NHERI Lehigh EF Capabilities and Protocols

James Ricles

NHERI Lehigh EF Director

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Large-Scale Real-time Hybrid Simulation - RTHS

RTHS EQ Simulation of Buildings with Dampers

What is Hybrid Simulation?

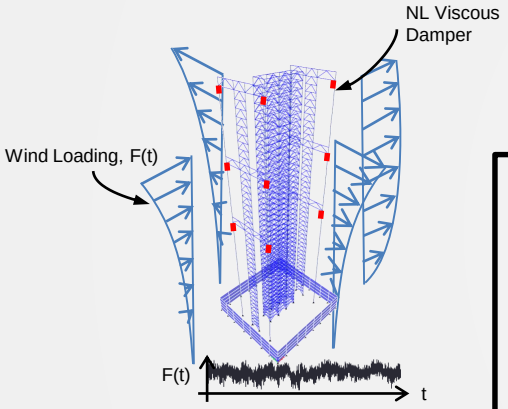
Overall Concept of Real-time Hybrid Simulation (RTHS): Structural System Subject to Predefined Wind Loading

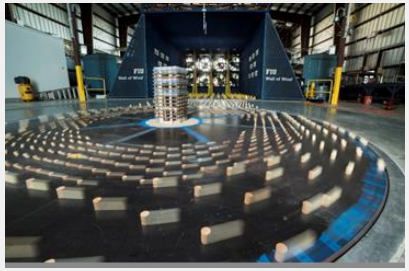
NSF CMMI: Semi-Active Controlled Cladding Panels for Multi-Hazard Resilient Buildings

- S. Laflamme (Iowa State), J. Ricles (Lehigh University), S. Quiel (Lehigh University)

Structural System

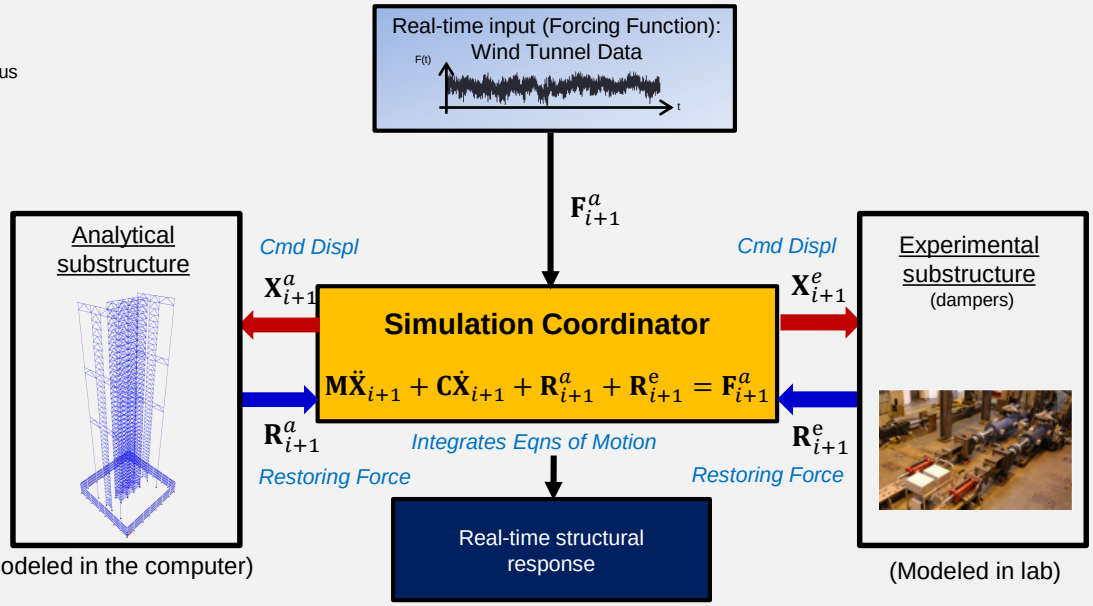
40-Story Building with Outriggers and Supplemental Dampers





Wind Tunnel Tests NHERI@FIU
Wind Load Determination

Hybrid Wind Simulation Experiments

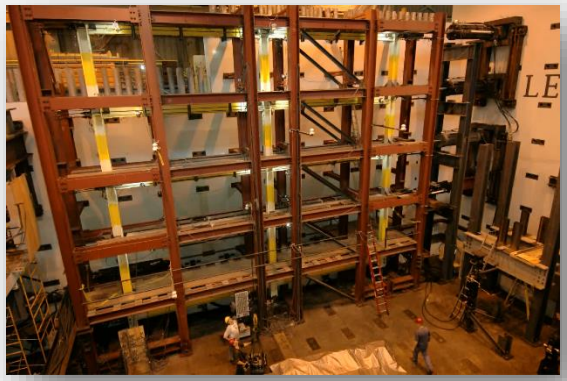


(Modeled in the computer)

(Modeled in lab)

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

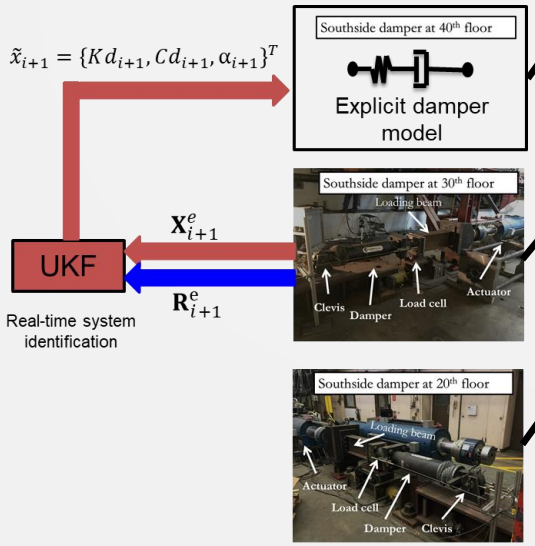
- Large-Scale Real-time Hybrid Simulation
- Large-Scale Hybrid Simulation - HS

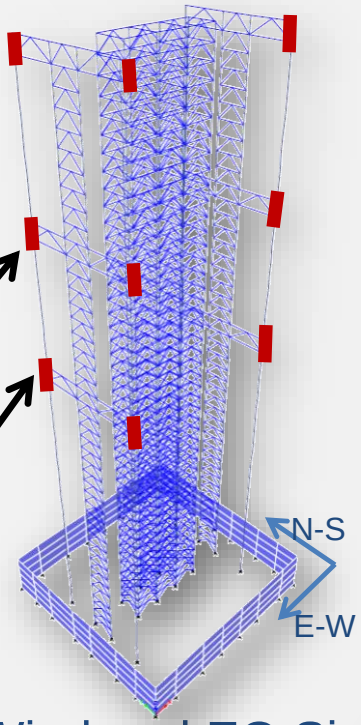


HS EQ Simulation of Buildings with SC-MRF

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

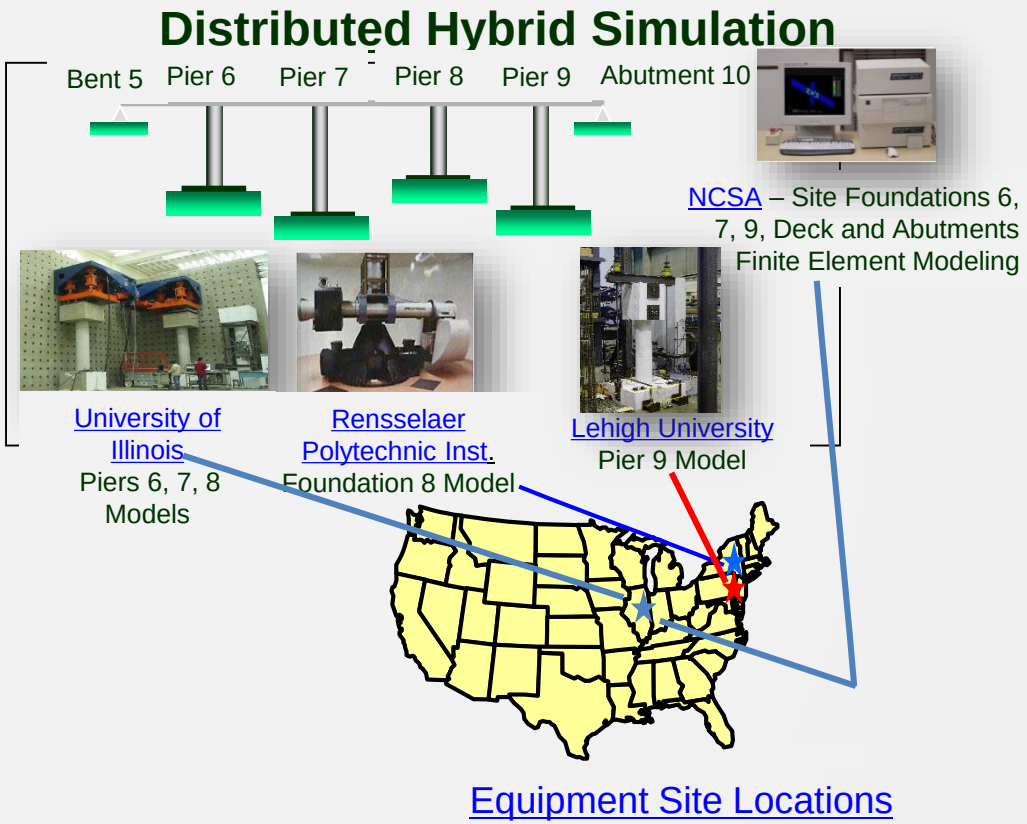
NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

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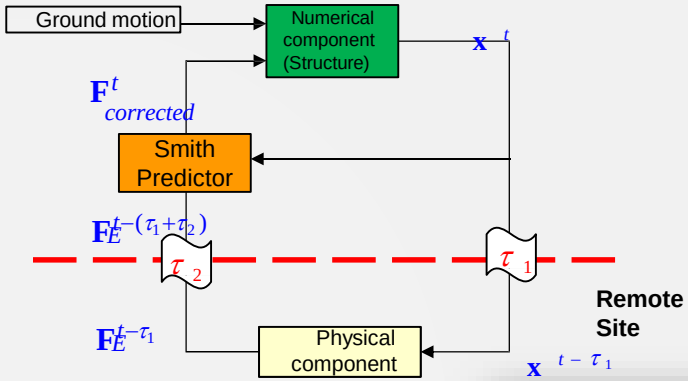
- Large-Scale Real-time Hybrid Simulation (with Real-time Online Model Updating)
- Large-Scale Real-time Hybrid Simulation with Multiple Experimental Substructures
- Geographically Distributed Hybrid Simulation
- Geographically Distributed Real-time Hybrid Simulation



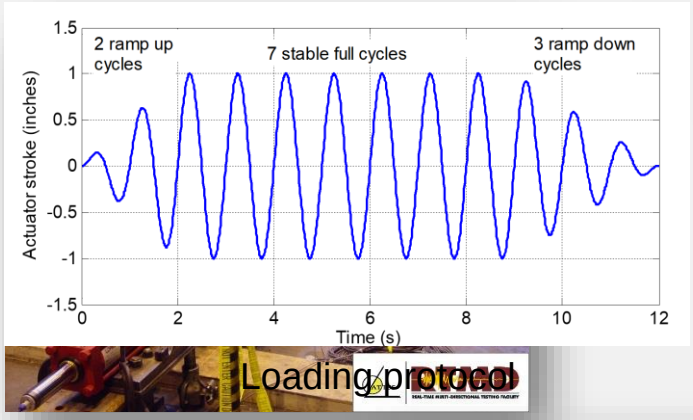
Lehigh

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 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) - QS



Loading protocol

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

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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

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- 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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- 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

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

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- Predefined load or displacements (Quasi-static testing or characterization testing)
- Dynamic testing
- Tsunami/storm surge debris impact
- Soil-pile interaction

Pile Lateral Load Test

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

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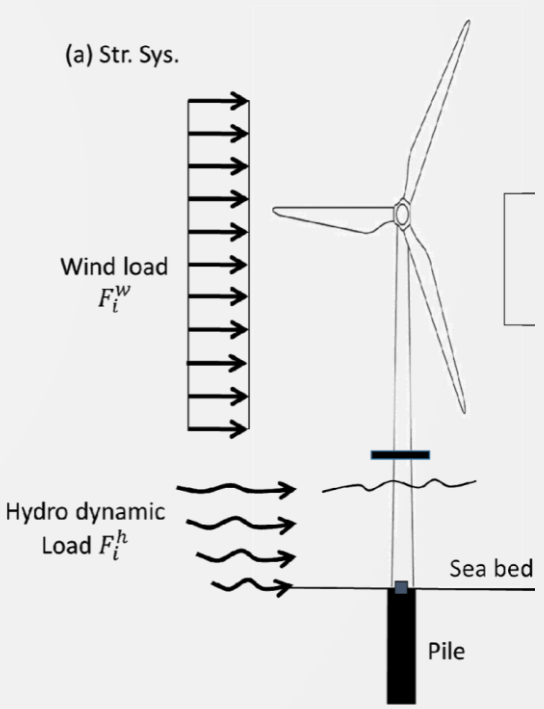
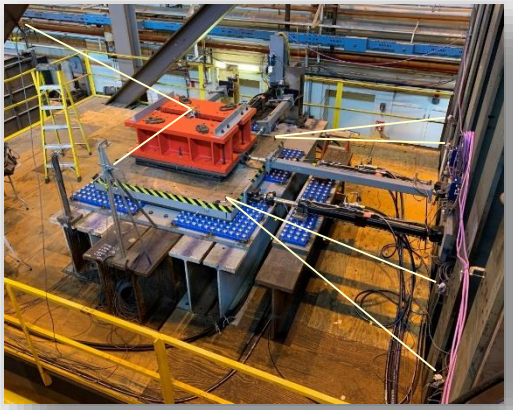
- Soil-pile interaction
- Real-time Hybrid Simulation of Offshore Wind Turbine Structures



