National Science Foundation

University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

NHERI Lehigh Project Portfolio

James Ricles, NHERI Lehigh PI
Lehigh University

Joint Researcher Workshop
UC San Diego, Lehigh & SimCenter

December 16-17, 2019
University of California, San Diego

LEHIGH NHERI
Real-Time Multi-Directional Testing Facility

University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

SIMCENTER
COMPUTATIONAL MODELING AND SIMULATION CENTER

NHERI Lehigh EF Capabilities for Natural Hazards Engineering Research

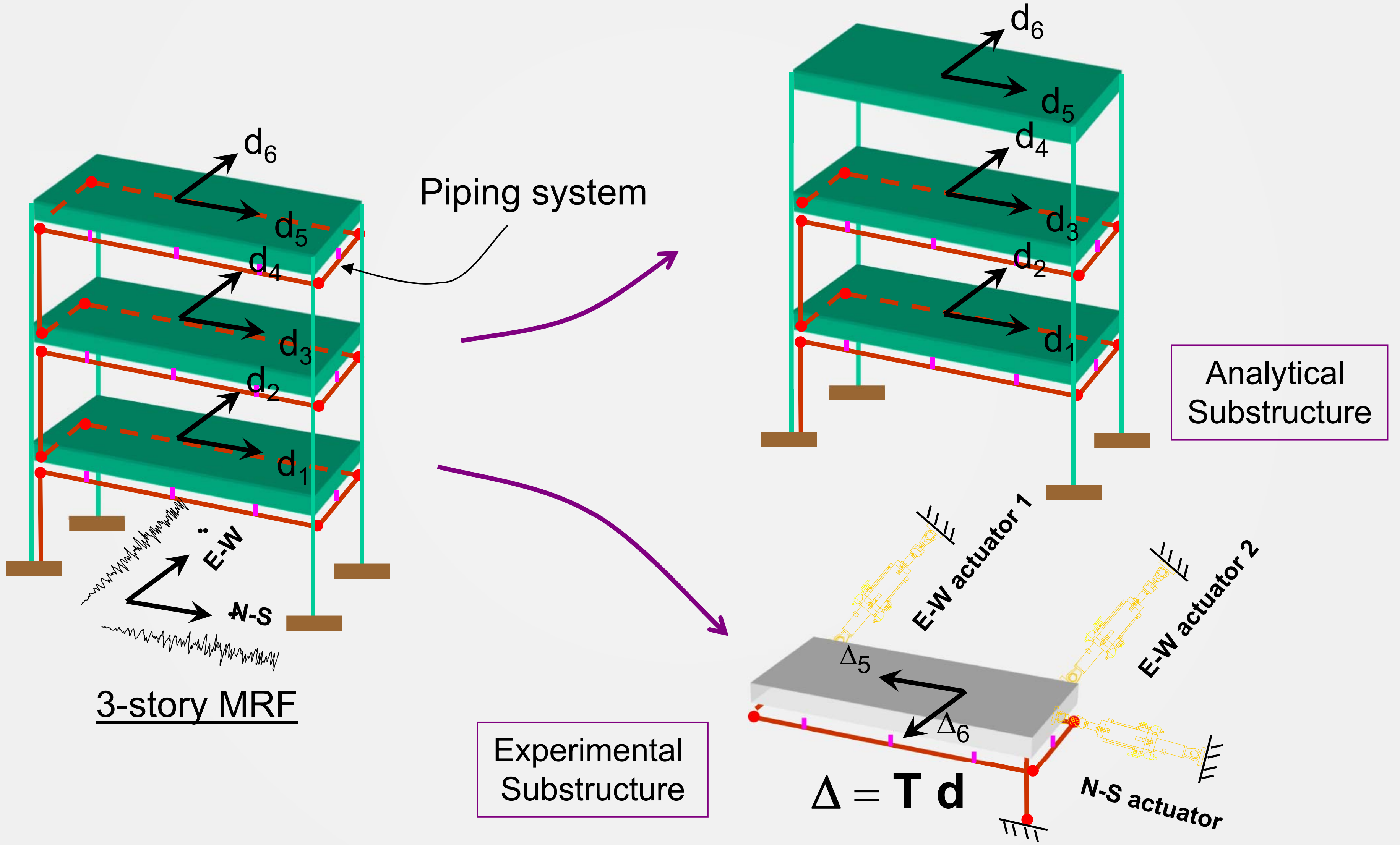
- Large-Scale Hybrid Simulation
- Large-Scale Real-Time Hybrid Simulation
- Large-Scale Real-Time Hybrid Simulation with Multiple Experimental Substructures
- Geographically Distributed Hybrid Simulation
- Geographically Distributed Real-time Hybrid Simulation
- Predefined Load or Displacement (Quasi-Static or Dynamic) Testing
- Dynamic Testing
- Real-time Hybrid Simulation with On-Line Model Updating, Machine-learning based computational modeling

Example Past Projects

Experiment	Capability
3-story building with piping system	Multi-directional real-time hybrid simulation
Self-centering moment-resisting frame (SC-MRF)	Large-scale hybrid simulation
Self-centering concentrically-braced frame (SC-CBF)	Large-scale hybrid simulation
Real-time testing of structures with dampers	Large-scale real-time hybrid simulation with multiple experimental substructures
Seismic hazard mitigation using passive damper systems	Predefined displacement dynamic testing (for characterization) Large-scale real-time hybrid simulations
Tsunami-driven debris	Dynamic testing (impact loading)
Post-tensioned coupled shear wall system	Complex large-scale multi-directional predefined force and displacement quasi-static testing
Inertial force-limiting floor anchorage systems for buildings	Predefined displacement dynamic testing (for characterization)
Cross-Laminated Rocking Wall-Floor Diaphragm Systems	Multi-directional quasi-static and hybrid simulation

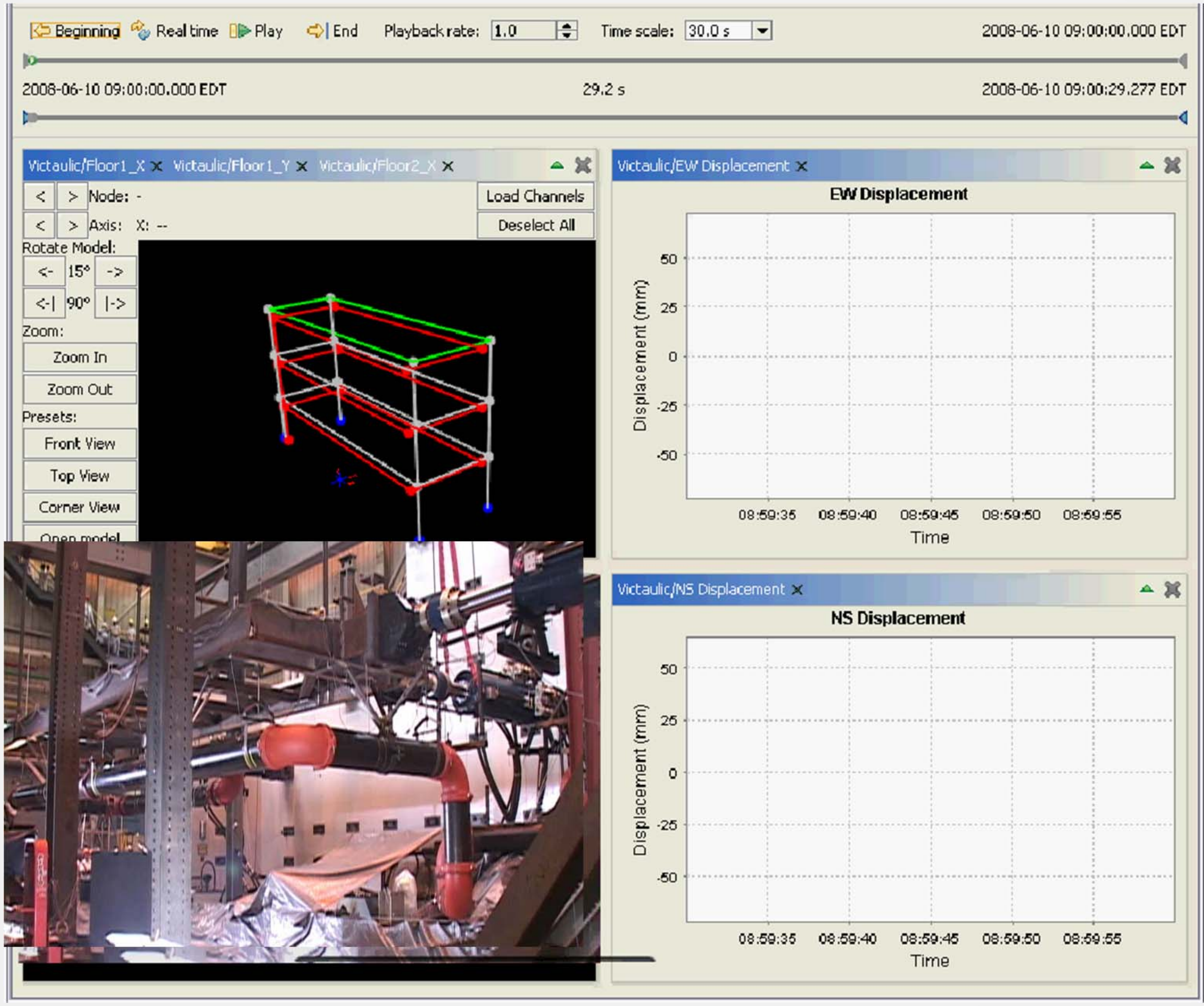
Multi-Directional Large-Scale Real-Time Hybrid Simulation of 3-story Building with Piping System

Multi-Directional Large-Scale Real-Time Hybrid Simulation



Multi-Directional Large-Scale Real-Time Hybrid Simulation of 3-story Building with Piping System

RTHS: 1994 Northridge EQ, Canogo Park (MCE)

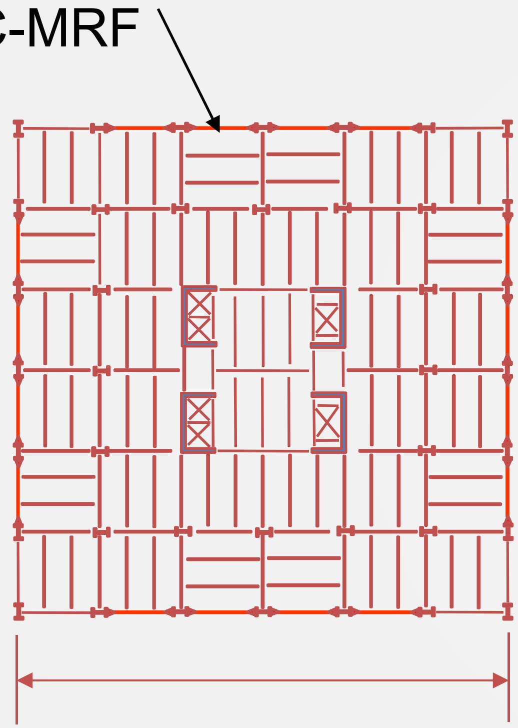


NEES

Self Centering Steel Moment-Resisting Frame (SC-MRF) Systems
Princeton, Purdue, Lehigh, NCREE

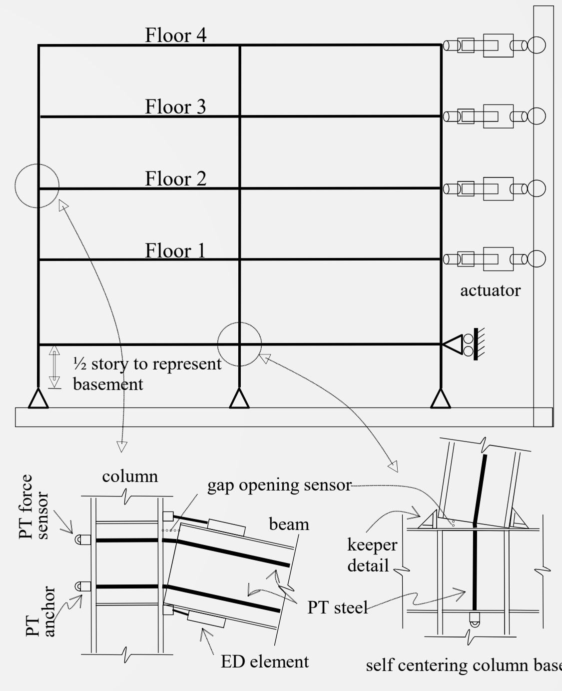
Large-Scale Hybrid Simulation

SC-MRF



6-story : 6 bays @ 30 ft = 180 ft

Plan of Prototype Building

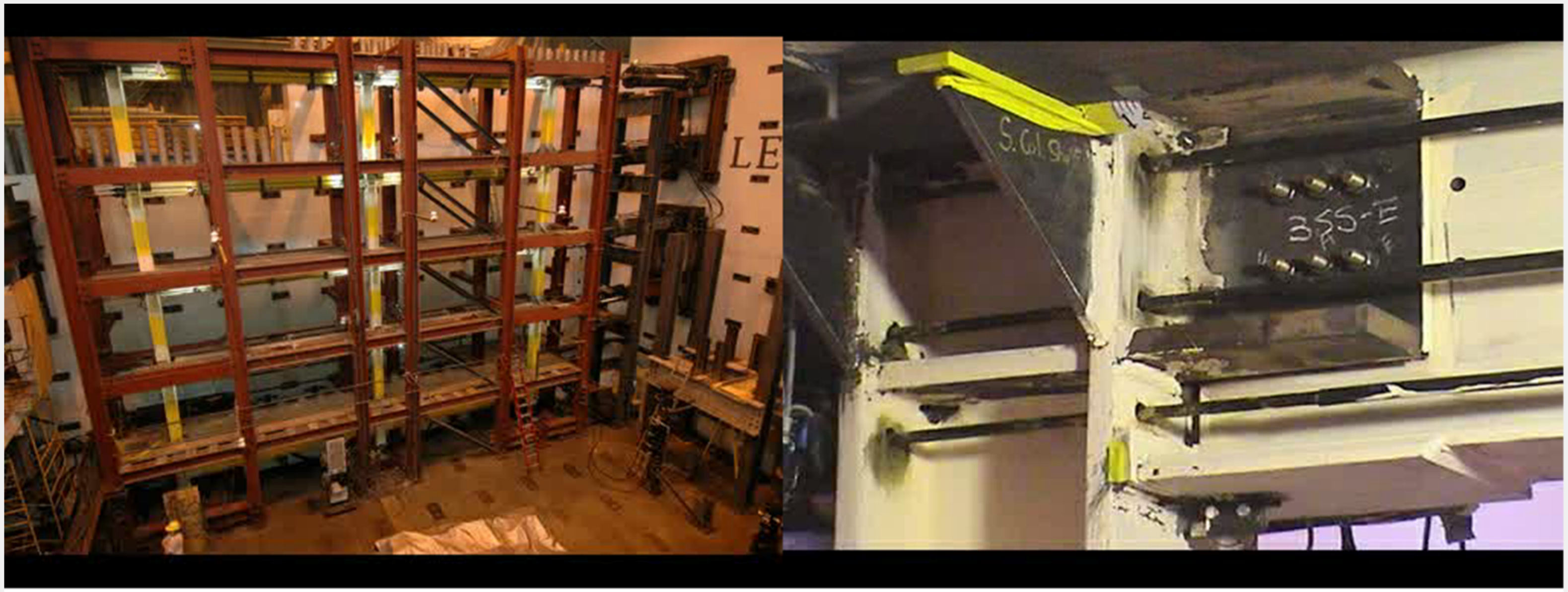


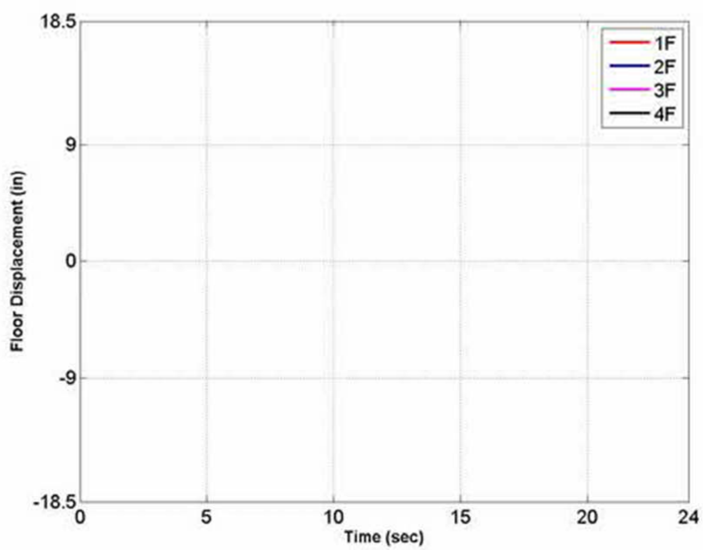
SC-MRF Experimental Substructure
(Floor Diaphragm, Gravity System, Mass, Inherent Damping in Analytical Substructure)

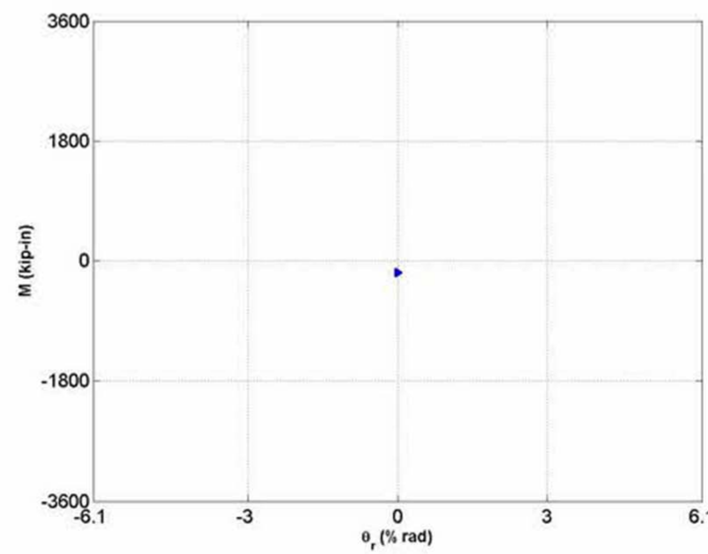
NEES

Self Centering Steel Moment-Resisting Frame (SC-MRF) Systems
Princeton, Purdue, Lehigh, NCREE

Large-Scale Hybrid Simulation (SC-MRF)



