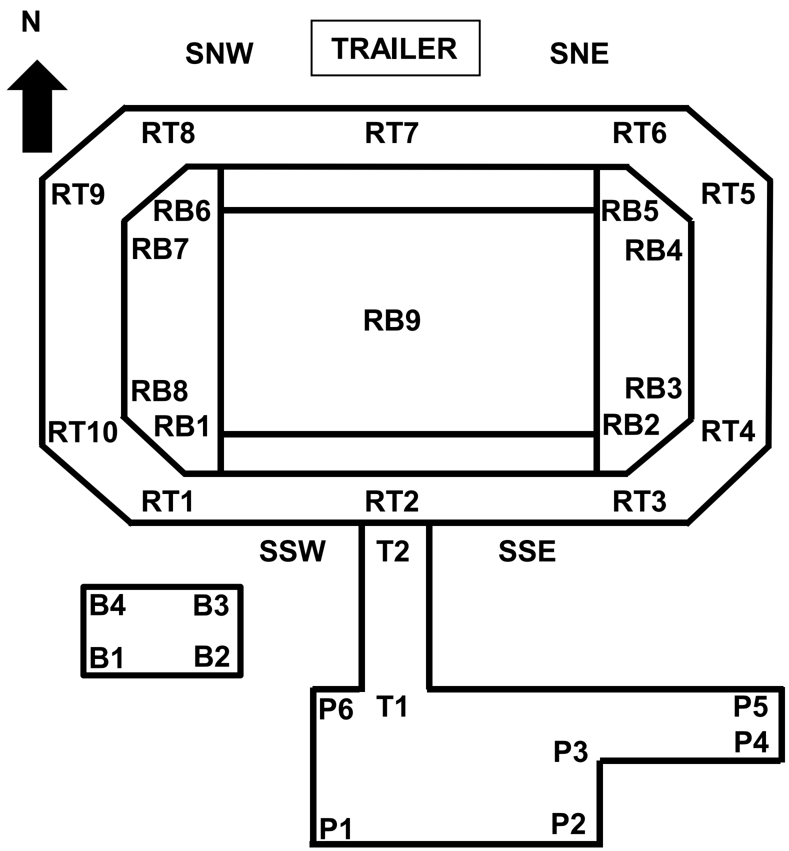
Servo-valves (Qty. 2E + 2W)	
Pilot 2nd Stage Rating (Manufacturer Moog)	**19 lt/min**
Pilot 3rd Stage Rating	**630 lt/min**
4th Stage Flow Rating	**10,000 lt/min**
Port Area Ratios	1:0.8:0.64:0.5
Valve Sleeve Windows Area Ratio	1:0.64



Bare Table Harmonic Shaking

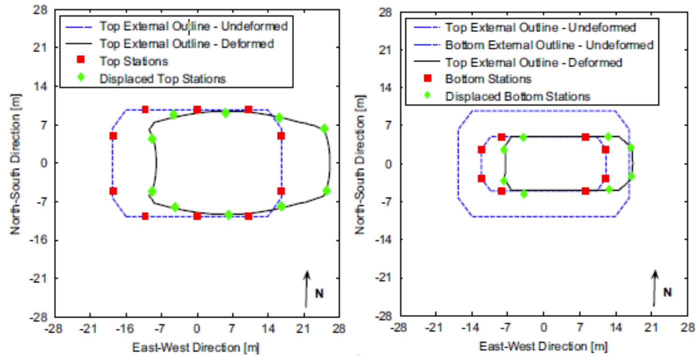
Forced Vibration Tests of the Reaction Mass at the NEES-UCSD Shake Table

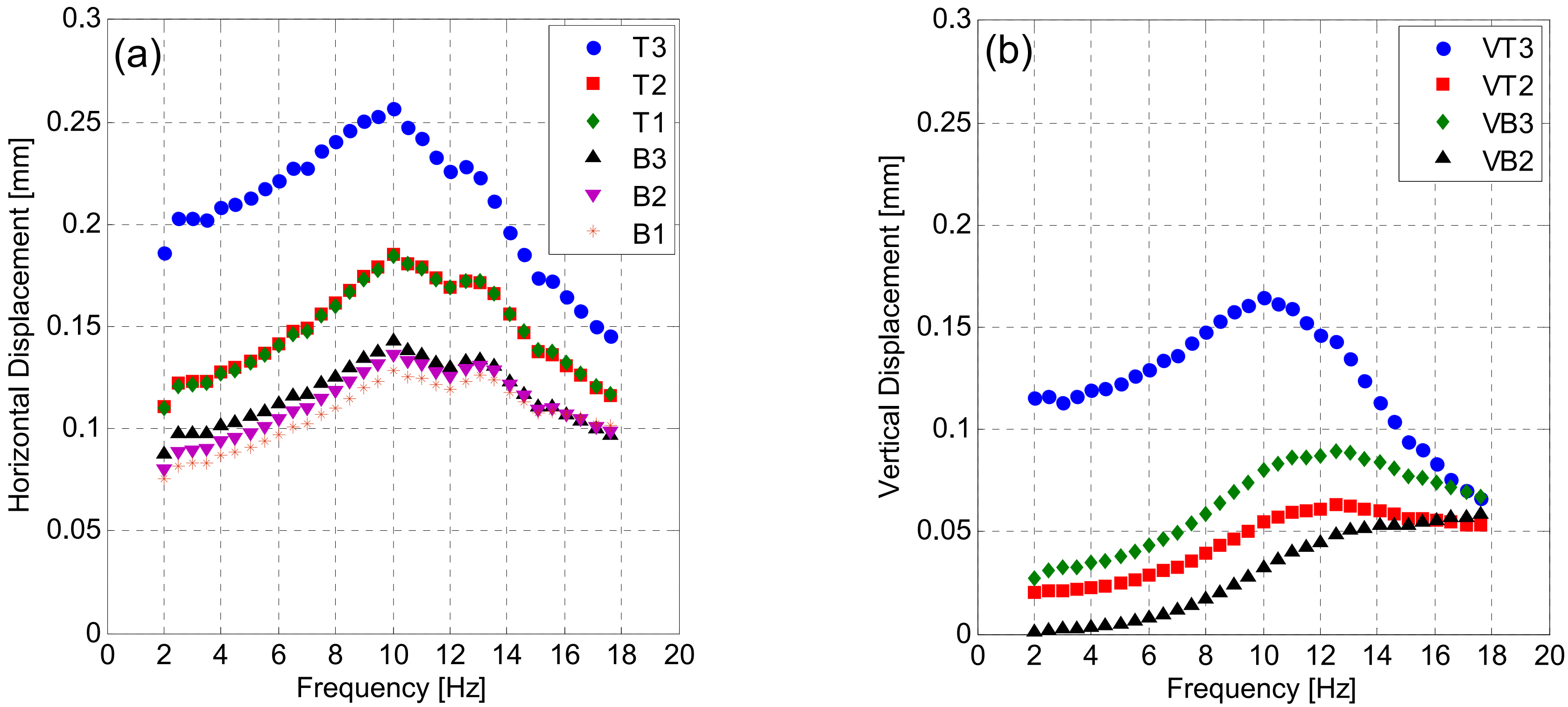
Commissioning Tests



Instrument locations on Reaction Block and adjacent foundations

Frequency Response Functions of Reaction Mass





Amplitudes of the EW (a) and vertical (b) frequency response functions of the reaction block for EW excitation. The results shown are based on Test 2 and correspond to scaled displacement amplitudes for a harmonic force of constant amplitude 6.8 MN.

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

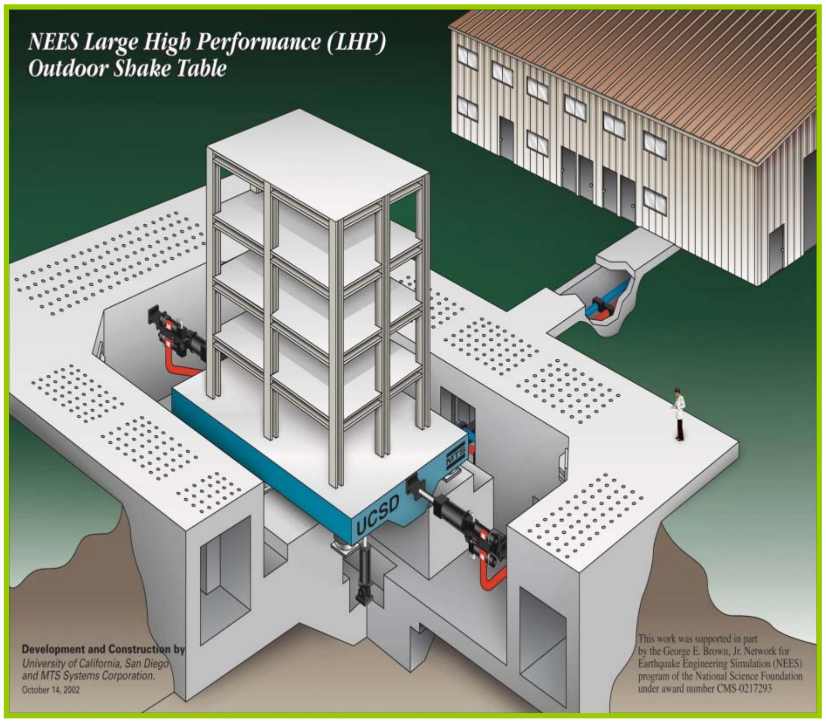
Instrumentation Overview

- Data acquisition system with over 600 channels that can be configured to accept:
  - Accelerometers
  - Linear displacement transducers
  - String potentiometers
  - Strain gauges
  - Load Cells
  - Pressure Cells
  - Soil pressure sensors
- High-speed cameras and GoPro cameras.
- GPS system providing dynamic displacement monitoring in three coordinates.
- Calibration equipment for data acquisition systems and sensors.

