National Science Foundation

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

UC San Diego JACOBS SCHOOL OF ENGINEERING Structural Engineering

NHERI@UC San Diego: Facility Description and Capabilities

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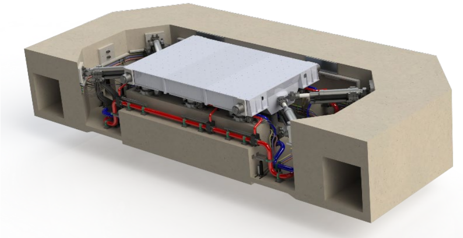
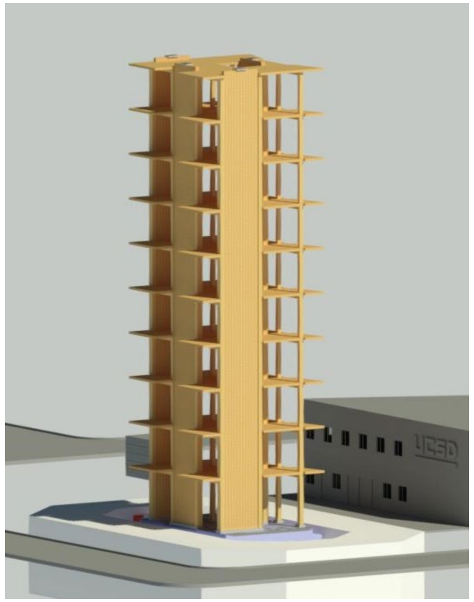




2023 PEER Annual Meeting

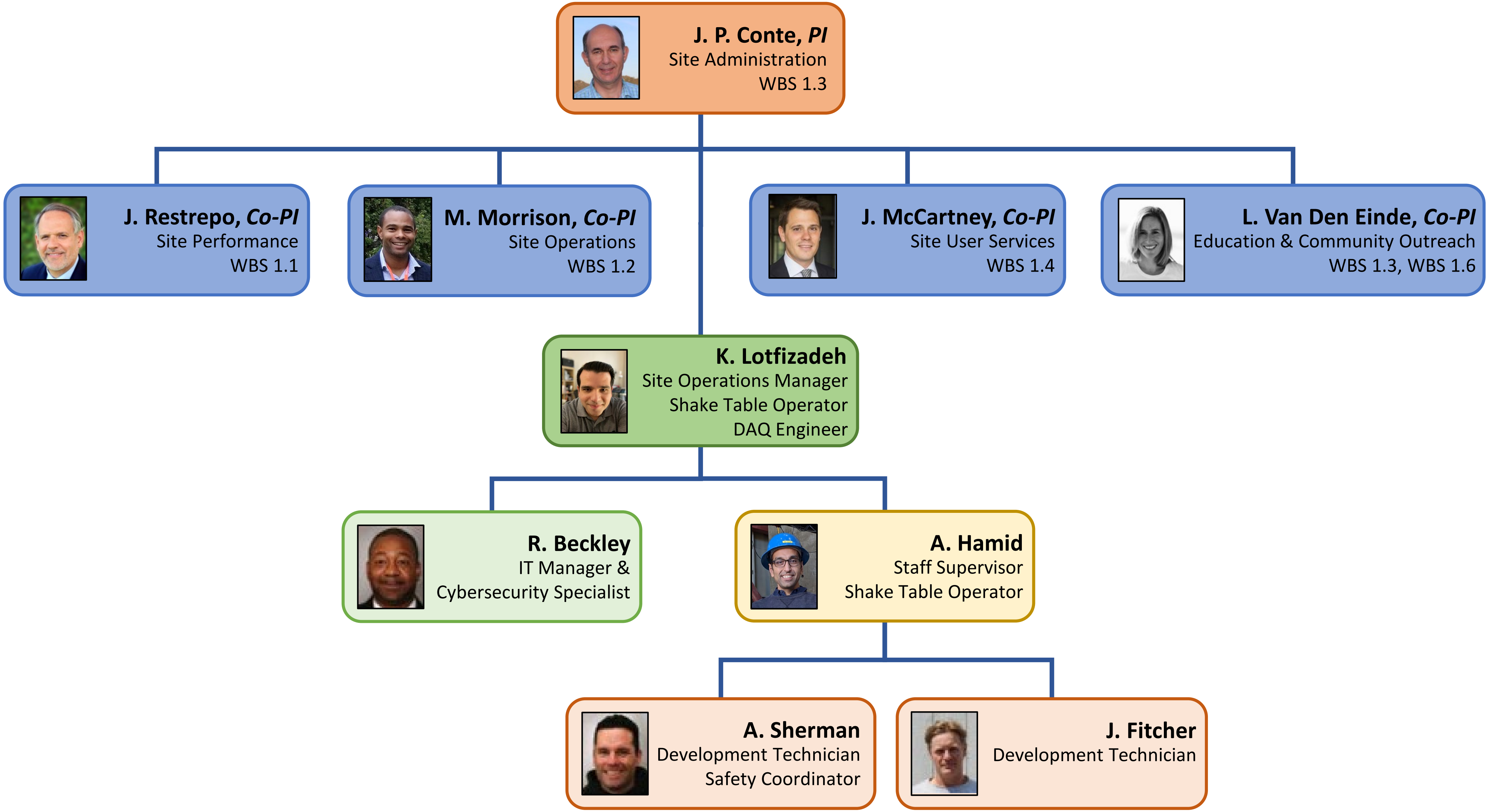
August 24-25, 2023
University of California, Berkeley

