NHERI@UC San Diego 3RD USERS TRAINING WORKSHOP

Objectives

- Familiarize prospective users of the NHERI@UC San Diego shake table with its simulation capabilities and 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 research proposals utilizing the NHERI Experimental Facility at UC San Diego, including the Educational and Community Outreach (ECO) aspect.

Workshop Program – Monday Morning

7:30 - 8:00am	Registration
8:00 - 8:15am	Welcome, Introduction of each Attendee & Workshop Schedule (J. Conte, UCSD)
8:15 - 9:15am	NHERI@UCSD: Facility Description and Capabilities (J. Conte, UCSD)
9:15 - 9:30am	NHERI DesignSafe: user tools & support (J. Padget, Rice Univ.)
9:30 - 9:45am	NHERI SimCenter (M. Schoettler, UC Berkeley)
9:45 - 10:15am	Nuts & Bolts: Instrumentation/DAQ, Cameras, IT Resources & Cybersecurity (D. McKay and R. Beckley, UCSD)
10:15 - 10:45am	Break
10:45 - 11:15am	Journey through a Project (Structural) (S. Pei, Colorado School of Mines)
11:15 - 11:45am	Journey through a Project (Geotechnical) (T. Shantz, Caltrans)
11:45 - 12:45am	Box Lunch (in SME) & bus to site (depart 12:45; arrive 1:15)

Workshop Program – Monday Afternoon

1:15 - 2:15pm	Facility Tour (depart 2:15; arrive at UCSD at 2:45)
2:45 - 3:15pm	Advances in Shake Table Hybrid Simulation (G. Mosqueda, UCSD)
3:15 - 3:35pm	Research Planning in a Nutshell (T. Hutchinson, UCSD)
3:35 - 4:00pm	Payload Opportunities (T. Hutchinson and B. Shing, UCSD)
4:00 - 5:00pm	Education, Outreach and Training (EOT) (L. Van Den Einde) & Open Discussion
5:00 - 7:00pm	Poster Session & Buffet/Reception in SME Courtyard

Presenters

- Robert Beckley, UC San Diego
- Joel Conte, UC San Diego
- Tara Hutchinson, UC San Diego
- Darren McKay, UC San Diego
- Gilberto Mosqueda, UC San Diego
- Jamie Padget, Rice University
- Shiling Pei, Colorado School of Mines
- Tom Shantz, Caltrans
- Benson Shing, UC San Diego
- Matt Schoettler, UC Berkeley
- Lelli Van Den Einde, UC San Diego

NHERI@UC San Diego: Facility Description and Capabilities

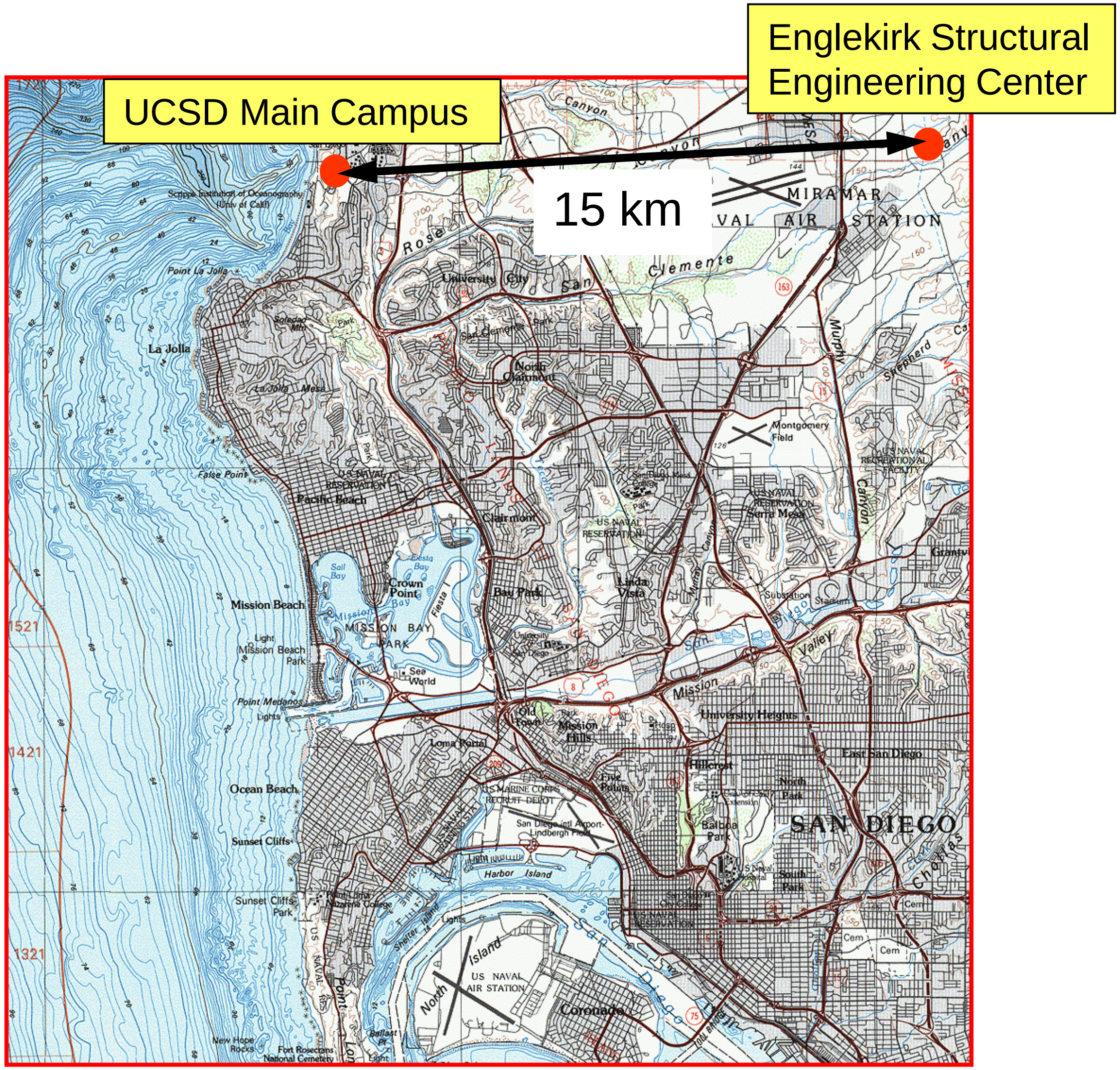
Joel Conte, Professor

University of California, San Diego

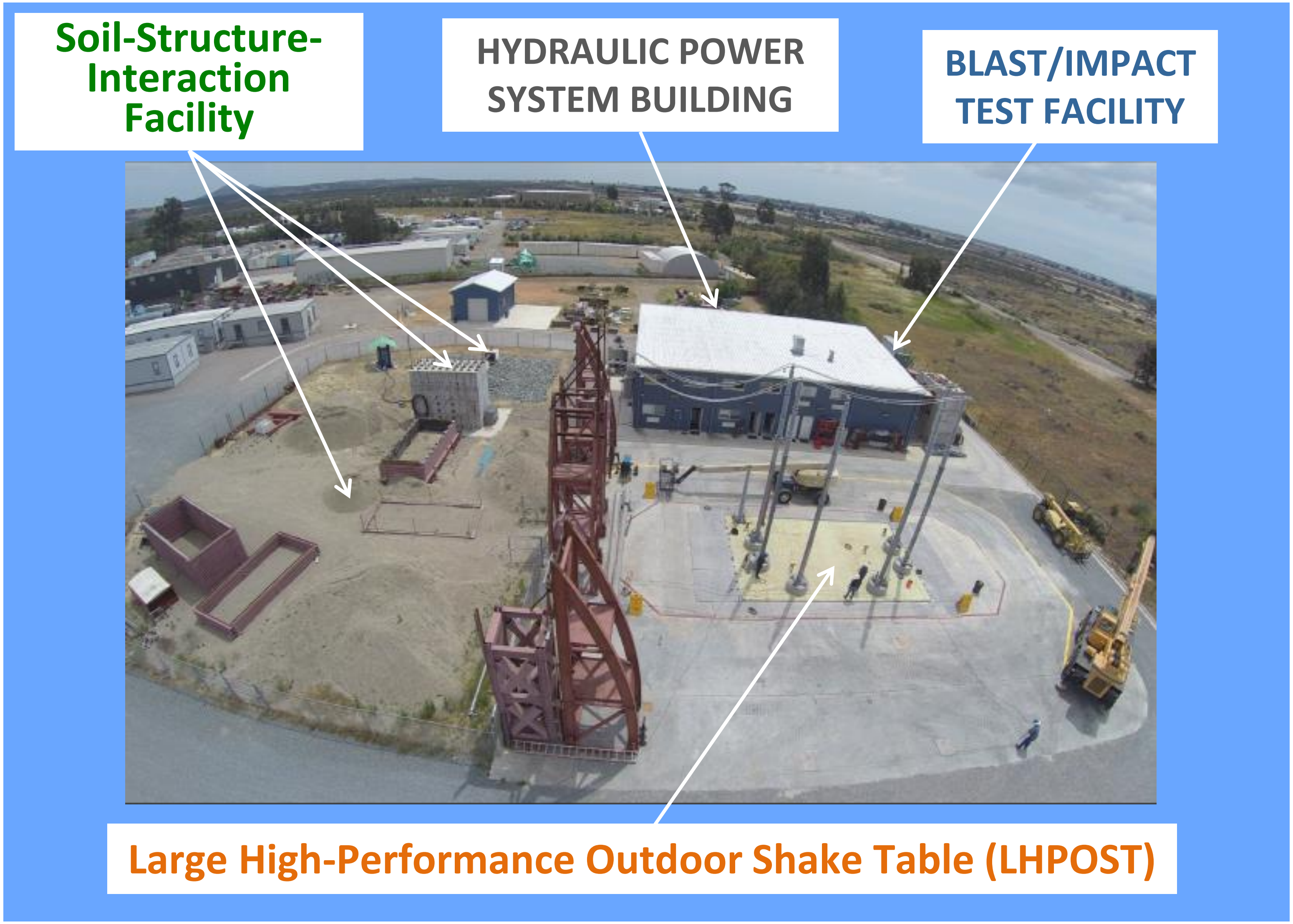
December 11, 2017

Natural Hazards Engineering Research Infrastructure (NHERI) Network

Englekirk Structural Engineering Center



Englekirk Structural Engineering Center



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Testing Laboratory TL-356

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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

NEES@UCSD Shake Table: 2004-2014

NHERI@UC San Diego Shake Table: 2016-2020

NHERI@UC San Diego Personnel

Joel Conte
PI
Site Admin.

Tara Hutchinson
Co-PI
Site User Services

Gilberto Mosqueda
Co-PI
Site Performance

Benson Shing
Co-PI
Site Operations

Lelli Van Den Einde
Co-PI
Education and
Community Outreach

José Restrepo
Senior Personnel

Enrique Luco
Senior Personnel

Darren McKay
Operations
Manager

Robert Beckley
IT Manager

Alex Sherman
Site Foreman
Development
Technician

Jeremy Fitcher
Development
Technician

Outline

- Overview of NHERI@UC San Diego 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 Set of Large-Scale Shake Table Tests Performed on the NHERI@UC San Diego Shake Table

Objectives of the NHERI@UC San Diego 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, geo-structures, and other civil infrastructure systems during earthquakes, ***from the initiation of damage to the onset of collapse***.

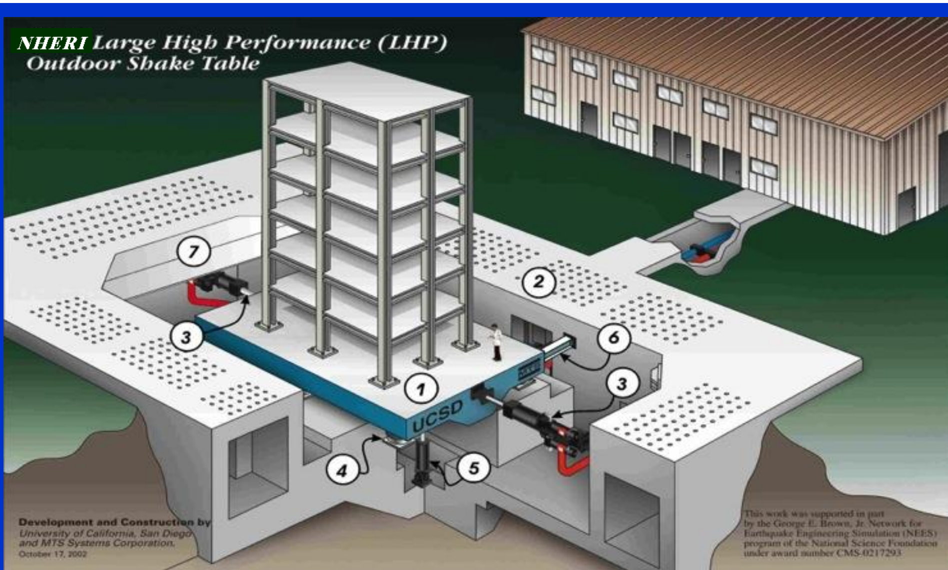
  - Experimental data to support the **development, calibration and validation of high-fidelity physics-based computational models** of structural/geotechnical/soil-foundation-structural systems that will progressively shift the current reliance on physical testing to model-based simulation for the seismic 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.
- 29 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

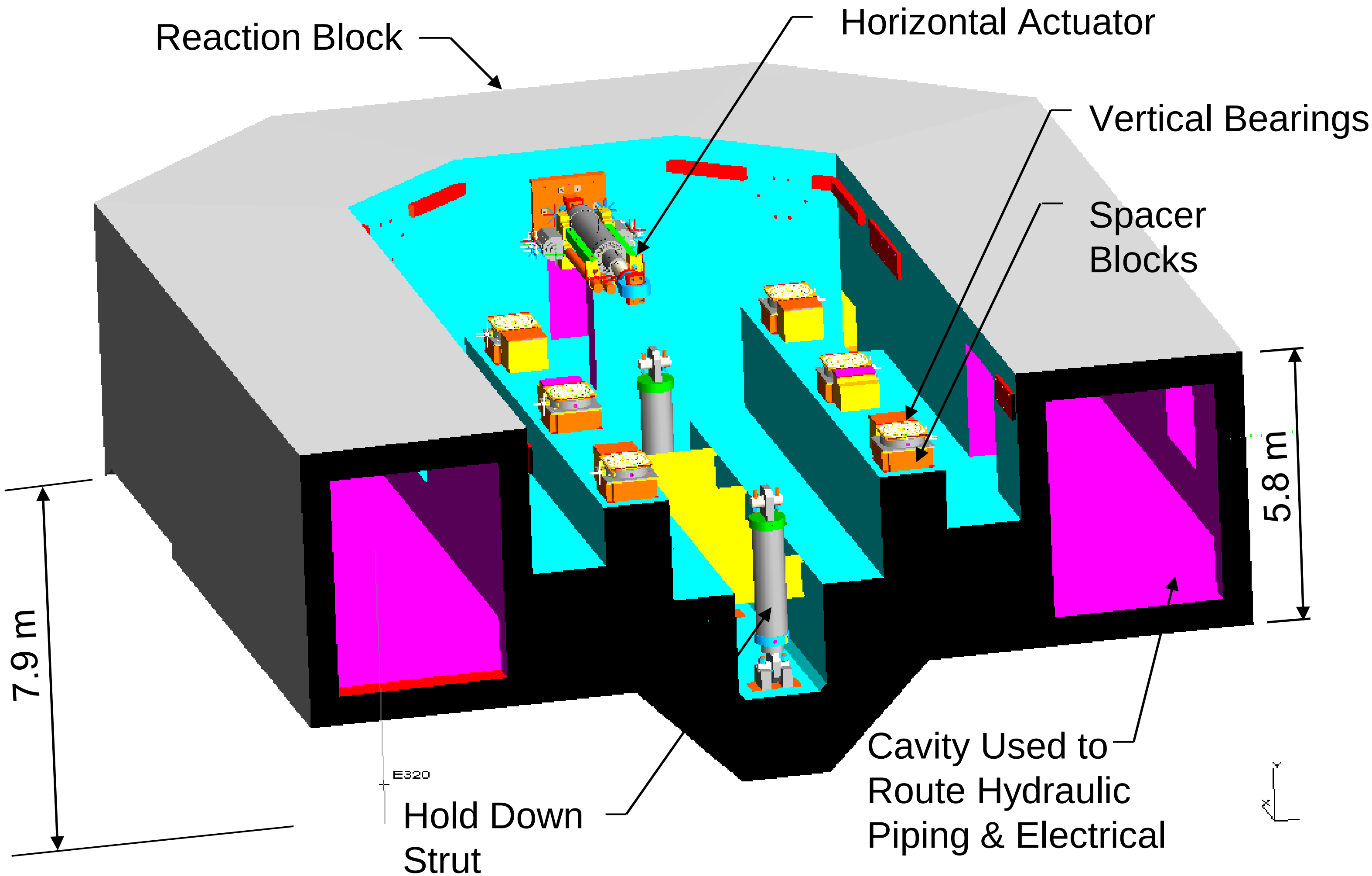


Performance Characteristics in Current 1-DOF Configuration	
Designed as a 6-DOF shake table, but built as a 1-DOF system to accommodate funding available	
Stroke	±0.75m
Platen Size	40 ft × 25 ft (12.2 m × 7.6 m)
Peak Velocity	**1.8 m/sec**
Peak Acceleration	4.7g (bare table condition); 1.2g (4.0MN/400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