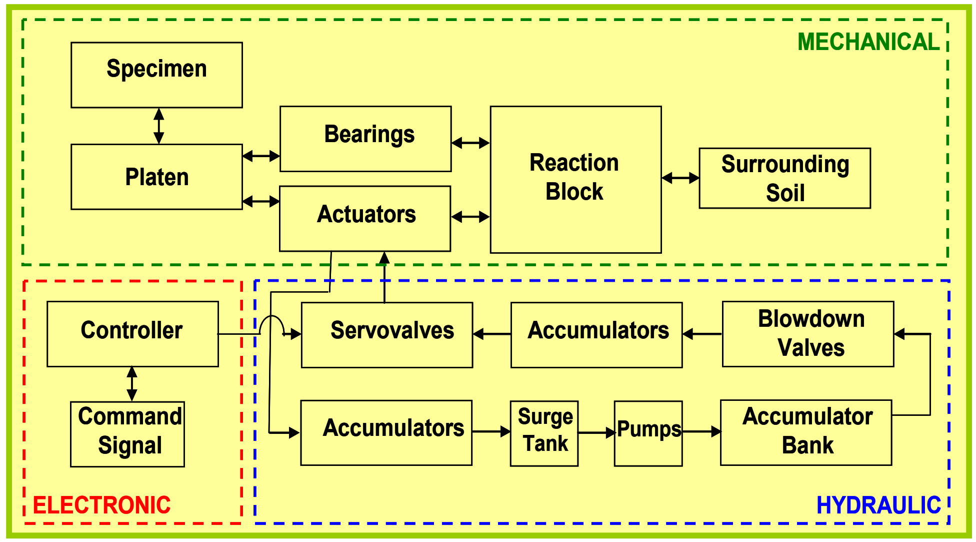
Shake Table Dynamics and Control Fidelity in Signal Reproduction & Sources of Signal Distortion

NHERI @ UCSD Workshop, 12-13 December, 2016

Components and Interaction Diagram of LHPOST System

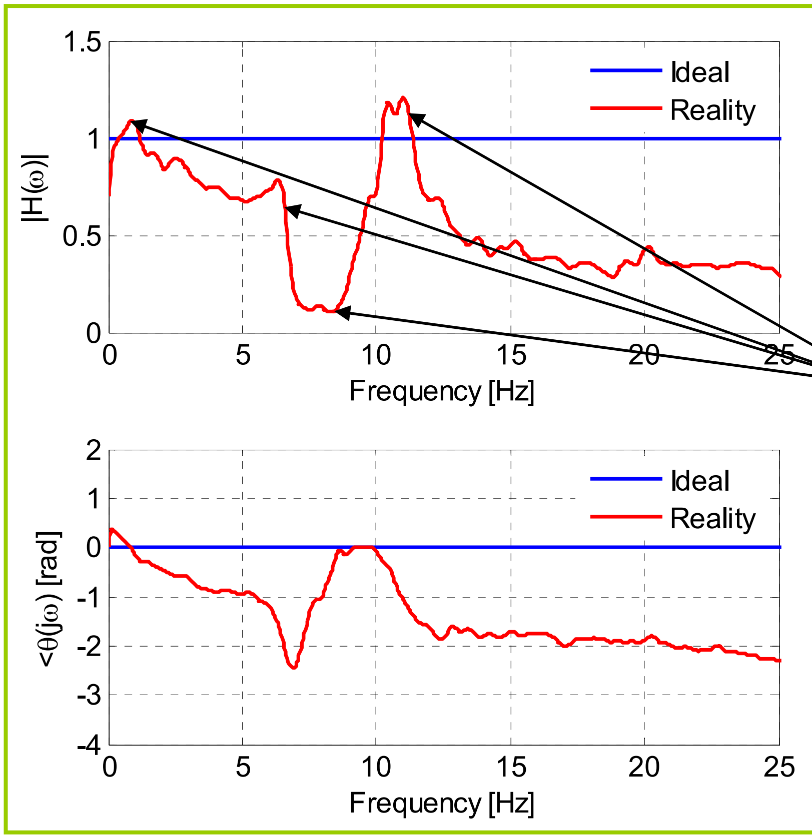


Components and Interaction Diagram



Ideal Shaking Table vs. Reality

- Ideal shaking table:
  - Reproduces commanded motion exactly
  - Is characterized by a transfer function with unit gain and zero phase shift over its entire operating frequency range under loaded table condition.

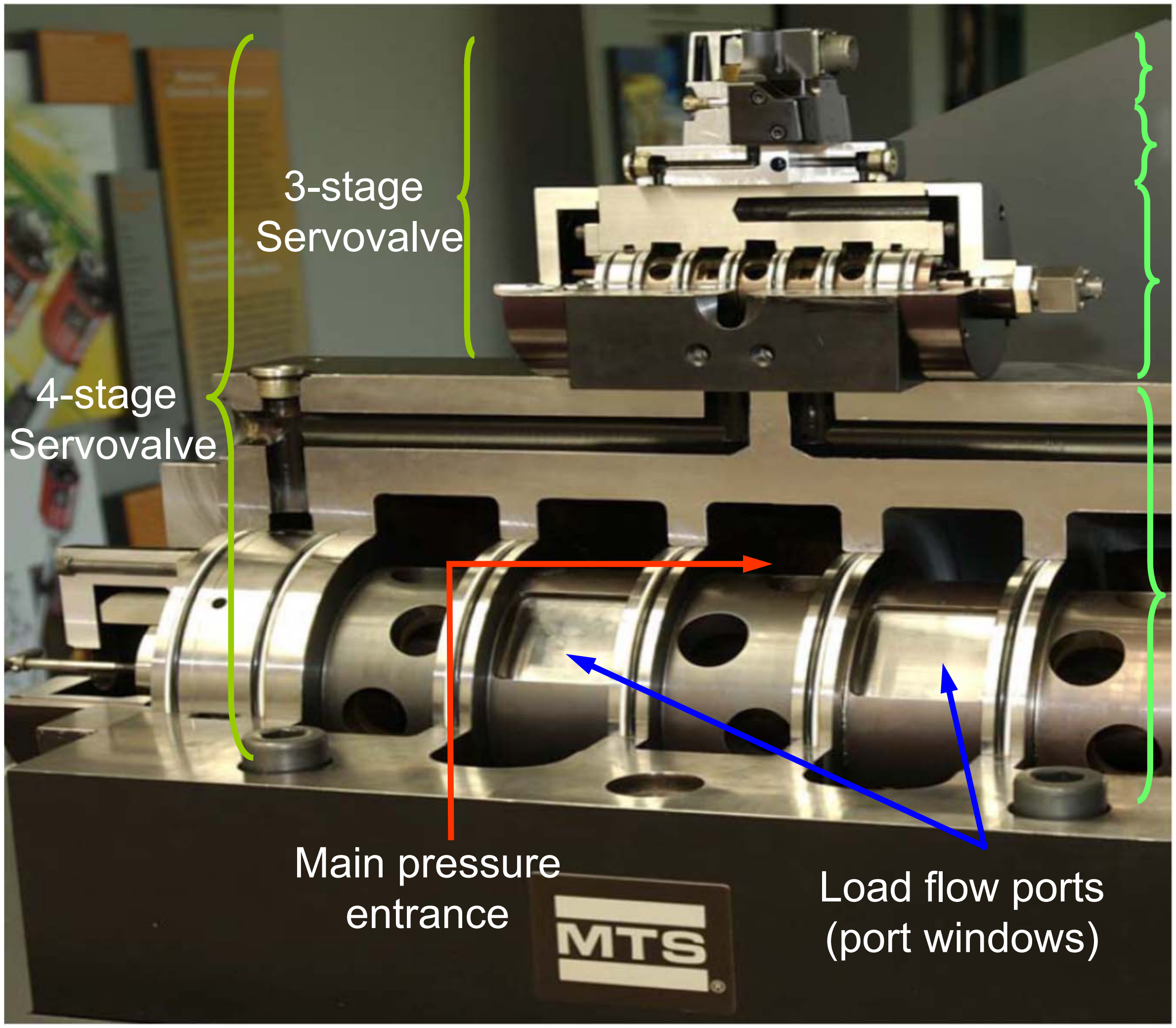


Due to various peaks and valleys in the shaking table system transfer function, the signal reproduced by the table differs from the commanded signal.

Sources of Signal Distortion

- Many potential sources of signal distortion and many of them are highly interdependent:
  - Hydraulic sources:
    - Servovalves (inherently nonlinear devices)
    - Oil Column resonance
    - Changes/fluctuations in the pressure supply
    - Flow limits
    - Force limits
    - Leakage flows in the servovalves and actuators
  - Mechanical sources:
    - Dissipative/Frictional forces
    - Mechanical resonances
    - Linear/Nonlinear specimen - table interaction
    - Backlash (bolted connections within the load train, actuator swivels)

High-Flow High-Performance Servovalves



1st stage (Pilot stage)

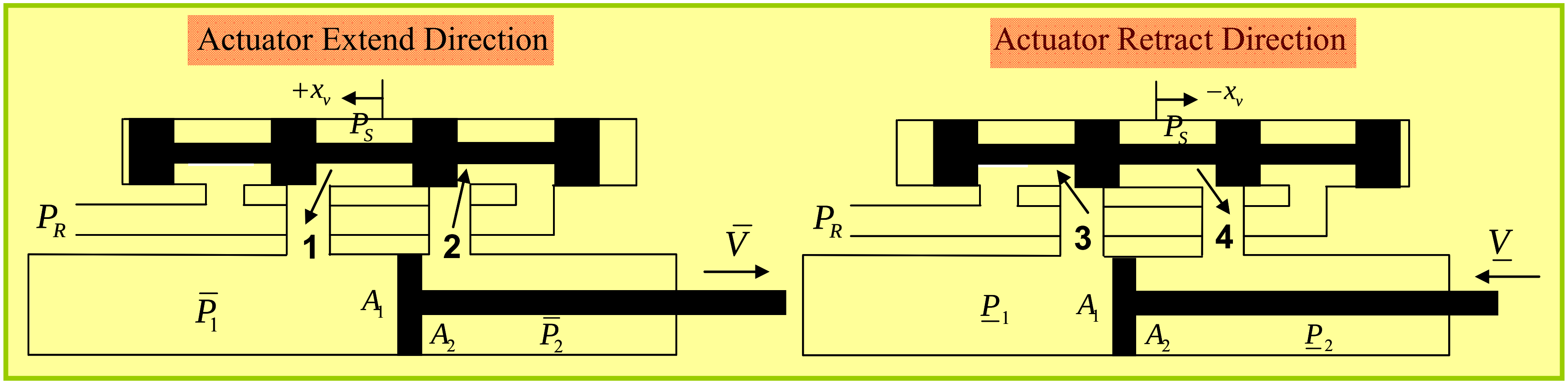
2nd stage

3rd Stage

4th Stage (Main stage)

Courtesy of MTS Systems Inc.

Hydraulics - Servovalves



$$q_1 = A_1 \cdot \bar{V} = K_v w_1 x_v \sqrt{P_S - \bar{P}_1}$$

$$q_2 = A_2 \cdot \bar{V} = K_v w_2 x_v \sqrt{\bar{P}_2 - P_R}$$

$$q_4 = A_2 \cdot \underline{V} = K_v w_4 x_v \sqrt{P_S - \underline{P}_2}$$

$$q_3 = A_1 \cdot \underline{V} = K_v w_3 x_v \sqrt{\underline{P}_1 - P_R}$$

K_v : Flow gain (linearized flow coefficient)
w_i : Valve port window widths
A_1, A_2 : Tension and compression piston areas
x_v : 4th stage valve spool displacement
P_s , P_R : Supply and return system pressures
$\bar{P}_1$ and $\bar{P}_2$: Actuator chamber pressures during extend direction
$\underline{P}_1$ and $\underline{P}_2$: Actuator chamber pressures during retract direction