Outline

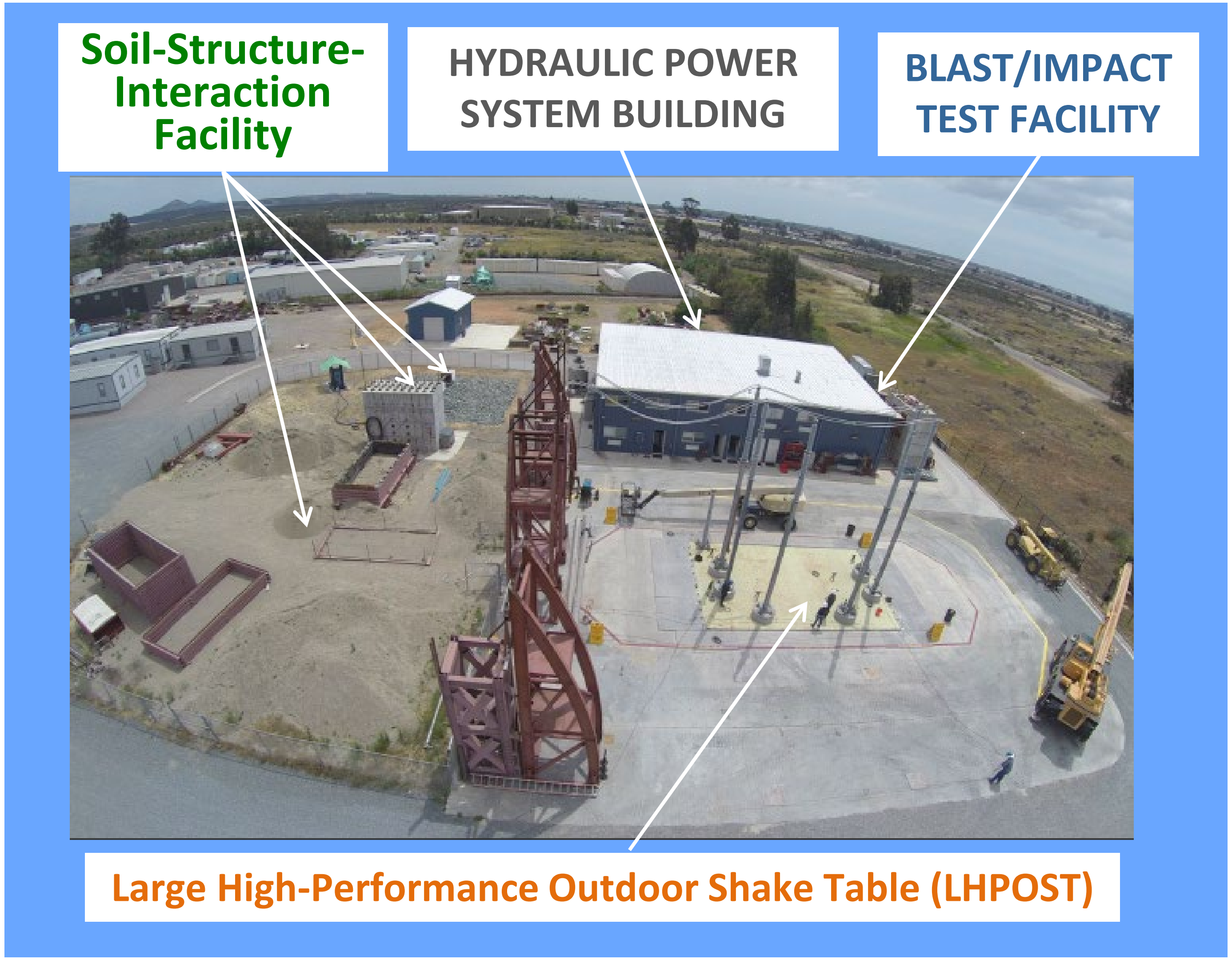
- Overview of Englekirk Structural Engineering Center
- Large High-Performance Outdoor Shake Table (LHPOST)
- Six-Degree-of-Freedom (6-DOF) Upgrade of LHPOST to LHPOST6
  - Design and Description of the Upgrade
  - Performance of the LHPOST6
- Instrumentation and Data Acquisition System
- New Research Opportunities Made Possible by LHPOST6

NHERI Operations Personnel

NHERI@UC San Diego Organization Chart



Overview:
Englekirk Structural Engineering Center (ESEC)


Soil-Structure-Interaction Facility
HYDRAULIC POWER SYSTEM BUILDING
BLAST/IMPACT TEST FACILITY
Large High-Performance Outdoor Shake Table (LHPOST)

ilac-MRA

IAS INTERNATIONAL ACCREDITATION SERVICE®

CERTIFICATE OF ACCREDITATION

This is to attest that

ENGLEKIRK STRUCTURAL ENGINEERING CENTER (UCSD)
10201 POMERADO ROAD
SAN DIEGO, CALIFORNIA 92131 U.S.A.

Testing Laboratory TL-1065

has met the requirements of AC89, *IAS Accreditation Criteria for Testing Laboratories*, and has demonstrated compliance with ISO/IEC Standard 17025:2017, *General requirements for the competence of testing and calibration laboratories.* This organization is accredited to provide the services specified in the scope of accreditation.

Effective Date May 31, 2023

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President

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Large High-Performance Outdoor Shake Table (LHPOST)

History

Design & Construction of LHPOST

2001 - 2004

- Funded by the National Science Foundation (NSF) under the George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) program
- Additional financial resources from the Department of Defense (Technical Support Working Group – TSWG) and UC San Diego

NEES@UC San Diego

2004 - 2014

- Operations and Maintenance Funded by the National Science Foundation (NSF) under the NEES program

NHERI@UC San Diego

2016 - 2022

- Operations and Maintenance Funded by the National Science Foundation (NSF) under the Natural Hazards Engineering Infrastructure (NHERI) program

6-DOF Upgrade to LHPOST6

2018 - 2022

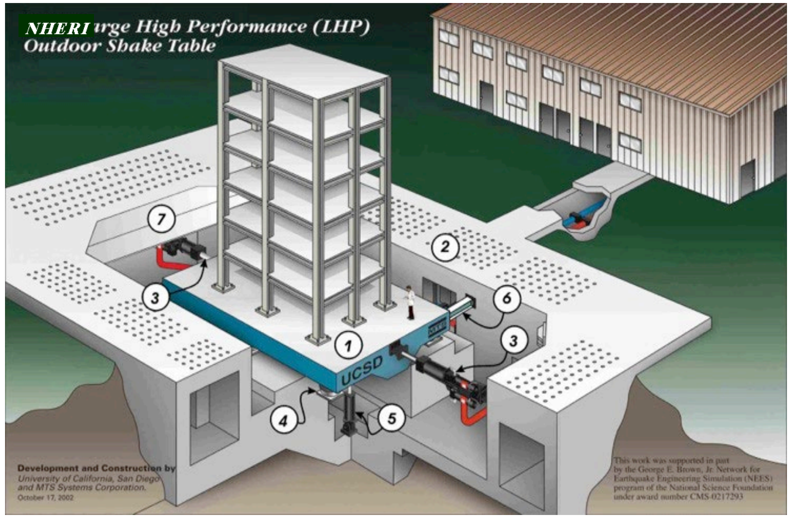
- Funded by the National Science Foundation (NSF)
- Additional financial resources from UC San Diego

