NHERI@UCSD Shake Table Users Training Workshop

Joel P. Conte, Professor

UC San Diego

December 14, 2015

Objectives

- Familiarize prospective users of the NHERI@UCSD 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

8:30 - 9:00am	Registration and Welcome
9:00 - 9:15am	Welcoming Remarks by Benson Shing, Chair of UC San Diego Department of Structural Engineering
9:15 -10:00am	Overview of NHERI Shake Table Experimental Facility at UC San Diego (J. Conte, UC San Diego)
10:00 -10:45am	Overview of NHERI Shake Table Experimental Facility at UC San Diego (J. Conte, UC San Diego)
10:45 -11:00am	Break
11:00 -11:45am	Large-Scale Shake Table Testing (J. Restrepo, UC San Diego)
11:45 - 12:30pm	Example of Total Project Planning – Case Study 1: “PCI Building” (R. Fleischman, U. of Arizona)
12:30 - 1:30pm	Lunch

Workshop Program – Monday Afternoon

1:30 - 2:30pm	Facility Tour
2:45 - 3:30pm	Instrumentation and Data Acquisition (D. Radulescu, R. Beckley, R. Astroza)
3:30 - 3:50pm	NSF Engineering for Natural Hazards (ENH) research program (Joy Pauschke, NSF)
3:50 - 4:05pm	Break
4:05 - 4:50pm	Modeling, Similitude and Simulation (A. Koutras, UC San Diego)
4:50 - 5:05pm	Break
5:05 - 5:50pm	Example of Total Project Planning – Case Study 2: "Geo-Structures" (A. Gavras, UC Davis)
6:00pm	Dinner

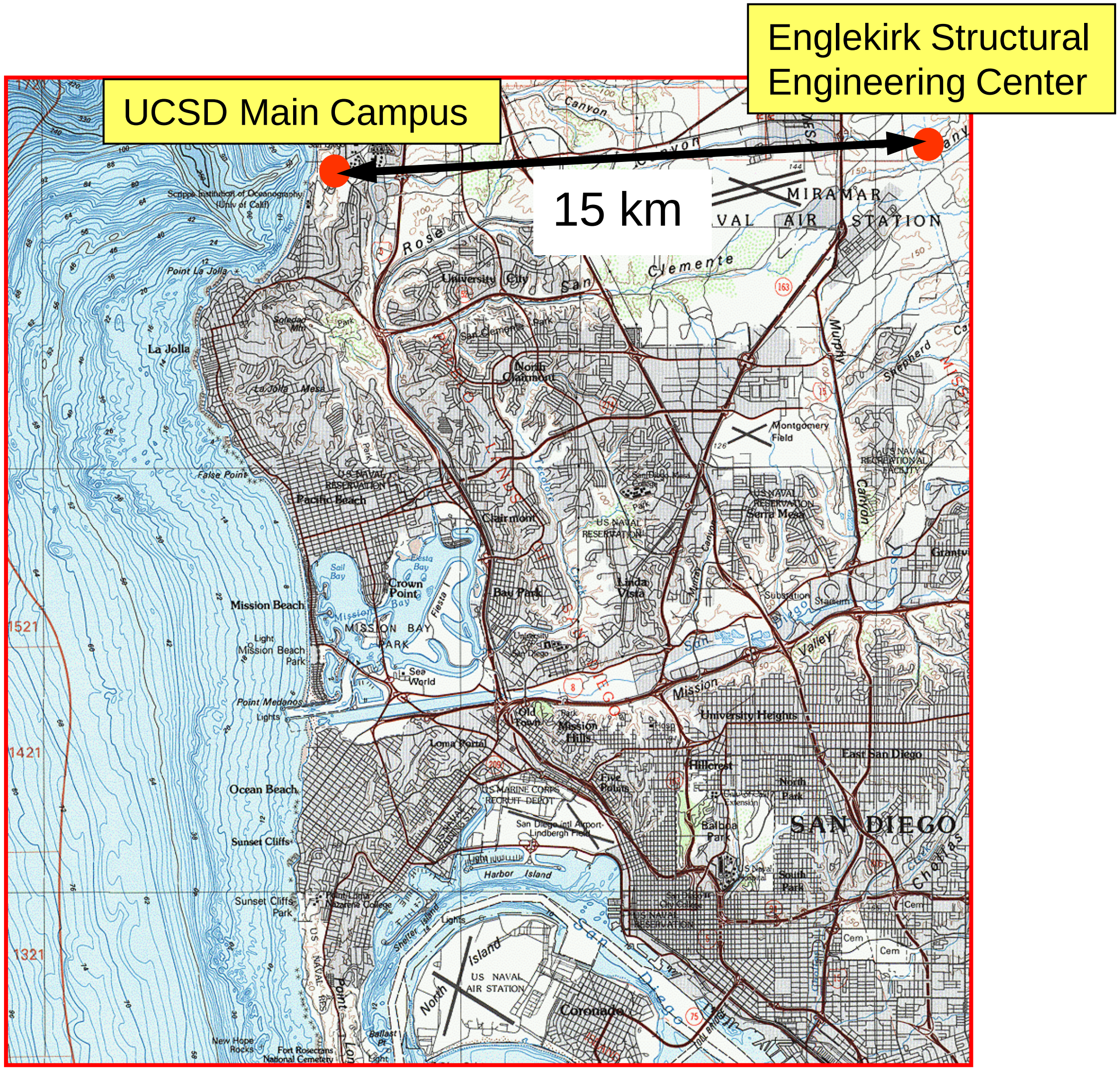
Workshop Program – Monday Afternoon

9:00 - 9:45am	Example of Total Project Planning – Case Study 3: "BNCS Building" (T. Hutchinson, UC San Diego)
9:45 - 10:30am	Data Management, Archiving and Sharing (Elide Pantoli, UC San Diego)
10:30 - 10:45am	Break
10:45 - 11:30am	Hybrid Shake Table Testing (Gilberto Mosqueda, UC San Diego)
11:30 - 12:00pm	Education and Community Outreach (L. Van Den Einde, UC San Diego)
12:00 - 12:30pm	Questions & Answers and Closure
12:30 - 1:00pm	Lunch