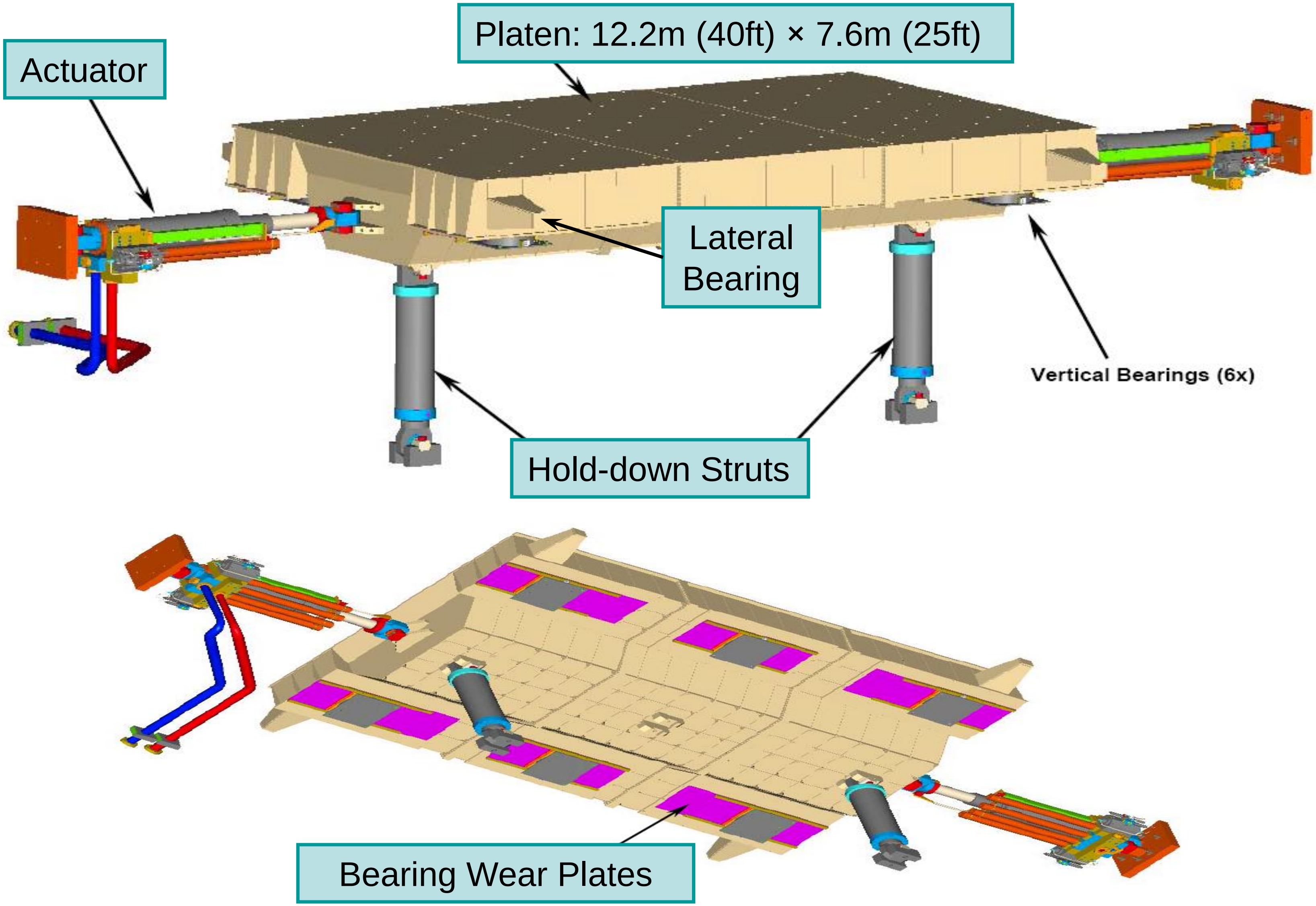
Capabilities/Provisions of NHERI@UCSD Site

- **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



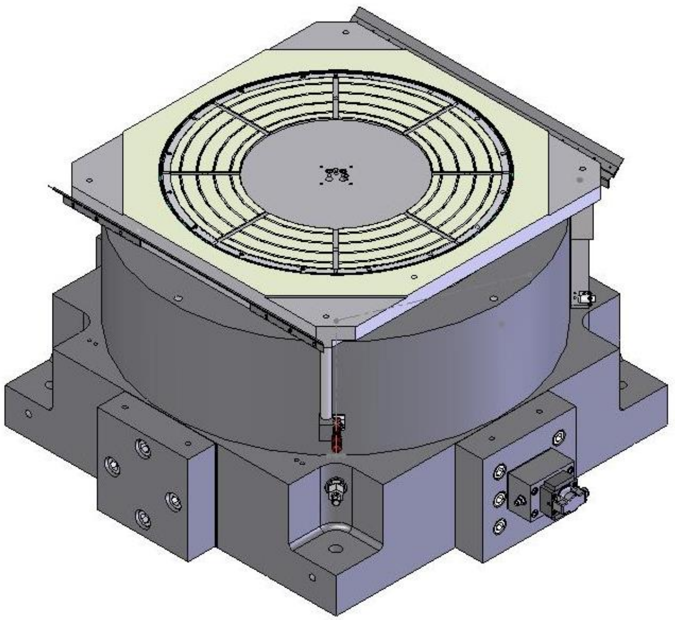
Platen, Actuators, Hold-Down Struts, and Bearing Wear Plates

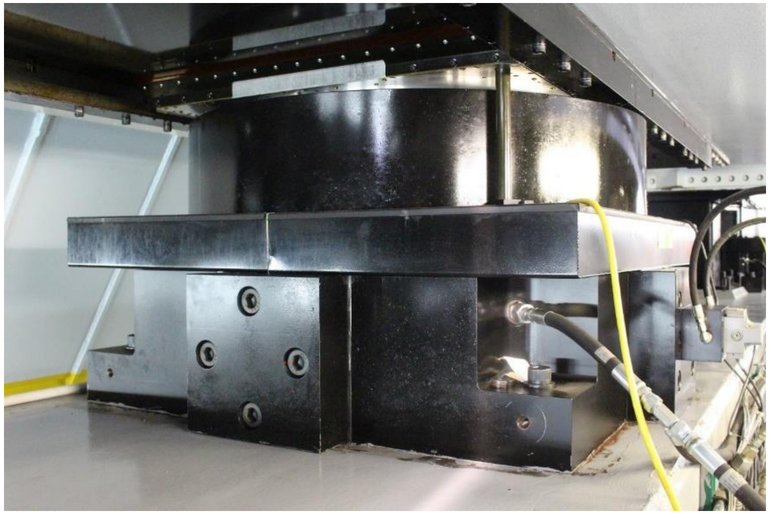


Technical Characteristics of Vertical Actuators

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



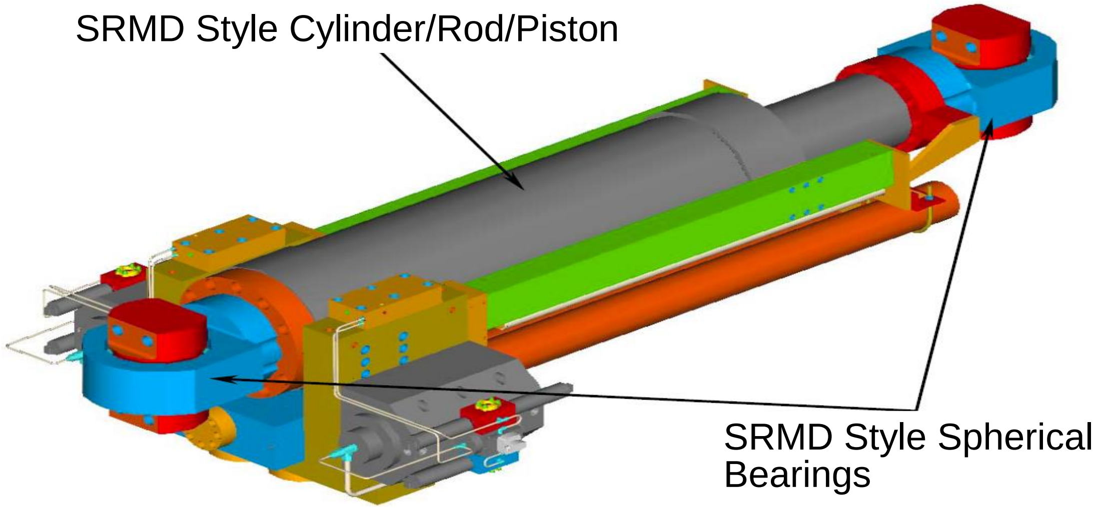


Technical Characteristics of Hold-down Struts

Hold-Down Struts (Qty. 2)	
Nitrogen Pressure	13.8 MPa
Uni-axial Stroke	2 m
Pin-to-Pin Length	3.3 m
Hold-down Force	**2.1 MN**
Effective Tension Area	0.15 m^2

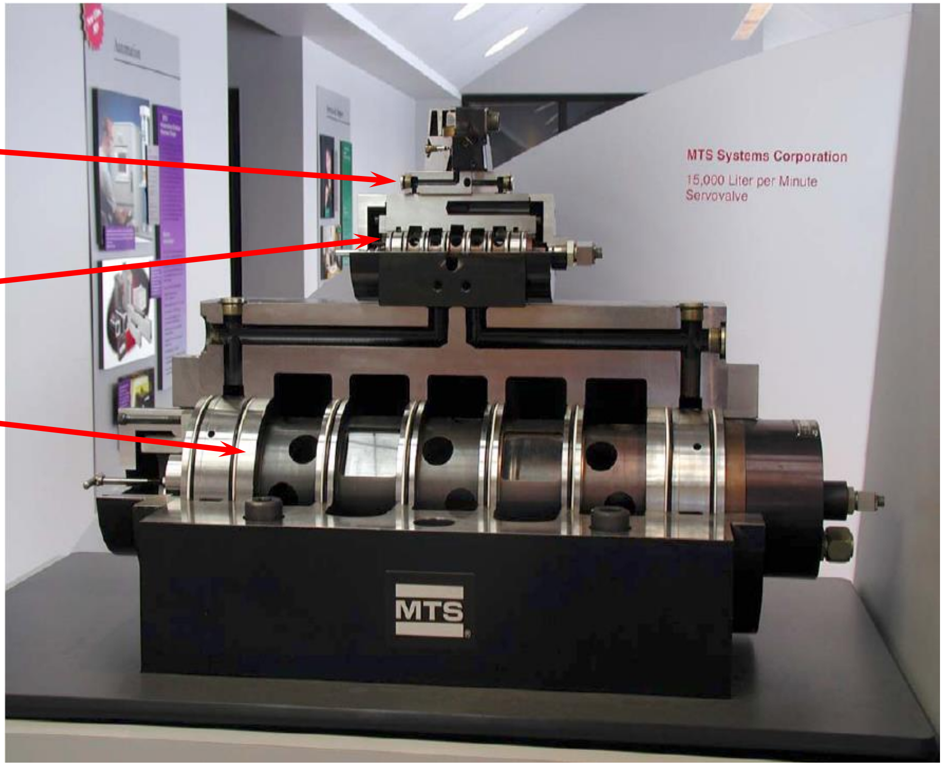
Technical Characteristics of Actuators

Actuators (Qty. 2)	
Stroke	**+/- 0.75 m**
Max. Velocity	**1.8 m/s**
Max. Acceleration (w/ 4MN Rigid Payload / Bare Table)	**1.25g / 4.7g**
Force Capacity (Tension / Compression)	**4.2 MN / 2.7 MN**
Rod Diameter	0.3048 m
Piston Diameter	0.5080 m
Total Effective Piston Area	0.332 m^2
Tension Area	0.2027 m^2
Compression Area	0.1297 m^2
Peak Extend Flow Rate	21,890 lt/m
Peak Retract Flow Rate	14,010 lt/m



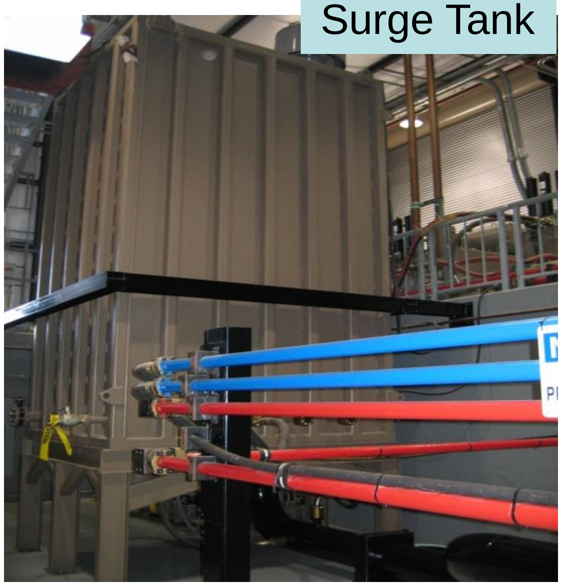
Technical Characteristics of Servovalves

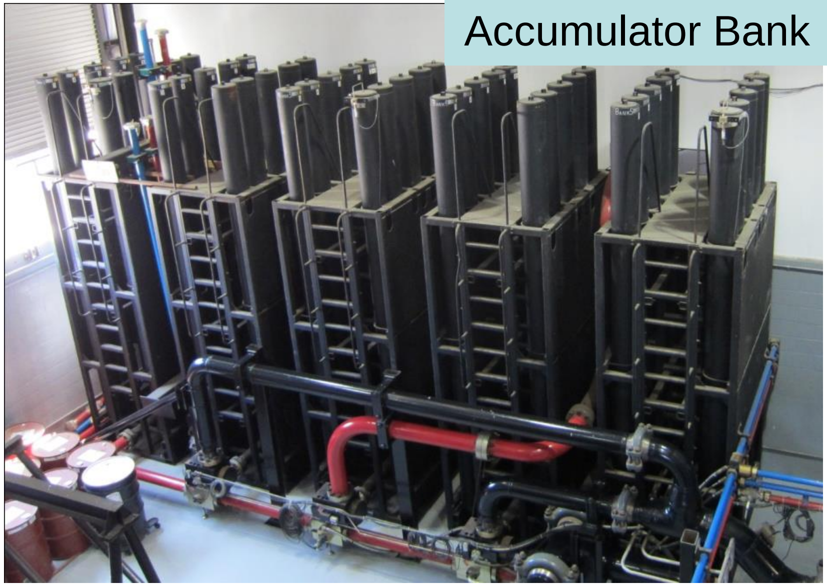
Servovalves (Qty. 2E+2W)	
Pilot 2nd Stage Rating (Manufacturer Moog)	**19 lt/min**
Pilot 3rd Stage Rating	**630 lt/min**
4th Stage Flow Rating	**10,000 lt/min**
Port Area Ratios	1:0.8:0.64:0.512
Valve Sleeve Windows Area Ratios	1:0.64