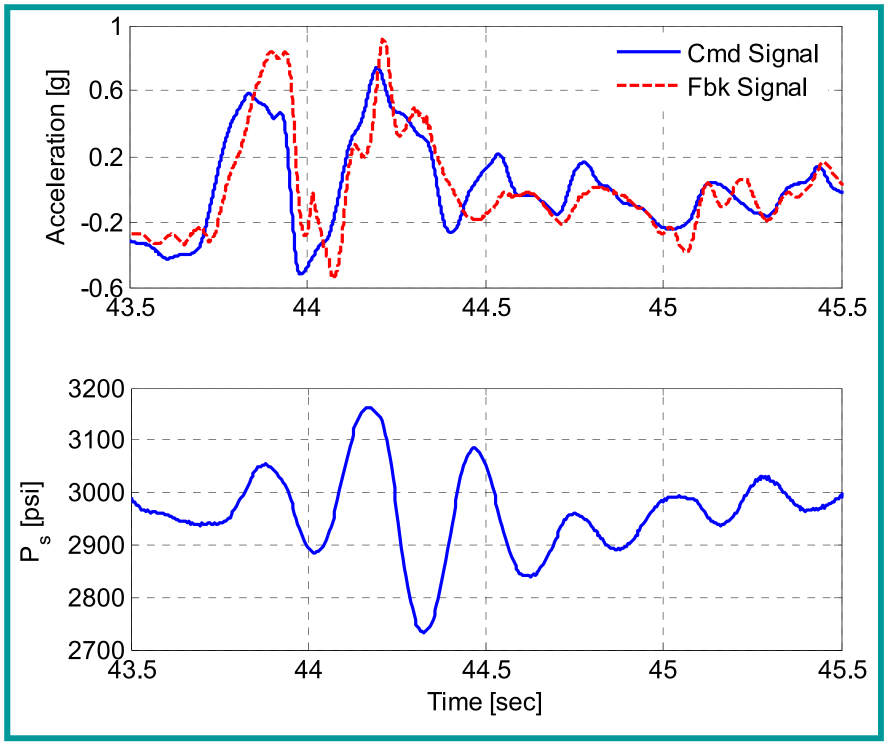
- Servo-valve flows present two independent sources of nonlinearity:
  - Load pressure nonlinearity or pressure drop - flow nonlinearity (explicitly represented by the square root term)
  - Flow gain nonlinearity (K_v changes as a function of orifice size)

Flow Gain Nonlinearity – Hydraulic Pressure Effects

- Hydraulic supply pressure fluctuates especially as the hydraulic demand is high. Inertial pressure spikes can cause noise and result in increased signal distortion.

$$K_v = \left(C_d w \sqrt{1/\rho}\right)\sqrt{P_S}$$

where C_d = discharge coefficient

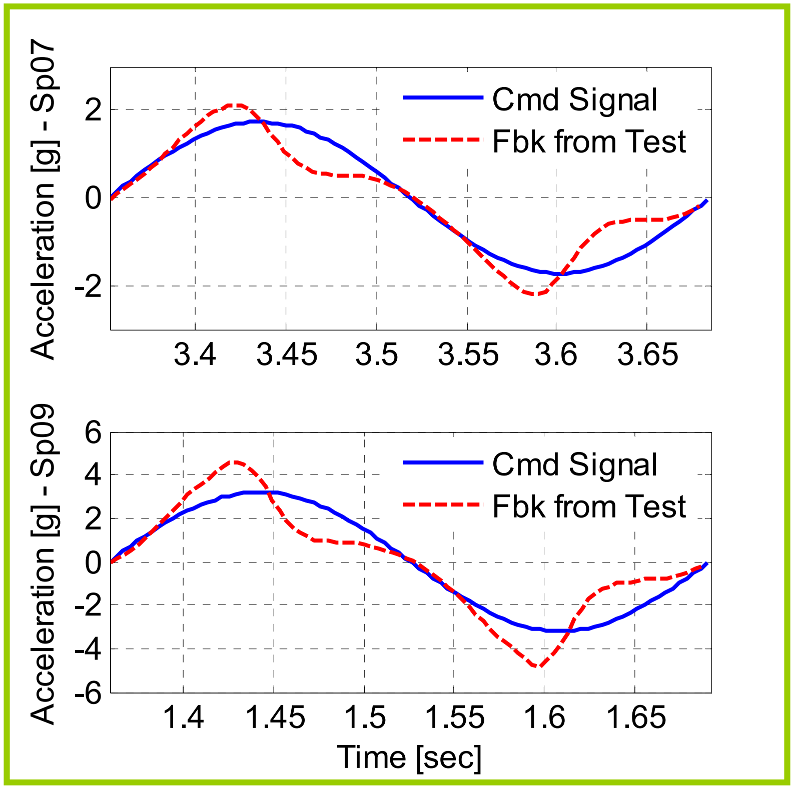


1994 Northridge Earthquake recorded at Sylmar Station (Seven-story R/C building specimen mounted on the table)

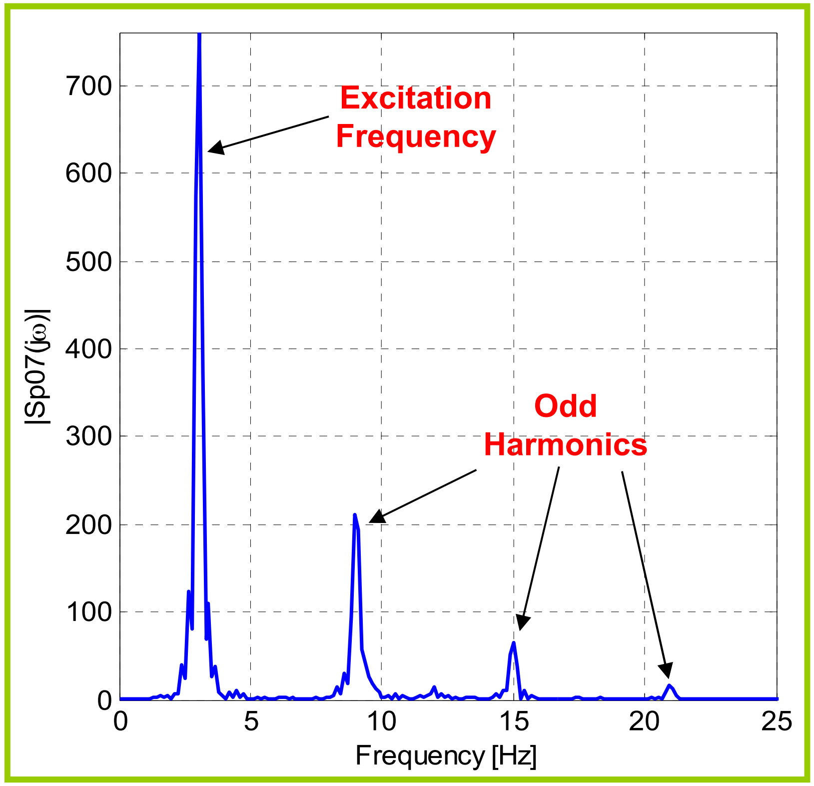
Change in supply pressure P_S at West actuator during test

Effect of Load Pressure Nonlinearity on Fidelity in Signal Reproduction

Sine Tests @ 3 Hz (Bare Table)



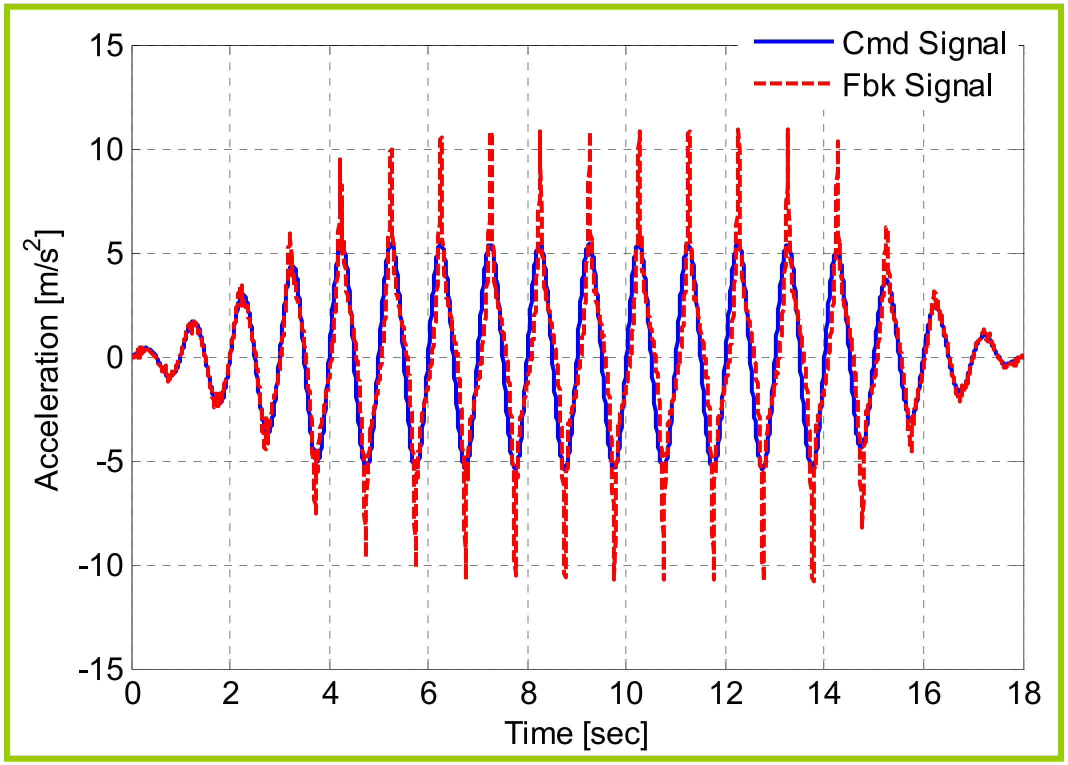
FFT of the Sp07 Test Fbk Signal

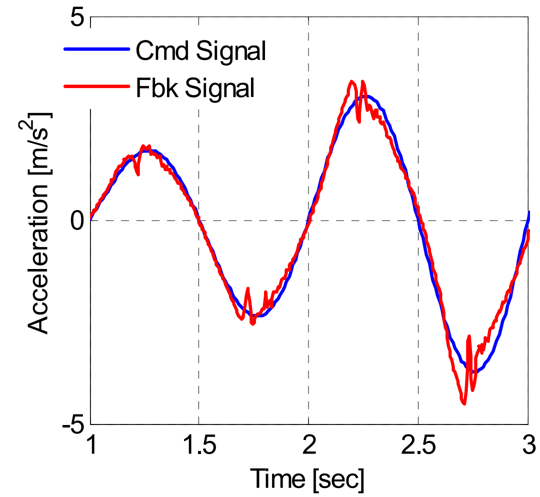


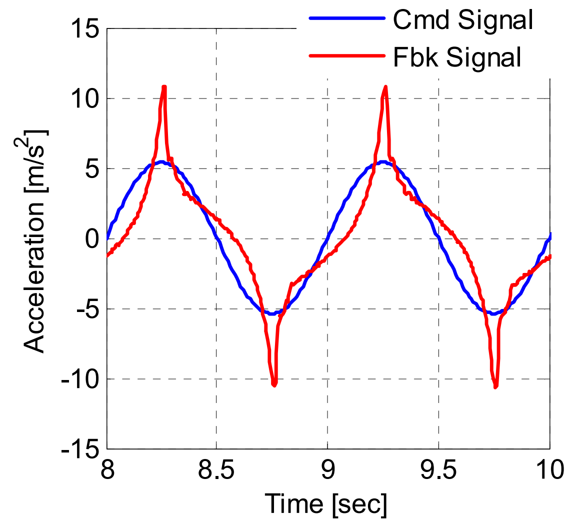
High acceleration signals suffer from load pressure non-linearity.