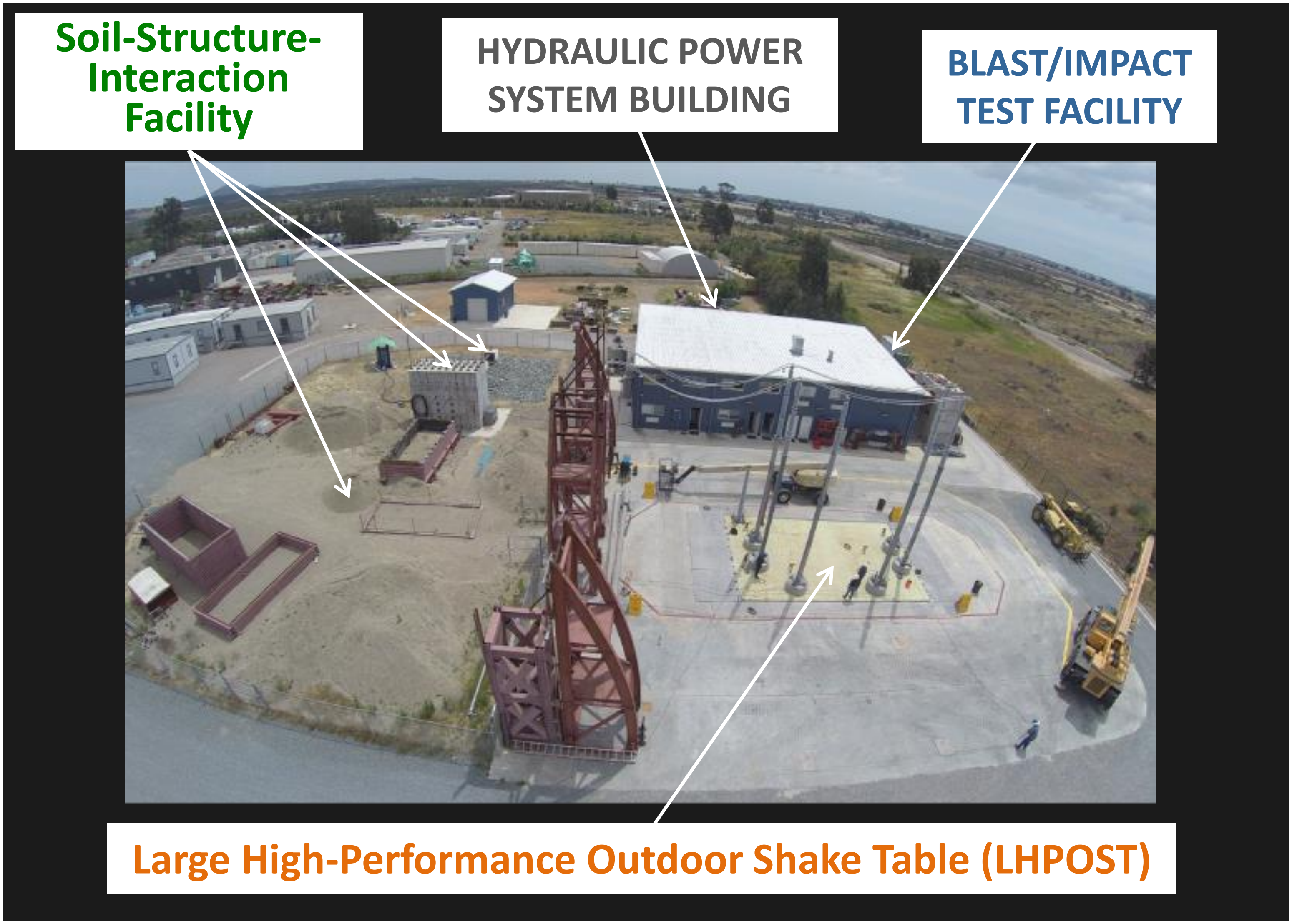
Presenters

- Rodrigo Astroza, UC San Diego
- Joel Conte, UC San Diego
- Andreas Gavras, UC Davis
- Andreas Koutras, UC San Diego
- Elide Pantoli, UC San Diego
- Jose Restrepo, UC San Diego
- Lelli Van Den Einde, UC San Diego
- Robert Beckley, UC San Diego
- Robert Fleischman, U. of Arizona
- Tara C. Hutchinson, UC San Diego
- Gilberto Mosqueda, UC San Diego
- Dan Radulescu
- Benson Shing, UC San Diego

Englekirk Structural Engineering Center



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

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

ilac-MRA

IAS ACCREDITED

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Print Date: 09/25/2013

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Soil-Foundation-Structure Interaction Facility

Bridge Abutment - Soil Interaction
(Caltrans)

Pile – soil interaction
(Port of Los Angeles)

NHERI@UCSD Shake Table Experimental Facility: Overview

Joel P. Conte, Professor

UC San Diego

December 14, 2015

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

Enrique Luco
Senior Personnel

José Restrepo
Senior Personnel

Dan Radulescu
Operations
Manager

Robert Beckley
IT Manager

Linda Johnson
Office Manager

Alex Sherman
Site Foreman

Outline

- Overview of NHERI@UCSD Shake Table Experimental Facility
  - Performance Characteristics
  - Capabilities and Limitations
- Large-Scale Shake Table Tests Performed on the NHERI@UCSD Shake Table
- Table Acceleration Tracking Performance
  - Acceleration Reproduction Fidelity

Mission Statement for NHERI@UCSD Team

- Maintain the shake table for safe, efficient, and accurate operation.
- Assist users with experiment planning, proposal preparation, specimen construction, instrumentation, data acquisition, test performance, specimen demolition and removal.
- Keep NHERI@UCSD at the forefront of experimental shake table technology.

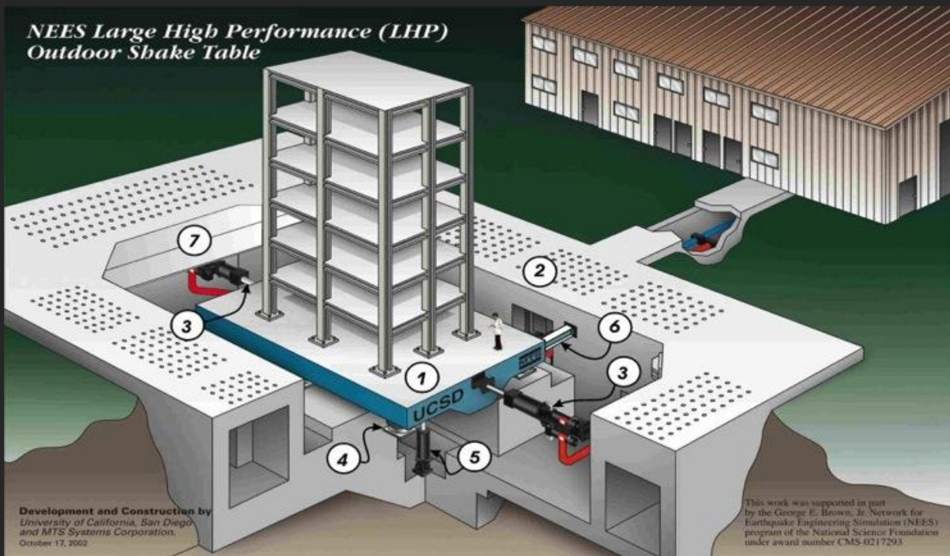
Role of NHERI@UC San Diego Experimental Facility in NSF NHERI Research Program

- Building a seismic-resilient and sustainable built environment requires the understanding and ability to predict more reliably the system-level response of buildings, critical facilities, lifelines, and other civil infrastructure systems to earthquakes.
- Support seismic testing, under near real-world conditions, of large structural, nonstructural, geotechnical, geostructural, and soil-foundation-structural (SFS) systems equipped with hundreds of sensors for detailed monitoring of their seismic response.
- Provide fundamental knowledge and data to support the development, calibration, and validation of high-fidelity, physics-based computational models of structural, geotechnical, and soil-foundation-structural systems.
- Provide validation tests for retrofit methods, protective systems, and the use of new materials, components, systems, and construction methods for seismic resilient and sustainable civil infrastructure.

