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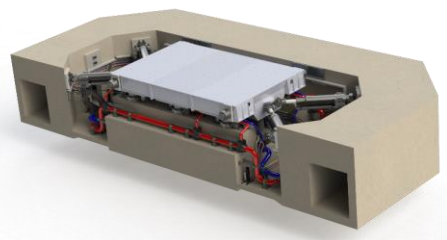
UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

Modeling of the Dynamic Interaction between the NHERI–UCSD 6-DOF Large High-Performance Outdoor Shake Table and TallWood Building Specimen

Chin-Ta (Kiida) Lai and Joel P. Conte

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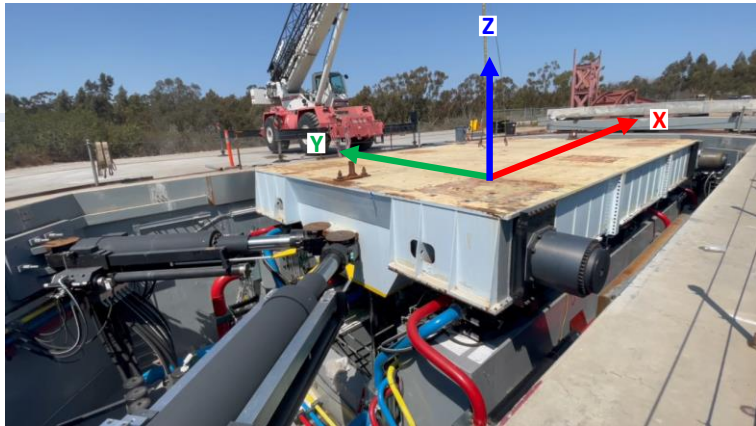
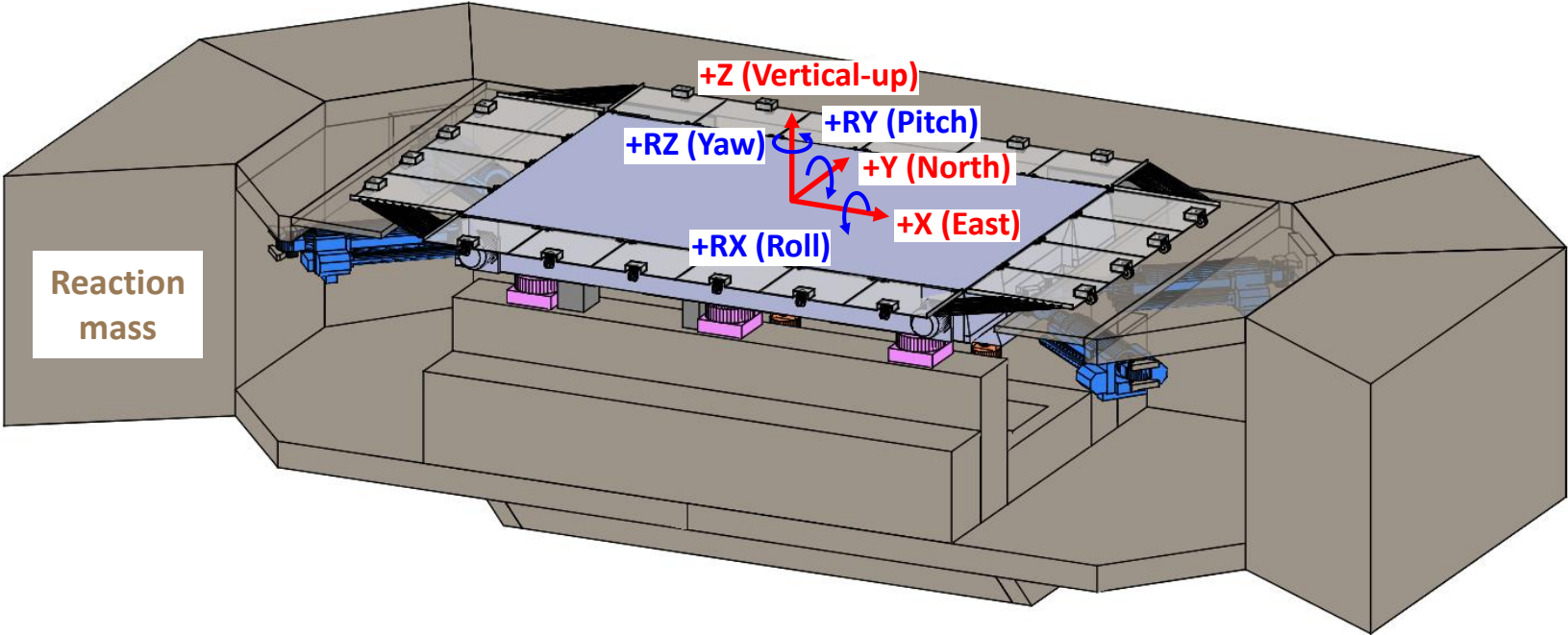
July 04, 2024



Outline

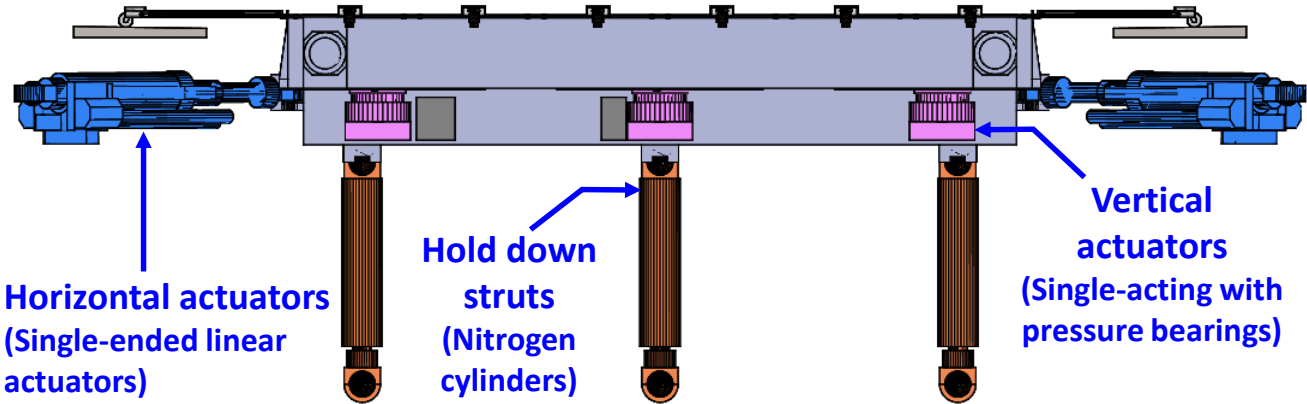
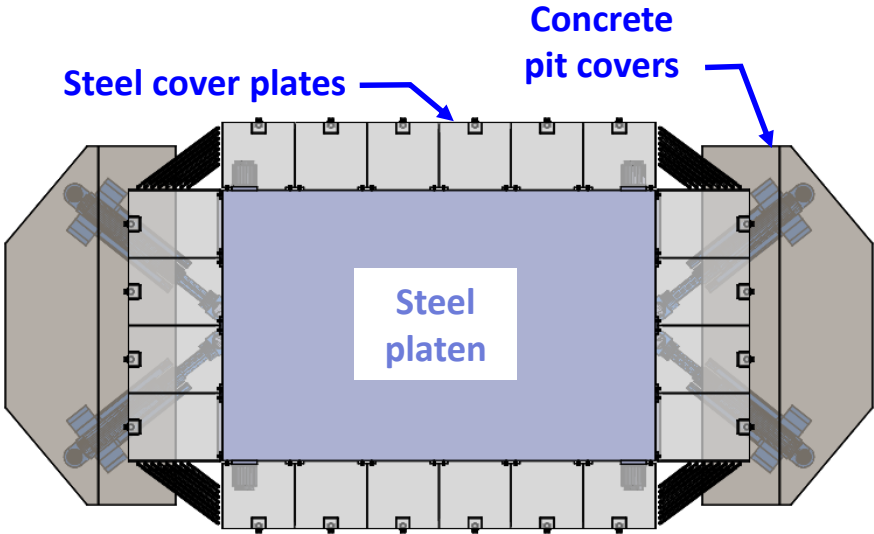
- Performance characteristics and system configuration of LHPOST6
- Numerical model of LHPOST6 under **bare table condition**
 - LHPOST6 closed-loop system
 - Modeling scheme for the hydraulic and mechanical parts of LHPOST6
- Numerical model of LHPOST6 under **loaded table condition**
 - 10-Story NEHRI TallWood Project
 - LHPOST6 model (in Simulink) and specimen model (in OpenSees)
 - Simulation results
- Concluding remarks and on-going/future work

