NHERI@UCSD
New Capabilities/Technologies: Hybrid Simulation and ECO

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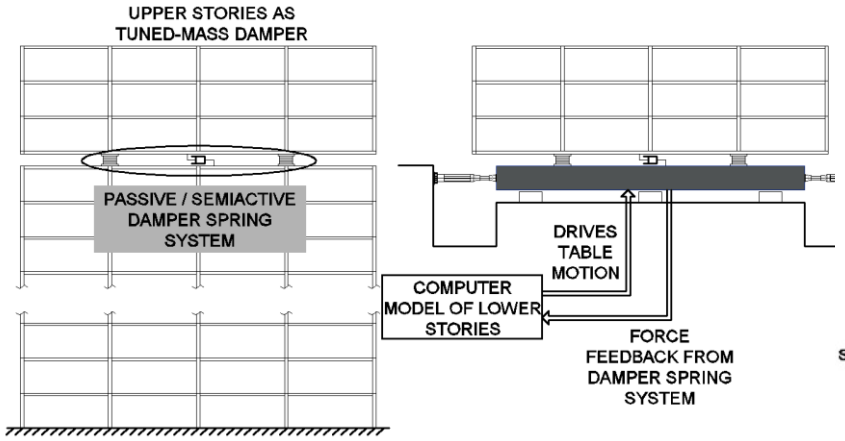
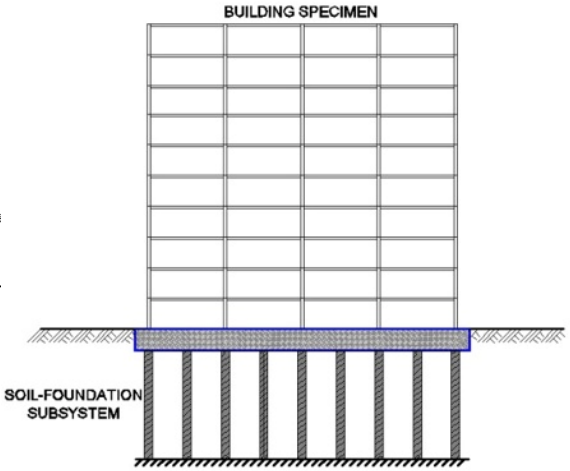
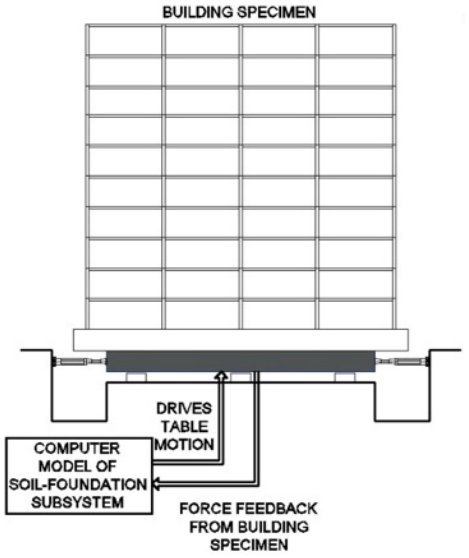
Application of Hybrid Simulation

- Simulate large and complex structures that exceed capabilities of the shake table such as long span bridges and tall buildings
  - Test a critical part of the structure at large scale
  - Numerically capture system level response
- Some type of structures exhibit rate dependent effects and distributed inertial forces requiring dynamic testing