Large High-Performance Outdoor Shake Table

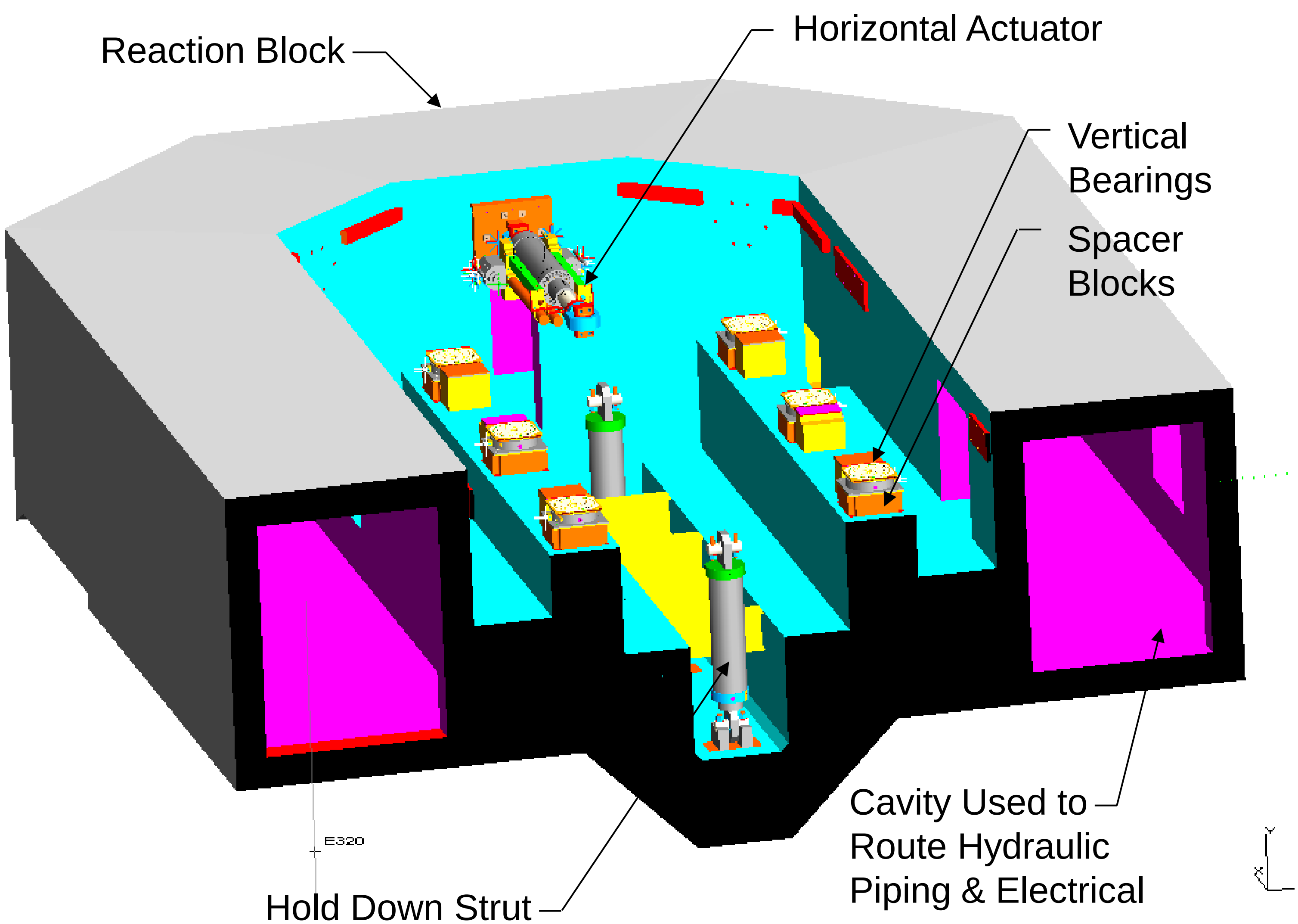
- Designed to permit accurate simulation of severe earthquake ground motions and, particularly, of strong near-source ground motions.
- Lack of height limitation allows testing of full- or very large-scale structural specimens.
- Table designed in 2001-2002, built in 2002-2004, and commissioned on October 1, 2004, under the NSF NEES Program.
- 24 major tests were performed In 10 years of operation:
  - Reinforced concrete buildings and bridge column
  - Precast concrete parking structure
  - Unreinforced and reinforced masonry building structures
  - Metal building structures
  - Woodframe buildings
  - Wind turbine
  - Soil retaining walls

Large High-Performance Outdoor Shake Table

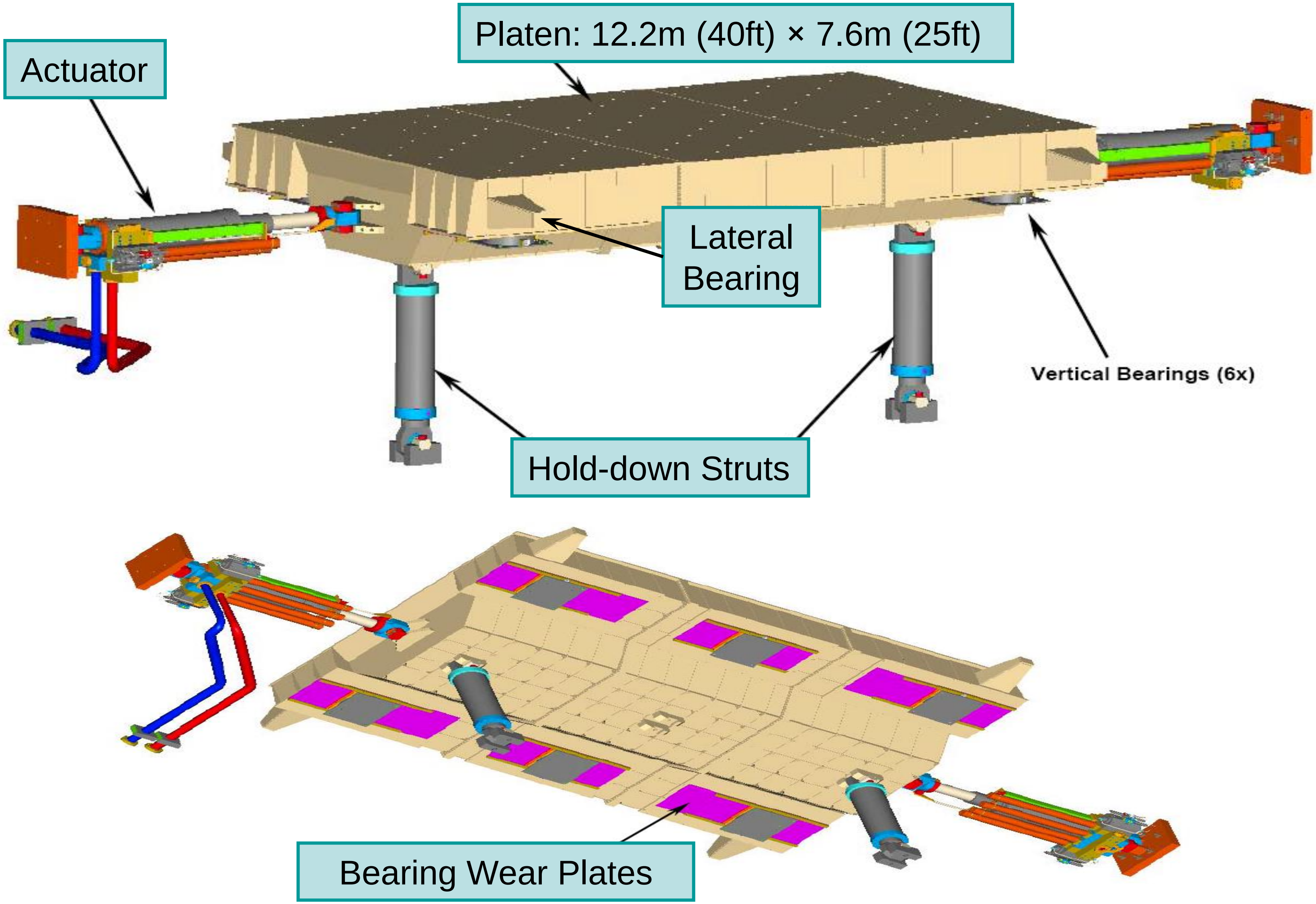


Performance Characteristics in Current 1-DOF Configuration	
Designed as a 6-DOF shake table, but built as a 1-DOF system to accommodate funding available	
Stroke	±0.75m
Platen Size	40 ft × 25 ft (12.2 m × 7.6 m)
Peak Velocity	**1.8 m/sec**
Peak Acceleration	4.7g (bare table condition); 1.2g (4.0MN/400 tons rigid payload)
Frequency Bandwidth	0.25 − 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)