Offshore Wind Turbine Structure - Aeroelastic and Hydrodynamic Loads

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
- 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

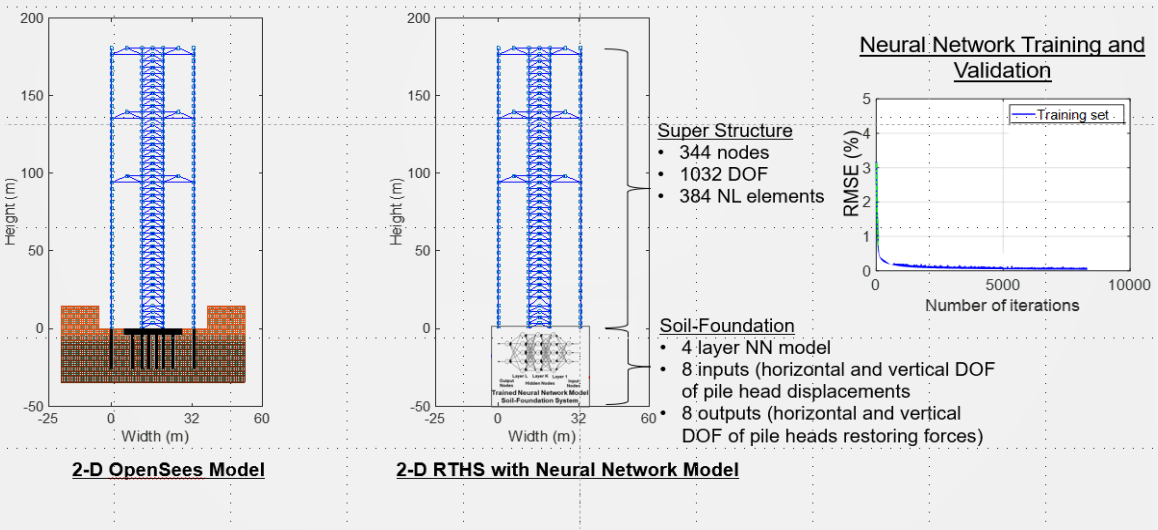


RTHS of Floor Isolation System using Multi-directional Shake Table

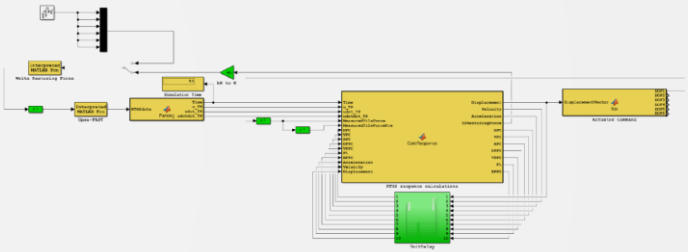
RII Track-4: Quantifying Seismic Resilience of Multi-Functional Floor Isolation Systems through Cyber-Physical Testing (OIA 1929151), **PI - Scott Harvey, University of Oklahoma**).

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

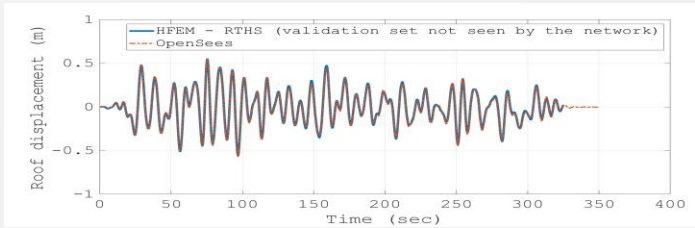
- Multi-directional Real-time Hybrid Simulation with Neural Networks and Machine Learning



Neural Network Model of Soil Training



Simulink Block – User Tool



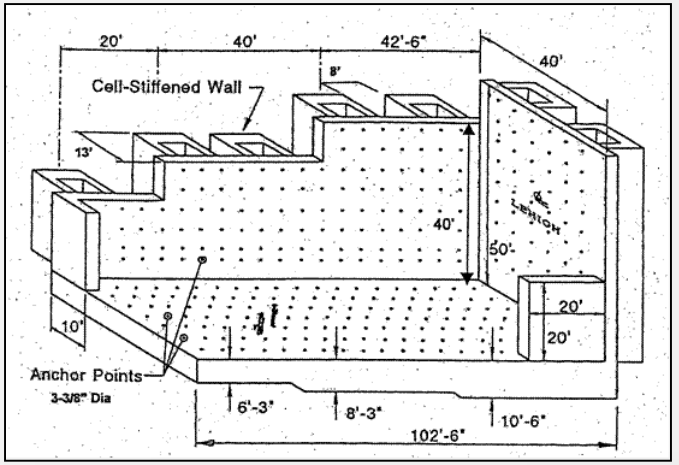
Comparison with OpenSees

RTHS with Soil-Foundation-Structural System Interaction

Al-Subaihawi, Safwan. (2021) “Real-time hybrid simulation of large structural systems under multi-natural hazards." *PhD dissertation,* Lehigh University, Bethlehem, PA.

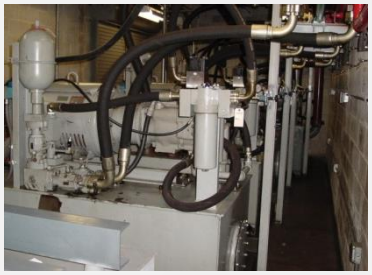
ATLSS Lab Infrastructure

- **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**

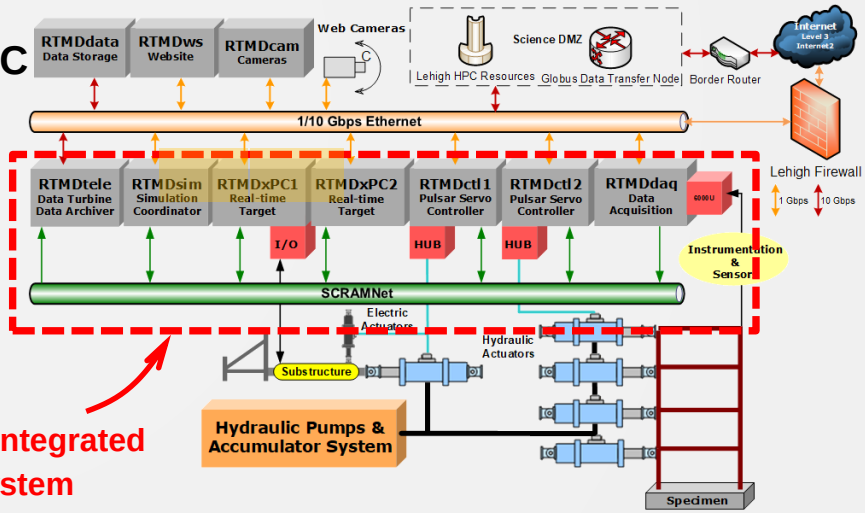


Other NHERI Lehigh EF Equipment

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

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 a Speedgoat RTPC 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



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

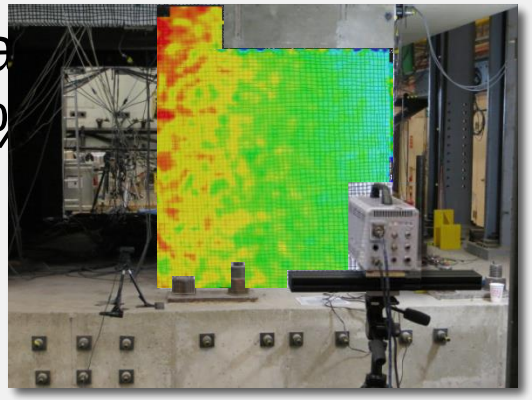
https://lehigh.designsafe-ci.org/resources

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

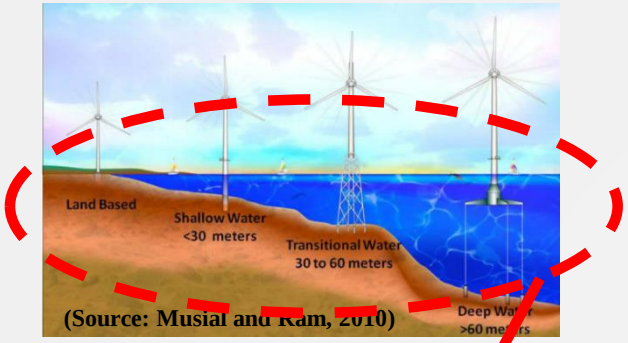
NEES@Lehigh Coupled Shear Wall Test Specimen with Multi-Directional Loading



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

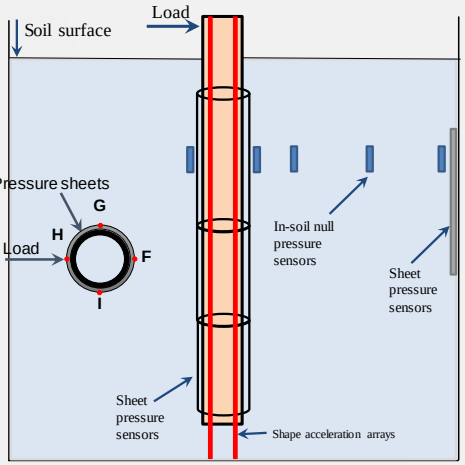
Soil-Structure Interaction Instrumentation

Professor Muhannad Suleiman

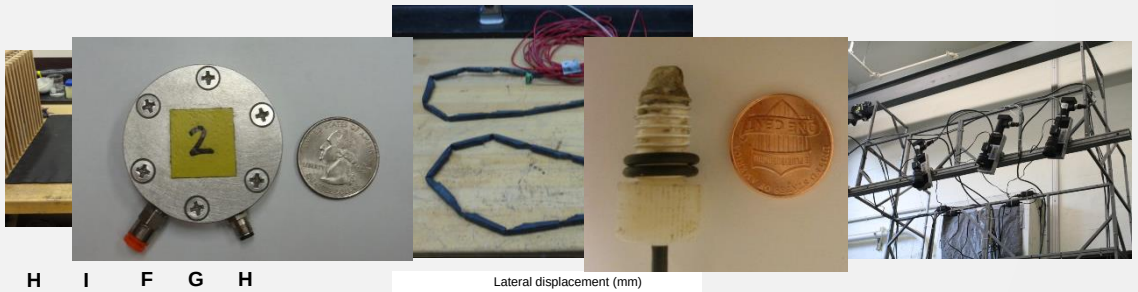


(Source: Musial and Ram, 2010)

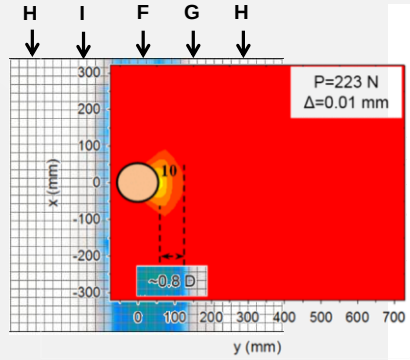
- Advanced instrumentation to understand SSI of foundation systems under different loading conditions
- Combine with hybrid simulation to improve analytical substructure models, or
- Hybrid simulation with soil included in experimental substructure