NHERI@UC San Diego Renewal

2022 - 2025

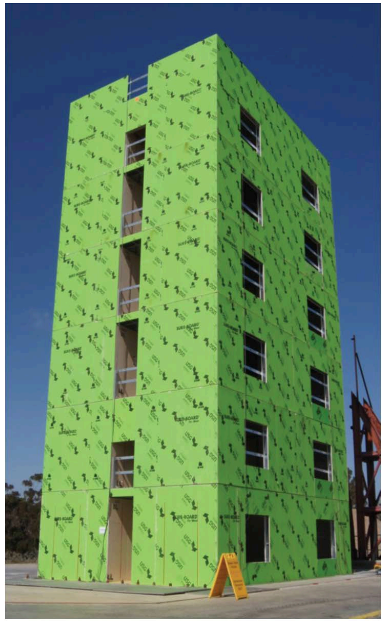
- Operations and Maintenance Funded by the National Science Foundation (NSF) under the Natural Hazards Engineering Infrastructure (NHERI) program

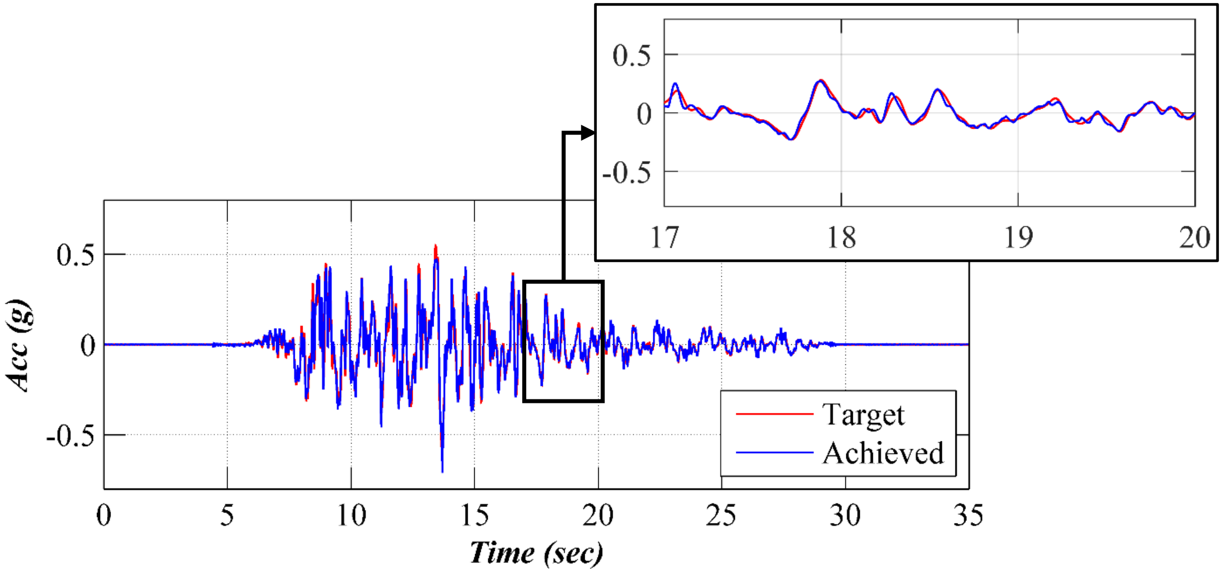
1-DOF Large High-Performance Outdoor Shake Table (LHPOST)

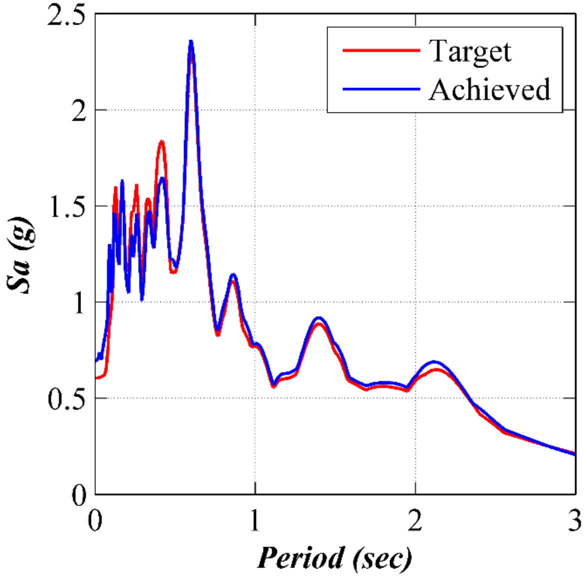


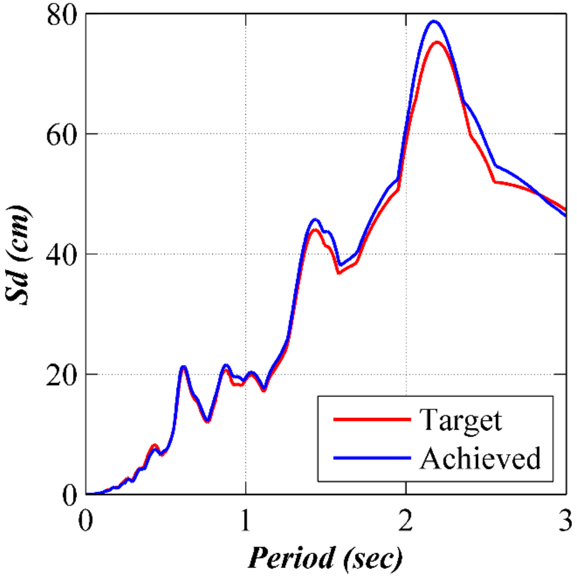
Performance Characteristics of LHPOST in Past 1-DOF Configuration (2004 – 2019)	
Designed as a 6-DOF shake table, but built as a 1-DOF system to meet funding available	
Stroke	**±0.75m**
Platen Size	40 ft × 25 ft (12.2 m × 7.6 m)
Peak Velocity	**1.8 m/sec**
Peak Acceleration	4.7g (bare table condition); 1.2g (4.0MN/400 tonf 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)

