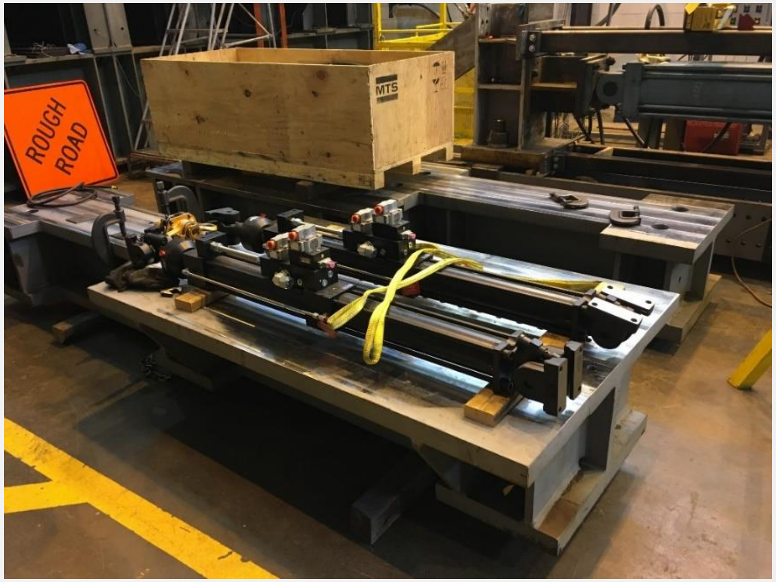
Laboratory Exercises: Characterization Testing of a Banded Rotatory Friction Damper

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



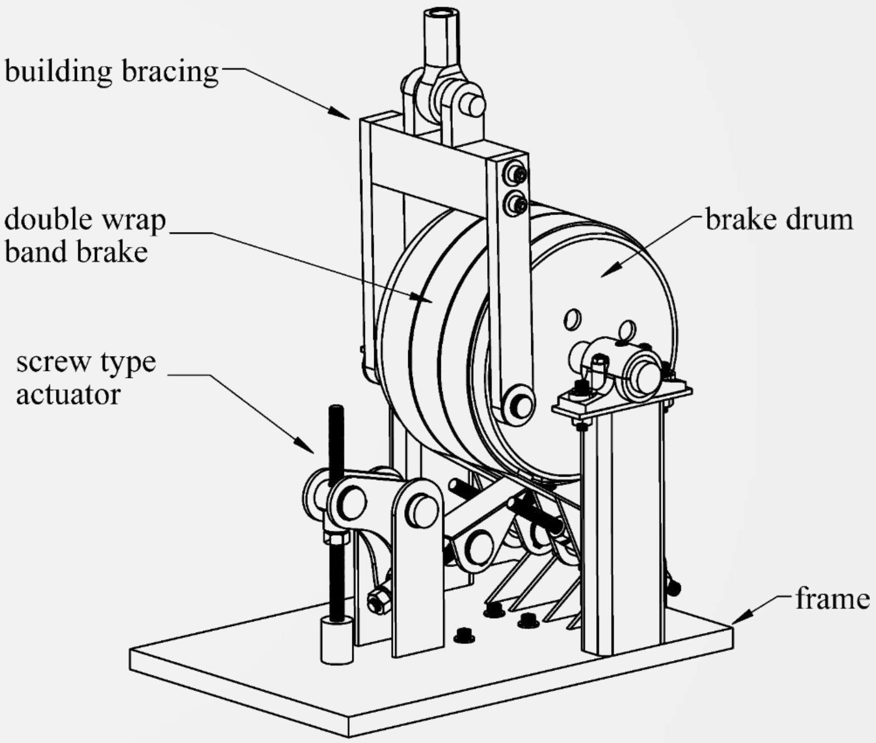
Actuator Specifications

	244.21G2	244.20G2s
Max Force	50 kN (11 kips)	82 kN (18.5 kips)
Max displacement	$\pm$254 mm ($\pm$10 in)	$\pm$177 mm ($\pm$7 in)
Max velocity	0.74 m/s (29 in/s)	0.43 m/s (51 in/s)
Servo Valve	30 gpm	90 gpm