Example of Signal Distortion from UNAM Shake Table – Time Histories

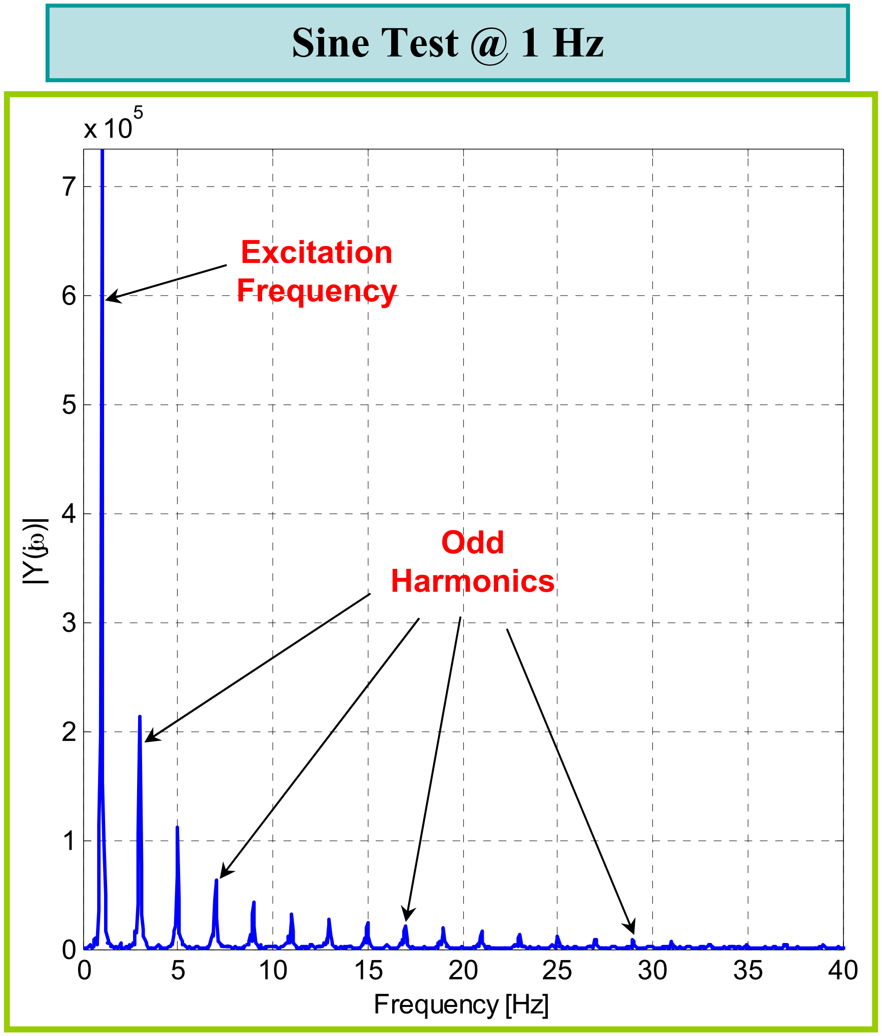
Sine Test @ 1 Hz





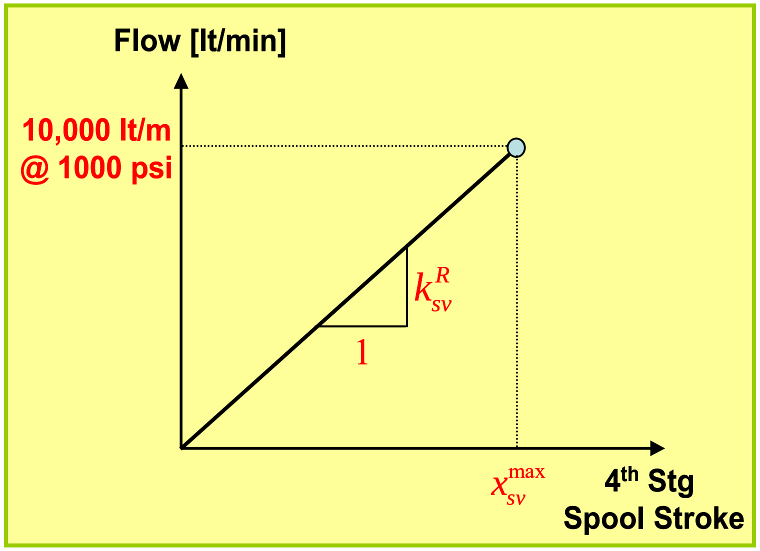


Example of Signal Distortion from UNAM Shake Table – Fourier Spectra



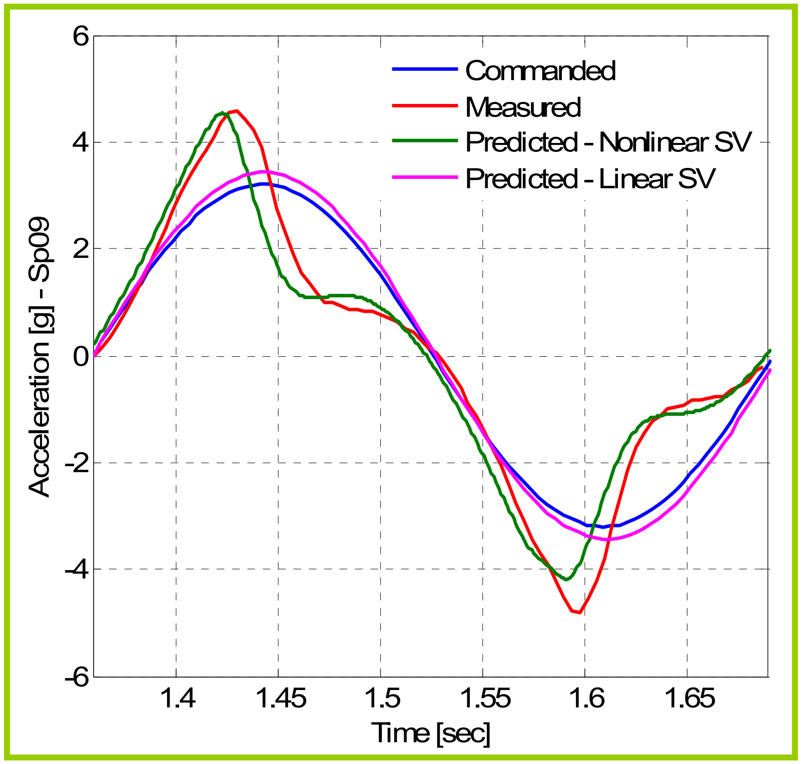
Simulation of Signal Reproduction with "Linearized" and Nonlinear Servovalve Models

Servo-valve Rated Flow Gain
Linearization of the Flow Equation
(Bernoulli's Equation)



Servo-valve Flow Gain
@ 3000psi - Linear

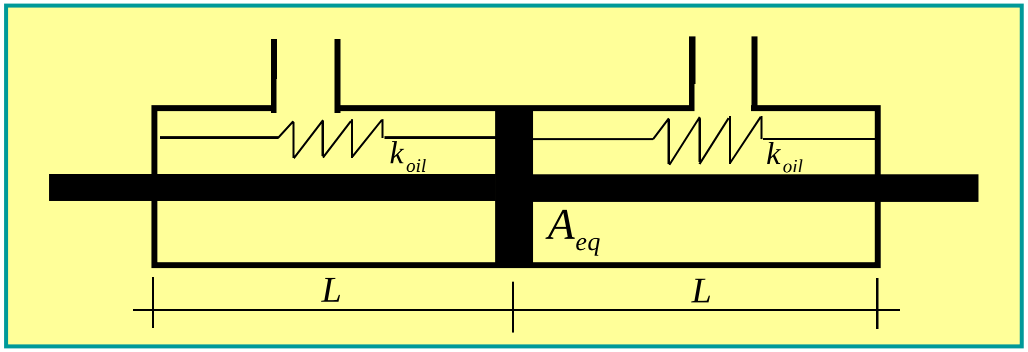
$$k_{sv} = k_{sv}^{R} \times \sqrt{3}$$



Oil Column Resonance

- The effective table mass of the system and the oil columns within the actuators define a mass-spring system with a natural frequency referred to as the oil column frequency.

Sketch of Double Ended Actuator



$$f_{oil} = \frac{1}{2\pi}\sqrt{\frac{2\left(\beta A_{eq}/L\right)}{m_{eff}}}$$

β : Effective bulk modulus of oil

m_{eff} : Effective mass of the table

A_{eq} : Piston area

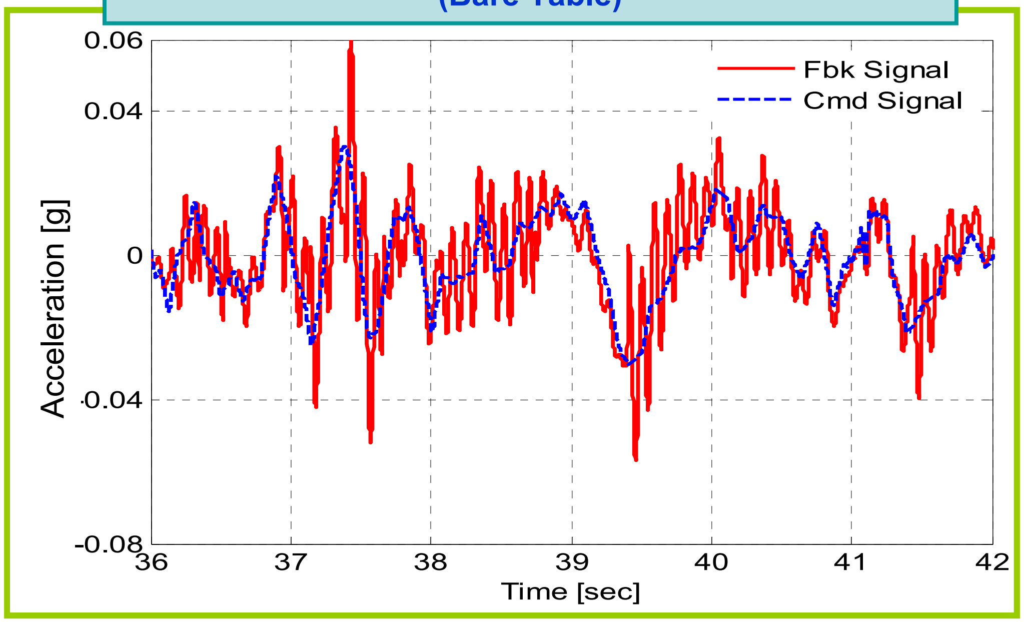
L : Oil column length

- Note that the oil column frequency depends on the effective mass of the "table + specimen".
- Oil column frequency of LHPOST under bare condition has been identified at 10.4 Hz.