Connection of Platen to Reaction Block

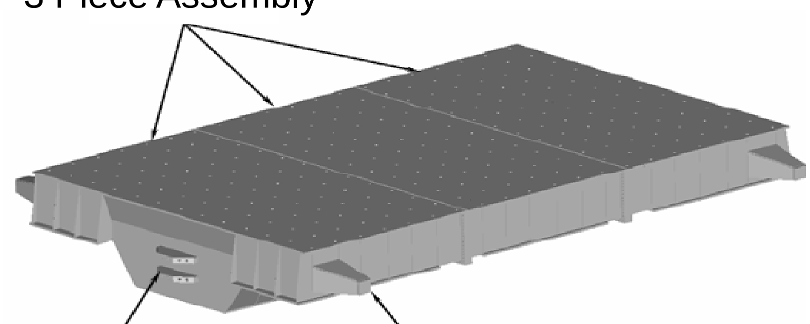


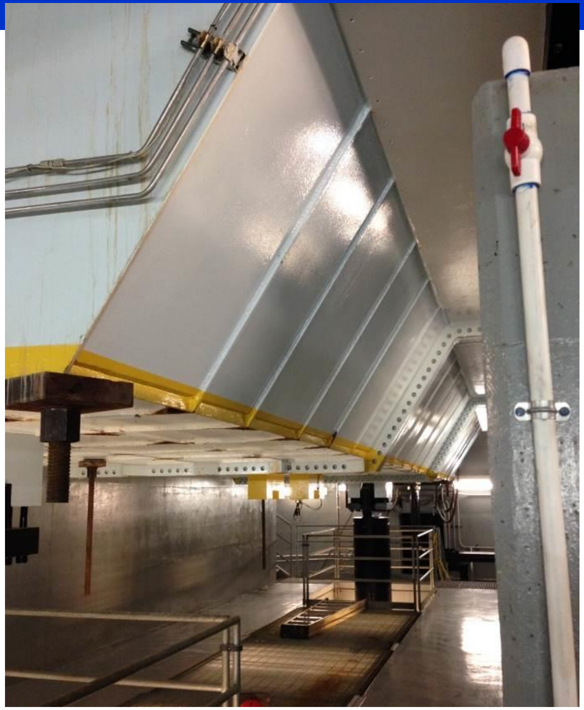
Platen, Actuators, Hold-Down Struts, and Bearing Wear Plates



Technical Characteristics of Table Platen

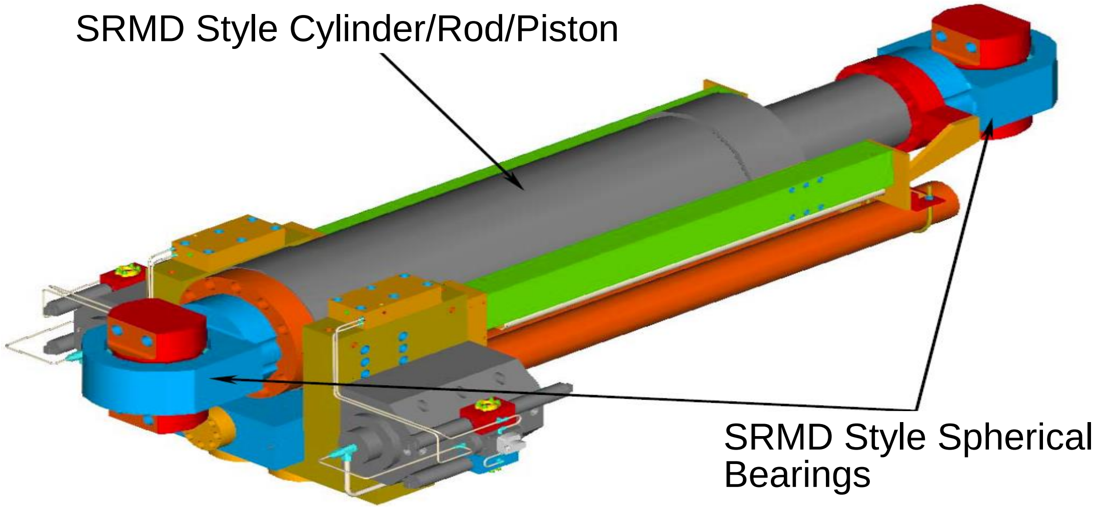
Table Platen	
Platen Dimensions	7.6m x 12.2m
Platen Weight Platen Effective Mass	1.128 MN 1.440 MN/g
Maximum Specimen Payload (Rigid Payload)	20 MN
Maximum Overturning Moment	50 MN-m





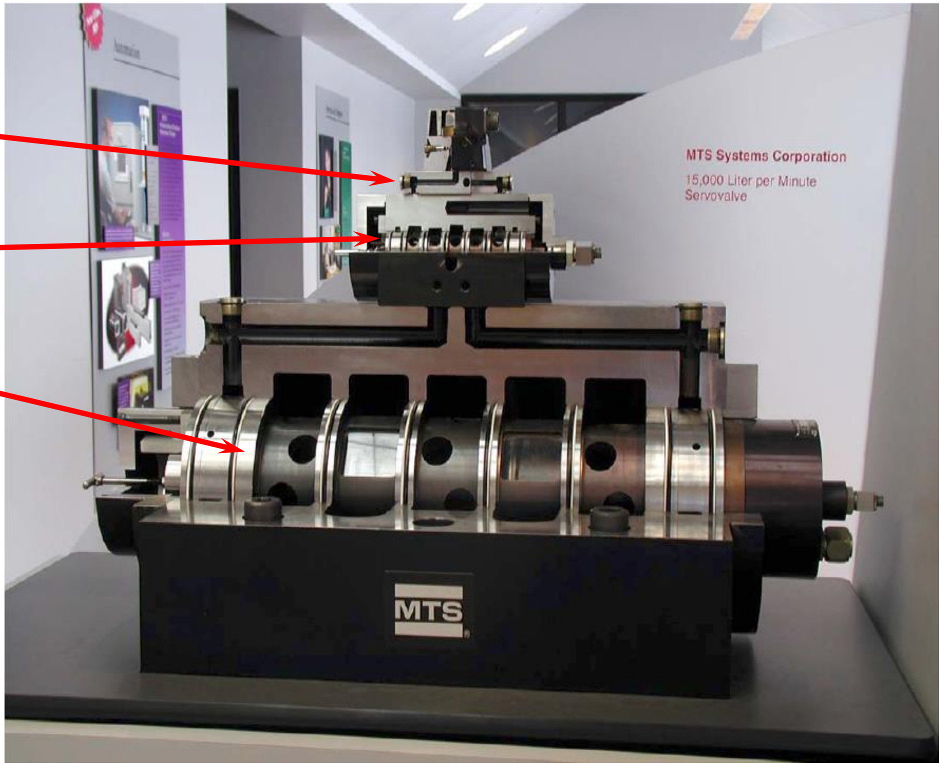
Technical Characteristics of Actuators

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

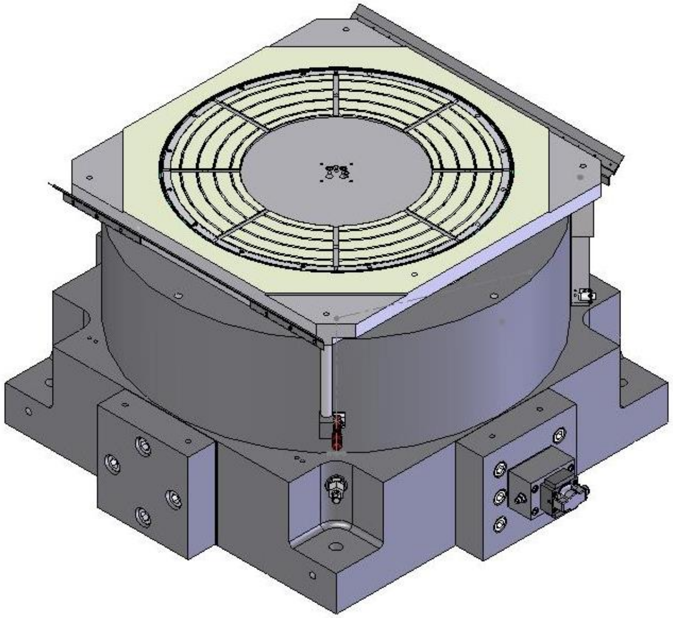


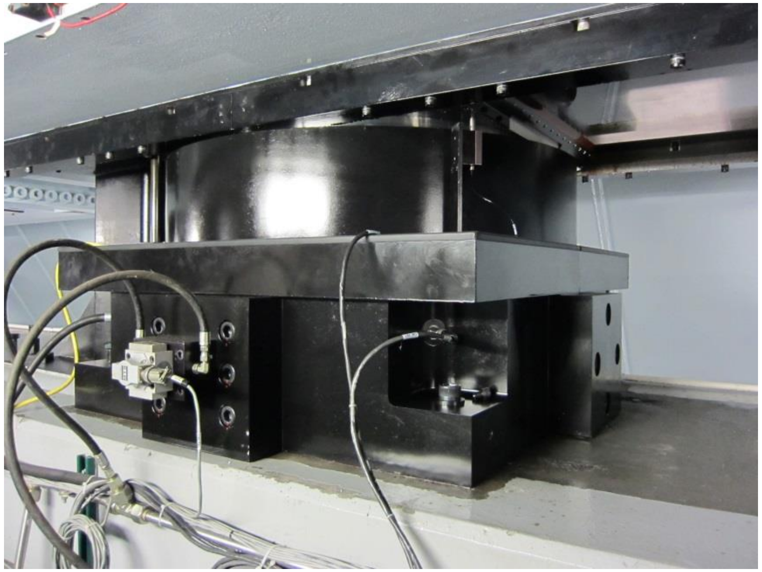
Technical Characteristics of Hold-down Struts