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

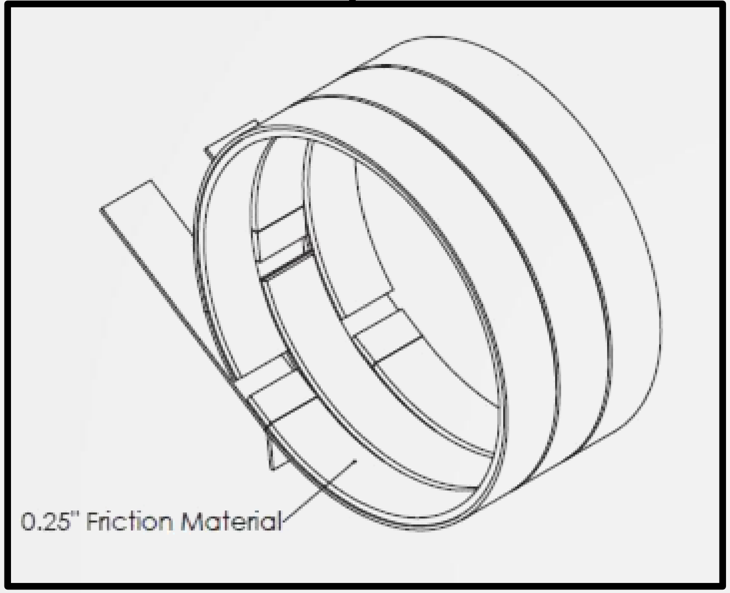


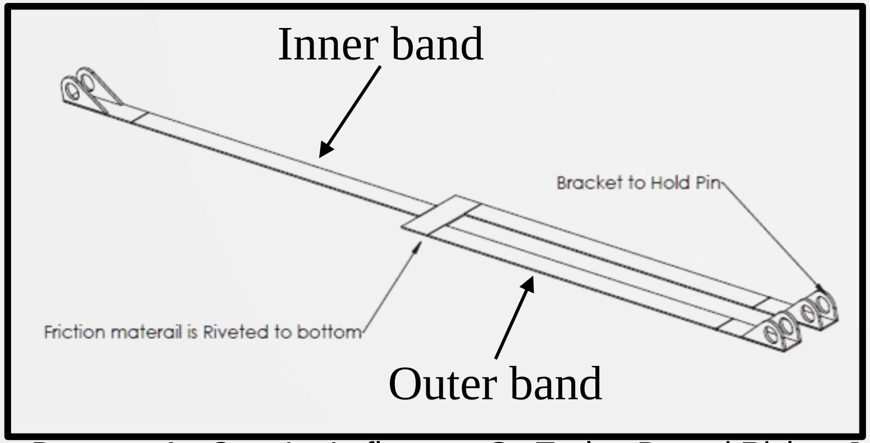
Banded Rotary Friction Damper (BRFD)