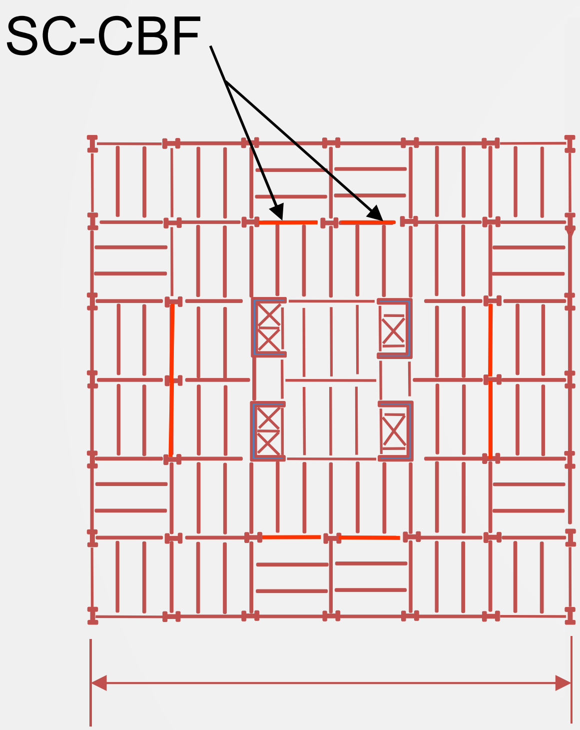




LEHIGH UNIVERSITY. ATLSS RTMD REAL-TIME MULTI-DIRECTIONAL SIMULATION NSF DESIGNSAFE-CI A NATURAL HAZARDS ENGINEERING COMMUNITY

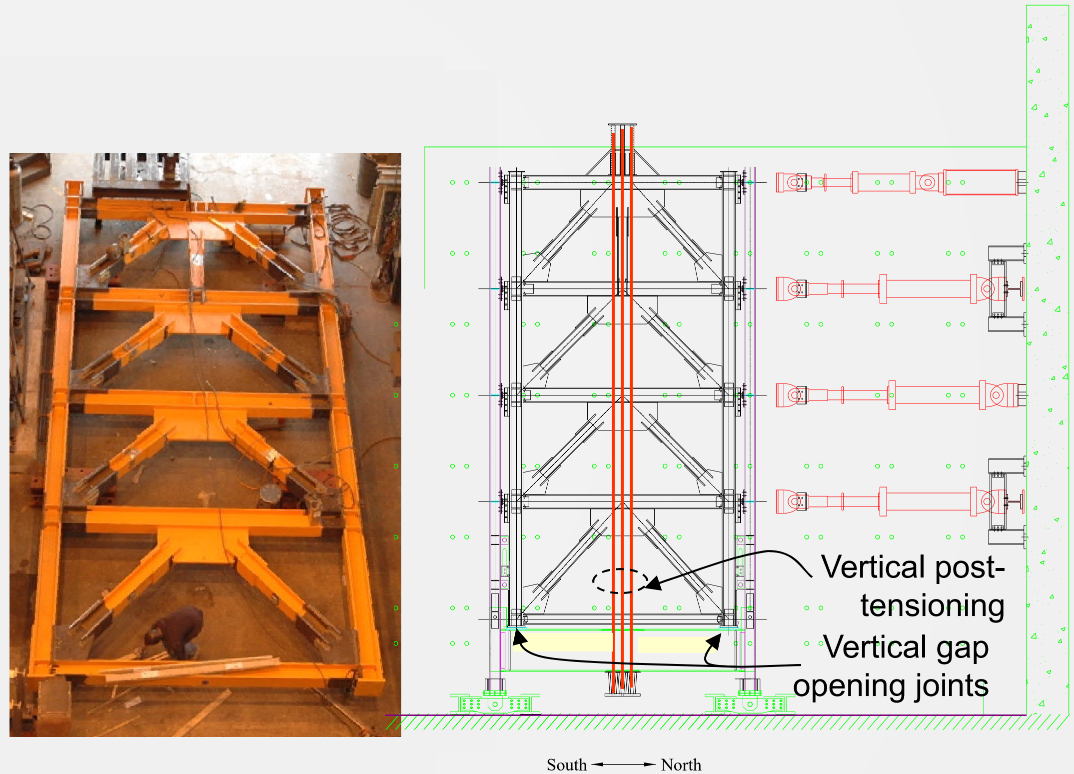
Self Centering Steel Concentrically-Braced Frame (SC-CBF) Systems
Princeton, Purdue, Lehigh, NCREE

Large-Scale Hybrid Simulation



6-story : 6 bays @ 30 ft = 180 ft

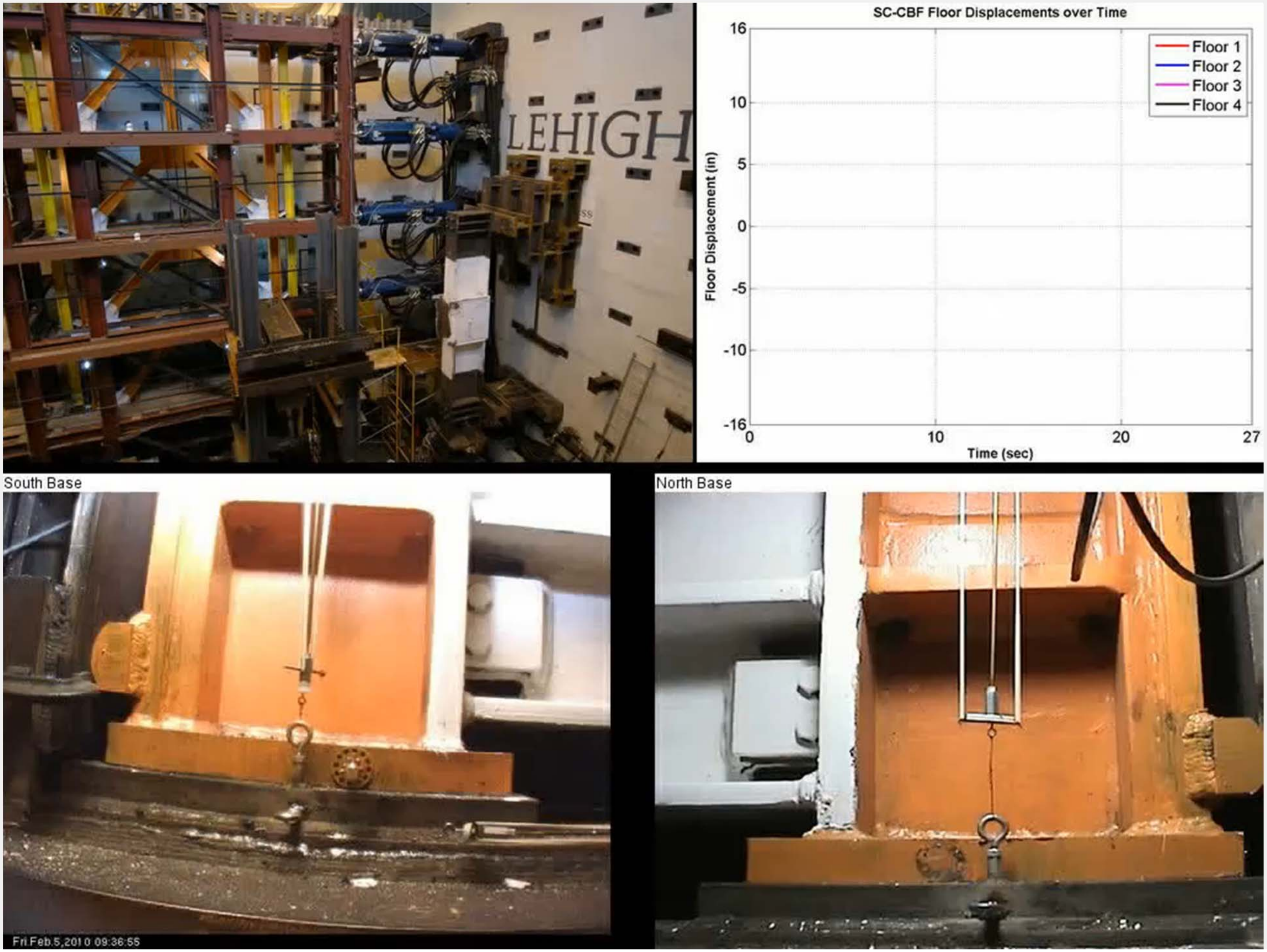
Plan of Prototype Building



SC-CBF Experimental Substructure
(Floor Diaphragm, Gravity System, Mass, Inherent Damping in Analytical Substructure)

NEES

Large-Scale Hybrid Simulation (SC-CBF)

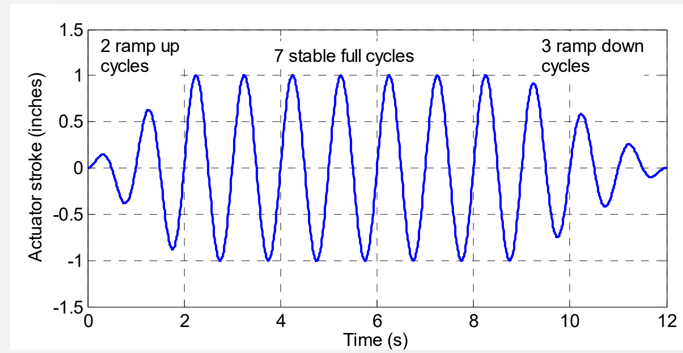


Seismic Hazard Mitigation in New Buildings Using Supplemental Passive (Nonlinear Viscous) Damper Systems

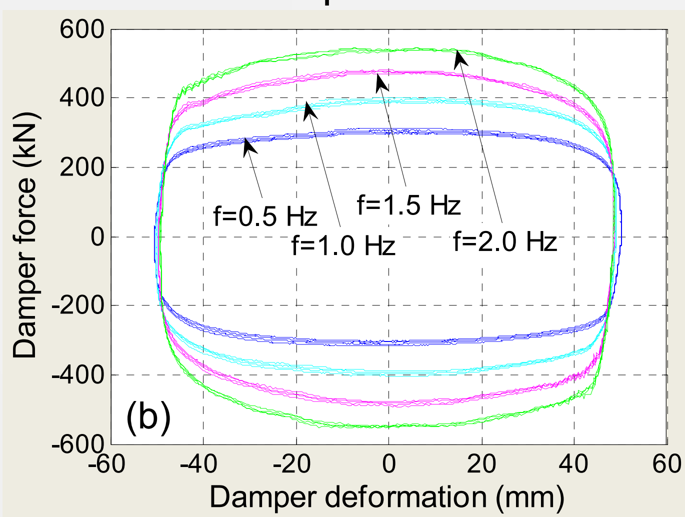
Cal State Pomona, Cal State Northridge, Lehigh

Predefined Displacement Dynamic Testing for Characterization

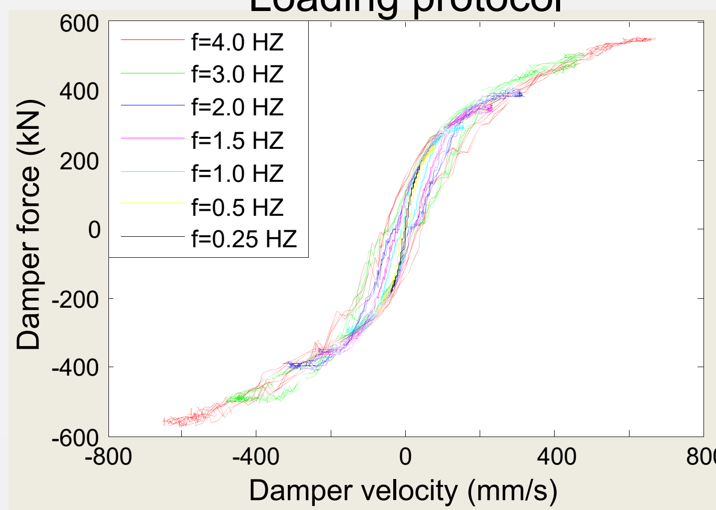
Damper testbed



Loading protocol



Damper force - deformation



Damper force - velocity

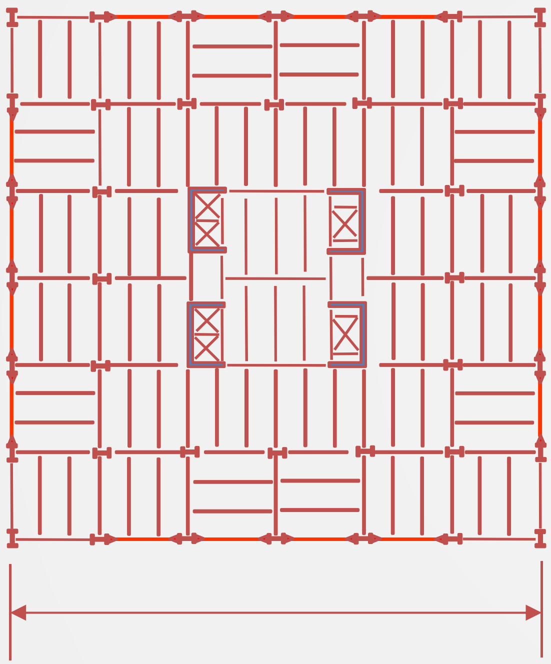
LEHIGH UNIVERSITY ATLSS RTMD REAL-TIME MULTI-DIRECTIONAL SIMULATION NSF DESIGNSAFE-CI A NATURAL HAZARDS ENGINEERING COMMUNITY

Seismic Hazard Mitigation in New Buildings Using Supplemental Passive (Nonlinear Viscous) Damper Systems

Cal State Pomona, Cal State Northridge, Lehigh

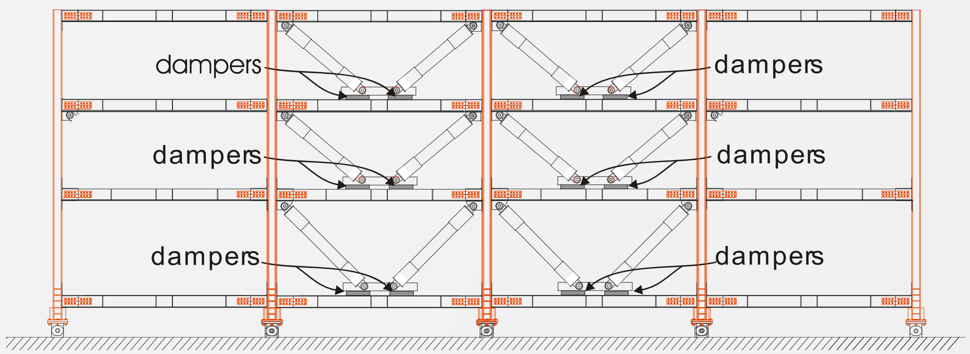
Large-Scale Real-Time Hybrid Simulation

Steel MRF with Passive Dampers



6-story : 6 bays @ 30 ft = 180 ft

Plan of Prototype Building



Elevation of MRF with Passive Dampers

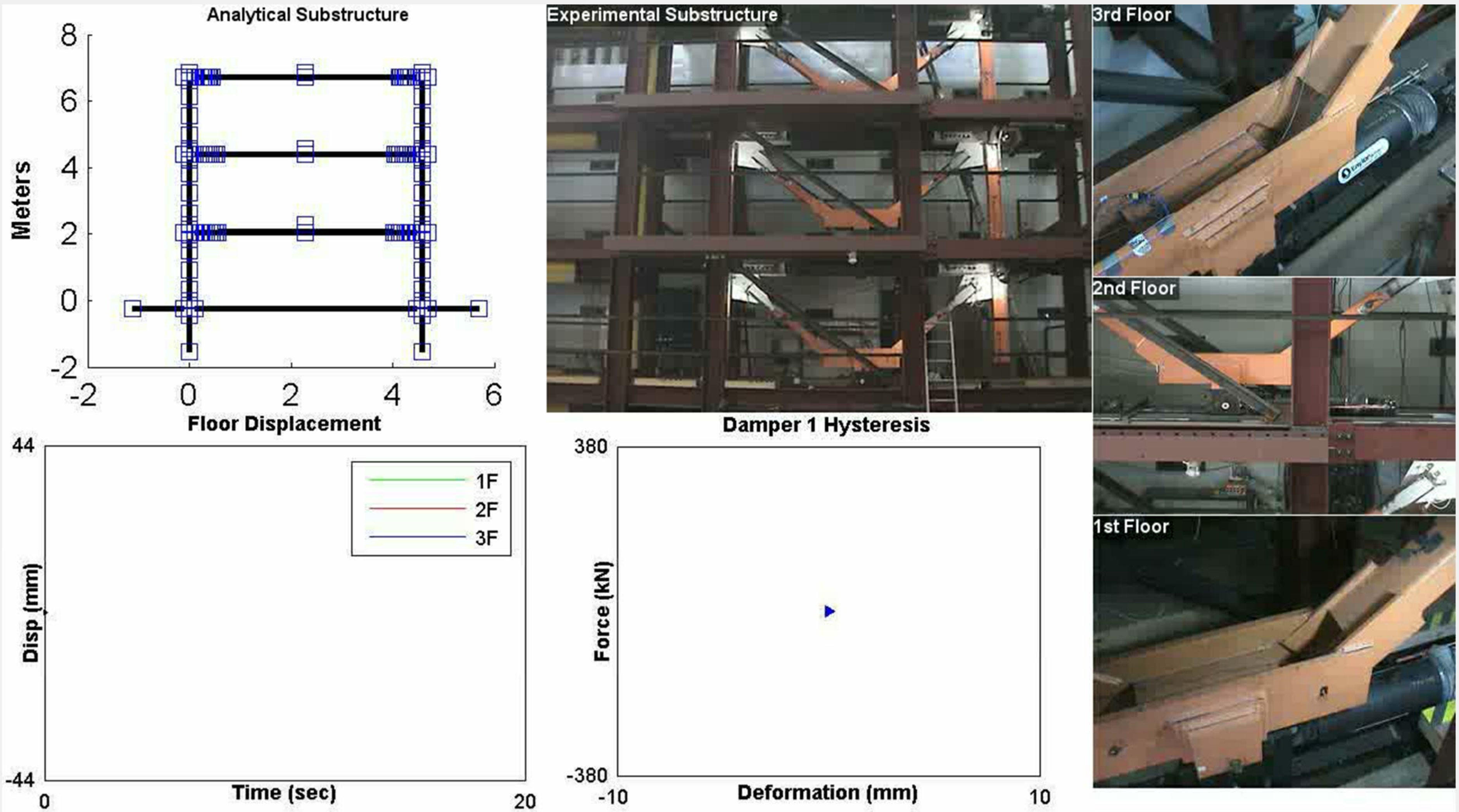
NEES

Seismic Hazard Mitigation in New Buildings Using Supplemental Passive (Nonlinear Viscous) Damper Systems

