NHERI Lehigh EF Capabilities and Protocols

James Ricles, PhD, PE

NHERI Lehigh EF Director

What is Hybrid Simulation?

What is (RT)HS? Why is it important?

(Real-Time) Hybrid Simulation

Performed in real time

Simulation of response

Cyber (analytical/numerical)

+

Physical (experimental)

- Well understood structural components
- Modelled numerically
- Various substructures possible for a given experimental substructure

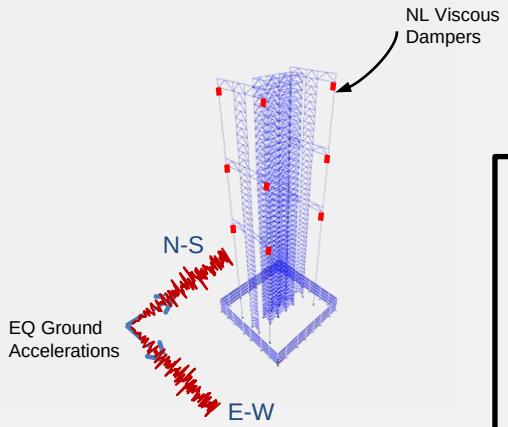
- Not well understood structural components
- Modelled physically with appropriate boundary conditions
- Easy to accommodate full-scale components

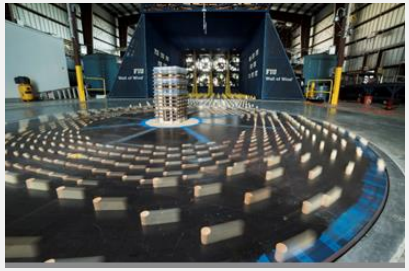
- Cost effective large-scale testing method
- Integrates benefits of numerical simulations & physical tests: Best of both worlds
- Comprehensive system and component response
- Rate dependent devices can be tested

Overall Concept of Real-time Hybrid Simulation: Structural System Subject to Multi-Natural Hazards

Structural System

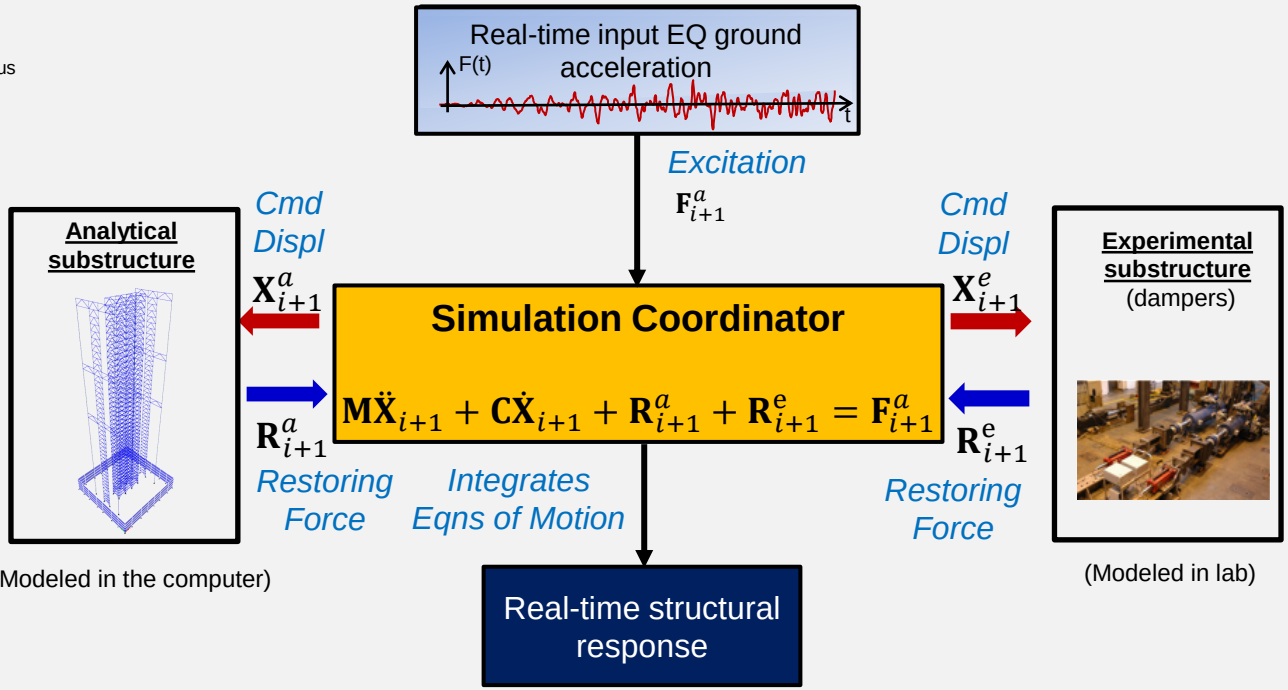
40-Story Building with Outriggers and Supplemental Dampers





Wind Tunnel Tests NHERI@FIU
Wind Load Determination

Hybrid Earthquake Simulation Experiments



(Modeled in the computer)

(Modeled in lab)

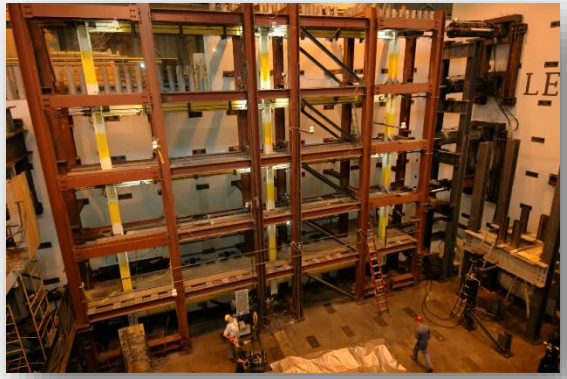
NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Large-Scale Real-time Hybrid Simulation - RTHS

RTHS EQ Simulation of Buildings with Dampers

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

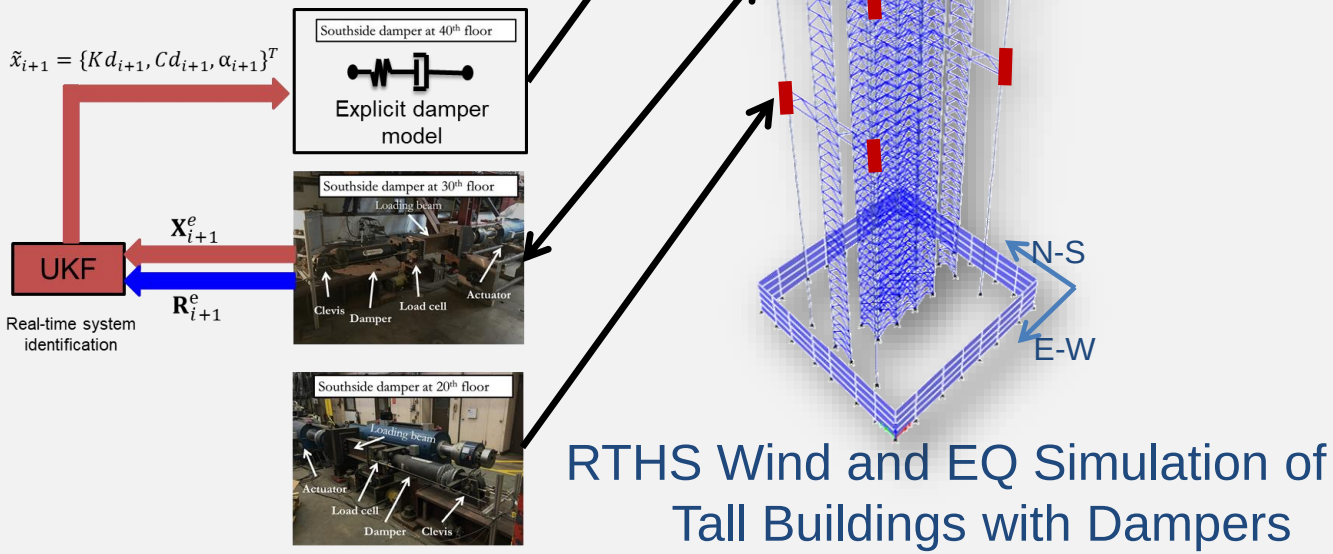
- Large-Scale Real-time Hybrid Simulation
- Large-Scale Hybrid Simulation - HS



HS EQ Simulation of Buildings with SC-MRF

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Large-Scale Real-time Hybrid Simulation
- Large-Scale Hybrid Simulation
- Large-Scale Real-time Hybrid Simulation (with Real-time Online Model Updating)



RTHS Wind and EQ Simulation of Tall Buildings with Dampers

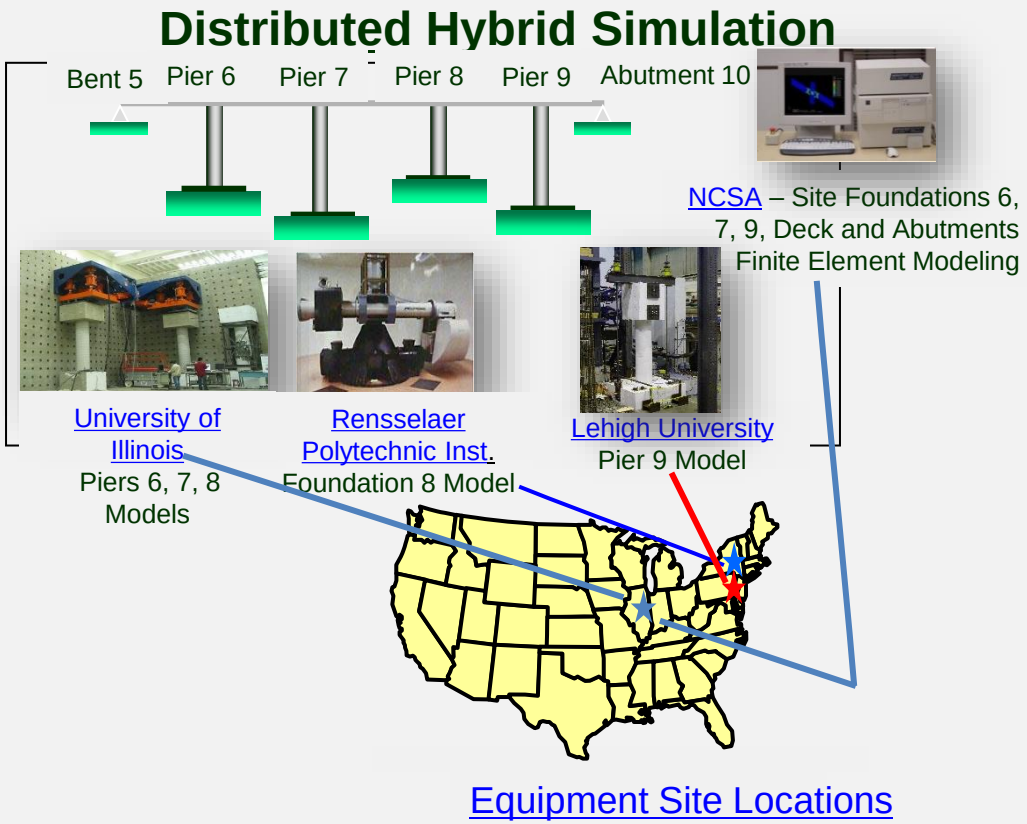
NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Large-Scale Real-time Hybrid Simulation
- Large-Scale Hybrid Simulation
- Large-Scale Real-time Hybrid Simulation (with Real-time Online Model Updating)
- Large-Scale Real-time Hybrid Simulation with Multiple Experimental Substructures