6-DOF Configuration – NEHRI@UCSD



1999/09/21 Chi Chi Earthquake
TCU065 Station Record

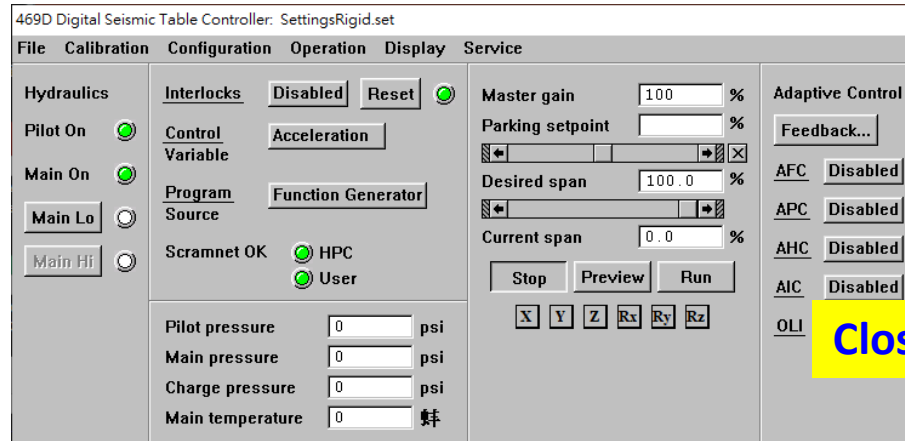
	Displacement Capacity	Velocity Capacity	Acceleration Capacity
Long (X)	± 35 in (± 0.89 m)	120 in/s (3 m/s)	3.7 g
Lateral (Y)	± 15 in (± 0.38 m)	100 in/s (2 m/s)	1.85 g
Vertical (Z)	± 5 in (± 0.127 m)	20 in/s (0.45 m/s)	3.4 g



Numerical model of LHPOST6
under
bare table condition

Introduction – LHPOST6 Closed-loop System

MTS 469D (6-DOF controller)



Servo valve Commands

Closed-loop control

Sensor feedbacks

Accelerometers
→ Platen acceleration



Pressure transducers
→ Actuator forces



LVDTs
→ Actuator displacements



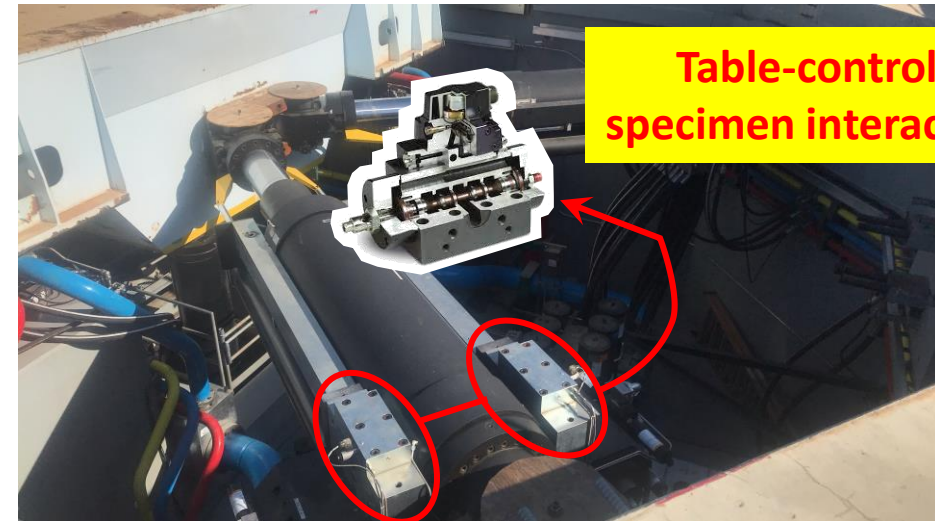
Plant:
Loaded (with specimen) table condition