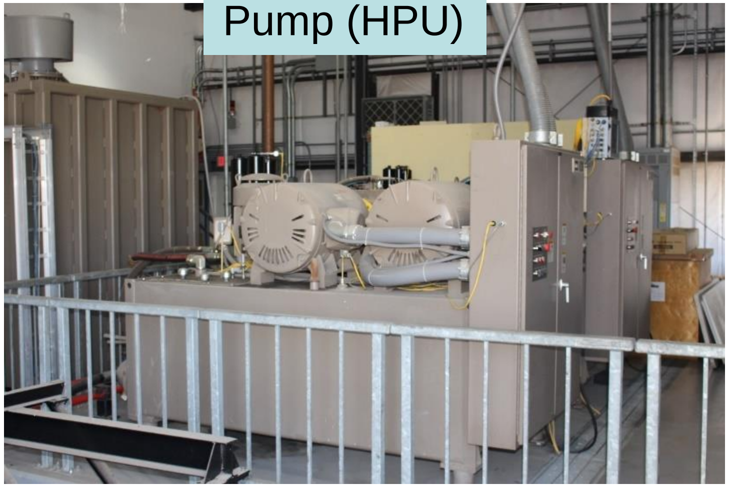


Technical Characteristics of Hydraulic Power System

Hydraulic Power System	
Accumulator Swept Displacement	**7.5 m**
Accumulator Bank Pressure	**35 MPa**
System Pressure	**20.7 MPa**
Blow-down 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


Surge Tank

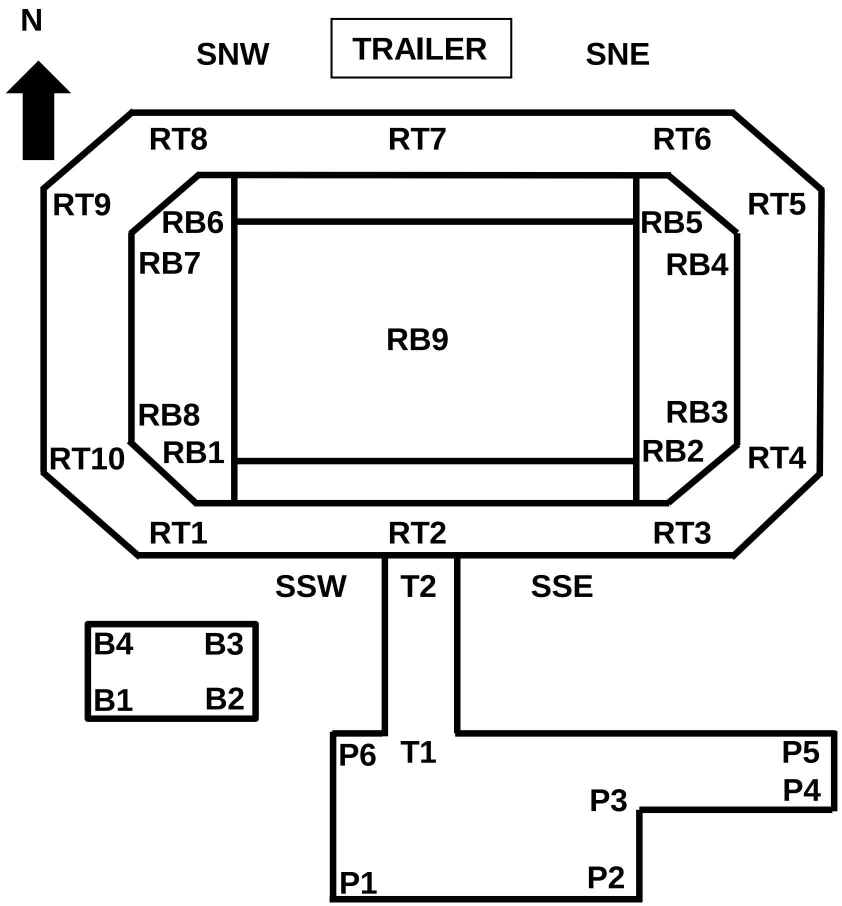

Accumulator Bank


Pump (HPU)

Bare Table Commissioning Tests

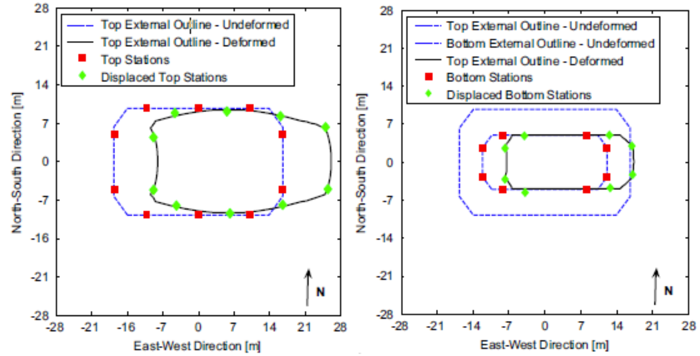
Forced Vibration Tests of the Reaction Mass at the NEES-UCSD Shake Table

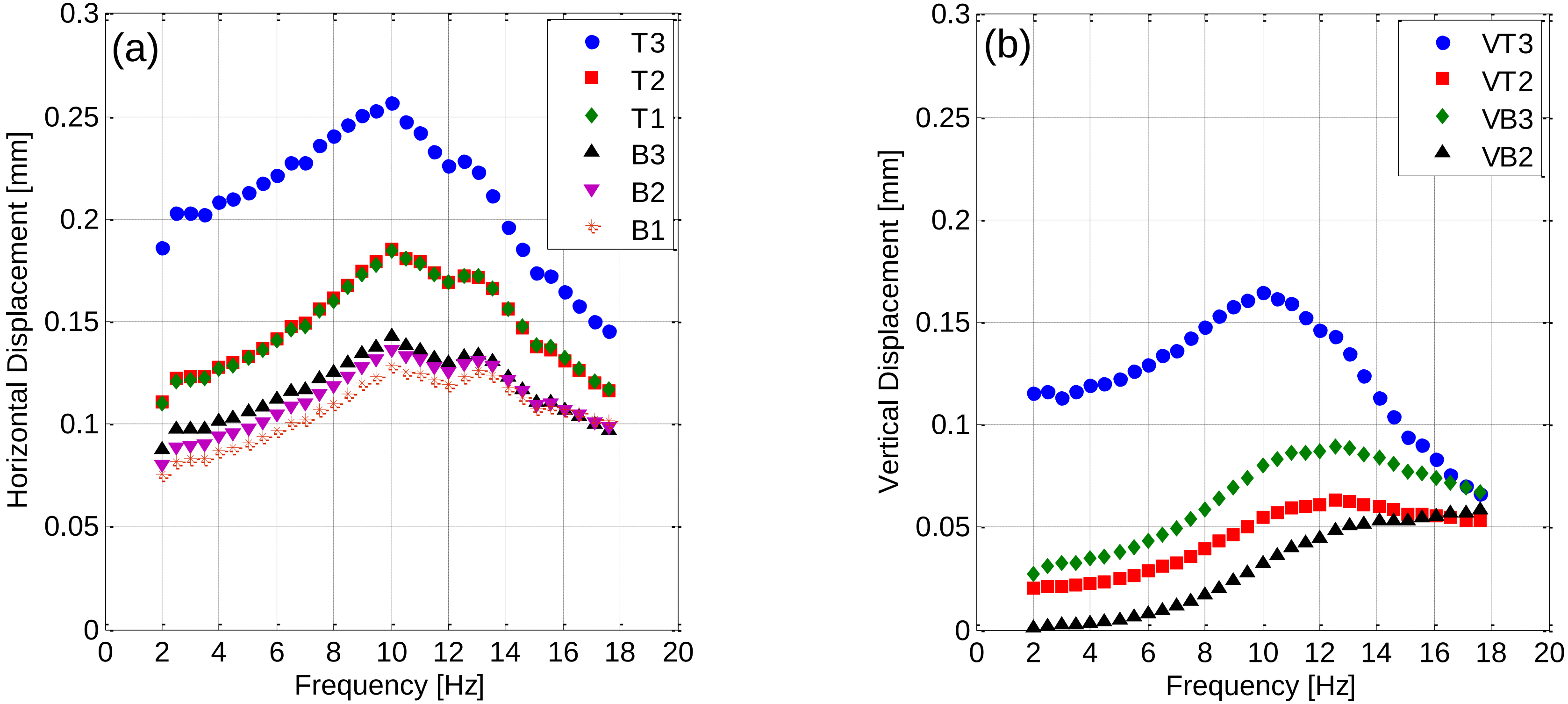
Commissioning Tests



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-structure 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-structure systems

Assembly of Laminar Soil Shear Box

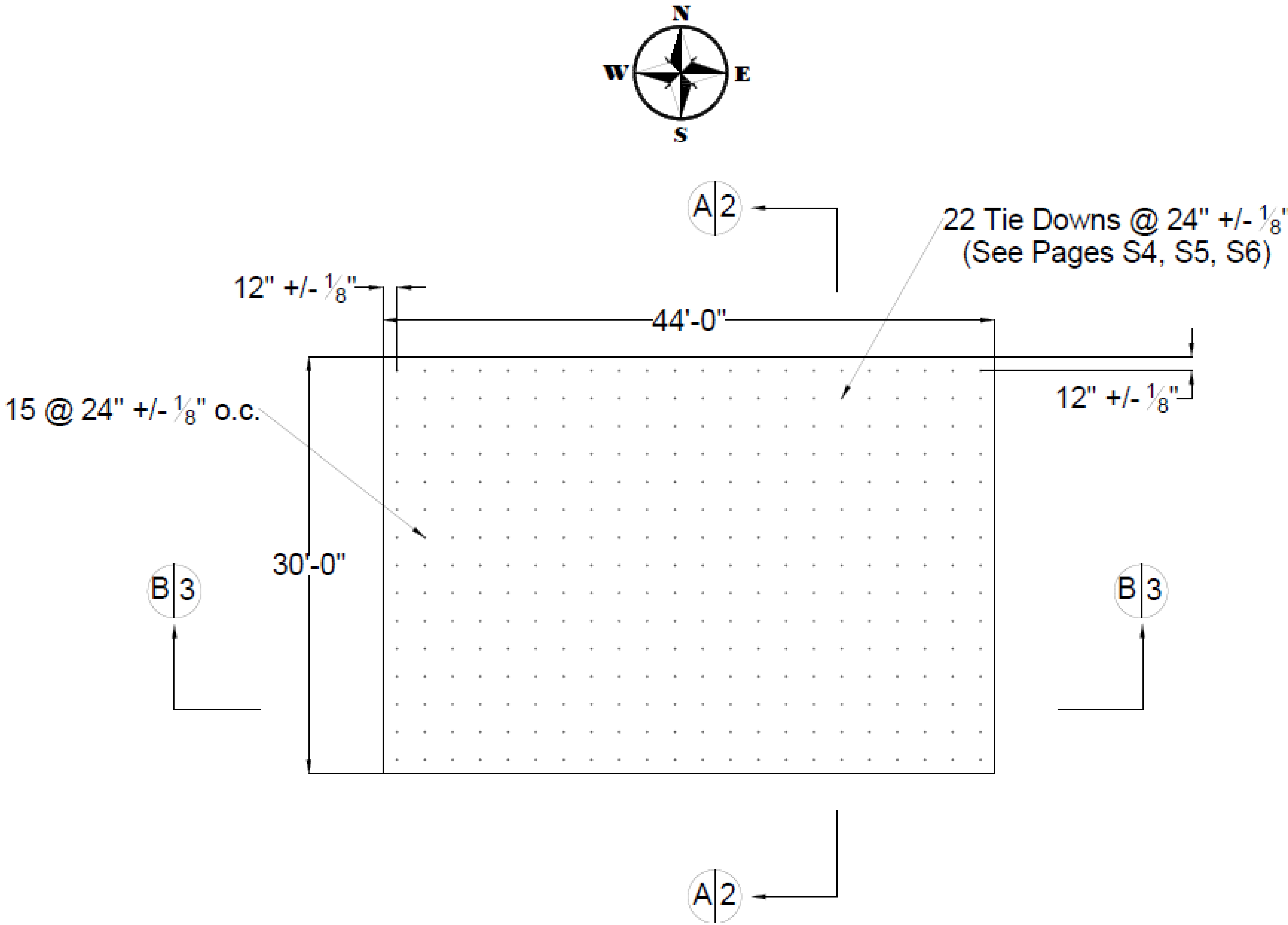
Assembly of Stiff Soil Confinement Box

Disassembly of Stiff Soil Confinement Box

Staging Facility

- In an effort to increase throughput at the NHERI@UCSD facility, a reinforced concrete staging slab with dimensions of 13.4 m × 8.8 m × 0.914 m deep (44 ft × 30 ft × 3 ft deep) was built near the shake table.
- Small to moderate size specimens (weighing up to 100 tons) can be constructed on the staging area then lifted onto the shake table platen, or partial assembly of components for large specimens can reduce construction time.

Staging Facility



Staging Facility

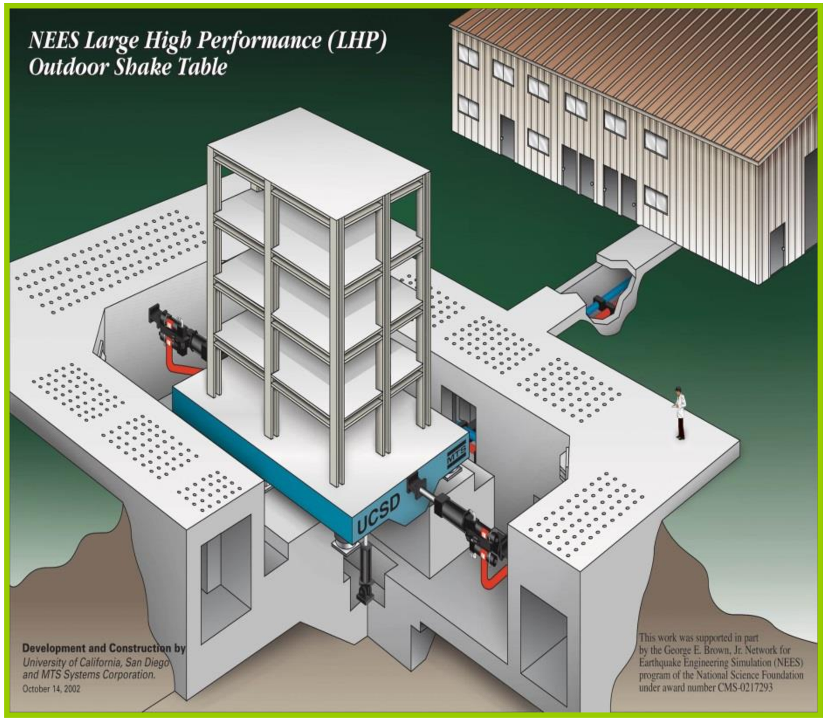
Instrumentation Overview

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

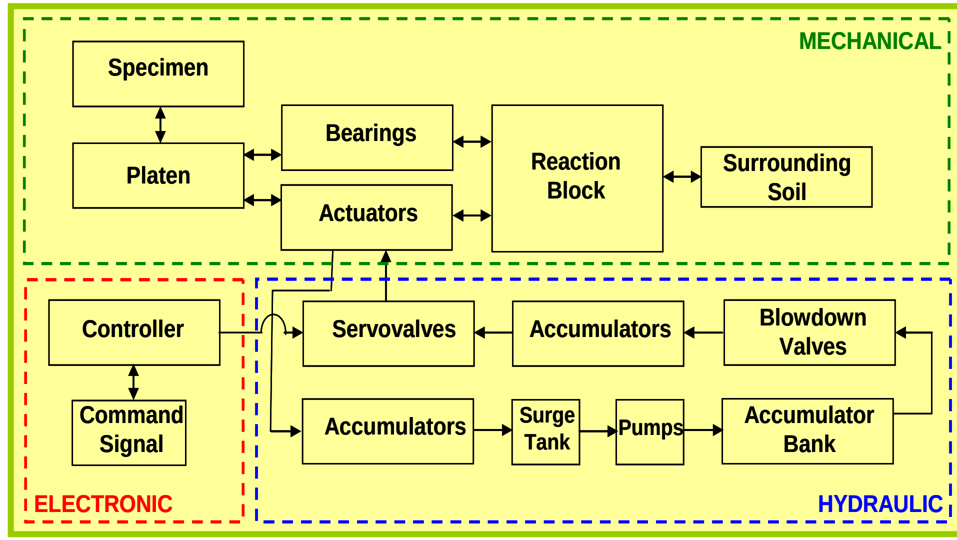
Shake Table Dynamics and Control Fidelity in Signal Reproduction & Sources of Signal Distortion