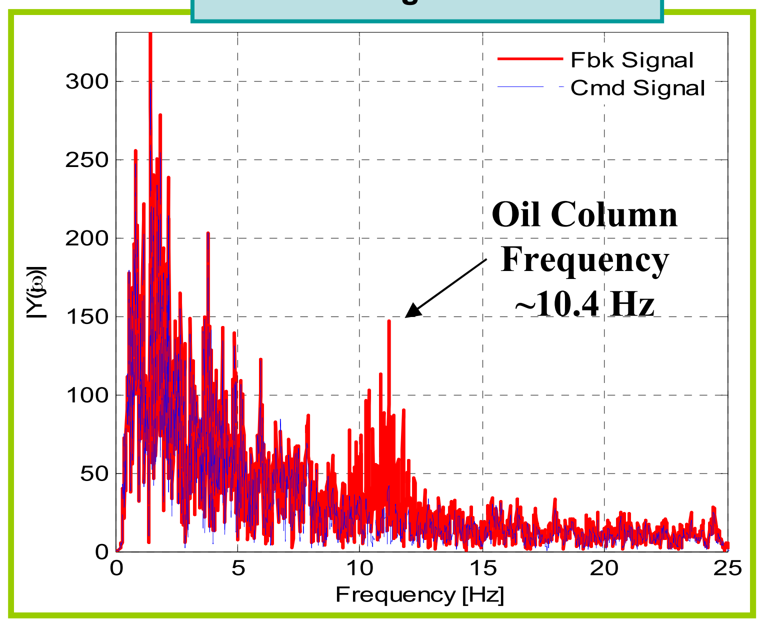
Effects of Oil Column on Fidelity in Signal Reproduction

- Oil column resonance distorts the commanded signal at and around the oil column frequency.
- On most shaking tables, the oil column frequency falls within the operating frequency range of the system.
- Operation of a shake table at or around the oil column frequency may result in high gain problems.
- Shake table operation at frequencies around 1/3 of oil column frequency will result, due to servovalve load pressure nonlinearity (odd harmonics are excited), in frequency components around the oil column frequency that will cause significant signal distortion.

1940 El Centro Record - Part of the Time History (Bare Table)

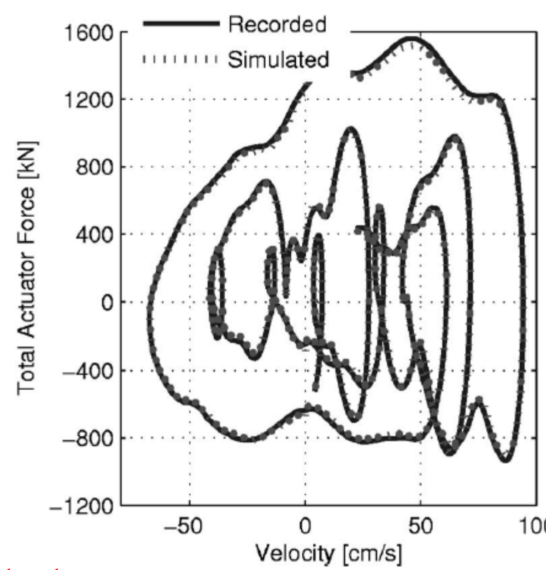


FFT of the Cmd and Fbk Signals



Mechanical Sources – Dissipative (friction, viscous) Forces

- Friction arises from a number of sources within the system, e.g., slide bearings, mechanical linkages, etc. Specific sources of friction depend on the design and layout of the shake table system.
- Frictional forces are typically not large, especially in the case of hydrostatic bearings.
- Signal distortion (high frequency) occurs during motion reversals.
- The magnitude of friction-induced distortions is approximately constant. Therefore such distortions are more significant for lower amplitude signals.

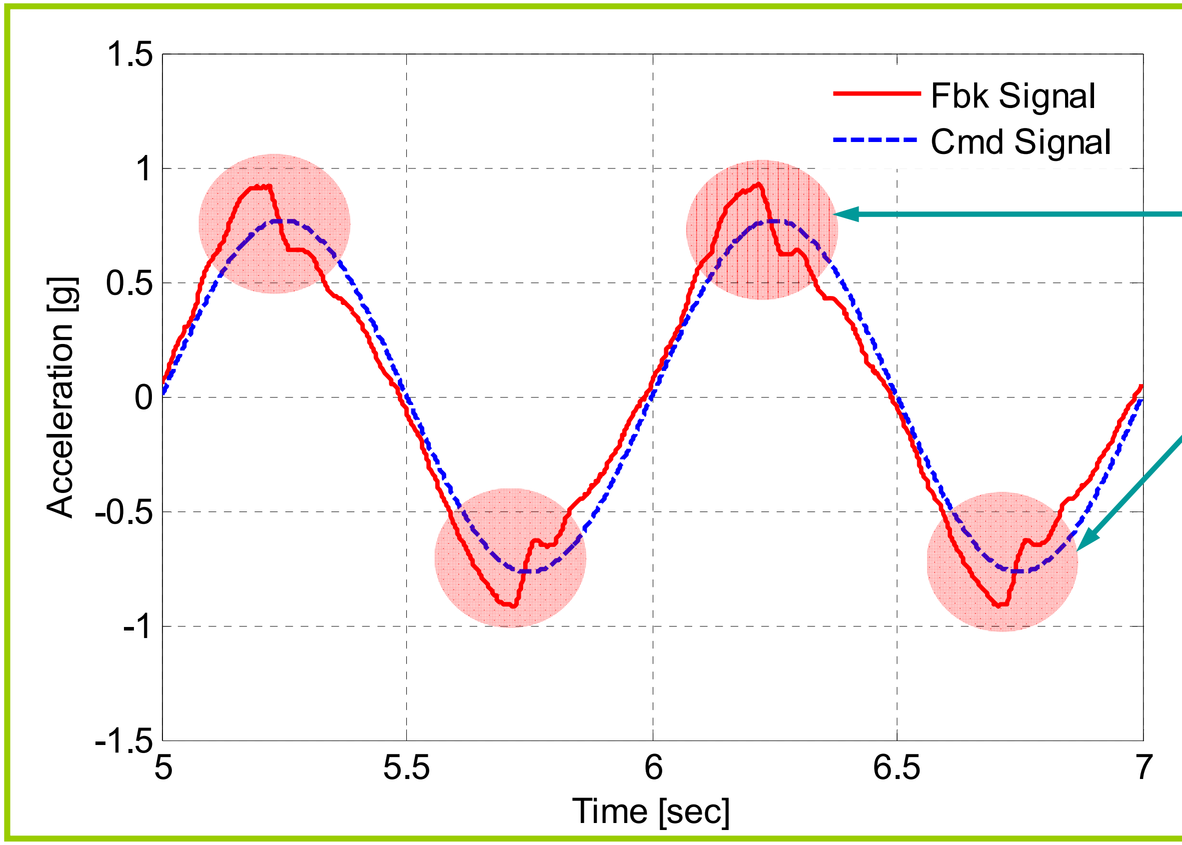


Identified Dissipative Force Model for LHPOST
(Bare Table)

$$F_{viscous}(t)+F_{Coulomb}(t)=\underbrace{C_e\left|\dot{u}_x\right|^{0.5}sign(\dot{u}_x)}_{\substack{\text{Viscous Force}\\ (C_e\,=\,44.6\text{ kN(s/m)}^{0.5})}}+\underbrace{F_{\mu_e}sign(\dot{u}_x)}_{\substack{\text{Friction Force - Constant}\\ (\sim 26.0\text{ kN}\,\Rightarrow\,\text{friction coeff. of }0.45\%)}}$$

Effects of Friction on Fidelity in Signal Reproduction

SR-11 Sinusoidal Test
f_{test}= 1 Hz and Amplitude = 0.769 g
(Bare Table)



High-frequency waveform distortions at motion reversals due to frictional forces. These waveform distortions may be large.

MTS Three-Variable Controller (TVC)

- **MTS Controller Model 469D** used on all large shake tables manufactured by MTS worldwide.

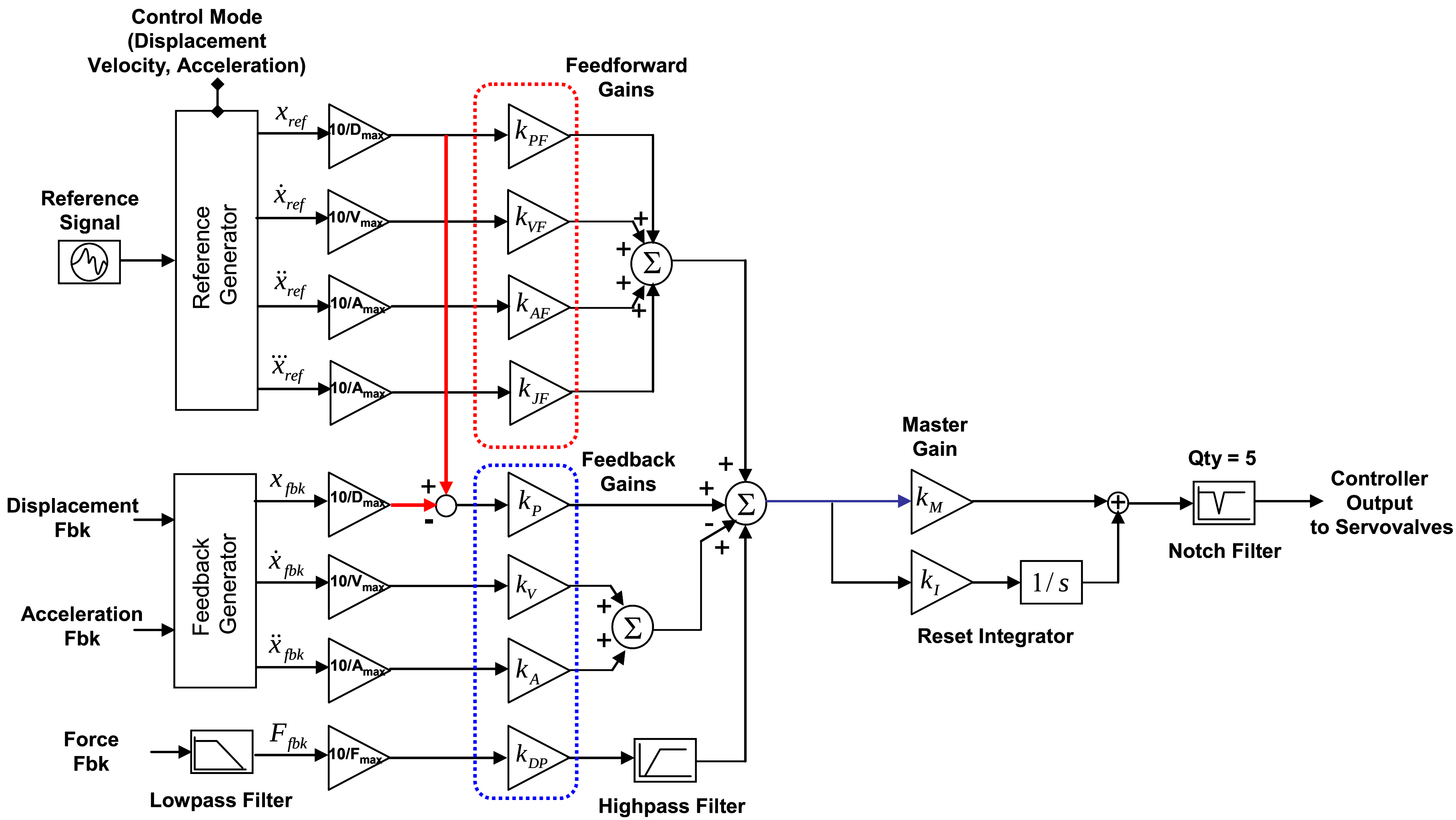
- TVC is a linear **state variable controller**. The three **state variables controlled by TVC** are:
  - Displacement
  - Velocity
  - Acceleration

  TVC can be set to run under displacement, velocity or acceleration mode.