Specimen (total)
base forces and
moments



Specimen

Table-control-
specimen interaction

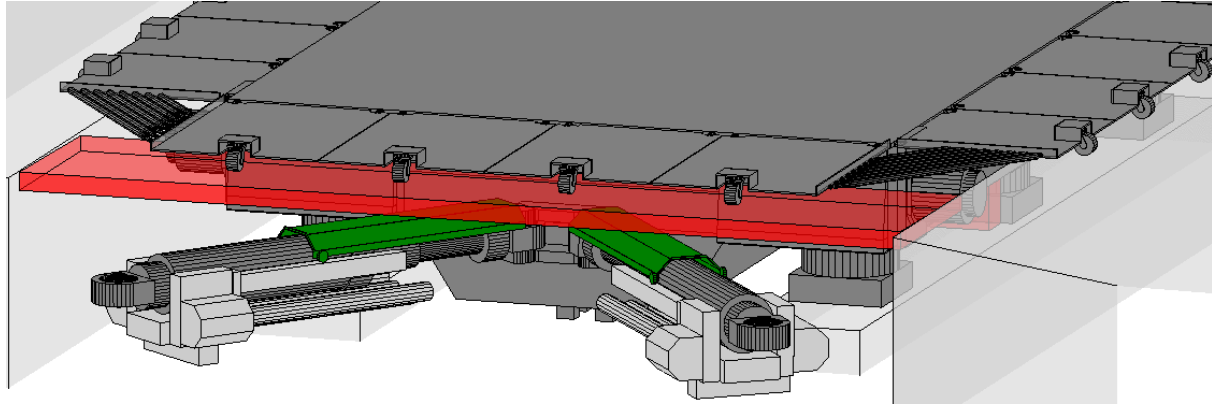


Ground
motion (table)
excitation

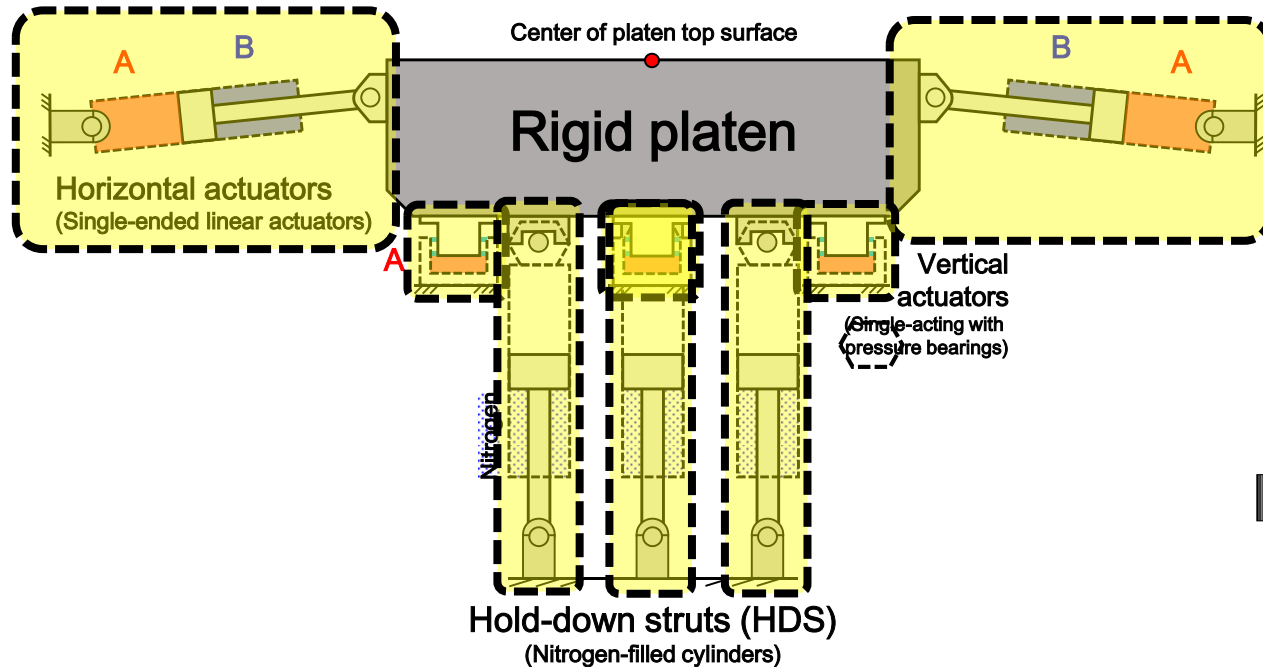
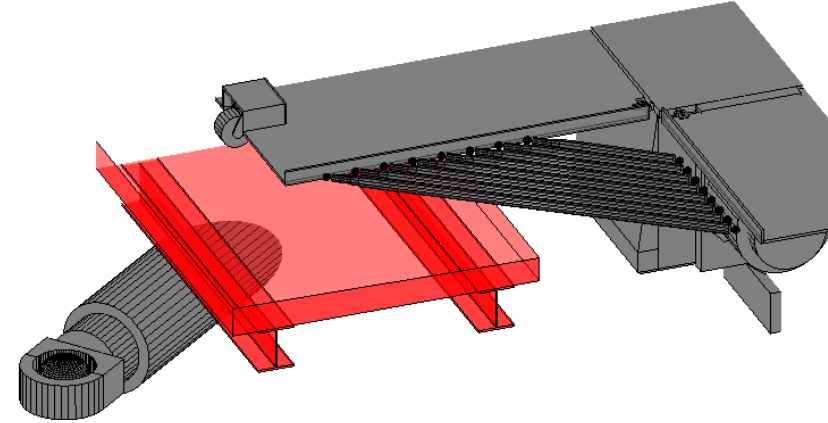
Hydraulic and mechanical components of LHPOST6

Kinematics Simulation of LHPOST6

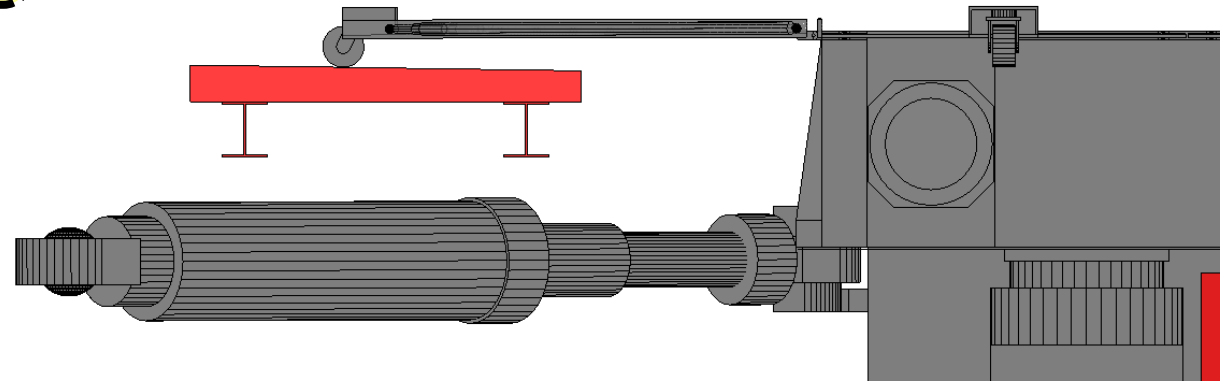
3D view when running tri-axial earthquake ground motion