Cal State Pomona, Cal State Northridge, Lehigh

Large-Scale Real-Time Hybrid Simulation

(MRF, Floor Diaphragm, Gravity System, Mass, Inherent Mass in Analytical Substructure)



Seismic Hazard Mitigation in New Buildings Using Supplemental Passive (Nonlinear Viscous) Damper Systems

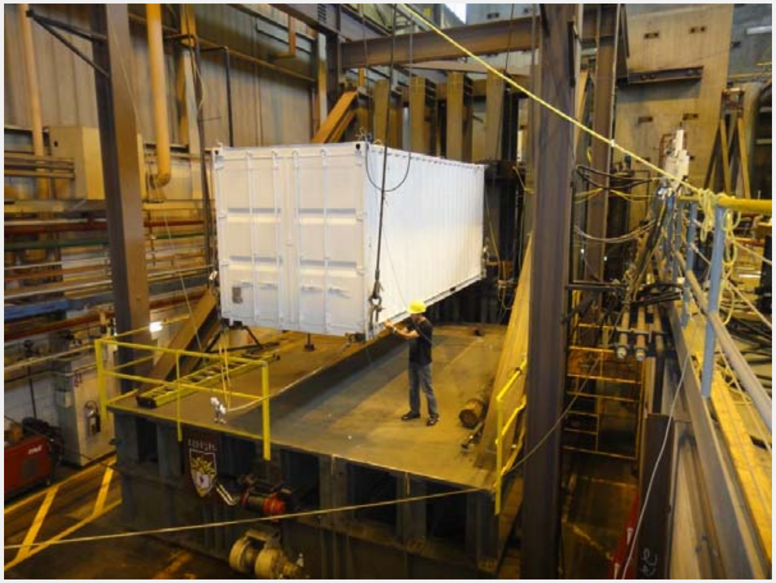
Cal State Pomona, Cal State Northridge, Lehigh

Large-Scale Real-Time Hybrid Simulation
(Floor Diaphragm, Gravity System, Mass, Inherent Mass in Analytical Substructure)

Experimental Substructure: MRF and Braced Frame with Dampers

Impact Forces from Tsunami-Driven Debris
University of Hawaii, Oregon State University, Lehigh

Dynamic Testing (Impact Loading)



Test Setup with Cargo Shipping Container Debris

High Speed Video of Impact of Cargo Shipping Container on Structure

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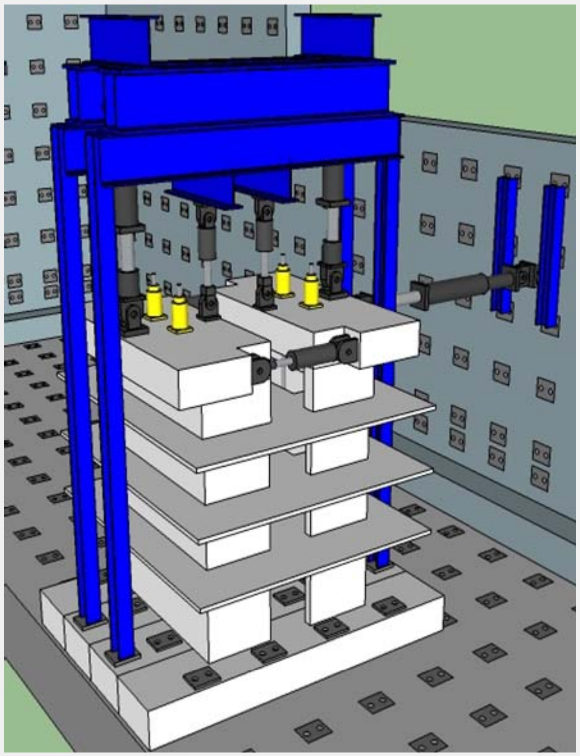
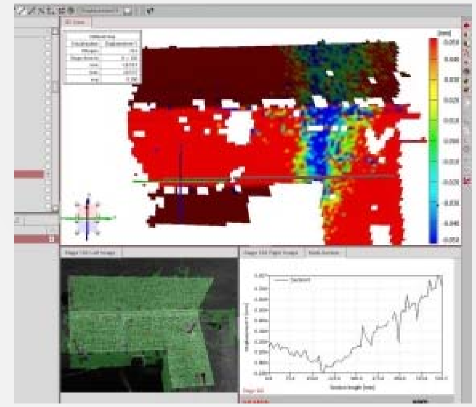
Post-Tensioned Coupled Shear Wall System
Notre Dame, University of Texas at Tyler

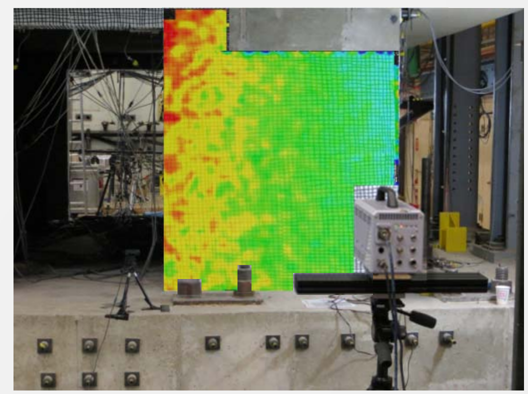
Complex Large-Scale Predefined Multi-Directional Force & Displacement (Quasi-Static) Testing



RC coupled shear wall test specimen with multi-directional loading. Upper 5 stories of 8-story building simulated with vertical force-controlled actuators. 1 displacement-controlled and 10 force-controlled (11 total) used for test.



Joint strains measured by DIC (S. Pakzad)



RC coupled shear wall pier vertical deformation measured by Digital Image Correlation (DIC) (M. McGinnis)

NEES

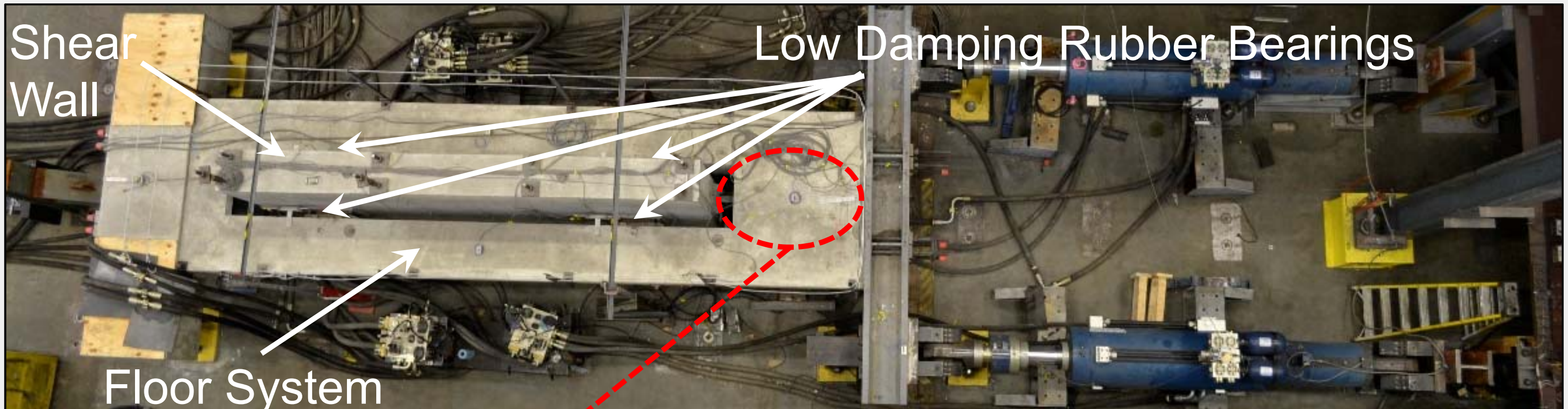
Post-Tensioned Coupled Shear Wall System
Notre Dame, University of Texas at Tyler

Complex Large-Scale Predefined Multi-Directional Force & Displacement (Quasi-Static) Testing

NEES

Inertial Force Limiting Floor Anchorage Systems for Buildings
University of Arizona, UCSD, Lehigh

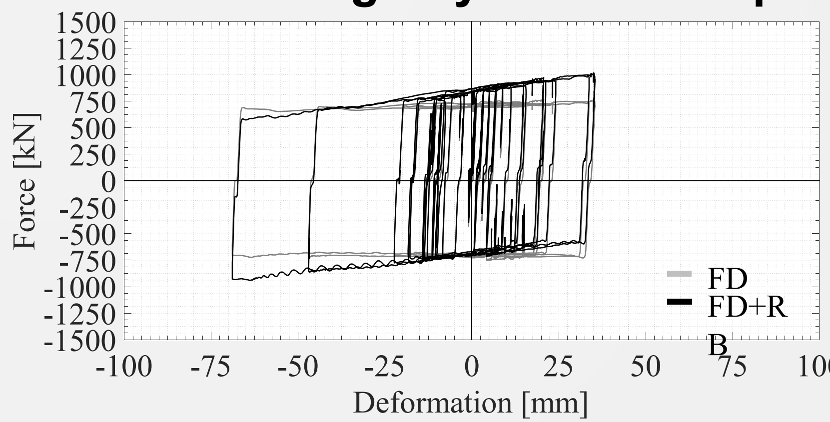
Predefined Displacement Dynamic Testing for Characterization



Friction Device for Floor Anchorage

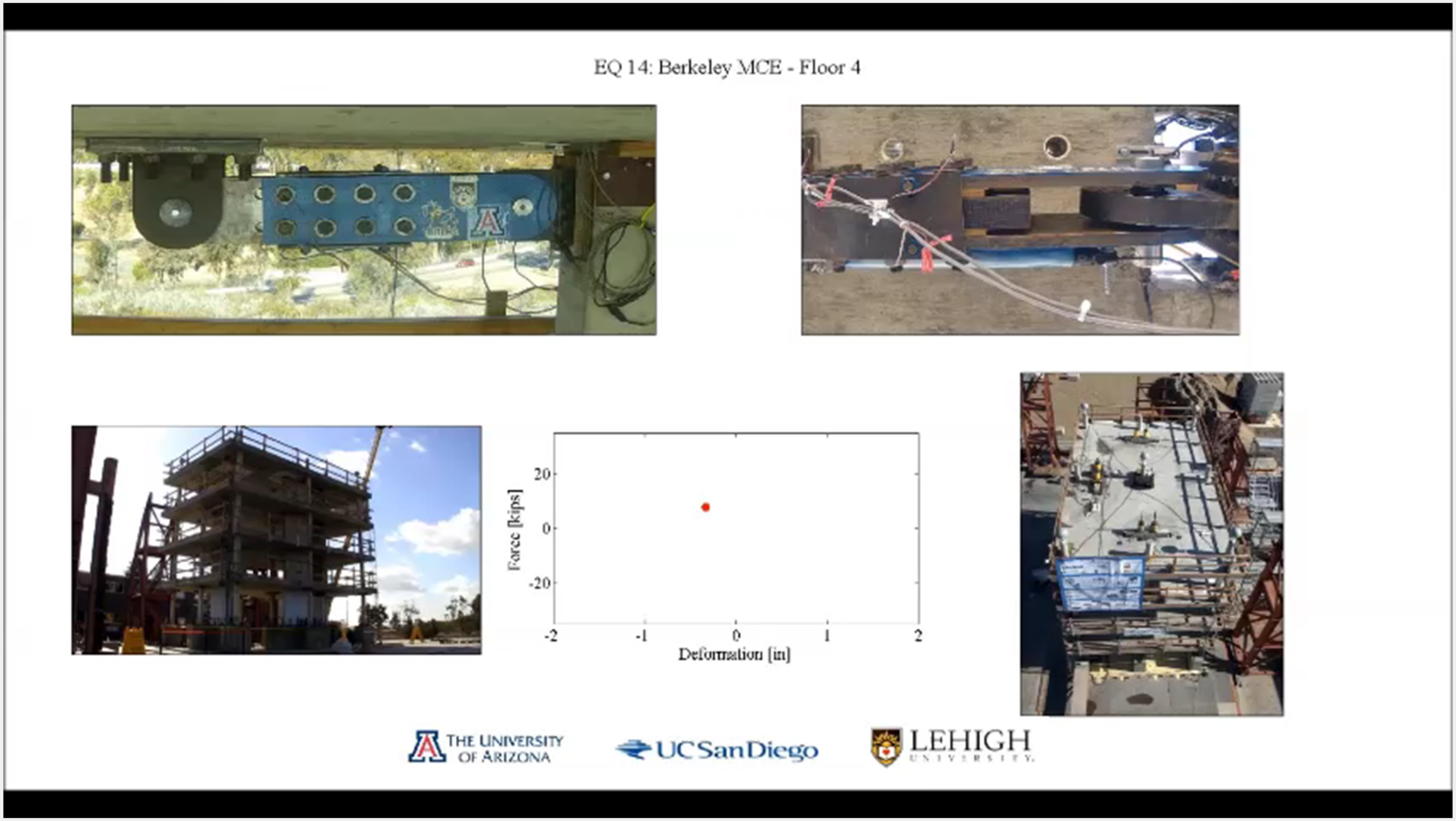
BRB was also Studied

Floor Anchorage Hysteretic Response



Inertial Force Limiting Floor Anchorage Systems Buildings
University of Arizona, UCSD, Lehigh

[Complimentary Shake Table Tests at NHERI UCSD]



Current Projects at NHERI Lehigh EF

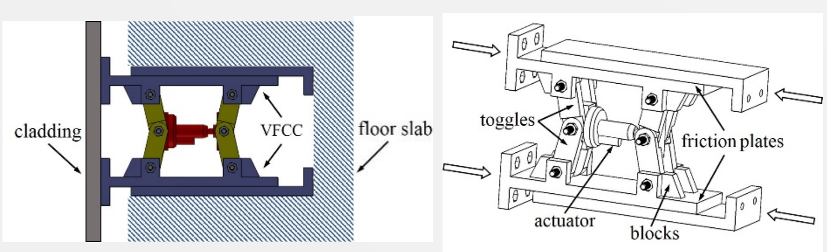
Project	Capability
Semi-Active Controlled Panel Cladding to Improve the Performance of Buildings under Multiple Hazards: Iowa State University (S. Laflamme)	Real-time hybrid simulation
Passive Controlled Panel Cladding to Improve the Performance of Buildings under Multiple Hazards: Lehigh University (J. Ricles, S. Quiel)	Real-time hybrid simulation
Development and Validation of Resilience-Based Seismic Design Methodology for Tall Wood Buildings (*Non-Structural System*): University of Nevada, Reno (Keri Ryan)	Complex predefined multi-directional displacement quasi-static testing
Development and Validation of Resilience-Based Seismic Design Methodology for Tall Wood Buildings (*Structural System*): Lehigh University (J. Ricles, R. Sause)	Complex predefined multi-directional displacement quasi-static testing; multi-directional hybrid simulation
Advancing Knowledge on the Performance of Seismic Collectors in Steel Building Structures: University of Arizona (R. Fleischman (PI) with C.-M. Uang (UCSD), J. Ricles, R. Sause (Lehigh University))	Complex large-scale predefined force and displacement quasi-static testing
Frame-Spine System with Force-Limiting Connections for Low-Damage Seismic-Resilient Buildings: University Illinois Urbana-Champaign (L. Fahnestock (PI), B. Simpson (OSU), R. Sause, J. Ricles (Lehigh University))	Multi-directional quasi-static and hybrid simulation
Multi-Hazard RTHS Studies of Tall Buildings with Response Modification Devices – NHERI Lehigh Capacity Building (NHERI Lehigh Staff)	Multi-directional Real-time hybrid simulation, online real-time model updating, machine-learning computational modeling

Current Projects at NHERI Lehigh EF

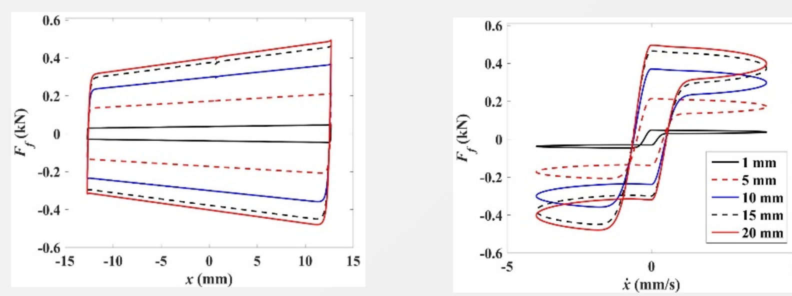
Collaborative Research: Semi-Active Controlled Panel Cladding to Improve the Performance of Buildings under Multiple Hazards: (CMMI 1463252) **Iowa State University (Simon Laflamme)**

Features Using NHERI Lehigh Underlined

- Project Overview
  - Improve performance of buildings for multiple hazards using semi-active controlled variable friction cladding panel connectors
  - Hazards: Earthquake, Wind (NHERI UF), Blast Loading
- Project Scope
  - Design cladding connectors and control laws
  - Construct prototype connector, perform characterization testing
  - Perform large-scale RTHS to validate numerical models and results (450 data sets from RTHS uploaded to DesignSafe to date)



Semi-Active Controlled Variable Friction Cladding Connector



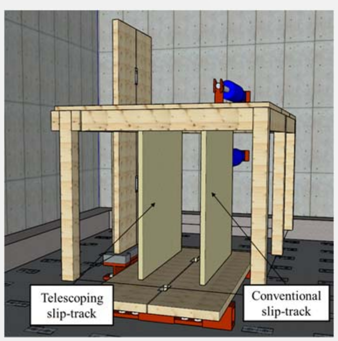
Dynamic Numerical Models

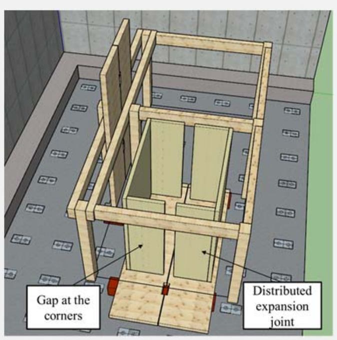
Current Projects at NHERI Lehigh EF

Collaborative Research: Development and Validation of Resilience-Based Seismic Design Methodology for Tall Wood Buildings: (CMMI 1635363)
University of Nevada, Reno (Keri Ryan)

Features Using NHERI Lehigh Underlined

- Project Overview
  - Develop seismic design methodology for tall wood buildings with high-performance structural and non-structural systems
  - Determine partition wall configurations for large lateral drift with minimized partition damage
- Project Scope
  - Conduct large-scale tests of partition wall systems under in-plane & out-of-plane (bi-directional) loading (& associated vertical motion)
  - Consider different partition slip track and other details to minimize damage