Tracking Performance of LHPOST (1-DOF)









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

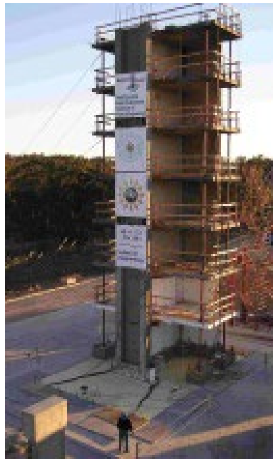
Use of LHPOST in Combination with Large Soil Boxes

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 **bridge abutments**, **earth retaining walls, slope stability in hillside construction,** and **underground structures.**
- To investigate **soil liquefaction** and its effect on the seismic response of soil-foundation-structural systems.

Select Set of Shake Table Tests on LHPOST (1-DOF)









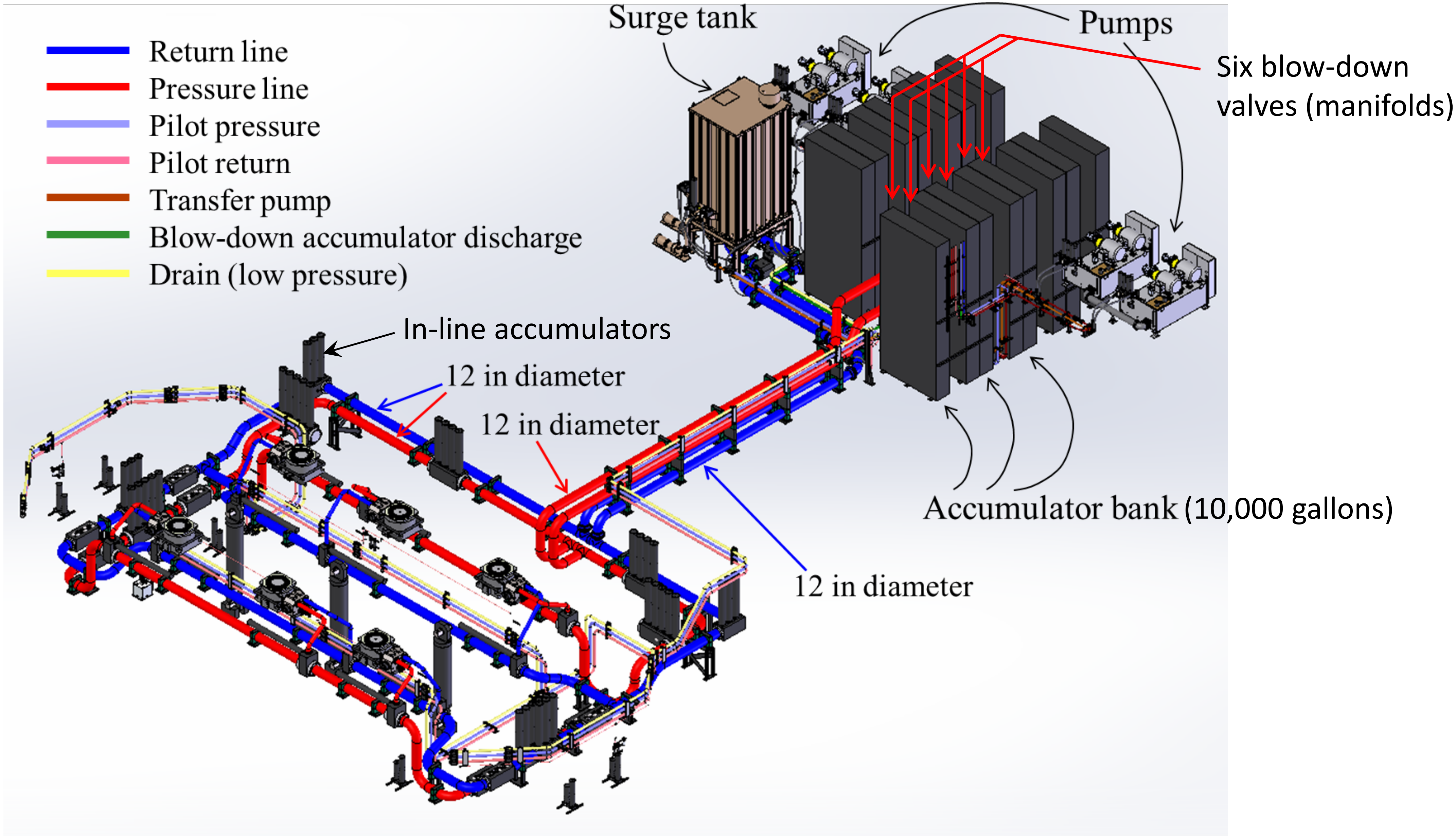







Six-Degree-of-Freedom (6-DOF) Upgrade of LHPOST to LHPOST6

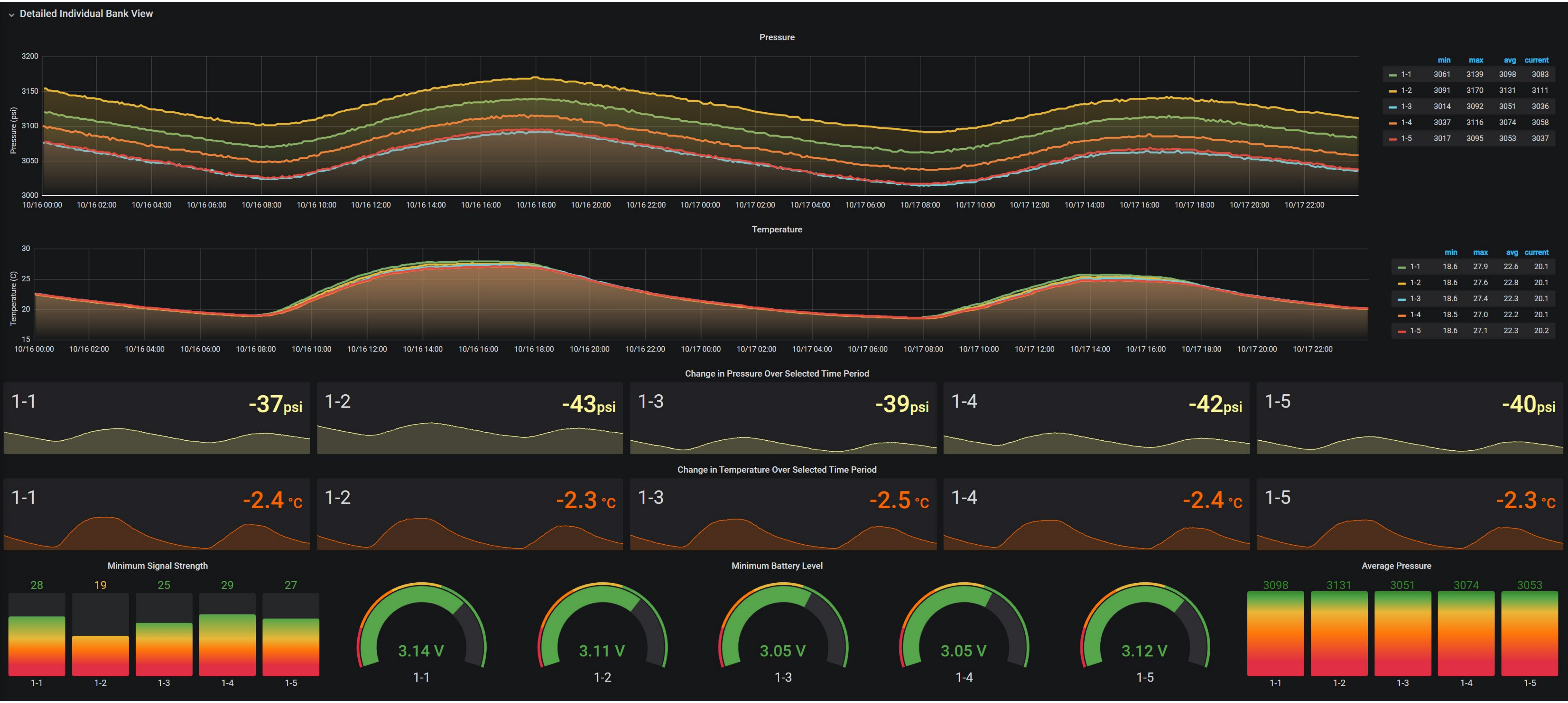
Hydraulic Power System of LHPOST6



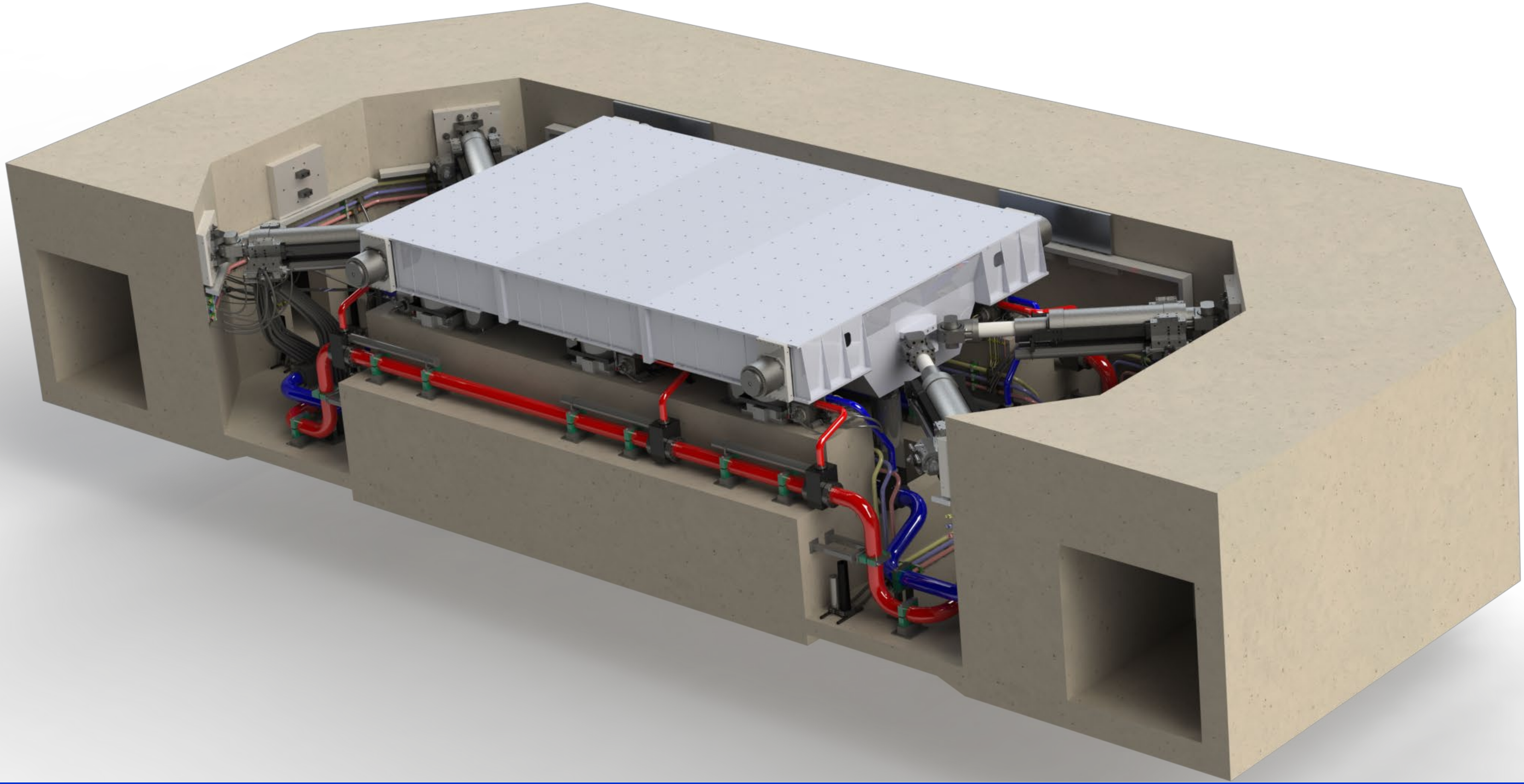
Accumulator Bank of LHPOST6

- Accumulator bank
  - 75 bottles total, 15 skids with 5 bottles each
  - 130 gallons per bottle
  - 3000 psi minimum Nitrogen pressure in each bottle in idle condition
- Pressure changes throughout the day with ambient temperature fluctuations
- Wireless real-time monitoring of pressure and temperature in each bottle
  - Equipped with wireless Sensonode Gold by Parker
