NHERI Lehigh Experimental Capabilities and Protocols

James Ricles
NHERI Lehigh Director

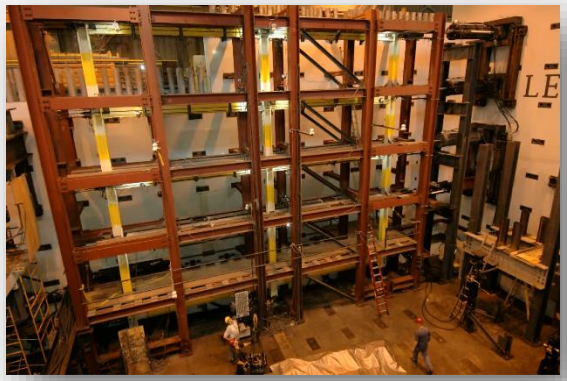
NHERI Lehigh EF

Outline

- Experimental Capabilities
- Test Beds
- Equipment
- Experimental Protocols
- IT Operations
- Cyber Infrastructure

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Large-Scale Hybrid Simulation



HS EQ Simulation of Buildings with SC-MRF

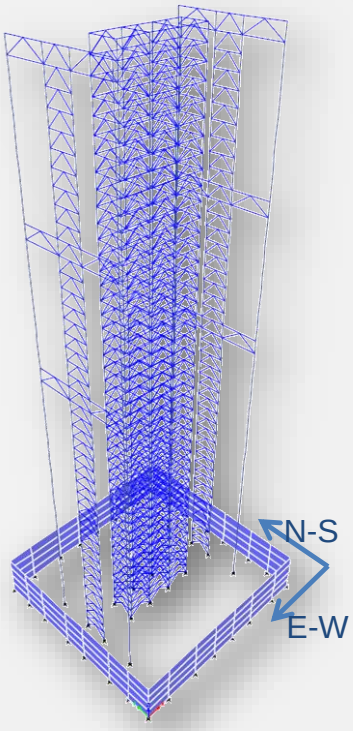
NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

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

RTHS EQ Simulation of Buildings with Dampers

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

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



RTHS Wind and EQ Simulation of Tall Buildings with Dampers

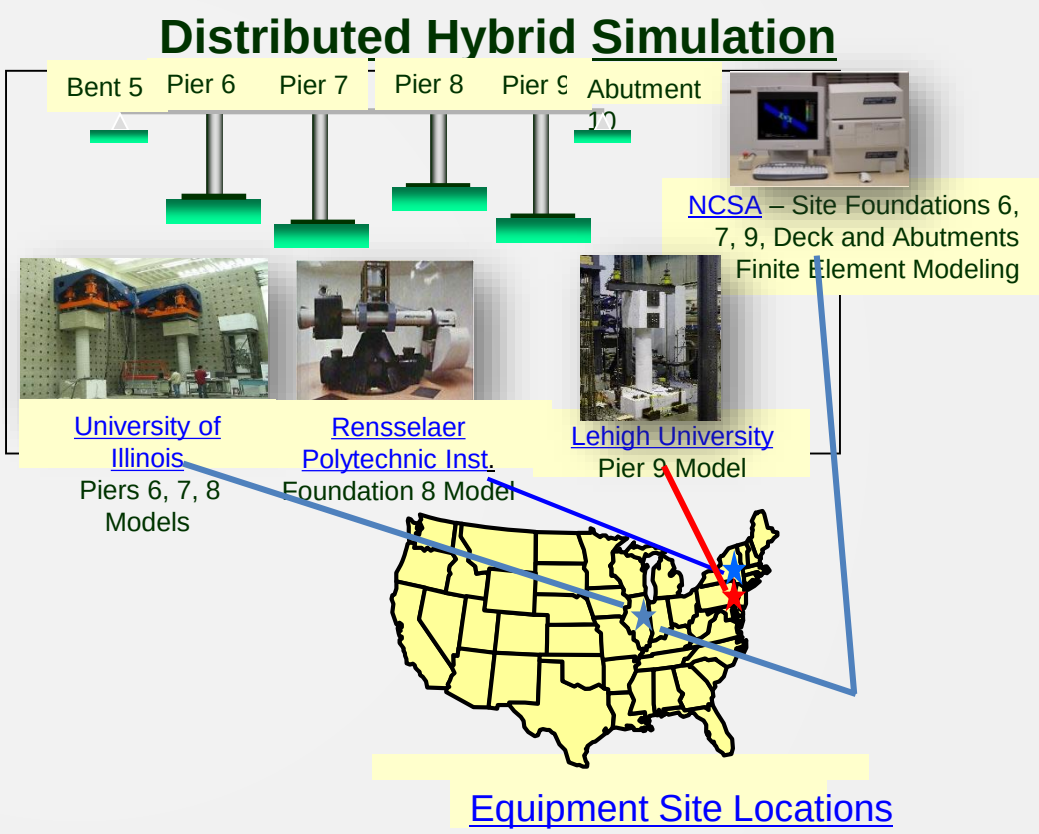
NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

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

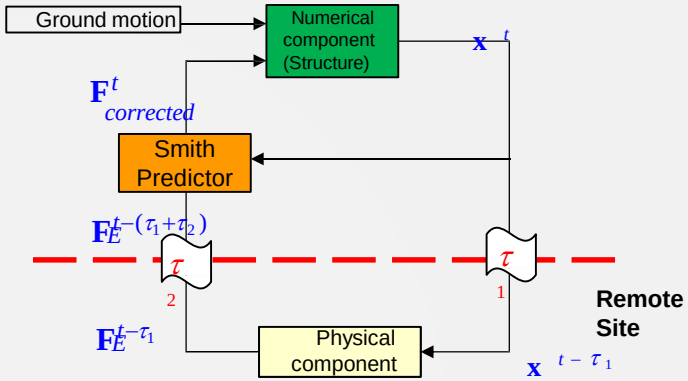
- Large-Scale Hybrid Simulation
- Large-Scale Real-time Hybrid Simulation
- Large-Scale Real-time Hybrid Simulation with Multiple Experimental Substructures
- Geographically Distributed Hybrid Simulation



Distributed RTHS EQ Simulation of I-10 Collector Bridge

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- Large-Scale 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



Lehigh

UIUC

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

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- 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)

Temperature Control Chamber

Characterization of Full-scale Semi-active and Passive Dampers

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- 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)

Characterization of Large-scale RC Coupled Shear Wall System

NHERI Lehigh EF Testing Capabilities for Natural Hazards Engineering Research

- 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

Multi-directional Dynamic Testing of Pipe Couplers

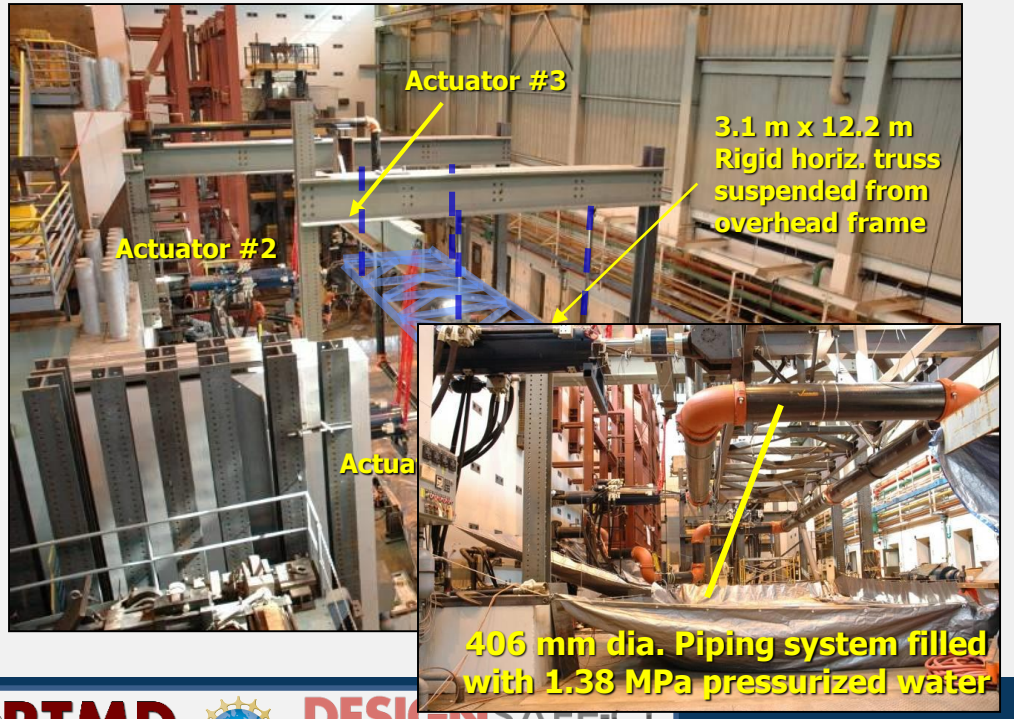
NHERI Lehigh EF/ATLSS Testbeds

- **Bracing Frame**
  - Perform experiments on test frame specimens of:
    - Up to 13.7 m (45 ft) in height
    - Up to 11 m (36 ft) in width

NHERI Lehigh EF/ATLSS Testbeds

- **Non-Structural Component Seismic Simulator**
  - Enables multi-directional real-time hybrid simulation of non-structural components and systems:
    - Up to 12.2 m (40 ft) in length
    - Up to 3.1 m (10 ft) in width

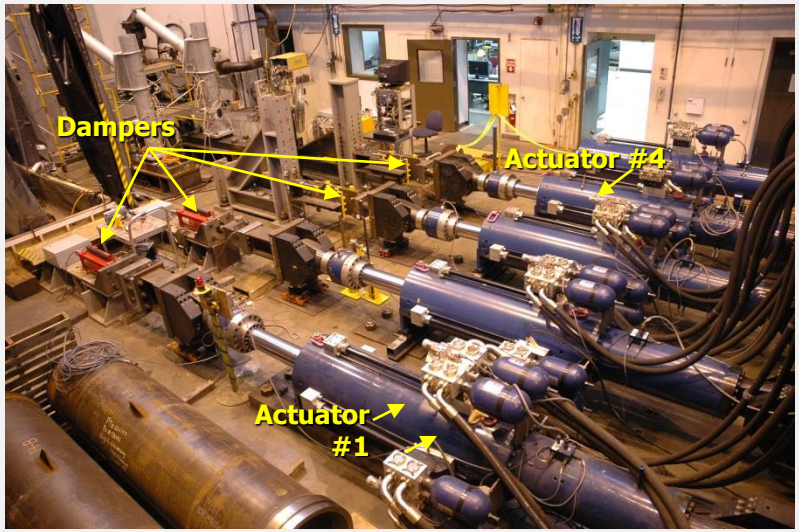
Multi-directional Real-time hybrid simulation of building piping system



NHERI Lehigh EF/ATLSS Testbeds

- **Full-scale Damper Testbeds**
  - Enables full-scale damper tests:
    - Damper characterization tests
    - Real-time hybrid simulations
  - Stoke, velocity, and force capacity:
    - +/- 500 mm (20 in.) stroke
    - 1140 mm/s (45 in/s) for 1700 kN actuators
    - 840 mm/s (33 in/s) for 2300 kN actuators

Real-time hybrid simulation of building with four passive dampers



NHERI Lehigh EF/ATLSS Testbeds

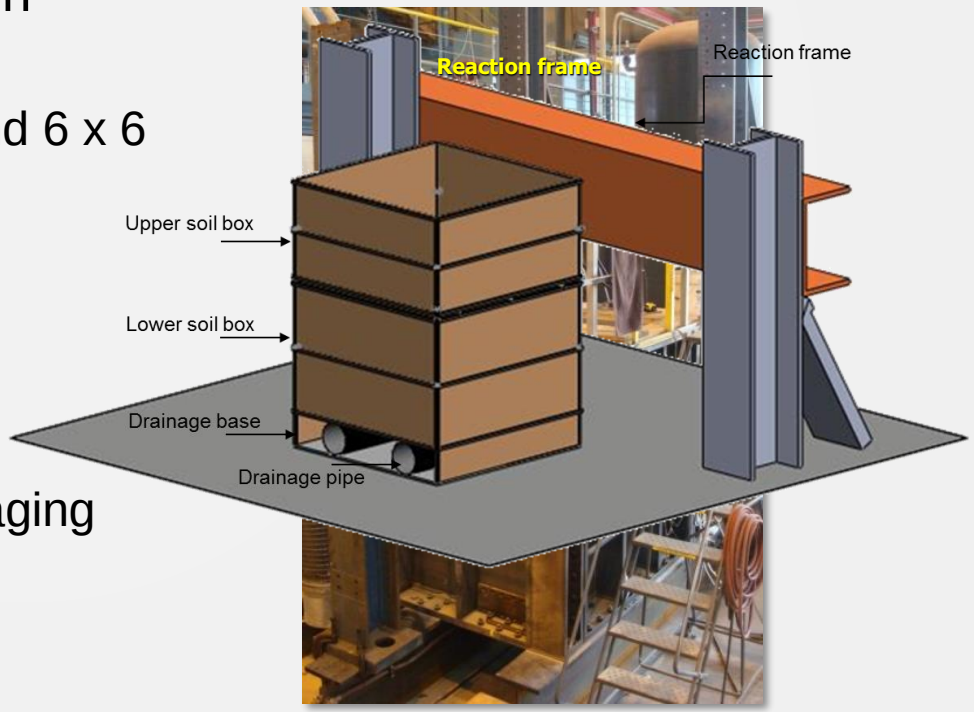
- **Tsunami Debris Impact Force Testbed**
  - Enables full-scale debris impact tests:
    - High speed DAQ; high speed 5000 fps cameras
    - High bandwidth, resolution load cells
    - Accelerometers, laser-displacement transducers

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

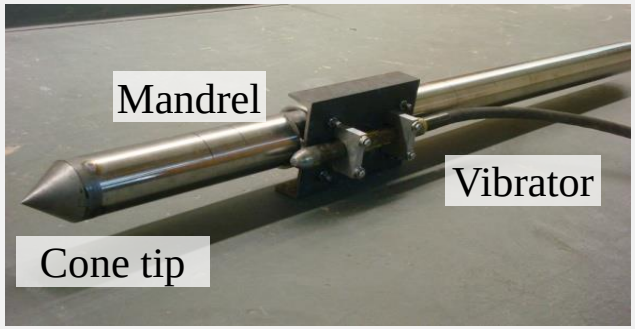
NHERI Lehigh EF/ATLSS Testbeds

- **Reduced-scale Soil Box**
  - 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

Soil-foundation structure interaction testbed

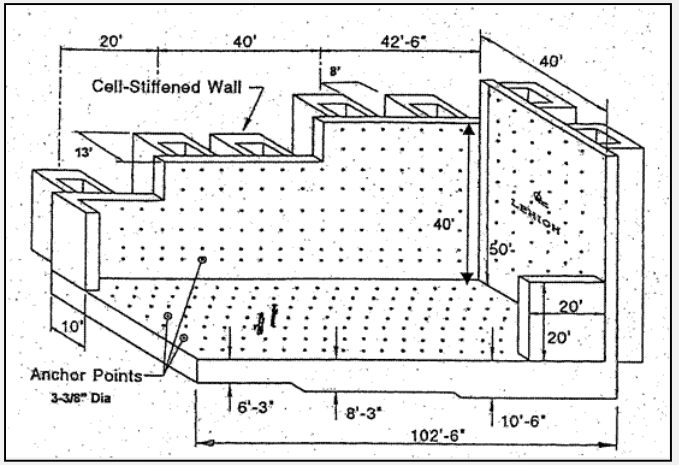


Soil-Structure Interaction Testbed



Existing ATLSS Infrastructure

- **3-D Multi-directional reaction wall facility**
  - 3-dimensional
  - Up to 15.2 m (50 ft) height
  - 1.5 m (5 ft) anchor point grid
- **Strong floor**
  - 12.2 m by 30.5 m (40 ft by 100 ft)
  - Anchor assembly capacity
    - 2,224 kN (500 kips) shear
    - 1,334 kN (300 kips) tension
- **Hydraulic Supply System**
- **Over 30 Hydraulic Actuators**
- **Large array of Conventional Sensors**
- **Crane**
- **Skilled staff**



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 variable axial piston pumps
- **Accumulator System (NHERI)**
  - 16 piston accumulators
    - 50.2 gal each
- **5 dynamic hydraulic actuators (NHERI)**
  - Maximum load capacity
    - 2 actuators: 517 kips at 3000 psi
    - 3 actuators: 382 kips at 3000 psi
  - Stroke
    - +/- 19.7 in
  - Maximum velocity
    - 45 in/s for 382 kip actuators
    - 33 in/s for 517 kip actuators
- **10 3-stage 550 gal/min Servovalves and HSMs (NHERI)**