RTHS EQ Simulation of Building with Multiple Dampers

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

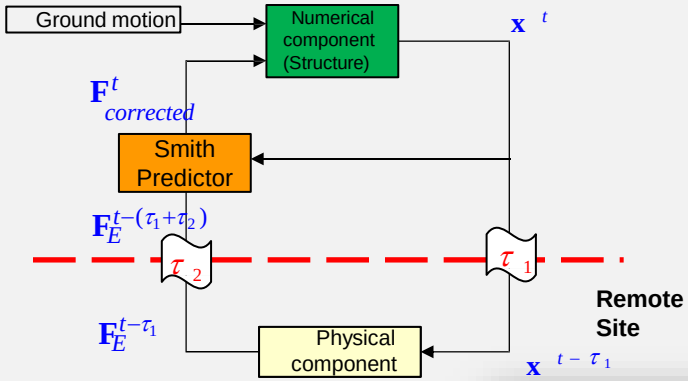
- Large-Scale Real-time Hybrid Simulation
- Large-Scale Hybrid Simulation
- Large-Scale Real-time Hybrid Simulation (with Real-time Online Model Updating)
- Large-Scale Real-time Hybrid Simulation with Multiple Experimental Substructures
- Geographically Distributed Hybrid Simulation



Distributed RTHS EQ Simulation of I-10 Collector Bridge

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Large-Scale Real-time Hybrid Simulation
- Large-Scale Hybrid Simulation
- Large-Scale Real-time Hybrid Simulation (with Real-time Online Model Updating)
- Large-Scale Real-time Hybrid Simulation with Multiple Experimental Substructures
- Geographically Distributed Hybrid Simulation
- Geographically Distributed Real-time Hybrid Simulation



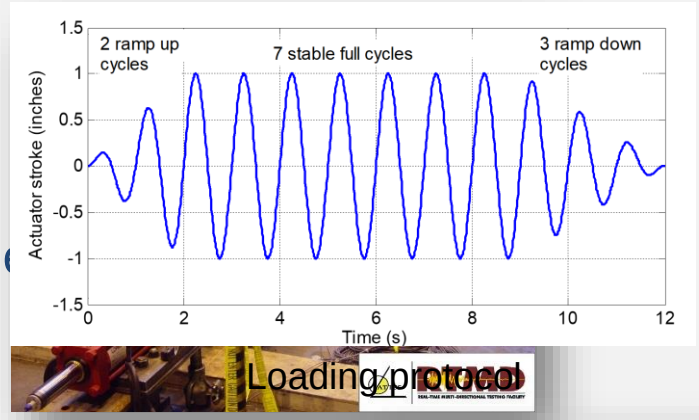
Lehigh

UIUC

RTHS EQ Simulation of Building with MR Dampers (Kim, Christenson)

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Large-Scale Real-time Hybrid Simulation
- Large-Scale Hybrid Simulation
- Large-Scale Real-time Hybrid Simulation (with Real-time Online Mode Updating)
- Large-Scale Real-time Hybrid Simulation with Multiple Experimental Substructures
- Geographically Distributed Hybrid Simulation
- Geographically Distributed Real-time Hybrid Simulation
- Predefined load or displacements (Quasi-static testing or characterization testing) - QS



Temperature Control Chamber

Characterization of Full-scale Semi-active and Passive Dampers for Wind and EQ

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Large-Scale Real-time Hybrid Simulation
- Large-Scale Hybrid Simulation
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- Large-Scale Real-time Hybrid Simulation with Multiple Experimental Substructures
- Geographically Distributed Hybrid Simulation
- Geographically Distributed Real-time Hybrid Simulation
- Predefined load or displacements (Quasi-static testing or characterization testing) - QS

Characterization of Large-scale RC Coupled Shear Wall System Subject to Lateral and Gravity Loading

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Large-Scale Real-time Hybrid Simulation
- Large-Scale Hybrid Simulation
- Large-Scale Real-time Hybrid Simulation (with Real-time Online Model Updating)
- Large-Scale Real-time Hybrid Simulation with Multiple Experimental Substructures
- Geographically Distributed Hybrid Simulation
- Geographically Distributed Real-time Hybrid Simulation
- Predefined load or displacements (Quasi-static testing or characterization testing)
- Dynamic testing - DT

Multi-directional Dynamic Testing of Pipe Couplers

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

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- Large-Scale Real-time Hybrid Simulation (with Real-time Online Model Updating)
- Large-Scale Real-time Hybrid Simulation with Multiple Experimental Substructures
- Geographically Distributed Hybrid Simulation
- Geographically Distributed Real-time Hybrid Simulation
- Predefined load or displacements (Quasi-static testing or characterization testing)
- Dynamic testing
- Tsunami/storm surge debris impact

Tsunami Debris Impact Test

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- Dynamic testing
- Tsunami/storm surge debris impact
- Soil-pile interaction

Pile Lateral Load Test

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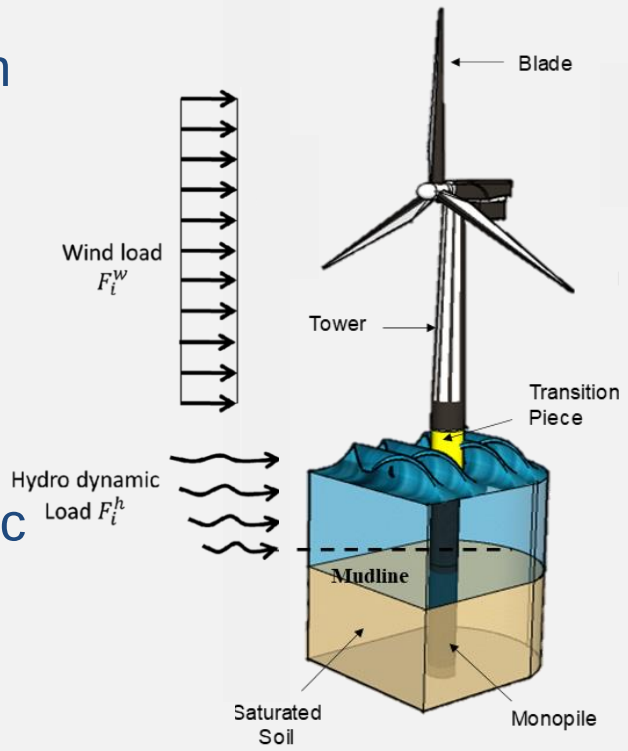
- Dynamic testing
- Tsunami/storm surge debris impact
- Soil-pile interaction
- Real-time Hybrid Simulation of Offshore Wind Turbine Structures



Offshore Wind Turbine Structure - Aeroelastic and Hydrodynamic Loads, Soil-Structure Interaction

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Large-Scale Real-time Hybrid Simulation
- Large-Scale Hybrid Simulation
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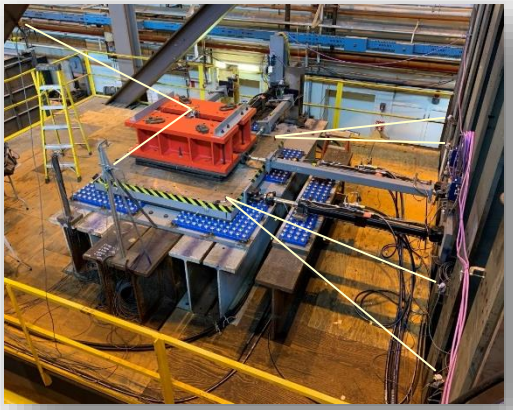
- Dynamic testing
- Tsunami/storm surge debris impact
- Soil-pile interaction
- Real-time Hybrid Simulation of Offshore Wind Turbine Structures
- Multi-directional Real-time Shake Table Hybrid Simulation

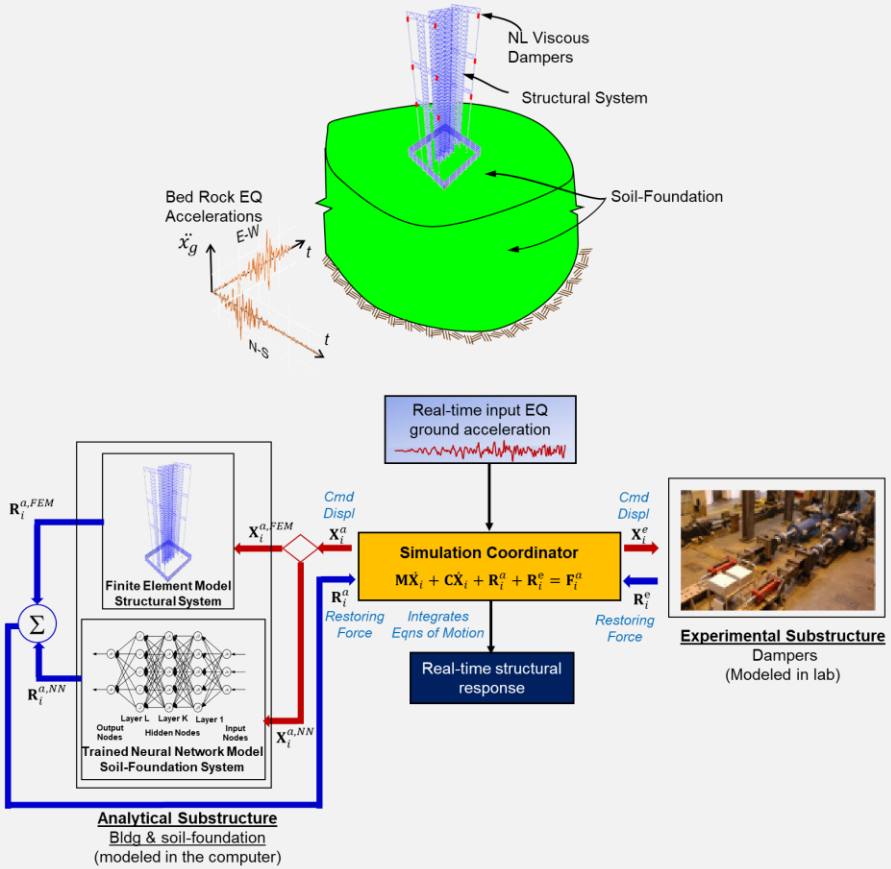


RTHS of Floor Isolation System using Multi-directional Shake Table

RII Track-4: Quantifying Seismic Resilience of Multi-Functional Floor Isolation Systems through Cyber-Physical Testing (OIA 1929151), **PI - Scott Harvey, University of Oklahoma**).

