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
## Example Project & Testing Types

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Pre-NEESR MISST: Multi-Site Soil-Structure-Foundation Interaction EQ Simulation Test – UIUC, RPI, Lehigh

**Distributed Hybrid Simulation Test Setup**

**UIUC**
Pier test subassembly

**UI-SIMCOR**
Pier test subassembly

**Lehigh University**
Pier test subassembly

**RPI**
Soil test subassembly

**NCSA**
Remaining soil, superstructure analytical subassembly

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I-10 Collector-Distributor 36
- Damaged during 1994 Northridge EQ

Schematic Courtesy of UIUC
Multi-directional Large-Scale Real-time Hybrid Simulation of 3-story Building with Piping System – Lehigh

Objectives

- Evaluate seismic performance of Victaulic grooved couplers for building piping systems
- Evaluate seismic performance of alternative pipe bracing details

![Grooved coupler](image1)

![Rigid bracing](image2)

![Flexible bracing](image3)
Multi-directional Large-Scale Real-time Hybrid Simulation of 3-story Building with Piping System – Lehigh

3-story MRF

Piping system

Analytical Substructure

Experimental Substructure

\[ \Delta = T \Delta \]
Multi-directional Large-Scale Real-time Hybrid Simulation of 3-story Building with Piping System – Lehigh
RTHS: 1994 Northridge EQ, Canogo Park (MCE)
NEESR-SG Self Centering Damage-Free Seismic Resistant Steel Frame Systems – Princeton, Purdue, Lehigh, MCEER

Large-Scale Hybrid Simulation

SC-MRF

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

Plan of Prototype Building

Schematic of SC-MRF Exper. Substructure (Diaphragm and Gravity Systems Analytically Defined)
NEESR-SG Self Centering Damage-Free Seismic Resistant Steel Frame Systems – MCE (2500 yr Return Period EQ) Hybrid Simulation Results
MCE (2500 yr Return Period EQ) Hybrid Simulation Results
NEESR-SG Self Centering Damage-Free Seismic Resistant Steel Frame Systems - Princeton, Purdue, Lehigh, MCEER

Large-Scale Hybrid Simulations

SC-CBF

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

Plan of Prototype Building

SC-CBF Exper. Substructure (Diaphragm and Gravity Systems Analytically Defined)

Vertical post-tensioning
Vertical gap opening joints
1995 Takitori, Japan EQ ($\mu_{MCE} + 3\sigma$) Simulation Results

Real-time Hybrid Simulation

MRF with Passive Dampers

Experimental Substructures
(MRFs, Diaphragm and Gravity Systems Analytically Defined)

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

Plan of Prototype Building
Full-Scale Nonlinear Viscous Dampers

Characterization testing

![Damper testbed](image)

![Loading Protocol](image)

**Damper force - deformation**

**Damper force - velocity**
- Cal St. Pomona, Cal St. Northridge, Lehigh

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

Plan of Prototype Building

Elevation of MRF with Passive Dampers

Real-time Hybrid Simulation – MRF, Gravity Frames Anl Sub
RTHS Phase-2: MCE level 1994 Northridge Earthquake RRS318 component

Real-time Hybrid Simulation: MRF + Braced Frame Exp Sub.
NEESR-SG Performance-Based Design and Real-time Large-scale Testing to Enable Implementation of Advanced Damping Systems – Purdue, UIUC, CUNY, UConn, Lehigh

Real-time Hybrid Simulation

MRF with MR dampers

Elevation of MRF with MR Dampers

Plan of Prototype Building

6-story : 6 bays @ 30 ft = 180 ft
NEESR-SG PBD and Real-time Large-scale Testing to Enable Implementation of Advanced Damping Systems – Purdue, UIUC, CUNY, UConn, Lehigh

RTHS: 1994 Northridge EQ (0.80*DBE), Semi-active MR

Experimental Substructure – CBF with MR Dampers

Analytical Substructure

MRF & lean-on column

2nd story MR Damper

1st story MR Damper

Floor Displacement

Disp. (mm)

0 20 40

Time (sec)

0 5 10 15 20

1st floor

2nd floor

3rd floor
NEESR-CR Impact Forces from Tsunami-driven Debris
Dynamic Impact Loading – Univ Hawaii, Oregon St., Lehigh

Dynamic Impact Loading

Test Setup Cargo Shipping Container Debris

High Speed Video of Impact of Cargo Shipping Container with Structure
NEESR-CR Post-Tensioned Coupled Shear Wall Systems – Notre Dame, University of Texas @ Tyler
Mixed Mode Hybrid Simulation Testing

NEES@Lehigh Coupled Shear Wall Test Specimen with Multi-Directional Loading
(Upper 5 floors analytically modeled)

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

Joint Strains Measured by DIC System (Pakzad)
Cyclic Quasi Static and Dynamic Load Testing

Experimental Setup Up

Floor Anchorage Hysteretic Response

Friction Device

Low Damping Rubber Bearings

Floor System

LFRS
NSF-CMMI: Enhancement of Vertical Element for Foundation Supported by Ureolytic Carbonate Precipitation
Lehigh, Arizona State
Vertical Tests on Biomodified Soil-Pervious Pile Systems
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Vertical Tests on Biomodified Soil-Pervious Pile Systems
NSF-CMMI: SSI of Active and Passive Laterally Loaded Piles – Lehigh, Lafayette College

Static Lateral Load Pile Tests
NSF-CMMI: SSI of Active and Passive Laterally Loaded Piles – Lehigh, Lafayette College

Static Lateral Load Pile Tests

<table>
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<tr>
<th>In-soil null pressure sensor NO.</th>
<th>Radial distance to pile center (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>152</td>
</tr>
<tr>
<td>2</td>
<td>152</td>
</tr>
<tr>
<td>3</td>
<td>737</td>
</tr>
<tr>
<td>4</td>
<td>152</td>
</tr>
<tr>
<td>5</td>
<td>356</td>
</tr>
<tr>
<td>6</td>
<td>356</td>
</tr>
<tr>
<td>7</td>
<td>76</td>
</tr>
</tbody>
</table>

Note:
- :SAA
- :In-soil null pressure sensors at depth of 352 mm below soil surface
NSF-CMMI: SSI of Active and Passive Laterally Loaded Piles – Lehigh, Lafayette College

Static Lateral Load Pile Tests

Applied load: 400 lb
NSF-CMMI: SSI of Active and Passive Laterally Loaded Piles – Lehigh, Lafayette College

Static Lateral Load Pile Tests
NSF-CMMI: SSI of Active and Passive Laterally Loaded Piles – Lehigh, Lafayette College

Static Lateral Load Pile Tests

- Graph showing lateral displacement (in.) vs. applied lateral load (N)
- Image of a pile with a coin for scale
- Image showing lateral load and displacement with annotations:
  - P = 223 N
  - Δ = 0.01 mm
  - ~0.8 D
NSF-CMMI: SSI of Active and Passive Laterally Loaded Piles – Lehigh, Lafayette College

Static Lateral Load Pile Tests