Other NHERI Lehigh EF Equipment

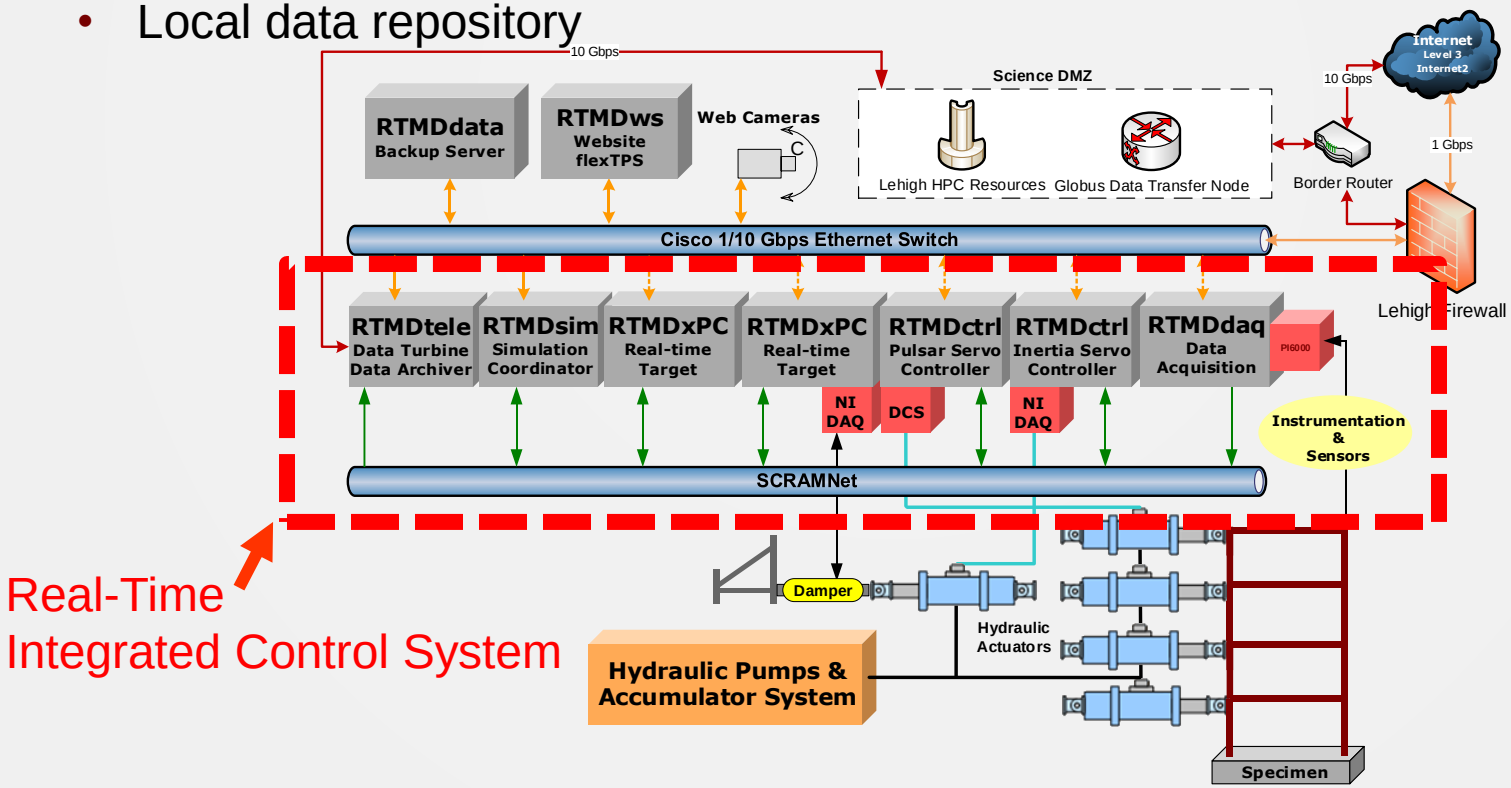
- High Speed 300+ Channel Data Acquisition System
- 3 Real-Time Targets for simulation coordination, including additional DAQ
- Two real-time servo-hydraulic controllers
- Sensors (displacement, accelerometers, inclinometers)
- Telepresence webcams
- Specs for all equipment found in User's Guide

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.

Other Major NHERI Lehigh EF Equipment

- Real-time Integrated Control System
  - Multiple Real-Time targets for simulation coordination with additional DAQ
  - Two real-time servo-hydraulic controllers
  - High Speed 300+ Channel Data Acquisition System
  - Web and Data telepresence system
  - Local data repository



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

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

NHERI Lehigh EF non-NHERI Equipment

Equipment	Year Acquired
Multi-Directional Reaction Wall System	
15.2m to 6.1m tall L-shaped reaction wall	1989
30.5m x 12.2m strong test floor	1989
Hydraulic Equipment	
20.7 MPa (3000psi) Hydraulic power system with 2270 liters/min	1988,1992**
Central hydraulic distribution system	1988,1992**
6-Vickers Service hydraulic manifolds (1500 liters/min)	n/a
Hydraulic Loading Equipment	
Sactec 2670 kN universal test machine	1992
MTS 245 kN fatigue test machine	1992
Hydraulic Actuators	
3-2680kN Hanna, +-750 mm stroke, 20mm/sec max. velocity*	1997
2-2050kN Hanna, +-480 mm stroke, 25mm/sec max. velocity*	1988
4-1500kN Hanna, +-480 mm stroke, 35mm/sec max. velocity*	1988
2-150kN Hanna, +-125 mm stroke, 35mm/sec max. velocity*	1988
2-1050kN Hanna +-125 mm stroke, 50mm/sec max. velocity*	1988
2-607kN Hanna, +-300 mm stroke, 80mm/sec max. velocity*	1988
8-580kN Hanna, +-125 mm stroke, 60mm/sec max. velocity*	1992
2-1000kN Hanna, +-125 mm stroke, 35mm/sec max. velocity*	1992

Users Guide Available ATLSS Actuators

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

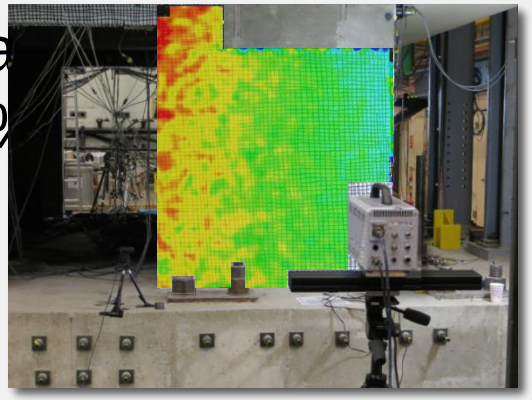
ATLSS Actuators

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%

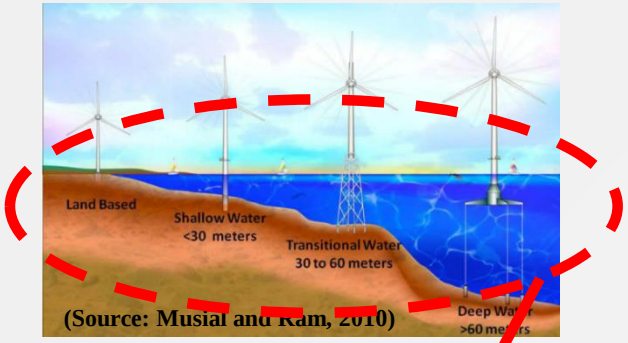
Figure F.4 DIC System

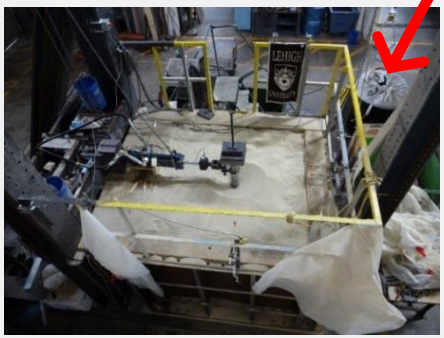
NEES@Lehigh Coupled Shear Wall Test Specimen with Multi-Directional Loading

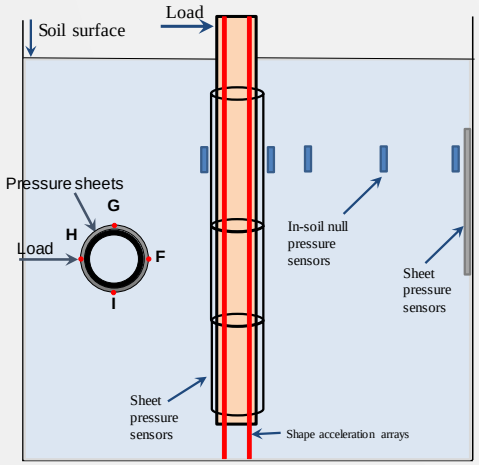


Digital Imaging Correlation System: reinforced concrete coupled-shear wall test specimen measured pier vertical displacements (courtesy M. McGinnis)

Soil-Structure Interaction Instrumentation

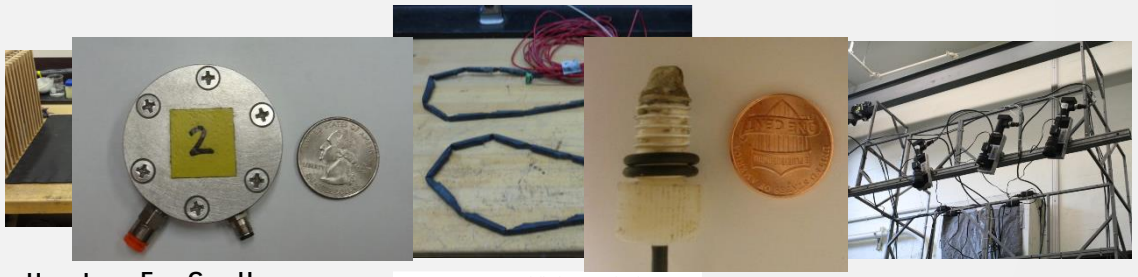


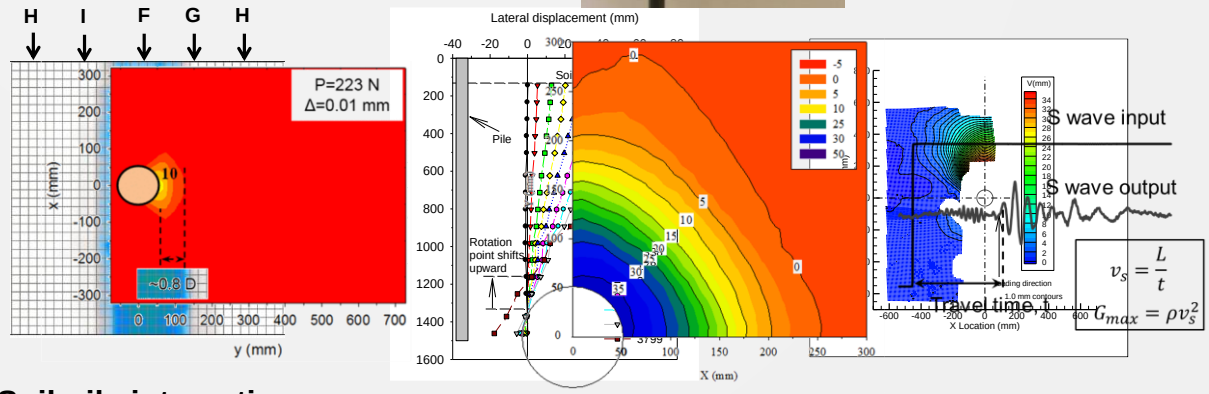




Test Setup and instrumentation

- 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





Soil-pile interaction pressure sensors

Pressure sensors

Shape acceleration arrays

S wave sensors

Digital image correlation

NHERI Lehigh EF - ATLSS Space and Resources

- **Specimen Prep**
  - 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

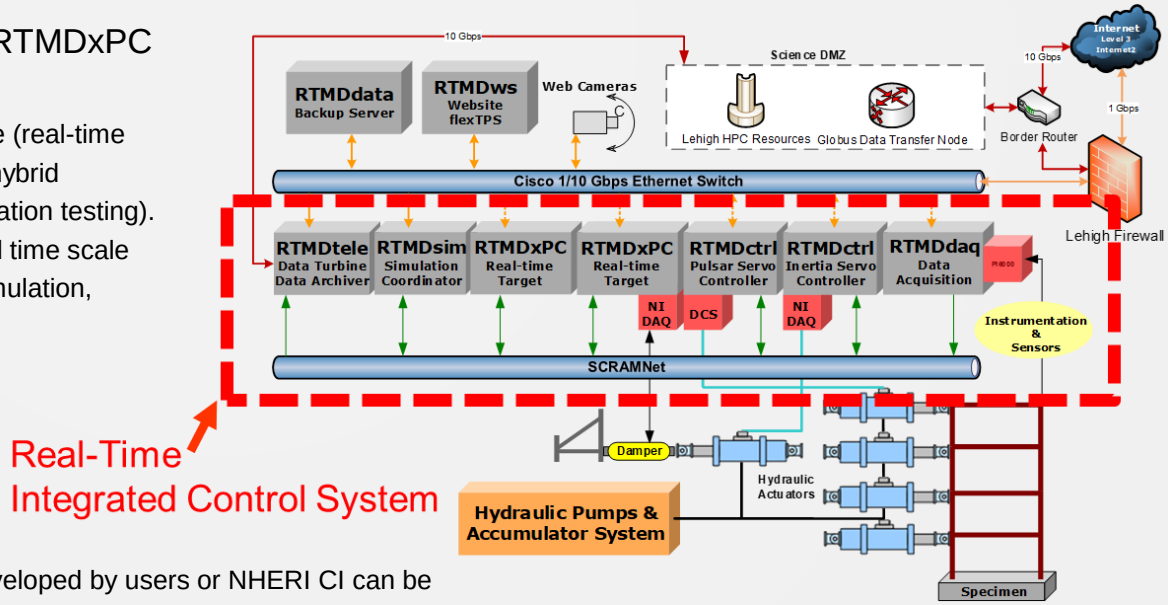
Mechanical testing

Auditorium – ECO Activities

NHERI Lehigh EF Experimental Protocols

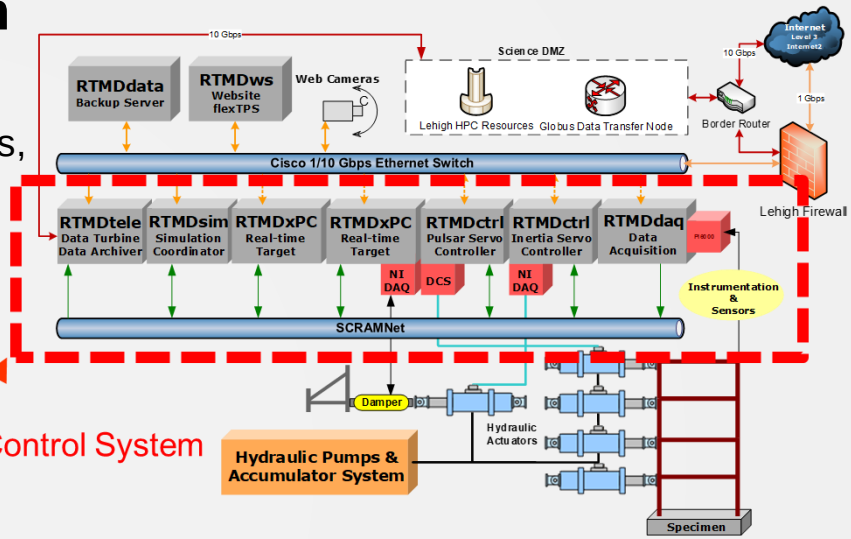
- **Real-time Integrated Control System**
  - Configured with experimental protocol required by user to perform test
    - Large-Scale Hybrid Simulation
    - Large-Scale Real-time Hybrid Simulation
    - Large-Scale Real-time Hybrid Simulation with Multiple Experimental Substructures
    - Geographically 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).
    - Experiments can be run at an expanded time scale (hybrid simulation, distributed hybrid simulation, quasi-static testing).
  - Distributed hybrid simulation via:
    - OpenFresco
    - Simcor
    - Custom software
  - Flexible-designed system
    - Software and middleware packages developed by users or NHERI CI can be plugged in and utilized for testing

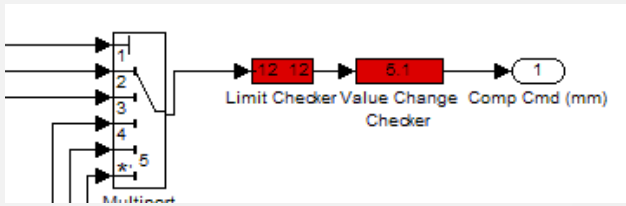
https://lehigh.designsafe-ci.org/protocols/experimental-protocol/