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Multi-directional Real-time Hybrid Simulation with Neural Network Models and Machine Learning

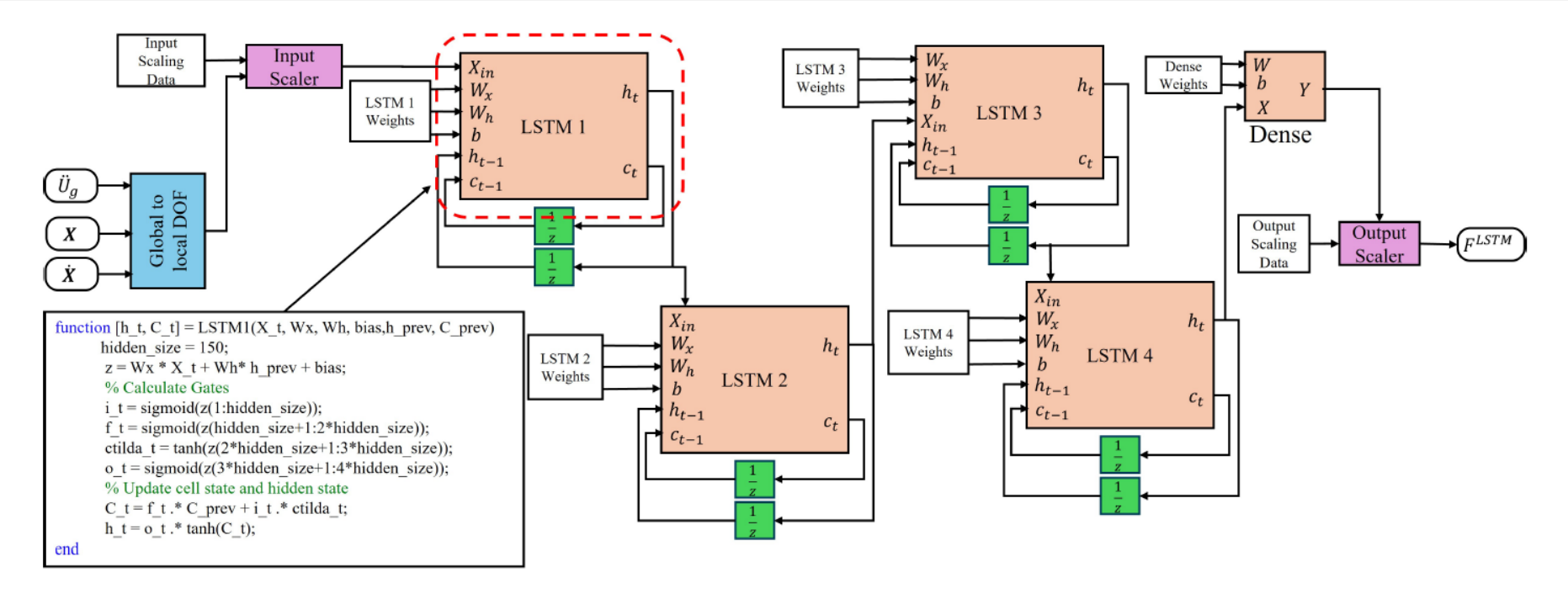


RTHS with Soil-Foundation-Structural System Interaction

Al-Subaihawi, S. (2023) “Real-time hybrid simulation of complex structural systems subject to multi-natural hazards." *PhD Dissertation,* Lehigh University, Bethlehem, PA.

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Multi-directional Real-time Hybrid Simulation with Neural Network Models and Machine Learning



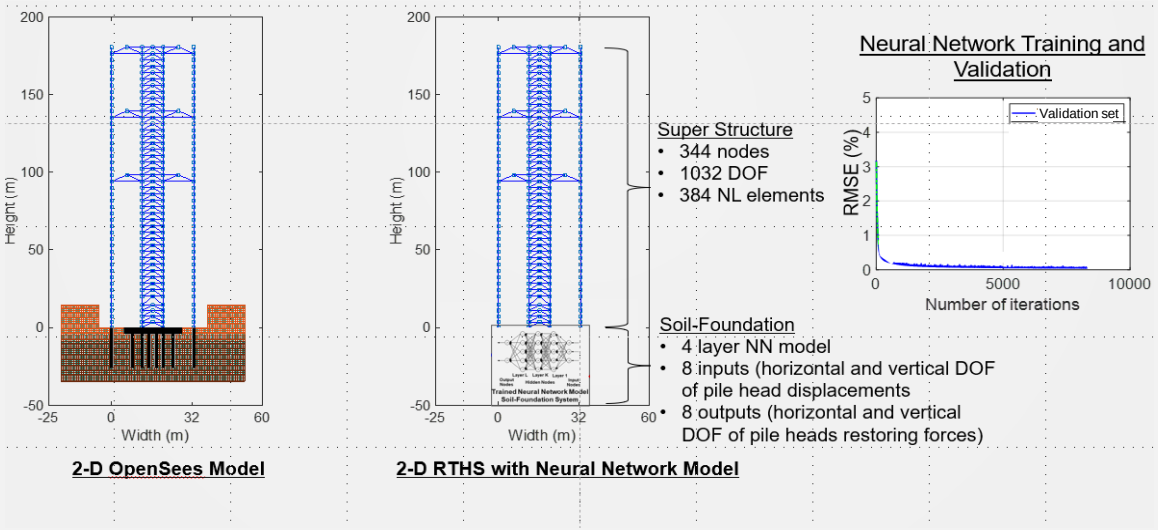
Simulink Block Diagram of LSTM Neural Network Model of Soil-Foundation System

RTHS with Soil-Foundation-Structural System Interaction

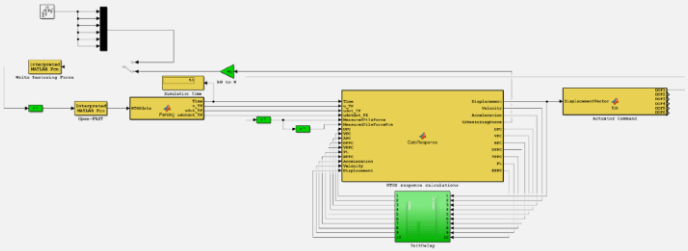
Malik, F. "Multi-Physics Real-Time Cyber-Physical Simulation of Complex Nonlinear Structural Systems with Soil-Foundation-Structure Interaction," *PhD Dissertation*, Lehigh University, in progress

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

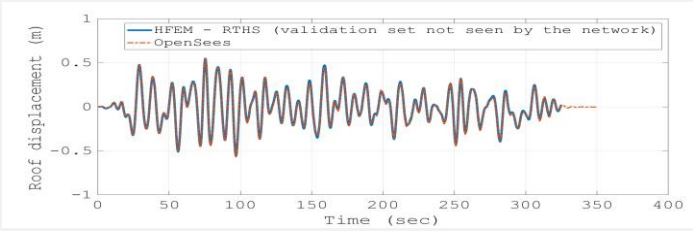
- Multi-directional Real-time Hybrid Simulation with Neural Network Models and Machine Learning



Neural Network Model of Soil Training



Simulink Block – User Tool



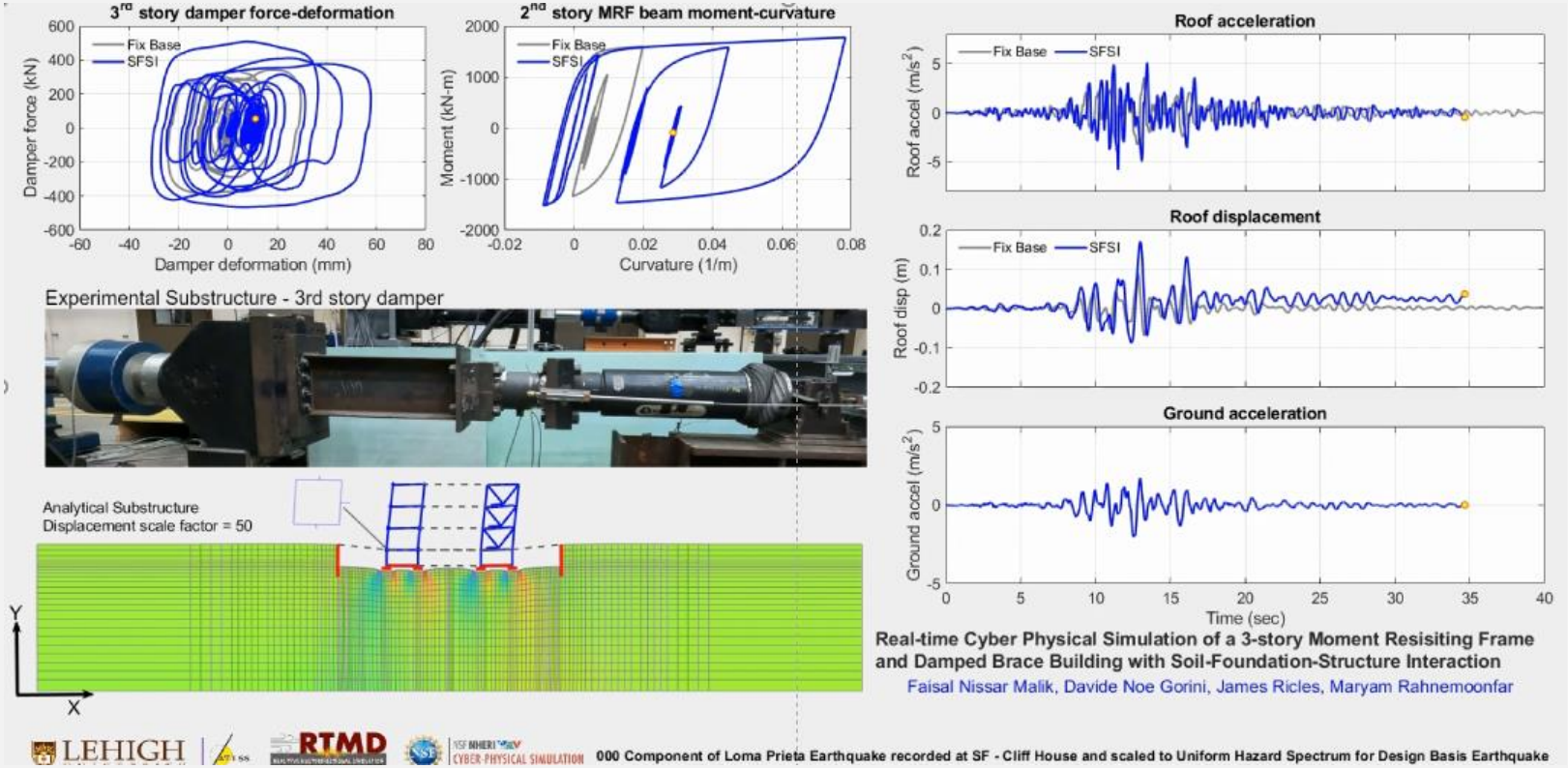
Comparison with OpenSees

RTHS with Soil-Foundation-Structural System Interaction

Al-Subaihawi, S. (2023) “Real-time hybrid simulation of complex structural systems subject to multi-natural hazards." *PhD Dissertation,* Lehigh University, Bethlehem, PA.