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 Vertical Bearings

Vertical Bearings (Qty. 6)	
Effective Bearing Area	0.519 m^2
Vertical Force Capacity	10.0 MN
Stroke	± 0.013 m

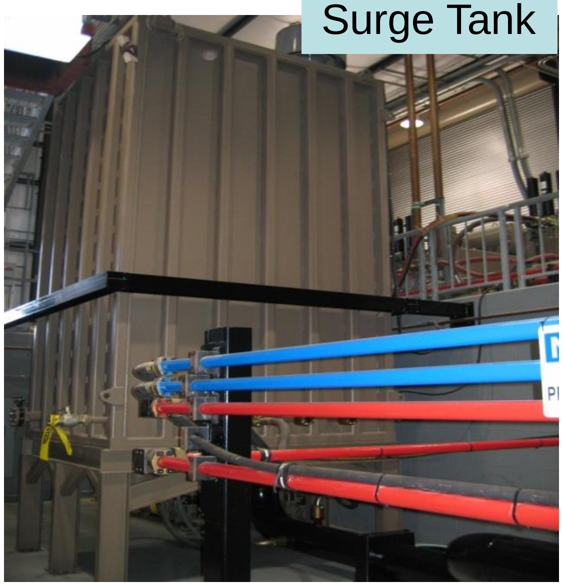




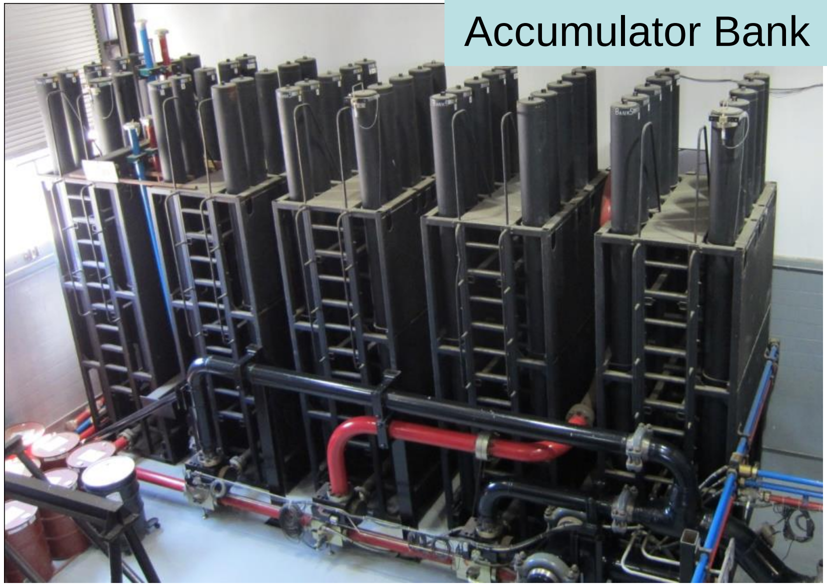
Technical Characteristics of Hydraulic Power System

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

Use of LHPOST in Combination with Large Soil Boxes

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

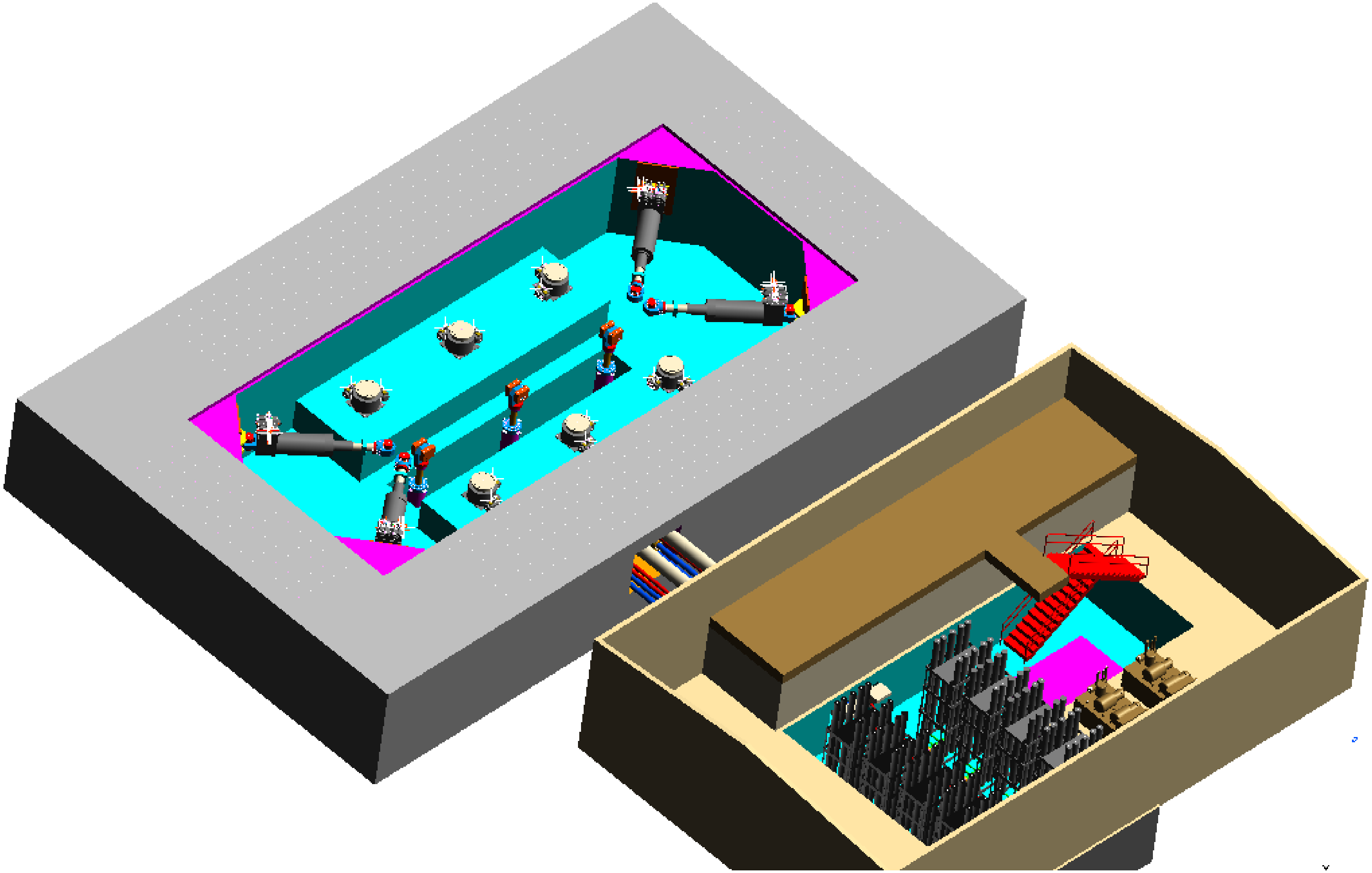
Stiff soil confinement box:
10.0m (L) × 4.6 or 5.8m (W) × 7.6m (H)

- 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

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
- High-speed cameras.
- GPS system providing dynamic displacement monitoring in three coordinates.
- Calibration equipment for data acquisition systems and sensors.