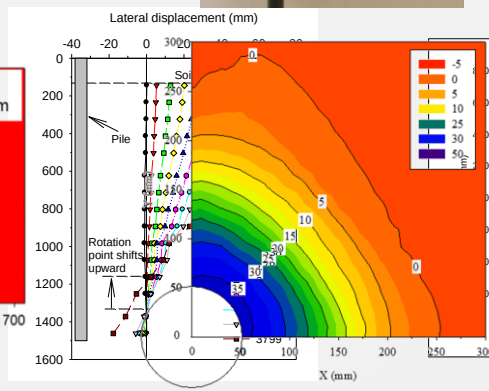
Test Setup and instrumentation



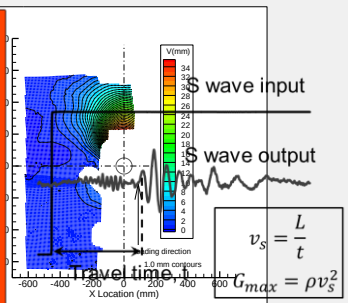
Pressure sensors



Soil-pile interaction pressure sensors



Shape acceleration arrays

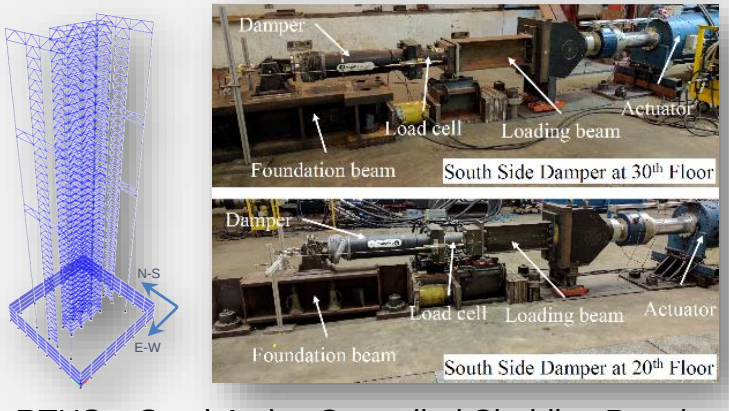


S wave sensors

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**

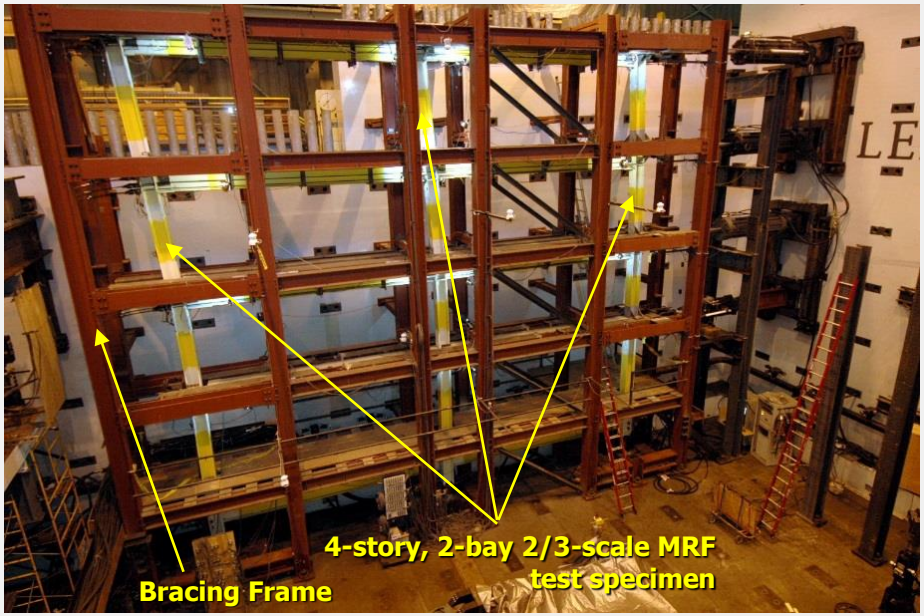
Specimen preparation staging area

Mechanical testing

Auditorium – ECO Activities

NHERI Lehigh EF Testbeds

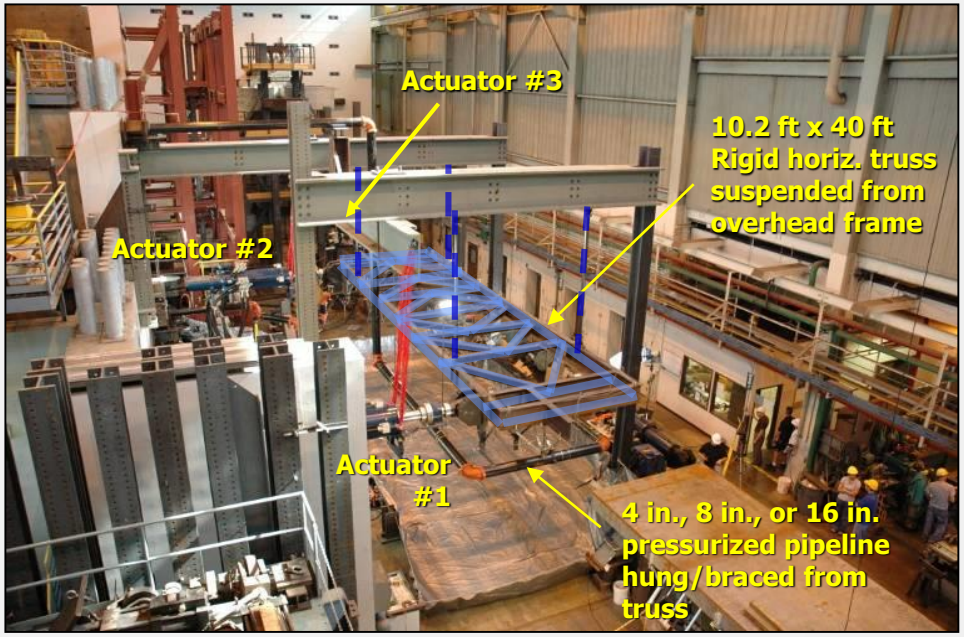
- **Lateral Load Resisting System Testbed**
  - Perform experiments on test frame specimens:
    - Up to 45 ft height
    - Up to 36 ft width
  - Large-scale lateral load system characterization tests
  - Real-time hybrid simulations



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

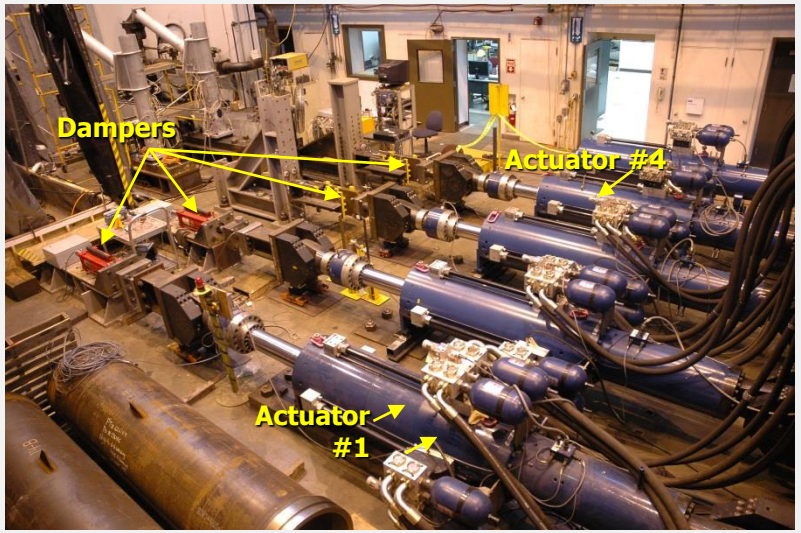


Multi-directonal Real-time hybrid simulation of building piping system

NHERI Lehigh EF Testbeds

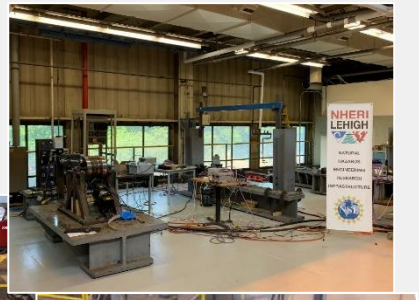
- **Full-scale Damper Testbeds**
  - Enables full-scale damper tests:
    - Damper characterization tests
    - Real-time hybrid simulations
  - Stoke, velocity, and force capacity:
    - +/- 20 in. stroke
    - 45 in/s for 382 kip actuators
    - 33 in/s for 517 kip actuators

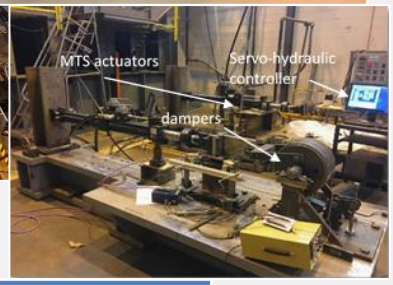
Real-time hybrid simulation of building with four passive dampers

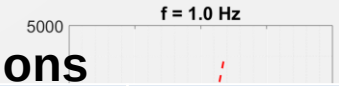


NHERI Lehigh EF Testbeds

- **Real-time Cyber-Physical Structural Systems Laboratory (CPSSL) – Real-time Testbeds**
  - 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
    - Five Hydraulic Actuators:
      - 2 - Model 244.21G2
      - 1 - Model 244.20G2S
      - 2 - Model 244.20
    - Two Electric Actuators (5000 lbs, 3 in stroke)
    - Independent Real-time Integrated Control and DAQ Systems







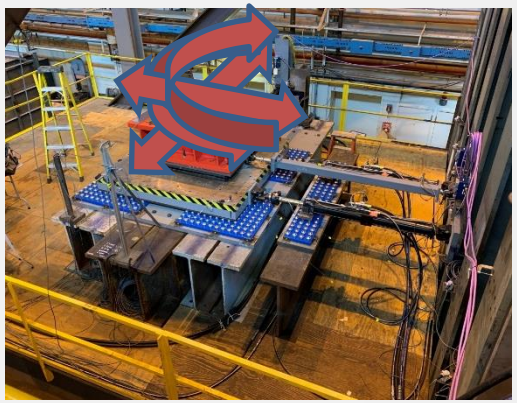
Actuator Specifications

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

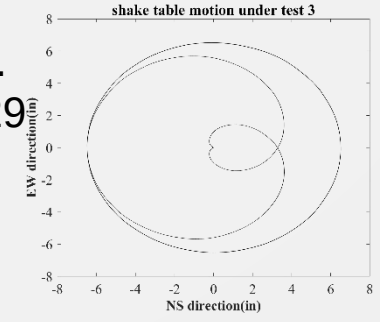
n Damper
ion tests

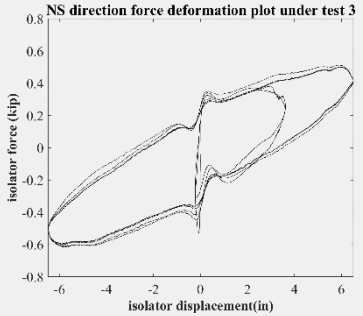
NHERI Lehigh EF Testbeds

- **Real-time Cyber-Physical Structural Systems Laboratory (CPSSL) – Multi-directional Shake Table**
  - 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
    - Independent Real-time Integrated Control and DAQ Systems
    - Multi-directional motions, including two orthogonal translations (X and Y-axis) and in-plane rotation
    - Multi-channel digital controller with 2048 Hz clock speed
    - A payload of 13 kips (5.9 tons) at 1g acceleration.
    - Table platen size of 6 ft × 6 ft.
    - Maximum table motions of ±7 in. (X-axis) and ±10 in. (Y-axis).Peak velocities of 51 inch/sec (X-axis) and 29 inch/sec (Y-axis)
    - Can be used for RTHS; QS; or conventional Shake Table mode



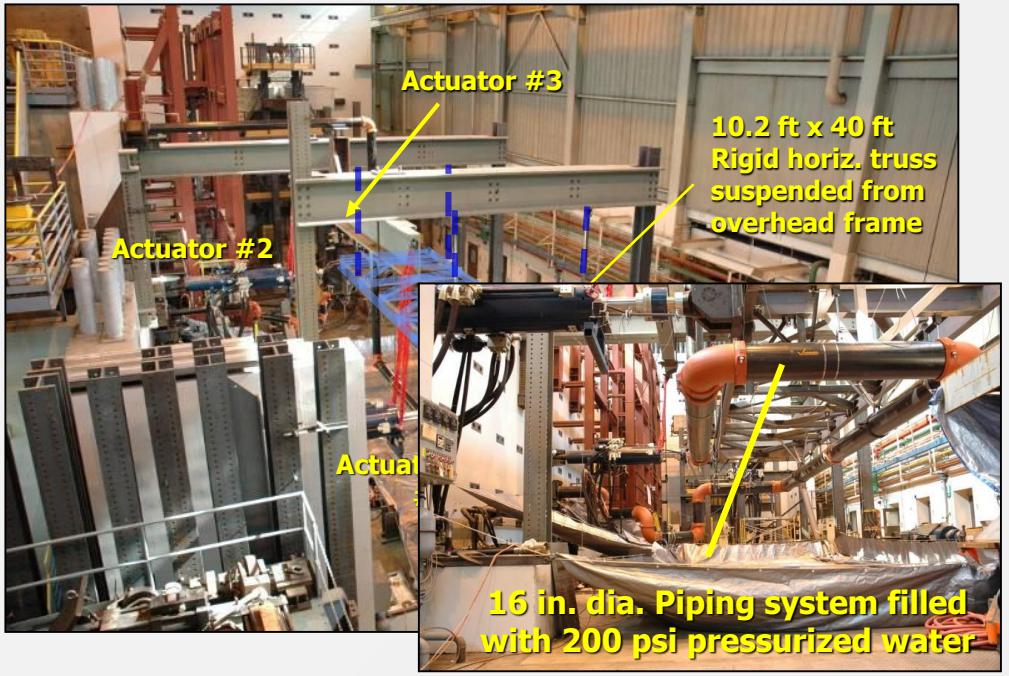
RTHS of Floor Isolation System using Multi-directional Shake Table
PI - Scott Harvey, University of Oklahoma





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

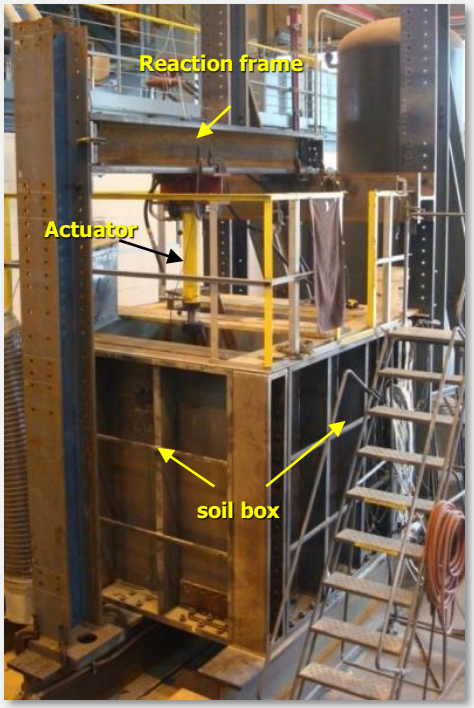
- **Tsunami & Storm Surge Debris Impact Force Testbed**
  - Enables full-scale debris impact tests:
    - High speed DAQ; high speed 5000 fps cameras
    - High bandwidth, resolution load cells
    - Accelerometers, laser-displacement transducers