Multi-physics RTHS: Seismic Real-time Hybrid Simulation with Soil-Foundation-Structure Interaction Using Neural Networks

Faisal Malik, Davide Noe Gorini, James Ricles, and Maryam Rahnesmoonfar
Lehigh University & Trento University

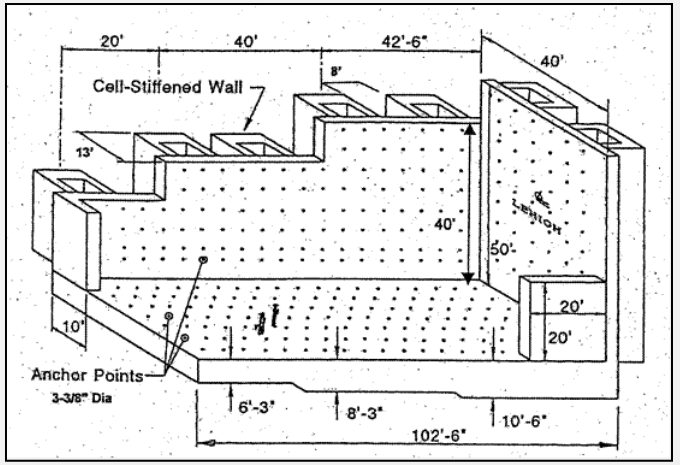


Malik, F. “Multi-Physics Real-Time Cyber-Physical Simulation of Complex Nonlinear Structural Systems with Soil-Foundation-Structure Interaction,“ PhD Dissertation, Lehigh Univ., in progress

Malik, F. Gorini, D,N, Ricles, J., and M. Rahnesmoonfar, (2024). “Multi-Physics Framework for Seismic Real-time Hybrid Simulations with Soil-Foundation-Structure Interaction,” *Engineering Structures*, in preparation

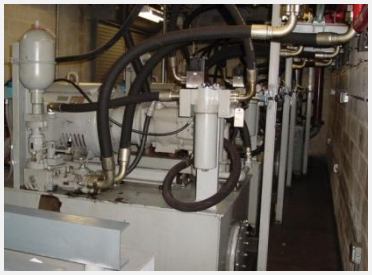
ATLSS Lab Infrastructure

- **3-D Multi-directional reaction wall facility**
  - 3-dimensional
  - Up to 50 ft height
  - 5 ft anchor point grid
- **Strong floor**
  - 40 ft by 100 ft
  - 5 ft anchor point grid
- **Hydraulic Supply System**
- **Over 30 Hydraulic Actuators**
- **Digital servo-hydraulic controllers**
- **Data Acquisition Systems**
- **Large array of conventional sensors**
- **Advanced sensors: Digital Image Correlation Systems**
- **Ancillary equipment: 40 kips crane, etc.**



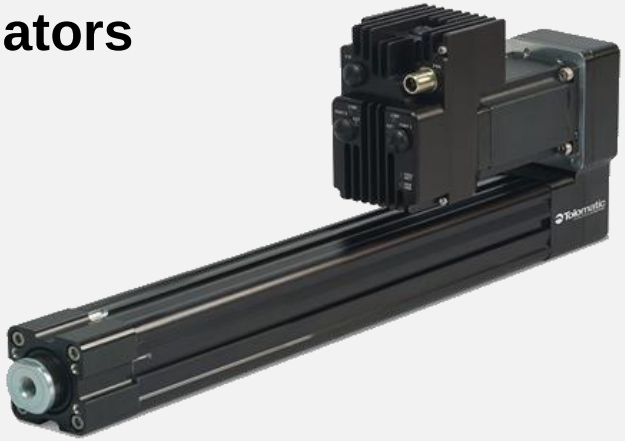
NHERI Lehigh EF Hydraulic Equipment and Power

- **Enables real-time EQ large scale demand to be imposed for up to 30+ seconds**
- **Hydraulic supply system (ATLSS)**
  - 5-120 gal/min pumps
- **Accumulator System (NHERI)**
  - 16 piston accumulators
    - 50 gal each
- **5 dynamic hydraulic actuators (NHERI)**
  - Maximum load capacity
    - 2 actuators: 517 kips
    - 3 actuators: 382 kips
  - Stroke
    - **+/- 20 in**
  - Maximum velocity
    - **45 in/s for 382 kip** actuators
    - **33 in/s for 517 kip** actuators
- **10 - 550 gal/min servovalves and HSMs**



NHERI Lehigh EF Electric Drives

- **2x Tolomatic High Force Electric Actuators**
  - EtherNet/IP real-time control
  - 6 in total stroke
  - 4000 lbf peak holding force
  - 0.25 in/s speed



- **4x Ultramotion Electric Actuators**
  - RS422 real-time control
  - 7 in total stroke
  - 270 lbf continuous force
  - 530 lbf peak force
  - 14 in/s speed

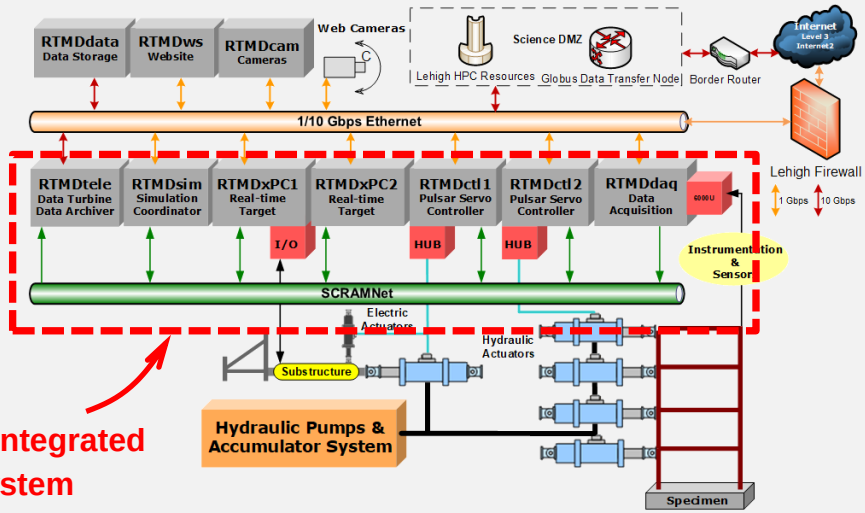
Other NHERI Lehigh EF Equipment

- High Speed 300+ Channel Data Acquisition System
- 3 Real-Time Targets for simulation coordination, including additional DAQ
- Three real-time servo-hydraulic digital controllers with mixed mode control
- Sensors (displacement, accelerometers, inclinometers)
- Telepresence webcams
- Specs for all equipment found in NHERI Lehigh EF User's Guide

https://lehigh.designsafe-ci.org/resources

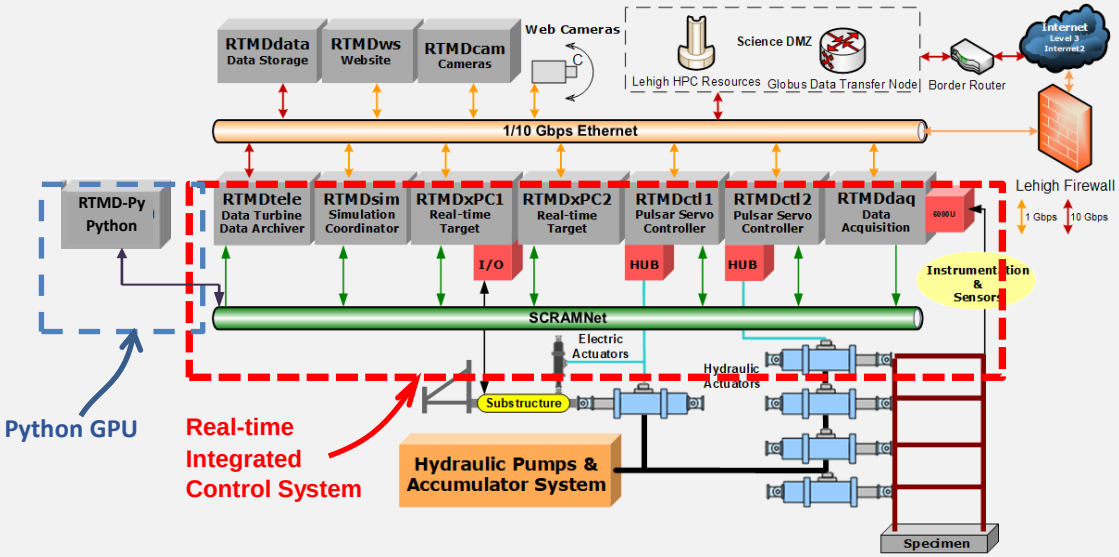
Real-time Integrated Control System

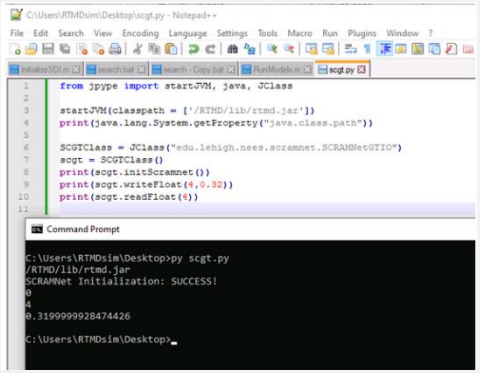
- **Configured with experimental protocol required by user to perform test**
  - Large-Scale Hybrid Simulation
  - Large-Scale Real-time Hybrid Simulation
  - Large-Scale Real-time Hybrid Simulation with Multiple Experimental Substructures
  - Geographically Distributed Hybrid Simulation
  - Geographically Distributed Real-time Hybrid Simulation
  - Predefined load or displacements (Quasi-static testing or characterization testing)
  - Dynamic testing
- **Testing algorithms reside on an RTMDxPC and run in real time**
  - Experiments can be run in true real-time (real-time hybrid simulation, real-time distributed hybrid simulation, dynamic testing, characterization testing).
  - Or, experiments can be run at an expanded time scale (hybrid simulation, distributed hybrid simulation, quasi-static testing).
- **Distributed hybrid simulation via:**
  - OpenFresco
  - Custom software
- **Flexible-designed system**
  - Software and middleware packages developed by users or NHERI CI can be plugged in and utilized for testing

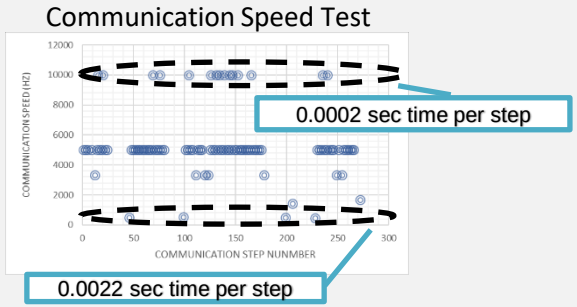


Real-time Integrated Control System

- **Neural Network Models and Machine Learning**
  - RTMD-Py Workstation: Python executed on Graphics Processor Units (GPUs)
  - Synchronized real-time communication using SCRAMNet
  - Communication Protocol: Java Native Interface Wrapper with C++ libraries







Malik, F., Marullo, T. and J. Ricles (2024). “AI-based Metamodels for Real-time Hybrid Simulation of Soil-Foundation-Structure Systems." *ATLSS Report,* Lehigh University, Bethlehem, PA.