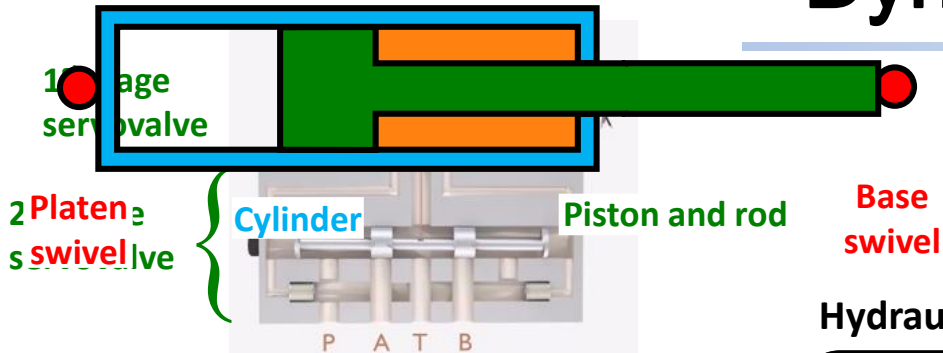
A closer view of cover plates



Side view when running vertical sine wave

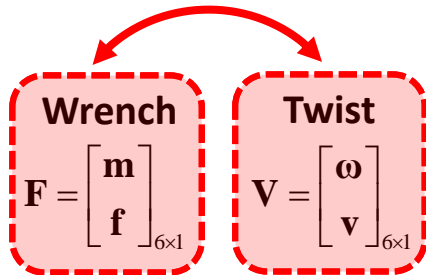


Dynamic Model Architecture

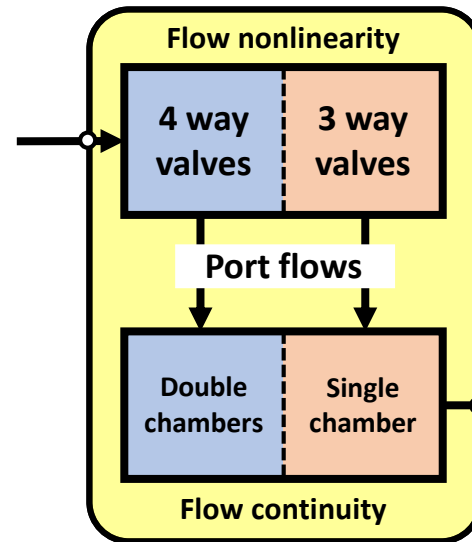


4th stage servovalve
spool displacements

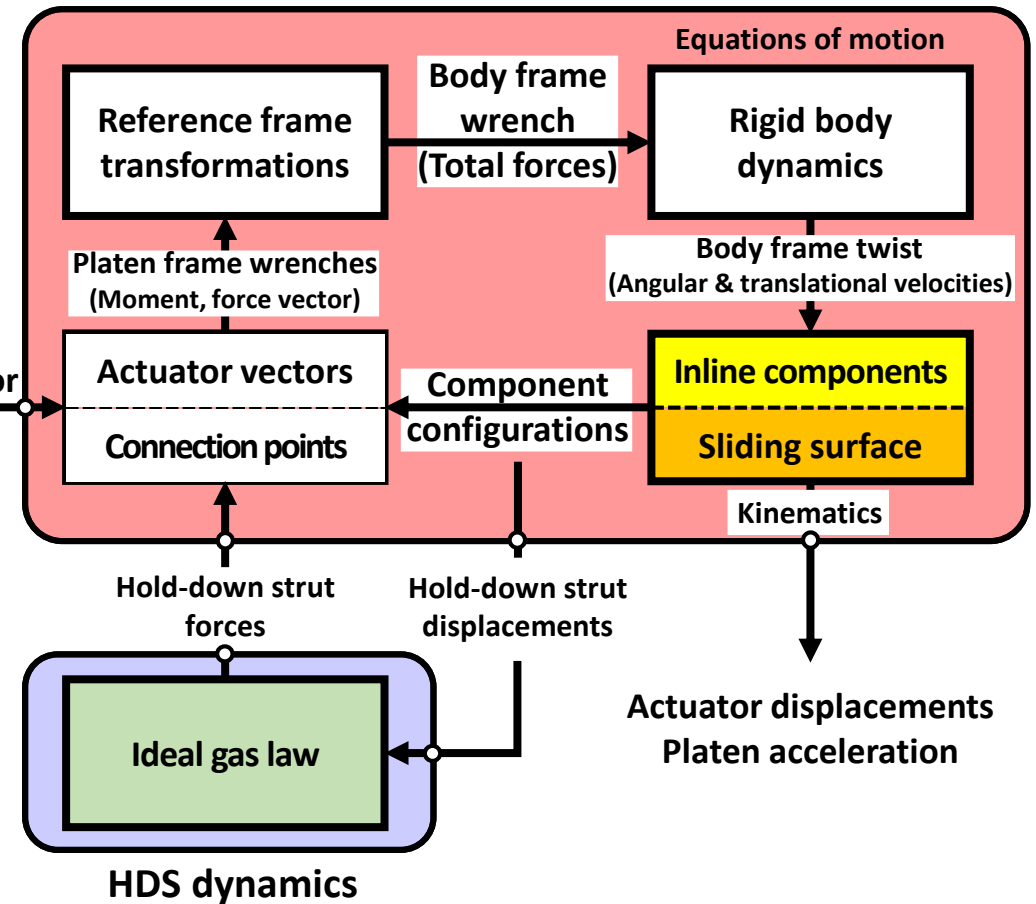
Generalized Newton's 2nd law



Hydraulic dynamics



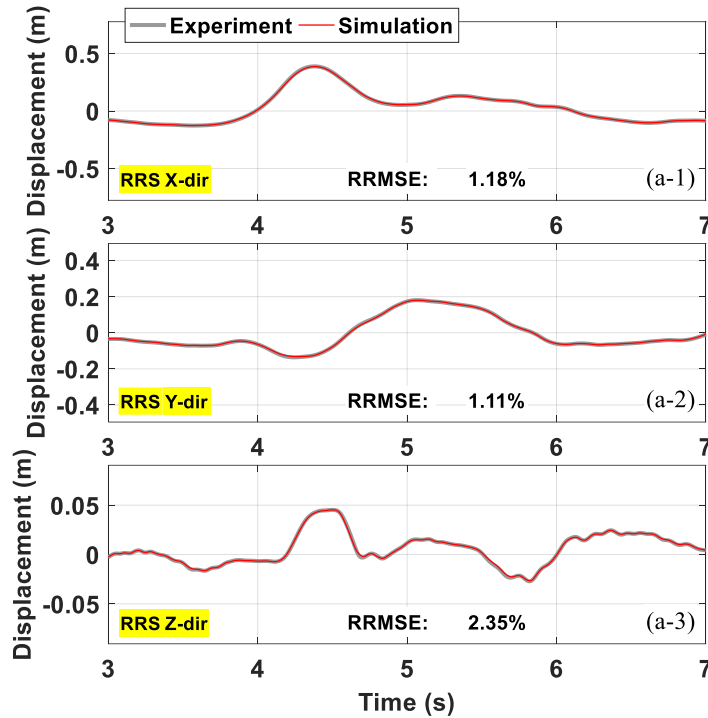
Kinematics & dynamics of the mechanical components
(Robotic analysis of 6-DOF rigid body dynamics)



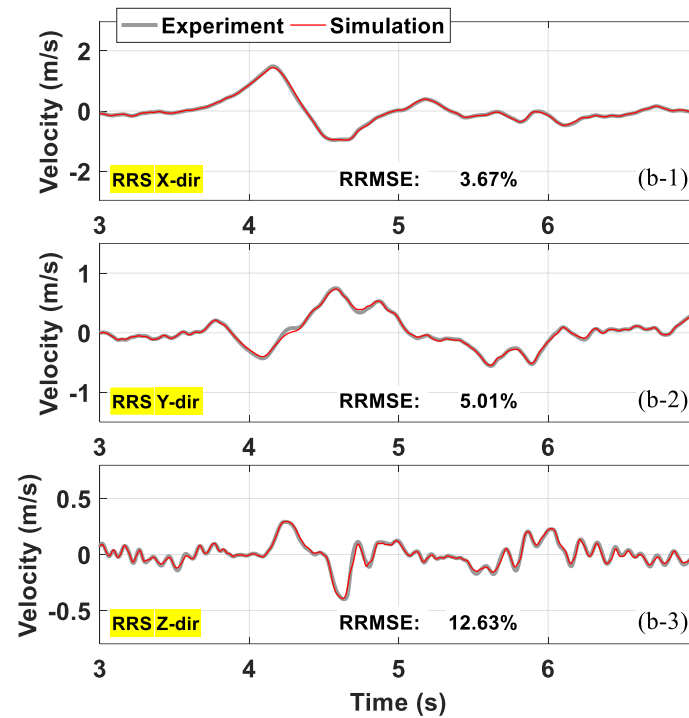
	Kinematics	Active/Passive
Horizontal Actuators	Linear actuator	Servo-hydraulic control (4-way valve)
Vertical Actuators	Sliding surface	Servo-hydraulic control (3-way valve)
Hold-down Struts	Linear actuator	Nitrogen pre-charged (passive component)