NHERI Lehigh EF Experimental Protocols

- **Real-time Integrated Control System**
  - Hydraulics-off mode
    - Used for validation of testing methods/algorithms, training, education
    - Both servo-hydraulic system, test structure and any analytical substructure modeled analytically
  - Safety
    - Software limits are enabled on the System.
    - Hardware actuator positon stroke and test specimen displacement limit switches placed.
    - Emergency stop system activated throughout laboratory





NHERI Lehigh EF Experimental Protocols

- **Real-time Integrated Control System**
  - Hybrid simulation:
    - Robust integration algorithms: Explicit mKR-α Integration Algorithm - Explicit unconditionally stable integration algorithm with controlled numerical energy dissipation and controlled overshoot (*Kolay and Ricles, 2014, 2017*).
    - Adaptive actuator control: Adaptive Time Series (ATS) Compensator *(Chae et al. 2013)* –
      - Negates both variable time delay and variable amplitude error response, using measured test structure state feedback to achieve accurate specimen displacements
      - No user-defined adaptive gains ➔ applicable for large-scale structures susceptible to damage (i.e., concrete structures)
      - Time delay and amplitude response factor can be easily estimated from the identified values of the coefficients

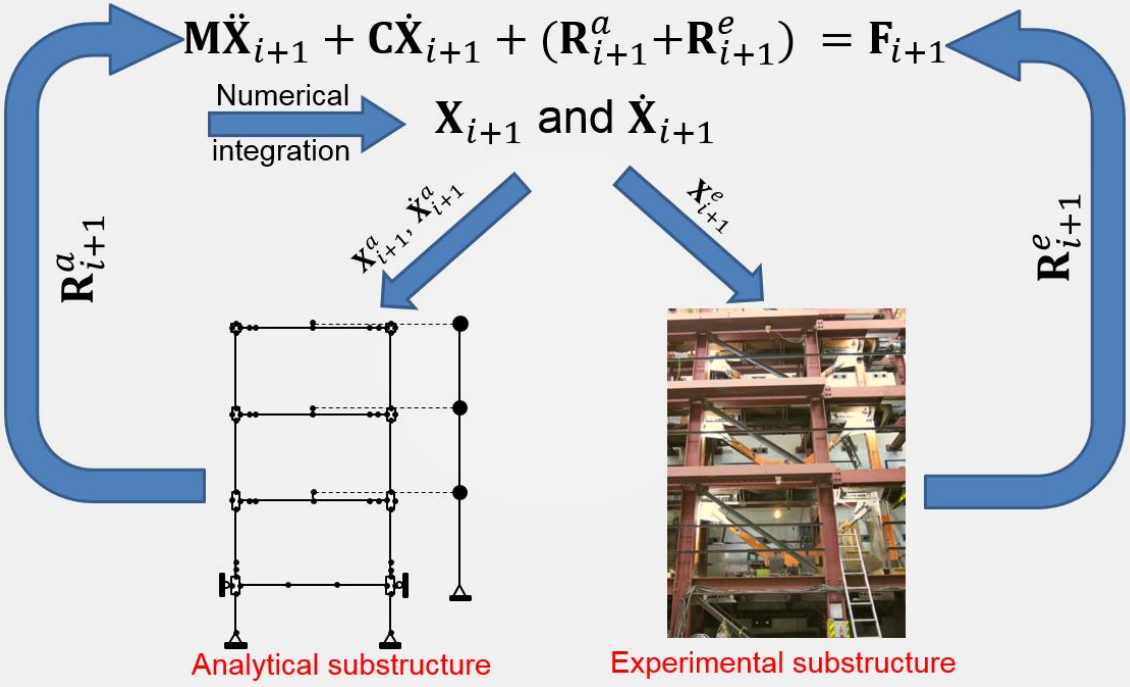
Kolay, C., & Ricles, J. (2014). "Development of a family of unconditionally stable explicit direct integration algorithms with controllable numerical energy dissipation." *Earthquake Engineering & Structural Dynamics*, *43*(9), 1361–1380. DOI:10.1002/eqe.2401

Kolay, C., and J.M. Ricles (2017). "Improved Explicit Integration Algorithms for Structural Dynamic Analysis with Unconditional Stability and Controllable Numerical Dissipation," Journal of Earthquake Engineering, http://dx.doi.org/10.1080/13632469.2017.1326423

Chae, Y., Kazemibidokhti, K., and Ricles, J.M. (2013). "Adaptive time series compensator for delay compensation of servo-hydraulic actuator systems for real-time hybrid simulation." Earthquake Engineering and Structural Dynamics, 42(11), 1697–1715, DOI: 10.1002/ eqe.2294.

NHERI Lehigh EF Experimental Protocols

- **Real-time Integrated Control System**
  - Hybrid simulation analytical substructure created by either
    - HybridFEM
    - OpenSees with OpenFresco interface



Schematic of hybrid simulation

HybridFEM

- MATLAB and Simulink based computational modeling and simulation coordinator software for dynamic time history analysis of inelastic-framed structures and performing real-time hybrid simulation
- Simulink architecture facilitates real-time testing through multi-rate processing
- Run Modes
  - MATLAB script for numerical simulation
  - Simulink modeling for Real-Time Hybrid simulation with experimental elements via Real-Time Targets, and hydraulics-off for training and validation of user algorithms.
- User's Manual for training

HybridFEM

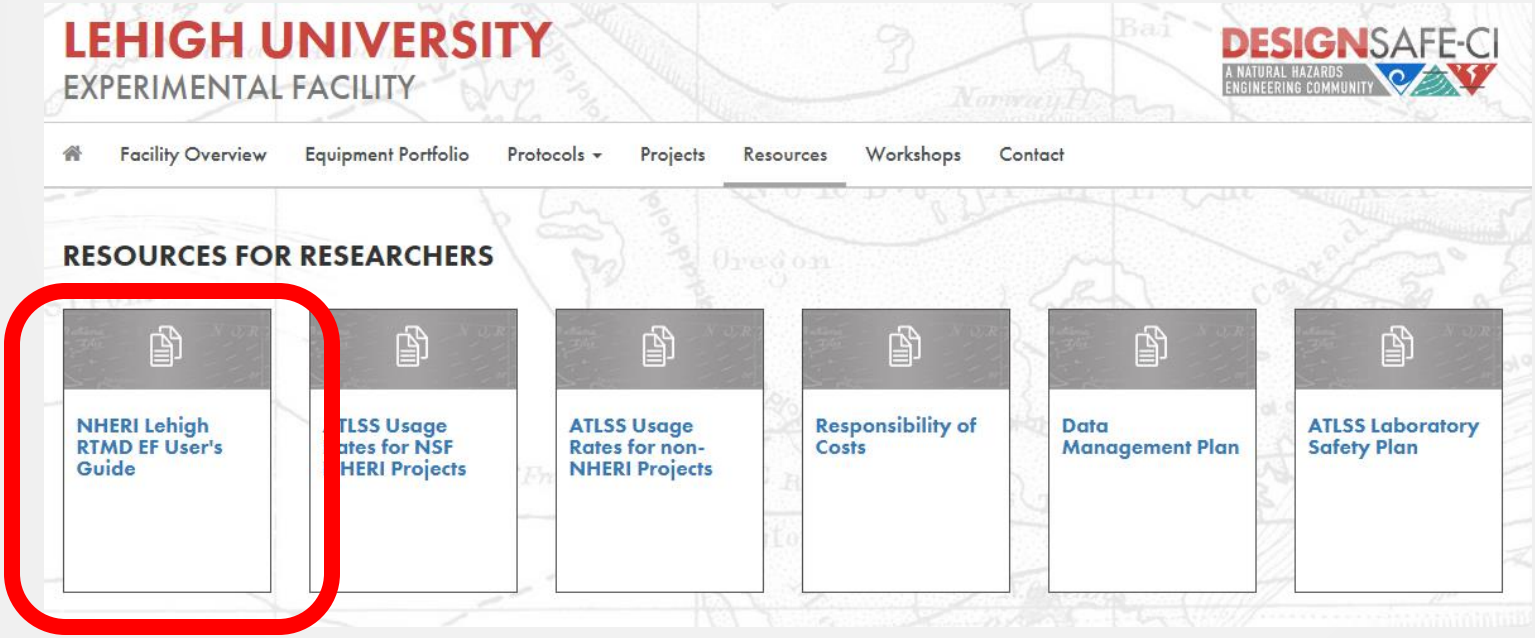
Configuration Options:

- Coordinate system of nodes
- Boundary, constraint and restraint conditions
- Elements
  - Elastic beam-column
  - Elastic spring
  - Inelastic beam-column stress resultant element
  - Non-linear spring
  - Displacement-based NL beam-column fiber element
  - Force-based beam NL column fiber element
  - Zero-length
  - 2D NL planar panel zone
  - Elastic beam-column element with geometric stiffness
- Geometric nonlinearities
- Steel wide flange sections (link to AISC shapes Database)
- Reinforced concrete sections
- Structural mass & inherent damping properties
- Adaptable integration methods
- Materials
  - Elastic
  - Bilinear elasto-plastic
  - Hysteretic
  - Bouc-Wen
  - Trilinear
  - Stiffness degrading
  - Concrete
  - Steel

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/



IT Operations and Cyber Infrastructure

Thomas Marullo

IT Systems Administrator

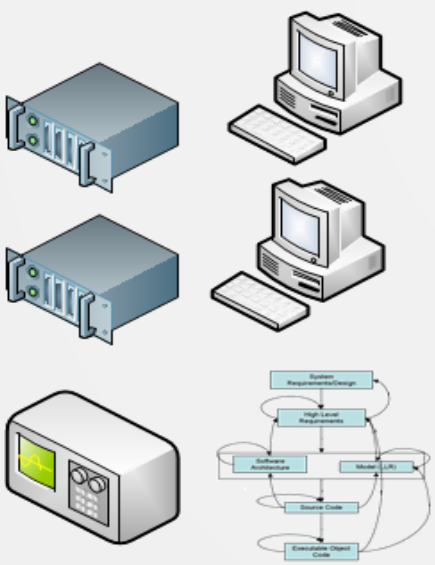
Overview

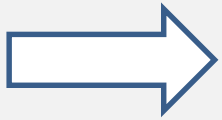
- IT Infrastructure and Equipment
- Hardware/Software Capabilities
- User Training and Testing
- Cybersecurity and Risk Mitigation

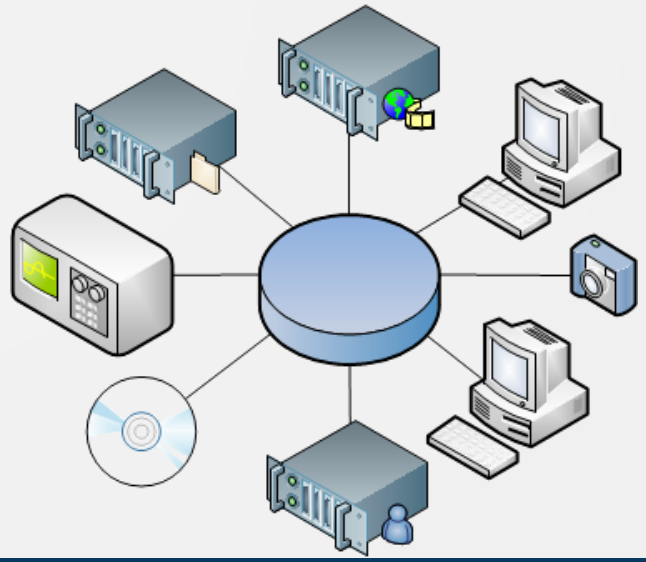
IT Mission

- Design IT Architecture from the ground up
- Complete control of all IT aspects to facilitate all types of required simulation techniques