  - Data captured by wireless gateway and passed to SQL server
  - Web-based user interface for local or remote monitoring

Accumulator Bank of LHPOST6



LHPOST6



Performance Characteristics of LHPOST6

Performance Characteristics of LHPOST6

Uniaxial performance characteristics of the LHPOST6
Sinusoidal motions - Bare table condition - Centered rigid payload of 4.9 MN (1,100 kips)

Platen size	12.2 m × 7.6 m (40 ft × 25 ft)					
Frequency Bandwidth	0 – 33 Hz					
Vertical Payload Capacity	20 MN (4,500 kip)					
	Sinusoidal motions - Bare table condition			Sinusoidal motions - Centered rigid payload of 4.9 MN (1,100 kips)		
	Horizontal X (E-W)	Horizontal Y (N-S)	Vertical Z (-)	Horizontal X (E-W)	Horizontal Y (N-S)	Vertical Z (-)
Peak Translational Displacement	±0.89 m (±35 in)	±0.38 m (±15 in)	±0.127 m (±5 in)	±0.89 m (±35 in)	±0.38 m (±15 in)	±0.127 m (±5 in)
Peak Translational Velocity	3.0 m/sec (118 in/sec)	2.0 m/sec (80 in/sec)	0.45 m/sec (17 in/sec)	3.0 m/sec (118 in/sec)	2.0 m/sec (80 in/sec)	0.55 m/sec (21 in/sec)
Peak Translational Acceleration	(5.8 g)(1) 3.7 g (2)	(4.7 g)(1) 1.85 g (2)	-3.4 g +31.1 g (1) +11.9 g (3)	(1.6 g)(1) 1.0 g (2)	(1.25 g)(1) 0.50 g (2)	-1.64 g +7.5 g (1) +2.5 g (2)