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

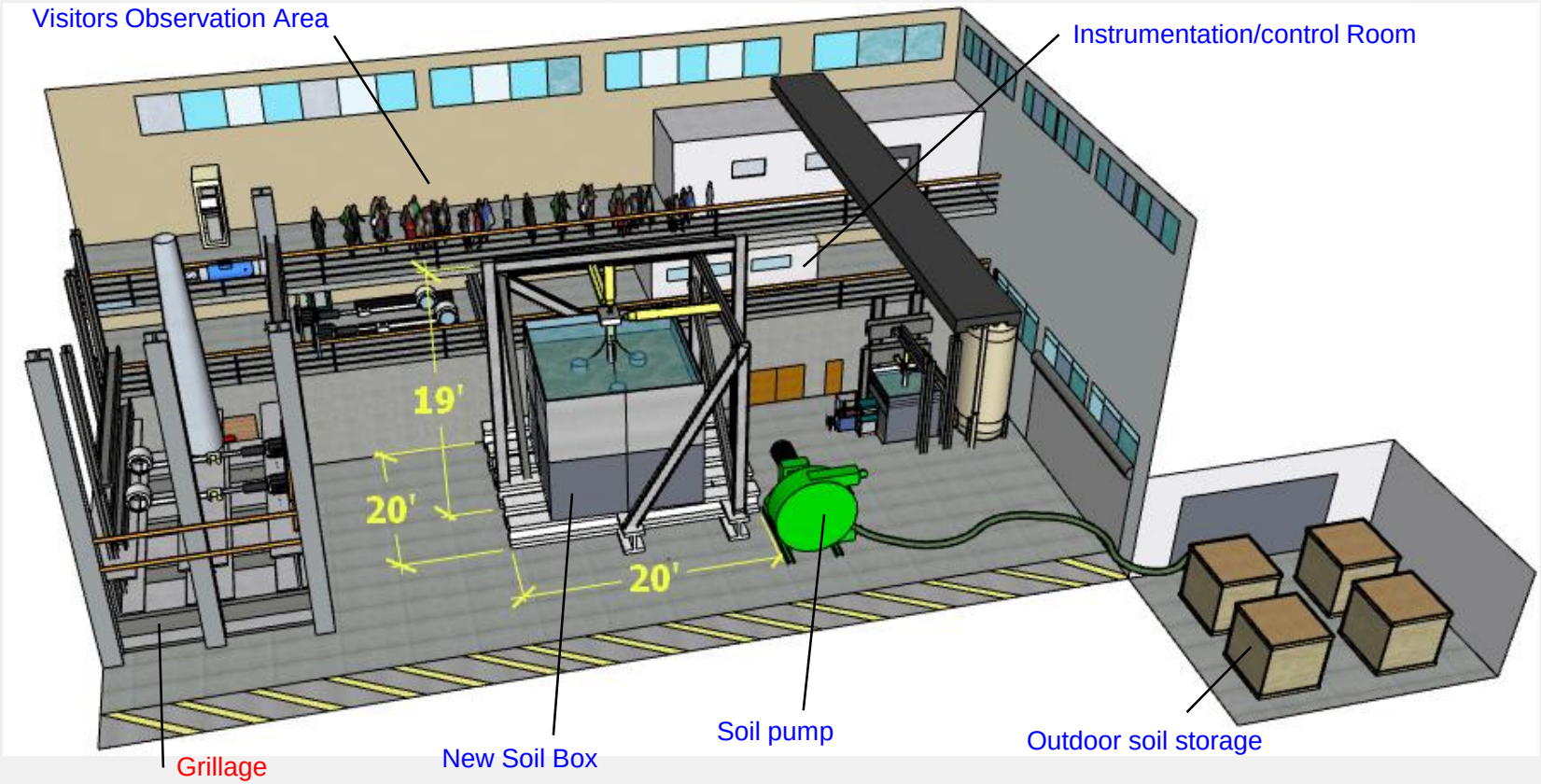


NHERI Lehigh EF Testbeds

- **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

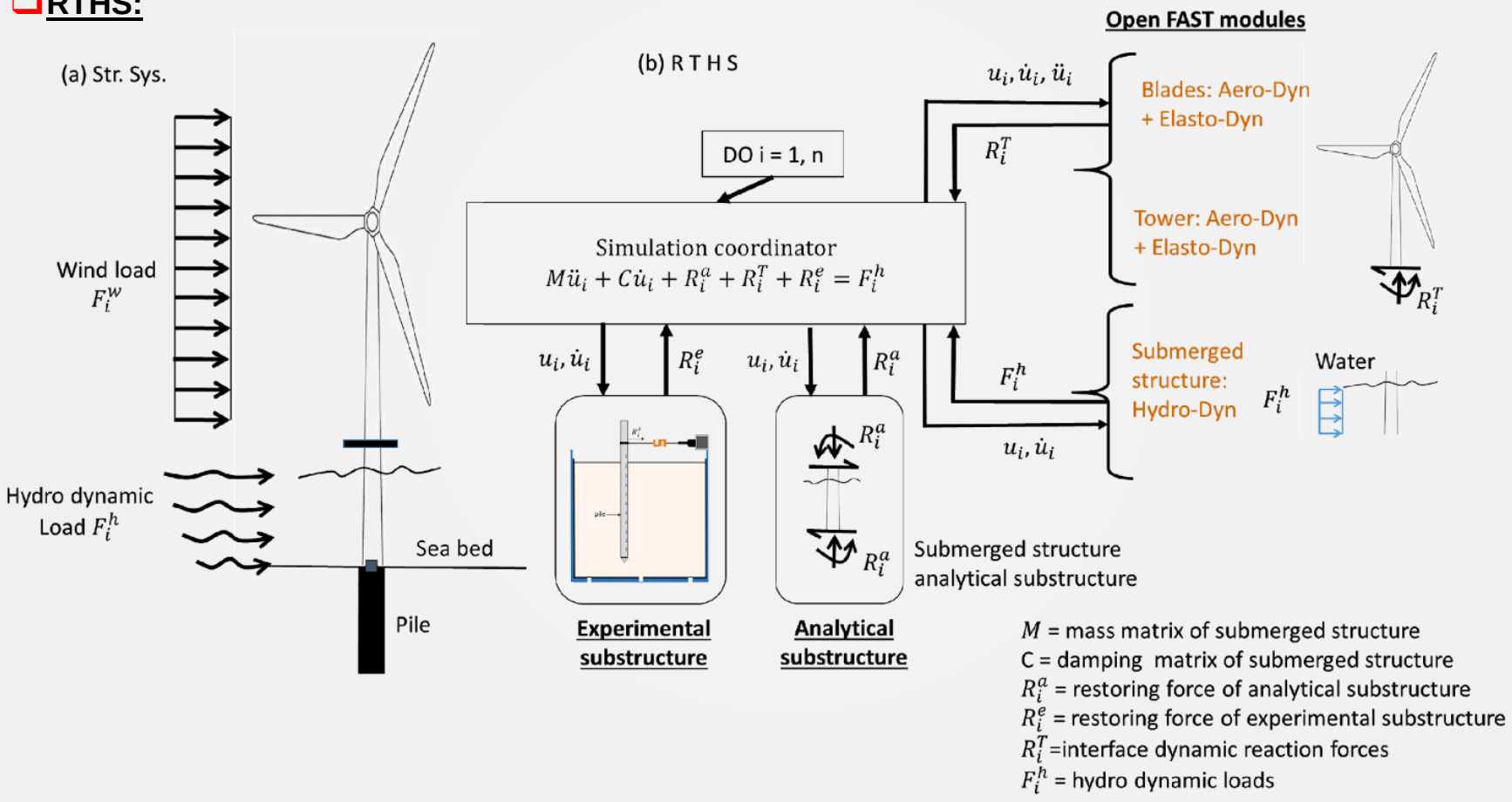
Offshore Wind Testing Facility



PI: Professor Muhannad Suleiman, CEE Dept

Offshore Wind Turbine Real-time Hybrid Simulation

❑ **RTHS:**

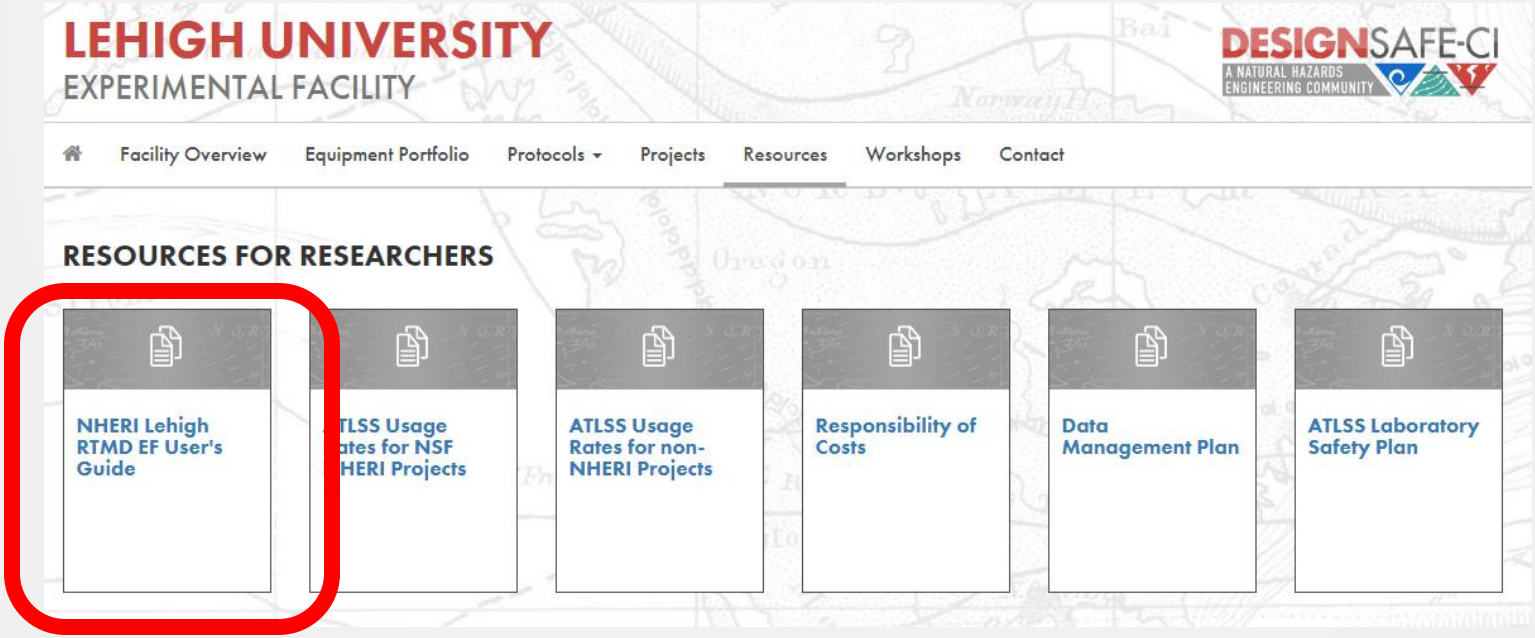


M = mass matrix of submerged structure
C = damping matrix of submerged structure
R_i^a = restoring force of analytical substructure
R_i^e = restoring force of experimental substructure
R_i^T =interface dynamic reaction forces
F_i^h = hydro dynamic loads