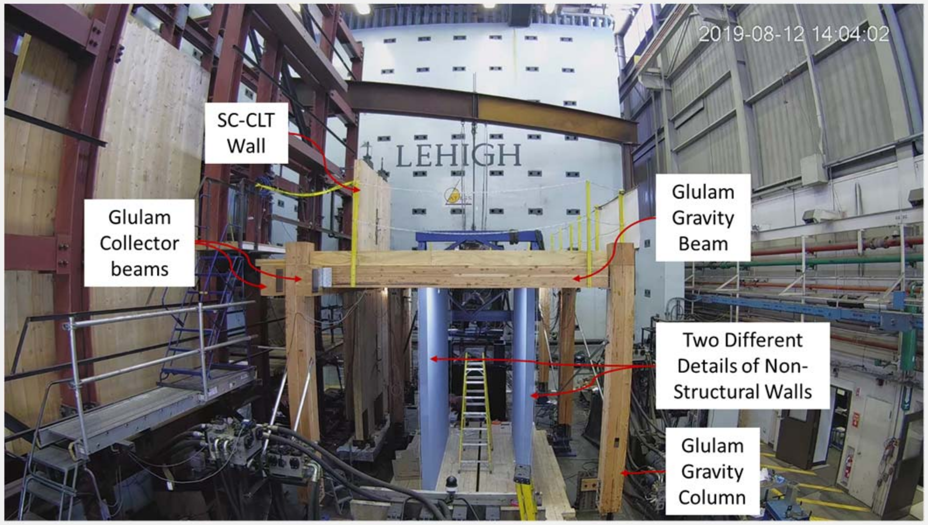


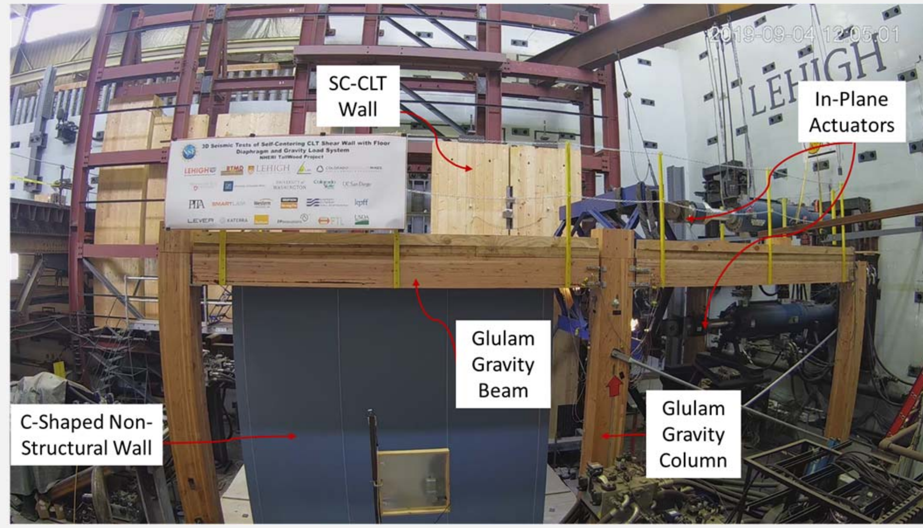
Test setup for partition wall testing

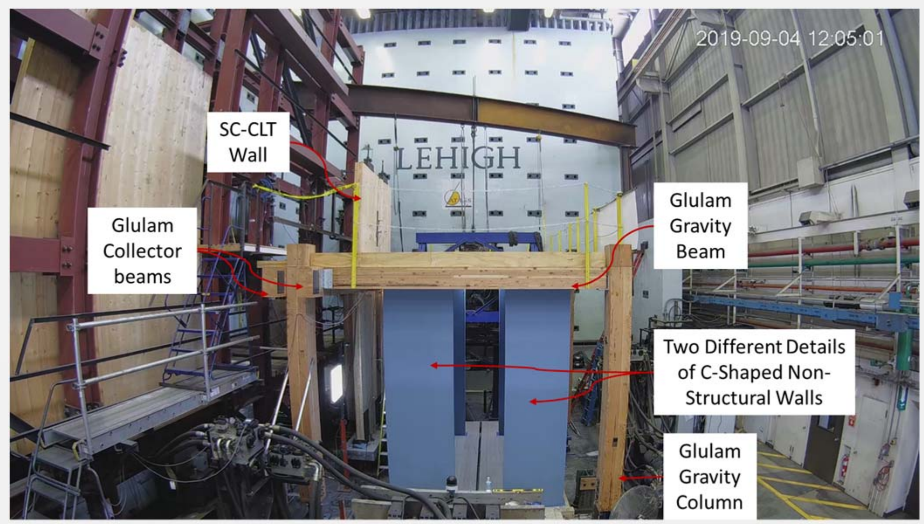
Test Phases	Objectives
Phase I.1-NS	Two independent flat partition walls tested to characterize slip behavior of different slip track details and measure forces in walls under bidirectional loading
Phase I.2-NS	Two independent C-shaped partition walls tested to characterize deformability with different details and measure forces in walls under bidirectional loading
Phase III-NS	Partition walls with dense layout tested under bidirectional loading

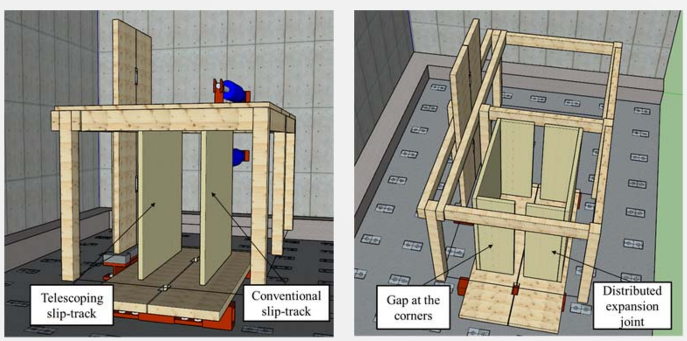
Test plan for partition wall testing

Current Projects at NHERI Lehigh EF









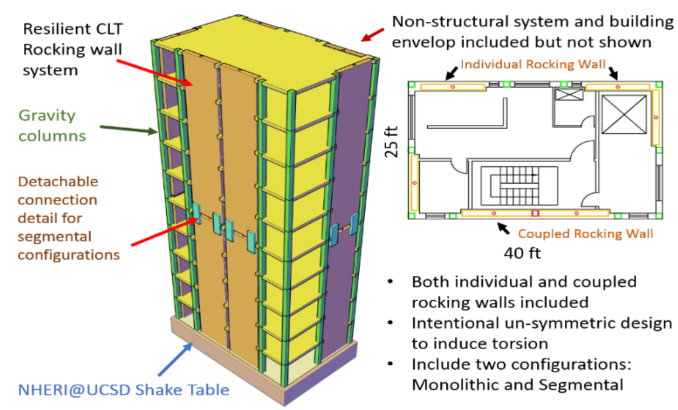
Test setup for partition wall testing

Current Projects at NHERI Lehigh EF

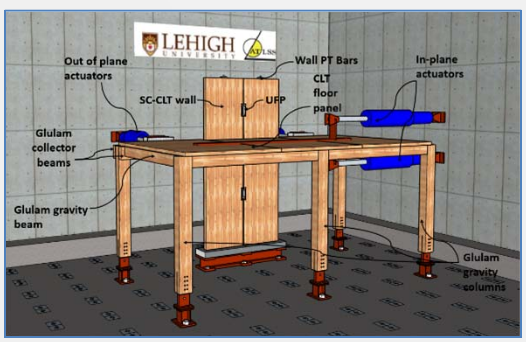
Collaborative Research: Development and Validation of Resilience-Based Seismic Design Methodology for Tall Wood Buildings: (CMMI 1635227) **Lehigh University (James Ricles, Richard Sause)**

<u>Features Using NHERI</u>
<u>Lehigh Underlined</u>

- Project Overview
  - ➢ Develop seismic design methodology for tall wood buildings with high-performance <u>structural</u> and non-structural systems
  - ➢ Study self-centering rocking cross-laminated timber (SC-CLT) wall with diaphragm and
- Project Scope
  - ➢ Conduct <u>large-scale</u> tests
    <u>out-of-plane (bi-directiona</u>
  - ➢ Project is supporting wor
    table tests (CSM, S. Pei)



➢ **Results of test specimen components are used for design of 10-Story CLT building shake table test specimen at University of California San Diego (UCSD) – led by Shiling Pei, University of Colorado School of Mines**

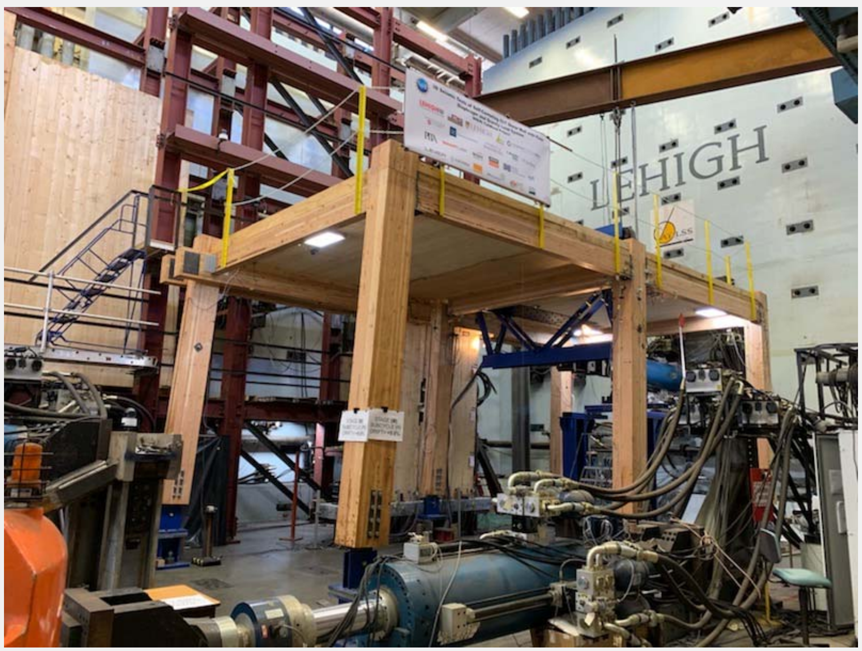


Test setup for subassembly testing

Test Phase
Phase I
Phase I.1-S
Phase I.2-S
Phase II
Phase II.1-S
Phase II.2-S
Phase III

Development and Validation of Resilience-Based Seismic Design Methodology for Tall Wood Buildings

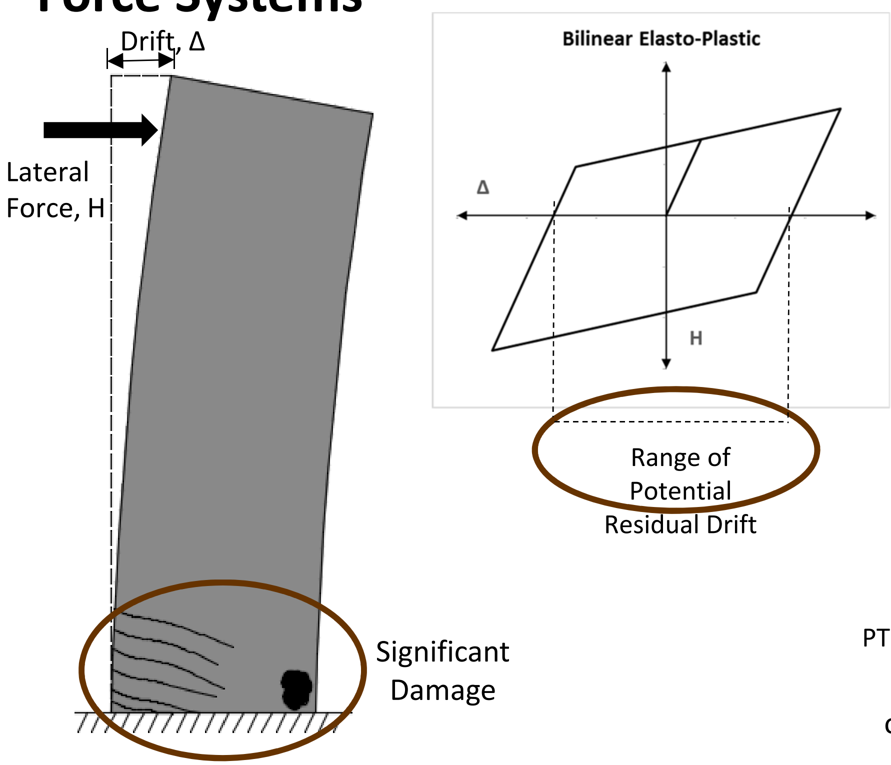
Alia Amer – PhD Graduate Research Assistant, Lehigh University



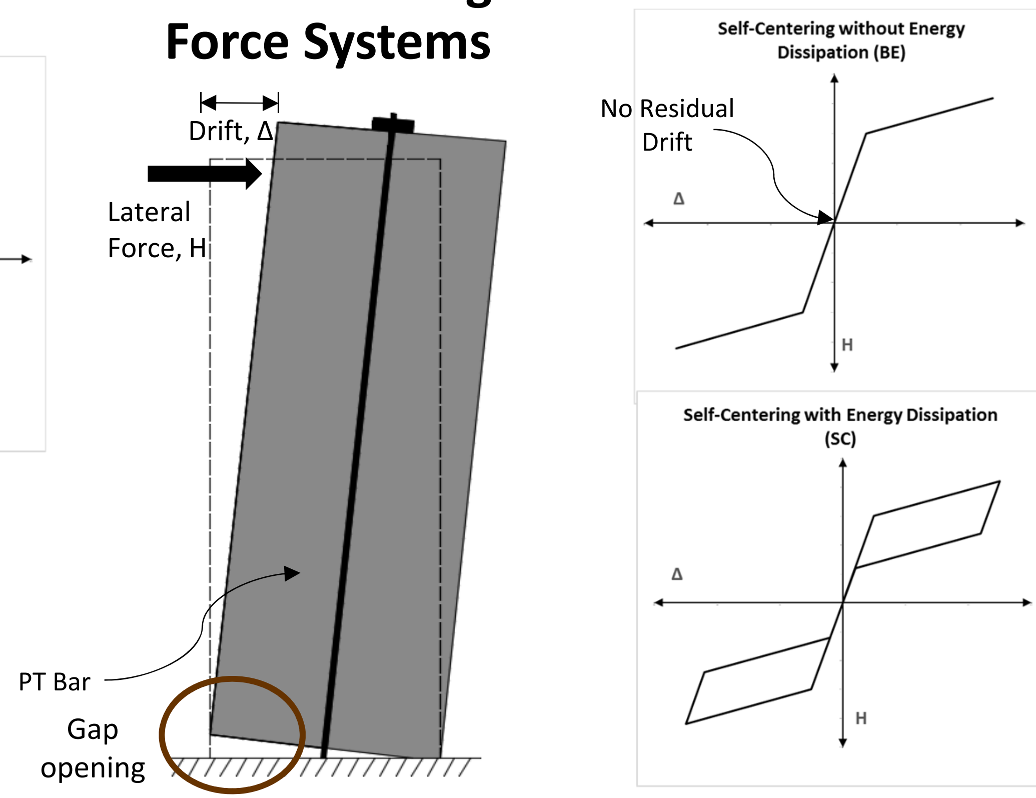
Test setup for subassembly testing

Development and Validation of Resilience-Based Seismic Design Methodology for Tall Wood Buildings

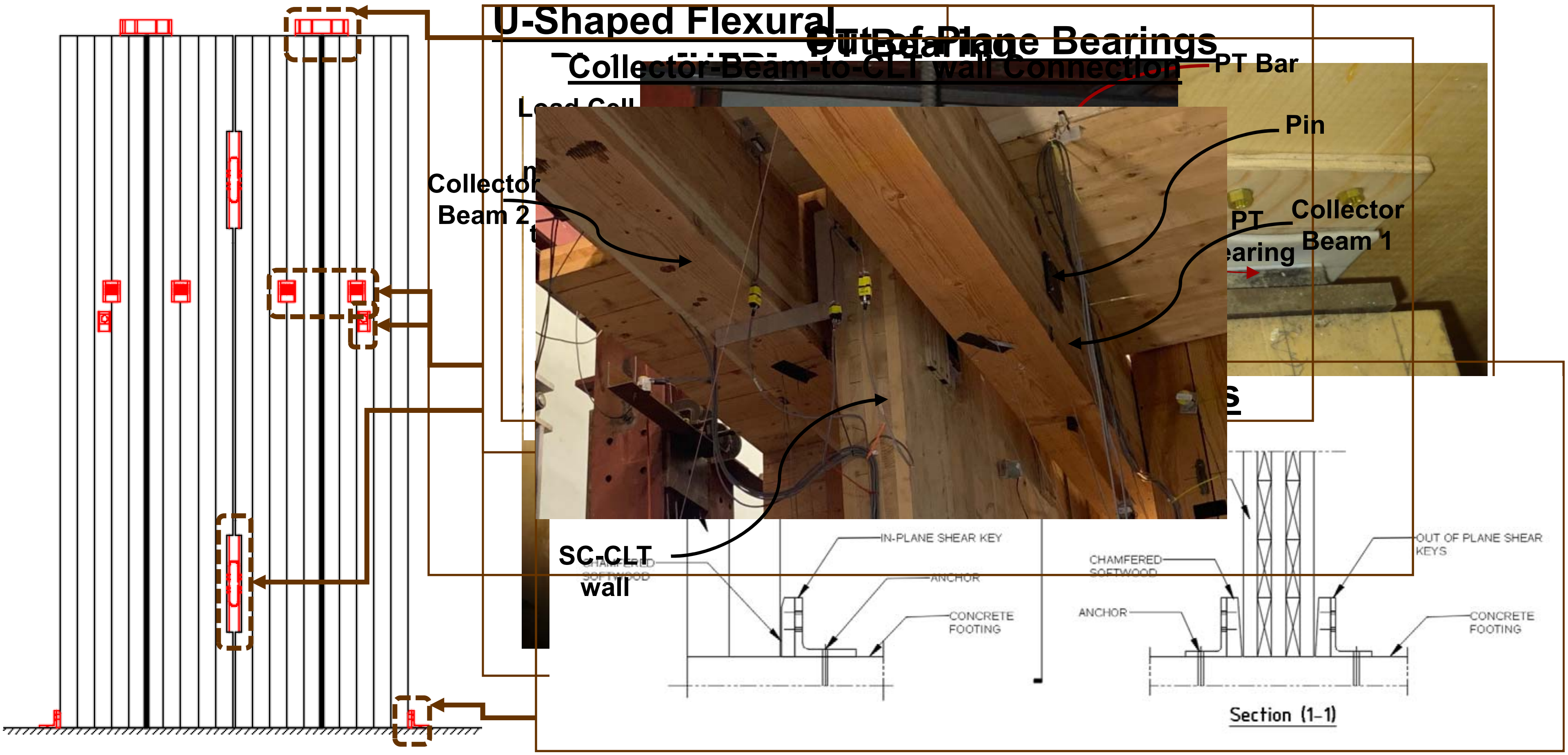
- **Conventional Shear Wall Lateral Force Systems**