NHERI @ UC San Diego 3RD Users Training Workshop, December 11, 2017

Components and Interaction Diagram of LHPOST System

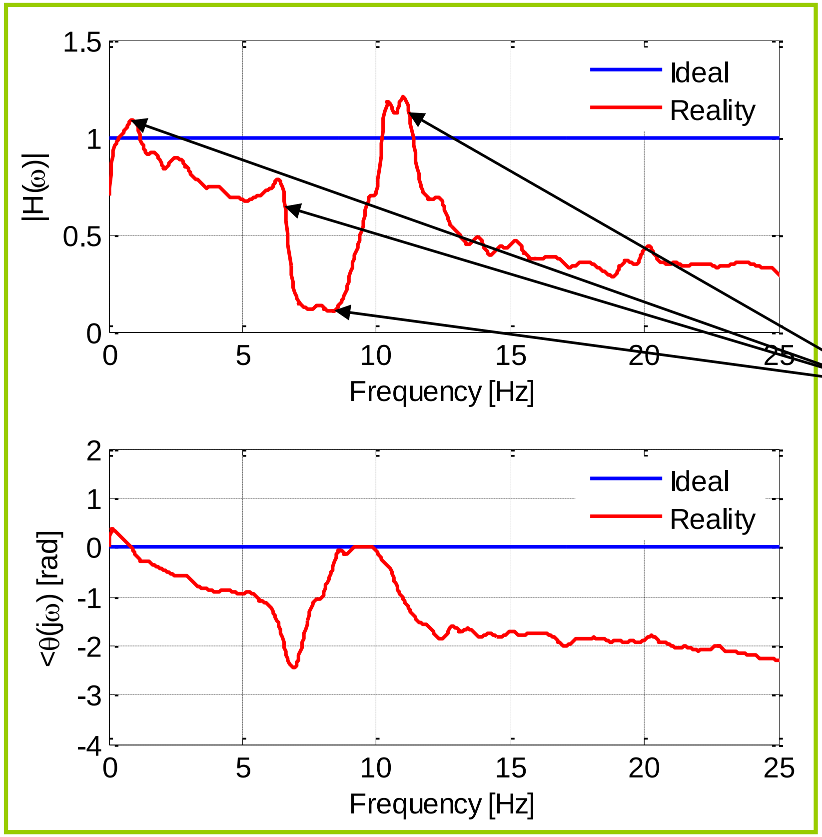


Components and Interaction Diagram



Components and Interaction Diagram of LHPOST System

- 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.

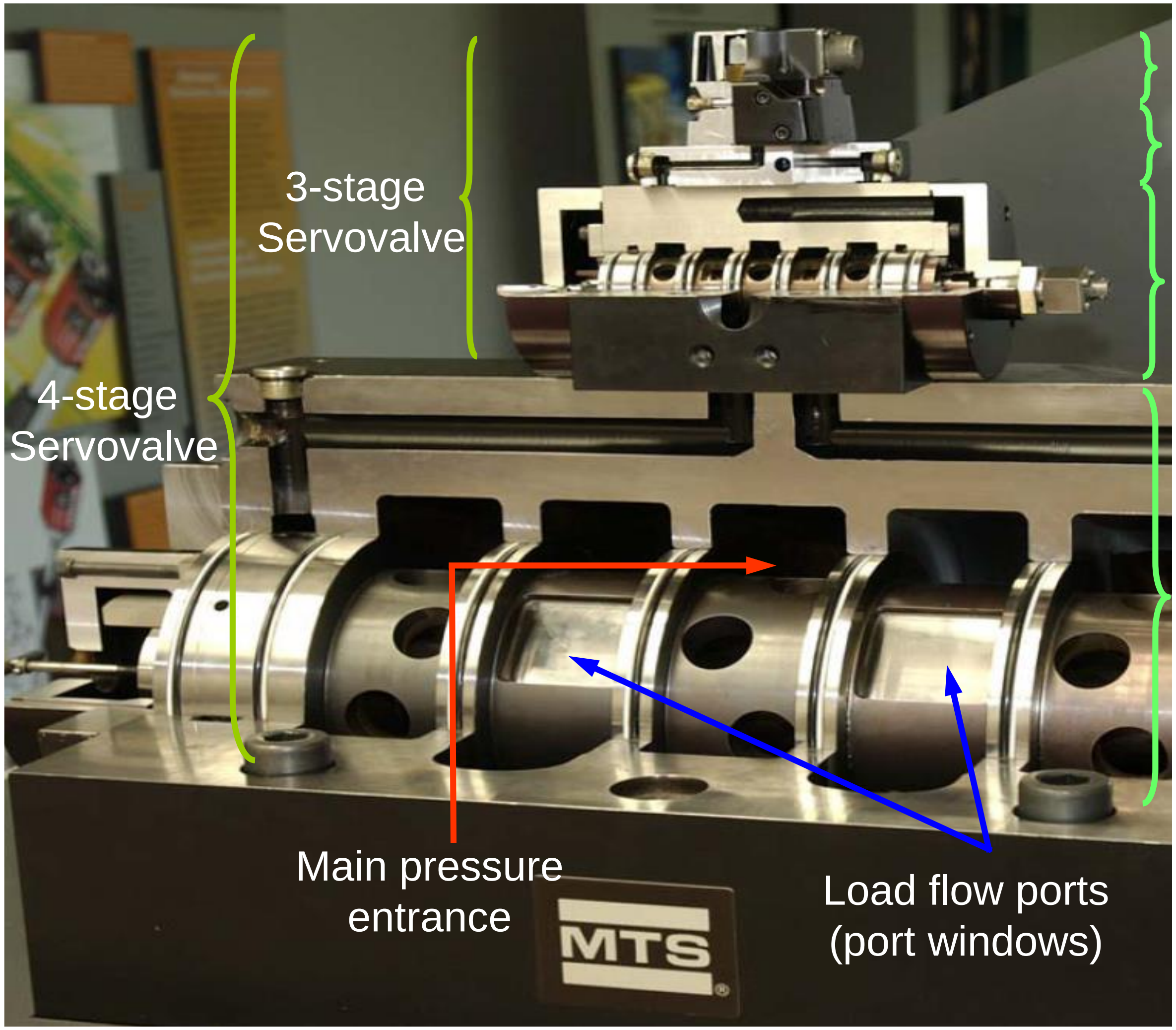


Due to various peaks and valleys in the shaking table system transfer function, the signal reproduced by the table differs from the commanded signal.

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)

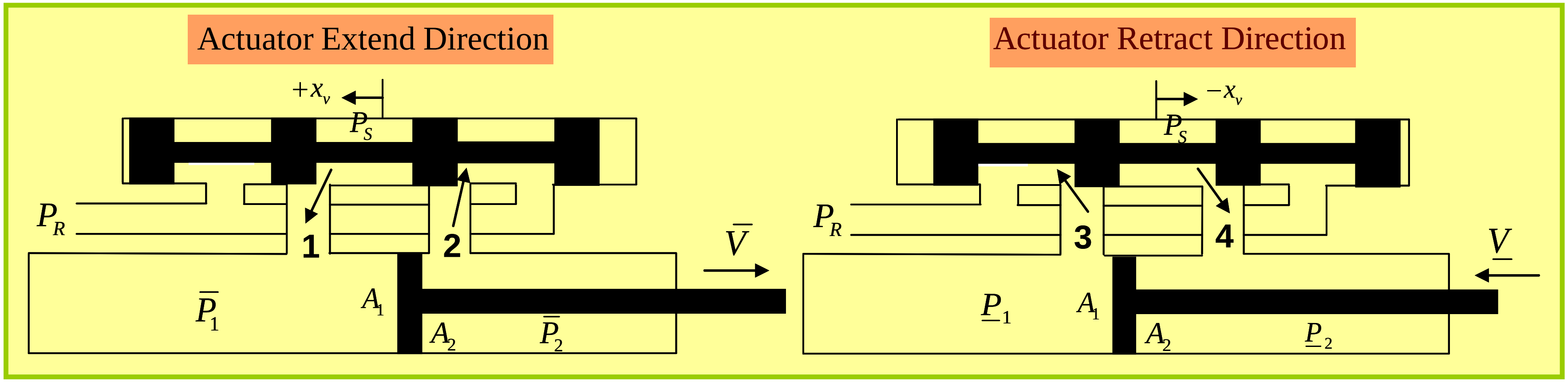
2nd stage

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	:	Compression and tension 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

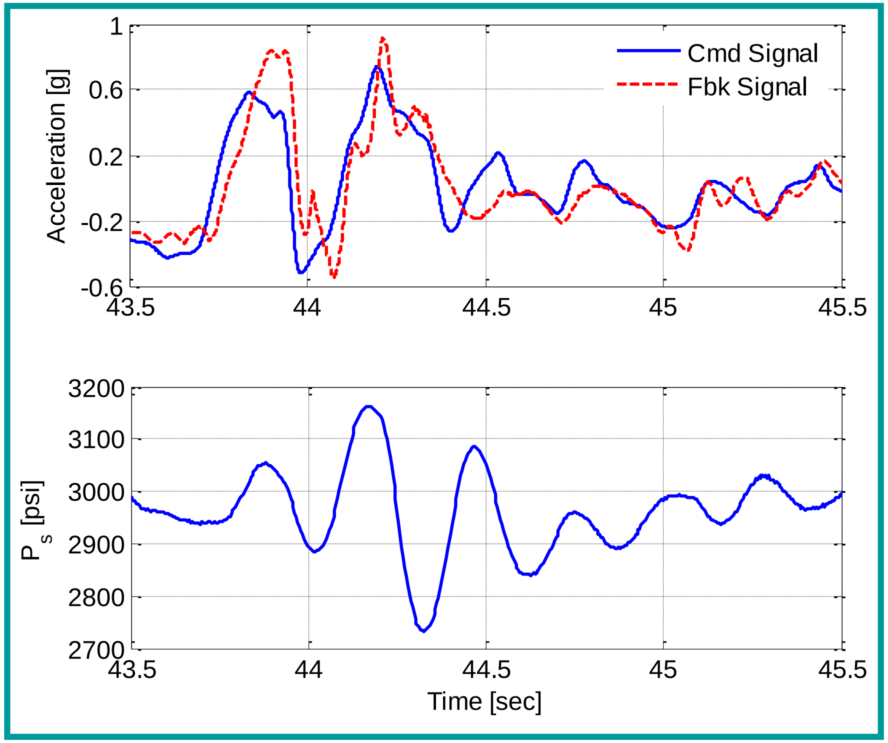
- Servo-valve flows present two independent sources of nonlinearity:
  - Load pressure nonlinearity or pressure drop - flow nonlinearity (explicitly represented by the square root term)
  - Flow gain nonlinearity (K_v changes as a function of orifice size)

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

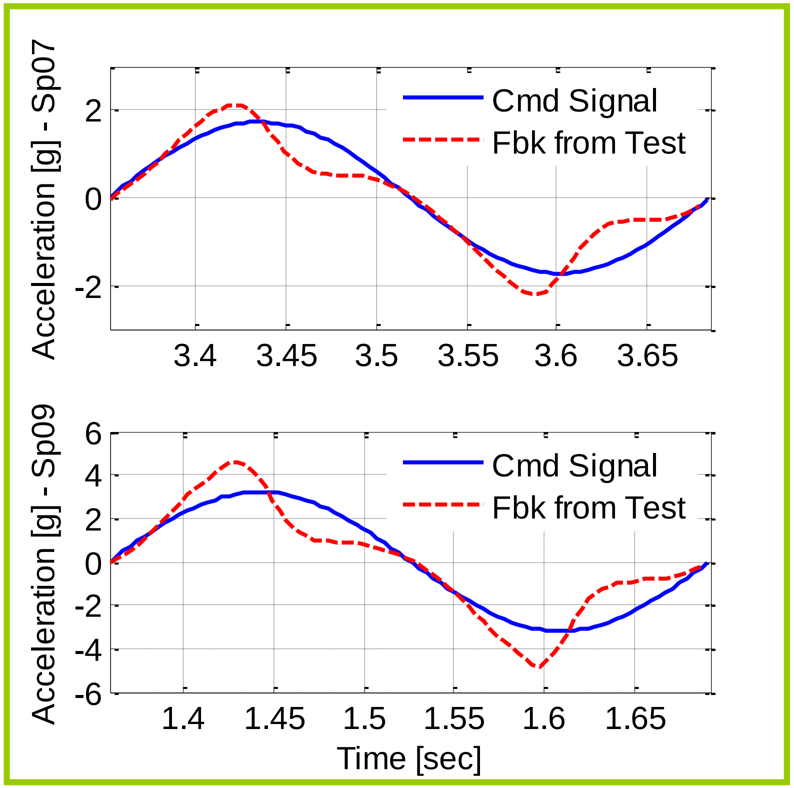


1994 Northridge Earthquake recorded at Sylmar Station
(Seven-story R/C building specimen mounted on the table)

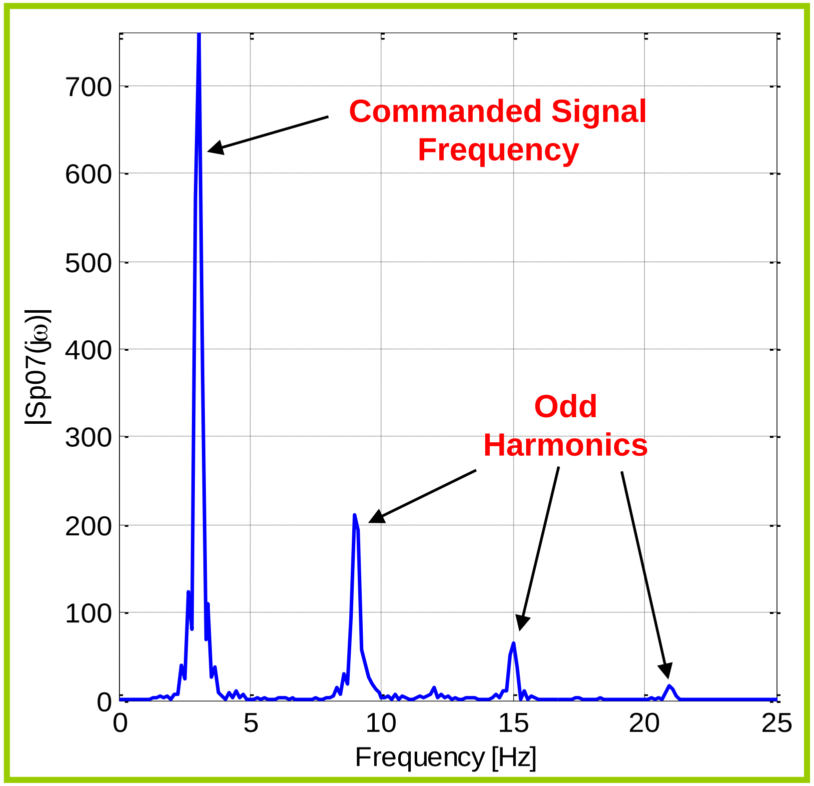
Change in supply pressure P_S at West actuator during test