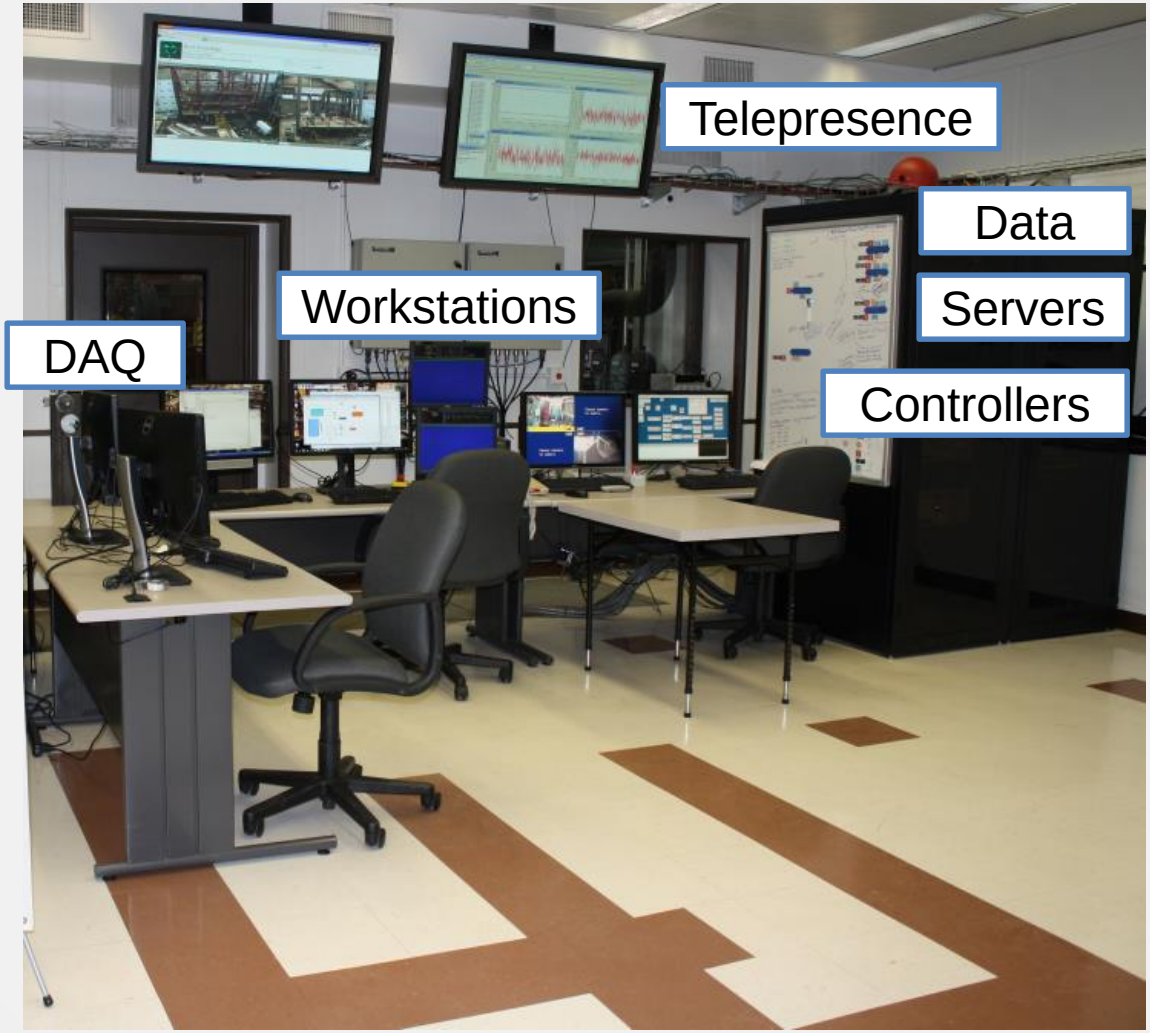
2004 **Present**



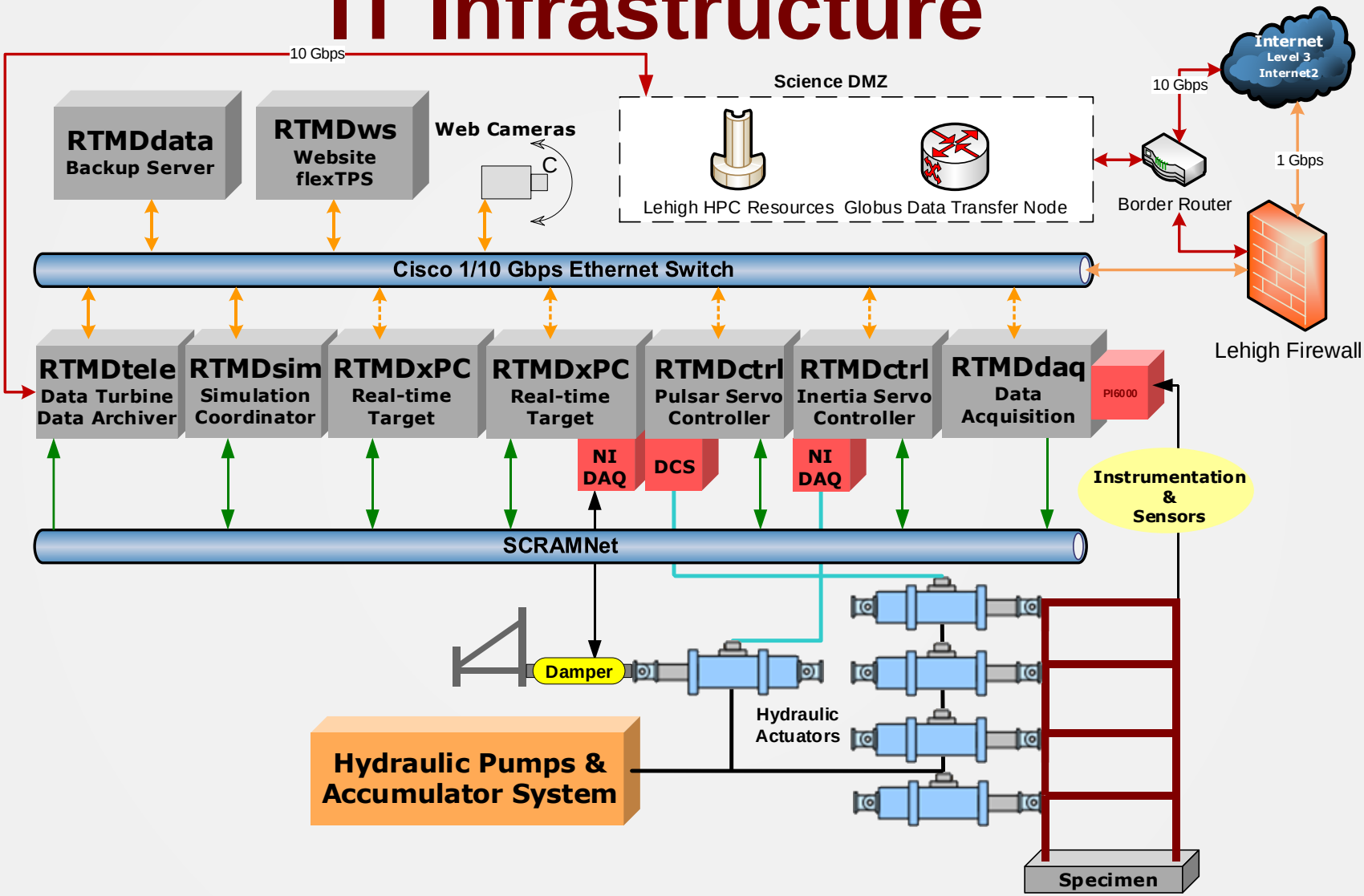




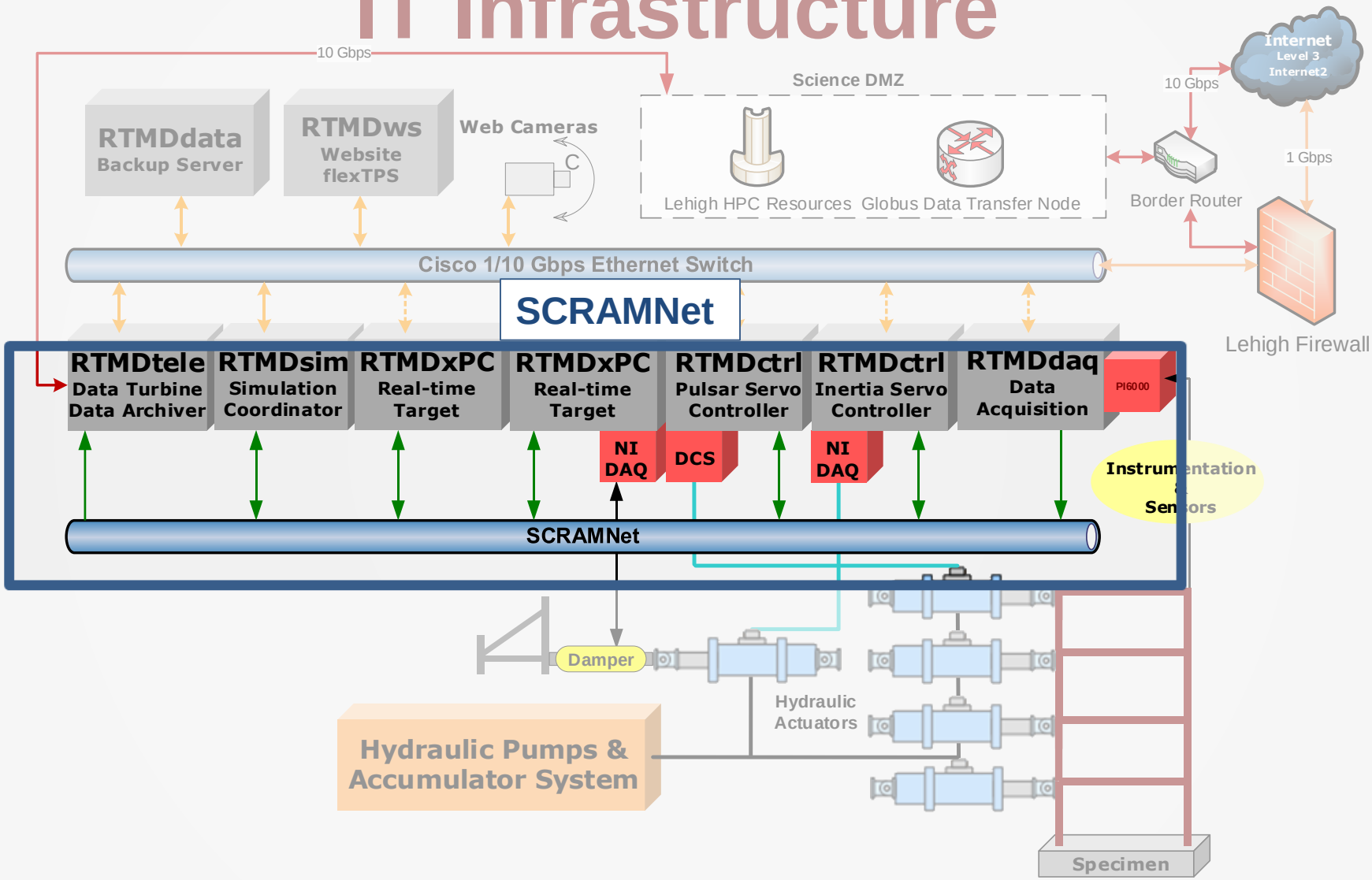
RTMD Control Laboratory



IT Infrastructure



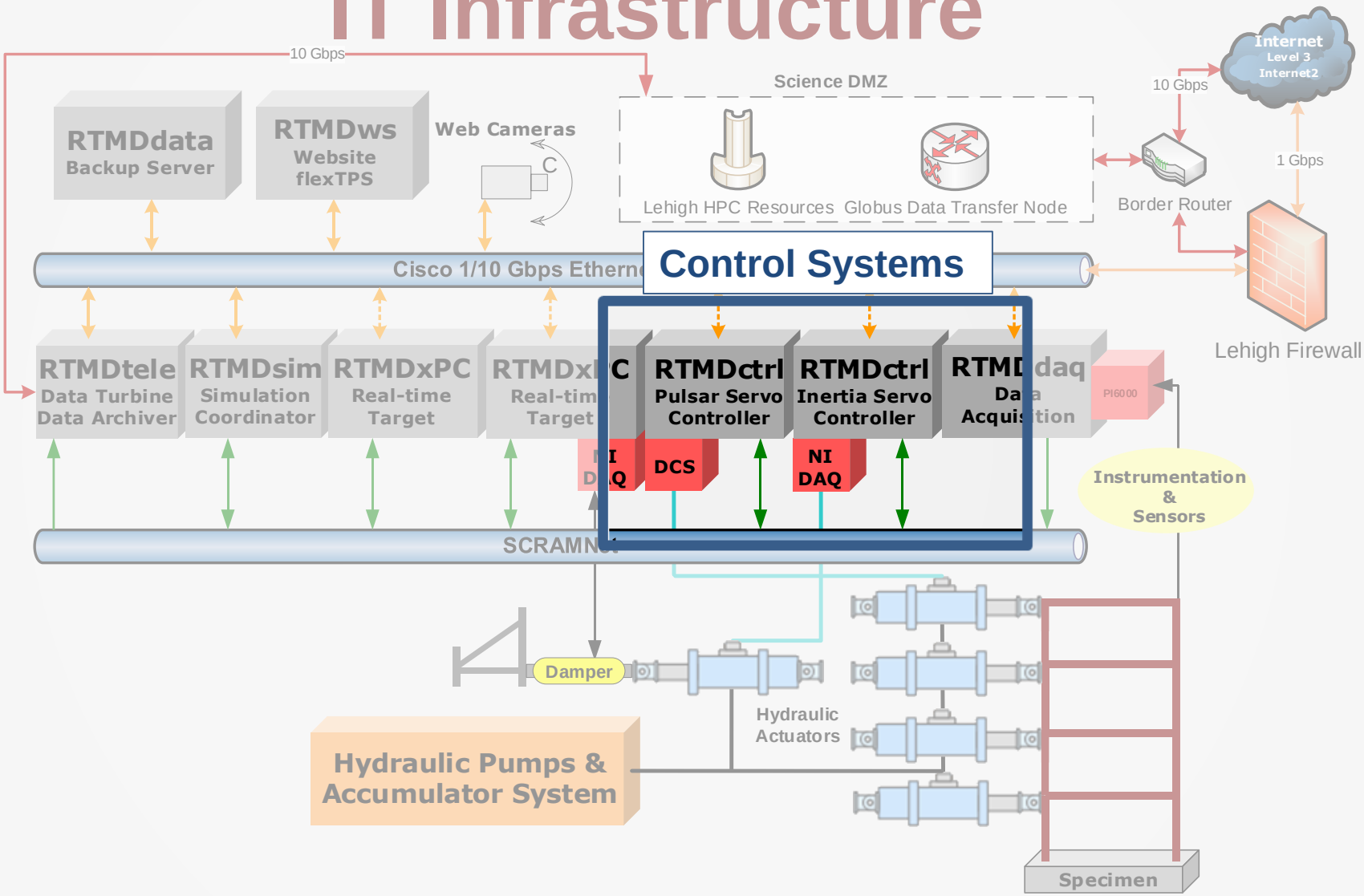
IT Infrastructure



SCRAMNet+

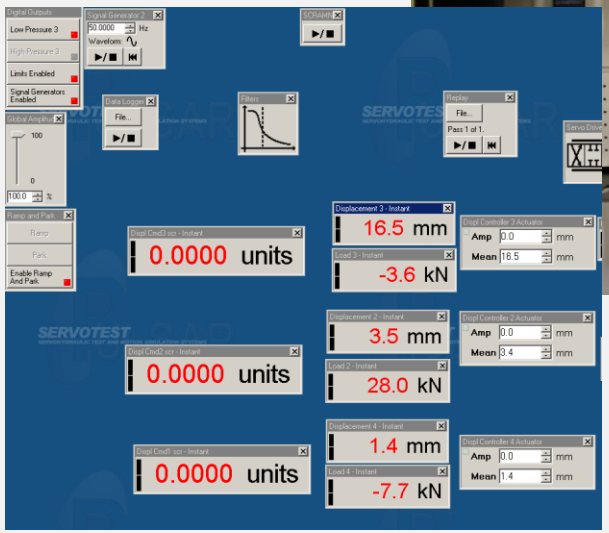
- Shared memory space for multiple systems
- High speed communication over fiber optics
- Mathworks/Java/C++ Support
- Flexible memory structure for defining multiple control and DAQ systems
- 2018 SCRAMNet GT Upgrade

IT Infrastructure



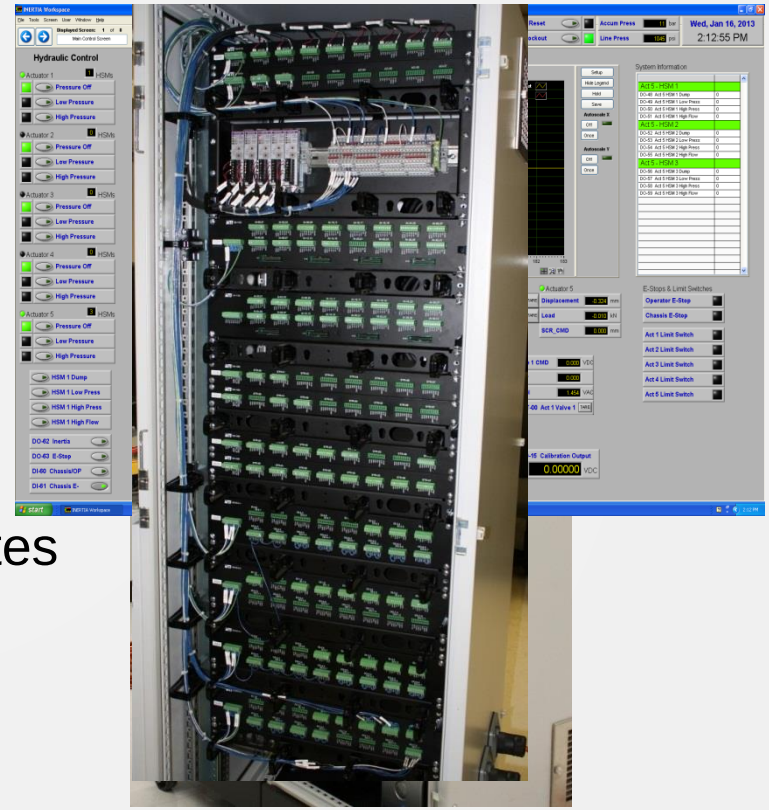
RTMDctrl

- Servotest Pulsar Control System
  - Configurable servo-control system for hydraulics actuator control
  - 1024Hz control rate
  - Fine tuning of PID loops
  - Customizable interface
  - 2018 Upgrade

