Laboratory Exercises: Characterization Testing of a Banded Rotatory Friction Damper

Liang Cao, Ph.D
NHERI Lehigh Research Scientist
Lehigh University
Lehigh Small-Scale Structural Dynamics Testing Facility

- Three MTS Actuators:
  - 2 - Model 244.21G2
  - 1 - Model 244.20G2S

<table>
<thead>
<tr>
<th></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>
</tr>
</tbody>
</table>
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

(a) Building Plan, and (b) Elevation

Two Possible Configurations for BRFD Installment

(a) Chevron

(b) Toggle
Procedure for Damper Characterization

- Develop a dynamic model
- Assign model parameters
- Predict model response
- Calculate error between model and measured experimental data
- Revise parameters to minimize error
- Predefined displacement tests
Characterization Test of BRFD Input Displacement and Test Matrix

<table>
<thead>
<tr>
<th>Amplitude mm (in.)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.4 (1.0)</td>
<td>0.10 0.50</td>
</tr>
<tr>
<td></td>
<td>16 (0.63) 80 (3.2)</td>
</tr>
</tbody>
</table>

Numbers in the cells are max velocities in mm/s (in/s)
Characterization Test of BRFD – Test Setup

- Column support
- MTS actuator
- Load cell
- Clevis
- Bracing
- BRFD
- Roller support
- Servo control monitor
- Foundation beam
- Load cell
Harmonic displacement input:
- Amplitude: 1 inch
- Frequency: 0.1 Hz and 0.5 Hz
- Applied force, $F_{\text{applied}}$: 50, 65 and 80 lb

Force amplification
$\left(\frac{F_{\text{damper}}}{F_{\text{applied}}}\right) = 112$
Computational Model for BRFD

- **LuGre friction model**
  \[ F_{\text{friction}} = \sigma_0 z + \sigma_1 \dot{z} + \sigma_2 \dot{x} \]
  \[ \ddot{z} = \dot{x} - \sigma_0 \frac{\dot{x}|}{g(\dot{x})} z \]
  \[ g(\dot{x}) = F_C + (F_S - F_C) e^{-\left(\frac{\dot{x}}{\dot{x}_S}\right)^2} \]
  - \( \sigma_0, \sigma_1 \text{ and } \sigma_2 \) are constants
  - \( z \) is an evolutionary variable and \( x \) is displacement
  - \( F_C \) is kinetic frictional force and \( F_S \) is static frictional force
  - \( \dot{x}_S \) is constant modeling the Stribeck velocity
  \[ F_{\text{damper}} = \frac{F_{\text{friction}}}{r} \]
  where \( r_b \) is the distance from the center of the drum to the brace and \( r \) is the drum radius


3 Stage Dynamic Model for BRFD

- Stage 1 (node A → node B)
  \[ F_1 = \text{LuGre friction model} \]
- Stage 2 (node B → node C)
  \[ F_2 = k_2 x \] (\( k_2 \) is constant)
- Stage 3 (node C → node A)
  \[ F_3 = k_3 x \] (\( k_3 \) is constant)

Smooth transition region

- Sigmoid function
  \[ m(x) = \frac{1}{1 + e^{-\gamma_1(x-x_0)/\gamma_2}} \]
  \( x_0 \) is the location of new stage and \( \gamma_1, \gamma_2 \) are constants
- Stage \( i \) → Stage \( j \)
  \[ F_{\text{friction}} = (1-m(x)) \times F_i + m(x) \times F_j \]

Damper Characterization Results

- Imperial Valley earthquake with $F_{\text{applied}} = 30$ lb

(a) time history of damper displacement
(b) time history of damping force $F_{\text{damper}}$
(c) force-displacement hysteretic response