Effect of Load Pressure Nonlinearity on Fidelity in Signal Reproduction

Sine Tests @ 3 Hz (Bare Table)



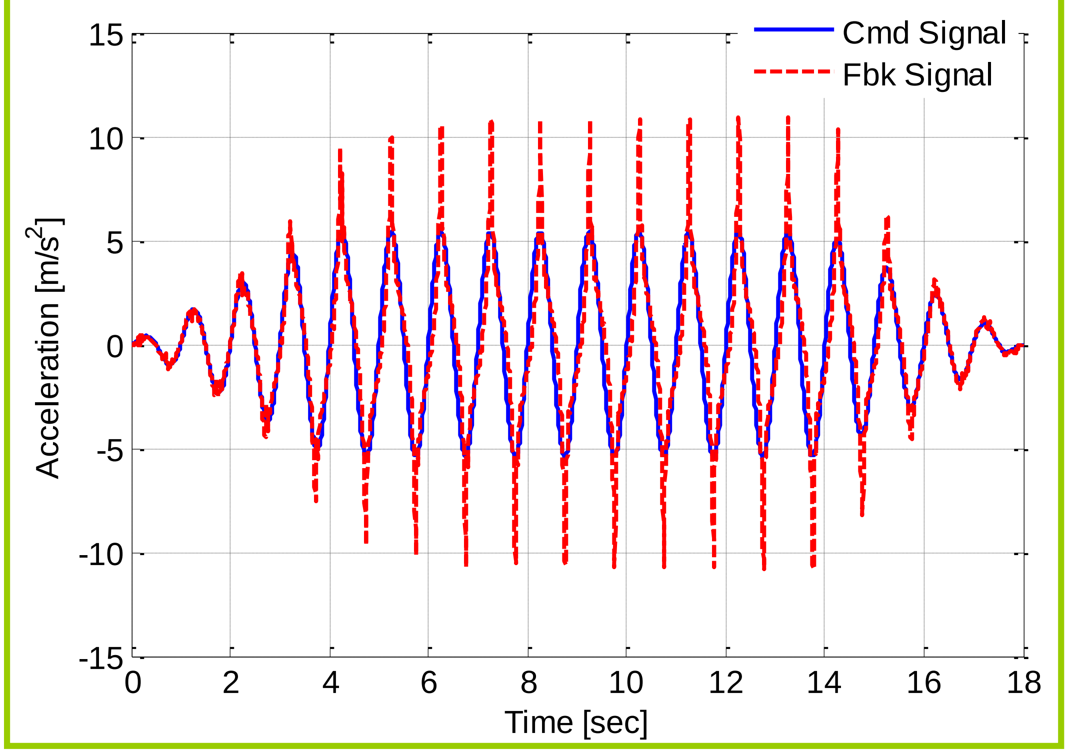
FFT of the Sp07 Test Fbk Signal

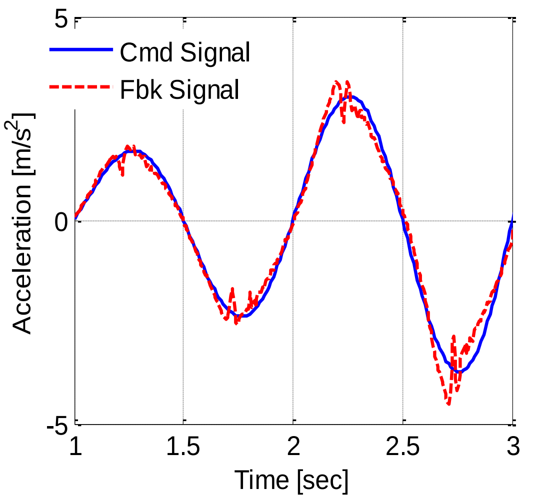


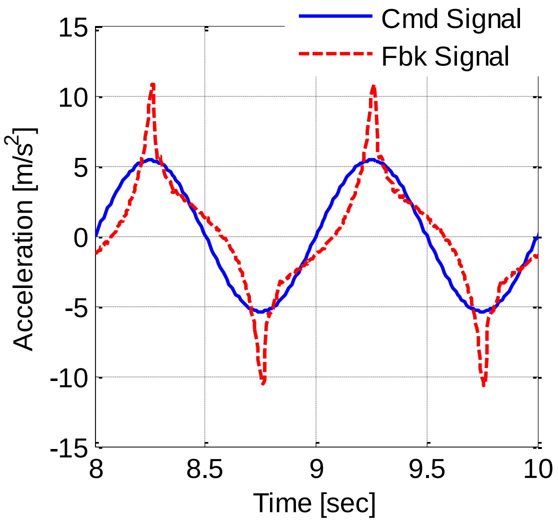
High acceleration signals suffer from load pressure non-linearity.

Example of Signal Distortion from UNAM Shake Table – Time Histories

Sine Test @ 1 Hz

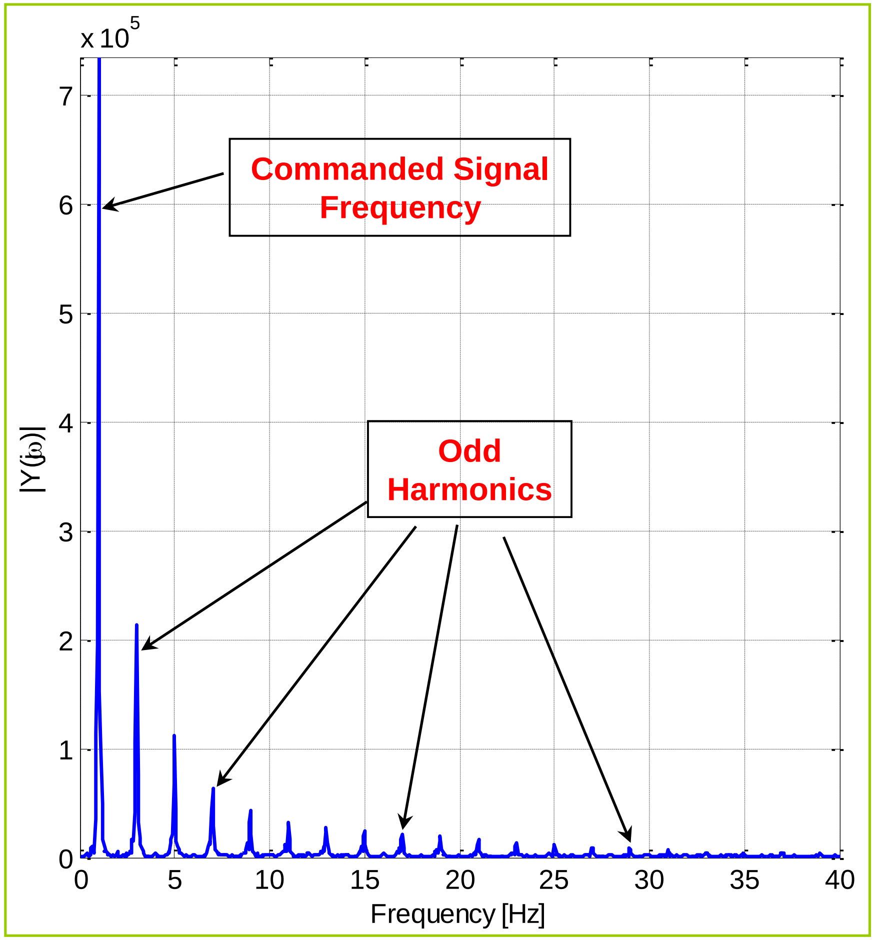






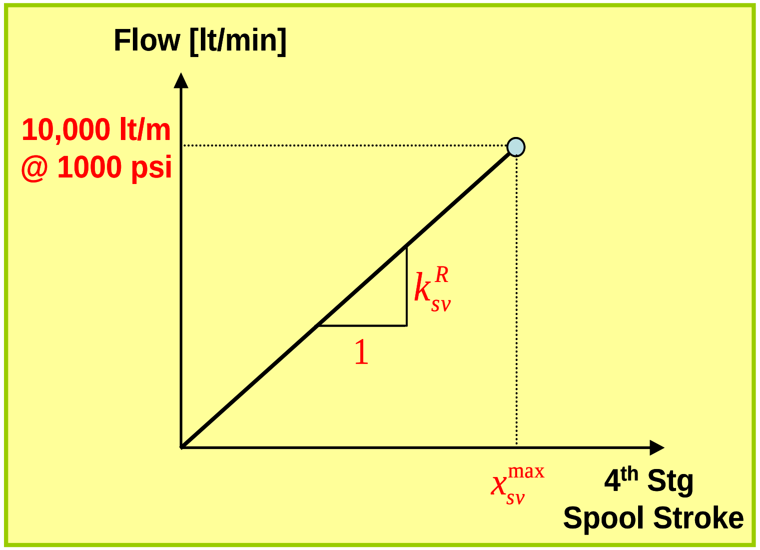
Example of Signal Distortion from UNAM Shake Table – Fourier Spectra

Sine Test @ 1 Hz



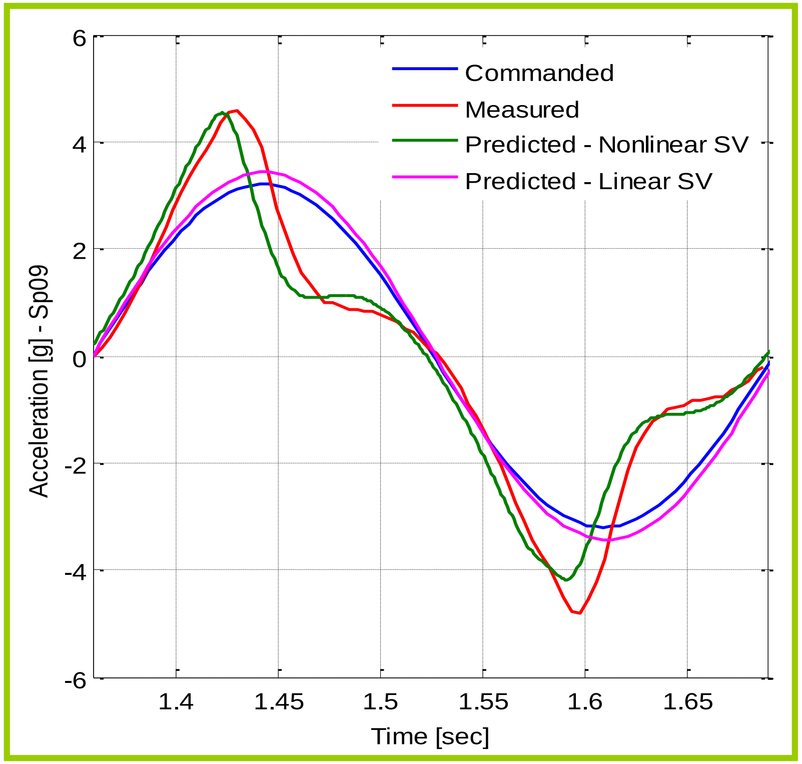
Simulation of Signal Reproduction with "Linearized" and Nonlinear Servovalve Models

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



Servo-valve Flow Gain
@ 3000psi - Linear

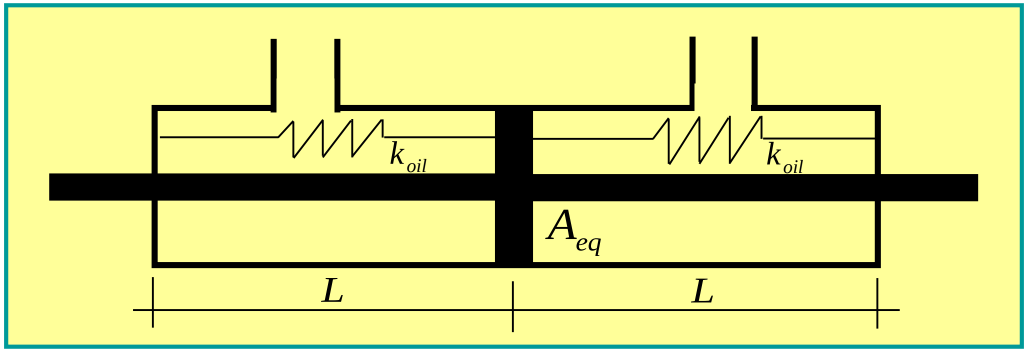
$$k_{sv} = k_{sv}^{R} \times \sqrt{3}$$



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

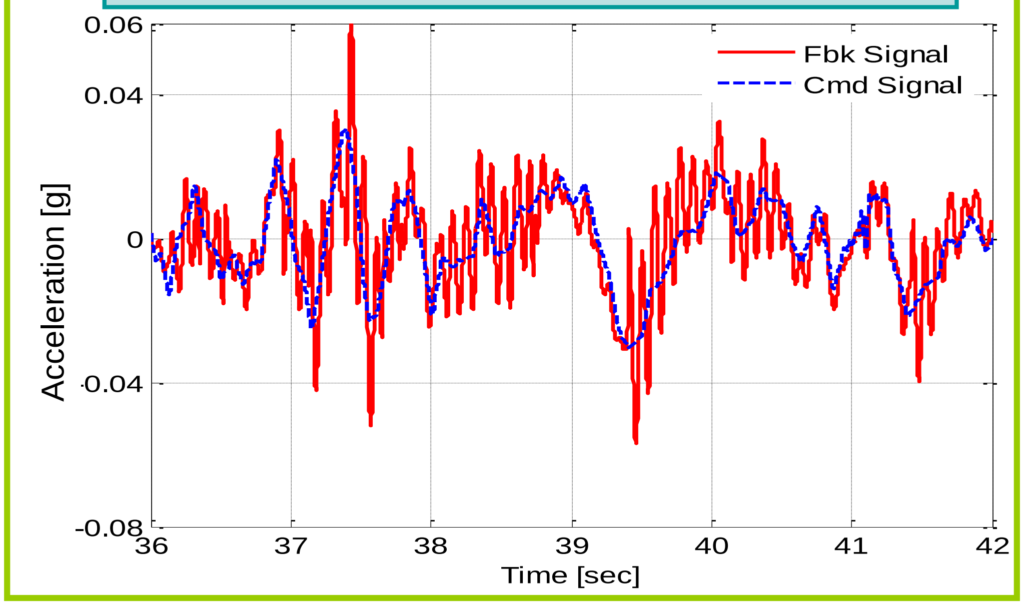
L : Oil column length

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

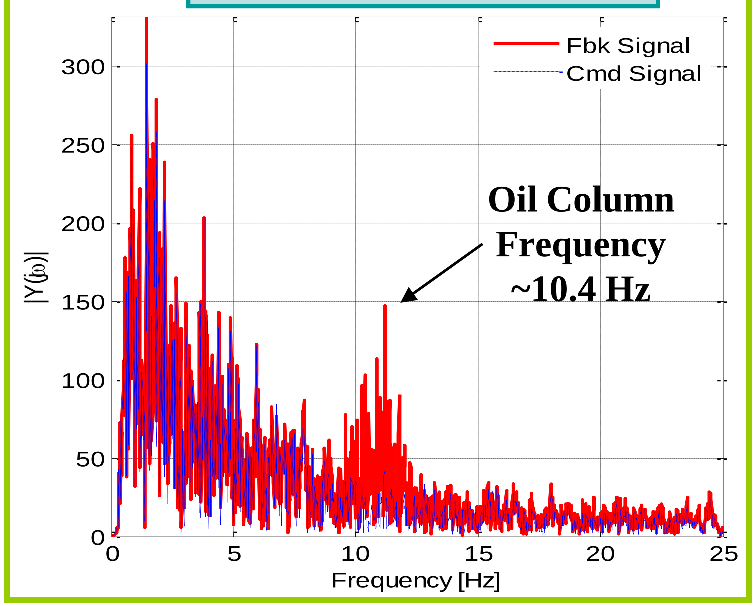
Effects of Oil Column on Fidelity in Signal Reproduction

- 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 may cause significant signal distortion.