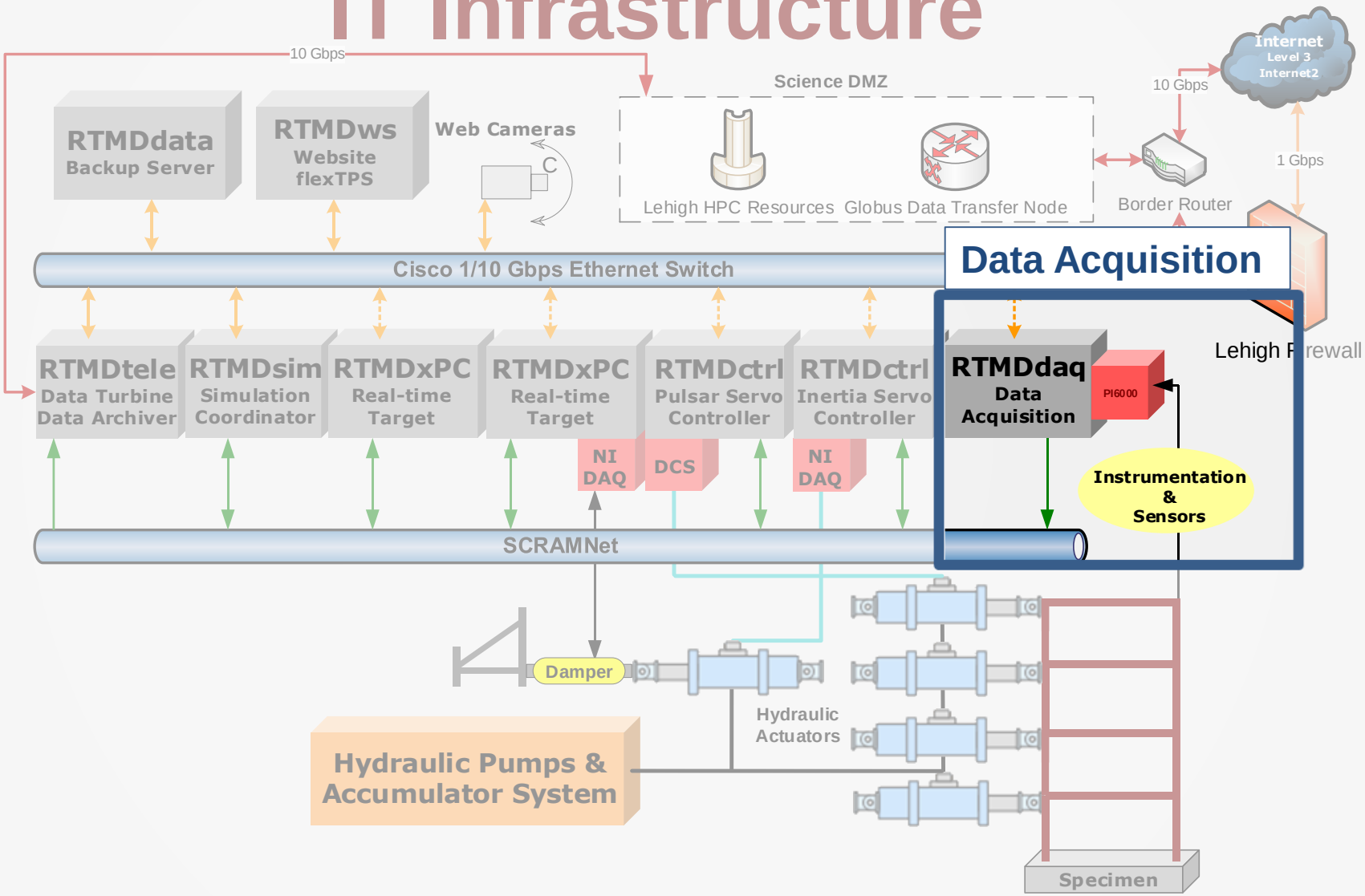


RTMDctrl

- 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

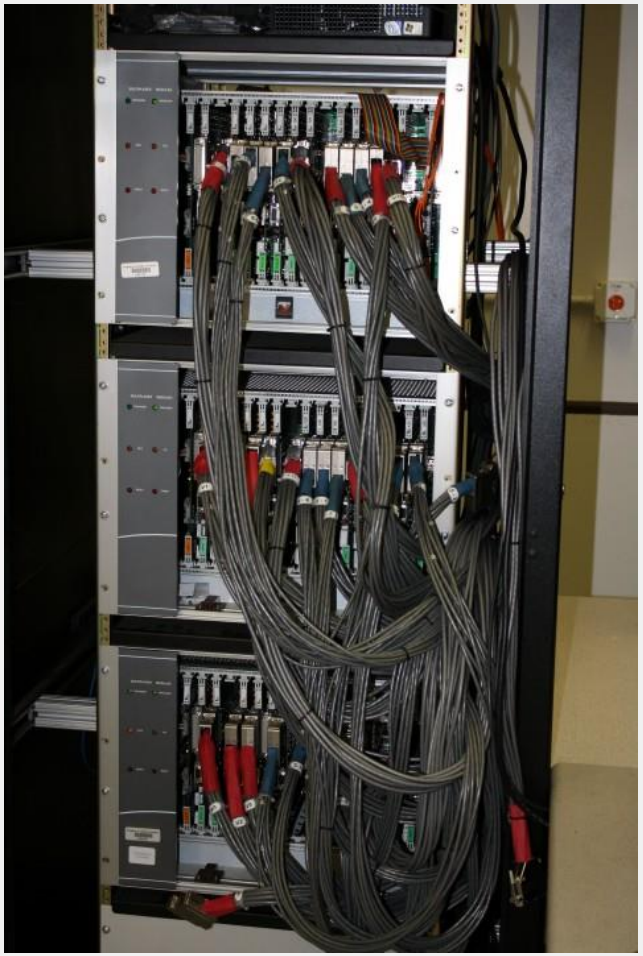


IT Infrastructure

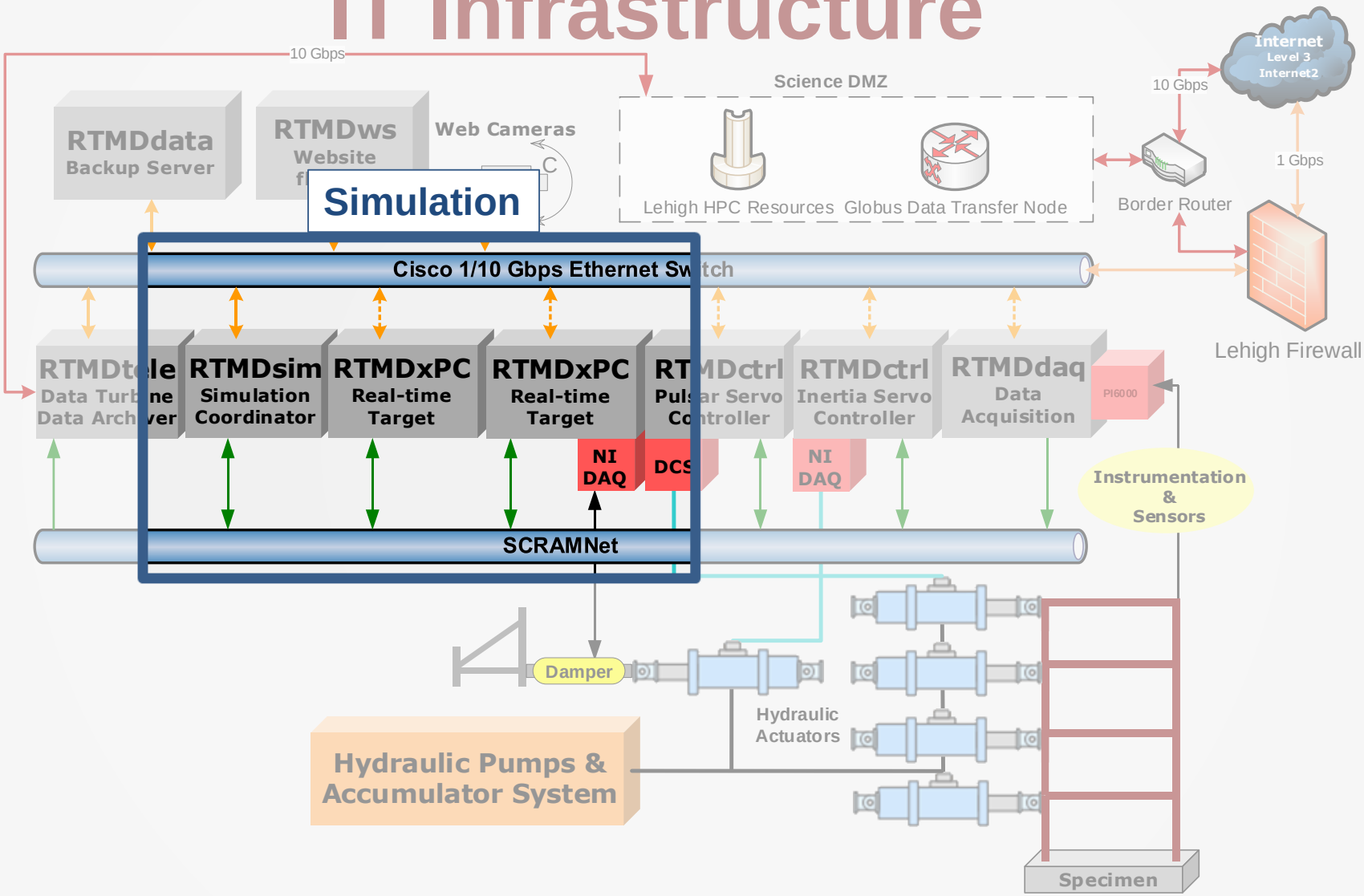


RTMDdaq

- Pacific Instruments 6000 Data Acquisition System
  - 304 channels, 384 expandable
    - Voltage, Strain, Thermocouple
  - Variable sampling rates
    - 4 kHz for Real-time Testing
  - Sensor list exporting for archival
  - 2018 USB Based Upgrade



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 real-time systems
- Multiple Targets
  - Defined roles
  - Parallel processing for larger, more complex models

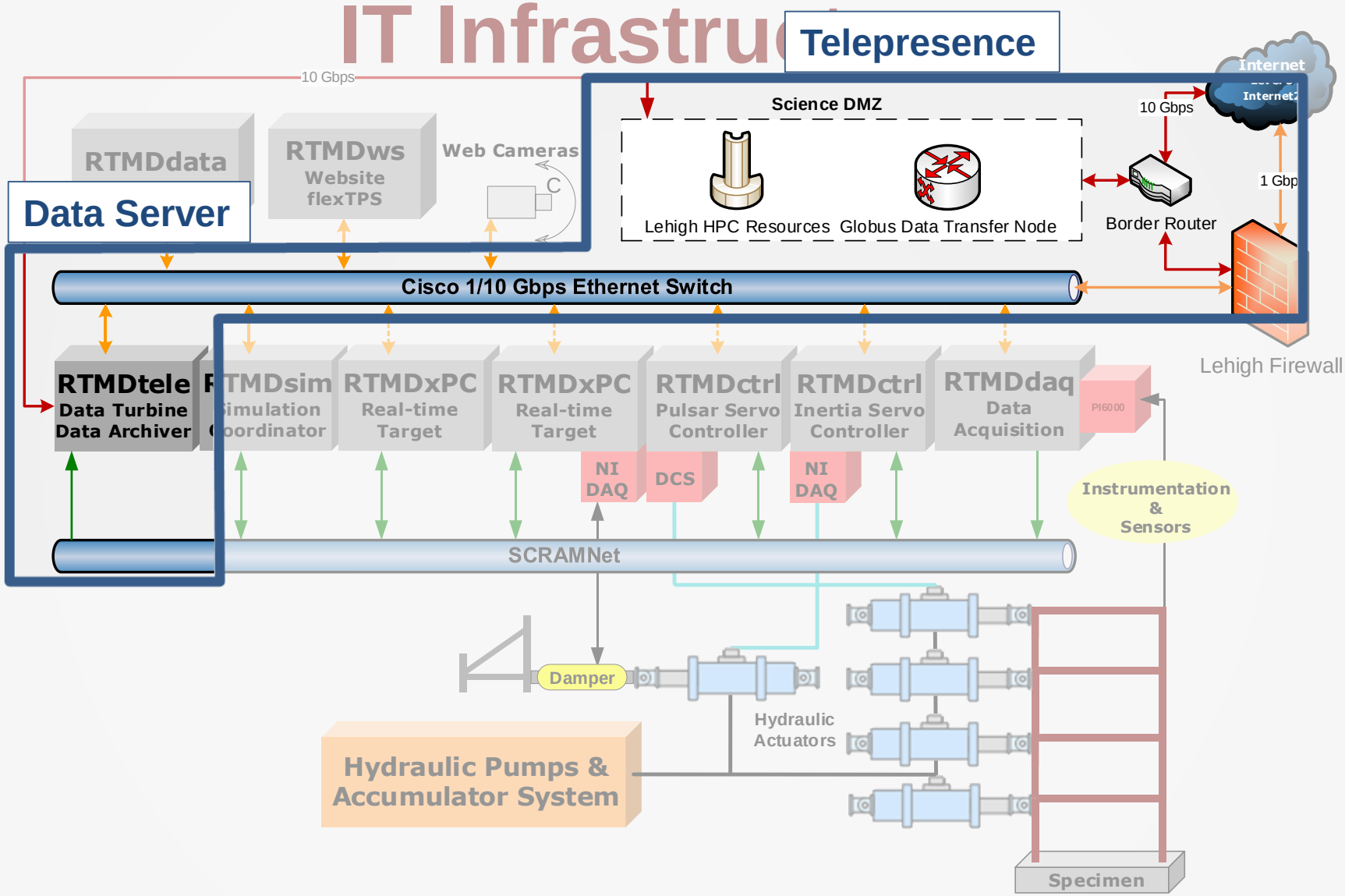
RTMDsim

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

RTMDxPC

- Speedgoat systems, CPU performance up to 4 GHz
- Industrial quality design for robustness
- Multi-core support for parallel processing
- Daisy chaining
- Available modules for DAQ and control
- Simple interface with Simulink and S-Functions
- Quick prototype turnaround

IT Infrastru

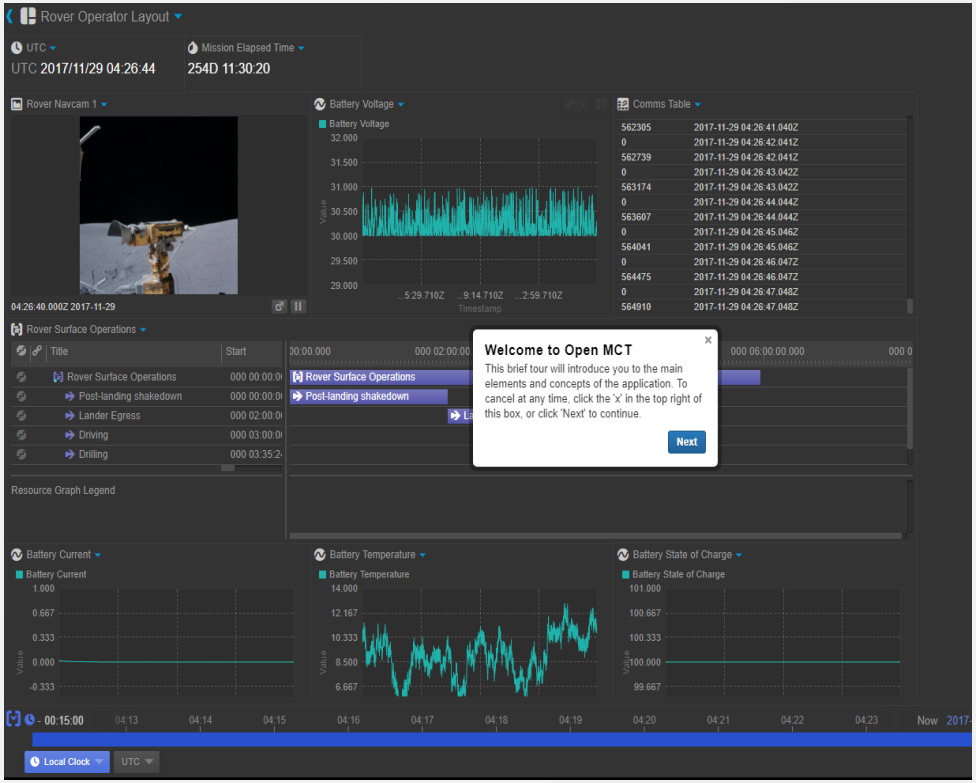


Telepresence

- Data Turbine (RBNB) (dataturbine.org)
  - Aggregates data from SCRAMNet using RTMD tools to define channel list, sample rate and duration
  - Streaming of data and images locally and remotely
  - Additional storage archive of test data
  - Working with Cycronix team with CloudTurbine

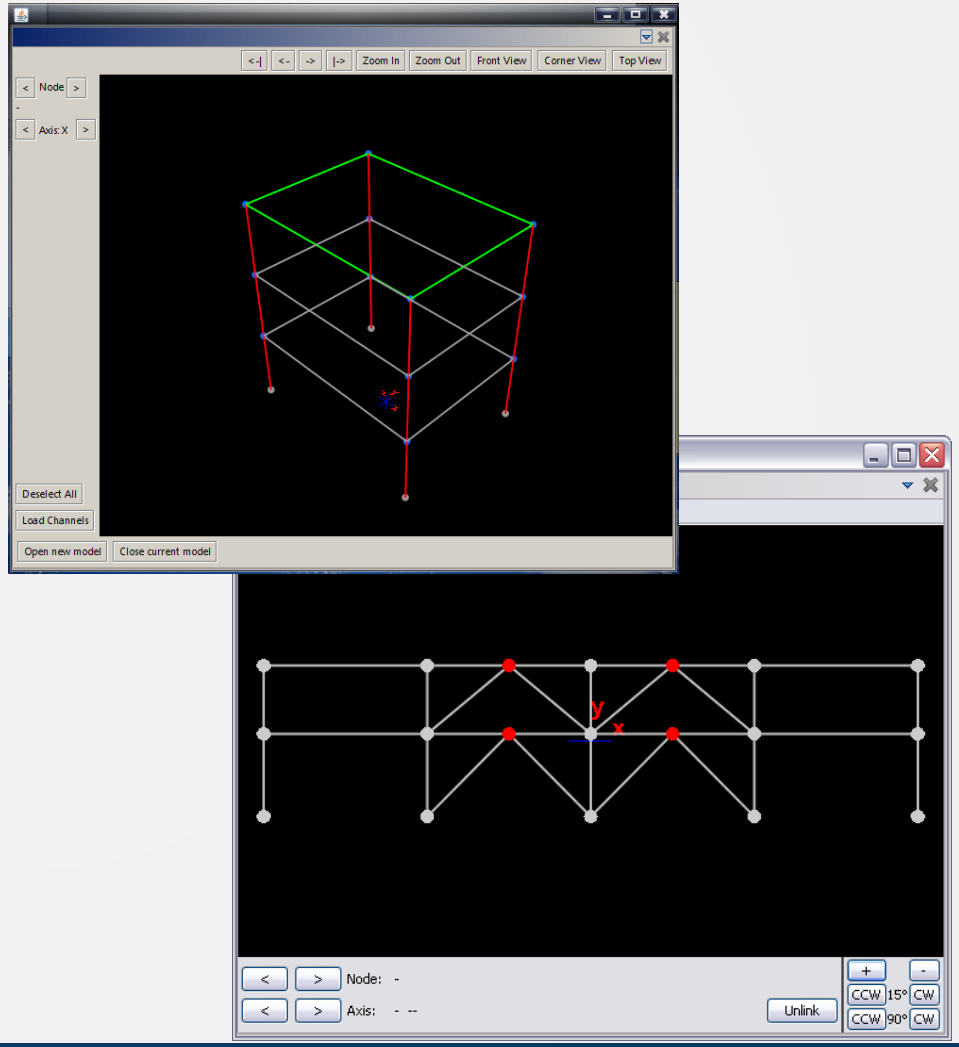
RDV

- Real-Time Data Viewer (RDV)
  - Connect from anywhere on any system
  - Invaluable tool for visualizing Real-Time Hybrid Simulations
  - Working with Cycronix team and NASA with OpenMCT