Future upgrade of LHPOST to 6 DOFs



Selected Set of Specimens tested on the LHPOST













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

PI - Prof. Tara Hutchinson, UC San Diego

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

PI - Prof. Tara Hutchinson, 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

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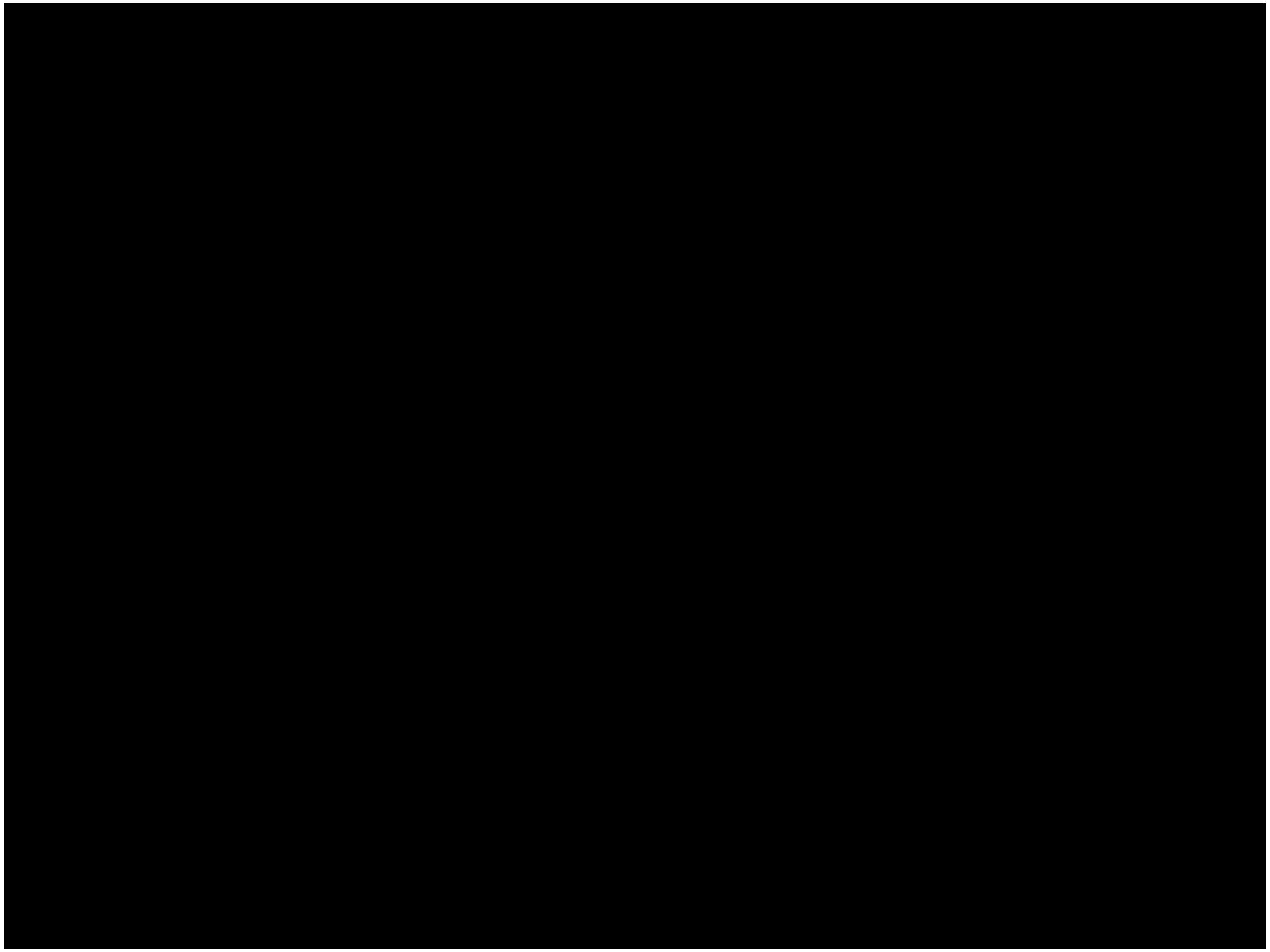

Seismic Risk Reduction for Soft-Story Woodframe Buildings

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

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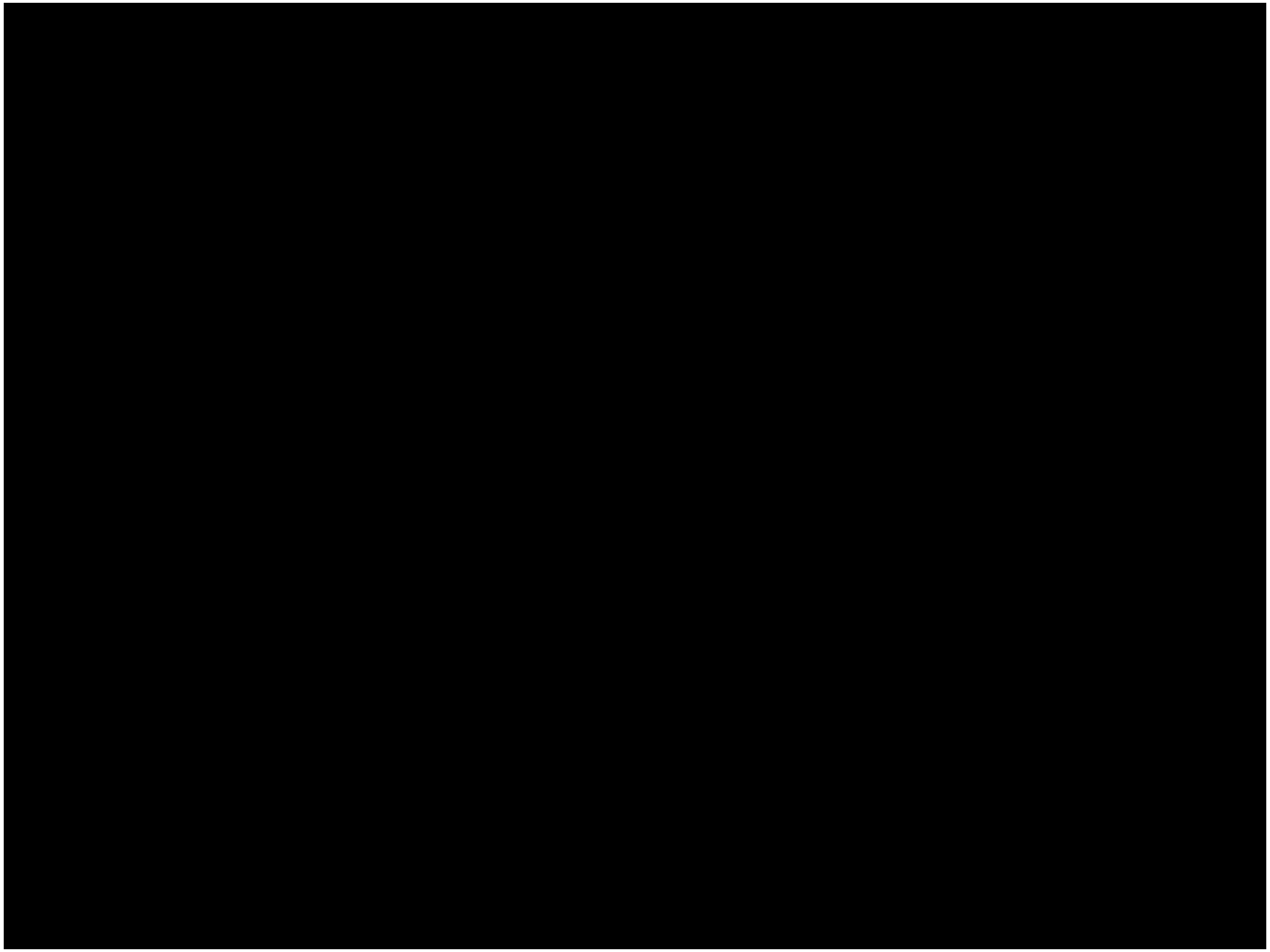
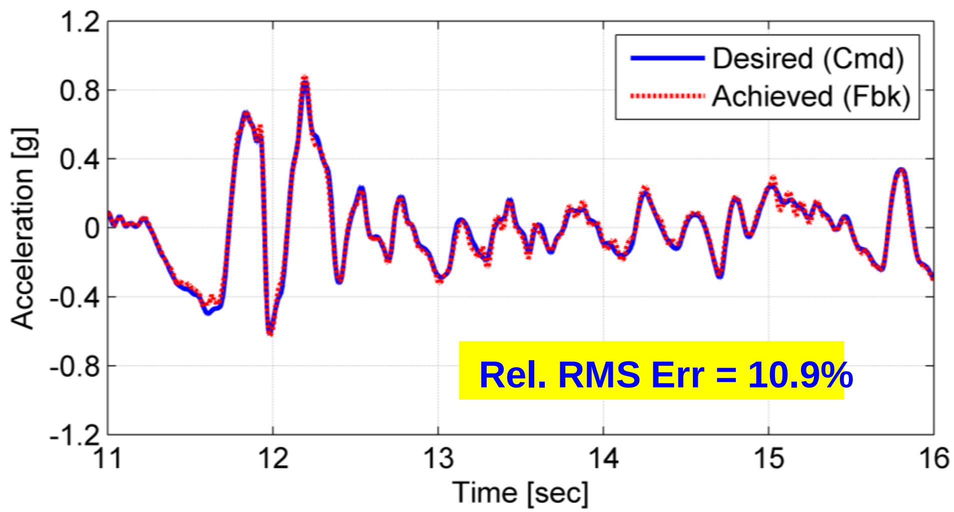