Peak Translational Force	10.6 MN (1) (2,380 kip)(1) 6.8 MN (2) (1,530 kip)(2)	8.38 MN (1) (1,890 kip)(1) 3.4 MN (2) (765 kip)(2)	-4.3 MN (4) +57.0 MN (5) (+12,800 kip)(5) +22.9 MN (6) (+5,150 kip)(6)	10.6 MN (1) (2,380 kip)(1) 6.8 MN (2) (1,530 kip)(2)	8.38 MN (1) (1,890 kip)(1) 3.4 MN (2) (765 kip)(2)	-4.3 MN (4) +57.0 MN (5) (+12,800 kip)(5) +22.9 MN (6) (+5,150 kip)(6)
Peak Rotation	2.22 deg (7)	1.45 deg (7)	3.8 deg	2.22 deg (7)	1.45 deg (7)	3.8 deg
Overturning Moment Capacity	32.0 MN-m (23,600 kip-ft)	35.0 MN-m (25,800 kip-ft)		45.1 MN-m (33,200 kip-ft)	50.0 MN-m (36,900 kip-ft)	

(1) Peak acceleration controlled by the actuator force capacities in the control zero-position of the table.

(2) Acceleration limit controlled by the reaction mass until further studies.

(3) Acceleration limit controlled by the design strength of the steel honeycomb platen.

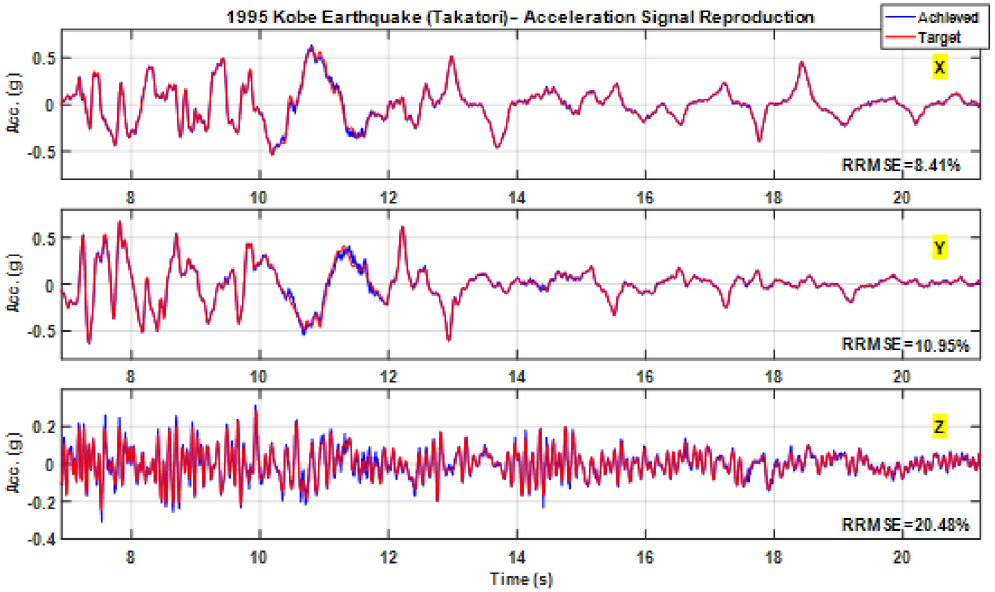
(4) Assuming a pressure of 125 psi in the chamber of each vertical actuator and accounting for the hold-down forces in the control zero-position of the table.