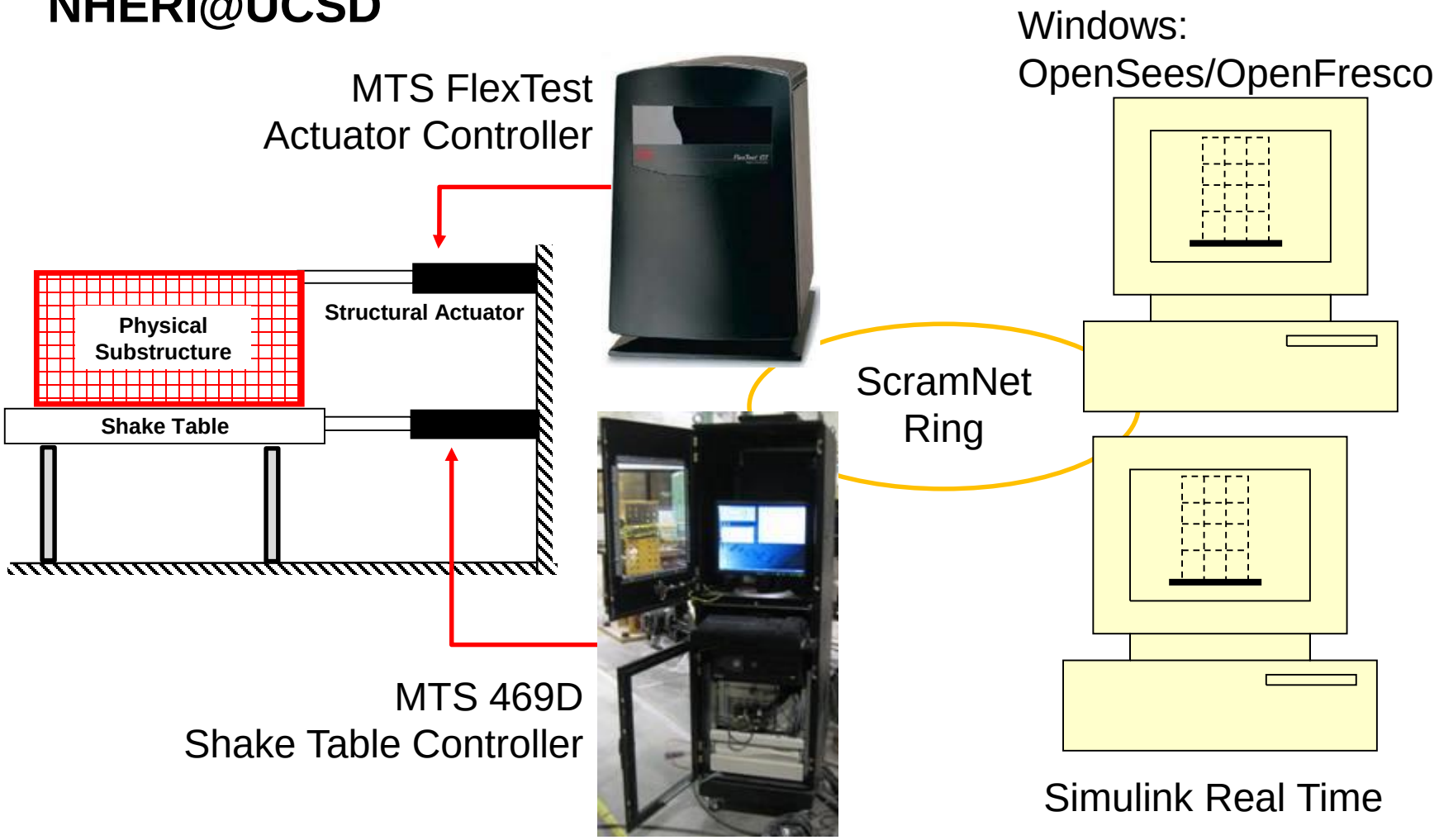






Hybrid Simulation Control System

- **Real time integrated computational capabilities available at NHERI@UCSD**



Real-time Hybrid Simulation Control System

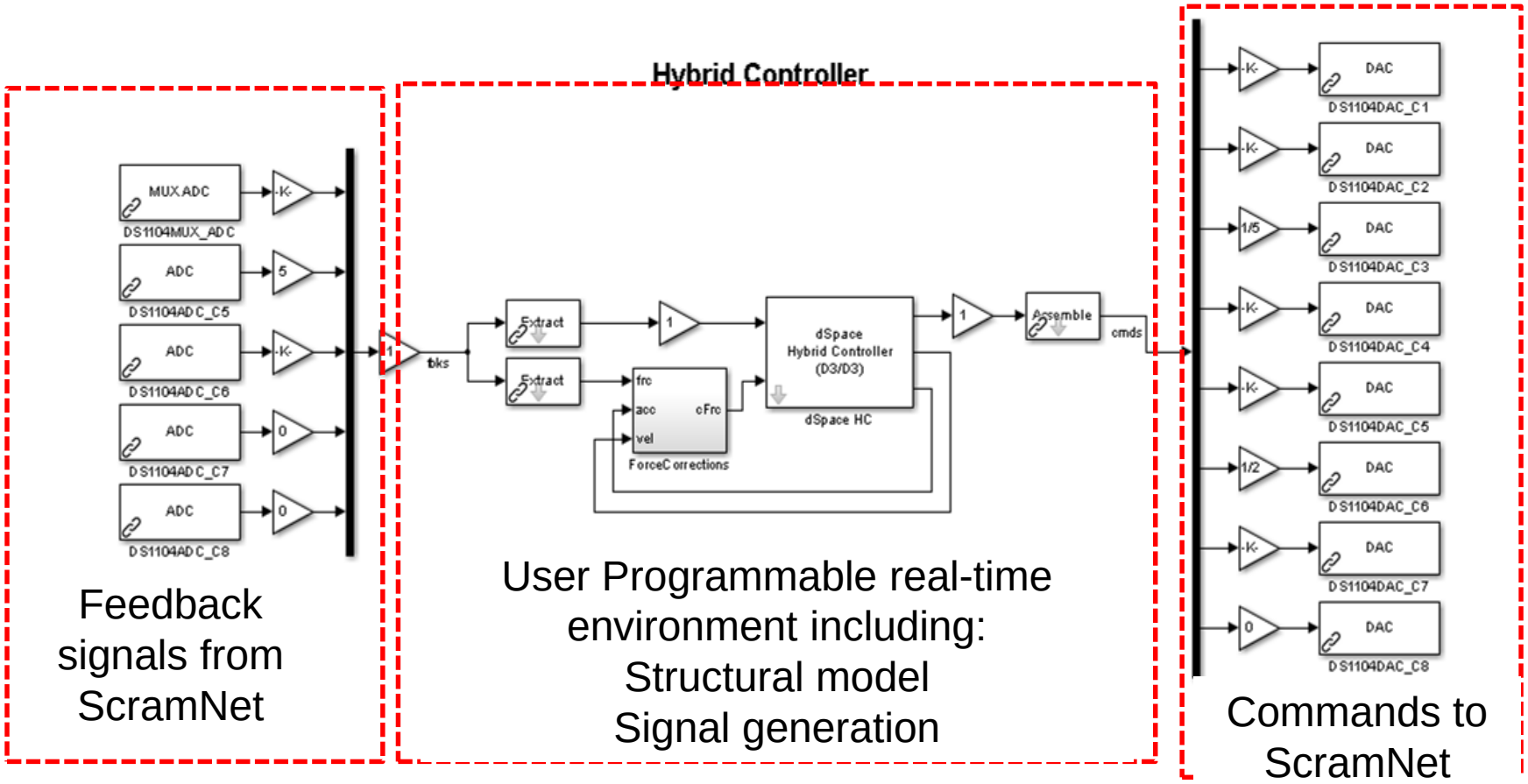
- **Hardware integrated through ScramNet Reflective Shared Memory for real-time communication between**
  - Exchange of data on the order of microseconds
- **MTS 469D Shake Table Controller**
  - Control commands receivedfrom ScamNet
- **Multi-channel MTS FlexTest Actuator Controller**
- **xPC Target/Simulink Real-Time**
  - User programmable environment using Matlab- Simulink that runs in real-time
  - Send commands and receive feedback from actuator controllers through ScramNet
- **External 50-ton dynamic actuator**

Real-time Hybrid Simulation Control System

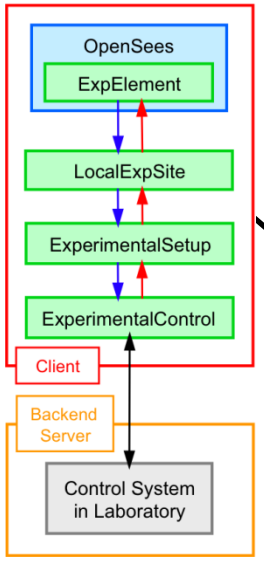
- **For hard real-time, users can program numerical structural model in Simulink**
- **Potential to interface with real time programs in other operating systems and program for structural analysis through ScramNet**
  - Applications with OpenSees/OpenFresco have been verified
- **Structural analysis software provides the advantage of access to libraries of integrators, elements etc.**
- **Delay and error compensation is critical to hybrid simulation and can be implemented in real-time environment**