Closed-loop System Level Validation under Bare Table Condition

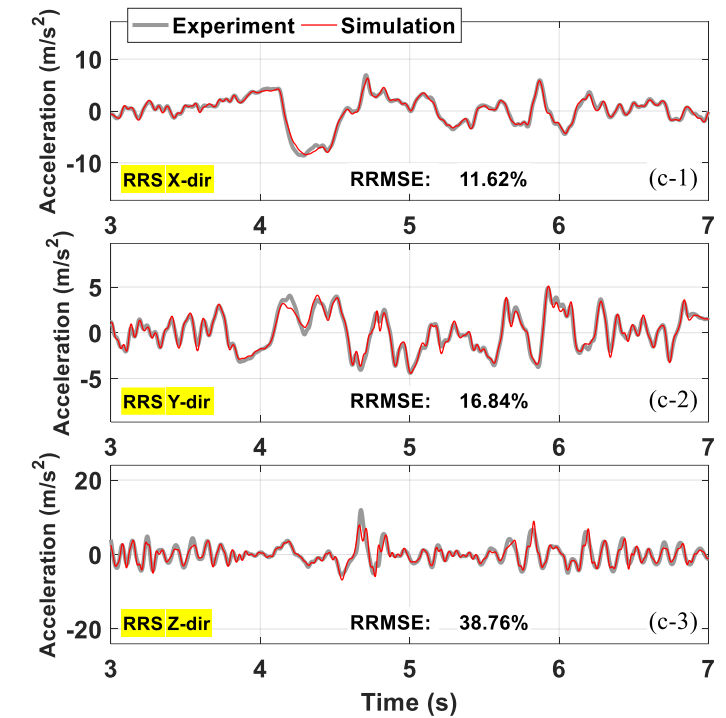
Displacement



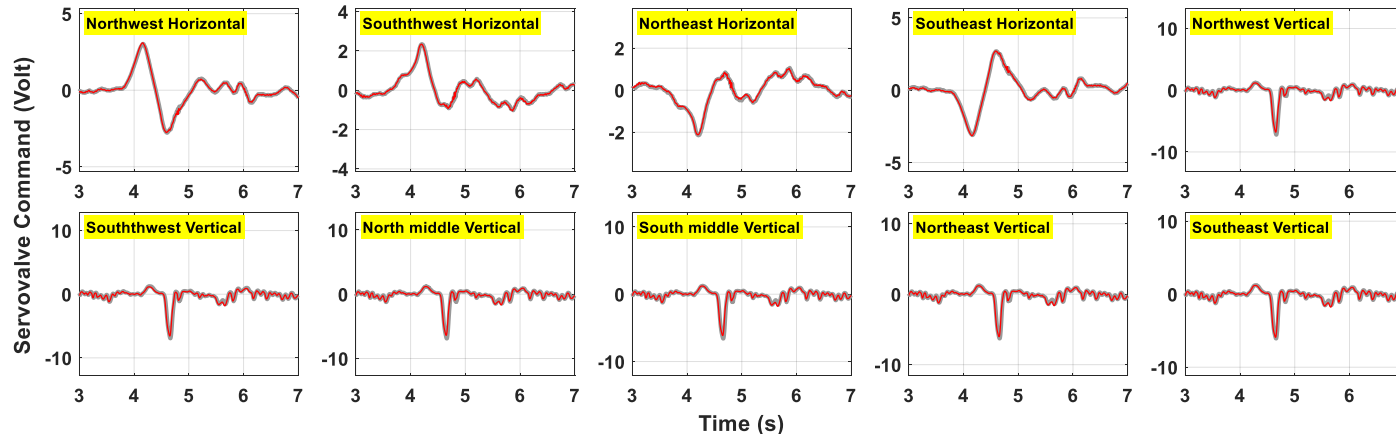
Velocity



Acceleration



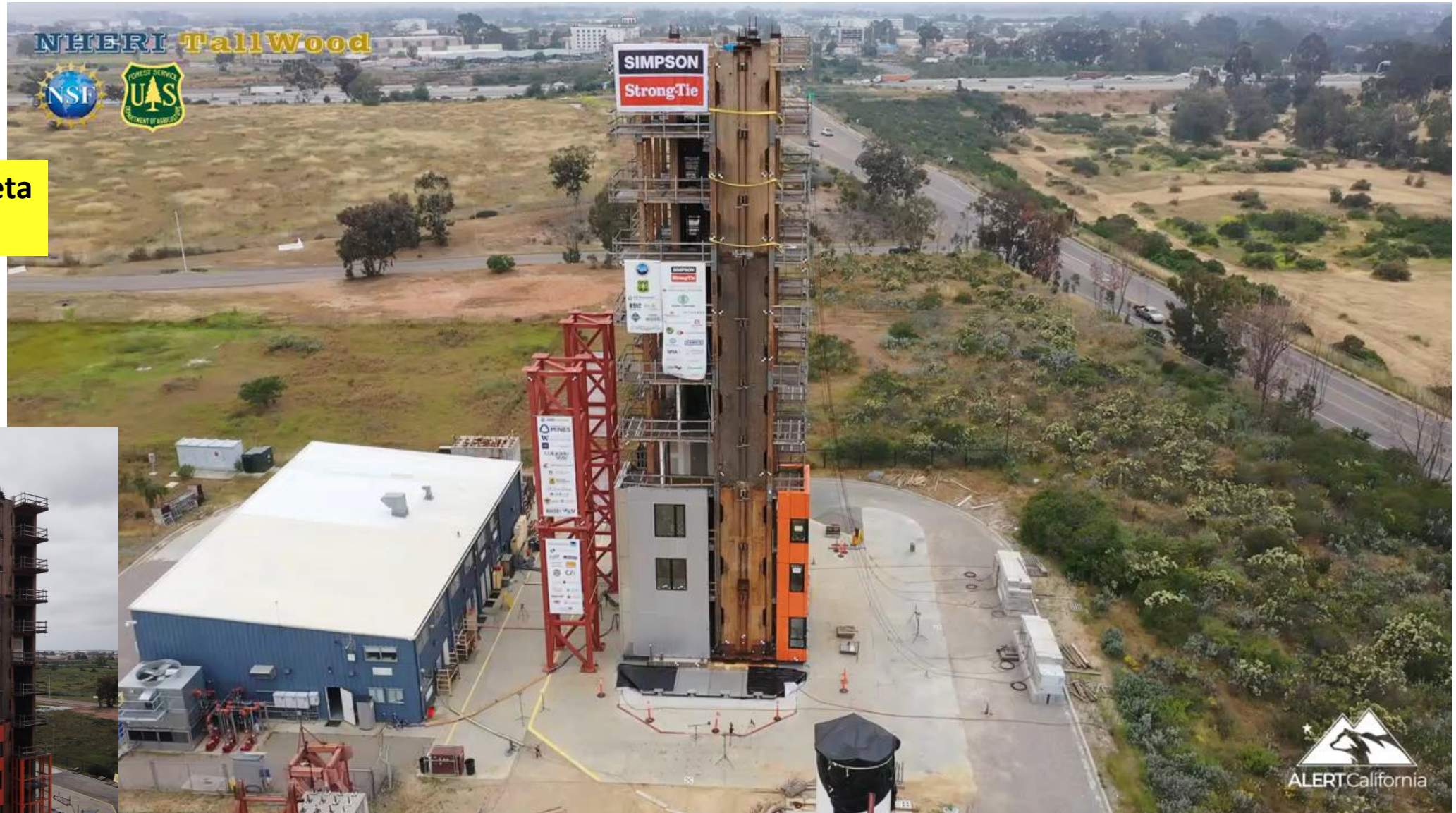
Servo valve command signals



1. Closed-loop simulation resolved the slow displacement drift problem.
2. The relative root mean square error between experimental and simulated table motion is low.

Numerical model of LHPOST6 under loaded table condition

TallWood 10-Story Mass Timber Building Project

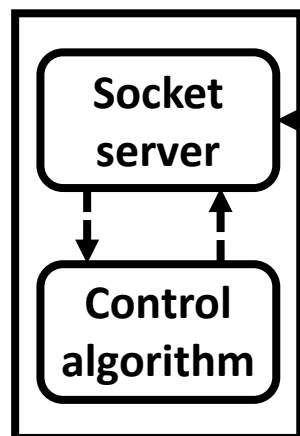


MCE: Loma Prieta
EQ (0.76 g)

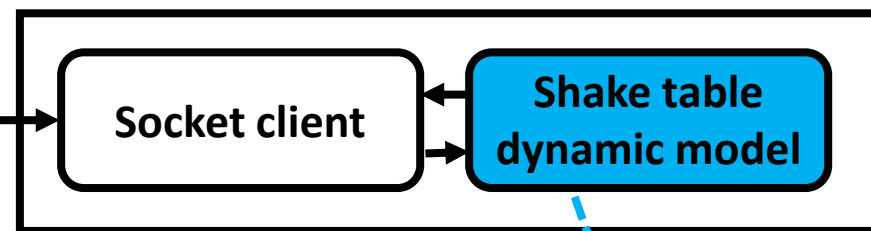


Simulation of Closed-Loop Dynamics under **Bare** Table Condition

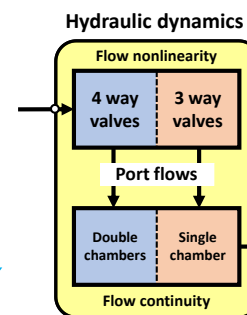
469D (Controller)