- TVC has **additional special features to compensate for linear/nonlinear sources of signal distortions** within the system for both harmonic and broadband command signals:
  - Amplitude/phase control
  - Adaptive harmonic cancellation
  - Adaptive inverse control (AIC)
  - On-line iteration (OLI)
  - Notch filters

- Depending on the control mode, only one state variable becomes the **primary control variable** with the others serving only as compensation signals to improve the damping and stability of the system.

MTS Three-Variable Controller (TVC)

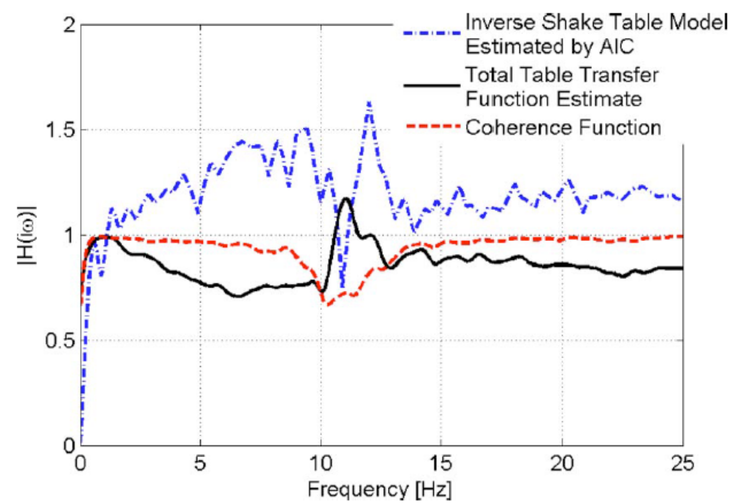


Courtesy of MTS
Systems Corporation

Tuning of LHPOST Controller (MTS 469D)

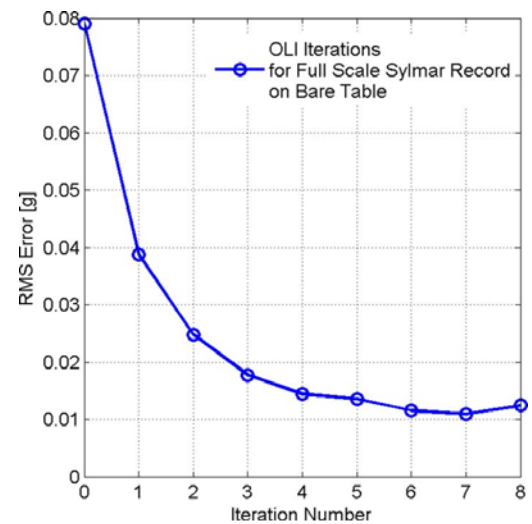
Tuning: Process of adjusting multiple control parameters (e.g., feedback and feedforward gains) and of preconditioning the input motion to optimize signal reproduction (tracking) capability of the shake table system.

Step 1: Iterative process in which the control parameters of the controller are manually adjusted iteratively in small increments while the (bare or loaded) table is in motion, until the total table transfer function (estimated recursively) is deemed satisfactory.

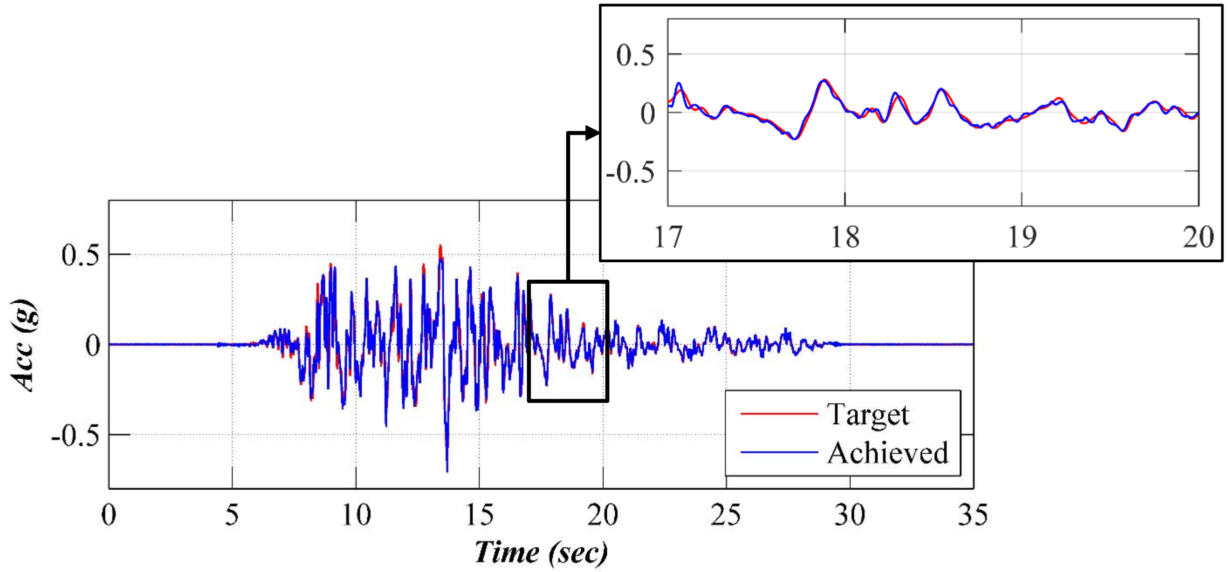


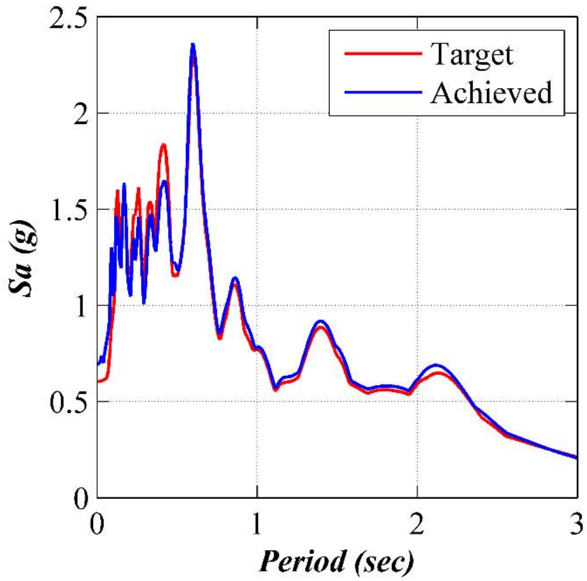
Step 2: Estimation of the inverse model of the plant using the adaptive inverse controller (AIC) technique.

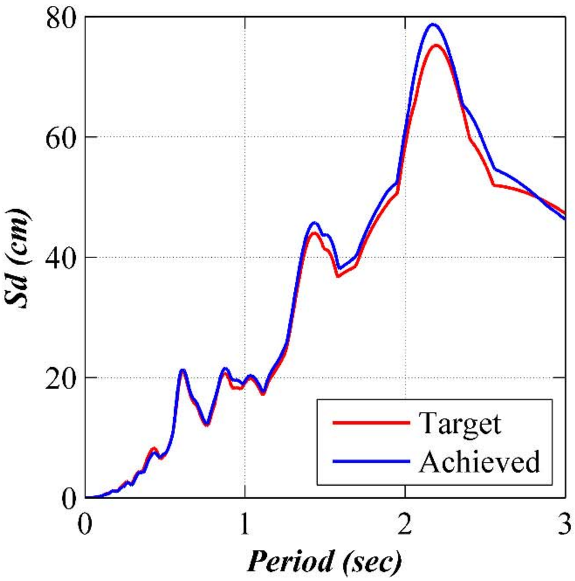
Step 3: Application of iterative time history matching technique called online iteration (OLI). The command input to the shake table controller (drive file) is repeatedly modified to optimize the match between the actual table motion and the desired/target motion.