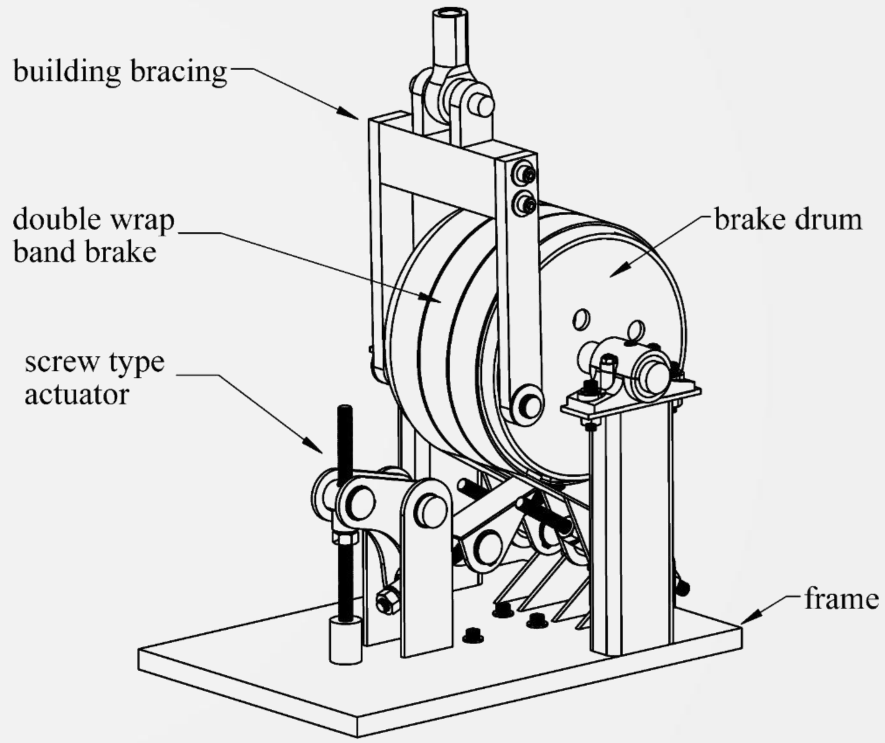
Downey, A., Cao, L., Laflamme, S., Taylor, D. and Ricles, J., (2016). High capacity variable friction damper based on band brake technology. Engineering Structures, 113, pp.287-298. doi:10.1016/j.engstruct.2016.01.035

Banded Rotatory Friction Damper (BRFD)