NHERI Lehigh EF Control Room

Control Center

- Houses Real-time Integrated Control System
- Camera Control
- Data Acquisition System and Server
- Data Streaming System
  - Video
  - Sensors
- Video Displays
- Local Repository

Instrumentation

- Displacement transducers
  - Strokes ranging from ±6.4mm (LVDTs) to 1524mm (linear potentiometers).
  - Temposonic position sensors with a ±760 mm stroke, to a ±1100 mm stroke.
  - All transducers are calibrated to within ±1% accuracy, with the LVDTs calibrated to within ±0.1%.
- Inclinometers ranging up to ±20 degrees with 1% accuracy.
- Each hydraulic actuator is equipped with a load cell.
  - All load cells are calibrated to within ±0.1% accuracy.

NHERI Lehigh EF non-NHERI Equipment

- Site leverages Non-NHERI equipment to provide capability, improve capacity and maintain throughput.
  - 30 Actuators
  - ATLSS Wineman Controller
  - 2 MTS 458 Controllers
  - MTS FlexTest 100 Controller
  - DAQ systems
  - Trilion System for Digital Image Correlation - full field displacement and strain
  - Transducers - over 96 LVDTs, 62 load cells, Temposonics (12 ATLSS)
  - SSI instrumentation
- Users Guide - Available ATLSS Equipment

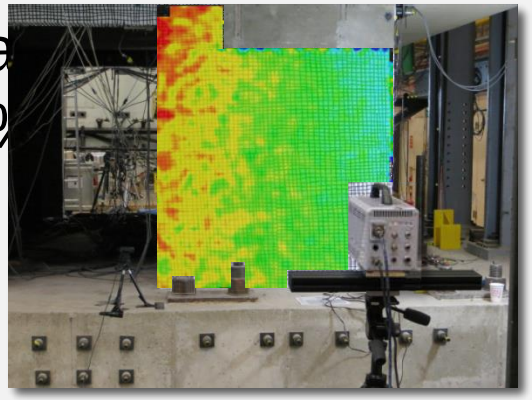
https://lehigh.designsafe-ci.org/resources

Instrumentation

- Digital imaging correlation (DIC) systems.
  - Utilize the 3D ethod.
  - Works on bot r pattern, thus simplifying sa
  - The same se to measure small and large obj m) a the range of (100%

Figure F.4 DIC System

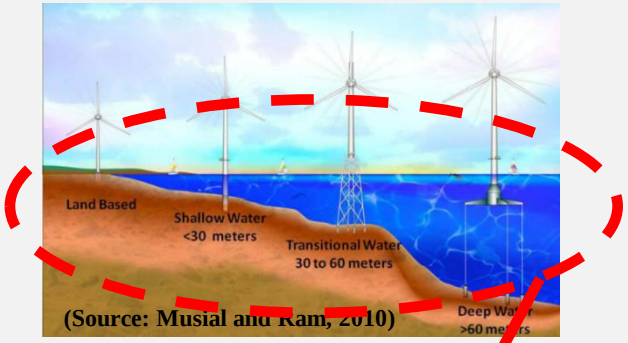
NEES@Lehigh Coupled Shear Wall Test Specimen with Multi-Directional Loading



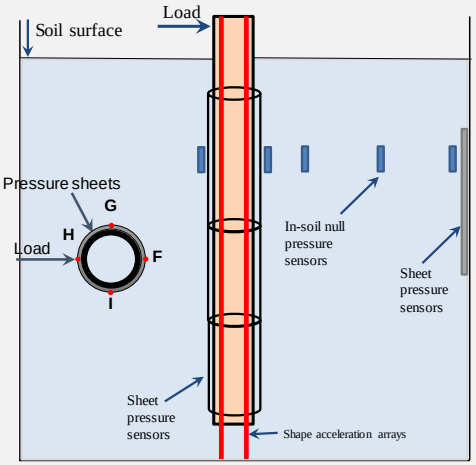
Digital Imaging Correlation System: reinforced concrete coupled-shear wall test specimen measured pier vertical displacements (courtesy M. McGinnis)

Soil-Structure Interaction Instrumentation

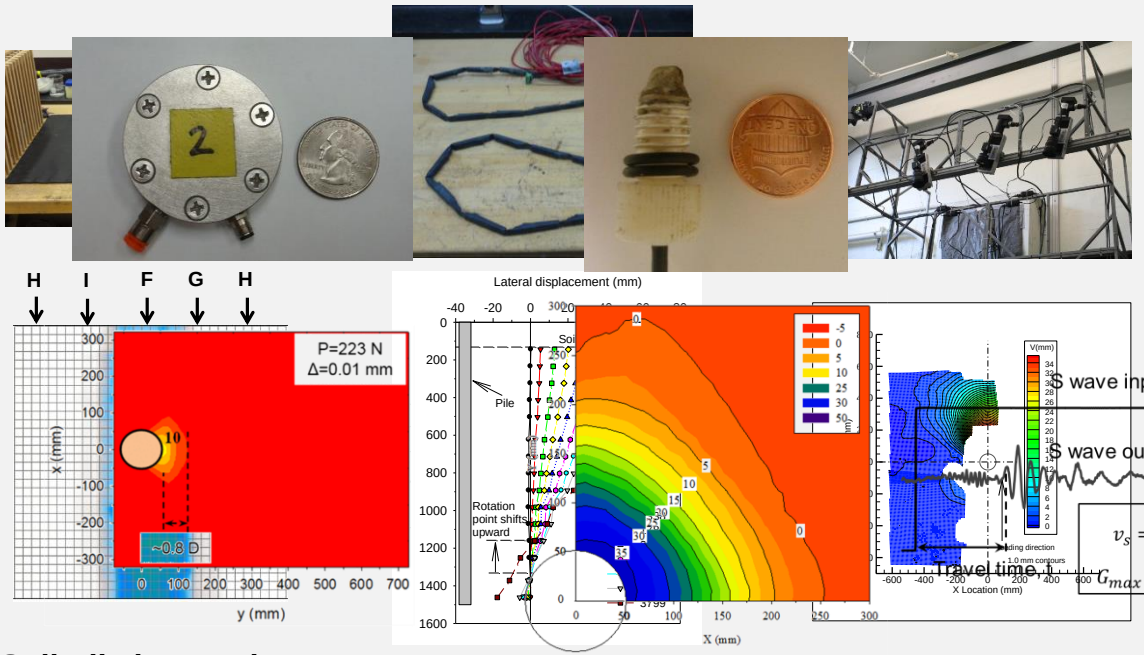
Professor Muhannad Suleiman



- Advanced instrumentation to understand SSI of foundation systems under different loading conditions
- Combine with hybrid simulation to improve analytical substructure models, or
- Hybrid simulation with soil included in experimental substructure



Test Setup and instrumentation



Soil-pile interaction pressure sensors

Pressure sensors

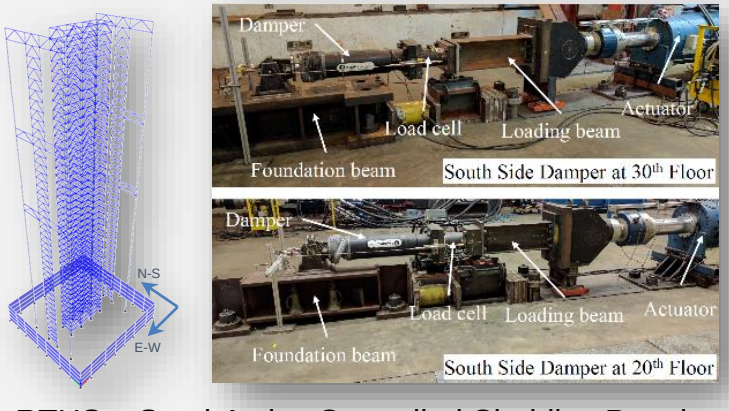
Shape acceleration arrays

S wave sensors

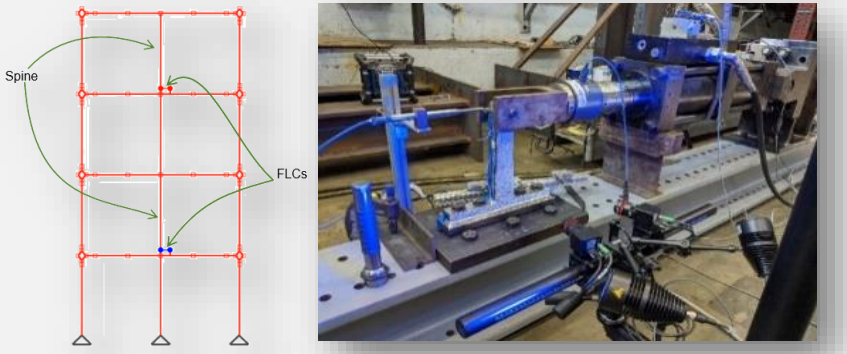
Digital image correlation

ATLSS Lab Infrastructure and NHERI Lehigh EF Equipment

- Combined resources enables multiple concurrent large-scale experimental projects to be conducted



RTHS – Semi-Active Controlled Cladding Panels for Multi-Hazard Resilient Buildings



HS – Frame-Spine System with Force-Limiting Connections for Low-Damage Seismic Resilient Buildings

QS & HS – A Resilience-based Seismic Design Methodology for Tall Wood Buildings

QS – Advancing Knowledge on the Performance of Seismic Collectors in Steel Building Structures

NHERI Lehigh EF: ATLSS Space, Resources, Accommodations

- **Specimen Prep Areas**
  - Staging Areas
  - Machine Shop
- **Laboratories**
  - Intelligent Structures
  - Mechanical Testing
  - Welding and Joining
  - Materials
  - Microscopy
- **Offices**: Faculty; Staff; Visiting Researchers
- **Meeting Rooms**: Auditorium; Conference Room
- **Storage Areas**
- **Secure Facility**