Tracking Performance of NHERI@UCSD Shake Table





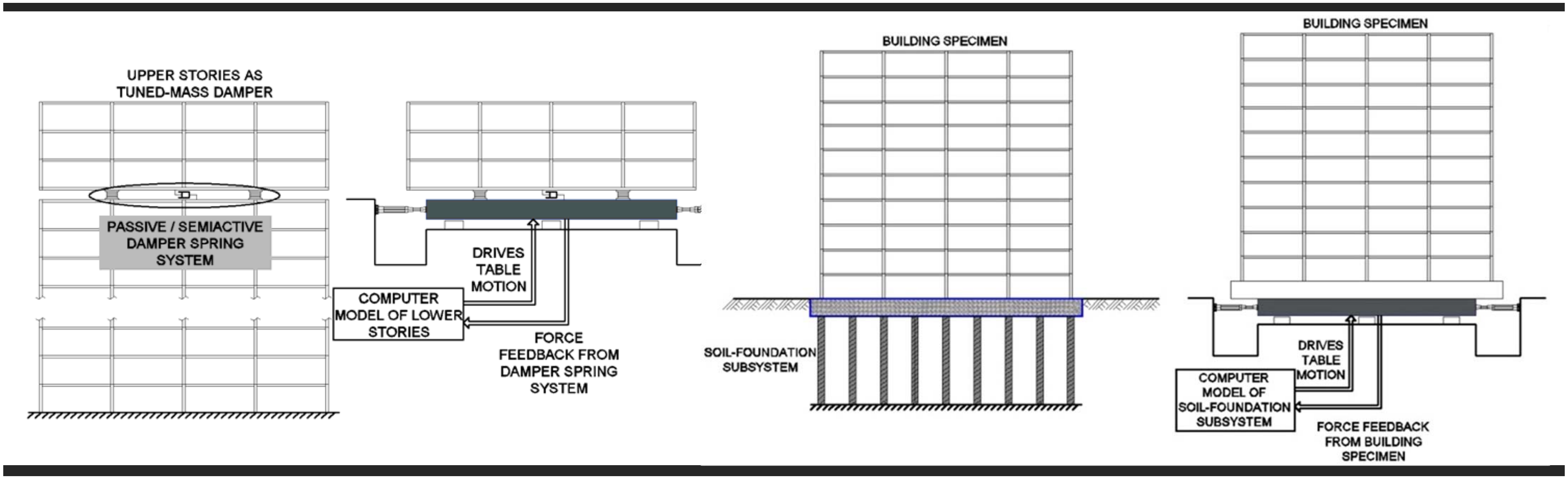


1994 Northridge Earthquake
Canoga Park (comp. 196)
Amplitude scaling: 1.55

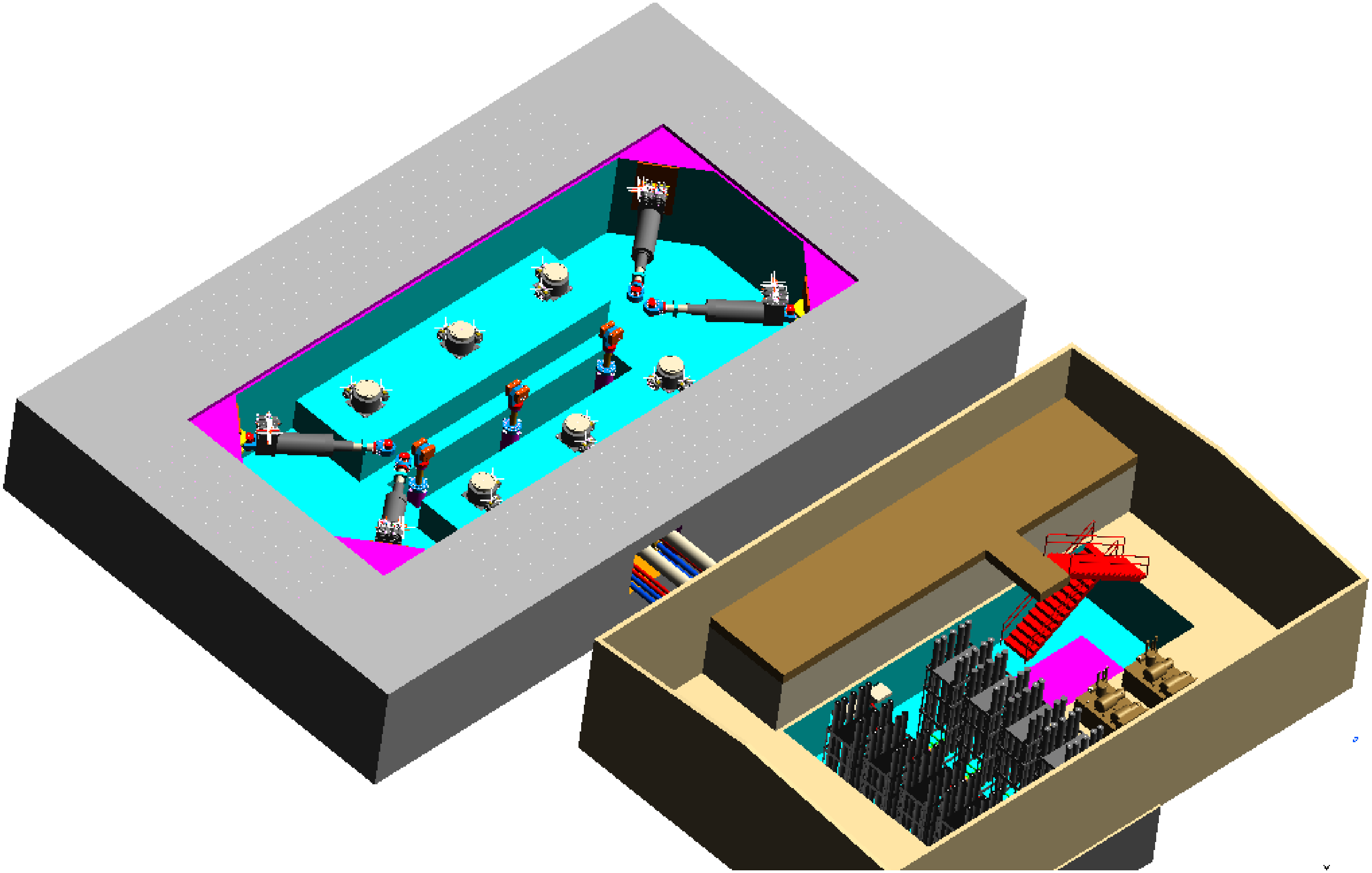
Hybrid Shake Table Testing

➢ **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
- Easy integration of OpenSees/OpenFresco open-source software framework
- 50-ton dynamic actuator
- Portable hydraulic power system



Future Upgrade to 6 DOF-Configuration

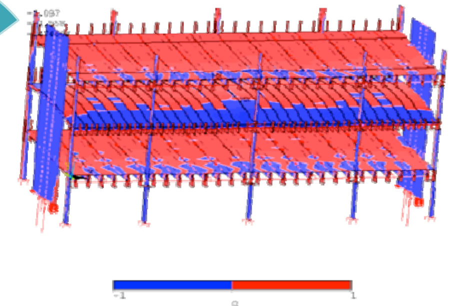


Selected Set of Specimens tested on the LHPOST

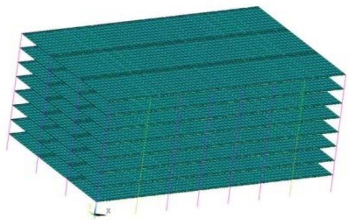
Integrated Experimental-Analytical Approach

Experimental Research
- Materials
- Structural components
- Structural systems

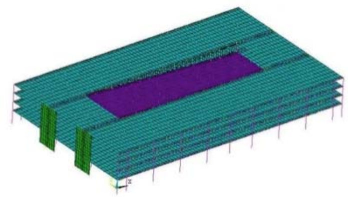
Computational Simulation
- Model development
- Model calibration
- Model validation



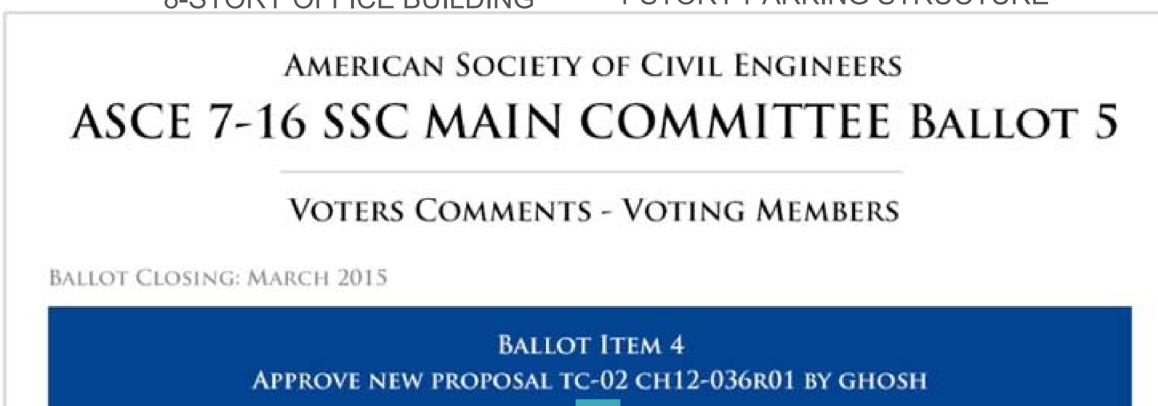
Design Provisions and Assessment Methods
- Development
- Verification through numerical simulation