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

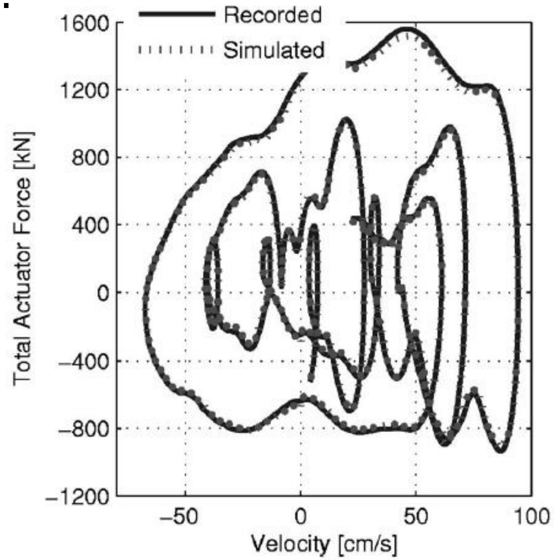


FFT of the Cmd and Fbk Signals



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 signal distortions is approximately constant. Therefore such distortions are more significant for lower amplitude signals.



Identified Dissipative Force Model for LHPOST
(Bare Table)

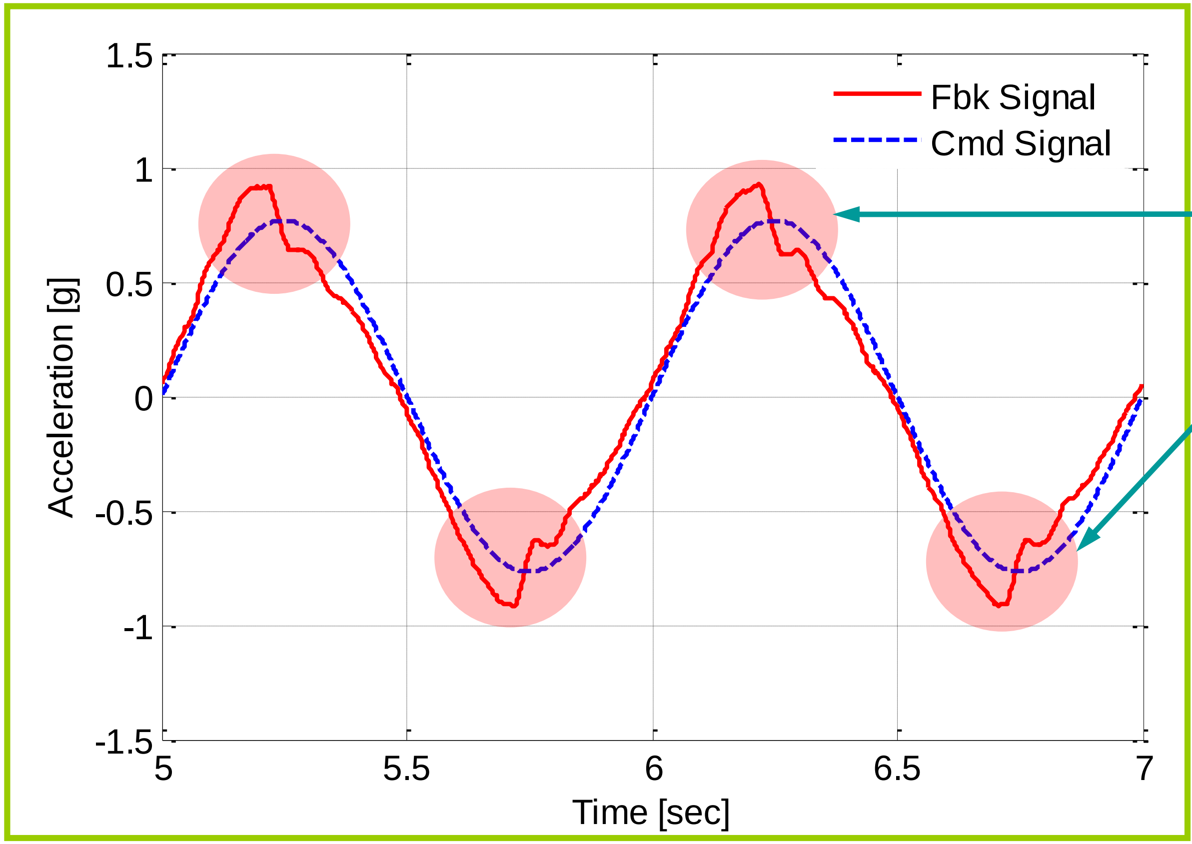
$$F_{viscous}(t) + F_{Coulomb}(t) = C_e \left|\dot{u}_x\right|^{0.5} sign(\dot{u}_x) + F_{\mu_e} sign(\dot{u}_x)$$

Viscous Force
(C_e = 44.6 kN(s/m)$^{0.5}$)

Friction Force - Constant
(~ 26.0 kN ⇒ 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.

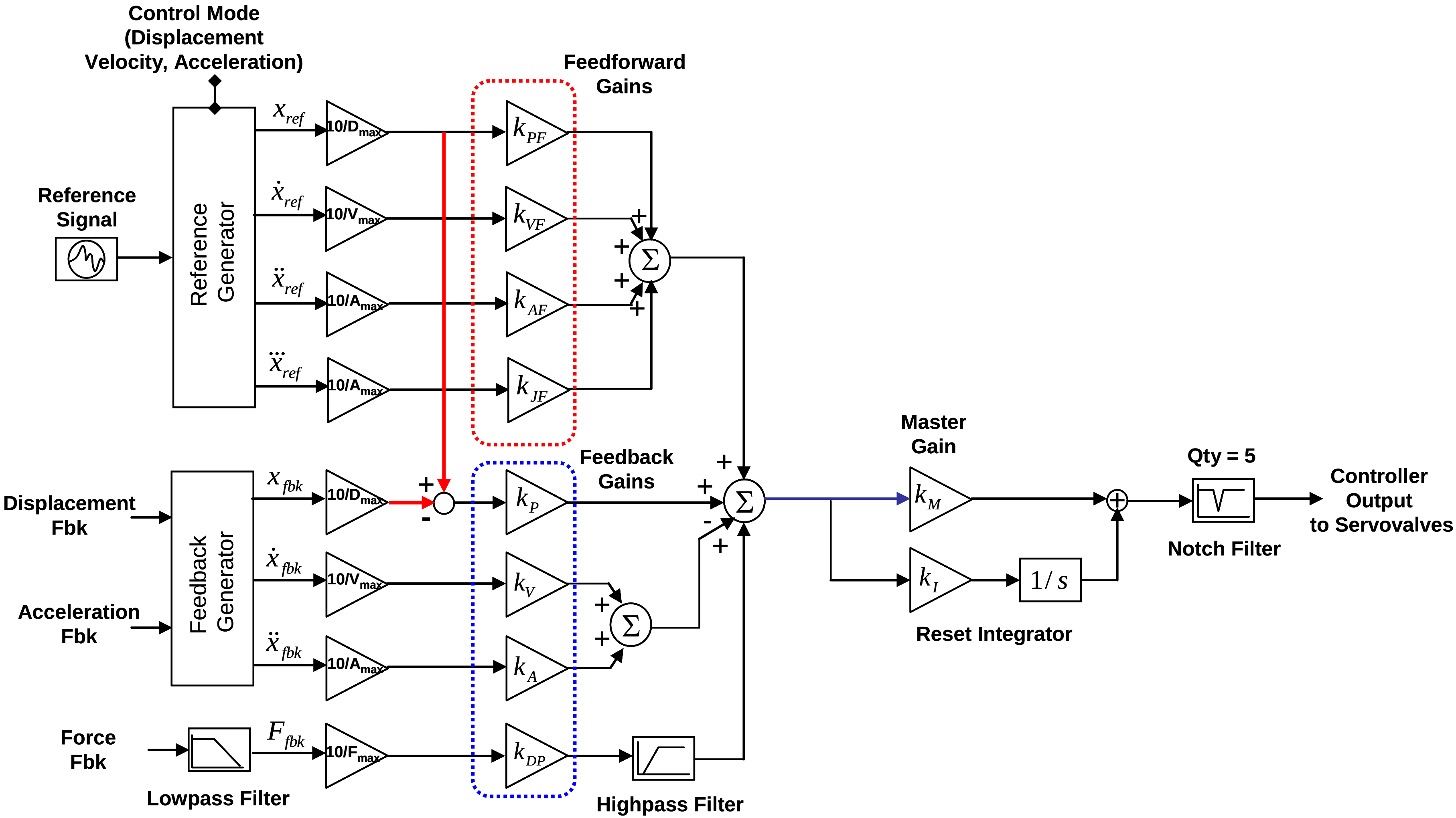
- TVC is a linear **state variable controller**. The three **state variables controlled by TVC** are:
  - Displacement
  - Velocity
  - Acceleration

  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): Iterative signal matching technique
  - 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)

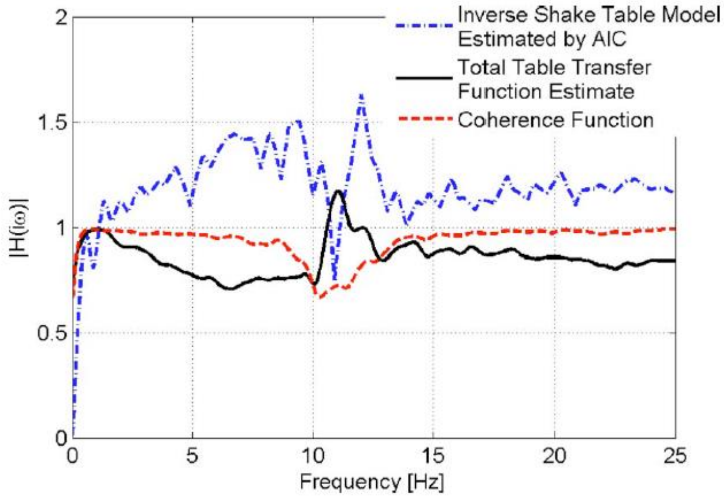


Courtesy of MTS
Systems Corporation

Tuning of LHPOST Controller (MTS 469D)

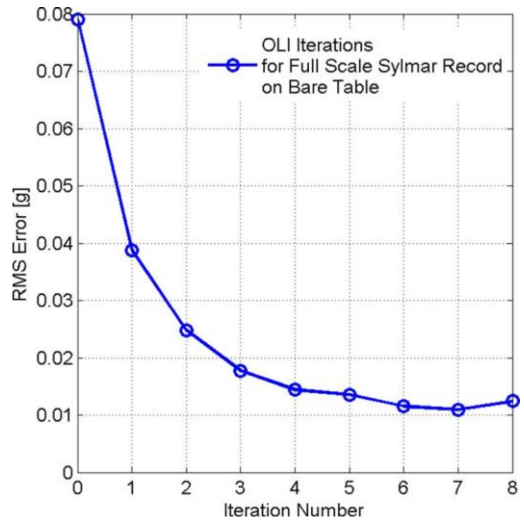
Tuning: Process of adjusting multiple control parameters (e.g., feedback and feedforward gains) and of preconditioning the input motion (through OLI) to optimize signal reproduction (tracking) capability of the shake table system.

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.

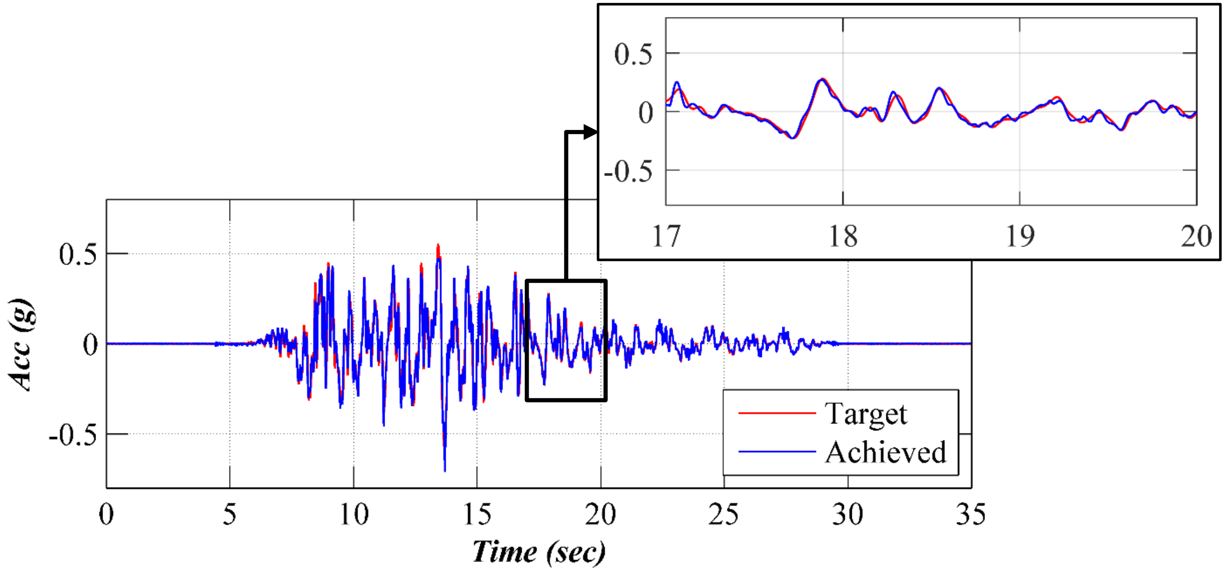


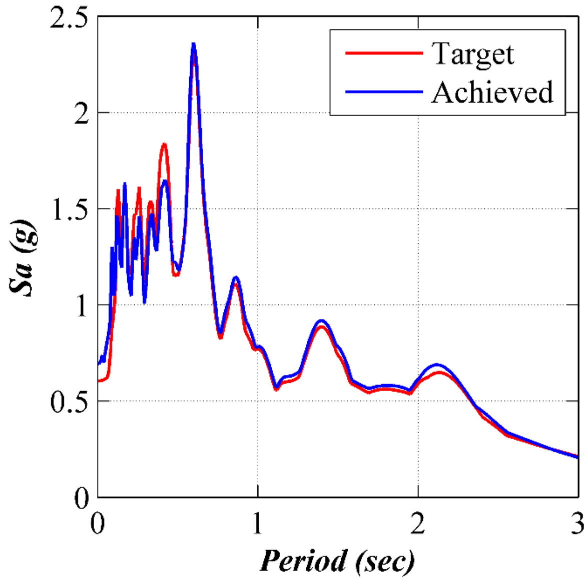
Step 2: Estimation of the inverse model of the plant using the adaptive inverse controller (AIC) technique.

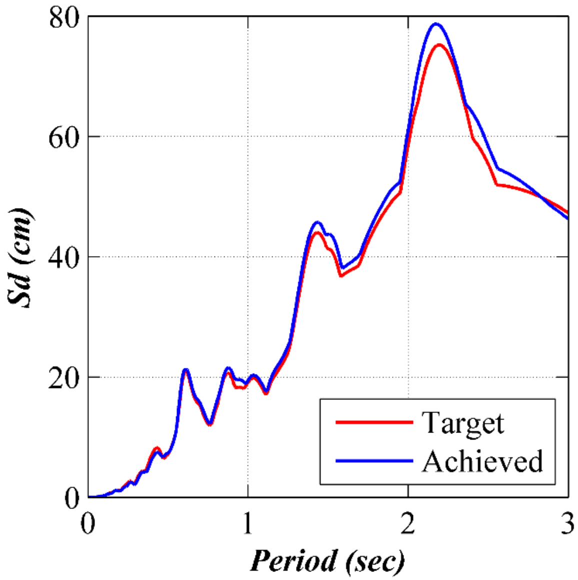
Step 3: Application of iterative time history matching technique called online iteration (OLI). The command input to the shake table controller (drive file) is repeatedly modified to optimize the match between the actual table motion and the desired/target motion.