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/



Researcher Training and Experiment Support

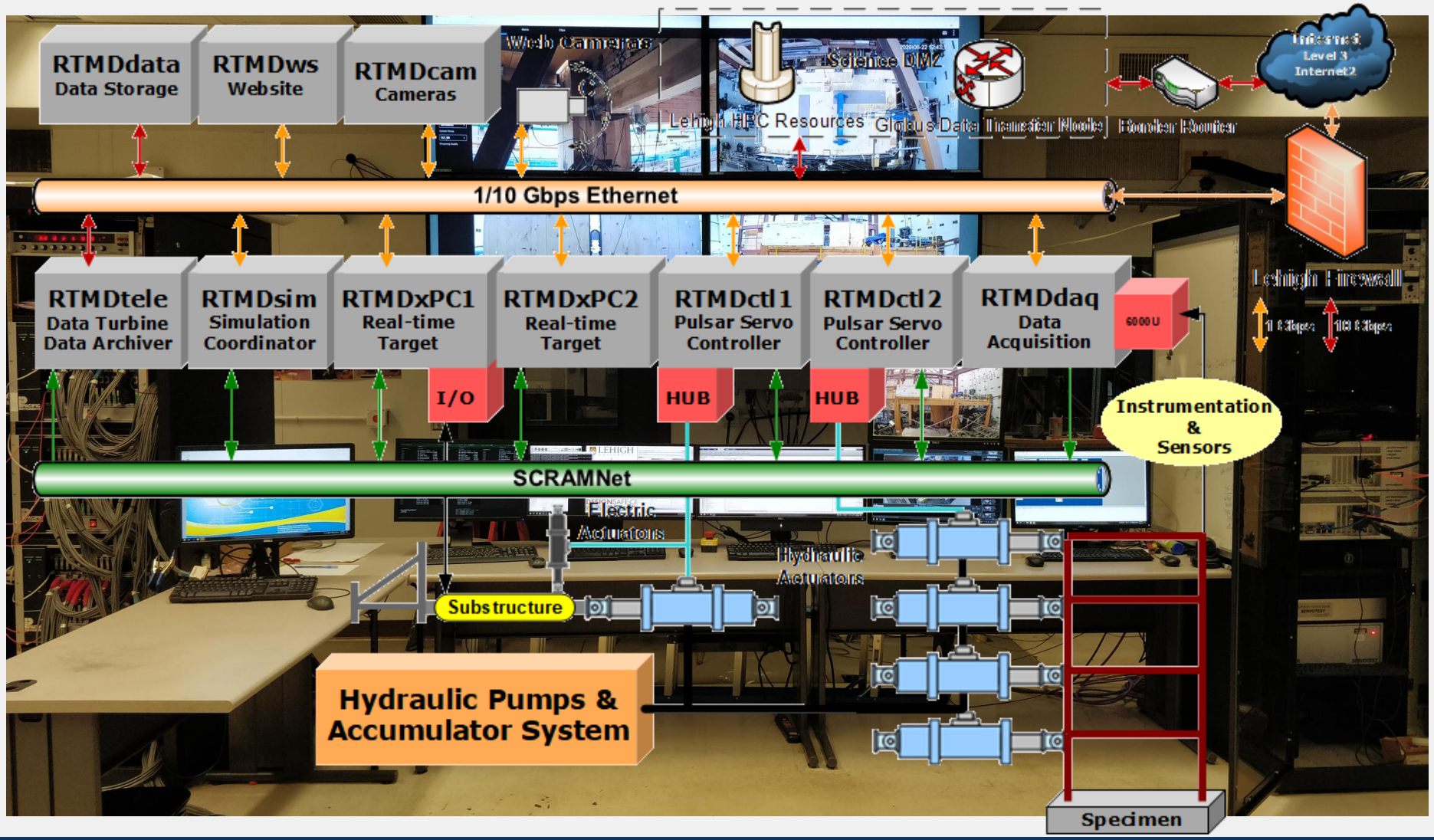
1. Researchers and NHERI Lehigh team work together on training, development of experimental protocols, instrumentation, control and safety plans
2. Create Project Workspace for future curation and publication on DesignSafe-CI Data Depot
3. On-site laboratory walk through and identification of IT systems with demonstrations
4. Validate control configuration through numerical and hydraulics off simulations
5. Configure data acquisition system for sensor equipment
6. Configure video acquisition system for cameras
7. Configure data streaming for local and remote data viewing
8. Determine safety protocols for equipment and specimen
9. Conduct experiments
10. Data is locally archived and synced with DesignSafe Project Warehouse
11. Research team processes data locally and stored in Data Depot at DesignSafe-CI into data model. Tools available to process data available locally and on DesignSafe-CI

NHERI Lehigh EF Overview

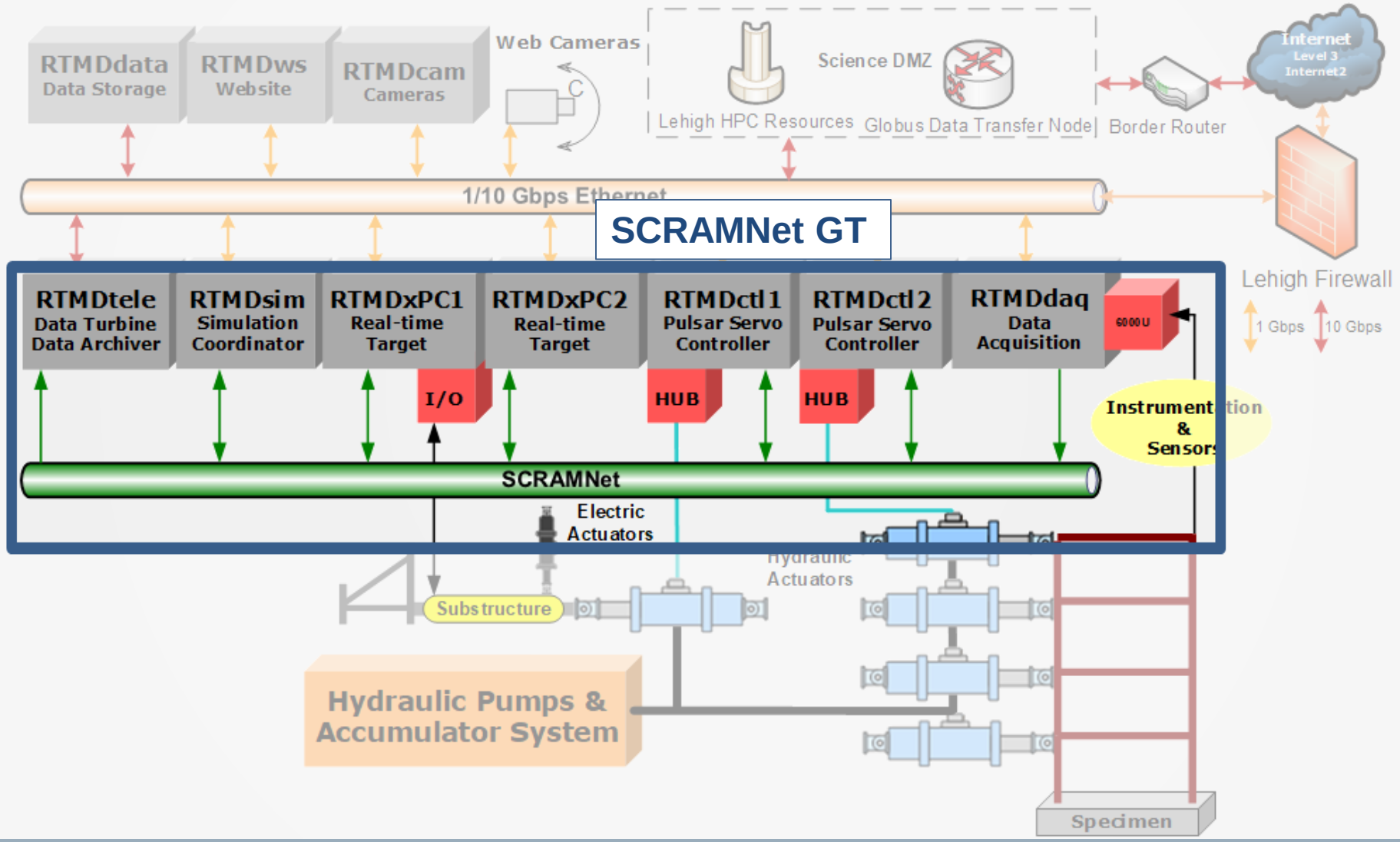
Thomas Murallo

NHERI Lehigh EF IT Systems Manager

IT Infrastructure



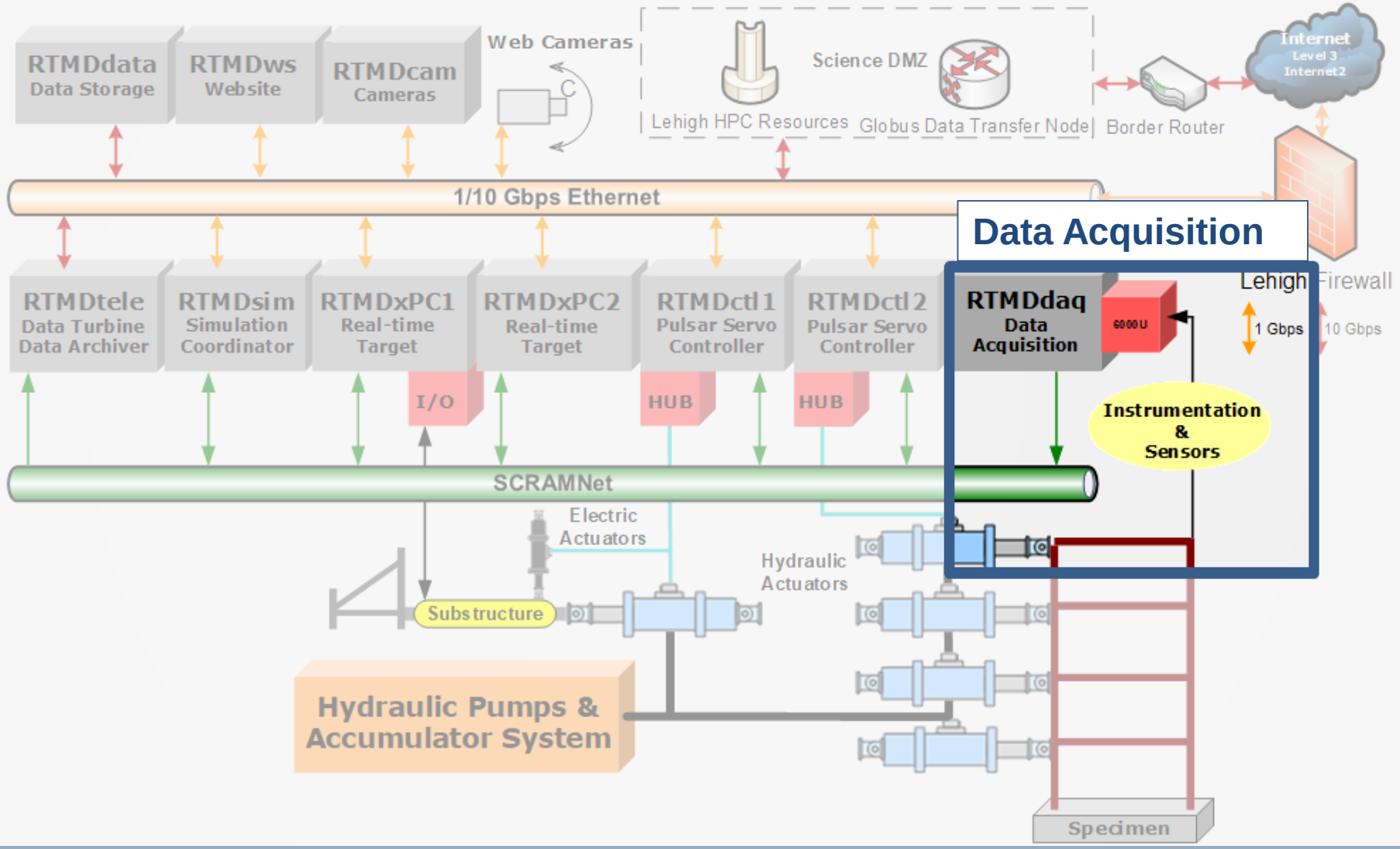
IT Infrastructure



SCRAMNet GT

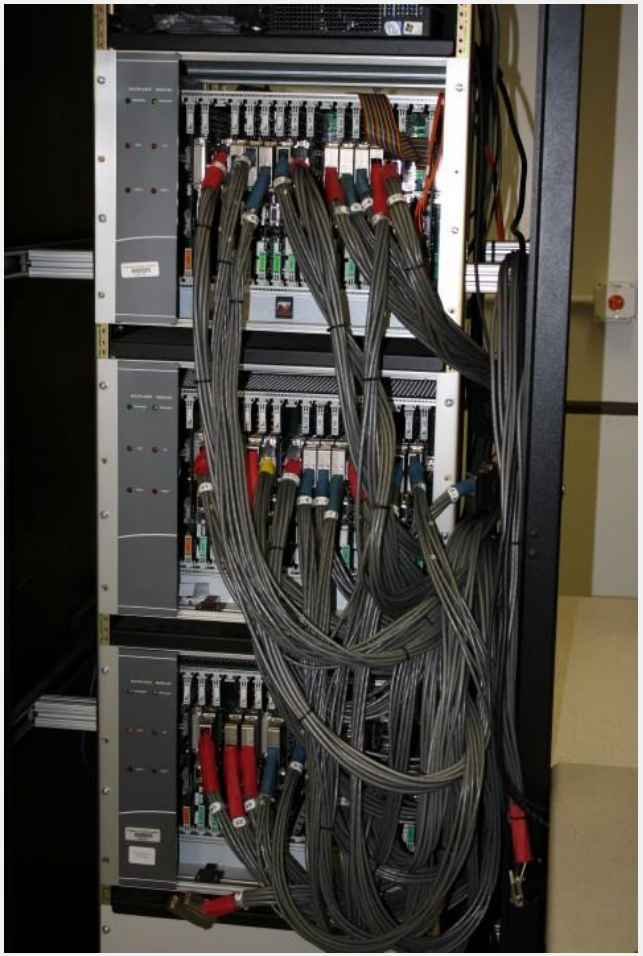
- Fiber-optic based High-Speed, Low-Latency Industrial Protocol for Real-time data control