Specimen preparation staging area

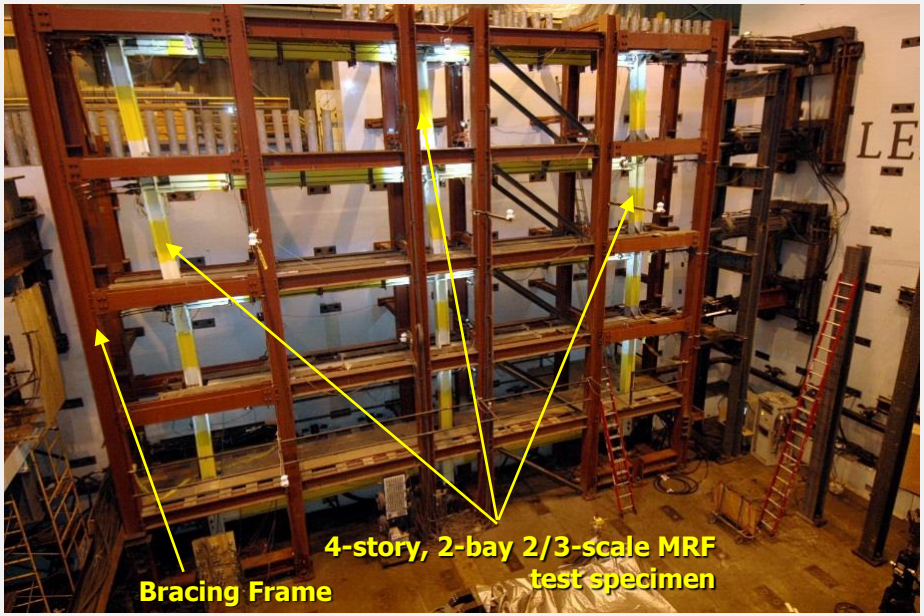
Mechanical testing

Auditorium – ECO Activities

NHERI Lehigh Testbeds

NHERI Lehigh EF Testbeds

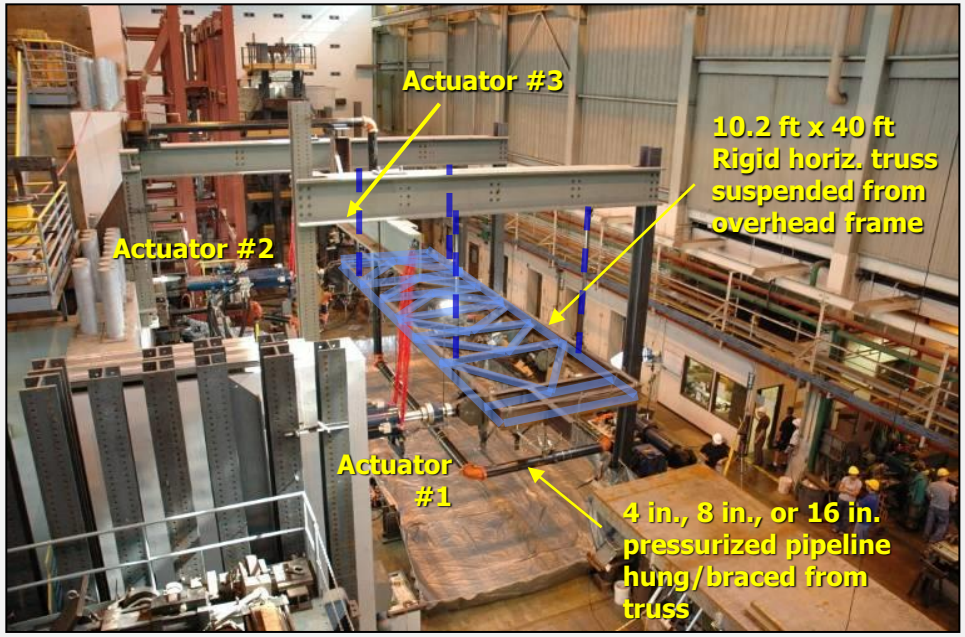
- **Lateral Load Resisting System Testbed**
  - Perform experiments on test frame specimens:
    - Up to 45 ft height
    - Up to 36 ft width
  - Large-scale lateral load system characterization tests
  - Real-time hybrid simulations



Hybrid simulation of building with self-centering resilient moment resisting frames

NHERI Lehigh EF Testbeds

- **Non-Structural Component Multi-Directional Seismic Simulator**
  - Non-structural components and systems:
    - ➢ Up to 40 ft length
    - ➢ Up to 10 ft width
  - Multi-directional real-time characterization testing
  - Multi-directional real-time hybrid simulations

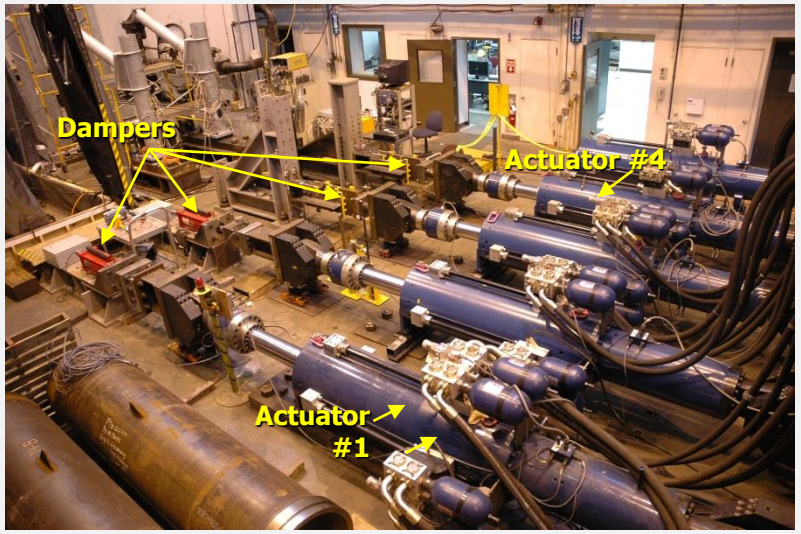


Multi-directonal Real-time hybrid simulation of building piping system

NHERI Lehigh EF Testbeds

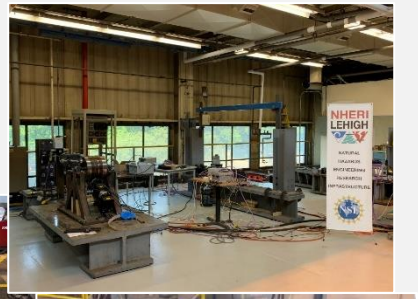
- **Full-scale Damper Testbeds**
  - Enables full-scale damper tests:
    - Damper characterization tests
    - Real-time hybrid simulations
  - Stoke, velocity, and force capacity:
    - +/- 20 in. stroke
    - 45 in/s for 382 kip actuators
    - 33 in/s for 517 kip actuators

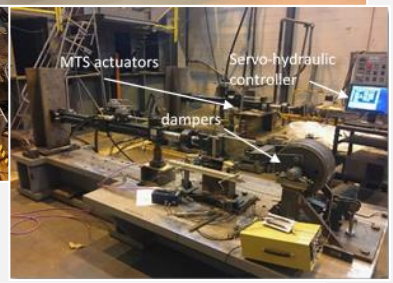
Real-time hybrid simulation of building with four passive dampers

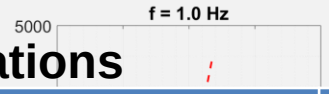


NHERI Lehigh EF Testbeds

- **Real-time Cyber-Physical Structural Systems Laboratory (CPSSL) – Real-time Testbeds**
  - 4000 ft^2 new resource created to enhance the research, ECO, and researcher training participant experience in cyber-physical systems (hybrid-simulation) with the goal of broadening the user base.
  - Small-scale, lower costs with test beds, creating more hands-on opportunities in cyber-physical systems testing.
  - Efficient resource for capacity building pilot studies.
    - Seven Hydraulic Actuators:
      - 2 - Model 244.21G2
      - 1 - Model 244.20G2S
      - 2 - Model 244.20
      - 2 - Model 244.31
    - Two Electric Actuators (5000 lbs, 3 in stroke)
    - Independent Real-time Integrated Control and DAQ Systems





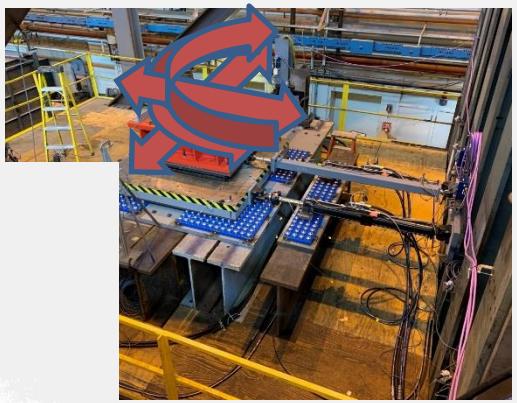


Actuator Specifications

	244.21G2	244.20G2s	244.20	244.31
Max Force	50 kN (11 kips)	82 kN (18.5 kips)	100 kN (22 kips)	250 kN (55 kips)
Max disp.	±254 mm (±10 in)	±177 mm (±7 in)	±76 mm (±3 in)	±127 mm (±5 in)
Max velocity	0.74 m/s (29 in/s)	1.29 m/s (51 in/s)	0.38 m/s (15 in/s)	0.48 m/s (19 in/s)
Servo Valve	30 gpm	90 gpm	30 gpm	90 gpm

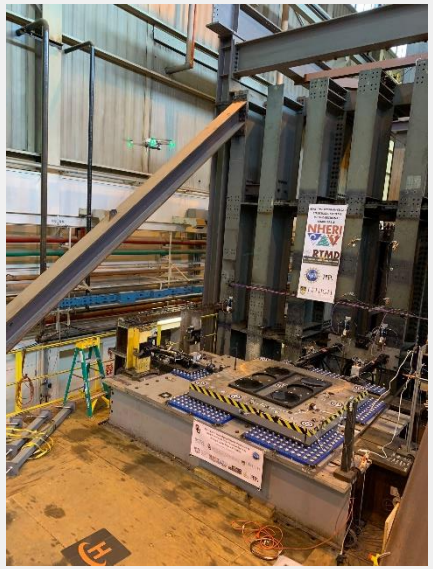
NHERI Lehigh EF Testbeds

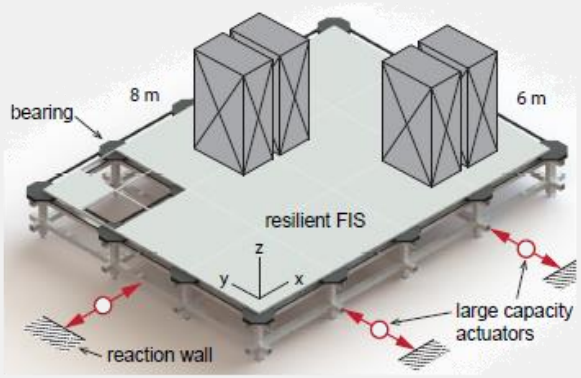
- **Real-time Cyber-Physical Structural Systems Laboratory (CPSSL) – Multi-directional Shake Table**
  - 4000 ft^2 new resource created to enhance the research, ECO, and researcher training participant experience in cyber-physical systems (hybrid-simulation) with the goal of broadening the user base.
  - Small-scale, lower costs with test beds, creating more hands-on opportunities in cyber-physical systems testing.
  - Efficient resource for capacity building pilot studies.