Double wrap band brake

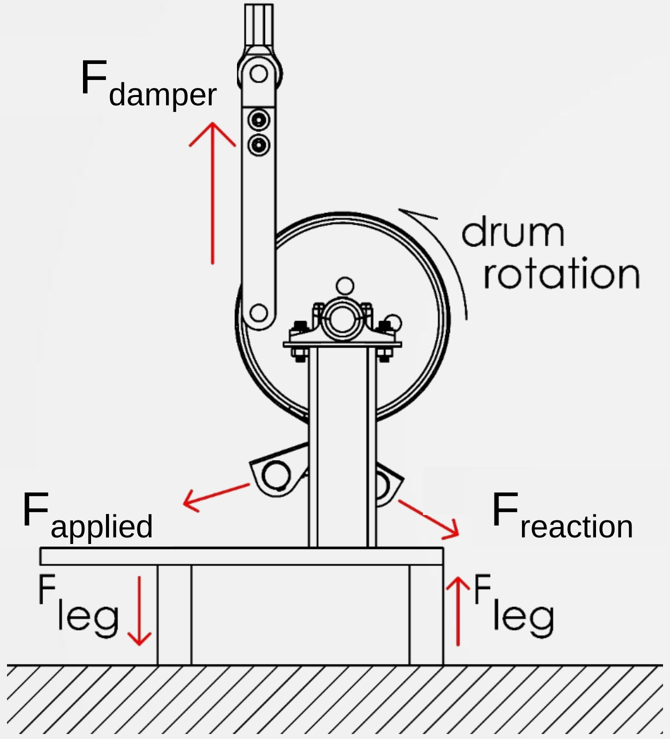




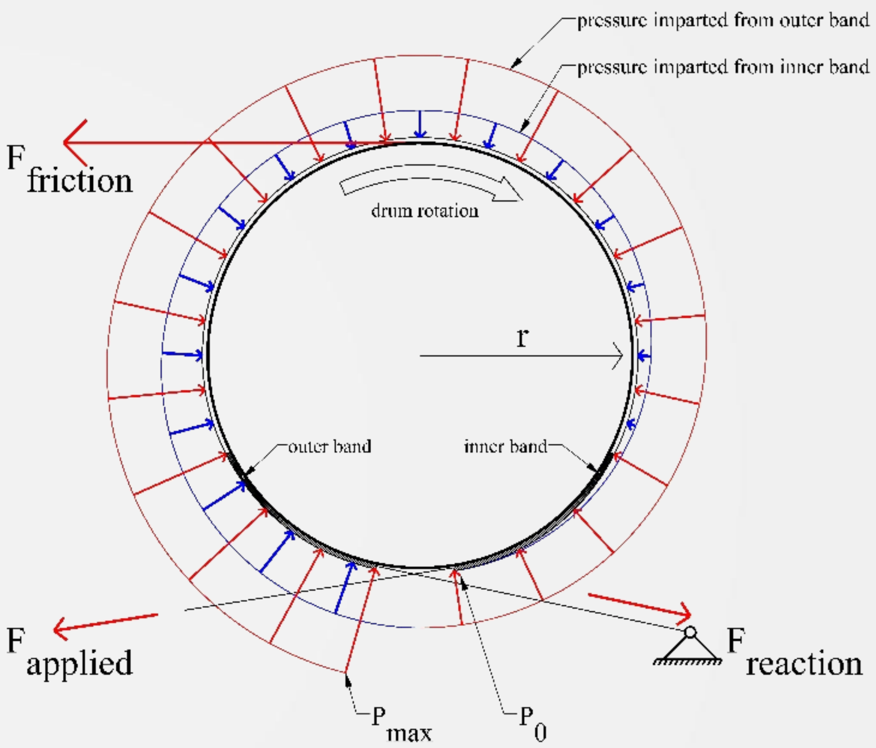


Downey, A., Cao, L., Laflamme, S., Taylor, D. and Ricles, J., (2016). High capacity variable friction damper based on band brake technology. Engineering Structures, 113, pp.287-298. doi:10.1016/j.engstruct.2016.01.035

Banded Rotary Friction Damper (BRFD)