Real-time Hybrid Simulation Control System

- **User defined structural model and boundary conditions can be implemented in Simulink for ‘hard’ real-time**



Advanced Numerical Models using OpenSees/OpenFresco



OpenSees Finite Element Model

OpenFresco Middleware

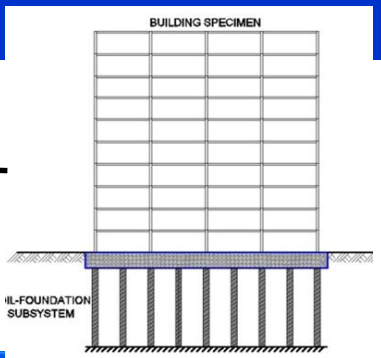
TCP/IP or SCRAMNet

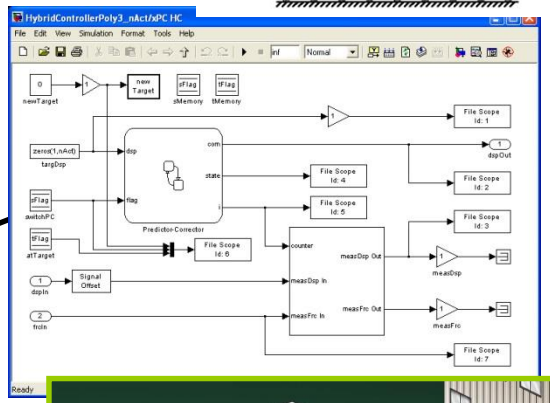
xPC-Target real-time Predictor-Corrector

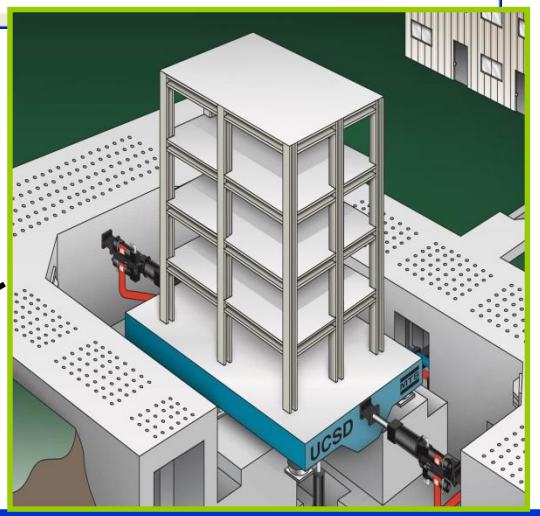
SCRAMNet

MTS 469D real-time Controller

Physical Specimen on Shake Table

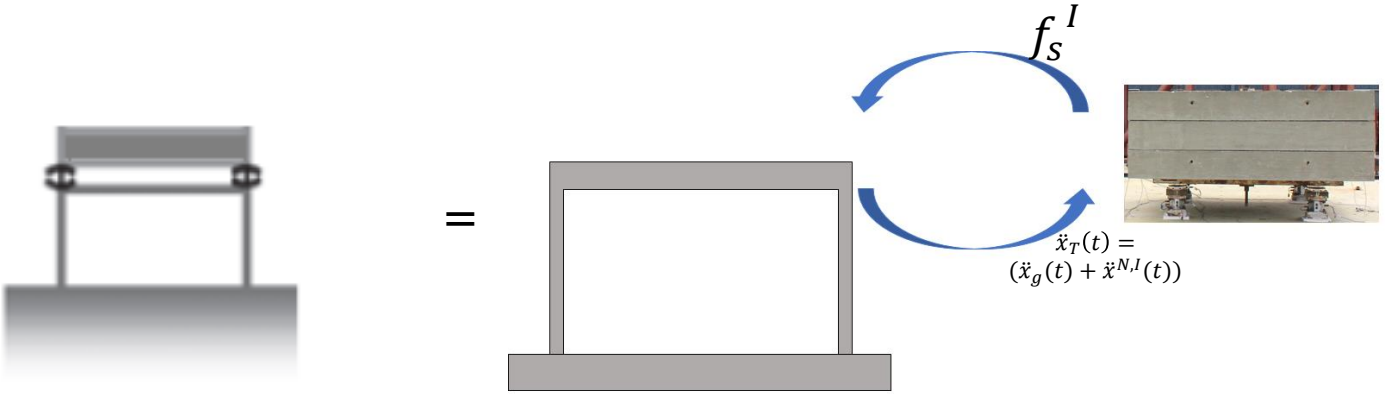






Recent Applications

- **Hybrid Simulation Commissioning Tests using LHPOST**
  - Collaborative development effort with NHERI SimCenter
  - Data workflow and curation with NHERI DesignSafe