IT Infrastructure

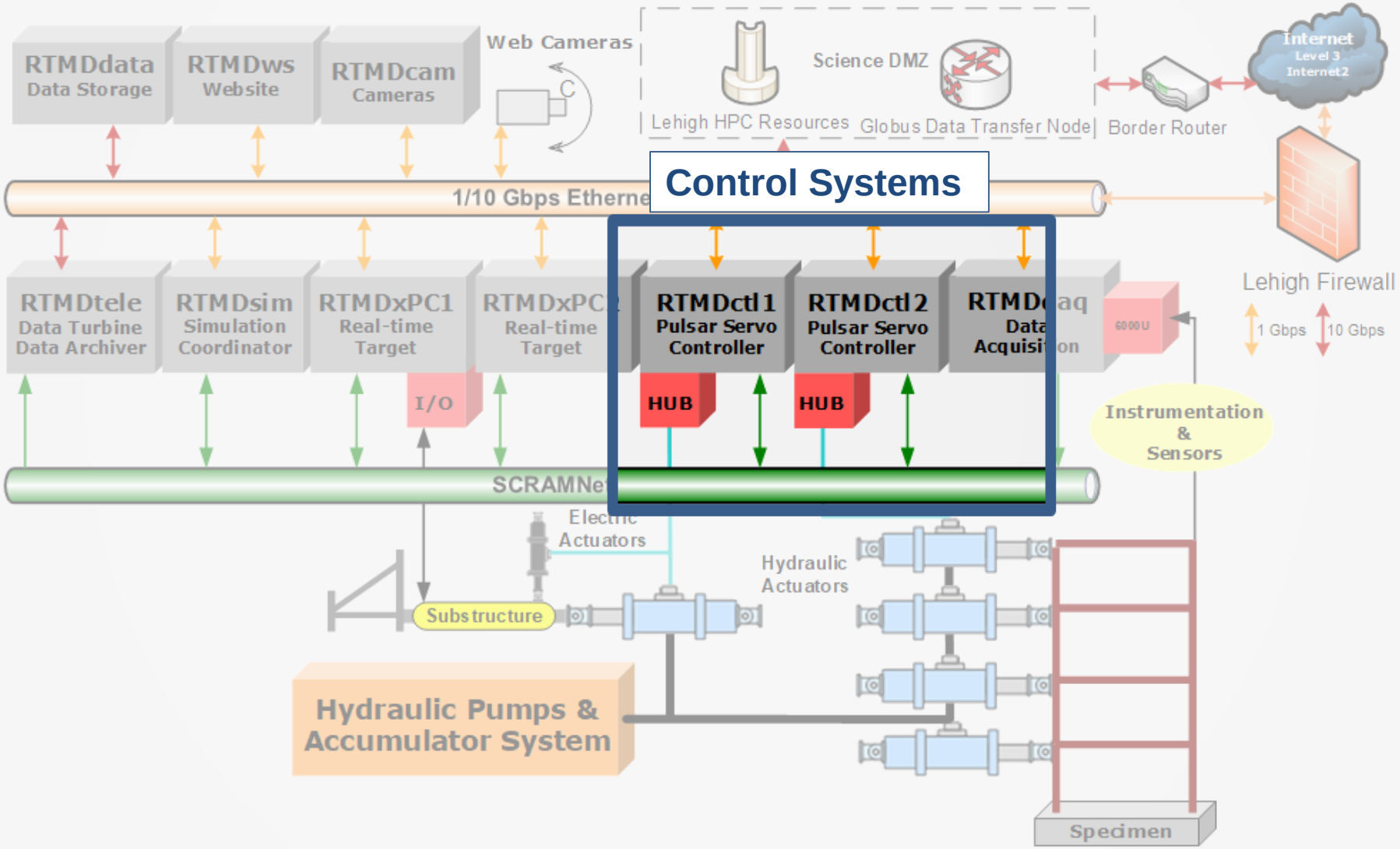


RTMDdaq

- Pacific Instruments 6000 Data Acquisition System
  - 304 channels, 384 expandable
    - Voltage, Strain, Thermocouple
  - Variable sampling rates
    - 4 kHz for Real-time Testing

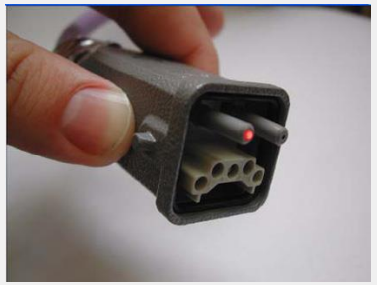


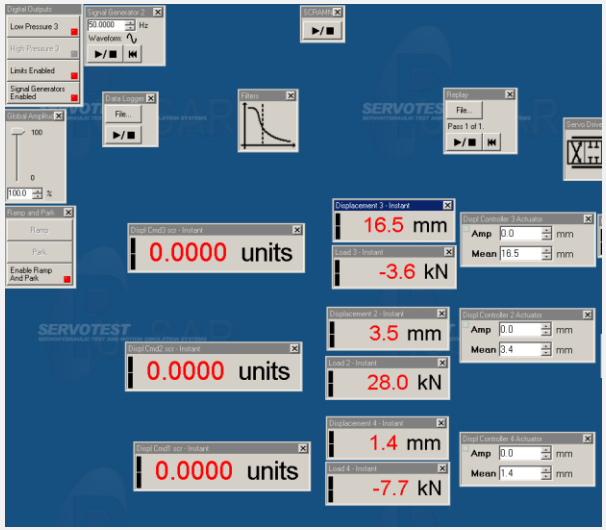
IT Infrastructure



RTMDctrl

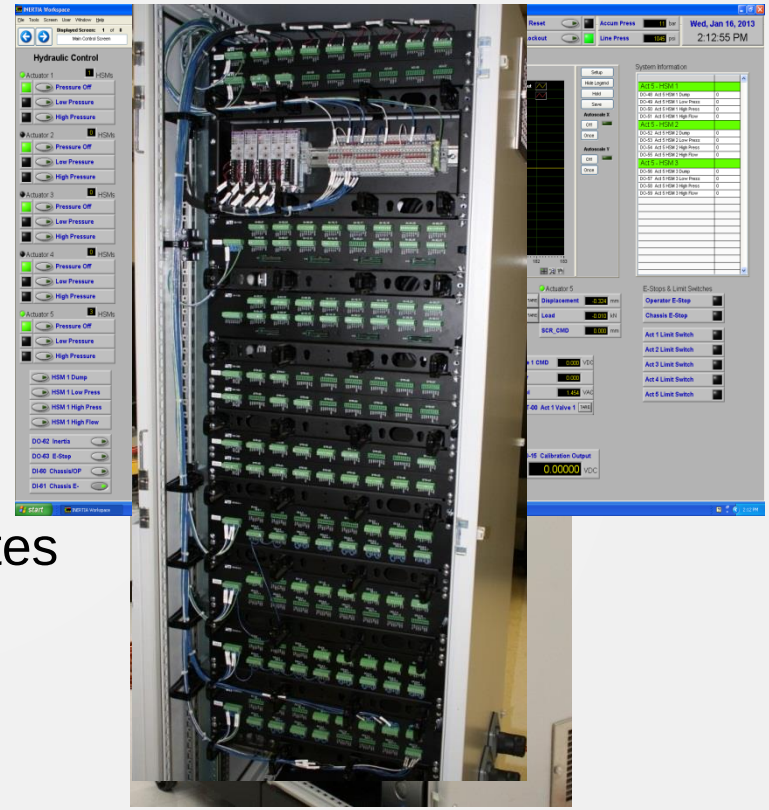
- Servotest Pulsar Hub Control System
  - Configurable servo-control system for hydraulics actuator PID control
  - 2048Hz or higher control rate
  - Wide vendor support
  - Customizable interface



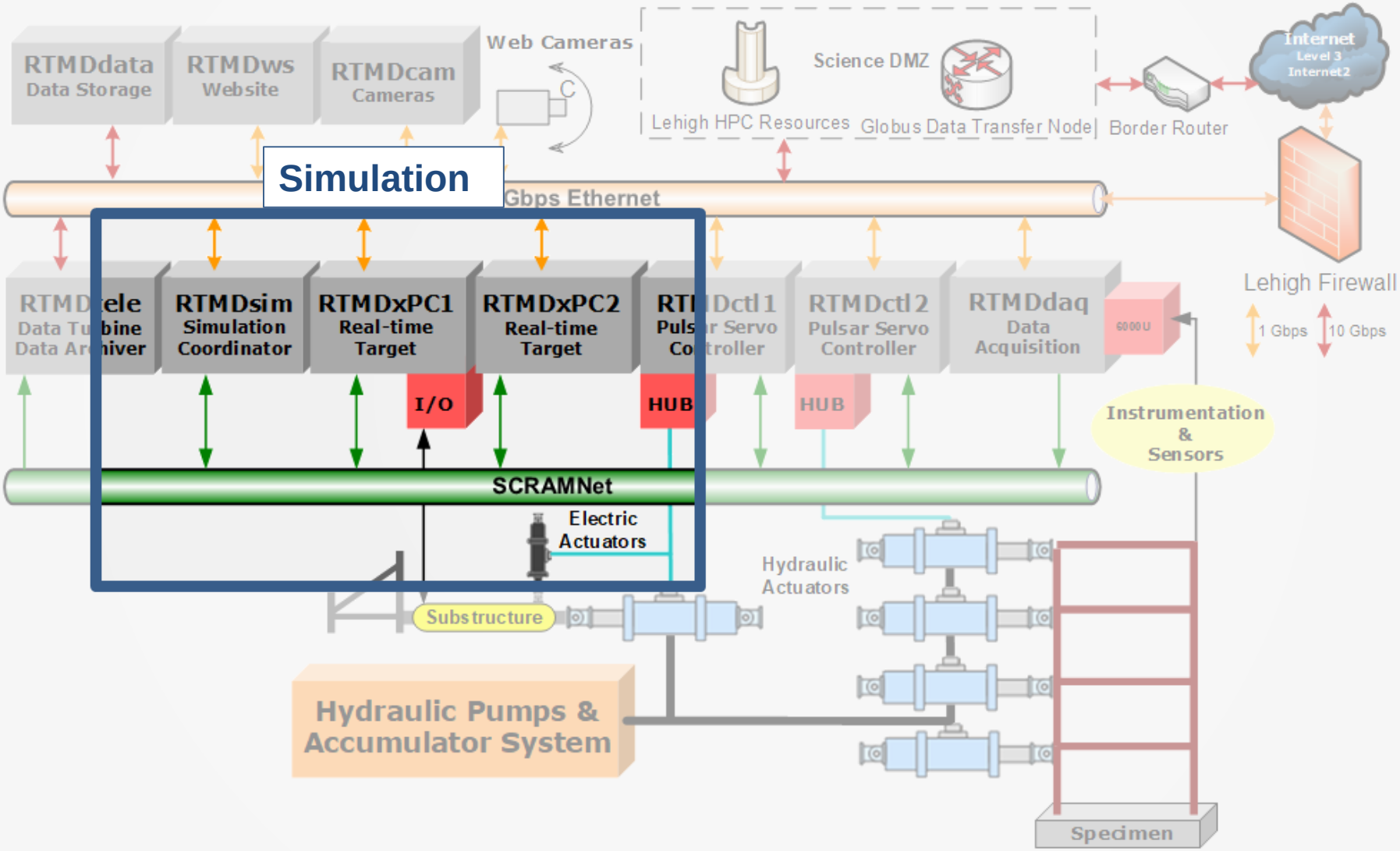


RTMDctrl

- Wineman INERTIA Control System
  - Unlimited multi-mode closed-loop control
  - Integrated test editor
  - Integrated with various NI modules
  - Integrated PID control loop tuning
  - Complete access to tuning system variables
  - Programmable control and DAQ rates



IT Infrastructure



Simulation – RTMDsim/RTMDxPC

- Host-Target configuration
  - Real-time and custom applications
- Dell i7 Precision Workstation
  - High power workstation for execution and processing
- Speedgoat Targets (Simulink Real-time)
  - Dedicated Intel i7 4Ghz 4-Core real-time systems
- Multiple Targets
  - Defined roles
  - Parallel processing for larger, more complex models