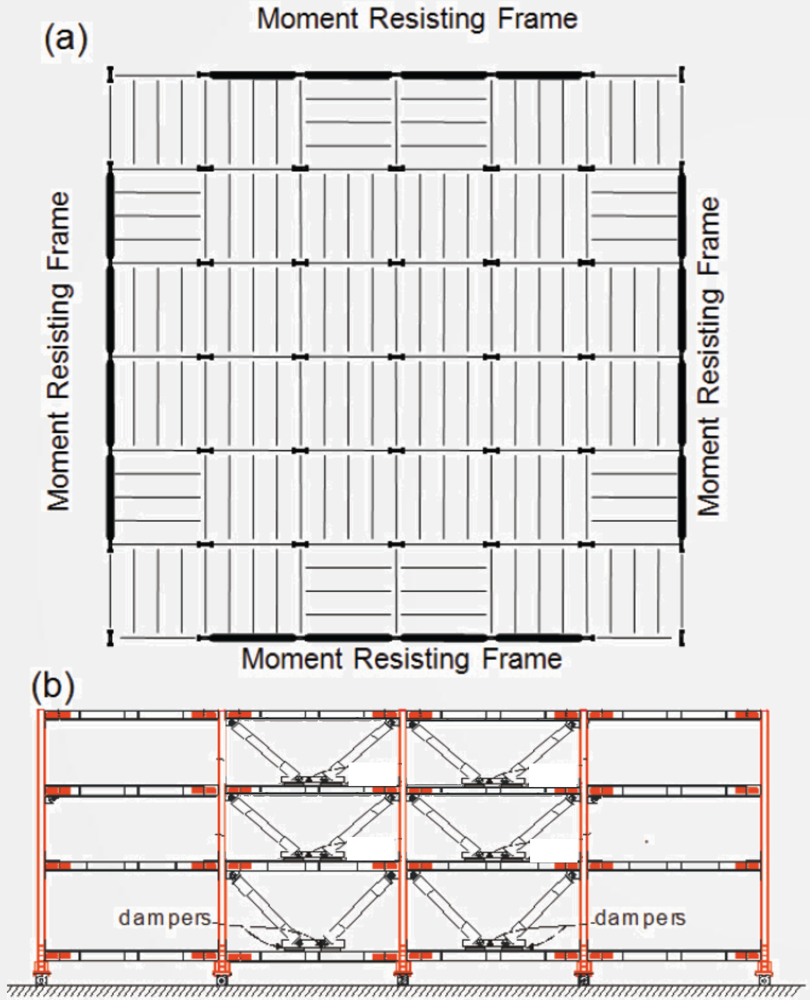
(a) Schematic of side view



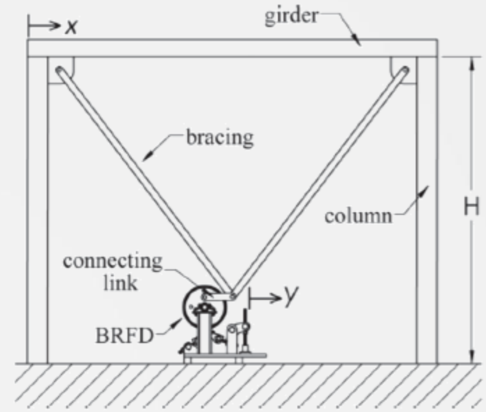
(b) Friction mechanism

Downey, A., Cao, L., Laflamme, S., Taylor, D. and Ricles, J., (2016). High capacity variable friction damper based on band brake technology. Engineering Structures, 113, pp.287-298. doi:10.1016/j.engstruct.2016.01.035