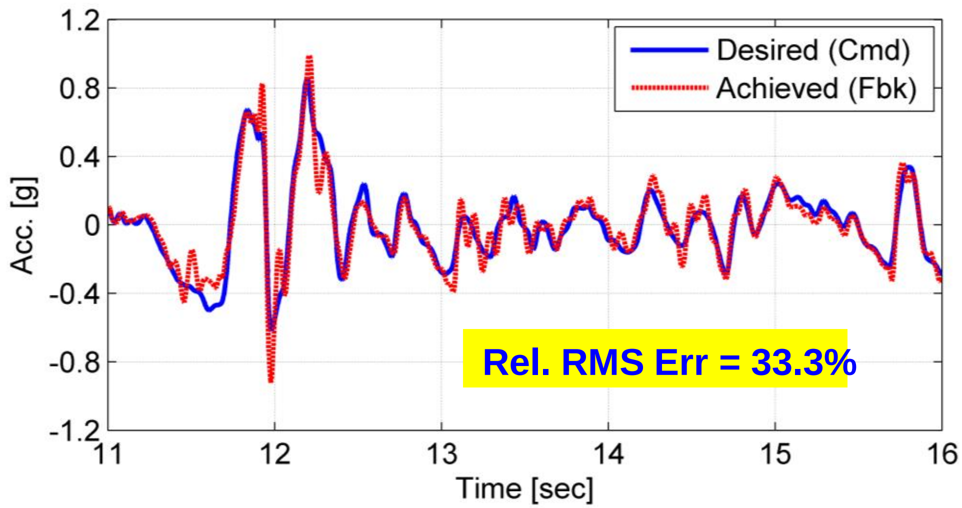
Seismically Isolated Unibody Residential Buildings for Enhanced Life-Cycle Performance

PI - Prof. Gregory Deierlein, Stanford University

Table Acceleration Tracking Performance
(1994 Northridge Earthquake Record at Sylmar Station)