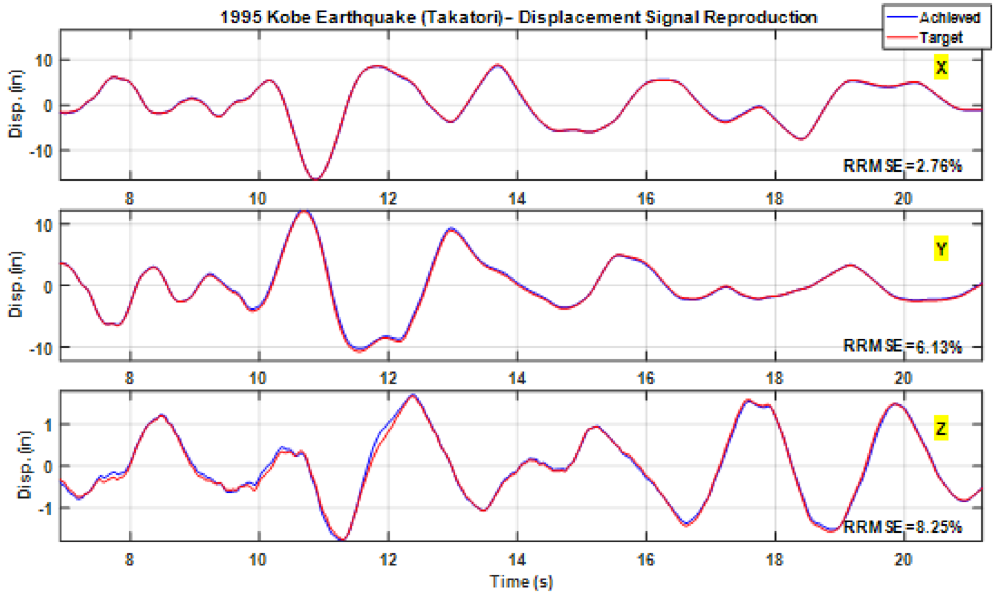
(5) Peak force controlled by the vertical actuator force capacities and accounting for the hold-down forces in the control zero-position of the table.

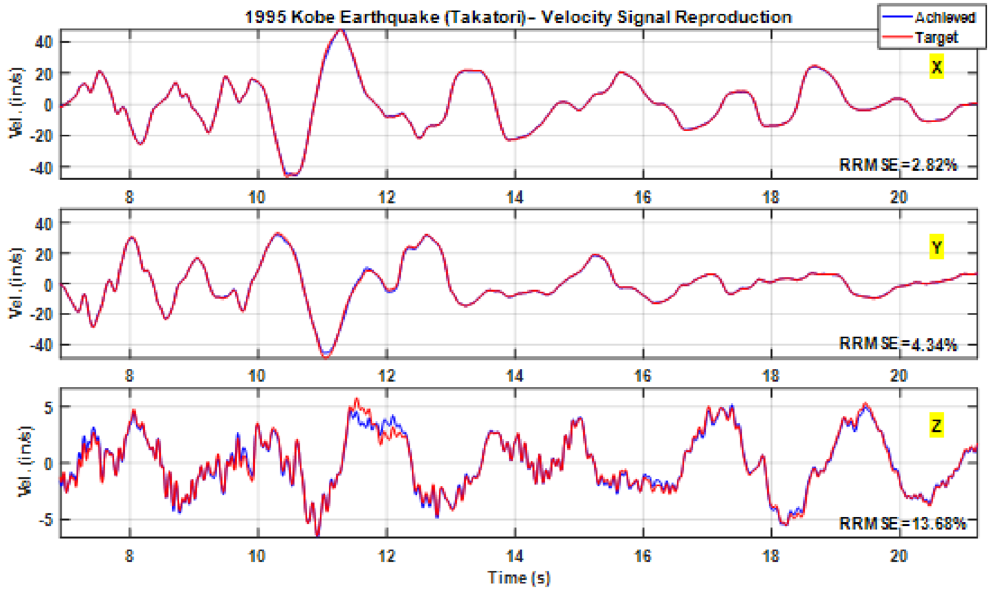
(6) Force limit controlled by the design strength of the steel honeycomb platen and accounting for the hold-down forces in the zero control position of the table.

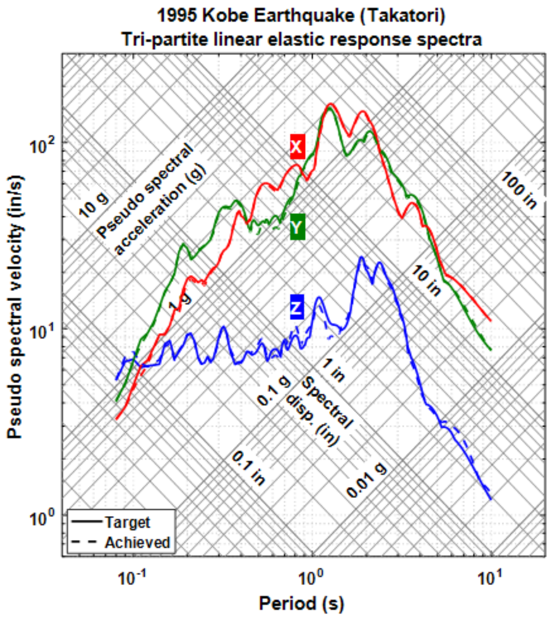
(7) Due to kinematics of the piston seals of the vertical actuators.