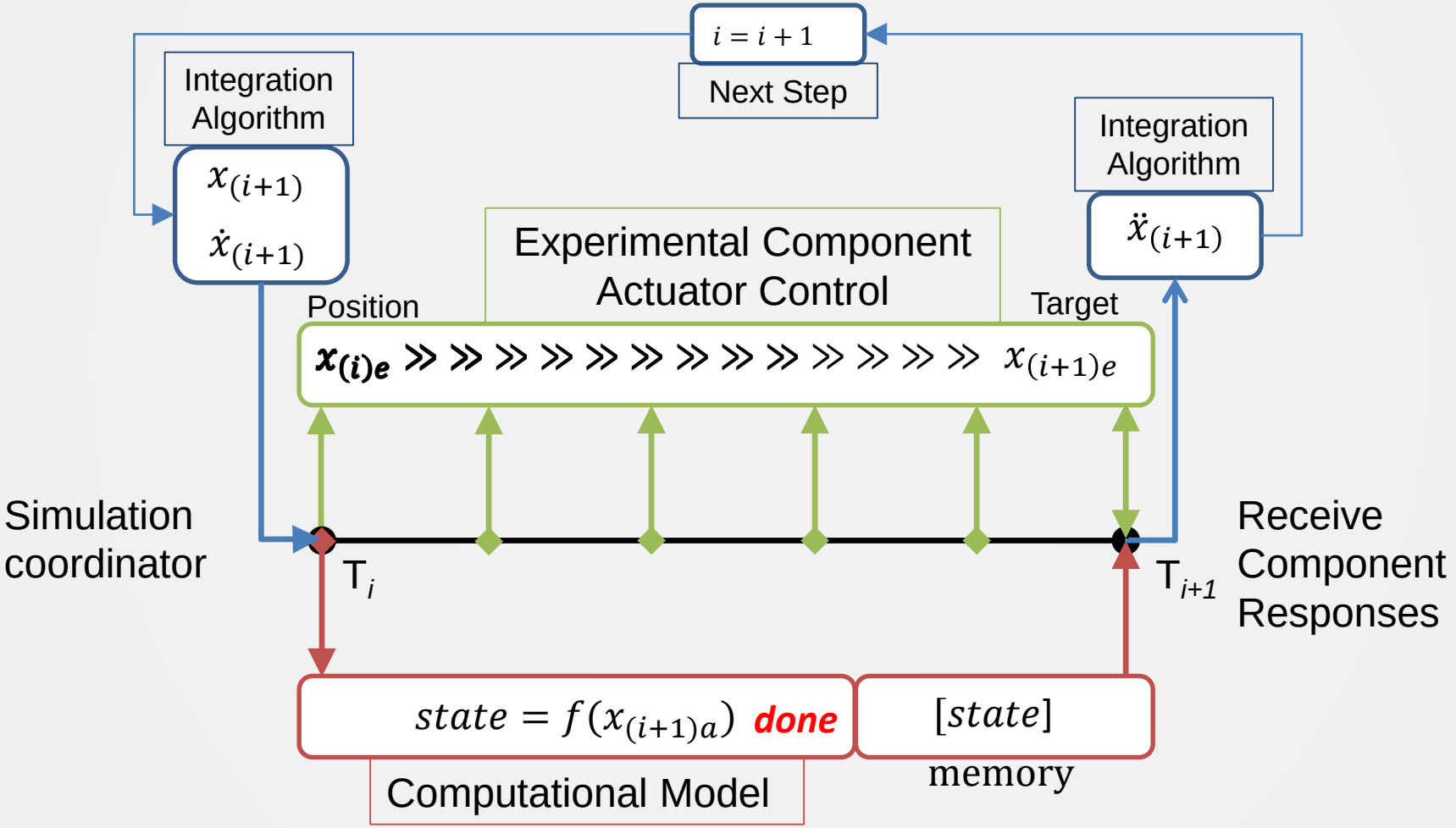
RTMDsim
Simulation Coordinator

- Host Workstation
  - MATLAB/Simulink Interface
  - Coordinator of synchronized control and data acquisition
  - Hydraulics on/off testing – numerical simulation for safety, validation & training
  - Process and analyze data

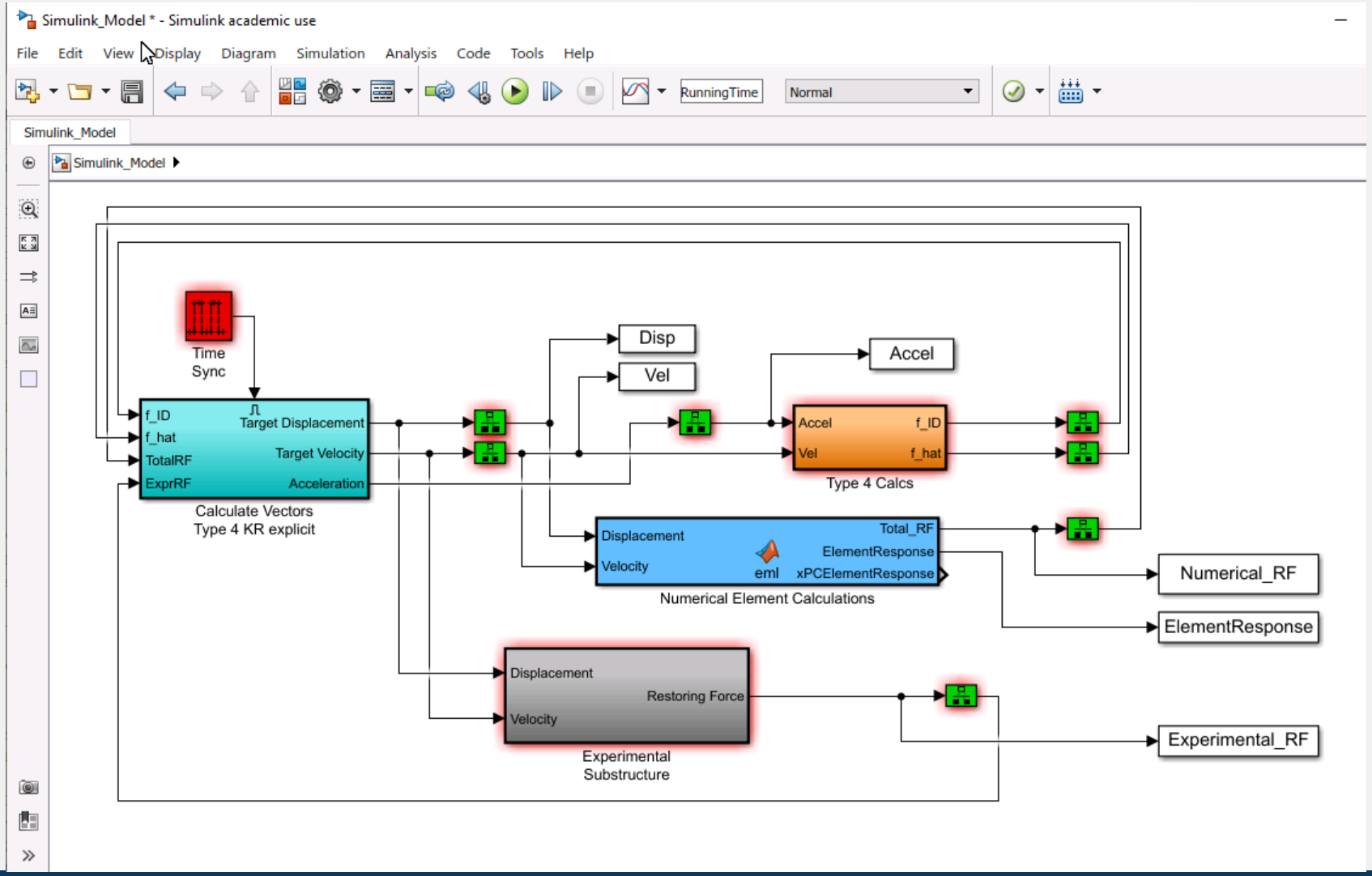
RTMDxPC
Real-Time Targets

- Speedgoat systems, CPU performance up to 4 GHz
- Industrial quality design for robustness
- Multi-core support for parallel processing
- Synchronized Multi-system execution
- Built-in modules for data acquisition and control
- “Bring your own model” infrastructure for researchers

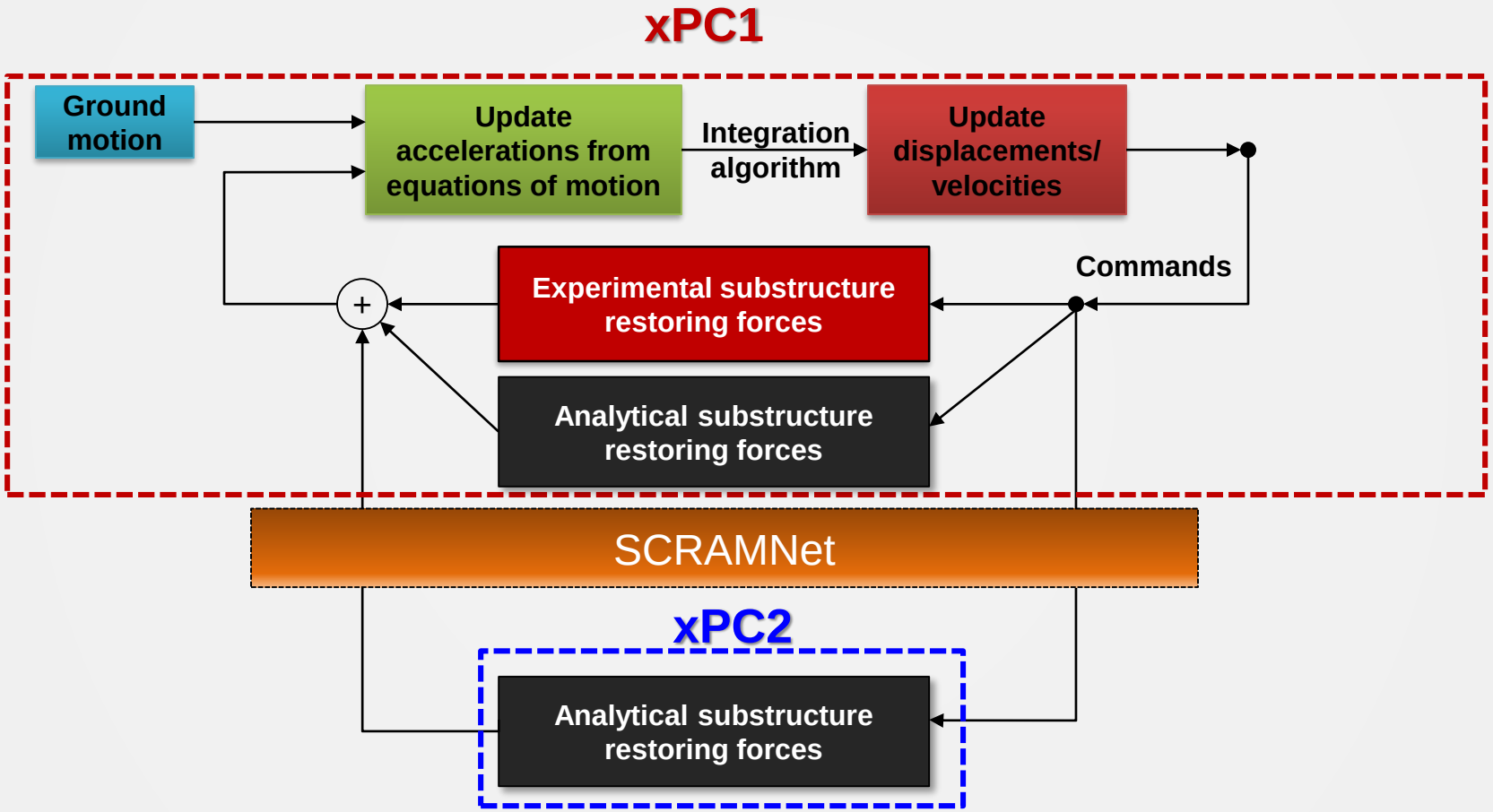
RTHS: Model Flow through Simulink Simulation



RTHS: Simulink

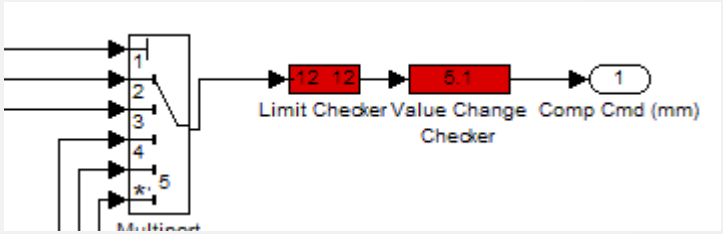


RTHS: Multiple Targets

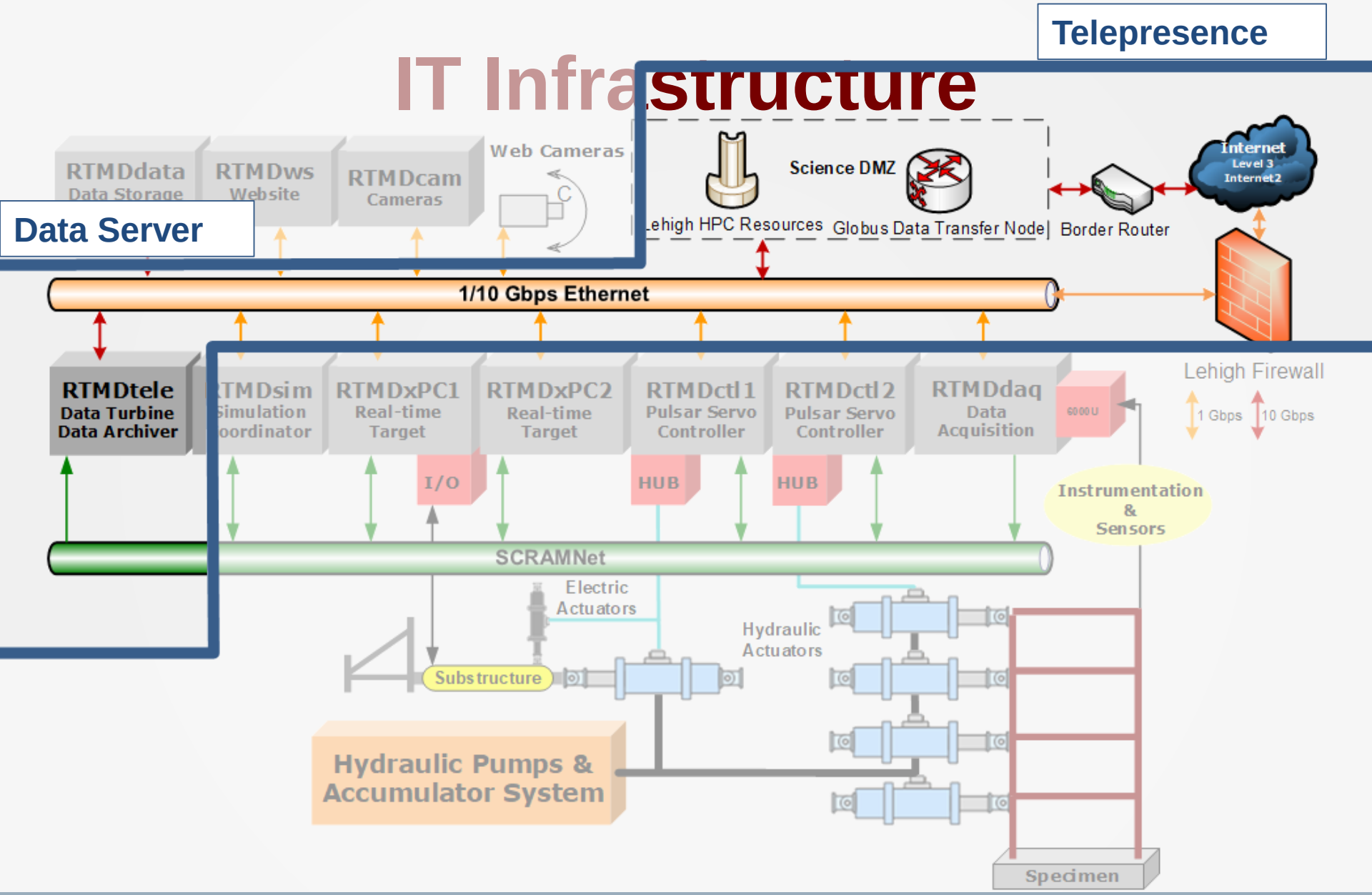


Simulation Safety

- Command software limits
  - Bound and rate limits
- Controller software limits
  - System trip and shutdown
- Hardware displacement limit switches
- E-Stop buttons