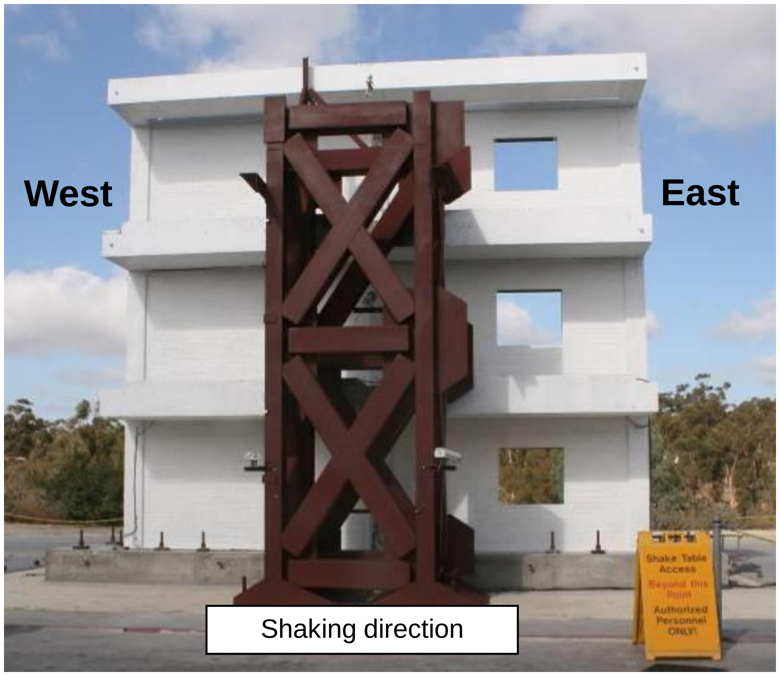
OLI @0.852g PGA
Test @0.852g PGA

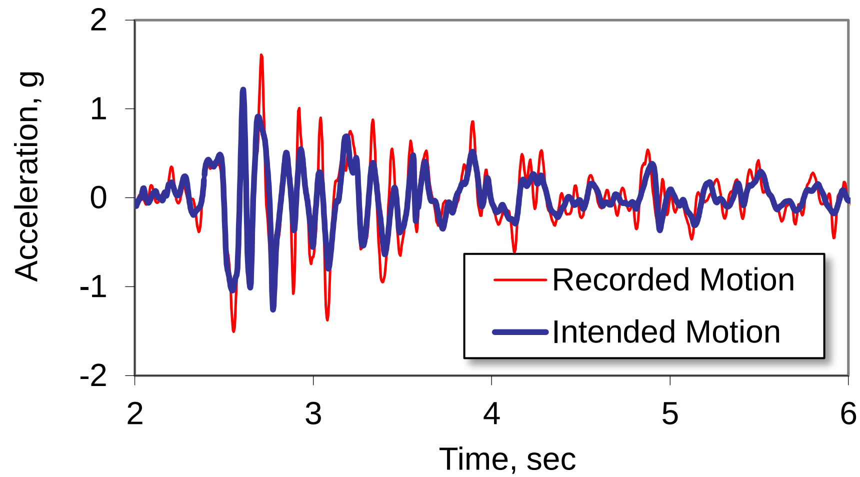


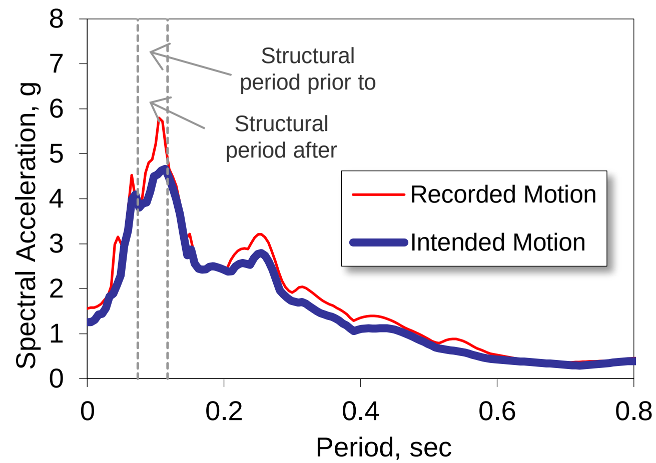
OLI @0.170g PGA
Test @0.852g PGA

Reinforced Concrete Frame Infilled with Unreinforced Masonry Walls

PI - Prof. Benson Shing, UC San Diego





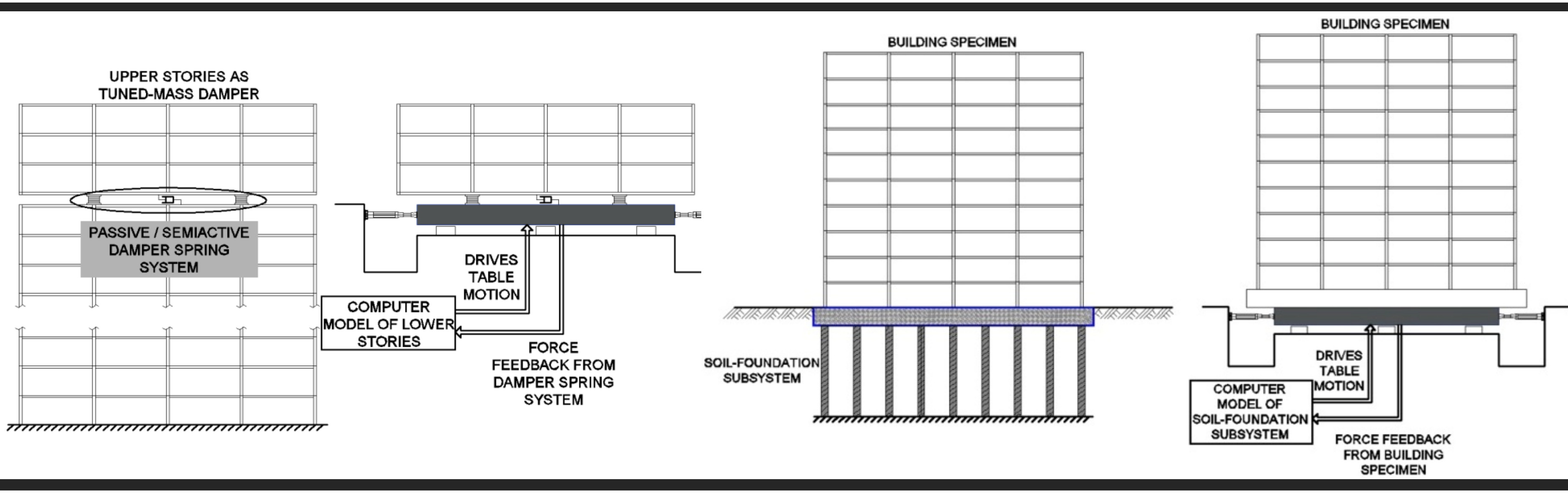


100% of Gilroy 3 (1989 Loma Prieta Earthquake)

- Corresponds to the MCE for San Diego for this structure
- Scaled in amplitude by 2.27
- Compressed in time by 0.542

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



Education and Community Outreach

Broad Public Dissemination

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


La estructura incluirá aisladores sísmicos chilenos

Recrearán en EE.UU. el terremoto del 27-F en un edificio experimental de cinco pisos

La actividad forma parte de un ciclo de simulación de sismos que tendrá lugar la próxima semana en la Universidad de California, en San Diego.

Así es la mesa vibradora que replica sismos

Tres desafíos

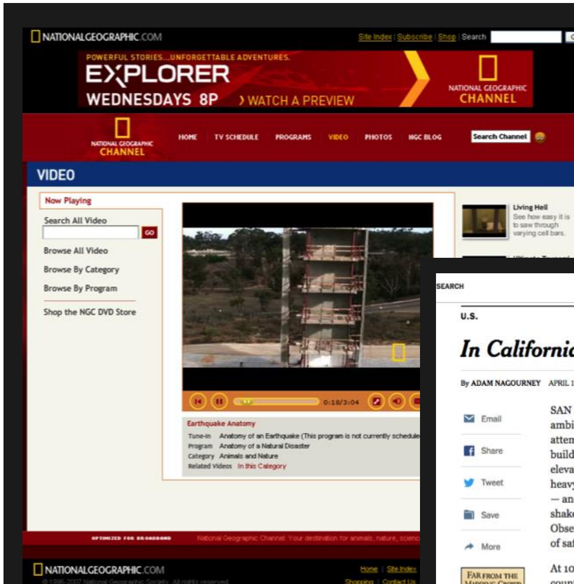
Crece desarrollo de aisladores

Para teléfonos inteligentes:

Dos aplicaciones nacionales sacan provecho al GPS

Canal 13C Documental sobre chilenos en Silicon Valley

Éxito de la cirugía: Edad del donante vivo no incide en un trasplante




The New York Times

U.S.

In California Quake Research, Boring Is the Hoped-for Result

By ADAM NAGOURNEY APRIL 17, 2012

SAN DIEGO — It was billed as one of the most ambitious earthquake simulations ever attempted. Engineers constructed a five-story building — complete with an operating room, an elevator, a kitchen loaded with glassware and a heavy air-conditioning unit perched on the roof — and placed it atop a platform known as a shake table on the outskirts of San Diego. Observers were issued hard hats and a strict set of safety instructions.

At 10:30 a.m. Tuesday, after an ominous countdown and as red warning lights whirled, the shake table unleashed the mechanical equivalent of a one-minute earthquake that replicated the 6.7-magnitude Northridge temblor that rolled through Los Angeles in 1994. It was the first of two earthquake re-enactments

Researchers conducted two earthquake simulations in San Diego on Tuesday. Sam Hodgson for The New York Times

Workflow

BEFORE signing of the contract:

NSF Researcher	NHERI Site
1. Contact site PI and send the proposal to check the feasibility of using the LHPOST.	1. Site to respond with comments regarding the test requirements, schedule, and site obligations.
2. Send NSF approval as a NHERI project.	
3. Send proposed Input Motions to check them against table performance limits.	

Workflow

AFTER the contract is signed:

NSF Researcher	NHERI Site
1. Prepare and send all contractors information to be added to the University system.	1. Present Site Safety Rules.
2. In case some portions of the specimen can be constructed off the table, coordinate with the site for space and equipment required.	2. Provide office space for the researcher and/or his/her students.
3. Prior to occupying the table, send the Input Motions to perform the OLI (table tuning/calibration).	3. Provide Internet access (telepresence, including real-time cameras).

Workflow

AFTER the contract is signed:

NSF Researcher	NHERI Site
4. Send instrumentation plan.	4. Provide technical assistance when requested.
5. Send a draft of the Test Sequence.	5. Install sensors and connect them to our DAQ system.
6. Send information related to sensors needed.	6. Install cameras per researcher instrumentation plan.
7. If the researcher uses his/her own DAQ, send information to check if it is possible to synchronize it with our DAQ.	7. Test the specimen.

Workflow

AFTER the contract is signed:

NSF Researcher	NHERI Site
8. Under the supervision of Alex Sherman (site foreman), begin construction of the specimen.	8. Remove the instrumentation.
9. After the end of testing, demolish the specimen and take it off site.	

THANK YOU!

NHERI@UC San Diego

NHERI@UC San Diego Personnel

Joel Conte
PI

Tara Hutchinson
Co PI

Gilberto Mosqueda
Co PI

Benson Shing
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Lelli Van Den Einde
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José Restrepo
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Dan Radulescu
Operations Manager

Robert Beckley
IT Manager

Linda Johnson
Office Manager

LHPOST Performance Specifications

- Size: 12.2 m x 7.6 m
- Vertical Payload: 20 MN
- Frequency Bandwidth: 0-20 Hz
- Phase 1: Uniaxial System:
  - Stroke: ± 0.75 m; Velocity: ± 1.8 m/sec; Acceleration: ± 3g
- Phase 2: Triaxial System:

Direction	Acceleration	Velocity	Displacement
Horizontal-X	±3g	±1.8m/s	±0.75m
Horizontal-Y	±1.5g	±0.9m/s	±0.375m
Vertical	±1.0g	±0.5m/s	±0.150m