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

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• Purpose
  • Education & Training
  • Small-scale Testing
• Three MTS Actuators:
  ➢ 2 - Model 244.21G2
  ➢ 1 - Model 244.20G2S

<table>
<thead>
<tr>
<th>Actuator Specifications</th>
<th>244.21G2</th>
<th>244.20G2s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Force</td>
<td>50 kN (11 kips)</td>
<td>82 kN (18.5 kips)</td>
</tr>
<tr>
<td>Max displacement</td>
<td>±254 mm (±10 in)</td>
<td>±177 mm (±7 in)</td>
</tr>
<tr>
<td>Max velocity</td>
<td>0.74 m/s (29 in/s)</td>
<td>0.43 m/s (51 in/s)</td>
</tr>
<tr>
<td>Servo Valve</td>
<td>30 gpm</td>
<td>90 gpm</td>
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Lehigh Real-time Cyber-Physical Structural Systems Laboratory

- Small-Scale Real-time Hybrid Simulation

Real-time hybrid simulation of a Small-scale Semi-active Friction Damper
Lehigh Real-time Cyber-Physical Structural Systems Laboratory

- 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

Placement of BRFD in Building

Two Possible Configurations for BRFD Installment

(a) Building Plan, and (b) Elevation

(a) Chevron

(b) Toggle
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

- Load cell
- Roller support
- BRFD
- Load cell
- Column support
- MTS actuator
- Servo control monitor
- Clevis
- Bracing
- Foundation beam
- Roller support
Harmonic displacement input:

- Amplitude: 1 inch
- Frequency: 0.5 Hz
- Applied force, $F_{\text{applied}}$: 50, 60 and 70 lb

Force amplification ($F_{\text{damper}}/F_{\text{applied}}$) = 71
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
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
Analytical Substructure Key Features:
• P-Δ effects included
• 32 Nodes
• 30 Nonlinear Force-based Fiber Elements
• 71 DOFs
• Time step for RTHS, Δt=3/1024 sec.

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

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RTHS of a 2-story Reinforced Concrete Building Equipped with Nonlinear Viscous Damper

Analytical Substructure (5x Deformation Scale)