Tracking Performance of NHERI@UCSD Shake Table



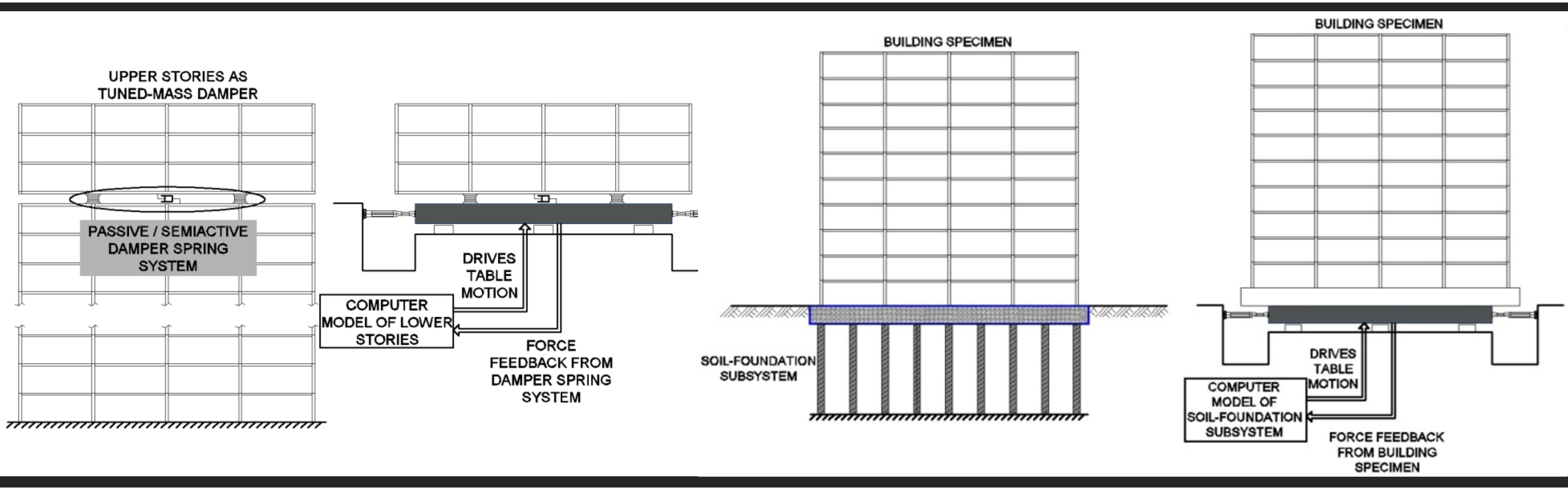




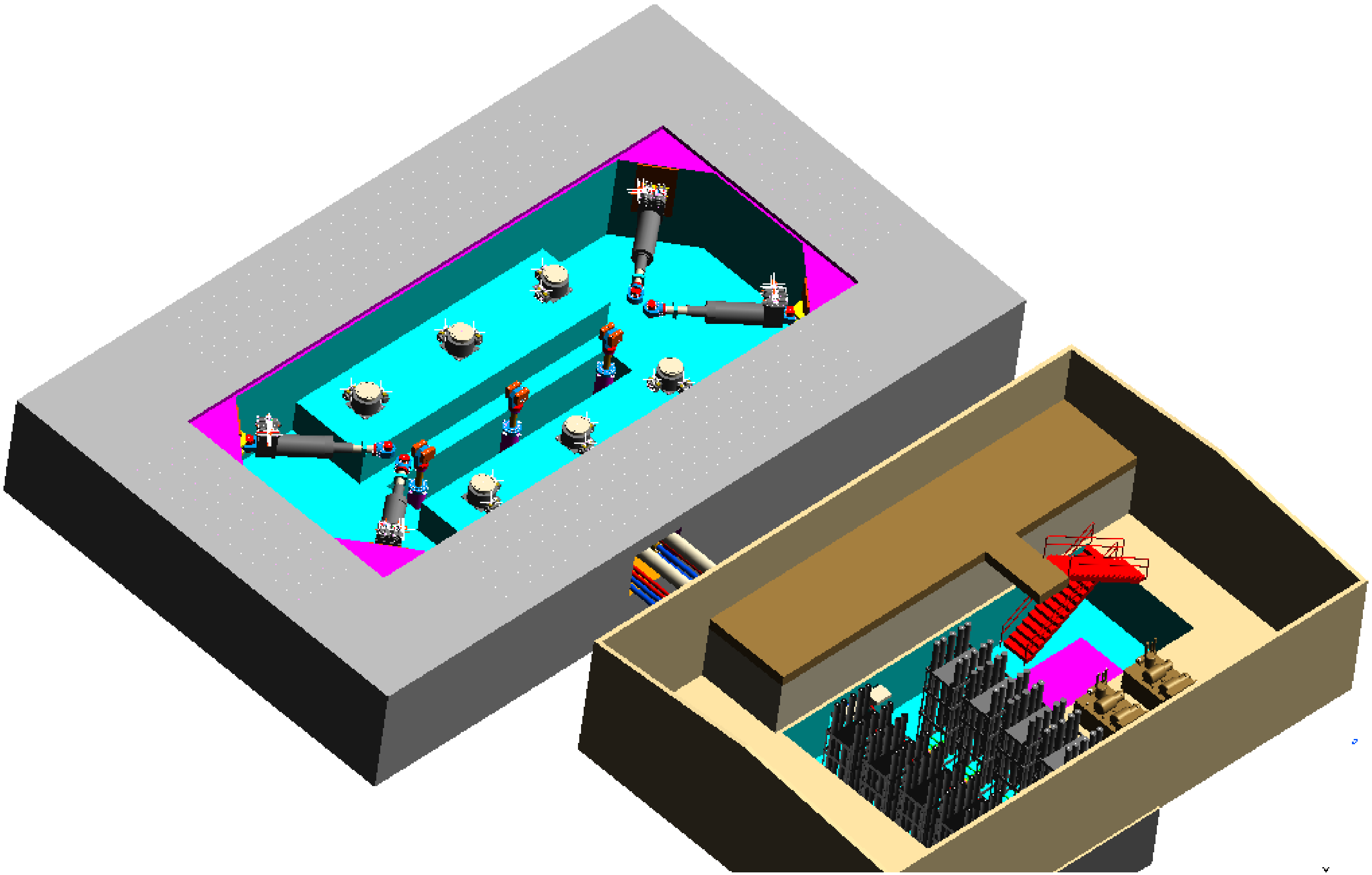
1994 Northridge Earthquake
Canoga Park (comp. 196)
Amplitude scaling: 1.55

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

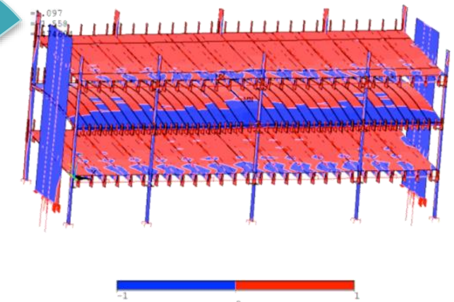
- Materials
- Structural components
- Structural systems

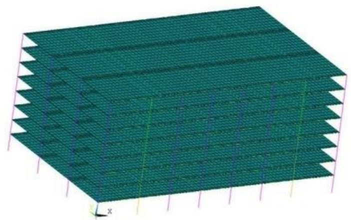
Computational Simulation

- Model development
- Model calibration
- Model validation

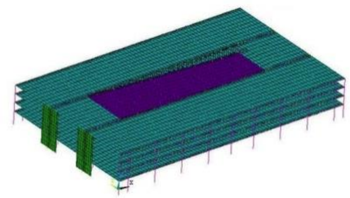
Design Provisions and Assessment Methods

- Development
- Verification through numerical simulation

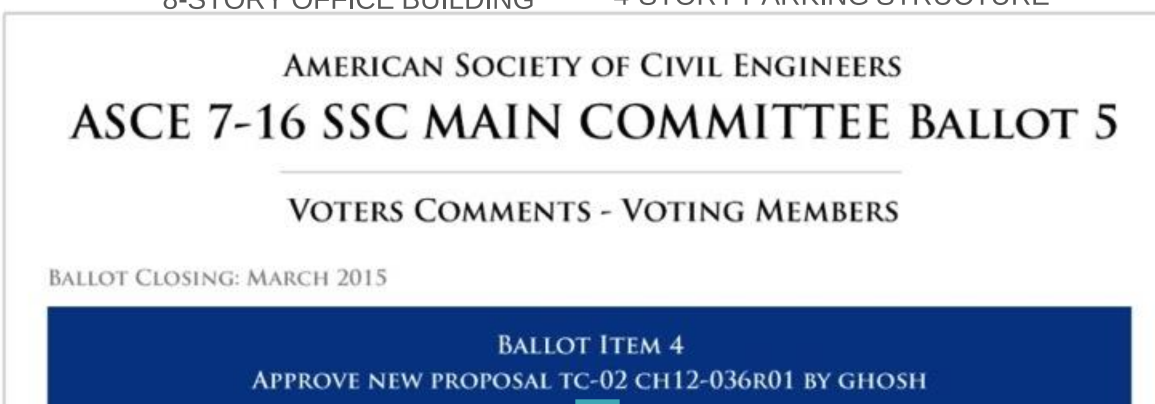




8-STORY OFFICE BUILDING



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

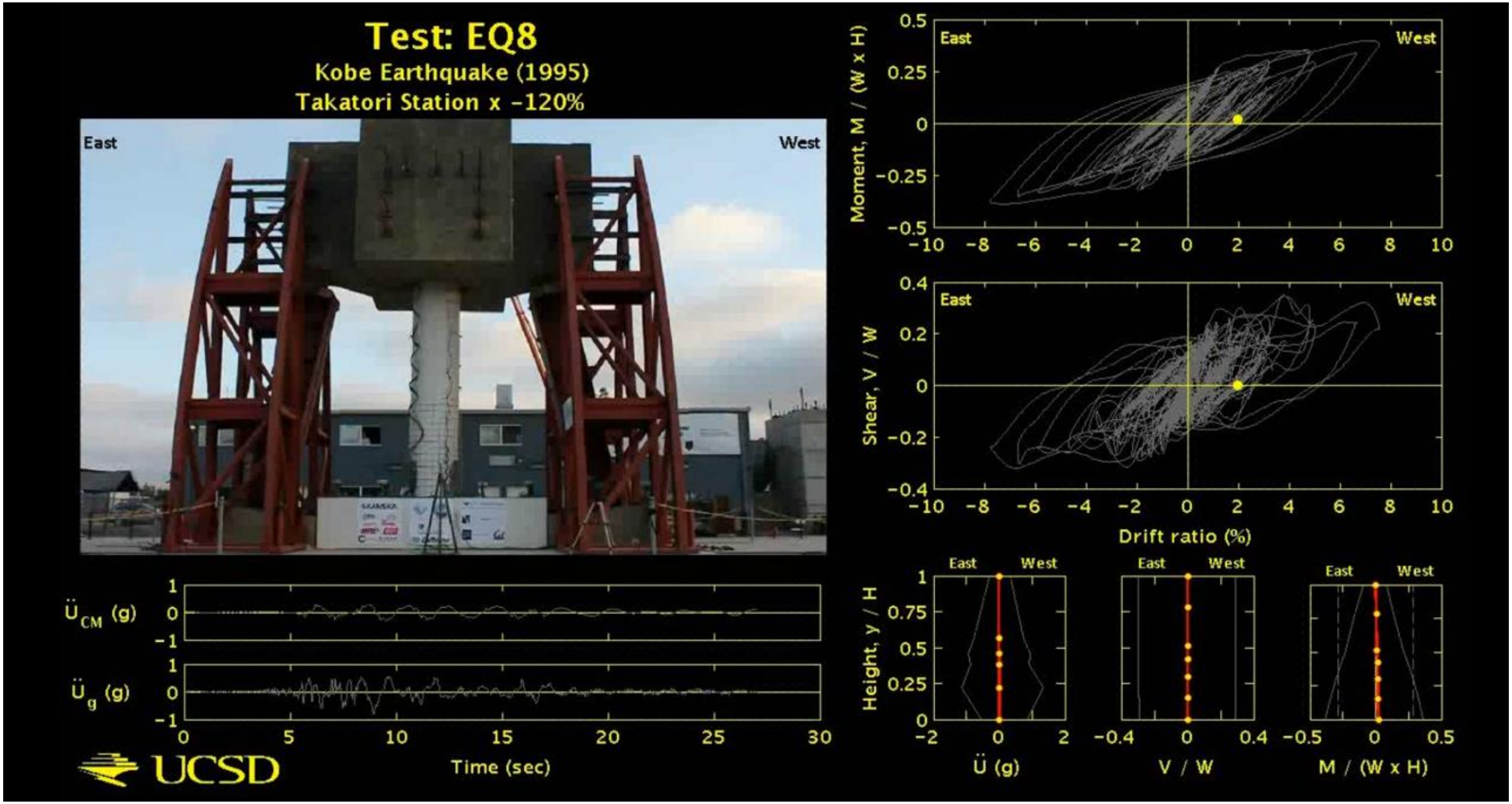
Development of a Seismic Design Methodology for Precast Building Diaphragms.

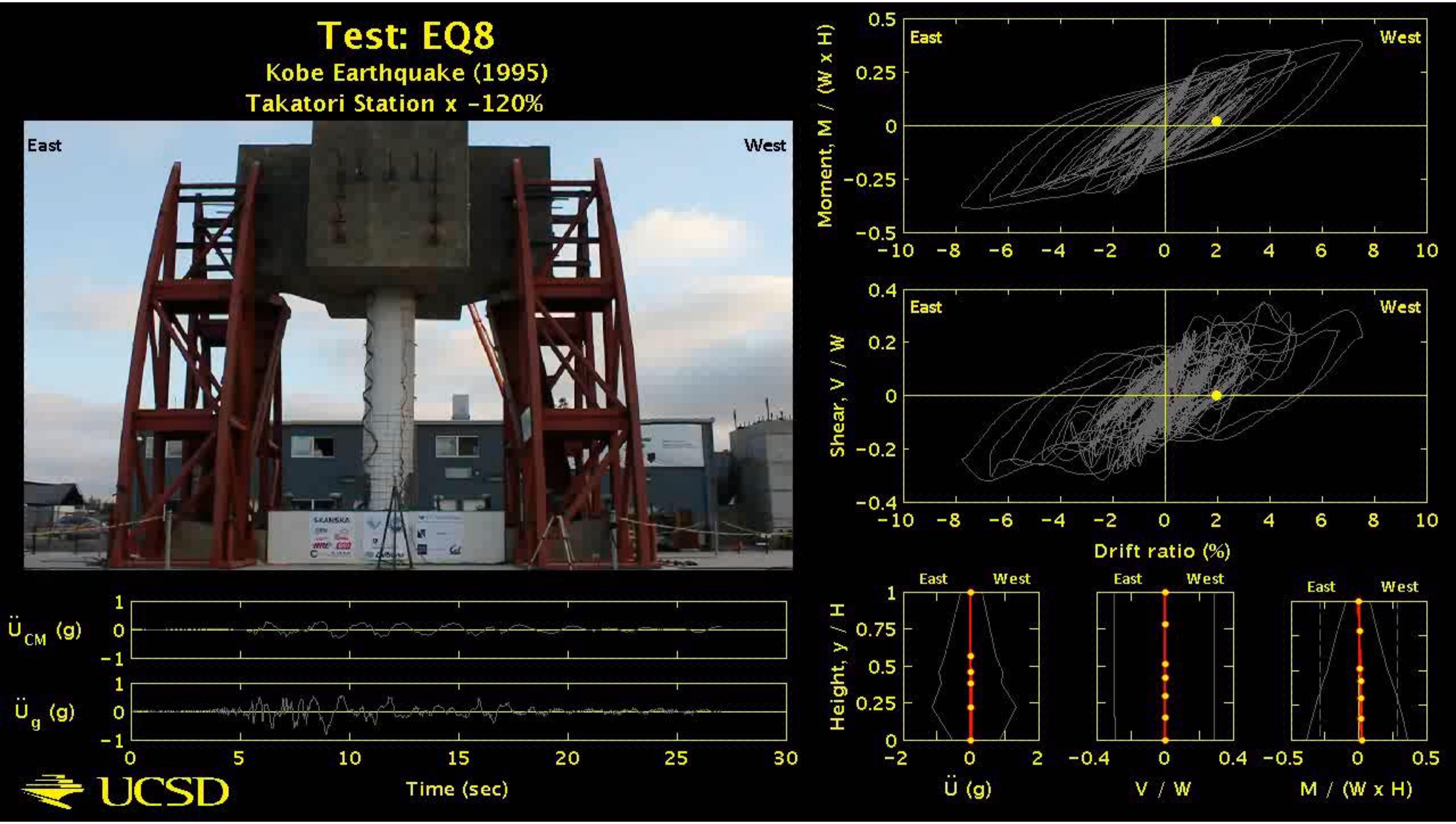
PI – Prof. Robert B. Fleischman University of Arizona