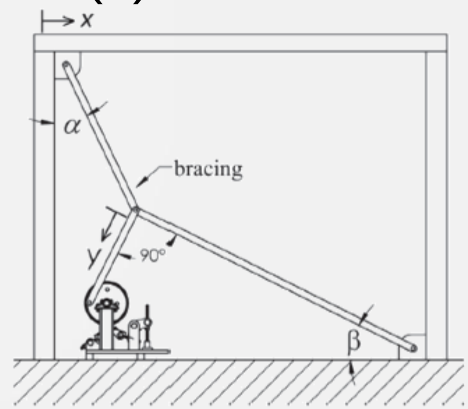
Placement of BRFD in Building



(a) Building Plan, and (b) Elevation



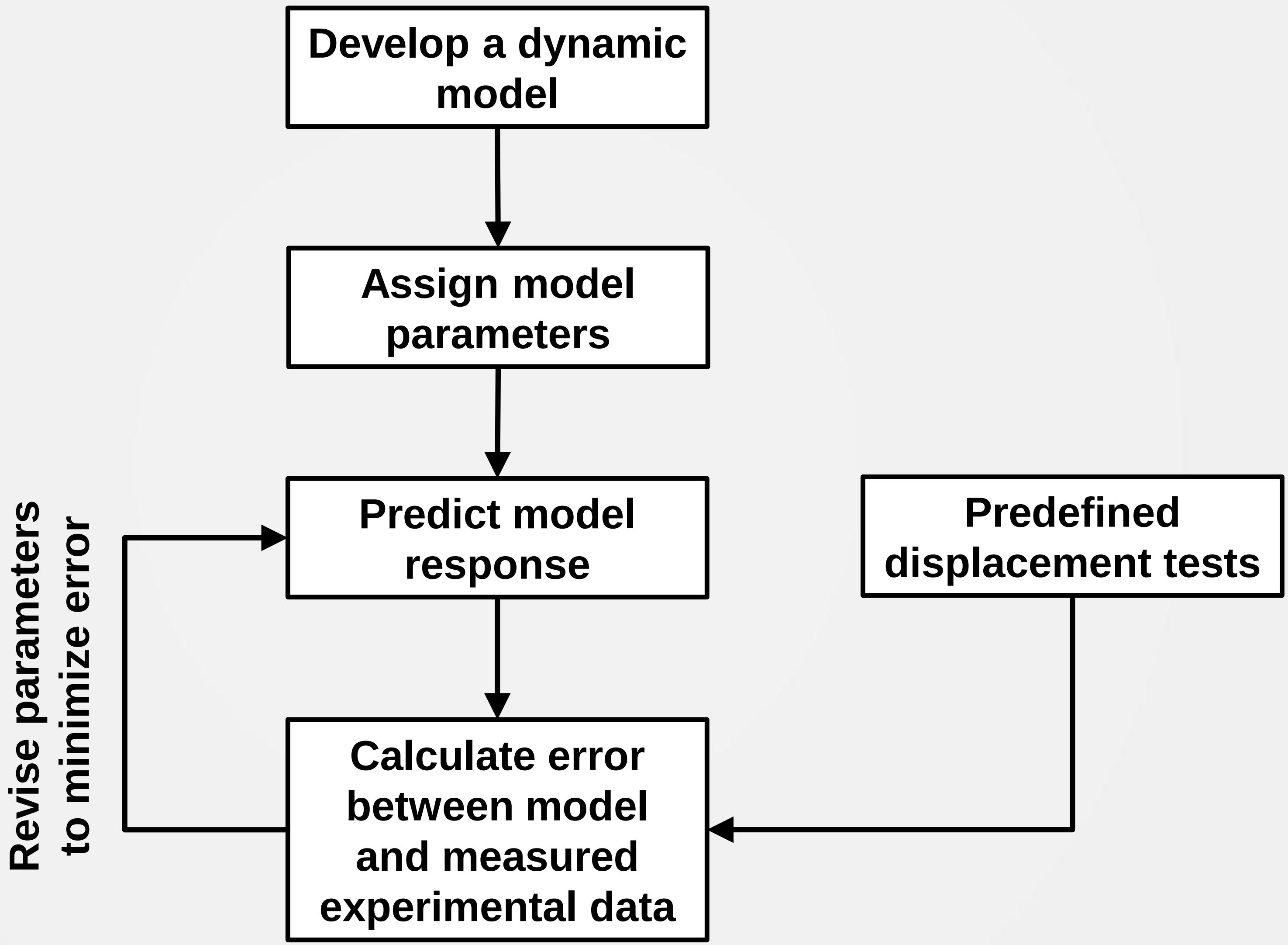
(a) Chevron



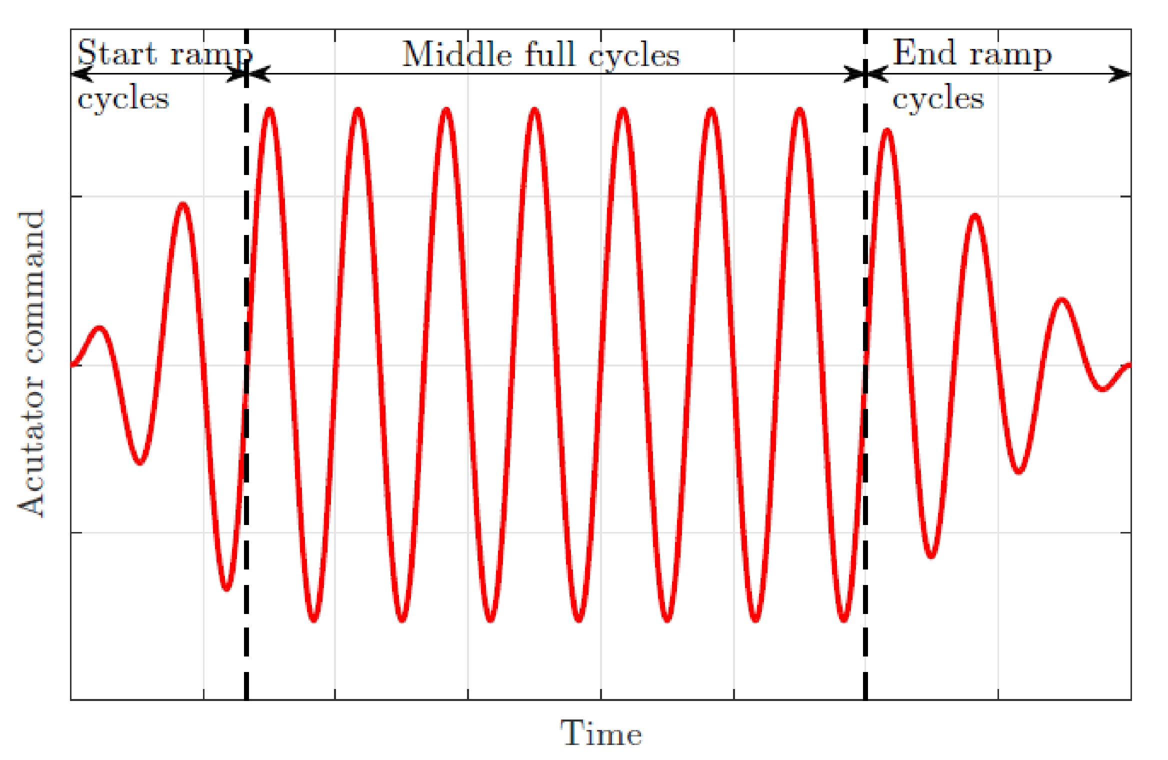