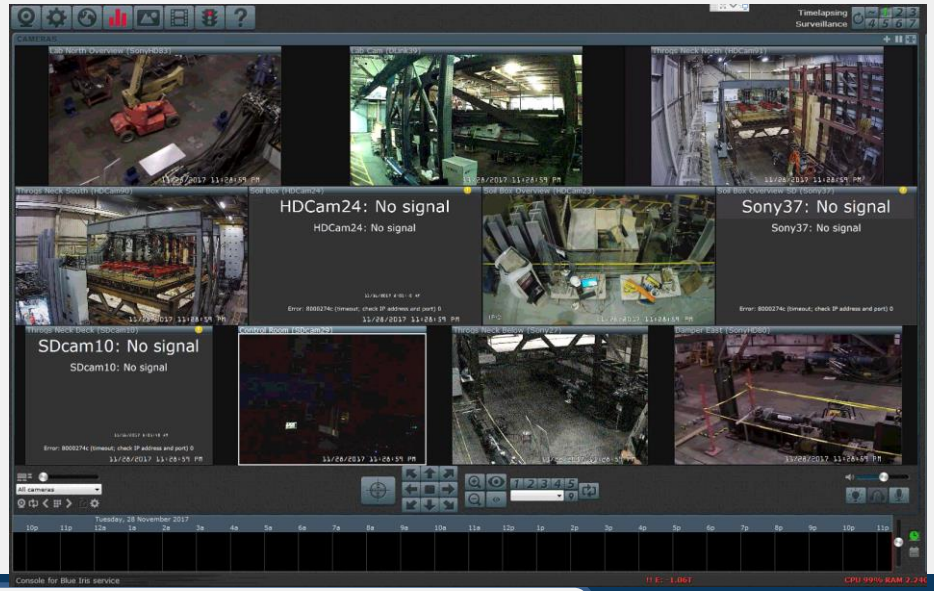
3D Model Panel for RDV

- 3D Modeling for RDV
- Real-time visualization complete structural system in hybrid simulation

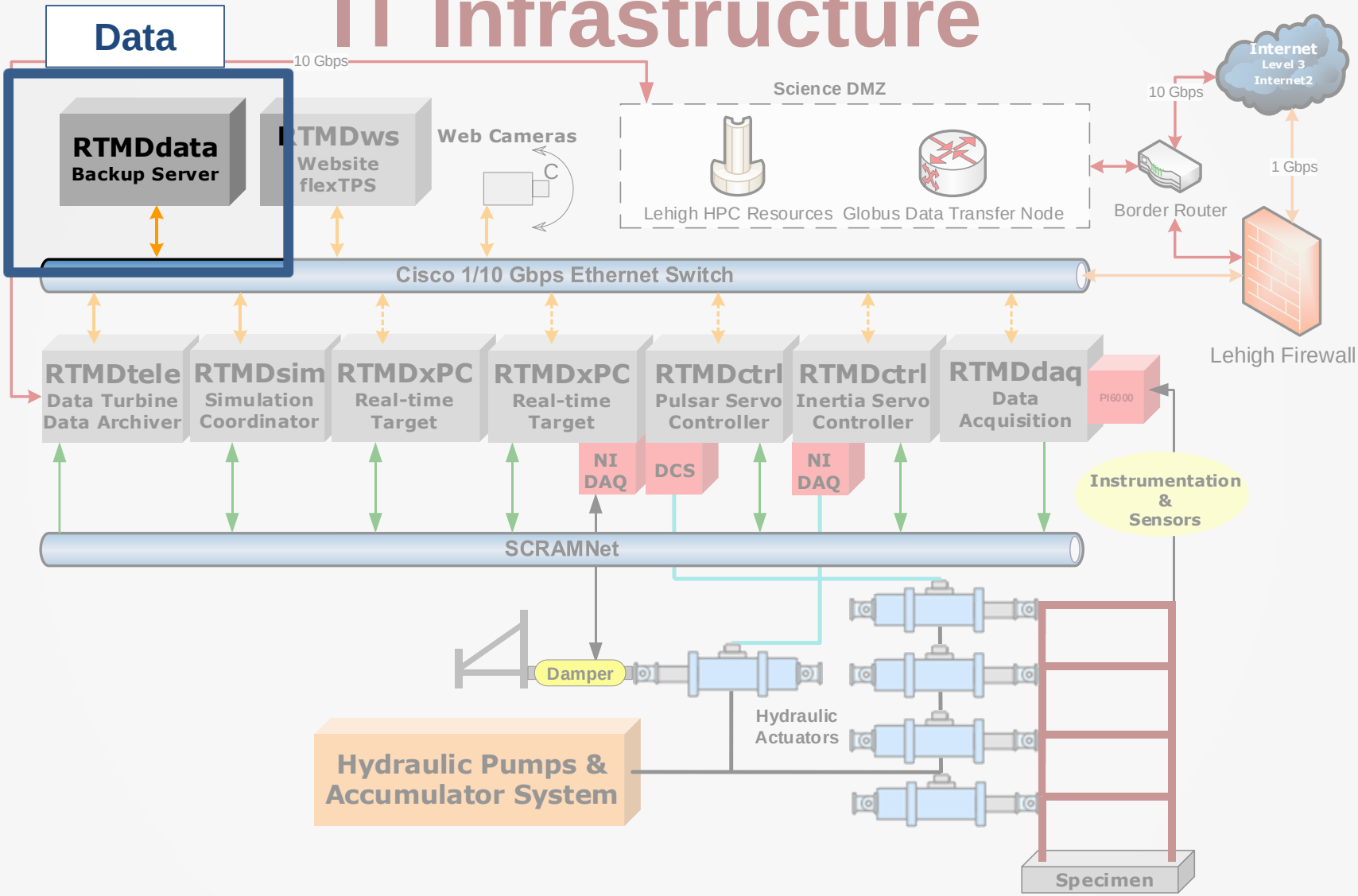


Telepresence

- Video/Imaging systems
  - (4) Sony SNC-EP550 HD
  - (9) GoPro Hero 3 Black camcorders
  - (2) Sony SNC-RZ30N network cameras
  - Nikon D70 D-SLR camera
  - HD camcorders available upon request through Lehigh
- Blue Iris
  - Portal for all users to access and control web cameras
  - Archived video available for previous experiments



IT Infrastructure



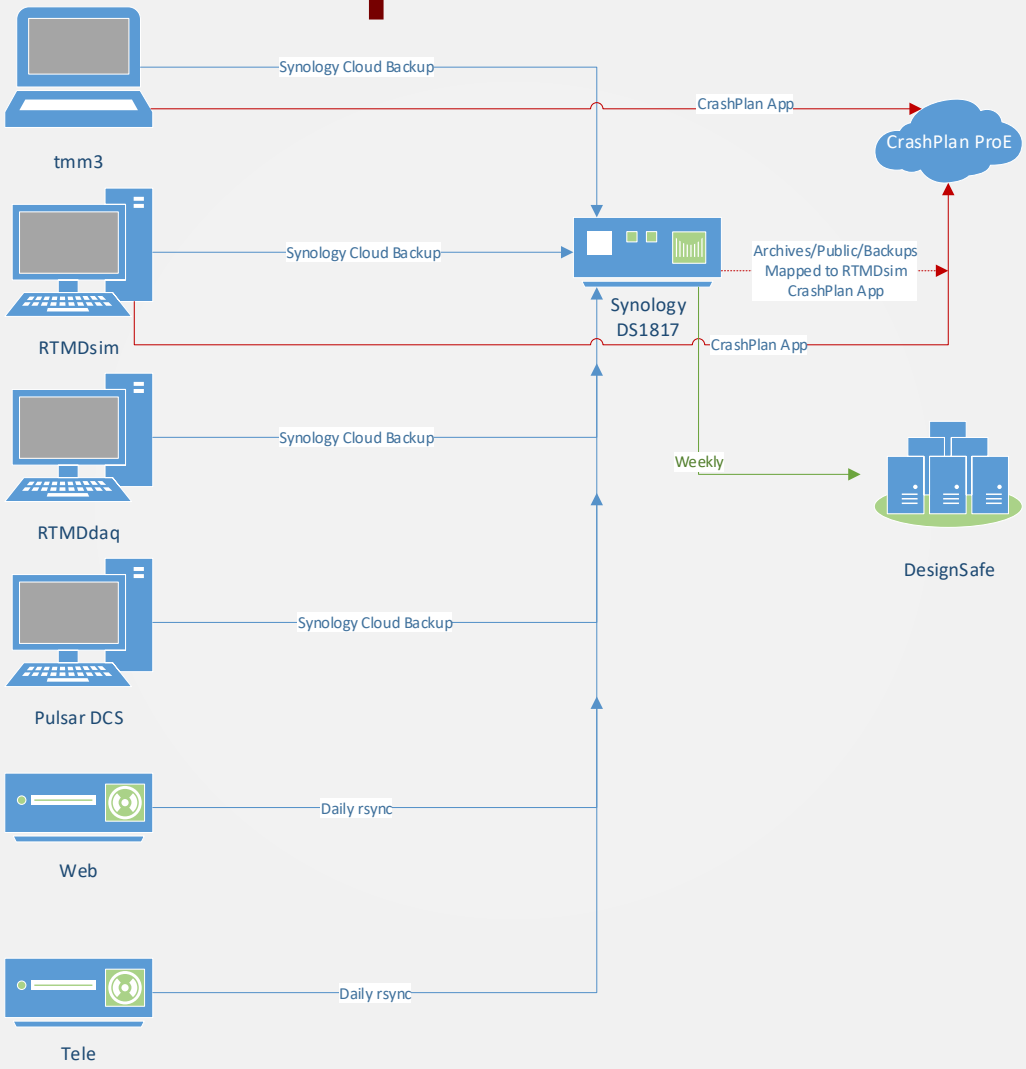
RTMDdata

- Synology DS 1817
  - 8 hard drive slots, 96 TB capacity up to 216 TB
  - 10Gb Connection
- Dual-disk Redundancy
- Network Attached Storage
- Public and Private storage

Data Management Plan

- Local repository for data storage managed by NHERI Lehigh with offsite backup risk mitigation through DesignSafe-CI
- Unlimited Google Drive space through Lehigh University
- Locally stored data adheres to the Lehigh University records retention policy or extended by the ATLSS Center IT management
- Included under NHERI Lehigh data management umbrella:
  - Unprocessed and RAW data from experiments
  - Converted and derived data sets using computational software
  - Experimental photos and videos
  - Computational models and analytical data sets
  - Scripts and software developed for project tasks
- Local curation utilizing folder/file structure
  - Project/Date/Task Description/Data Set; format “testname_date”
- DesignSafe-CI curation through Data Depot and Data Model

Backup Procedure

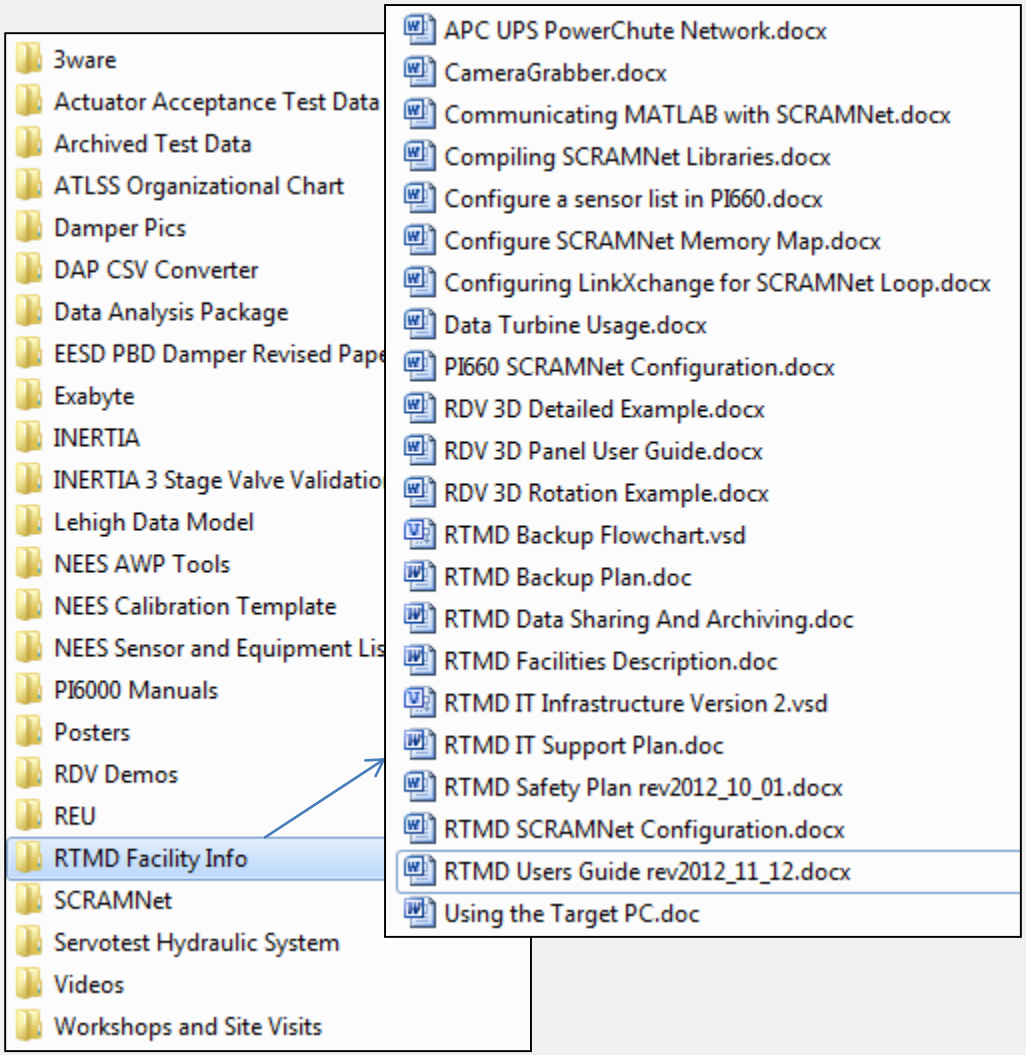


Software Capabilities

- Components for simulation coordination
  - MATLAB, Simulink (RT)
  - LabVIEW RT/VeriStand (Wineman Inertia)
  - Lehigh HybridFEM through Matlab, Simulink
  - OpenSEES via OpenFresco
  - SIMCOR (UIUC), ANSYS

Training: Documentation

- User's Guide
- Repository of technical documents, demos and video tutorials
- Available to all users

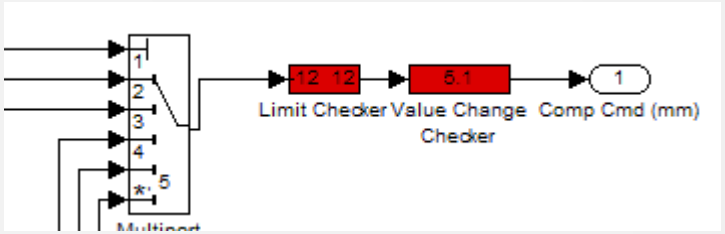


Training: Hands on

- Familiarize users with Testing and IT equipment
- Introduce users to software and user tools
- Describe all safety requirements
- Perform validation studies on physical test bed
- Demonstrate various simulation techniques

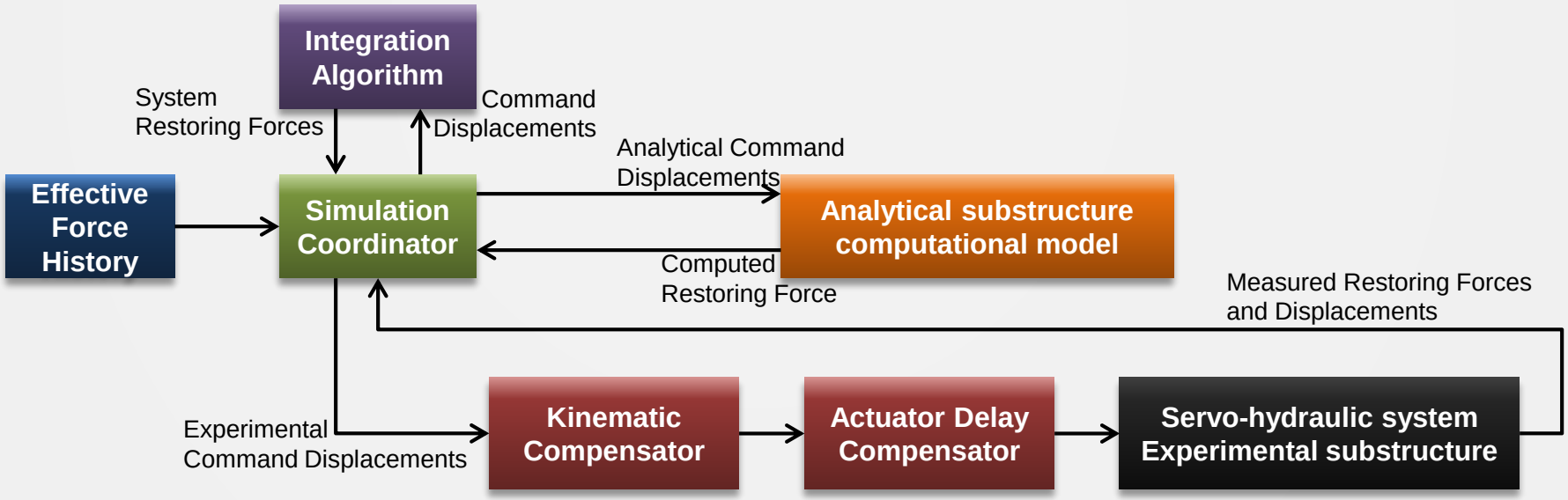
Simulation Safety

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



Hybrid Simulation Components

- Simulation coordinator
- Integration algorithm
- Computational model of analytical substructure
- Kinematic error compensator
- Actuator delay compensator
- Experimental substructure