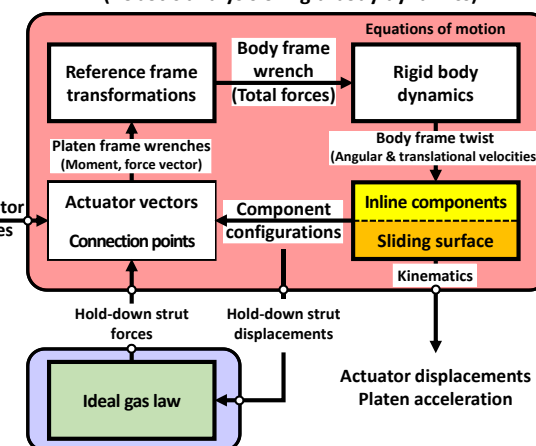
Matlab/Simulink (LHPOST6 platen dynamics)



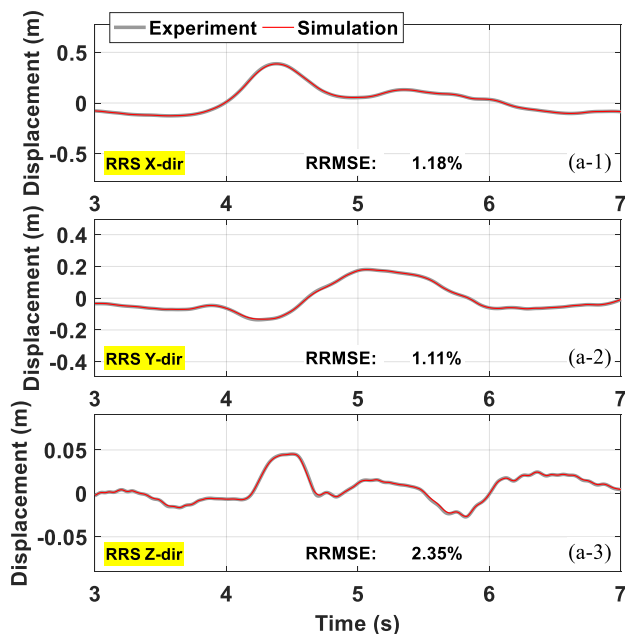
Data transfer
via **UDP**



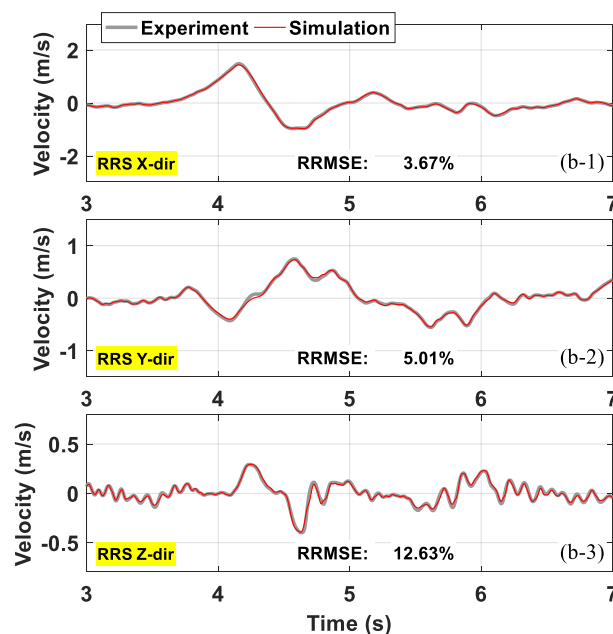
Kinematics & dynamics of the mechanical components (Robotic analysis of rigid body dynamics)