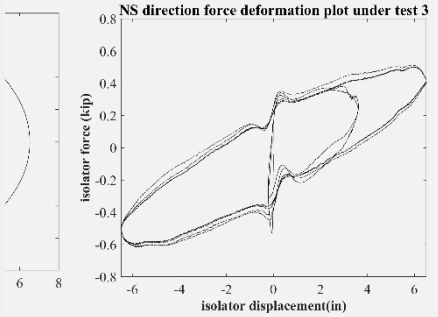
Floor Isolation System using
directional Shake Table
arvey, University of Oklahoma

- Independe
  DAQ Syste
- Multi-direct
  translation
- Multi-chan
  speed
- A payload
- Table plate
- Maximum
  (Y-axis).Pe
  inch/sec (Y
- Can be use
  Table mod



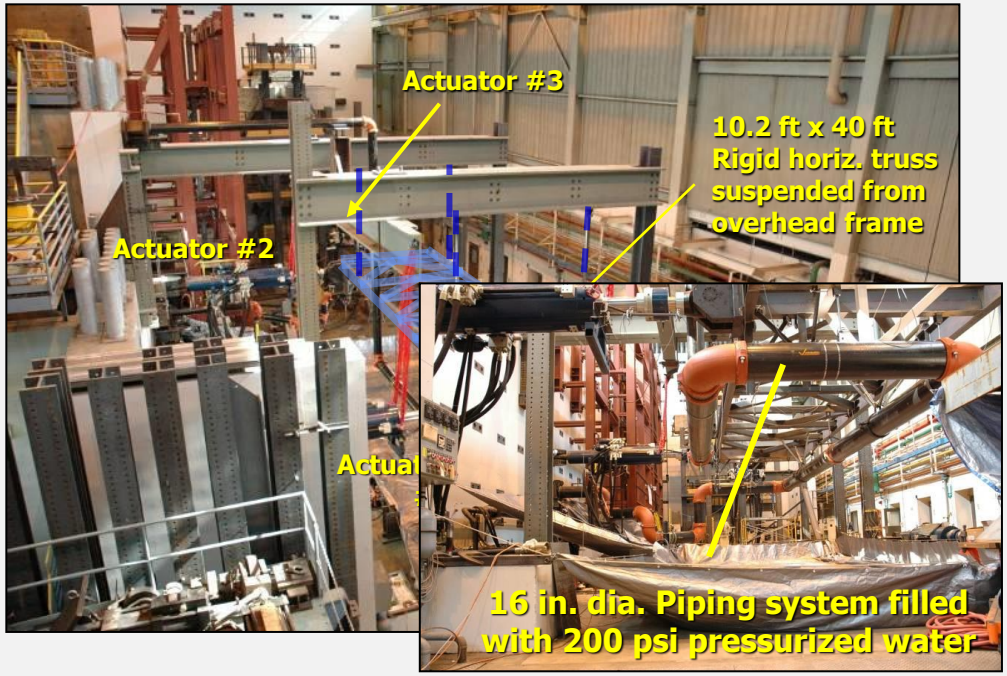


FIS RTHS Testbed using Shake Table



NHERI Lehigh EF Testbeds

- **Non-Structural Component Multi-Directional Seismic Simulator**
  - Non-structural components and systems:
    - Up to 40 ft length
    - Up to 10 ft width
  - Multi-directional real-time characterization testing
  - Multi-directional real-time hybrid simulations



Multi-directonal Real-time hybrid simulation of building piping system

NHERI Lehigh EF Testbeds

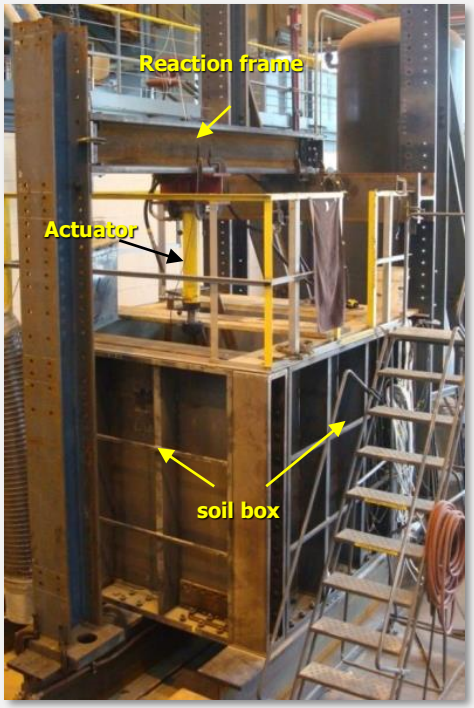
- **Tsunami & Storm Surge Debris Impact Force Testbed**
  - Enables full-scale debris impact tests:
    - High speed DAQ; high speed 5000 fps cameras
    - High bandwidth, resolution load cells
    - Accelerometers, laser-displacement transducers

Real-time simulation of impact forces from tsunami shipping container debris

NHERI Lehigh EF Testbeds

- **Reduced-scale Soil Box** - Professor Muhannad Suleiman, CEE Dept
  - Enables soil-structure interaction research
    - Flexible designs (6 x 6 x 6 ft and 6 x 6 x 3 ft in size)
    - Actuators with load cells; data acquisition system
    - Sensors for soil and foundation response measurements
    - Advanced sensors - Digital Imaging Correlation System

Soil-foundation structure interaction testbed

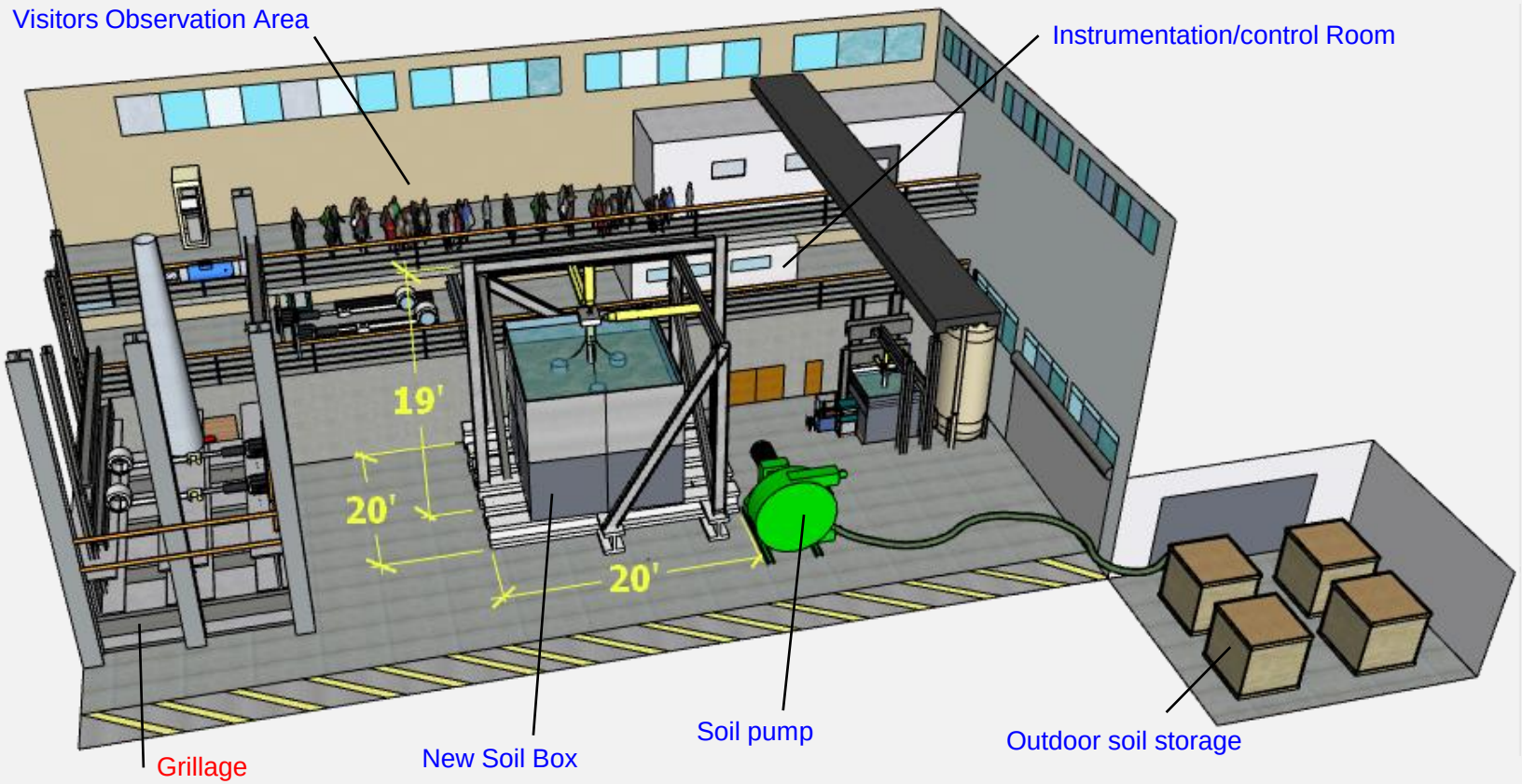


NHERI Lehigh EF Testbeds

- **Large-scale Soil Box** - Professor Muhannad Suleiman, CEE Dept
  - Enables soil-structure interaction research
    - (15 x 15 x 20 ft in size)
    - Actuators with load cells; data acquisition system
    - Sensors for soil and foundation response measurements
    - Advanced sensors - Digital Imaging Correlation System