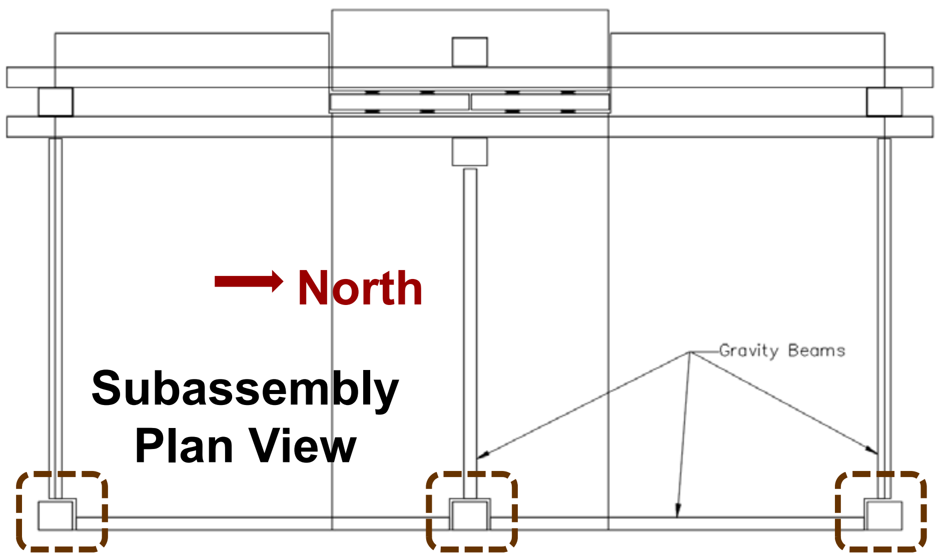
- **Self-Centering Shear Wall Lateral Force Systems**

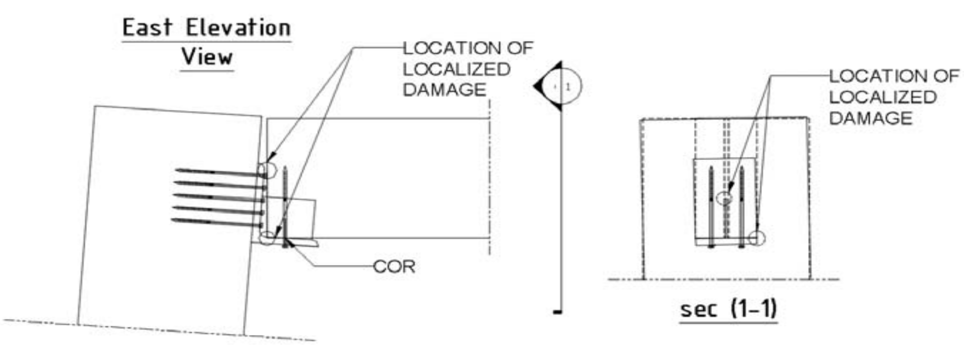


SC-CLT Wall Components



Gravity-Beam-to-Column Connection

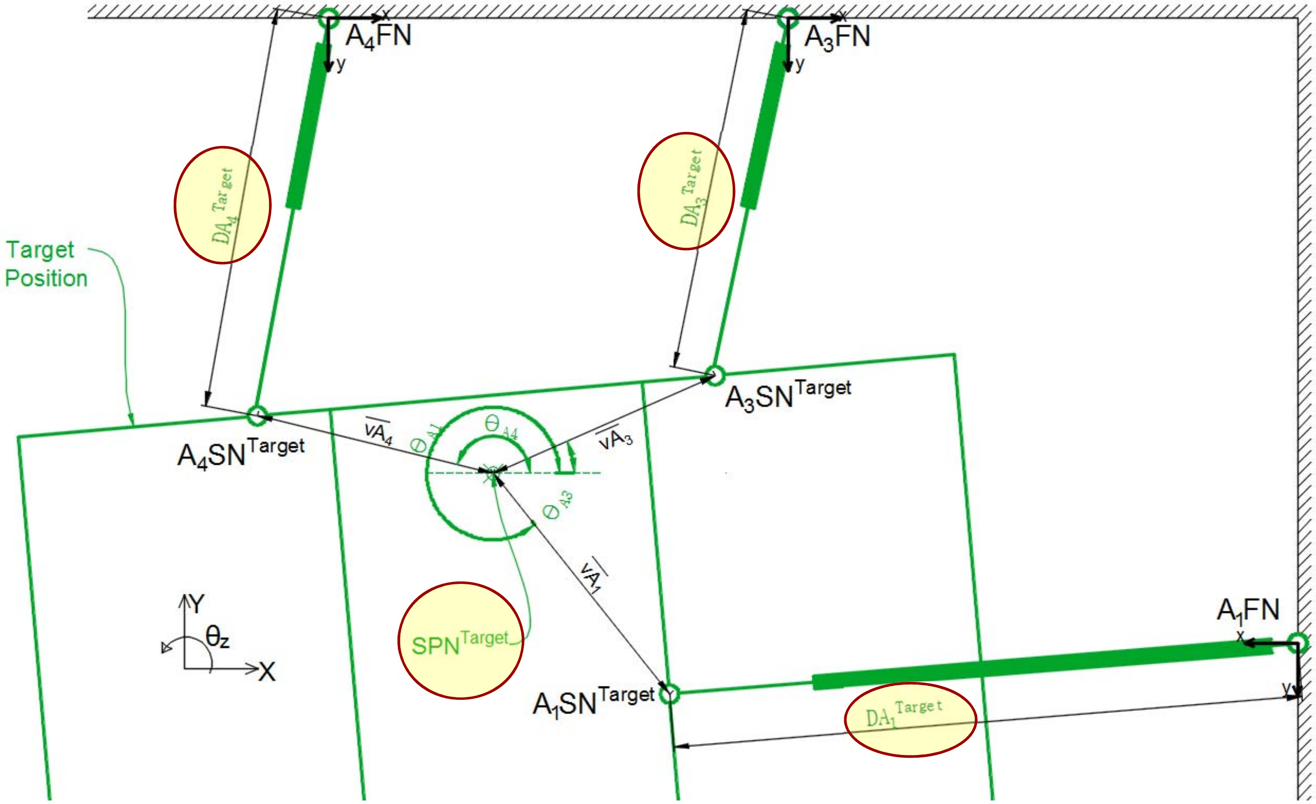




East Elevation View of Middle Column

- 7% in-plane deformation before contact
- 2.3% out-of-plane free rotation

Actuator Displacements



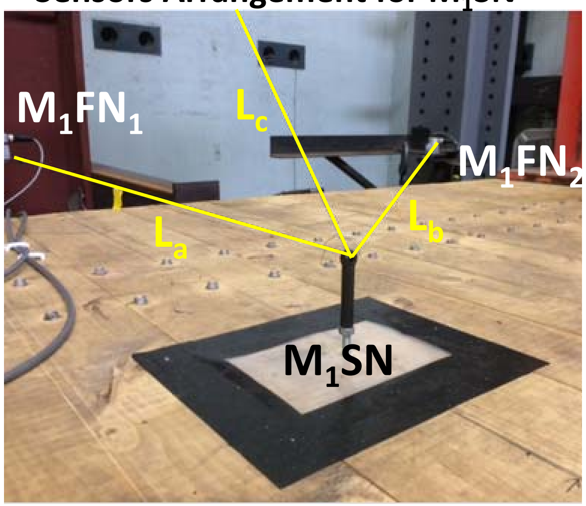
- A_kSN: k[th] actuator structure node
- A_kFN: k[th] actuator fixed node
- DA_k: k[th] actuator distance between ASN and AFN

Plane View of Floor Diaphragm

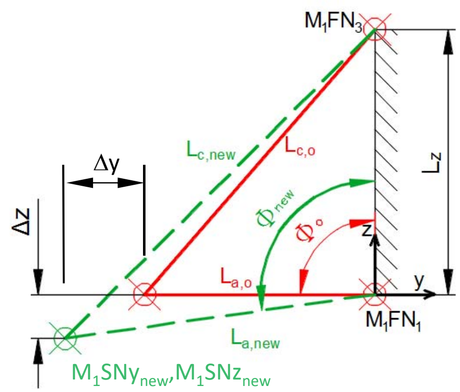
Tracking Multi-directional motions of Test Specimen

- Tracking of displaced position –
  - Master Structural Node (MSN)
  - Exact solution of based on triangularization using sensor arrangement
  - Law of cosines and sines

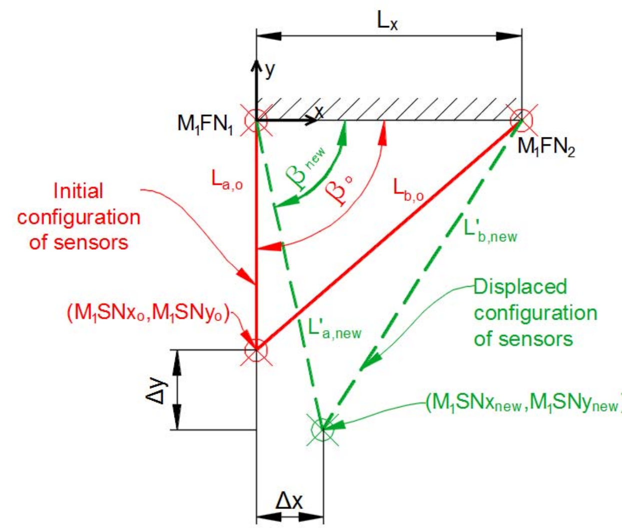
Sensors Arrangement for M_1SN



Vertical Displacement



Planar displacement



$$\Phi_{new} = f(L_{a,new}, L_{c,new}, L_z)$$

$$\beta_{new} = f(L'_{a,new}, L'_{b,new}, L_x)$$

- **Local in-plane displacement of M_1SN**

$$M_1SNx_{new} = L'_{a,\,new} \cos(\beta_{new})$$

$$M_1SNy_{new} = -L'_{a,\,new} \sin(\beta_{new})$$

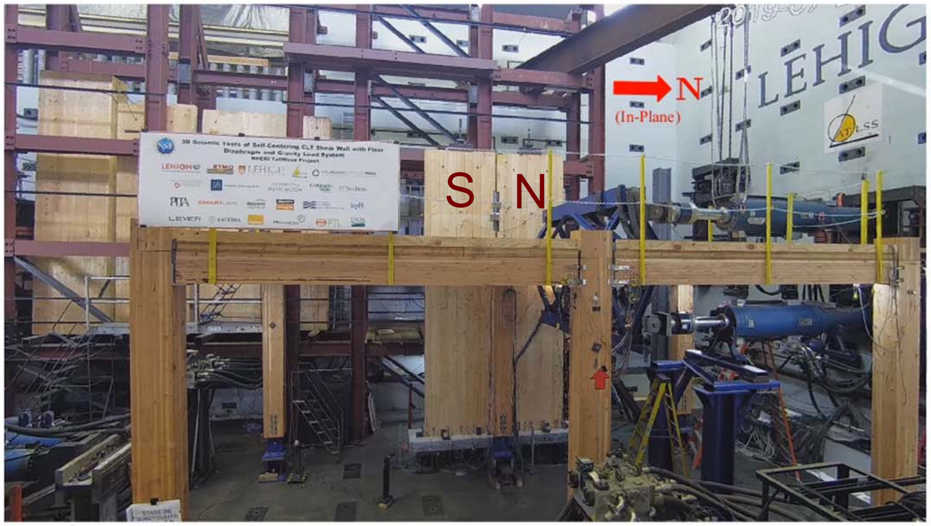
- **Displaced position of M_1SN in Global Reference Coordinates**

$$M_1SNX = M_1SNx_{new} + M_1FN_1X$$

$$M_1SNY = M_1SNy_{new} + M_1FN_1Y$$

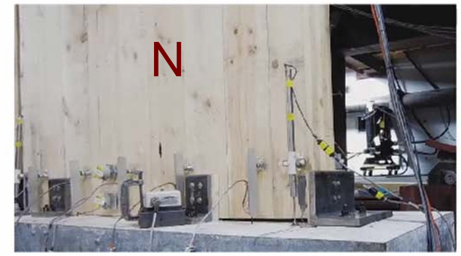
Development and Validation of Resilience-Based Seismic Design Methodology for Tall Wood Buildings

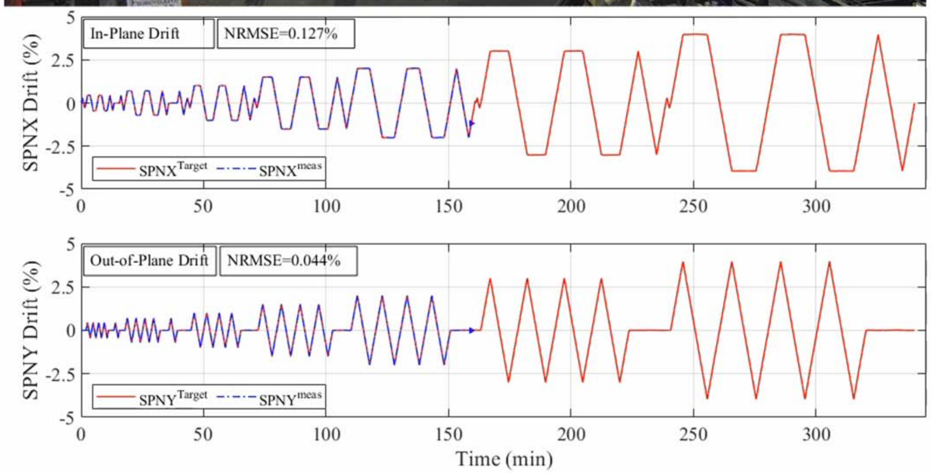
Experimental Substructure (0.625-Scale)



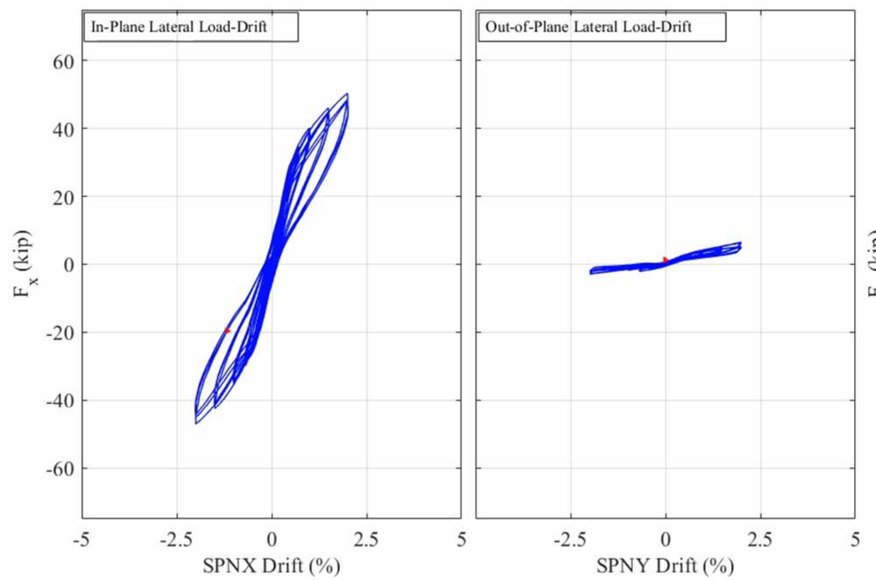
South Wall Panel

North Wall Panel





Comparison of Target vs. Measured Subassembly Drift



Multi-Directional Cyclic Testing of CLT Subassembly

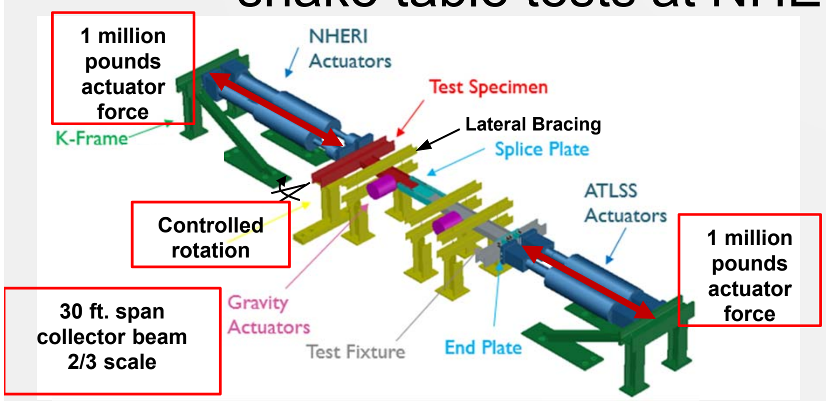
NSF NHERI LEHIGH UNIVERSITY ATLSS RTMD REAL-TIME MULTI-DIRECTIONAL SIMULATION NATURAL HAZARDS ENGINEERING RESEARCH INFRASTRUCTURE

Current Projects at NHERI Lehigh EF

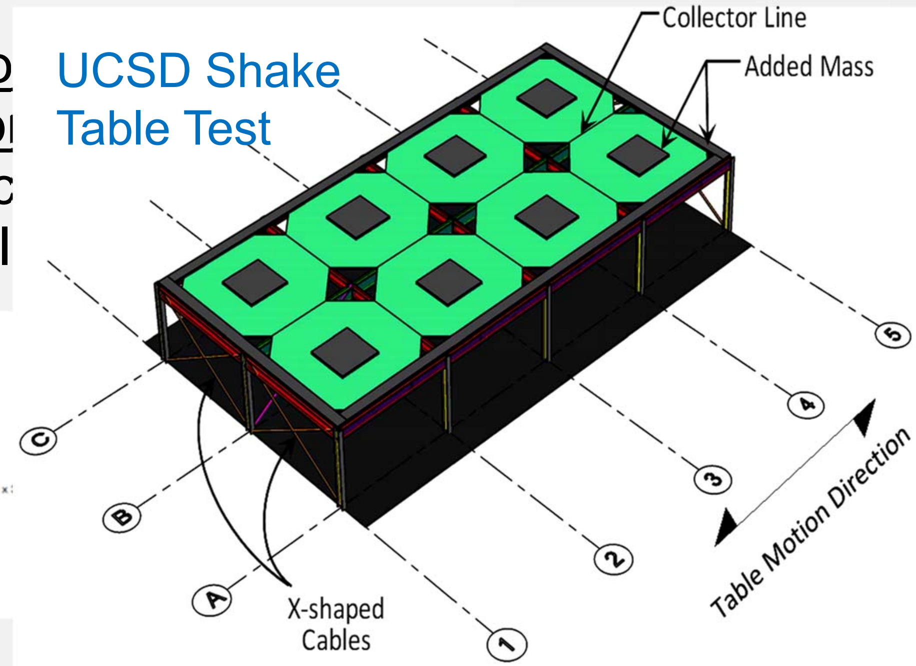
Advancing Knowledge on the Performance of Seismic Collectors in Steel Building Structures: (CMMI 1662816) **University of Arizona (Robert Fleischman (PI), Chia-Ming Uang, James Ricles, Richard Sause)**

