NHERI Lehigh Real-time Cyber-Physical Structural Systems Laboratory – Overview and Demonstration

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Real-time Cyber-Physical Structural Systems Laboratory (CPSSL) – Real-time Testbeds

- **Purpose**
  - Education & Training
  - Reduced-scale Testing

- **Seven MTS Actuators:**
  - 2 - Model 244.21G2
  - 1 - Model 244.20G2S
  - 2 - Model 244.20
  - 2 - Model 244.31

- **Five Dampers:**
  - Four Nonlinear Viscous Dampers
  - One Rotary Friction Damper

### Actuator Specifications

<table>
<thead>
<tr>
<th></th>
<th>244.21G2</th>
<th>244.20G2s</th>
<th>244.20</th>
<th>244.31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Force</td>
<td>50 kN (11 kips)</td>
<td>82 kN (18.5 kips)</td>
<td>100 kN (22 kips)</td>
<td>250 kN (55 kips)</td>
</tr>
<tr>
<td>Max disp.</td>
<td>±254 mm (±10 in)</td>
<td>±177 mm (±7 in)</td>
<td>±76 mm (±3 in)</td>
<td>±127 mm (±5 in)</td>
</tr>
<tr>
<td>Max velocity</td>
<td>0.74 m/s (29 in/s)</td>
<td>1.29 m/s (51 in/s)</td>
<td>0.38 m/s (15 in/s)</td>
<td>0.47 m/s (18 in/s)</td>
</tr>
<tr>
<td>Servo Valve</td>
<td>30 gpm</td>
<td>90 gpm</td>
<td>30 gpm</td>
<td>90 gpm</td>
</tr>
</tbody>
</table>
Real-time Cyber-Physical Structural Systems Laboratory (CPSSSL) – Real-time Testbeds

- Reduced-Scale Real-time Hybrid Simulation

Real-time hybrid simulation of a reduced-scale semi-active friction damper
Real-time Cyber-Physical Structural Systems Laboratory (CPSSL) – Real-time Testbeds

- Small-Scale Real-time Hybrid Simulation
- Predefined load or displacements (Quasi-static testing or characterization testing)

Characterization test of a Small-scale Passive Viscous Damper
Banded Rotatory Friction Damper (BRFD)

Damper Specifications

• 45 kN (10 kips) force capacity
• 305 mm (12 in) diameter drum
• Mechanically reliable & robust
• US Patent: # 9,896,836

Banded Rotatory Friction Damper (BRFD)

Double wrap band brake

Banded Rotary Friction Damper (BRFD)

(a) Schematic of side view

(b) Friction mechanism

Banded Rotatory Friction Damper (Second Generation)

New Design Features

- Semi-active mechanism is achieved using two Tolomatic electric actuators
- Three individual frictional bands are manufactured.
- Two load cells are installed on connections between electric actuators and frictional bands.
Procedure for Damper Characterization

1. Develop a dynamic model
2. Assign model parameters
3. Predict model response
4. Calculate error between model and measured experimental data
5. Revise parameters to minimize error
6. Predefined displacement tests
Characterization Test Input Displacement
Characterization Test of BRFD – Test Setup

[Image of test setup with labeled parts: Safety relays, Column support, MTS actuator, MTS Load cell, Roller support, Foundation beam, Load cells, Teflonomatic electric actuators, Servo control monitor.]

[Image credits: Lehigh University, NSF, RTMD]
BRFD Characterization Test Results

Harmonic displacement input:
- Amplitude: 1 inch
- Frequency: 0.5 Hz
- Applied force, $F_{\text{applied}}$: 0.16, 0.2 and 0.25 kN

Force amplification\( (F_{\text{damper}}/F_{\text{applied}}) = 112 \)
Characterization Test of Nonlinear Viscous Dampers

Nonlinear viscous damper property:
- Capacity : 6.6 kips (29 kN)
- Stroke length : ±2 inch (±50 mm)
- Nominal output force: $F=1.7V^{0.4}$ (kip)
Characterization Test of Nonlinear Viscous Damper – Test Setup

- Column support
- MTS actuator
- Load cell
- Viscous damper
- Foundation beam
- Roller support
Nonlinear Viscous Damper Characterization Test Results

Harmonic displacement input:
- Amplitude : 1 inch
- Frequency : 0.5, 1, 2 and 3 Hz

(a) force-displacement
(b) force-velocity
RTHS of a 2-story Reinforced Concrete Building

- 2-story RC special moment resisting frame (SMRF) building in Los Angeles area on a stiff soil site
- Objectives of study
  - Improve seismic performance using BRFD/nonlinear fluid viscous dampers
  - Assess performance using RTHS
  - Utilize MKR-α integration algorithm and ATS actuator control

* Column confining zones measure 22" from the face of the beams and 33" from the base of the column.
2D RTHS Substructures

Analytical Substructure

- P-\( \Delta \) effects included
- 32 Nodes
- 30 Nonlinear Force-based Fiber Elements
- 71 DOFs
- Time step for RTHS, \( \Delta t=3/1024 \) sec.

Experimental Substructures

- Numerical damper
- Experimental damper

Excitation Input:
- Ground Motion: Kocaeli, Turkey 1999
- Hazard Level: Maximum Considered Earthquake (MCE) 7.51 Magnitude
RTHS of a 2-story Reinforced Concrete Building Equipped with BRFD

Analytical Substructure (5x Deformation Scale)

Experimental Substructure

Real-Time Hybrid Simulation of a Two-Story Concrete Structure equipped with Banded Rotary Friction Device (BRFD) at the 1st Story
1/2 Scale Structure with 4x Time Elongation
Ground Motion: Kocaeli, Turkey 1999
Hazard Level: Maximum Considered Earthquake (MCE) 7.51 Magnitude
RTHS of a 2-story Reinforced Concrete Building Equipped with Nonlinear Viscous Damper

Analytical Substructure (5x Deformation Scale)

Experimental Substructure

First-story column base, south side

Real-Time Hybrid Simulation of a Two-Story Concrete Structure equipped with Non-Linear Viscous Damper (NIVD) at the 1st Story 1/2 Scale Structure at Real-Time Execution
Ground Motion: Kocaeli, Turkey 1999
Hazard Level: Maximum Considered Earthquake (MCE) 7.51 Magnitude

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REAL-TIME MULTIFUNCTIONAL STRUCTURAL SYSTEMS
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