$$M^N\ddot{x}(t) + C^N C\dot{x}(t) + K^N x(t) = -M^N L\ddot{x}_g(t) + f_s^I$$

$$M^E\ddot{x}(t) + C^E\dot{x}(t) + K^E x(t) = -M^E L\ddot{x}_T = -M^E L(\ddot{x}_g(t) + \ddot{x}^{N,I}(t))$$

where f_s^I only affects the interface DOF

Assuming no mass in the interface of the experimental

Recent Applications

- **Hybrid Simulation Commissioning Tests using LHPOST**
  - Two different approaches were implemented for the hybrid simulation computational drivers
    - ✓ programmed fully in Simulink RT
    - ✓ Numerical model in OpenSees/OpenFresco
  - Displacement control of shake table
  - Two different integrator algorithms were used: the generalized Alpha-Operator-Splitting and the explicit KR-alpha (adapted to shake table sub-structuring)
  - Application of adaptive time delay compensation was used (ATS compensator, Chae et al (2013))
  - SDOF and MDOF numerical models were implemented

Hybrid Simulation using LHPOST

➢ Experimental Setup

- Rigid Mass (56 kip) over four triple friction pendulum bearings

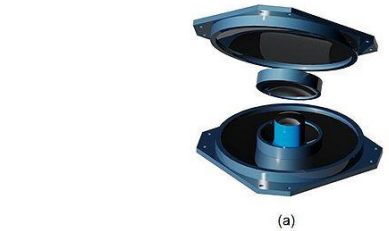
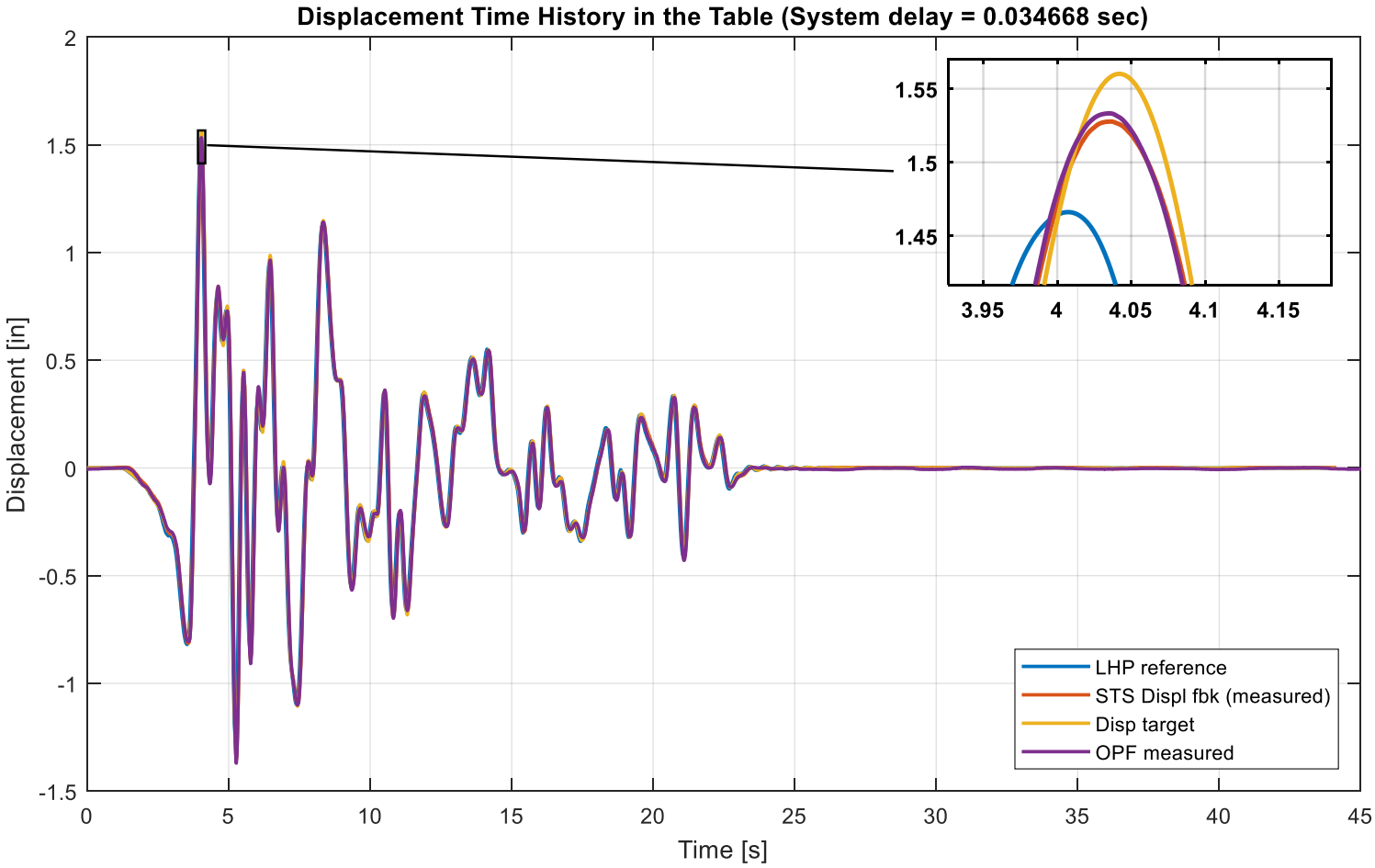