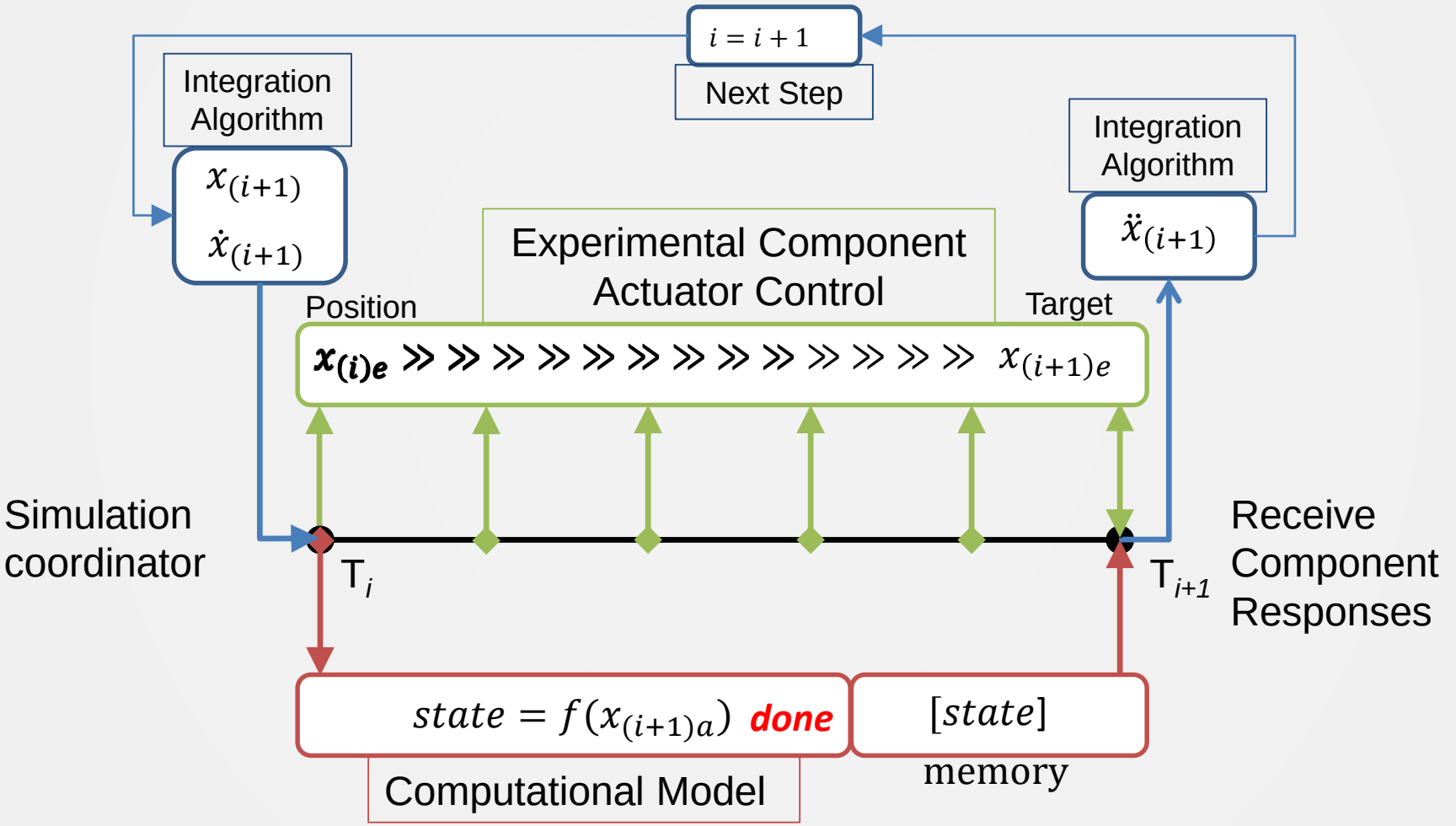


Hybrid Simulation Modules

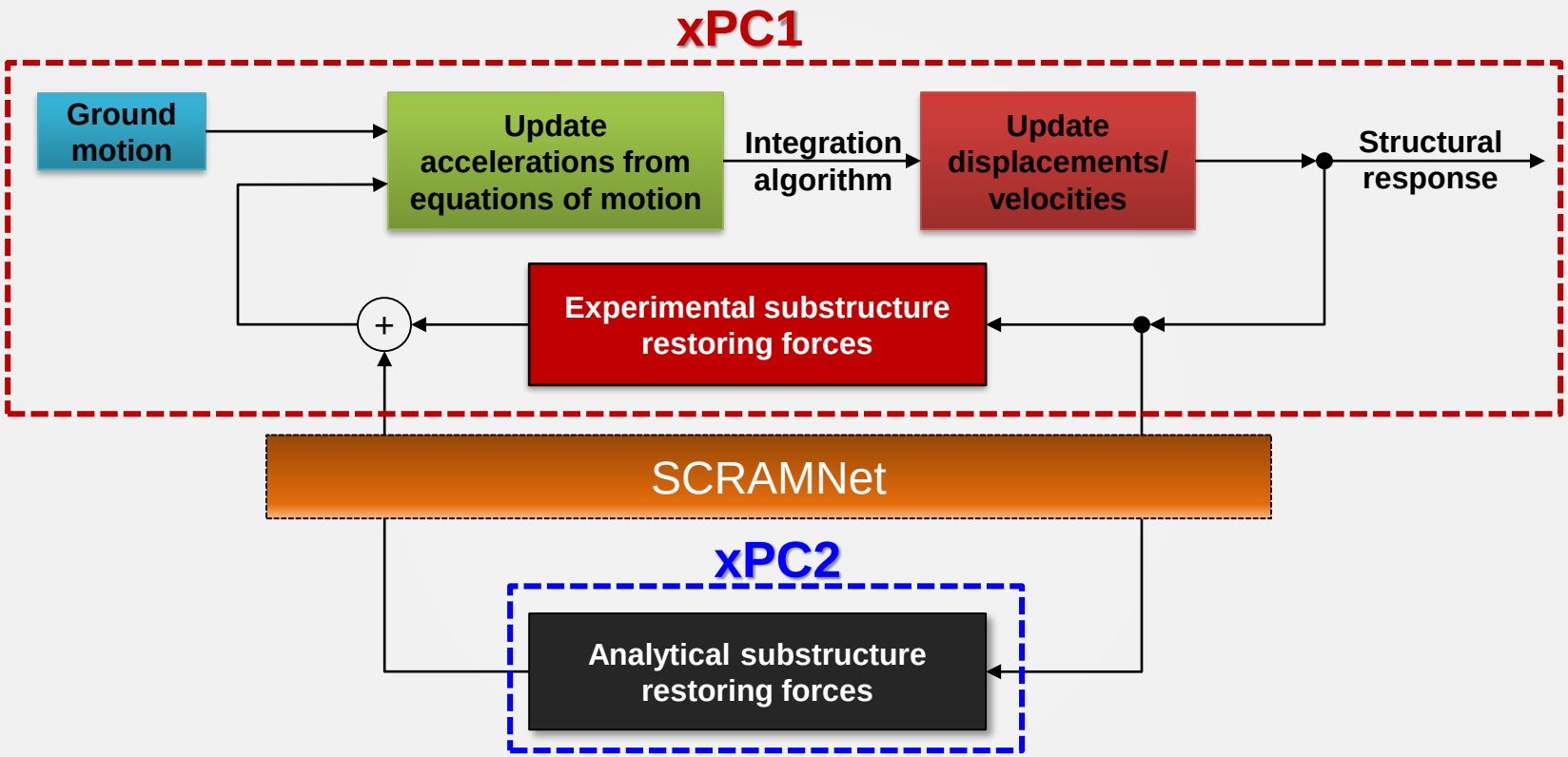
Module	Developer	Status
Simulation Coordinator	Marullo and Chen(1)	Open Source
CR Integration Algorithm	Chen and Ricles(2)	Open Source
Actuator Control: Inverse Compensation	Chen and Ricles(2)	Open Source
Actuator Control: Adaptive Inverse Compensation	Chen and Ricles(1)	Open Source
Actuator Control: Adaptive Time Series Compensation	Chae, Ricles, and Kazemibidokhti(1)	Open Source
Actuator Control: Kinematic Error Compensation	Mercan and Ricles(1)	Open Source
Computational Modeling/Sim Coordinator: HybridFEM	Karavasilis, Seo, and Ricles(2)	Available on xPC for all users. Open Source

(1) developed by NEES@Lehigh
(2) developed by users

RTHS: Model Flow

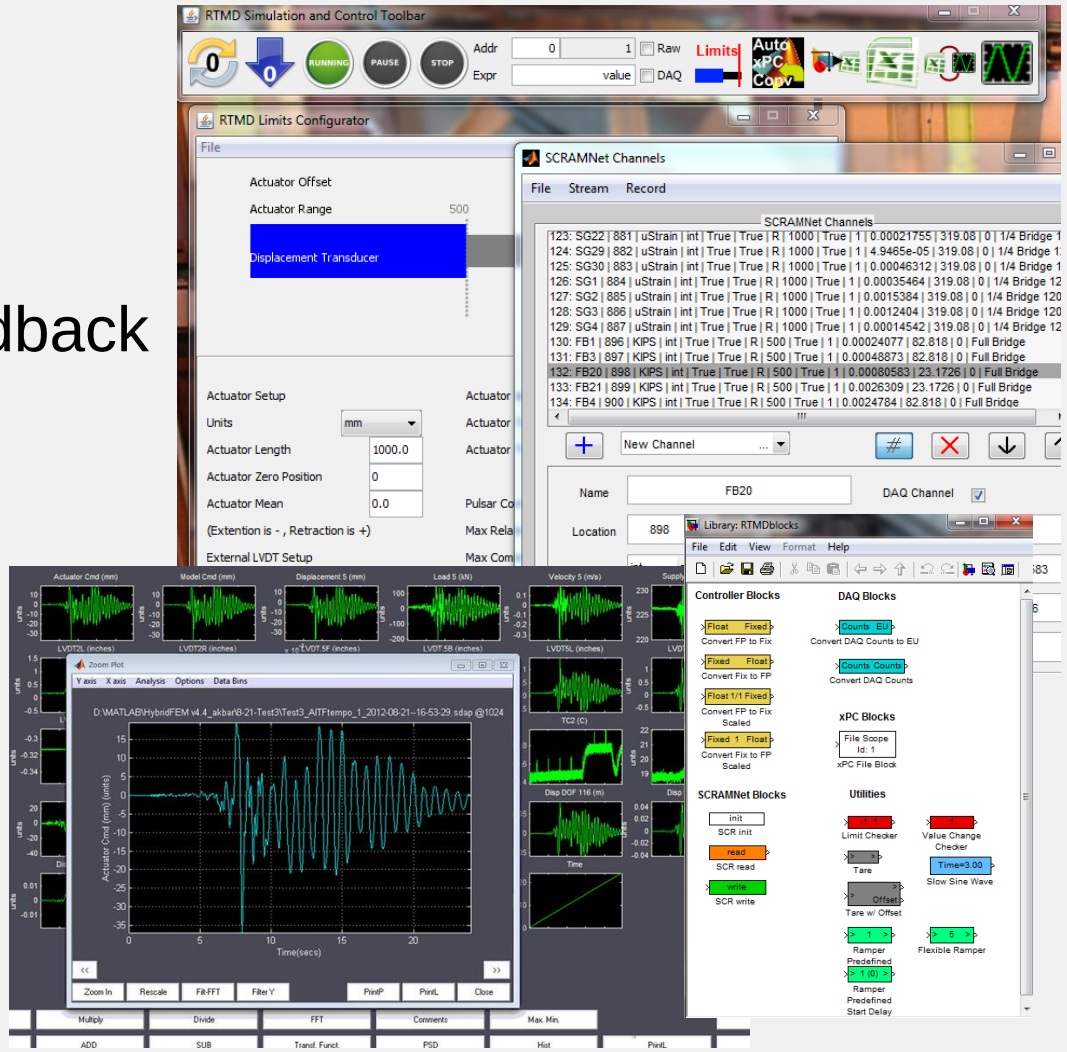


RTHS: xPC Grid



Site Developed Tools

- User Tools
  - XML configurations
    - Control and Feedback
    - Data Conversion
    - Telepresence
  - Safety Limits
  - Simulink Libraries
  - Data Analysis

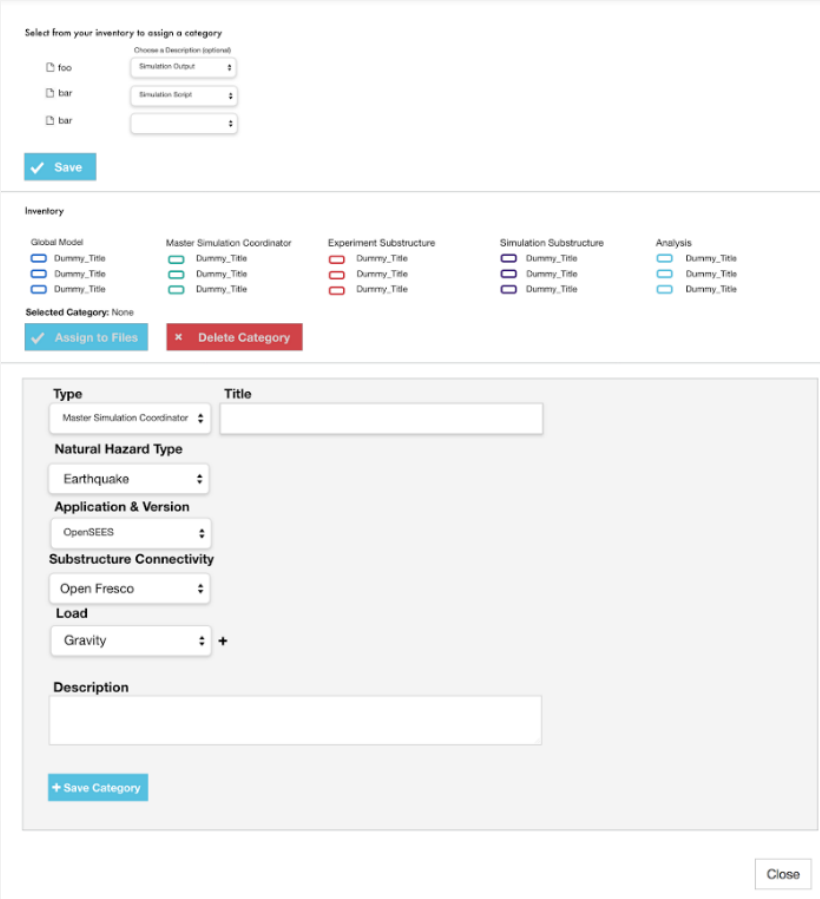


IT Experiment Support
Start to Finish

1. Researchers and NHERI Lehigh team work together on training, development of experimental protocols, instrumentation, control and safety plans
2. Create project storage and collaboration space on DesignSafe-CI Data Depot
3. Design control configuration through numerical and hydraulics off simulations for validation
4. Configure data acquisition system for sensors
5. Configure video acquisition system for cameras
6. Configure data stream for local and remote data viewing
7. Initiate safety protocols and run experiment
8. Data is locally archived and queued up for offsite sync
9. 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

Lehigh Hybrid Data Model

- Improve existing schemas
- Focuses on model components and assembly
- Hybrid simulation metadata
- Currently integrating into NHERI Data Depot



Lee. C.H., Chin, C.H., Marullo, T., Bryan, P., Sause, R., and J. Ricles, "Data Model for Large-Scale Structural Experiments," Journal of Earthquake Engineering, 12:1, 115 – 135, 2007

Lee, C.-H., Chin, C.H., Marullo, T., Bryan, P., Sause, R., and Ricles, J. M., "Development of NEES Data Model for Large-Scale Structural Experiments," ATLSS Report No. 06-16, Center for Advanced Technology for Large Structural Systems, Lehigh University, Bethlehem, PA, December 2006.