(b) Toggle

Two Possible Configurations for BRFD Installment

Procedure for Damper Characterization



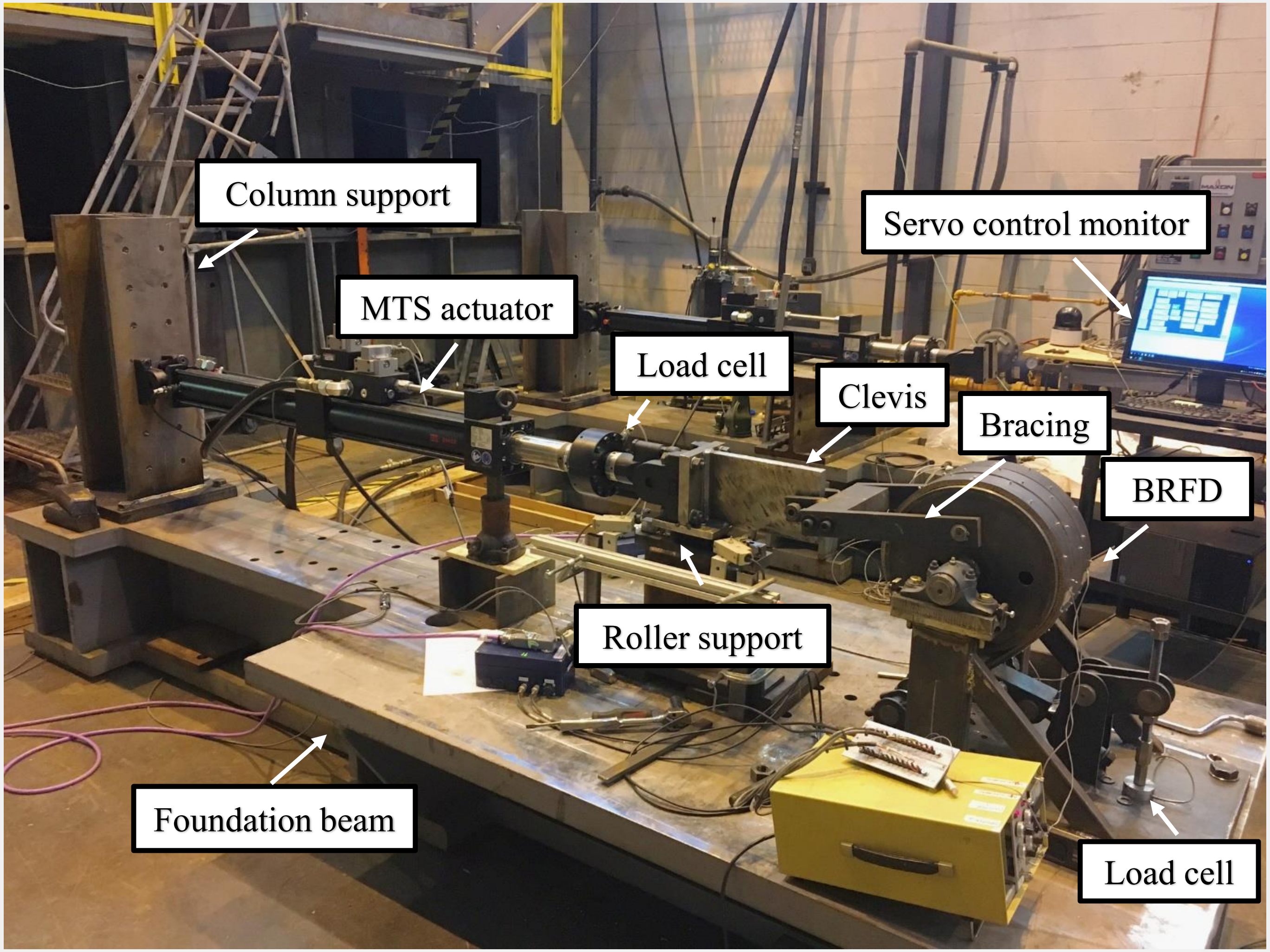
Characterization Test of BRFD Input Displacement and Test Matrix