IT Infrastructure



Data Streaming

- Data Turbine (RBNB) (dataturbine.org)
  - Aggregates data from systems integrated on SCRAMNet GT ring
  - Storage archive of test data based on timestamps
- Real-Time Data Viewer (RDV)
  - Plot-based and numerical observation of data locally and remotely
  - Time-controlled playback

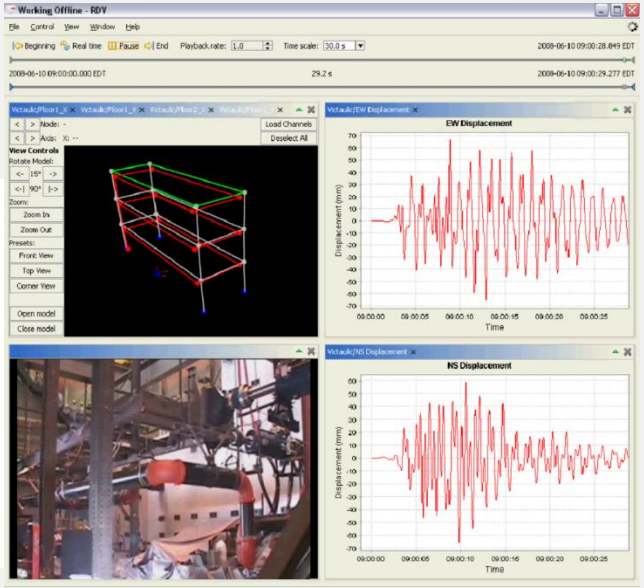
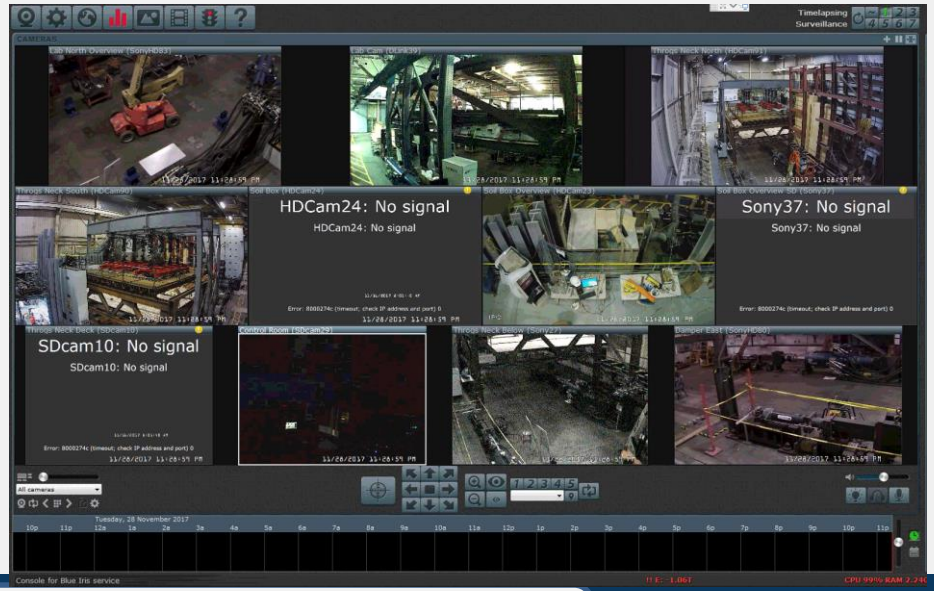
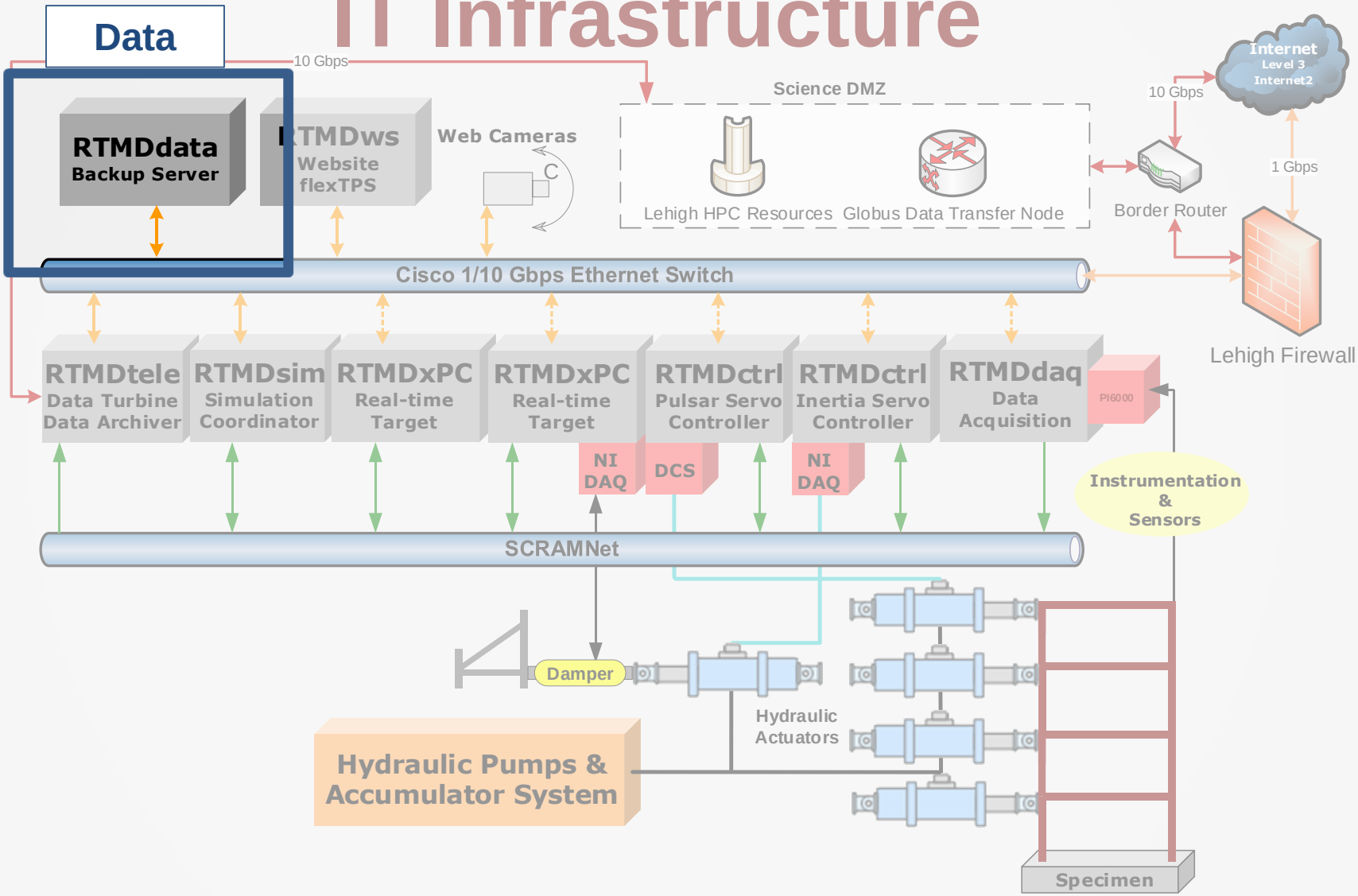


Photo and Video Capabilities

- Video/Imaging systems
  - (24) Amcrest Bullet/PTZ IP Cameras (up to 8k)
  - (4) Sony SNC-EP550 HD (720p HD)
  - (9) GoPro Hero 3 Black camcorders (1080p60 HD)
  - (8) Sony SNC-RZ30N network cameras (SD Security)
  - Nikon D70 D-SLR camera
  - Additional camera equipment upon request through LU Media
- Blue Iris Servers
  - Portal for all users to access and control web cameras
  - Archived video available for previous experiments



IT Infrastructure



RTMDdata

- Synology DS 1817
  - 50TB Expandable
  - 10Gb Connection
- Dual-disk Redundancy
- Network Attached Storage
- Mirrored to DesignSafe through Globus

Data Management Plan

- Local repository for data storage managed by NHERI Lehigh with offsite backup risk mitigation through DesignSafe-CI
- Google Drive and Crashplan cloud storage
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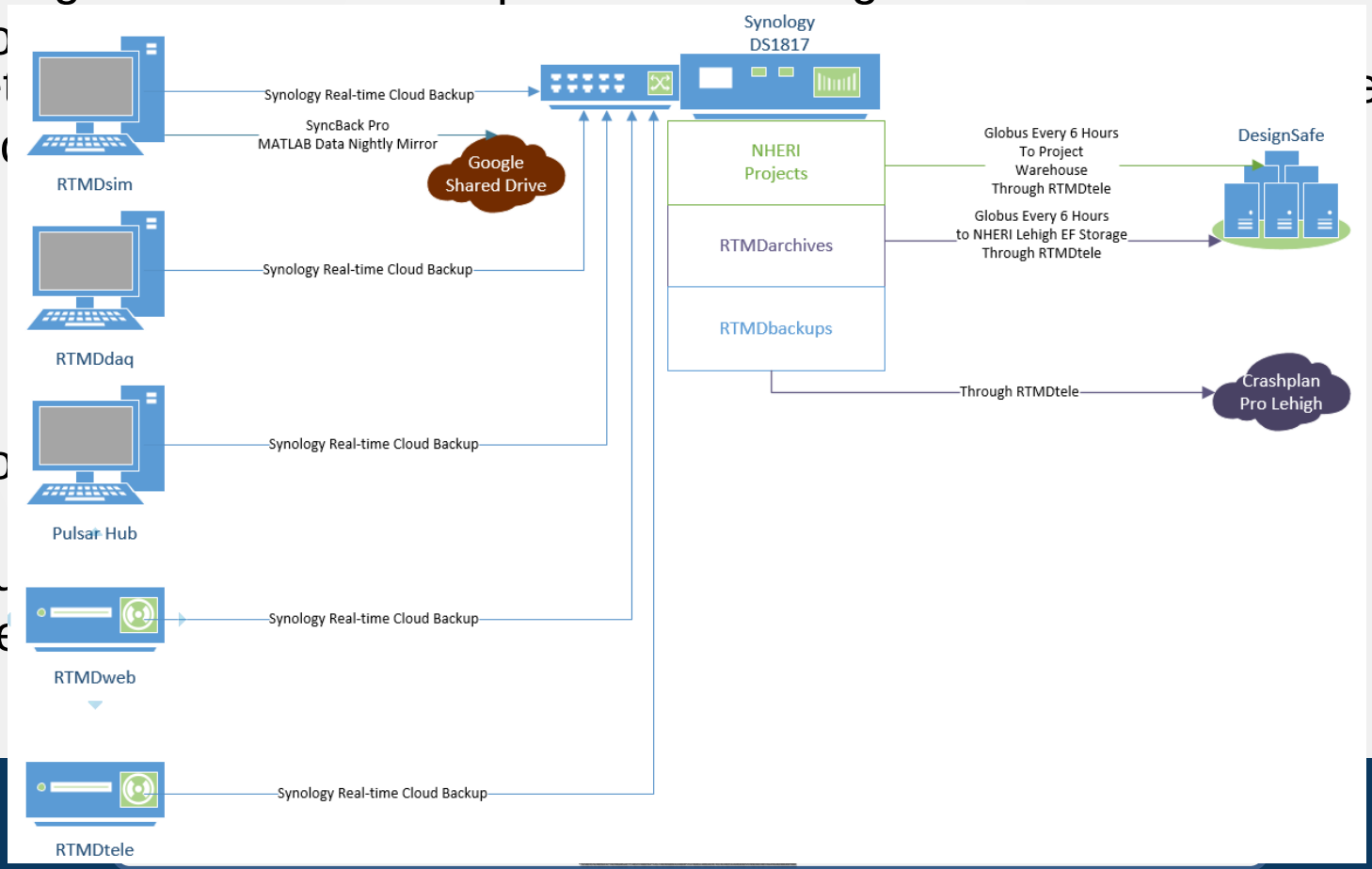

Lehigh NHERI EF Website

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

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

The Lehigh NHERI Experimental Facility is supported by a grant from the National Science Foundation (#1520765).

Thank you