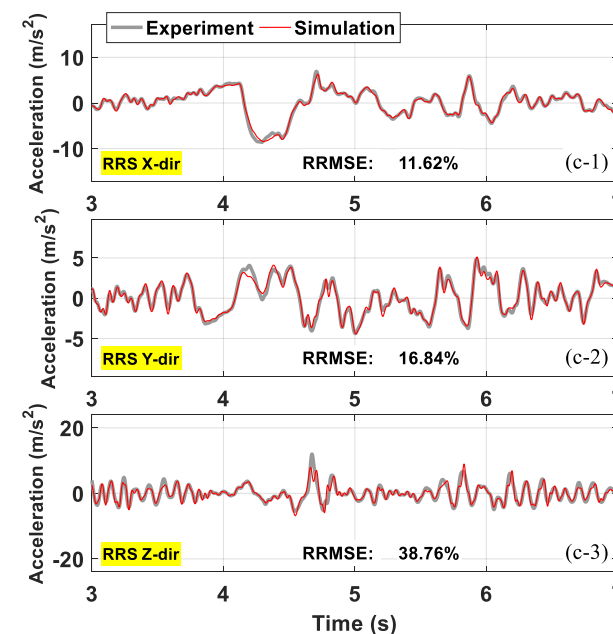
Displacement



Velocity

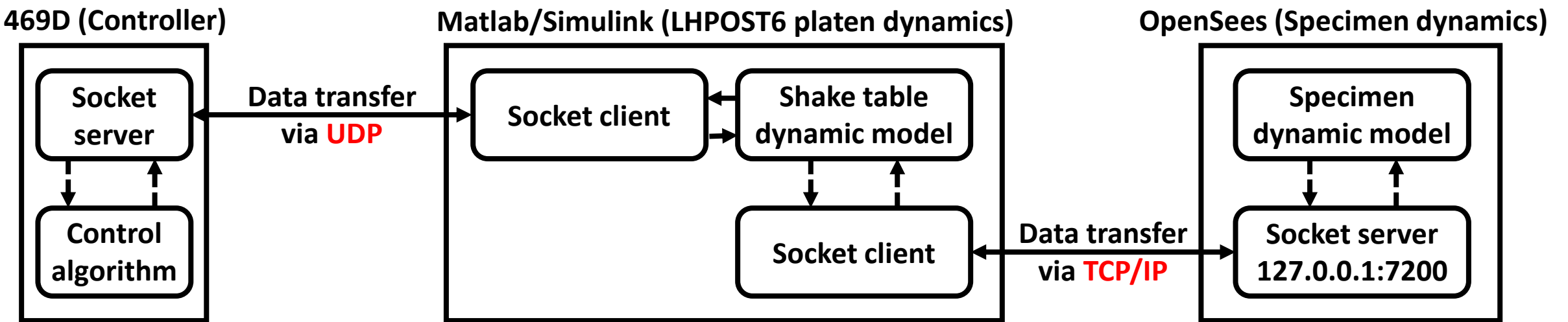


Acceleration

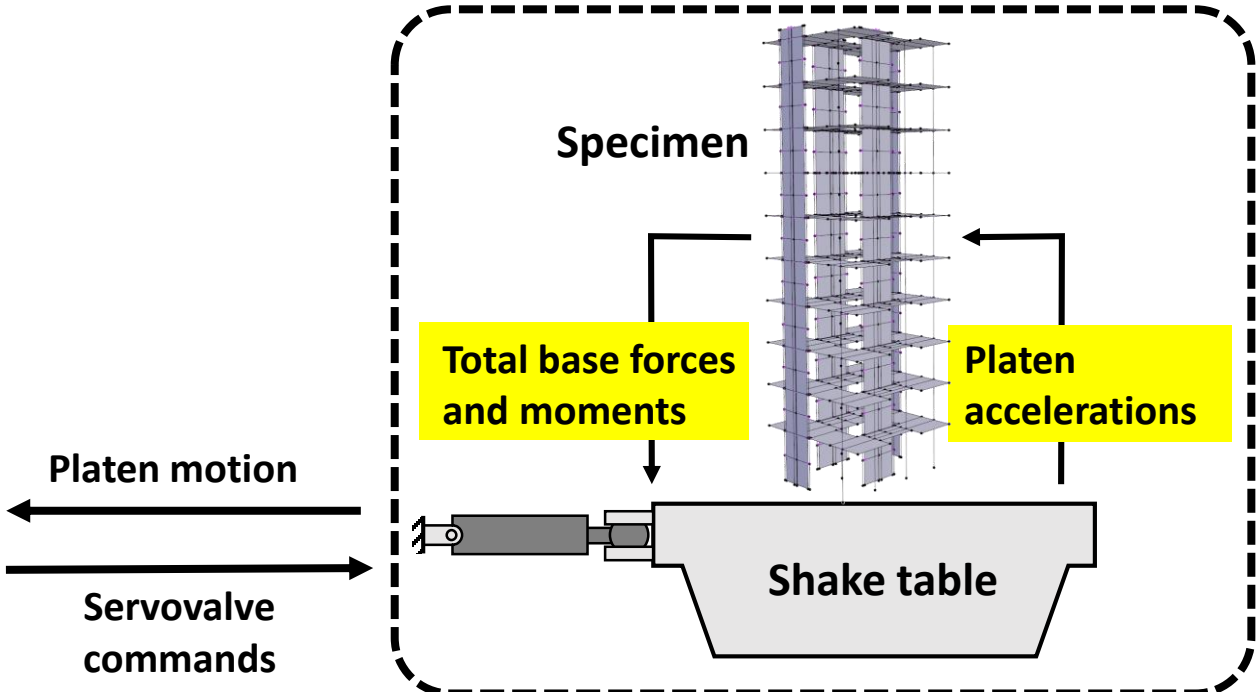
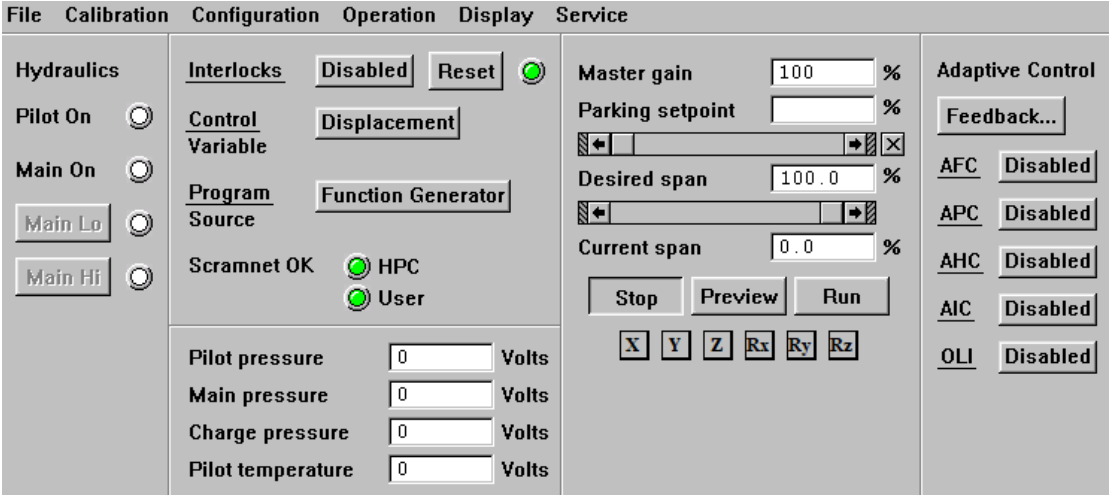


1. Optimal drive file, obtained after several iterations conducted on the real LHPOST6, is used.
2. The relative root mean square error (RRMSE) between the numerically predicted and measured achieved table motions is low.

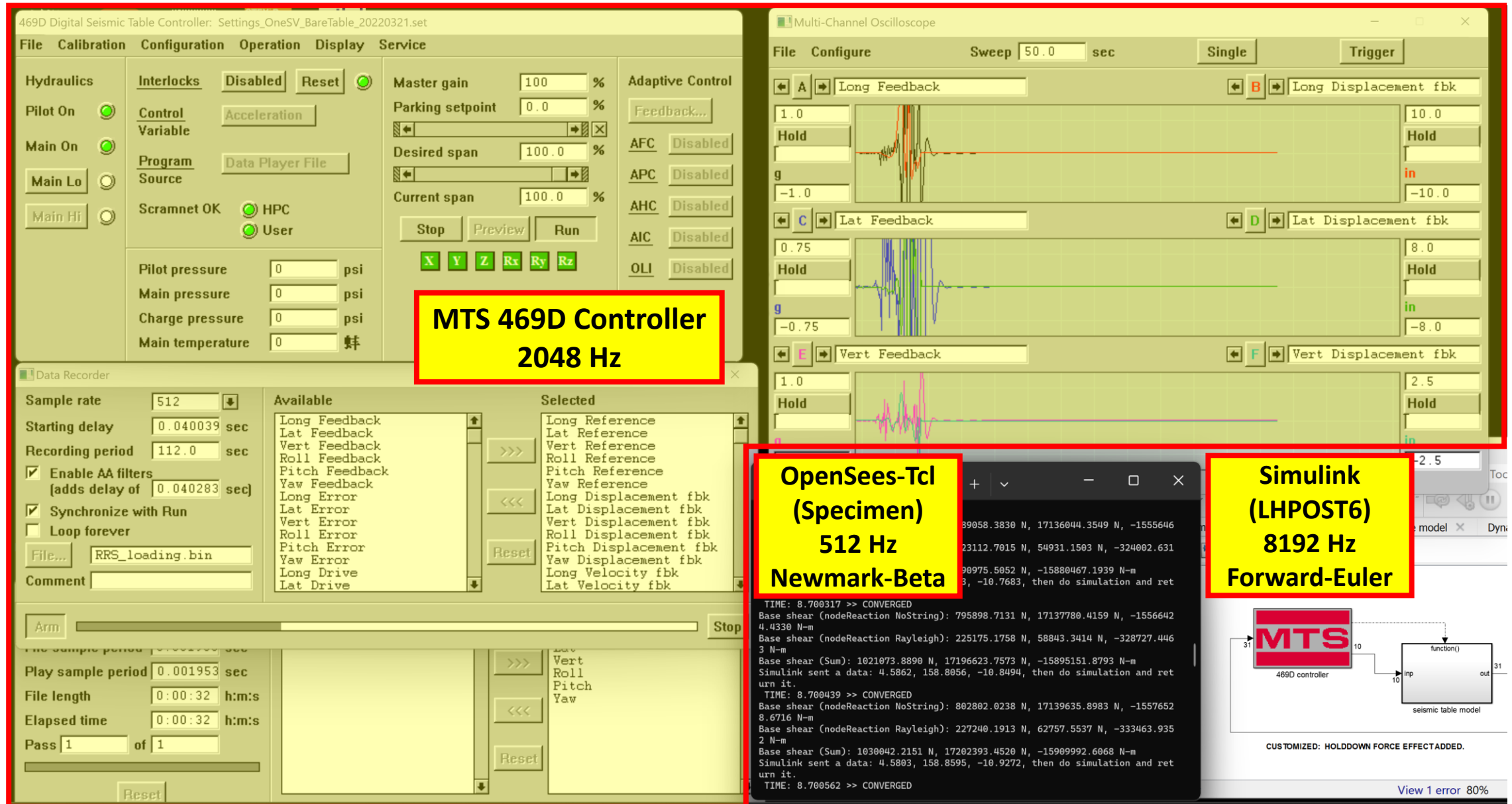
Simulation of Closed-Loop Dynamics under **Loaded** Table Condition



469D (Controller)