Figure 1: Triple friction pendulum bearing
(a) Three-dimensional view
(b) Section view and basic parameters

Hybrid Simulation using LHPOST

➢ Experimental Results

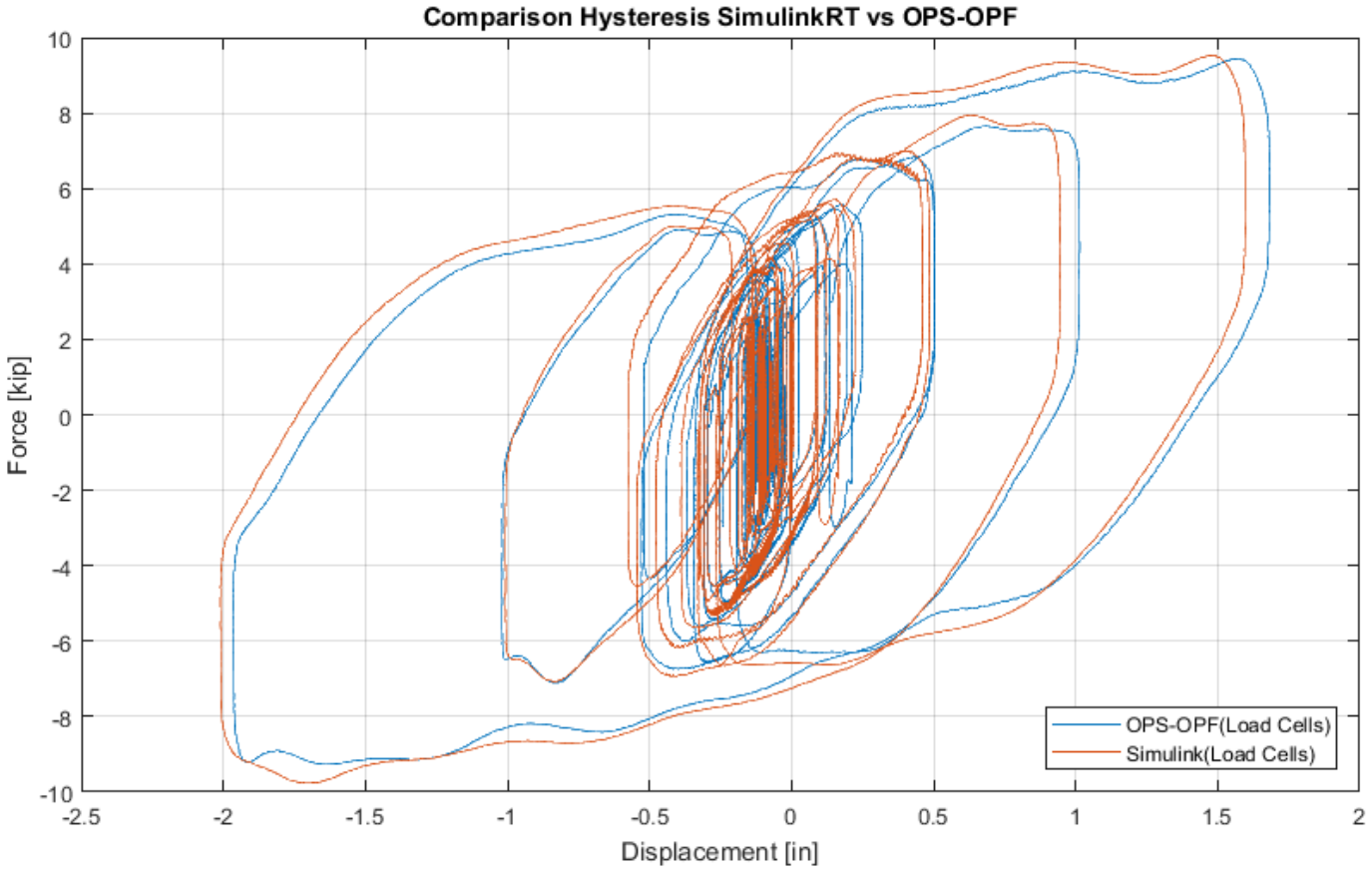


The time delay (average 34 ms) introduced by the shake table system was alleviated with an ATS compensator.