Features Using NHERI Lehigh Underlined

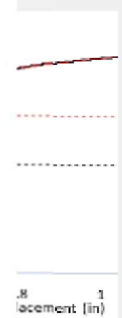
- Project Overview
  - ➢ Investigate failure-critical seismic collector steel seismic force resisting system
  - ➢ FE analyses, large-scale tests and shake-table tests of floor diaphragms and collectors
- Project Scope
  - ➢ Large-scale (1000k axial fo … or connections (tension/compr …
  - ➢ FE models and studies of c … shake table tests at NHERI …



Test setup for collector connection testing



Collector connection details



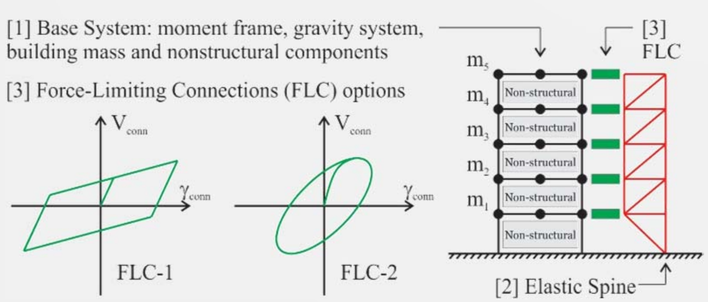
FE analyses

Current Projects at NHERI Lehigh EF

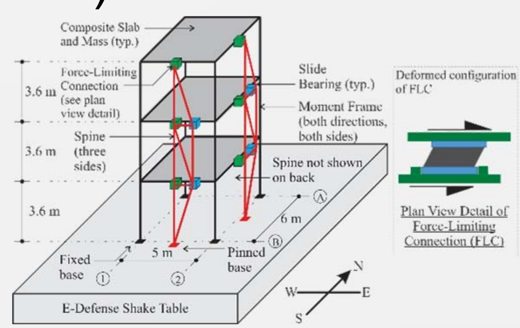
Frame-Spine System with Force-Limiting Connections for Low-Damage Seismic-Resilient Buildings: **University of Illinois (Larry Fahnestock (PI)), OSU (Barbara Simpson), Lehigh (Richard Sause and James Ricles)**

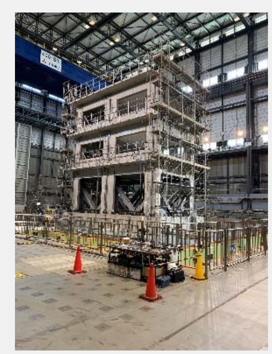
Features Using NHERI Lehigh Underlined

- Project Overview
  - Develop novel steel frame-spine lateral-force-resisting system with force-limiting connections to protect building from damaging lateral drift and accelerations, providing resilient structural and non-structural building performance
  - FE analyses, large-scale component tests, and shake-table tests of building
- Project Scope
  - Conduct large-scale tests on connections at Lehigh
  - FE models at OSU, design studies at UIUC, and shake table tests at E-Defense (NHERI/E-Defense MOU).



Connection Component Testing at NHERI Lehigh

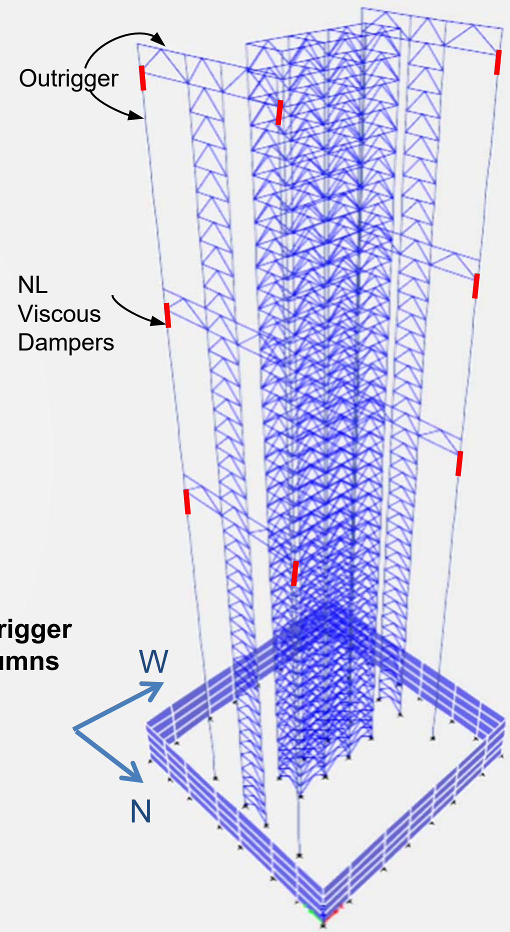


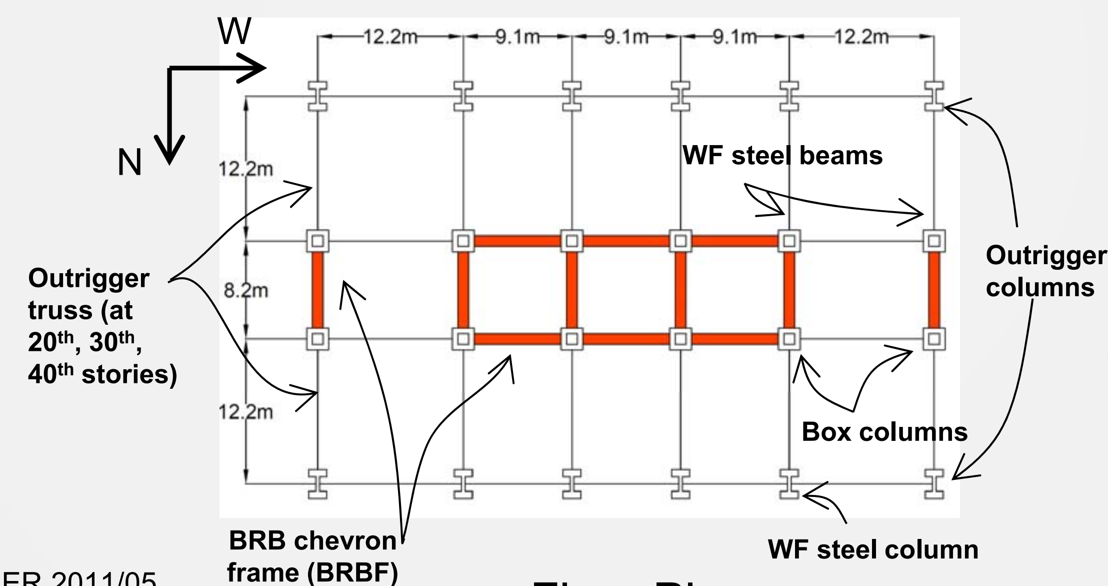


E-Defense Shake Table Testing

Multi-hazard RTHS of a Tall Building

- 40-story (+4 basement) BRBF building in Los Angeles designed by SGH[1] for PEER Tall Building Initiative case studies – BRBFs with Outriggers
- Project Objectives
  - Improve performance using nonlinear fluid viscous dampers with outriggers
  - Assess performance of structure under multi-hazards using RTHS
- Project Scope
  - Extend MKR-α integration algorithm and ATS actuator control to wind natural hazard
  - Real-time Online model updating – explicit-based NL Maxwell model
  - Machine Learning-based computational modeling





Floor Plan

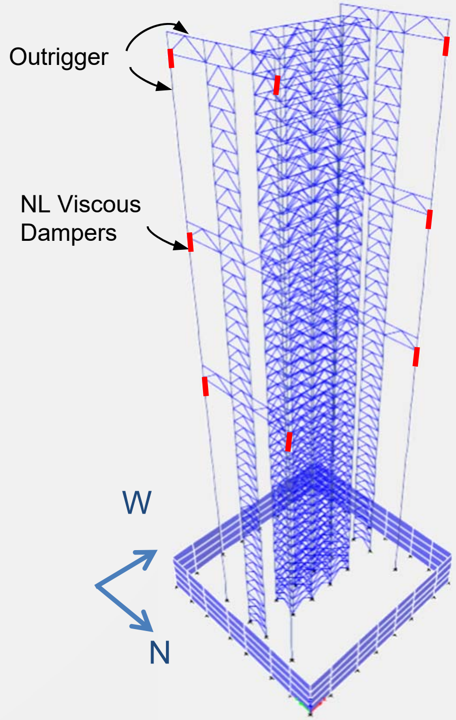
[1] Moehle et al., PEER 2011/05

Al-Subaihawi, S., Kolay, C., Thomas Marullo, Ricles, J. M. and S. E. Quiel, "Assessment of Wind-Induced Vibration Mitigation in a Tall Building with Damped Outriggers Using Real-time Hybrid Simulations," *Engineering Structures*, accepted for preparation, 2019.

Kolay, C., Al-Subaihawi, S., Thomas Marullo, Ricles, J. M. and S. E. Quiel, "Multi-Hazard Real-Time Hybrid Simulation of a Tall Building with Damped Outriggers," *International Journal of Lifecycle Performance Engineering*, accepted for preparation, 2019.

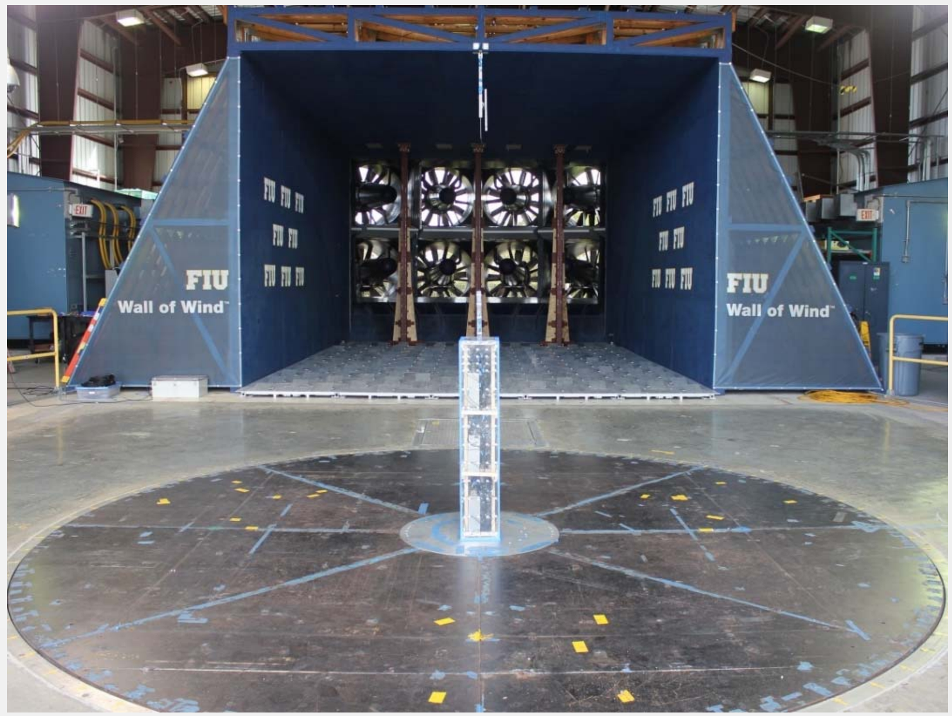
Multi-Hazard RTHS of Tall Building – EQ & Wind

- Bidirectional EQ ground motions
  - 1989 Loma Prieta EQ – Saratoga Aloha Ave Station scaled to MCE (2500 year return period) hazard level
- Bidirectional wind loading
  - Wind speed of 110 mph, 700 MRI
  - Exposure B



Wind Loading
Aerodynamic Wind Testing @ FIU WOW

- Aerodynamic wind testing at the NHERI FIU WOW to obtain wind pressure time histories distributed on the building.



Courtesy: Amal Elawady
and Arindam Chowdhury, FIU

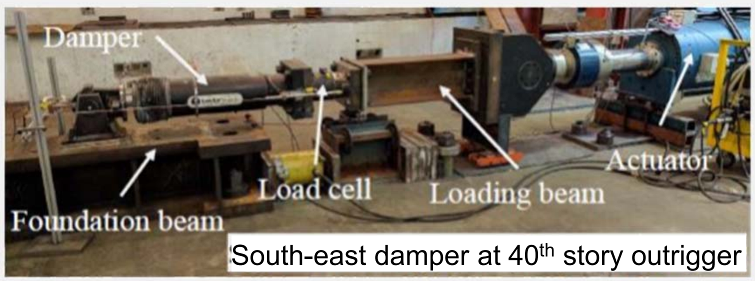
RTHS Configuration

- Use of:
  - Explicit MKR-α Integration Algorithm
  - Adaptive Time Series Compensator for Actuator Control
  - Online Model Updating (OMU) – explicit-based NL Maxwell model
  - Explicit Force-based Nonlinear Fiber Element – Analytical Substructure

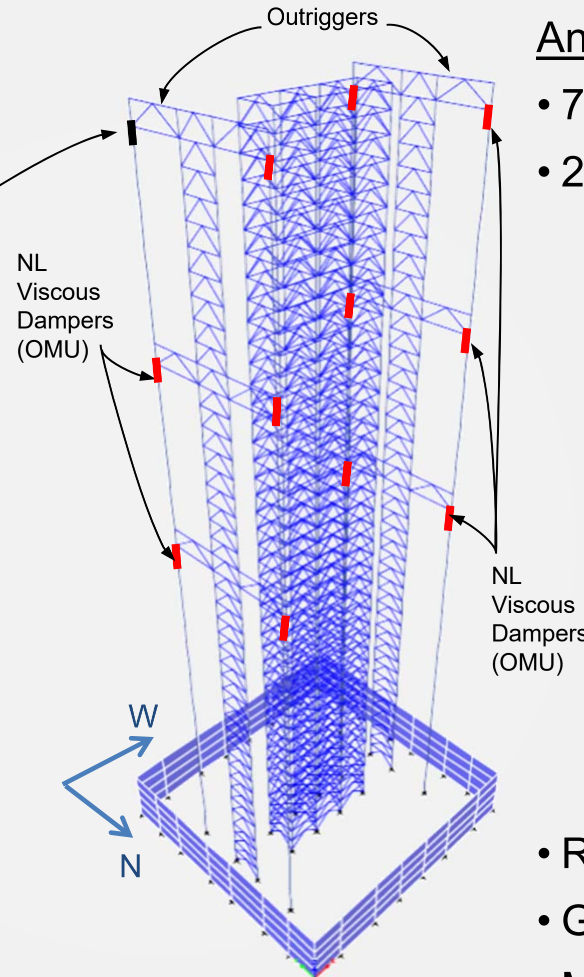
MKR-α parameter and ATS coefficients

Natural Hazard	Time Step, Δt (sec)	ρ_∞	ATS Coefficients			Comments
			a_{0k}	a_{1k}	a_{2k}	
Wind	$\frac{6}{1024}$	0.866	Fixed	Adaptive	Fixed	Wind: static component with dynamic gusts - 1st mode linear response
EQ	$\frac{6}{1024}$	0.50	Adaptive	Adaptive	Adaptive	EQ: Multi-mode non-linear response

RTHS Substructures



Experimental Substructure –
NL Fluid Viscous Damper



Analytical Substructure

Analytical Sub. Key features:

- 7902 DOF
- 2974 Elements
  - 2411 Nonlinear Explicit Force-based fiber elements
  - 11 Nonlinear Explicit Maxwell Elements[1] with real-time on-line model updating (dampers placed in each outrigger at 20th, 30th, & 40th floors)
  - 552 Nonlinear truss elements
- Reduced Order Modeling
- Geometric nonlinearities
- Mass
- Inherent damping of building

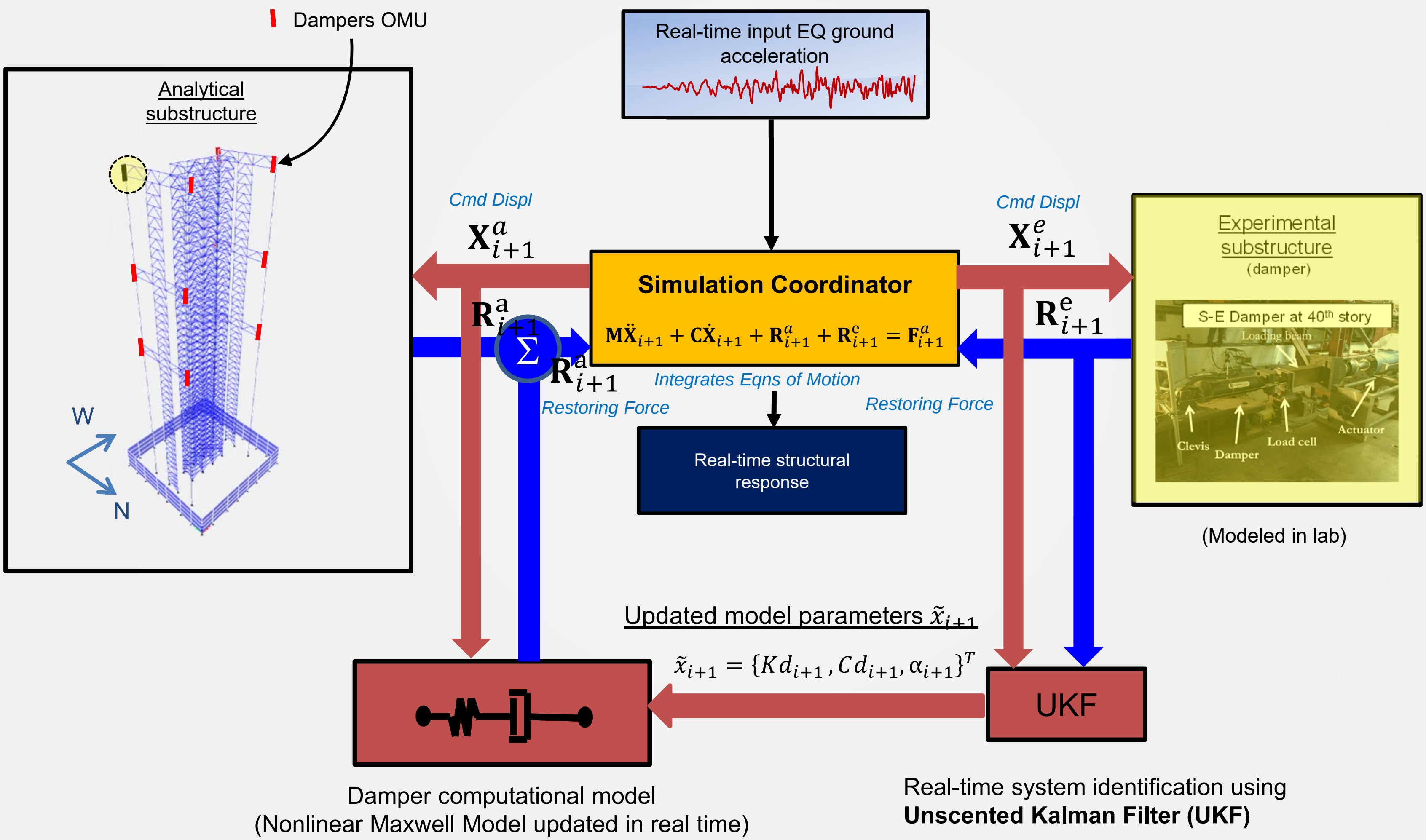
[1] Al-Subaihawi, S. (2020). *Real-time Hybrid Simulation of Complex Structural Systems Subject to Multi-Hazards*. PhD Dissertation, CEE Dept., Lehigh University.