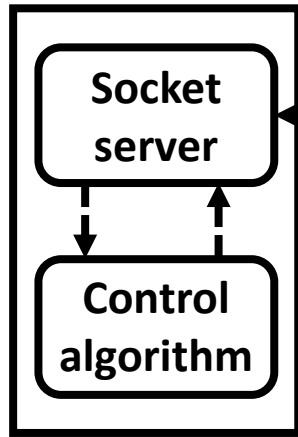


Closed-Loop Simulation of LHPOST6 under Loaded Table Condition

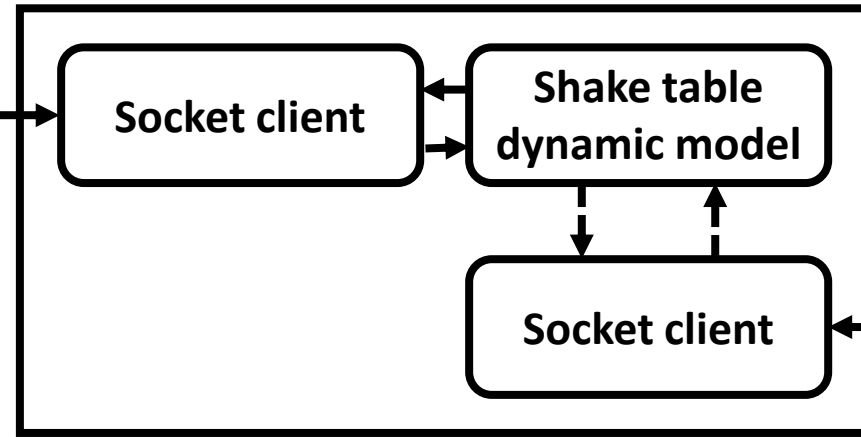


Closed-loop Simulation Results with the 10-story TallWood Building

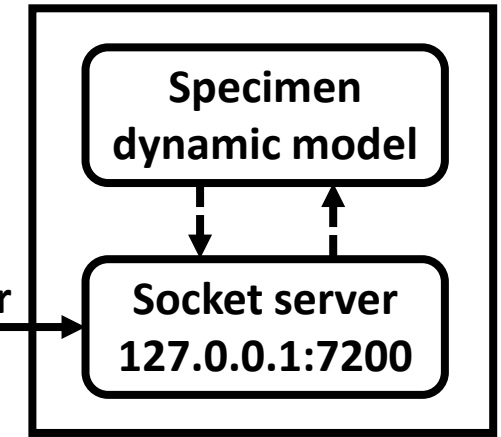
469D (Controller)



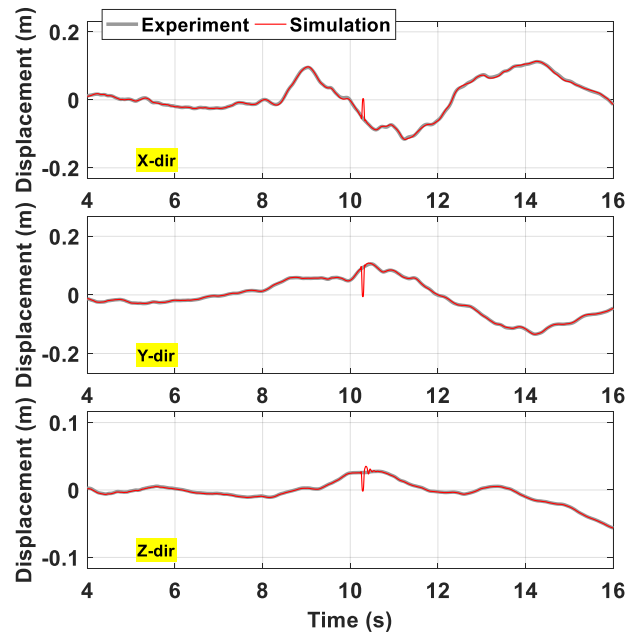
Matlab/Simulink (LHPOST6 platen dynamics)



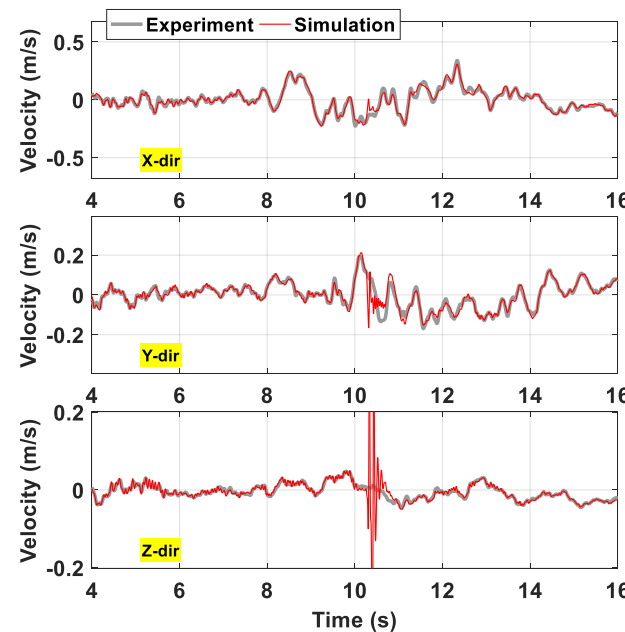
OpenSees (Specimen dynamics)



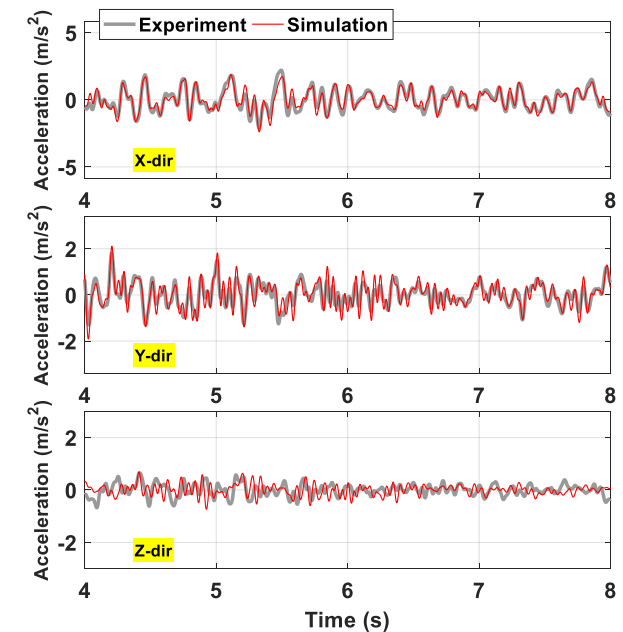
Displacement



Velocity



Acceleration



Summary

Concluding Remarks

- The numerical model of the LHPOST6 includes the plant portion of the closed-loop system and consists of three components: (1) hydraulic dynamics (i.e., servo-hydraulic actuators), (2) hold-down strut restoring forces, and (3) 6-DOF rigid body platen dynamics.
- Comparison study (comparison between numerically simulated and measured platen responses under bare table condition) under bare table condition and the simulation results are in close agreement with the measured/experimental results.
- The simulation methodology for the loaded table condition is developed and enables the study of the table-control-specimen interaction. OpenSees is successfully coupled with the Simulink model of the shake table system.

Future Work

- Improve, calibrate and validate the modeling of the dissipative forces and improve the overall calibration of the LHPOST6 model to improve the prediction accuracy.
- Use the closed-loop LHPOST6 model to tune, off-line, the MTS 469D controller to account for table-control-specimen interaction. The models and analysis methods developed in this study are will also prove useful when conducting real-time hybrid shake table tests.

Acknowledgements

□ Funding support:

National Science Foundation:

- Construction of LHPOST facility (2002-2004)
- Operation and Maintenance of NEES/NHERI LHPOST facility (2004-2014; 2016-2025)
- 6-DOF Upgrade of LHPOST (2018-2022)

UC San Diego:

- Matching funds towards construction of LHPOST facility and its upgrade to 6-DOF

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Prof. Guido Camata (ASDEA Software Technology, University of Chieti-Pescara)

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