Hybrid Simulation using LHPOST

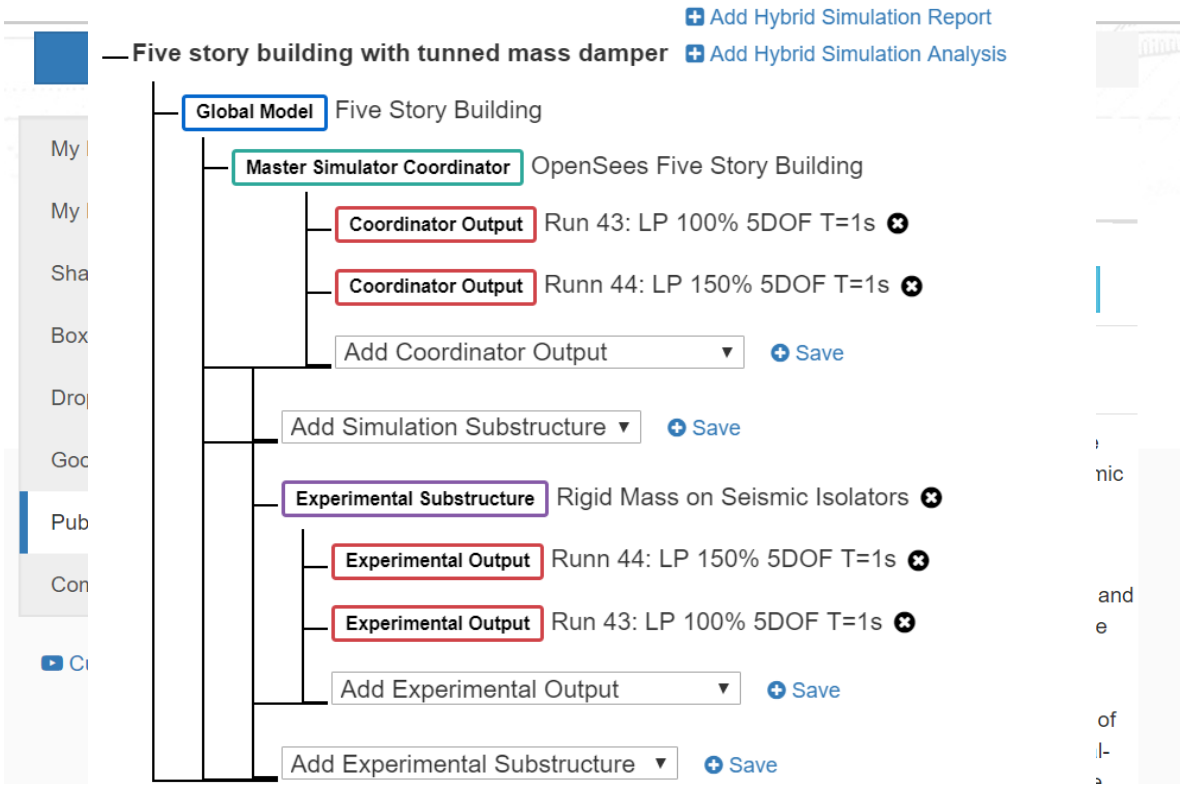
- **Experimental Results**

  The results using OPS-OPF and Simulink Real Time as the computational driver compare well.



Publication of Data

- **UCSD LHPOST Hybrid Commissioning Tests have been published using Hybrid Simulation Data Model on DesignSafe**



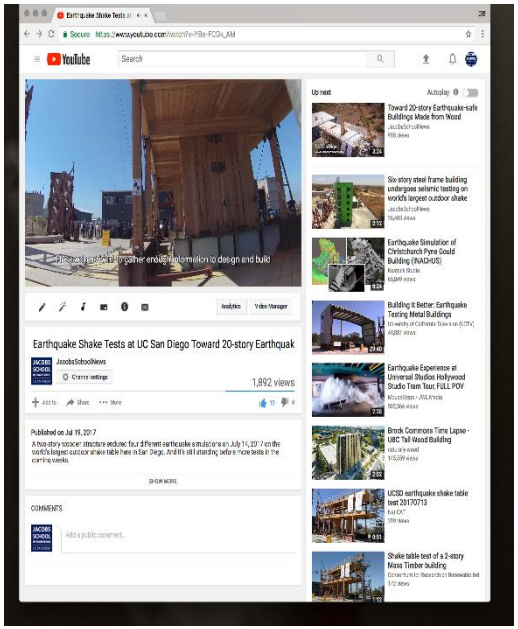
Vega, Manuel; Schellenberg, Andreas; Caudana, Humberto; Mosqueda, Gilberto, (2018-12-06), "Five story building with tunned mass damper" , DesignSafe-CI [publisher], Dataset, doi:10.17603/DS2C687

NHERI@UC San Diego ECO Goals

1. **To support technology transfer to practitioners and future engineers and promote implementation of research results into practice.** (WBS 1.5.1)
2. **Highlight innovative research conducted at NHERI@UC San Diego facilities** (WBS 1.5.2)
3. **Demonstrate the benefits of research to the public and critical decision makers** (WBS 1.5.2)

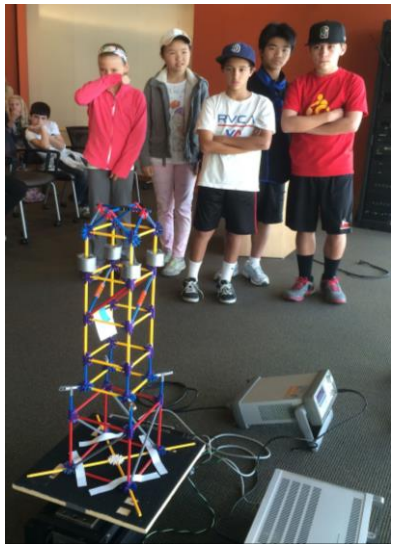
Tours & Professional Development Workshops

Jacobs School Media Relations Group



NHERI@UC San Diego ECO Goals

4. **Engage students and broaden participation of groups typically underrepresented in STEM** (WBS 1.5.3)
5. **Professionally develop undergraduate and graduate students** (WBS 1.5.3 and 1.5.4)
6. **Provide unique and stimulating experiences for undergraduates in high-quality engineering research** (WBS 1.5.4)



Seismic Outreach Ambassador Program

NHERI REU program

NHERI 4 Kids

Concluding Remarks

- **Hybrid Commissioning tests demonstrate new capabilities that can expand the complexity of large-scale geotechnical and structural systems that can be tested on LHPOST.**
- **Large-scale ECO activities broaden participation of community in hazard research**
- **NHERI@UCSD supports the implementation special initiatives by research community**
- **The upgraded LHPOST6 will provide new opportunities for research and outreach**