Real-time Hybrid Simulation with Online Model Updating – Unscented Kalman Filter (UKF)

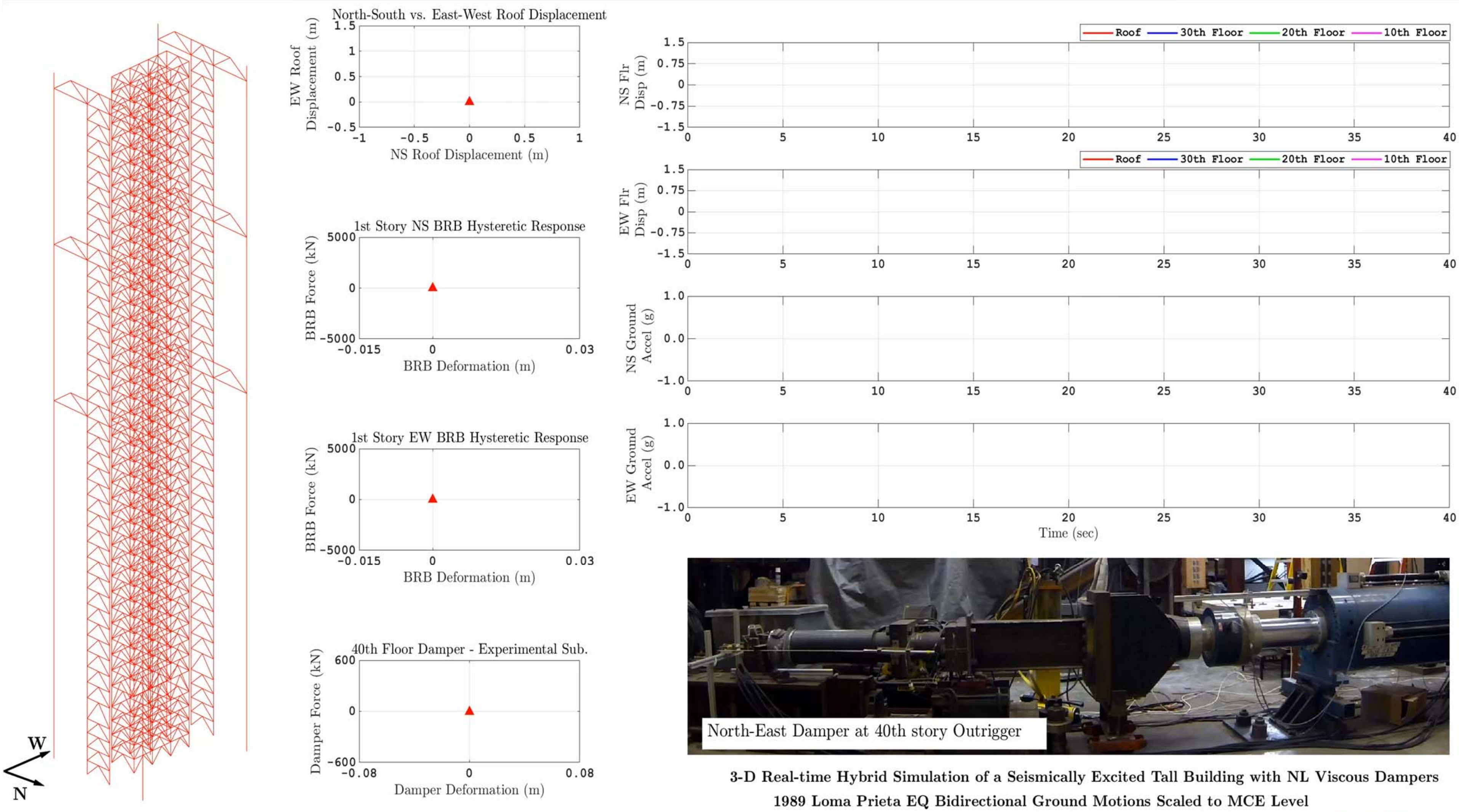
- Real-time Model Updating
  - 40th story @ S-E corner: damper modeled physically
  - Remaining 11 dampers at 20th, 30th, and 40th stories modeled numerically with real-time model updating
    - Use real-time model updating via Unscented Kalman Filter (UFK) to numerically model the 11 dampers
    - Development of explicit, non-iterative Nonlinear Maxwell Damper Model for real-time hybrid simulation
    - Development of methodology to tune and implement the UKF for real-time identification of nonlinear viscous dampers

Al-Subaihawi, S. (2020). *Real-time Hybrid Simulation of Complex Structural Systems Subject to Multi-Hazards*. PhD Dissertation, CEE Dept., Lehigh University.

Real-time Hybrid Simulation with Online Model Updating – Unscented Kalman Filter (UKF)



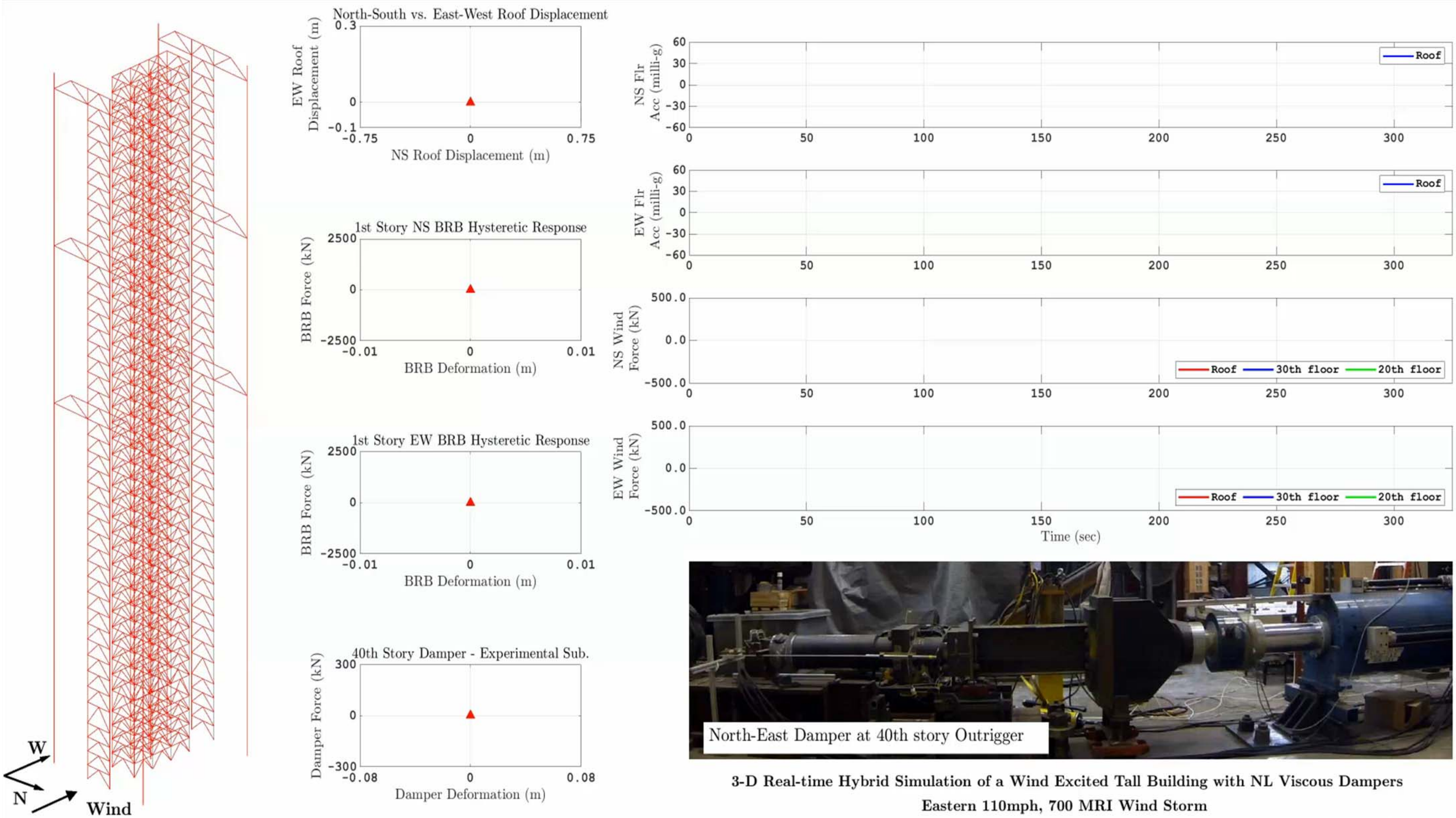
3-D Real-time Hybrid Simulation
1989 Loma Prieta EQ Bidirectional Ground Motions Scaled to MCE



Motions scaled by factor of 5 in animation

Al-Subaihawi, S., Marullo,T., Cao, L., Kolay, C. and J.M. Ricles, (2019) “3D Multi-Hazard Real-Time Hybrid Simulation Studies of a Tall Building with Damped Outriggers”.

3-D Real-time Hybrid Simulation
110 mph, 700 MRI Wind Storm (EW Windward Direction)



Motions scaled by factor of 20 in animation

Al-Subaihawi, S., Marullo,T., Cao, L., Kolay, C. and J.M. Ricles, (2019) “3D Multi-Hazard Real-Time Hybrid Simulation Studies of a Tall Building with Damped Outriggers”.

3-D RTHS Results: Roof RMS Lateral Accelerations

East to West 110 mph, 700 Year MRI Wind

RMS Roof Accelerations (mG)

Floor	No Dampers		With Dampers	
	EW	NS	EW	NS
40	7.0	31.5	6.9	16.2

Peak Roof Accelerations (mG)

Floor	No Dampers		With Dampers	
	EW	NS	EW	NS
40	28.8	90.3	25.8	59.0

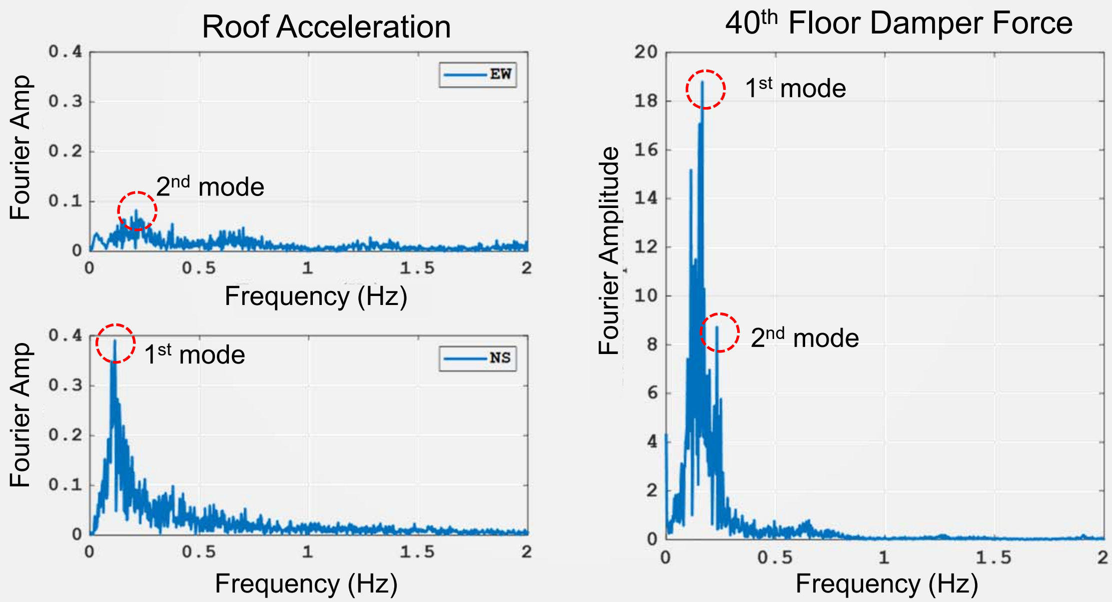
Dampers added to outriggers at 20^{th}, 30^{th}, and 40th stories:

- RMS Acceleration: 2% reduction in EW, 49% reduction in NS
- Peak Acceleration: 10% reduction in EW, 35% reduction in NS

Note: Outrigger frames are in NS direction

Building Roof Accelerations and Damper Force - 700 Year MRI Wind

- The frequency decomposition of the recorded roof accelerations shows that they are dominated by the response of the 1st mode (translational mode orthogonal to windward direction)
- The frequency decomposition of the 40th story damper force has primary contribution from 1st mode (in plane of the outrigger frames)



- 1st and 4th modes are in NS direction
- 2nd and 5th modes are in EW direction
- 3rd and 6th modes are torsional modes

Frequency Decomposition of Roof Displacement and Damper Force

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3-D RTHS Results: BRB Maximum Ductility
1989 Loma Prieta EQ Scaled to MCE

BRB Maximum Ductility Demand (Δ_b^{max}/Δ_y)

Story	No Dampers		With Dampers	
	EW	NS	EW	NS
1	3.2	3.0	3.2	2.1

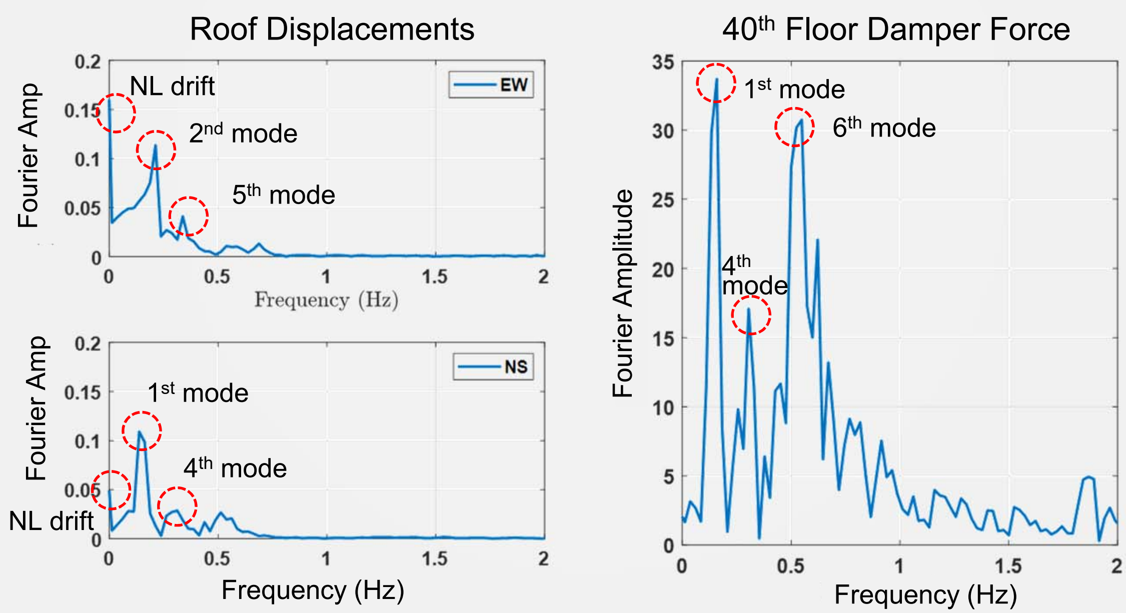
Dampers added to outriggers at 20th, 30th, and 40th stories:

- BRB ductility demand: Minimal reduction in EW, 30% reduction in NS

  Note: Outrigger frames are in NS direction

Building Roof Displacements and Damper Force – Loma Prieta EQ scaled to MCE

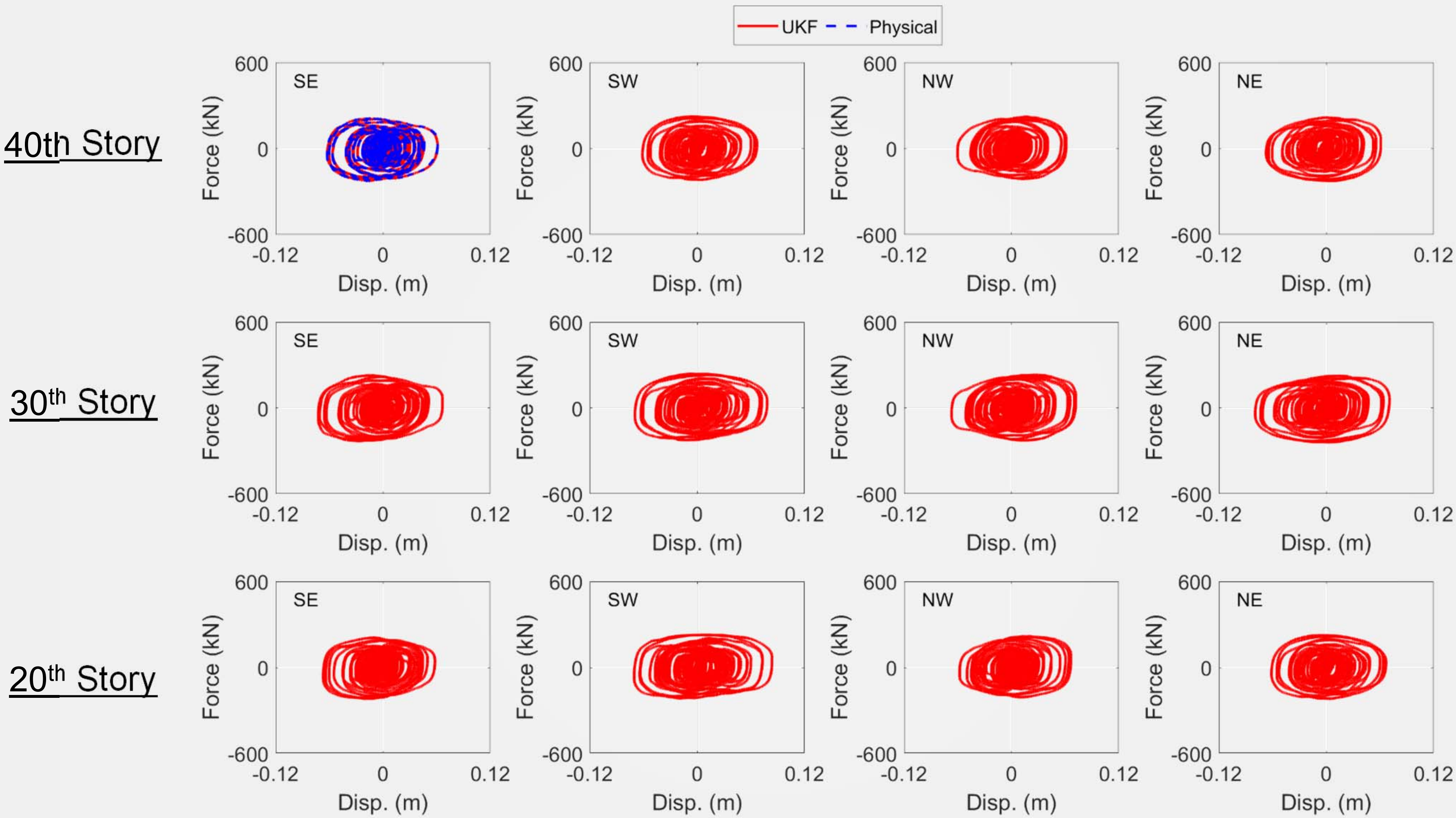
- The frequency decomposition of the recorded roof displacements shows that they are dominated by the response of the 1st and 2nd modes (translational modes in NS & EW directions)
  - ➢ Inelastic displacement is evident in frequency decomposition.
- The frequency decomposition of the 40th story damper force has considerable contribution from higher modes



- 1st and 4th modes are in NS direction
- 2nd and 5th modes are in EW direction
- 3rd and 6th modes are torsional modes

Frequency Decomposition of Roof Displacement and Damper Force

Damper Hysteretic Response – 700 MRI Wind



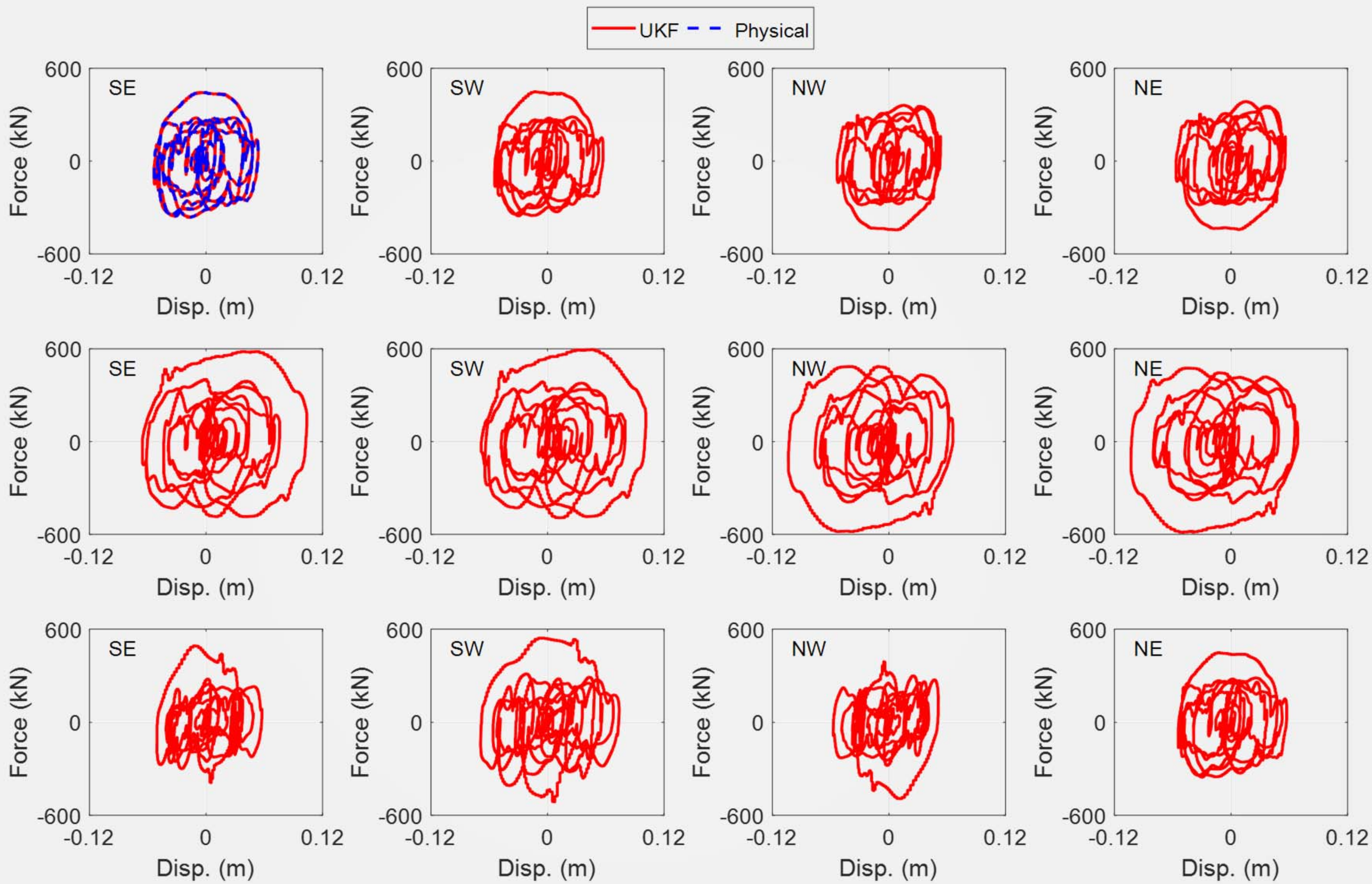
40th Story @ SE: Experimental Substructure
All other dampers: Real-time Model Updating is UKF

Damper Hysteretic Response – EQ MCE Level

40th Story

30th Story

20th Story

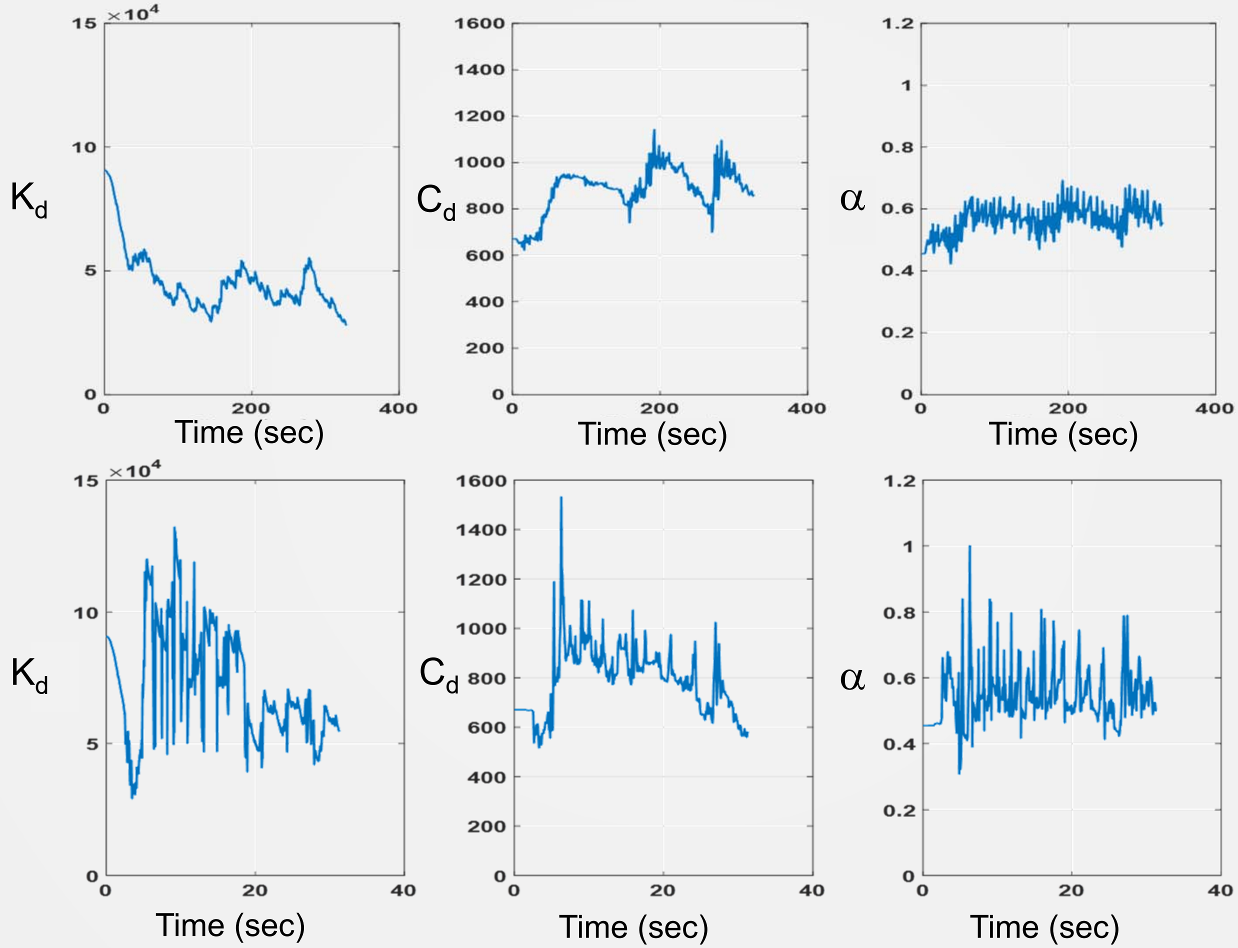


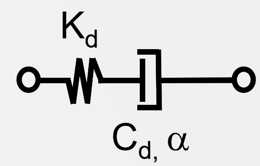
40th Story @ SE: Experimental Substructure
All other dampers: Real-time Model Updating is UKF

Online Model Updating – UKF
Variation of Nonlinear Maxwell Model Parameters

Wind

EQ





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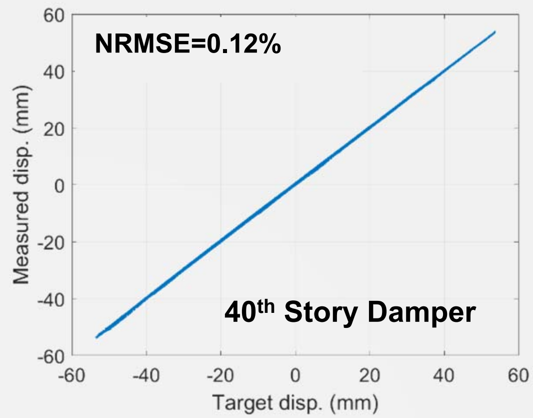
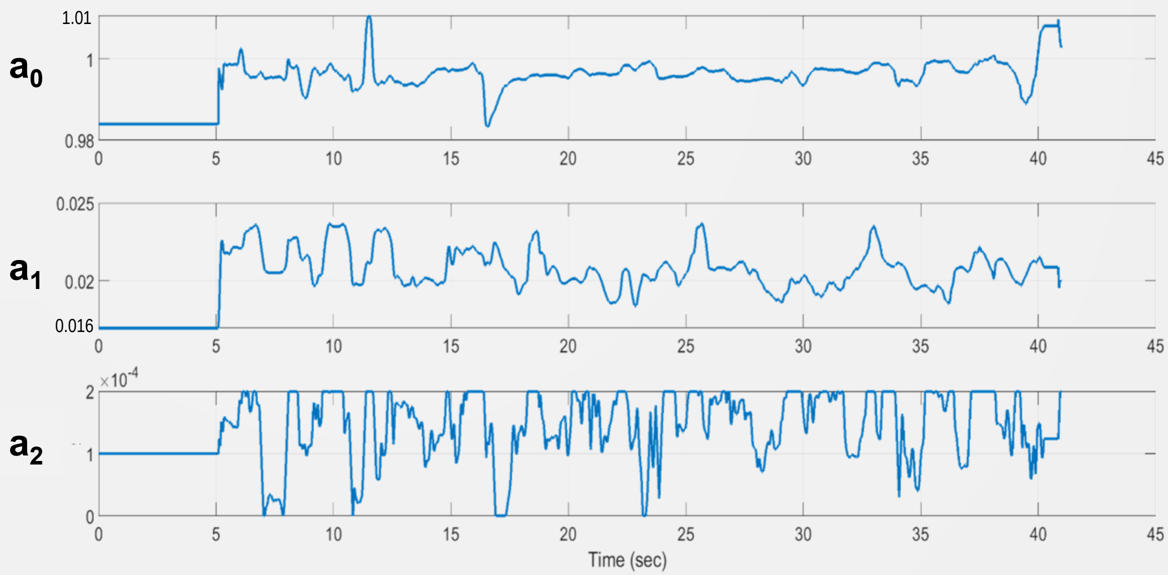
Actuator Control – Loma Prieta EQ @ MCE RTHS

Synchronized Subspace Plots:
Target vs. Measured Displacement



Time History of Adaptive Coefficients – 40th Story Damper



Amplitude Correction

$$A_k^{(j)} \approx \frac{1}{a_{0k}^{(j)}} = 0.982 \sim 1.01$$

Delay Compensation

$$\tau_k^{(j)} \approx \frac{a_{1k}^{(j)}}{a_{0k}^{(j)}} = 16 \sim 53 \text{ msec}$$

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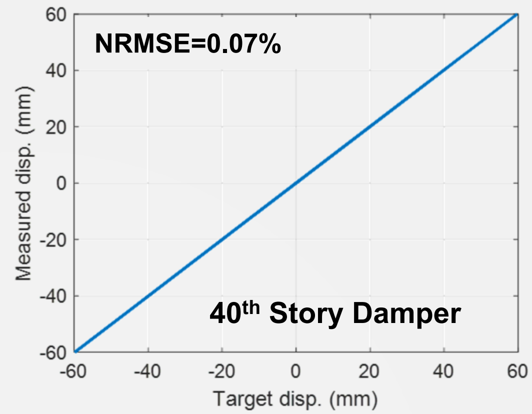
Actuator Control – 700 MRI Wind RTHS

Synchronized Subspace Plots:
Target vs. *Measured Displacement*



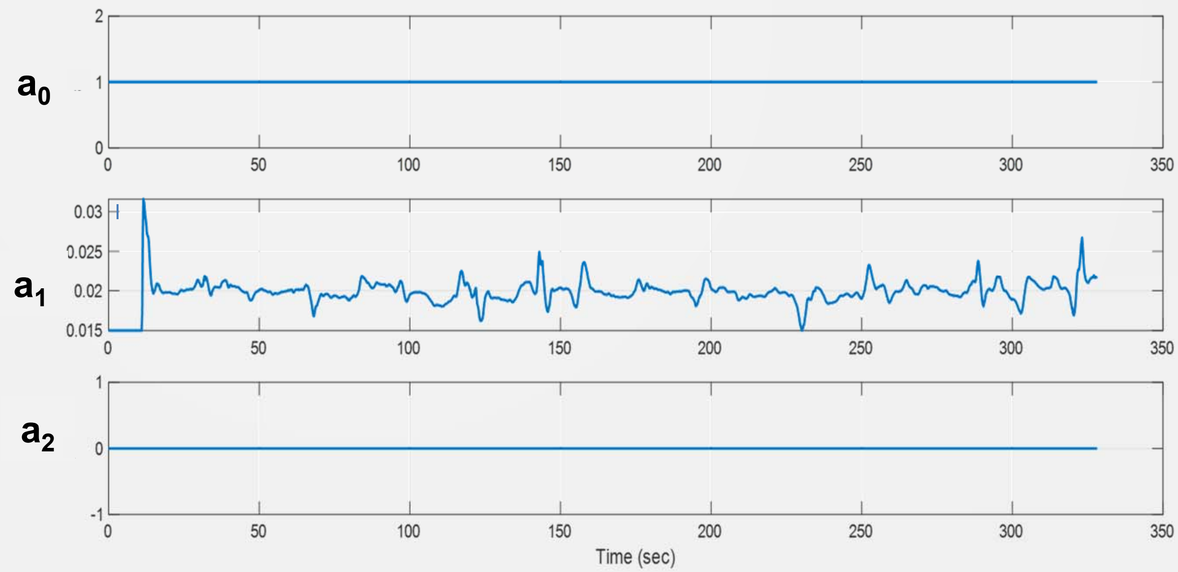
Time History of Adaptive Coefficients – 40th Story Damper

Amplitude Correction

$$A_k^{(j)} \approx \frac{1}{a_{0k}^{(j)}} = 1.0$$

Delay Compensation

$$\tau_k^{(j)} \approx \frac{a_{1k}^{(j)}}{a_{0k}^{(j)}} = 15 \sim 32 \text{ msec}$$



Researcher Opportunities: Payload Projects

- Payload project opportunities through NSF funding
  - Consult NHERI Lehigh webpage for current projects
  - NHERI Lehigh staff will work with you and PIs of existing project to develop payload project

https://lehigh.designsafe-ci.org/protocols/payload-project-protocol/

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DESIGNSAFE-CI
A NATURAL HAZARDS ENGINEERING COMMUNITY

Facility Protocols Projects Resources Outreach Contact

NHERI LEHIGH EF PAYLOAD PROTOCOL

Revision 0; 6/30/16.

1. All ongoing and newly funded projects at the NHERI Lehigh Experimental Facility are posted on the site's website to enable researchers to identify potential payload project opportunities.
2. Interested payload researchers should review the posted information for the ongoing/new project scope, schedule, and additional relevant data to determine feasibility of proposing a payload project.
3. If additional project detail is required, payload researchers are encouraged to contact project PI directly to foster collaboration towards the project.

Thank You