Cybersecurity- LTS

- Lehigh University Library & Technology Services is responsible for umbrella cybersecurity policy and management
  - University border firewall and intrusion protection
  - System and network monitoring
  - Incident response plan
  - Data management and backup plan
  - Email Encryption and spam protection
  - Annual NSF Cybersecurity summit

Cybersecurity – Framework

- SANS (SysAdmin, Audit, Network and Security) - 20 Critical Controls
- Continuous Risk and Vulnerability Assessment and Security Strategies
  - Enterprise Systems
  - Email
  - Library
  - All Central Storage
  - VM Cluster
  - Network Infrastructure Services

Cybersecurity – Risk Reduction

- Annual Disaster Recovery Exercises
- Beazley – (Cyber-insurance)
- NESSUS – (Vulnerability Assessment and Scanning)
- Identity Finder – (Sensitive Data Leakage Prevention - DLP)
- Data Reduction Efforts – Remove, Redact, Restrict
- Crashplan – (Data Backup)
- Bitlocker – (Full Disk Data Encryption)
- Virtru and GPG – (Encrypted Email Solutions)
- Distributed Denial of Service (DDoS) Protection through Level3 Networks
- Cisco firewall collective intelligence for Intrusion Detection and anti-malware

Cybersecurity – Endpoint

- Border Anti-malware Subscription – (Cisco firewall Anti-malware)
- Microsoft System Protection and Malwarebytes – (Antivirus on the Endpoint hosts)
- Secunia CSI (Corporate Security Inspector) – (Endpoint Applications Patching and Software Inventory)
- VMWare Horizons – (Virtual Site Access Technologies to Enterprise Systems)
- Google Vault and Logstash/Kibana – Discovery, Monitoring and Incident Response Dashboards

Cybersecurity – NHERI Lehigh EF

- NHERI IT Manager maintains a local cyber security policy and procedure
  - Weekly updates of operating systems to maintain integrity
  - Password protected systems under the LU domain
  - Restricted remote access to NHERI systems and telepresence
  - Secured system racks, offices and building doors
  - LAN firewalls and intrusion protection

Software Lifecycle Management

- **Mission:** To provide software solutions to users
  - Vendor solutions
    - Mathworks – Simulation – LU License
    - Servotest – Hydraulic Control – Annual SMC
    - Pacific Instruments – DAQ – Annual SMC
    - LabVIEW HIL Suite – NI – LU License + EF License
  - Community Software
    - OpenSEES, OpenFresco – Simulation
    - Data Turbine – Data Telepresence
  - In-House Development
    - HybridFEM – Simulation – OpenSource

- Lehigh University offers a wide range of propriety software and alternative open source and community supported options

Interaction with DesignSafe-CI

- Lehigh was first EF to design a DesignSafe-CI EF Website
- Contribute a Large-Scale and Hybrid Data Model schema
- Test and recommend DesignSafe-CI website functionality
- Perform beta testing of data management software

Website

http://lehigh.designsafe-ci.org

LEHIGH UNIVERSITY
EXPERIMENTAL FACILITY

DESIGNSAFE-CI
A NATURAL HAZARDS ENGINEERING COMMUNITY

Facility Overview | Equipment Portfolio | Protocols | Projects | Resources | Workshops | Contact

FACILITY OVERVIEW

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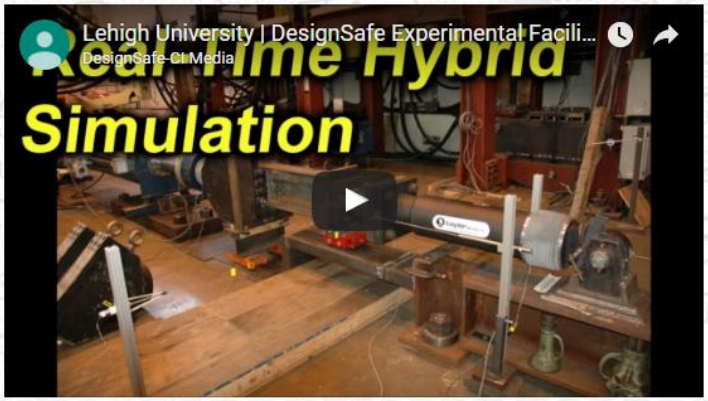
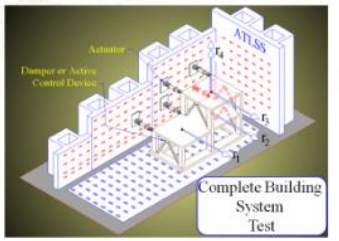
To help meet the grand challenge of community resilience to natural hazards, the Natural Hazards Engineering Research Infrastructure (NHERI) Lehigh Experimental Facility (EF) was funded by the National Science Foundation (NSF) to be a world-class, open-access facility that enables researchers to address 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.
4. Geographically distributed real-time hybrid earthquake simulation which combines DHS and RTHS.
5. Dynamic testing (DT) which loads large-scale physical models at real-time scales through predefined load histories.
6. Quasi-static testing (QS) which loads large-scale physical models at slow rates through predefined load histories.





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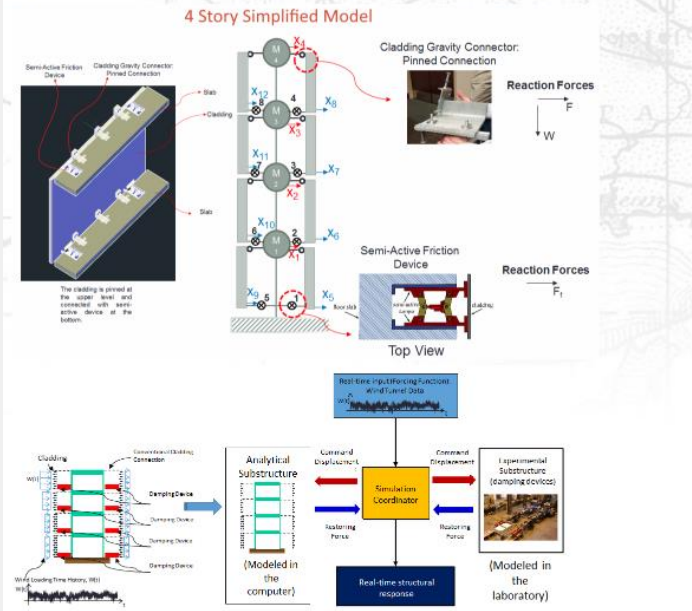
PROJECTS

Collaborative Research: Semi-Active Controlled Cladding Panels for Multi-Hazard Resilient Buildings – Passive Damper Device Study

CMMI 1463497 – PI James Rioles, Lehigh University; co-PI Spencer Quiel, Lehigh University

Building facades typically consist of cladding that is placed on the outside perimeter of the structure. Traditionally, cladding serves purposes of providing architectural envelope and protection to the occupants from the outside elements. The goal of this research project is to rethink cladding systems as multi-functional structural units. Not only would the cladding serve its traditional purposes, but it would also be engaged as an engineered system to protect the structure against multiple hazards, including seismic, wind, and blast loads. Cladding serves both as the point of application of externally applied lateral loads such as wind and blast as well as a contributor of added inertia to seismic or wind-induced vibrations. This project will explore the use of semi-active controlled connections between cladding and the structural framing of a building - these connections will be capable of providing variable damping to mitigate the effects of extreme loading. The results of the project will engage the cladding on a building to enhance a structure's resilience to multiple hazards. The professions of architecture and structural engineering will need to collaborate in design of cladding in the future.

The focus of this project is to develop computational simulation of a prototype semi-active damping device, installed between the cladding and structural frame, to the varying loading frequencies and intensities from multiple hazards. The objective of the system is twofold: (1) to engage the cladding as a mass damper to mitigate interstory drift due to lateral load vibrations; and (2) to utilize the device as an energy dissipator under lateral loads. An innovative semi-active device with decentralized control laws will be developed to satisfy the varying energy dissipation and control objectives associated with each hazard. The research team will perform advanced nonlinear numerical simulations of realistic buildings with semi-active damping devices to assess the various parameters that influence the control laws and performance of the devices. The simulations will be validated through large-scale experiments in the laboratory. The experiments will include real-time hybrid simulations for wind and seismic loading that account for the complete building system and its interactions with the semi-active damping devices and cladding. Airblast shock tube tests will be conducted to simulate blast loading. Performance-based design procedures will be established to integrate the design of semi-active cladding within a holistic structural design approach.



Collaborative Research: Semi-Active Controlled Cladding Panels for Multi-Hazard Resilient Buildings

CMMI 1463262 – PI Simon Laflamme, Iowa State University

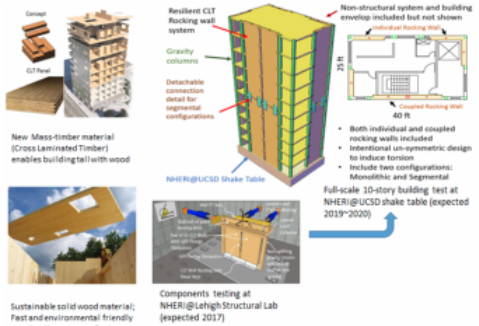
Building facades typically consist of cladding that is placed on the outside perimeter of the structure. Traditionally, cladding serves purposes of providing architectural

Collaborative Research: A Resilience-based Seismic Design Methodology for Tall Wood Buildings – Structural Component Studies

CMMI 1635227 – PI James Rioles, Lehigh University; co-PI Richard Sause, Lehigh University
CMMI 1638164 – PI Shiling Pei, Colorado School of Mines
CMMI 1635168 – PI James Dolan, Washington State University

As the U.S. population continues to grow in urban communities, the demand for tall residential and mixed-use buildings in the range of eight to twenty stories continues to increase. Buildings in this height range are commonly built using concrete or steel. A recent new timber structural innovation, known as cross laminated timber (CLT), was developed in western Europe and is now being implemented around the world as a sustainable and low carbon-footprint alternative to conventional structural materials for tall buildings. However, an accepted and validated design method for tall CLT buildings to resist earthquakes has not yet been developed, and therefore construction of these tall wood buildings in the United States has been limited. This research will break this barrier by investigating a seismic design methodology for resilient tall wood buildings that can be immediately re-occupied following a design level earthquake and quickly repaired (compared to current building systems) after a large earthquake. Using the seismic design methodology developed in this project, the research team will work with practitioners across the engineering and architectural communities to design, build, and validate the performance of a ten-story wood building by conducting full-scale sub-assembly system testing at the National Science Foundation (NSF)-supported Natural Hazards Engineering Research Infrastructure (NHERI) experimental facility at Lehigh University, followed by full-scale tests at the NSF-supported NHERI outdoor shake table at the University of California at San Diego. This research will enable a new sustainable construction practice that is also cost-competitive, thereby increasing demands for engineered wood production, providing added value for forest resources, and enhancing job growth in the construction and forestry sectors. As part of the research, the experimental programs will serve to provide outreach to the public and stakeholders on issues related to seismic hazard mitigation, modern timber engineering, and resilient building concepts.

The goal of this research is to investigate and validate a seismic design methodology for tall wood buildings that incorporates high performance structural and non-structural systems. The methodology will quantitatively account for building resilience. This will be accomplished through a series of research tasks planned over a four-year period. These tasks will include mechanistic modeling of tall wood buildings with several variants of post-tensioned rocking CLT wall systems, fragility modeling of structural and non-structural building components that affect resilience, full-scale bi-directional testing of building sub-assembly systems, development of a resilience-based seismic design methodology, and finally a series of full-scale shake table tests of a ten-story CLT building specimen to validate the investigated design. The structural systems investigated will include post-tensioned CLT rocking walls in both monolithic and segmental rocking configurations. Implementing segmental rocking walls in a full building system will be a transformative concept that has yet to be realized physically. The rocking wall systems will be investigated under the context of holistic building behavior, including gravity systems and non-structural components. The research team will further push the boundary of existing performance-based seismic design by developing a design procedure that explicitly considers the time needed for the building to resume functionality after an earthquake. With the large-scale testing capacity provided by the NHERI experimental facilities, the design methodology will be experimentally validated, which will at the same time generate a landmark data set for tall wood buildings under dynamic loading that will be available to the broader research and practitioner community through the NHERI DesignSafe-ci.org Data Depot. The project will facilitate implementation of this new structural archetype by interfacing closely with practitioners in the Pacific Northwest interested in tall CLT buildings as a cost-competitive design option. Graduate and undergraduate students, including community college students, will actively participate in this research and gain valuable knowledge and experience, which will prepare them to become leaders in sustainable building practices using modern engineered wood materials.



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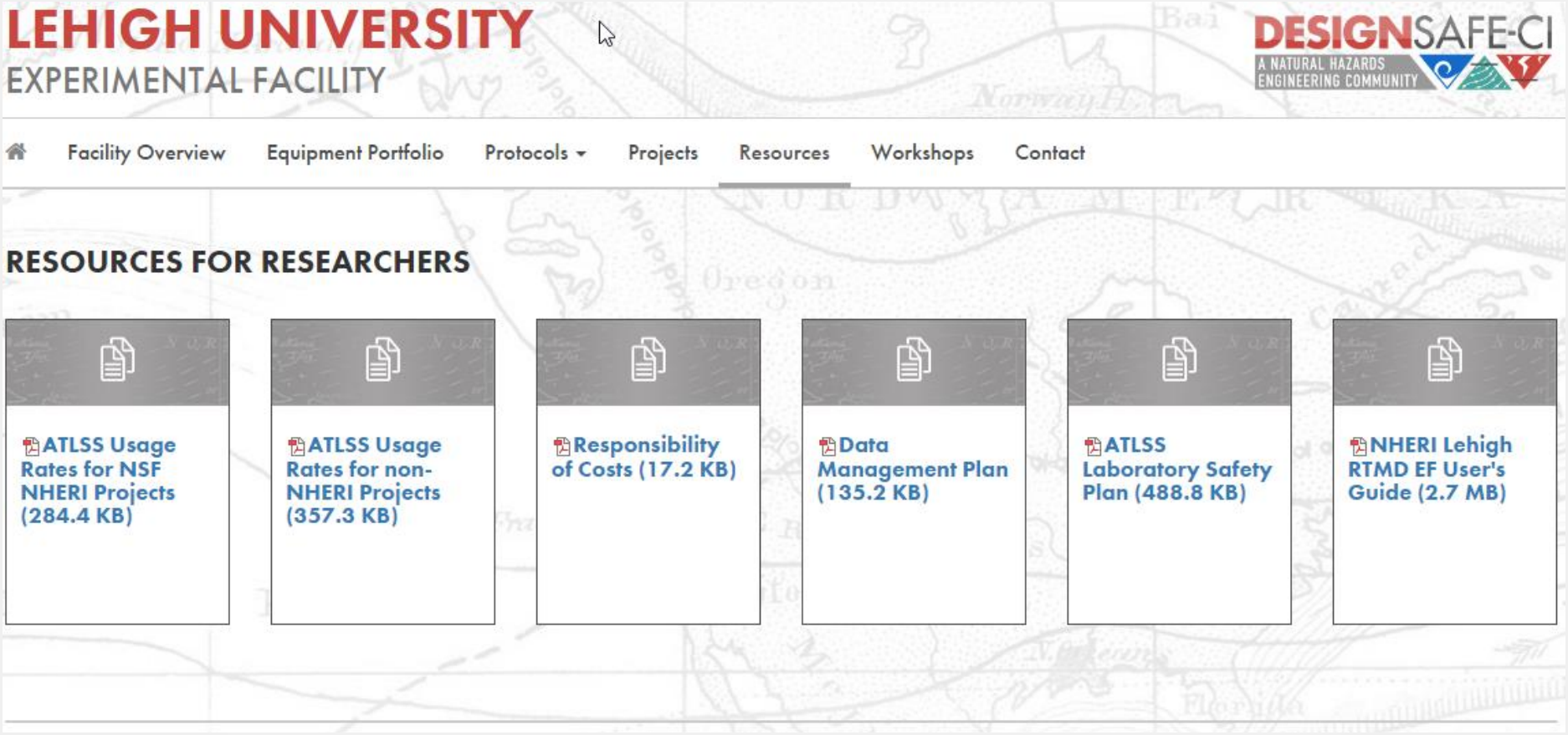
Website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RESOURCES FOR RESEARCHERS
ATLSS Usage Rates for NSF NHERI Projects (284.4 KB)
ATLSS Usage Rates for non-NHERI Projects (357.3 KB)
Responsibility of Costs (17.2 KB)
Data Management Plan (135.2 KB)
ATLSS Laboratory Safety Plan (488.8 KB)
NHERI Lehigh RTMD EF User's Guide (2.7 MB)

Thank you!