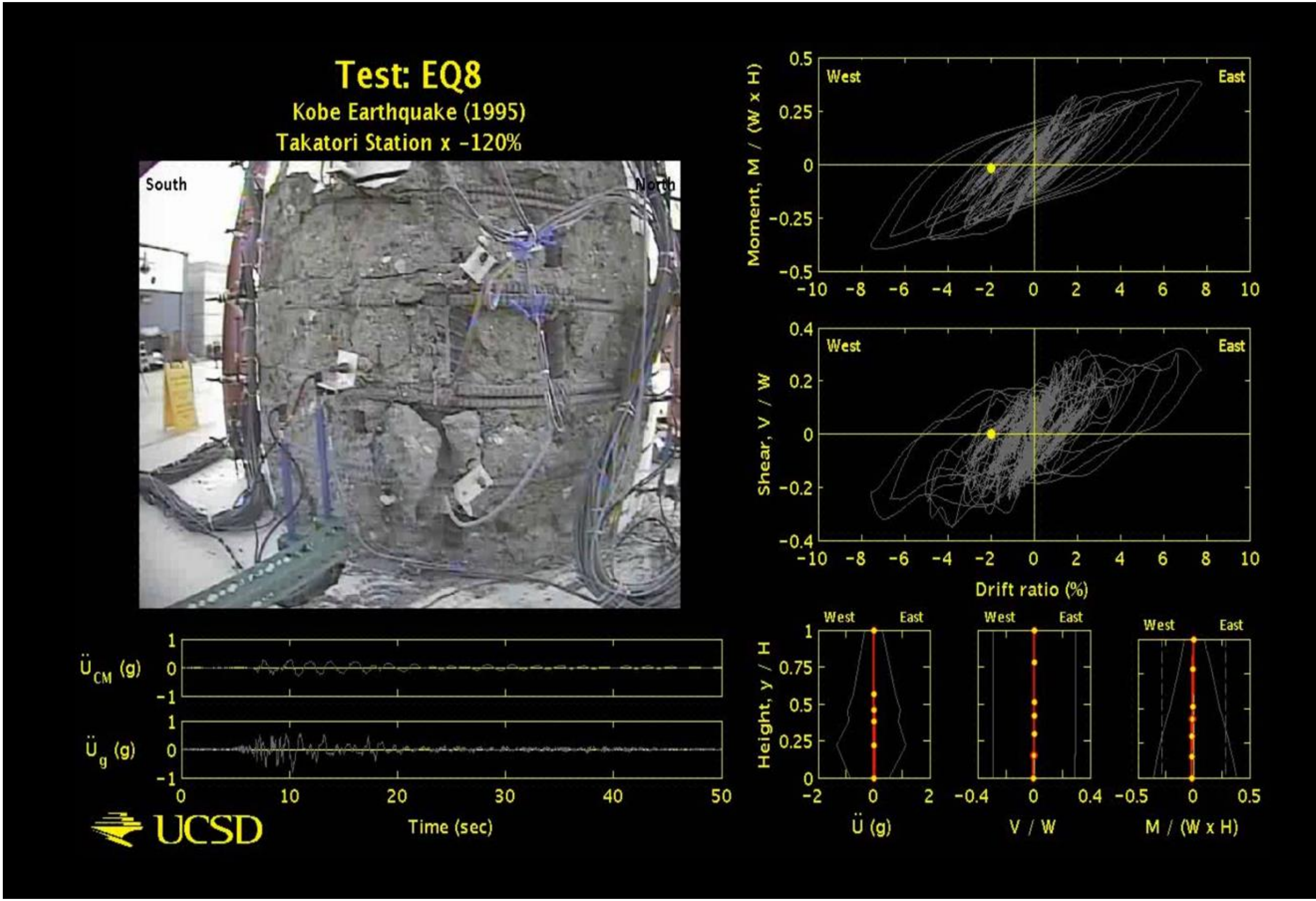

NEES

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
West
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Moment, M / (W x H)
Shear, V / W
Drift ratio (%)
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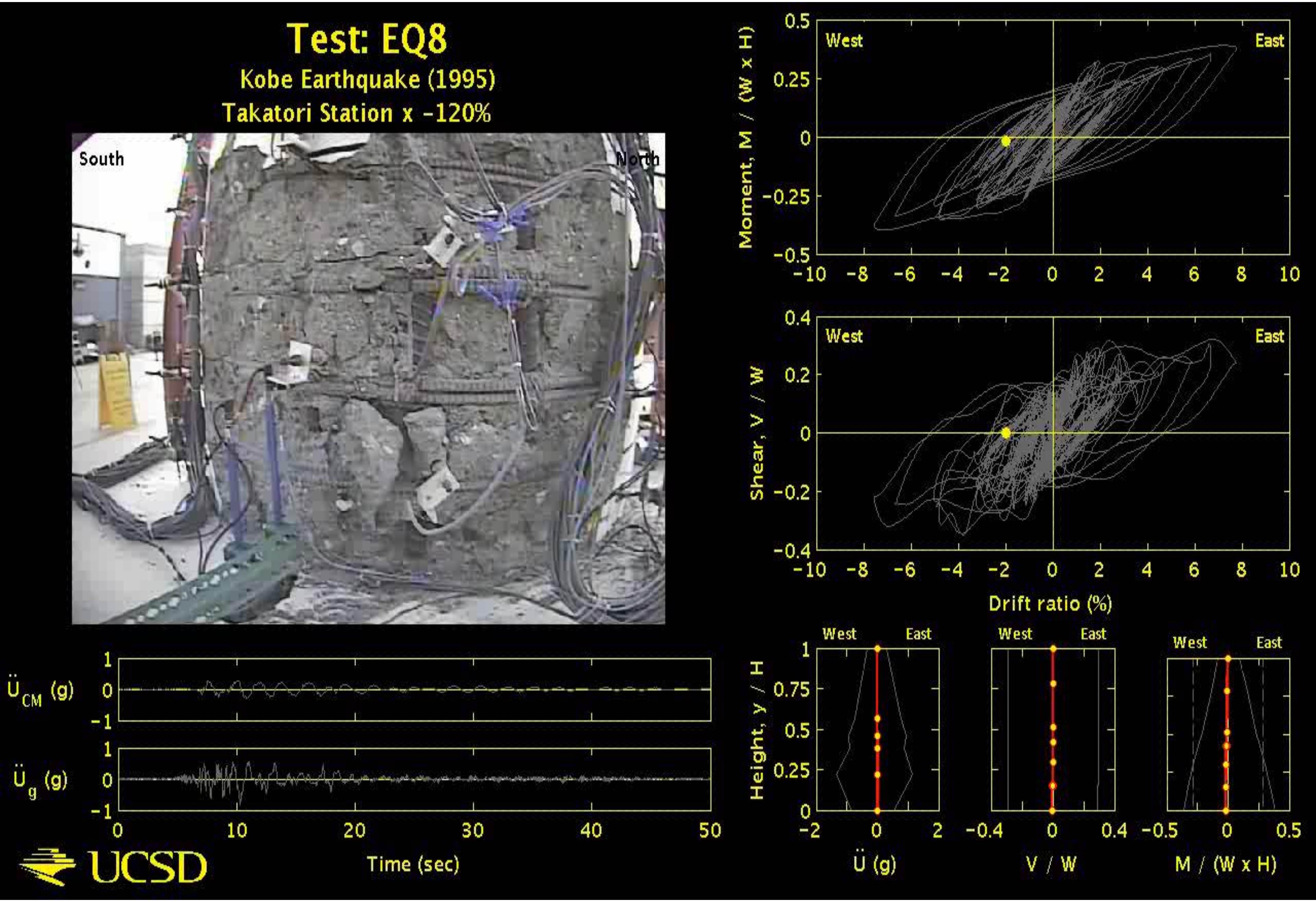
$\ddot{U}_{CM}$ (g)
$\ddot{U}_g$ (g)
Time (sec)
UCSD


Test: EQ8
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Drift ratio (%)
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V / W
M / (W x H)
Ü_CM (g)
Ü_g (g)
Time (sec)
UCSD

Collapse Vulnerability and Seismic Design of Metal Buildings

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

Full-Scale Structural and Non-Structural Building System Performance During Earthquakes

PI - Prof. Tara Hutchinson, UC San Diego

[redacted]

Full-Scale Structural and Non-Structural Building System Performance During Earthquakes

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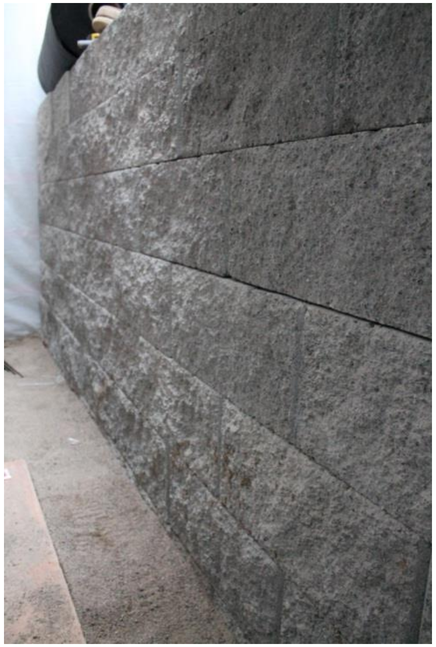
Full-Scale Structural and Non-Structural Building System Performance During Earthquakes

PI - Prof. Tara Hutchinson, UC San Diego

Seismic Performance Tests of Full-Scale Retaining Wall

PI – Prof. Patrick Fox, UCSD

22 ft. Above Table Elevation

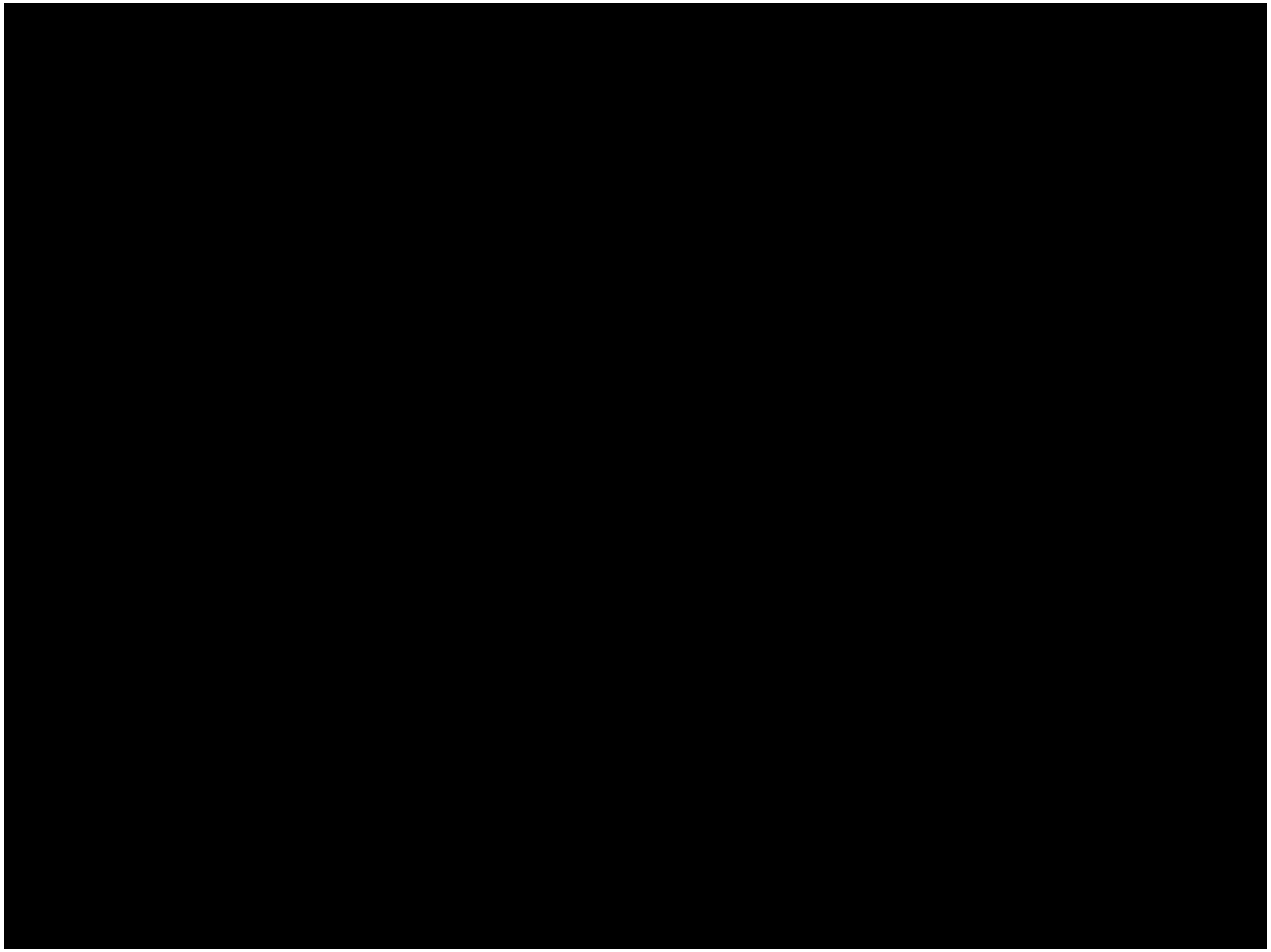


Earthquake Performance of Full-Scale Reinforced Soil Wall

PI: Prof. Patrick Fox, UC San Diego

Earthquake Performance of Full-Scale Reinforced Soil Wall

PI: Prof. Patrick Fox, UC San Diego



Seismic Risk Reduction for Soft-Story Woodframe Buildings

PI - Prof. John W. van de Lindt, Colorado State University

Seismic Risk Reduction for Soft-Story Woodframe Buildings

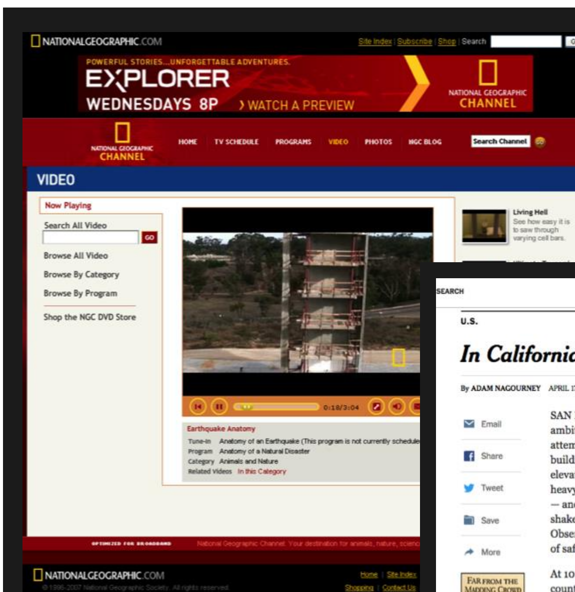
PI - Prof. John W. van de Lindt, Colorado State University

Soil-Foundation-Structure Interaction Test

PI – Prof. Marios Panagiotou, UC Berkeley

Broad Public Dissemination

- Jacobs School of Engineering Communications and Media Relations
- International, National, Regional, and Local Exposure

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