Target vs. Achieved Tri-Axial Ground Motion - 1995 M6.9 Kobe, Japan, Takatori Station









AC-156 Compatible Earthquake, Tri-Axial Ground Motion

1978, M7.4 Tabas, Iran, Tri-Axial Ground Motion

Synthetic 6-DOF Ground Motion

1989 Loma Prieta Earthquake, MCER Level, XYZ (5/17/2023)

Instrumentation and Data Acquisition

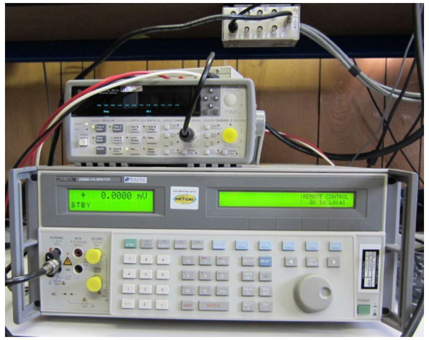
Instrumentation and Data Acquisition

- Objectives
  - Provide quality management system
  - Provide nationally and internationally recognized testing data and reports
  - Maintain a calibrated sensor and equipment inventory
- Documentation
  - Documentation master log file
  - General documentation
  - Standard operation procedures
  - In-house calibration procedures
  - Sensory inventory
  - Equipment inventory
  - Calibration reports

Accelerometers

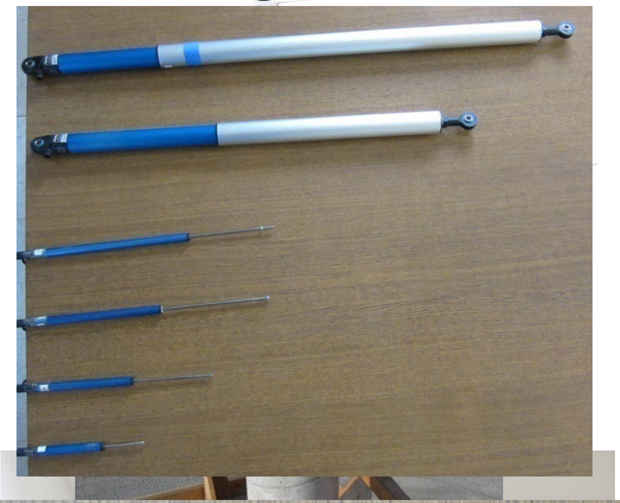
Displacement transducers

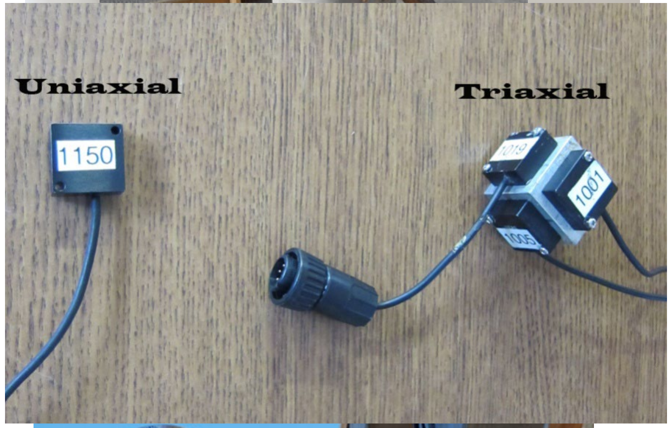
Accelerometer linearity



Reference equipment

- Instrumentation available:
  - 251 MEMS-Based Accelerometers (±5g and ±10g)
  - 305 Linear Displacement Transducers (1 to 20 in)
  - 154 String Potentiometer Displacement Transducers (2 to 120 in)
  - 28 Inclinometers (±15 deg)
  - 4 Load Jacks
  - 31 Load Cells (up to 20,000 lbs)
  - 32 Soil Pressure Transducers
- GNSS System:
  - 10 Receivers Operating at 100 Hz
- Cameras:
  - Drones (DJI Phantom 4 Pro)
  - GoPro Cameras (4K and 1080p)
  - End-to-end Live Video Streaming Production System

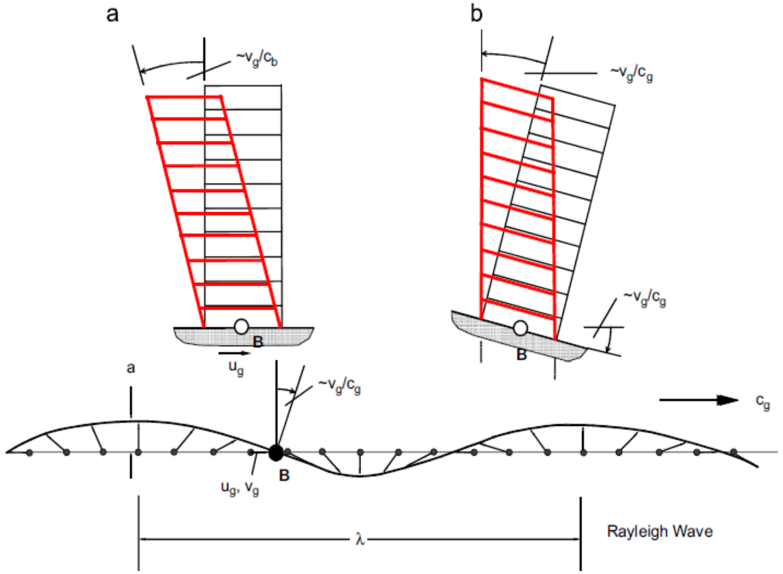




New Research Opportunities Made Possible by LHPOST6

New Research Opportunities Made Possible by LHPOST6

- Investigate the combined effect of realistic near-field translational and rotational earthquake ground motions applied as dynamic excitation to full 3D and large/full-scale structural, geotechnical, or soil-foundation-structural systems, including:
  - Effects of SSI (both kinematic and inertial)
  - Non-linear soil and structural behavior
  - Soil liquefaction
  - Seismic compression



Geometric interpretation of how horizontal translation and rocking can contribute to the total drift in a simple building during passage of a Rayleigh wave [Trifunac, 2009]

Van Den Einde, L., Conte, J.P., Restrepo, J.I., Bustamante, R., Halvorson, M., Hutchinson, T.C., Lai, C.T., Lotfizadeh, K., Luco, J.E., Morrison, M.L. and Mosqueda, G., 2021. ***NHERI@ UC San Diego 6-DOF large high-performance outdoor shake table facility. Frontiers in Built Environment***, 6, p.580333.

For More Information About NHERI@UC San Diego LHPOST6

- Join us at our annual NHERI@UC San Diego User/Researcher Training Workshop
  - December 14-15, 2023
  - Registration begins soon
- Visit us on the web:
  - DesignSafe: ucsd.designsafe-ci.org
  - UCSD: nheri.ucsd.edu
- Contact one of the NHERI@UC San Diego team members:
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  - Lelli Van Den Einde, lellivde@ucsd.edu

Thank You