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

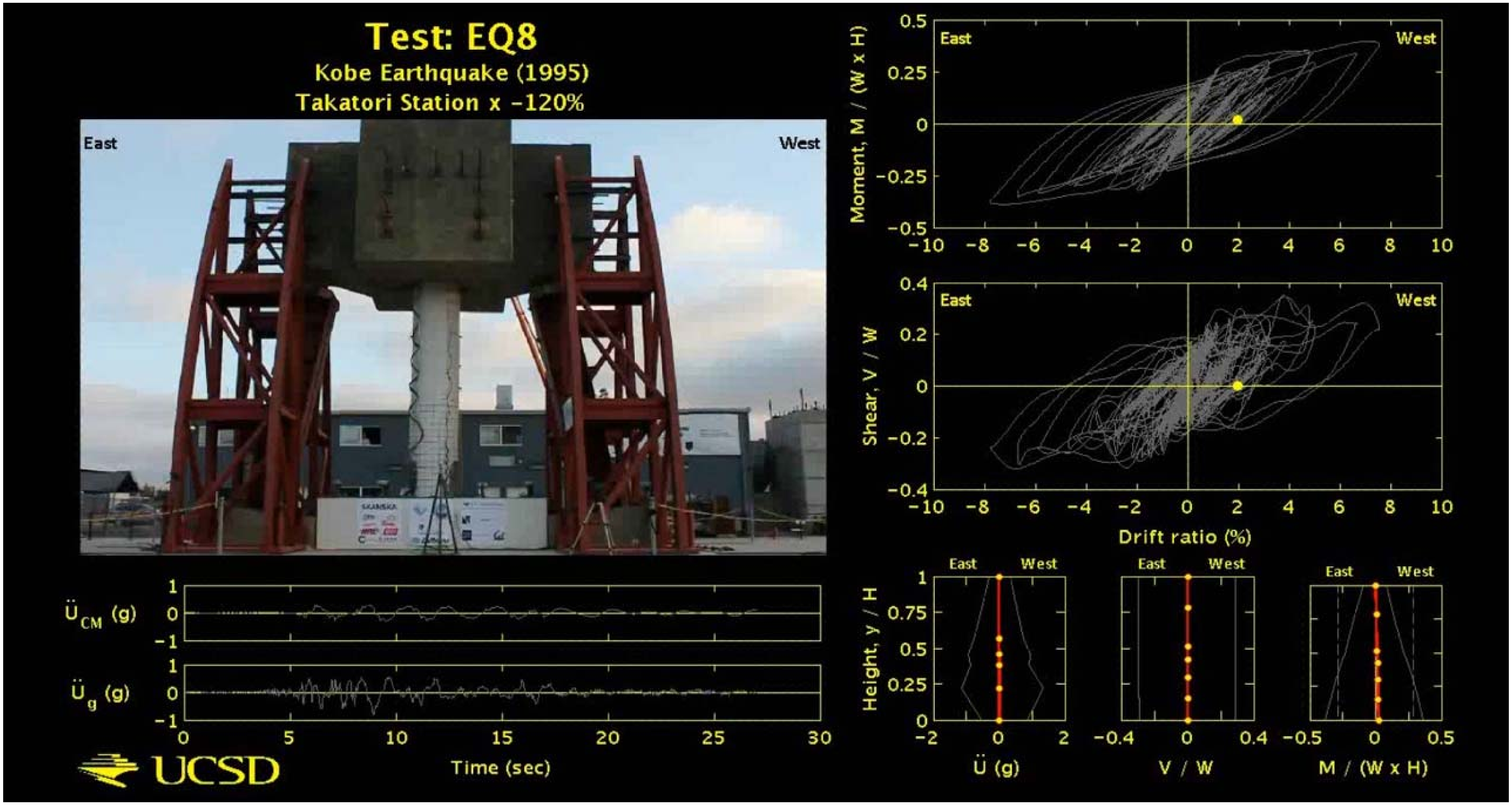
BALLOT CLOSING: MARCH 2015

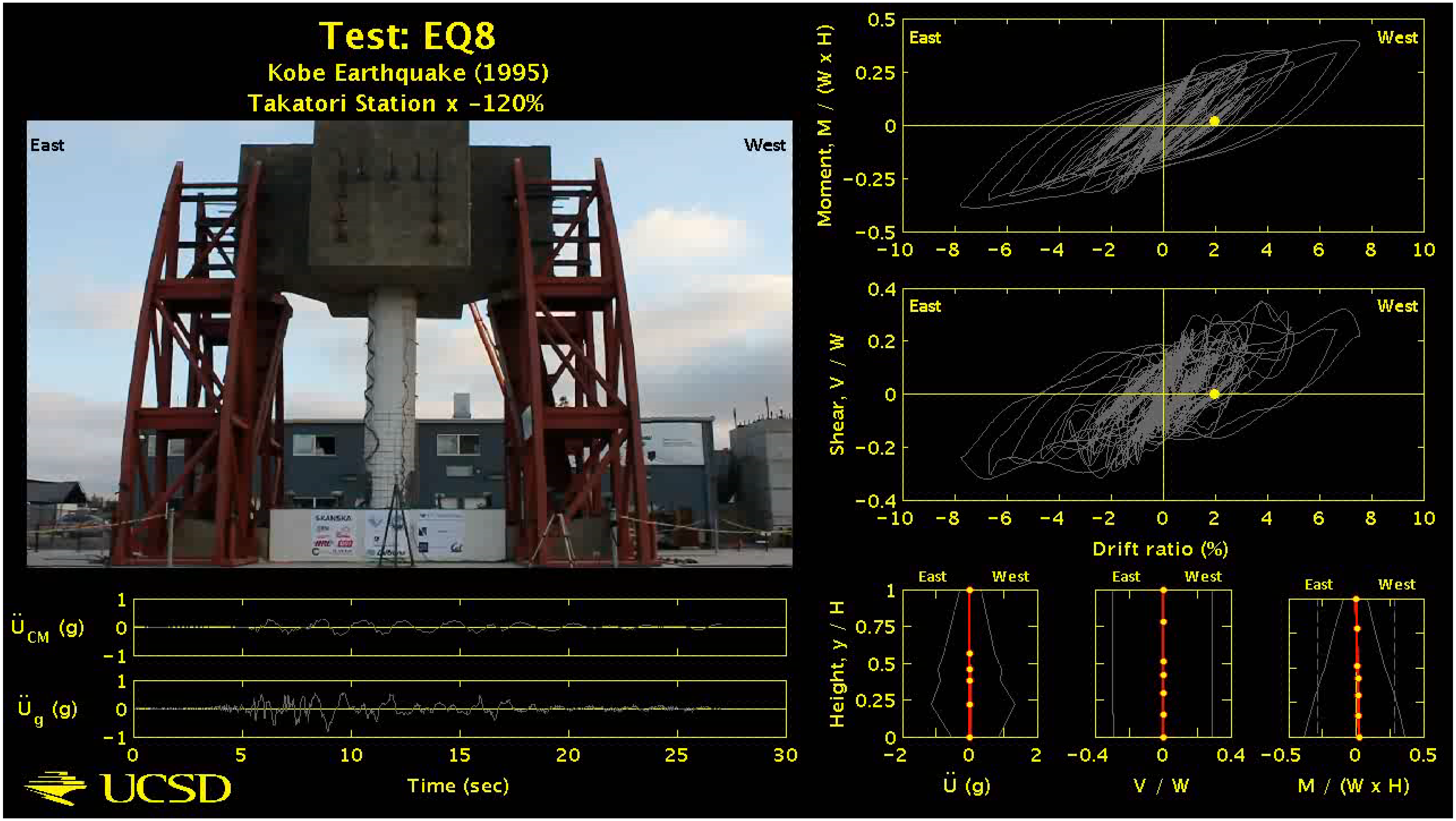
BALLOT ITEM 4
APPROVE NEW PROPOSAL TC-02 CH12-036R01 BY GHOSH

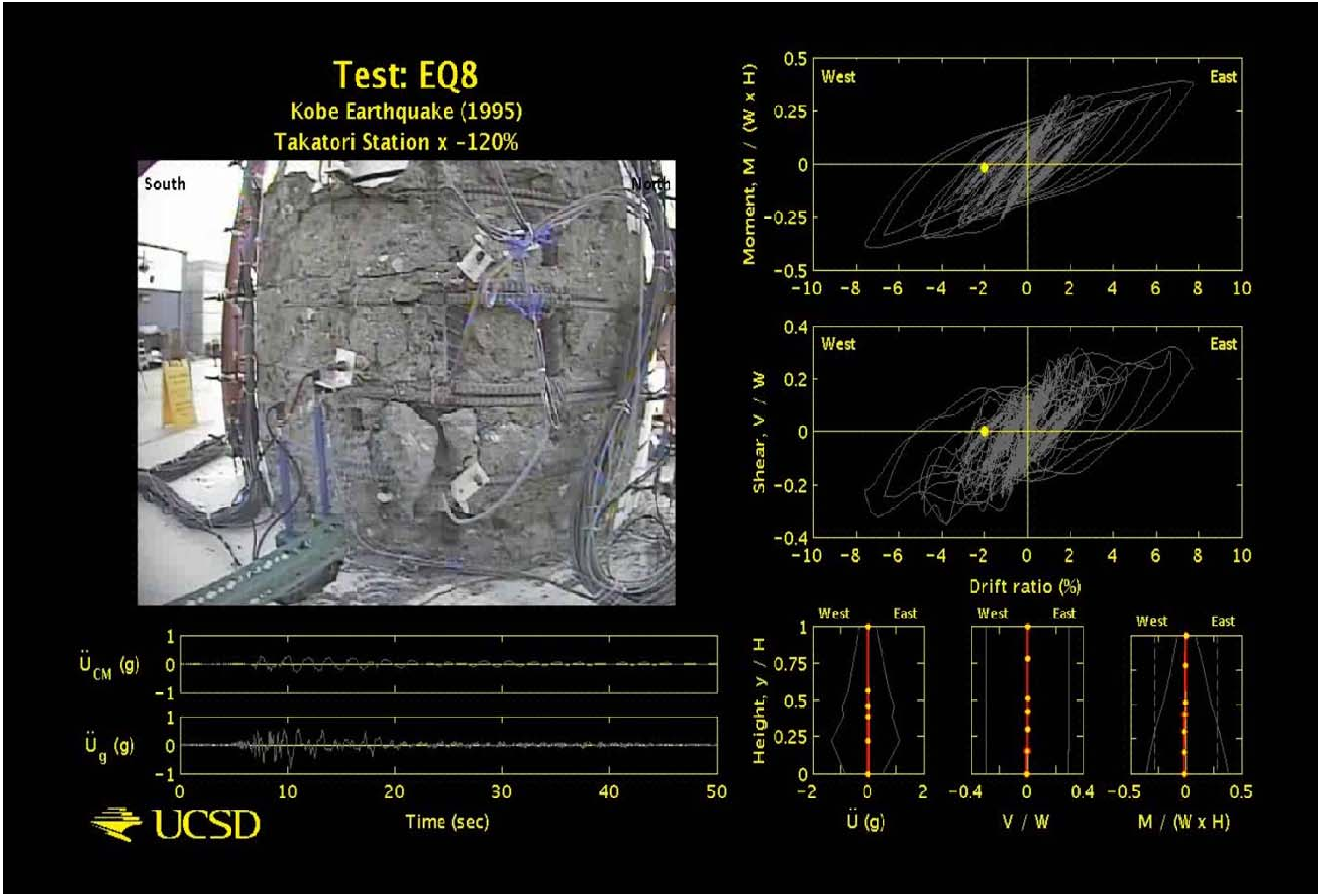
EARTHQUAKE RESILIENT INFRASTRUCTURE

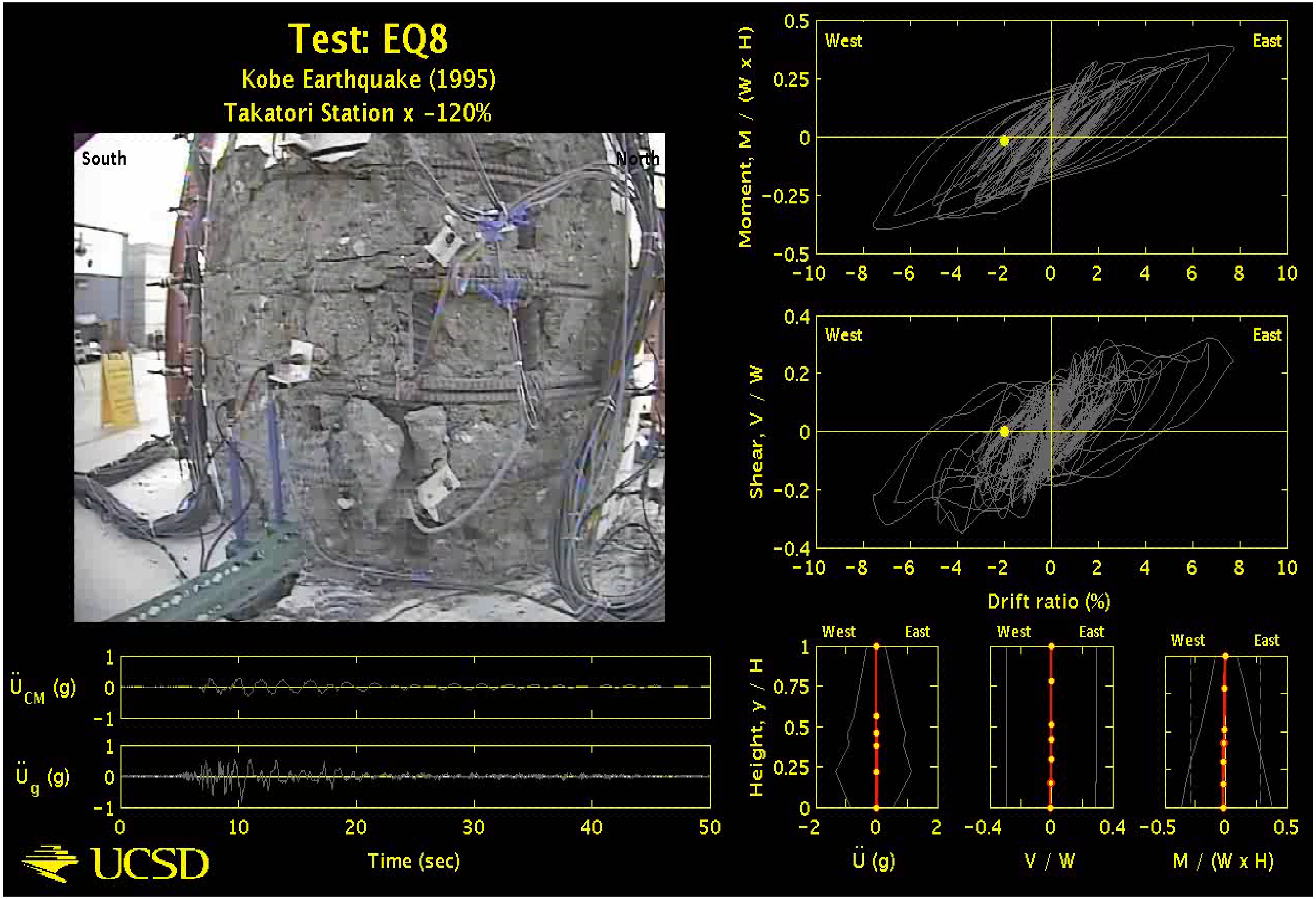
Large Scale Validation of Seismic Performance of Bridge Columns

PI: Prof. Jose Restrepo, UC San Diego




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)
$\ddot{U}_{CM}$ (g)
$\ddot{U}_g$ (g)
Time (sec)
UCSD


Test: EQ8
Kobe Earthquake (1995)
Takatori Station x -120%
South
North
Moment, M / (W x H)
West
East
Shear, V / W
Drift ratio (%)
Height, y / H
Ü (g)
V / W
M / (W x H)
$\ddot{U}_{CM}$ (g)
$\ddot{U}_g$ (g)
Time (sec)
UCSD


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

Collapse Vulnerability and Seismic Design of Metal Buildings

PI: Prof. Chia-Ming Uang, UC San Diego

Earthquake Performance of Full-Scale Reinforced Soil Wall

PI: Prof. Patrick Fox, UC San Diego

Earthquake Performance of Full-Scale Reinforced Soil Wall

PI: Prof. Patrick Fox, UC San Diego

Seismically Isolated Unibody Residential Buildings for Enhanced Life-Cycle Performance

PI - Prof. Gregory Deierlein, Stanford University

Seismically Isolated Unibody Residential Buildings for Enhanced Life-Cycle Performance

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THANK YOU !
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