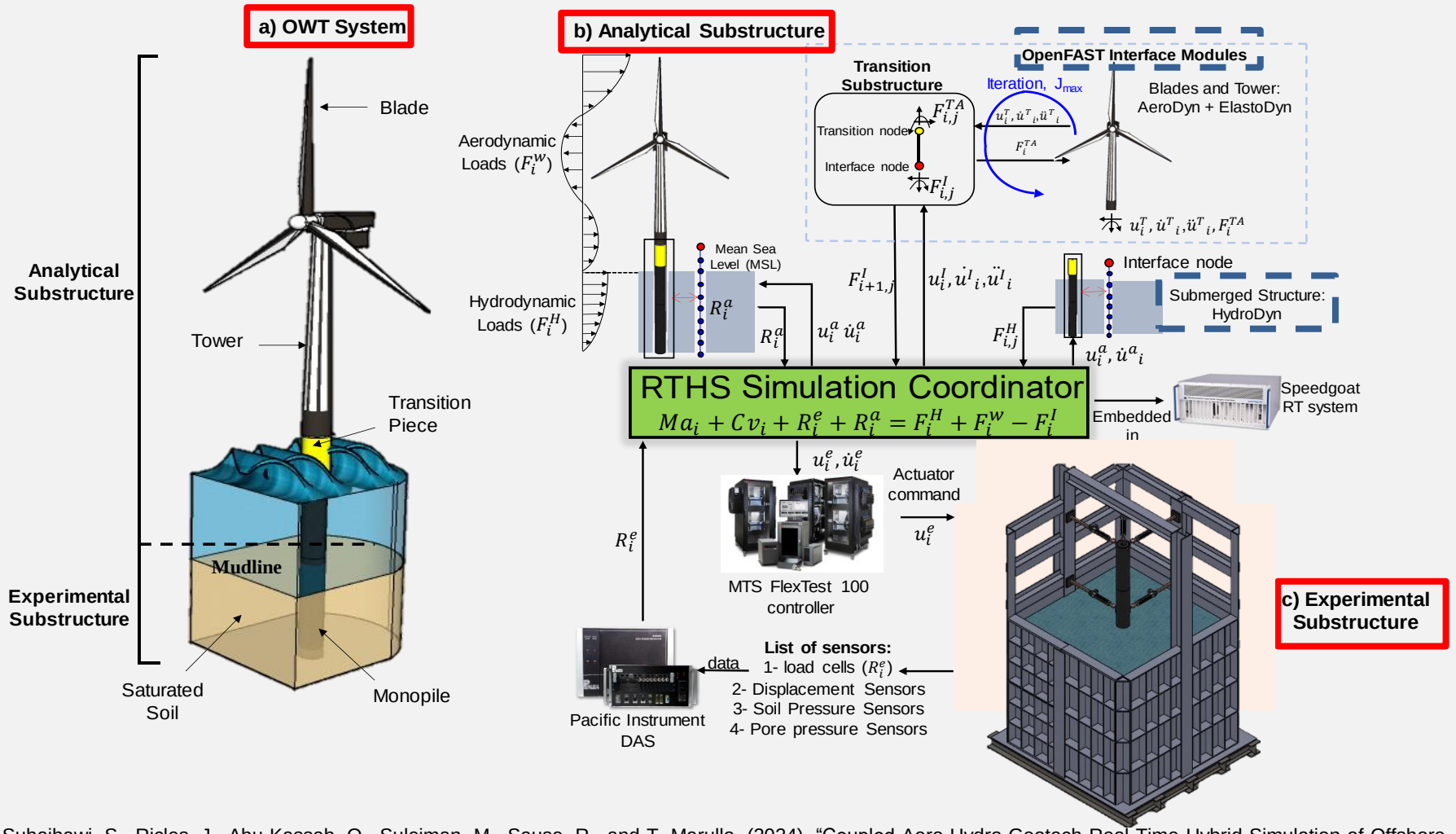
Soil-foundation structure interaction testbed

Offshore Wind Testing Facility



PI: Professor Muhannad Suleiman, CEE Dept

Real-time Hybrid Simulation of Offshore Wind Turbine Systems



Al-Subaihawi, S., Ricles, J., Abu-Kassab, Q., Suleiman, M., Sause, R., and T. Marullo, (2024). "Coupled Aero-Hydro-Geotech Real-Time Hybrid Simulation of Offshore Wind Turbine Monopile Structures," *Journal of Engineering Structures*, 303 (2024) 117463, https://doi.org/10.1016/j.engstruct.2024.117463.

Abu-Kassab, Q., Suleiman, M., Al-Subaihawi, S., Ricles, J., Marullo, T., Sause, R., Wyckoff, K., Magargal, L., Banerjee, A., Jaworski, J., Mekkawy, M. (2024). Construction of a Real-Time Hybrid Simulation Testing Facility and Validation for Offshore Wind Turbine System Behavior under Realistic Wind and Wave Loading Conditions. *Proceedings Geo-Congress 2024*.

NHERI Lehigh EF Testbeds

- **Large-scale Furnace**
  - Enables fire testing of structural and nonstructural components
    - Reconfigurable
    - Actuators with load cells; data acquisition system
    - Advanced sensors - Digital Imaging Correlation System

Reconfigurable large-scale furnace

Lehigh NHERI EF Website

https://lehigh.designsafe-ci.org/

LEHIGH UNIVERSITY
NHERI EXPERIMENTAL FACILITY

DESIGNSAFE-CI
A NATURAL HAZARDS ENGINEERING COMMUNITY

Facility | Protocols | Projects | Resources | Outreach | Contact

LATEST NEWS

June 3rd, 2022

NHERI Lehigh Virtual Researcher Workshop
This NHERI Lehigh researcher workshop will be held virtually to enable participants to learn more about the facility's resources and capabilities, and their utilization for conducting natural hazard research.
Workshop Registration

September 24th, 2021

Small Group Research Planning Workshop
Interested in scheduling a small group research planning workshop in order to write a successful NSF proposal that uses the NHERI Lehigh Experimental Facility? More information can be found at the Small Group Research Planning page.

September 8th, 2021

Creation of the NHERI Lehigh Real-time Cyber-Physical Structural Systems Testing Laboratory
The NHERI Lehigh Experimental Facility now features the NHERI Lehigh Real-time Cyber-Physical Structural Systems Testing Laboratory (RCPSS). The RCPSS was created to serve as a valuable resource to enhance the experience of participates in research, education and community outreach (ECO) activities, and training in cyber-physical systems (i.e., hybrid simulation) applied to natural hazards engineering problems. The RCPSS features five test beds that have dedicated dynamic actuators along with a multi-directional shake table. The RCPSS provides small-scale, lower costs test beds, creating more hands-on opportunities in cyber-physical systems testing. The RCPSS provides an efficient resource for conducting low-cost pilot studies in natural hazards engineering.

Curious how the RCPSS can enhance your understanding of hybrid simulation and advance your research? More information can be found at RCPSS.

FACILITY OVERVIEW

To help meet the grand challenge of community resilience to natural hazards, the Natural Hazards Engineering Research Infrastructure (NHERI) Lehigh Experimental Facility (EF) was funded by the National Science Foundation (NSF) to be a world-class, open-access facility that enables researchers to address key research questions associated with the challenge of community resilience. The NHERI Lehigh EF has a unique portfolio of equipment, instrumentation, infrastructure, testbeds, experimental simulation control protocols, large-scale simulation and testing experience along with know-how that does not exist elsewhere in the United States. The unique strength of the NHERI Lehigh EF is accurate, large-scale, multi-degree-of-freedom and multi-directional simulations of the effects of natural hazard events on civil infrastructure systems (i.e., buildings, bridges, industrial facilities, etc.) with potential soil-foundation effects..

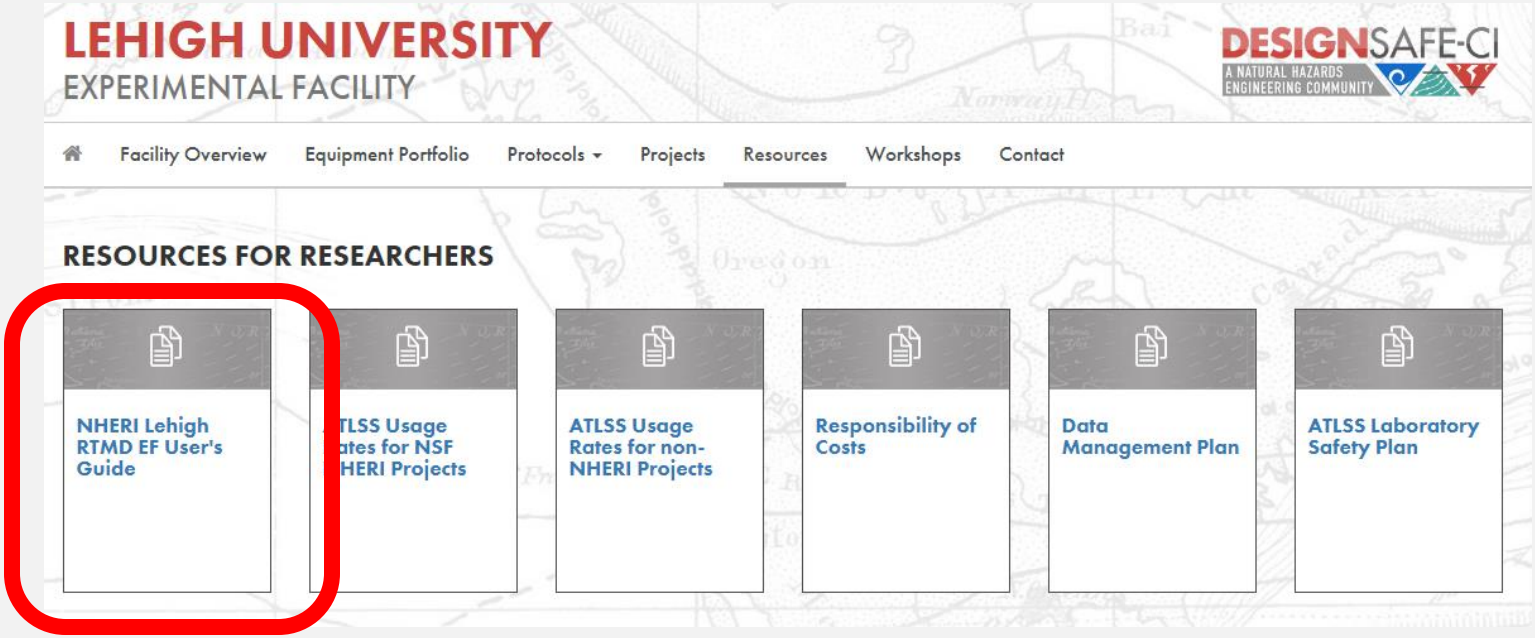
The types of laboratory simulations and tests enabled by the NHERI Lehigh EF include:

1. Hybrid simulation (HS) which combines large-scale physical models with computer-based numerical simulation models.
2. Geographically distributed hybrid simulation (DHS) which is a HS with physical models and/or numerical simulation models located at different sites.
3. Real-time hybrid earthquake simulation (RTHS) which is a HS conducted at the actual time scale of the physical models.

Users Guide

- Details of the Equipment Specifications, Experimental Protocols, and Equipment Inventory are given in the User's Guide

https://lehigh.designsafe-ci.org/resources/



Thank you