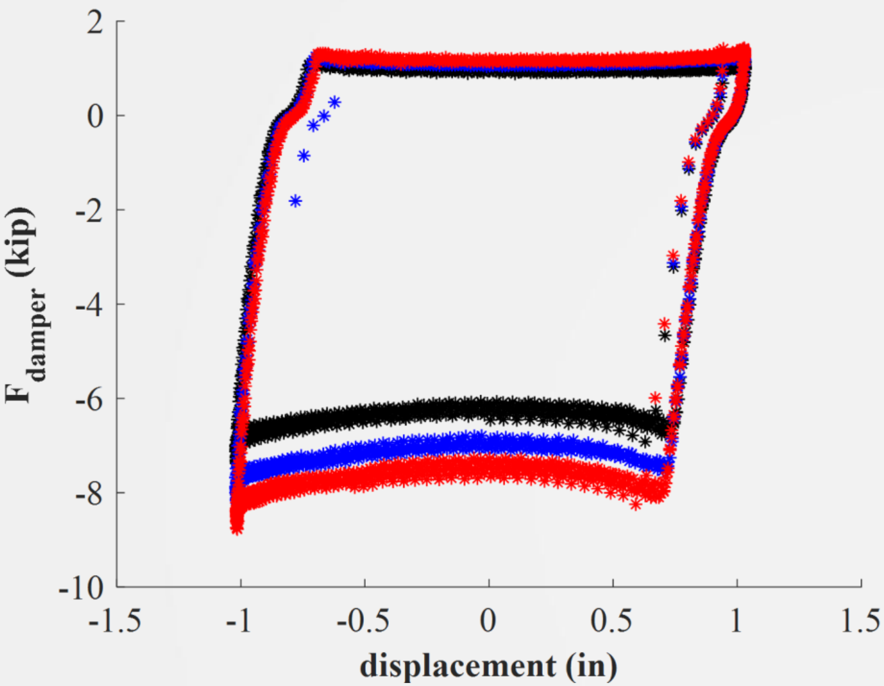
Amplitude mm (in.)	Frequency (Hz)	
	0.10	**0.50**
25.4 (1.0)	16 (0.63)	80 (3.2)

Numbers in the cells are max velocities in mm/s (in/s)

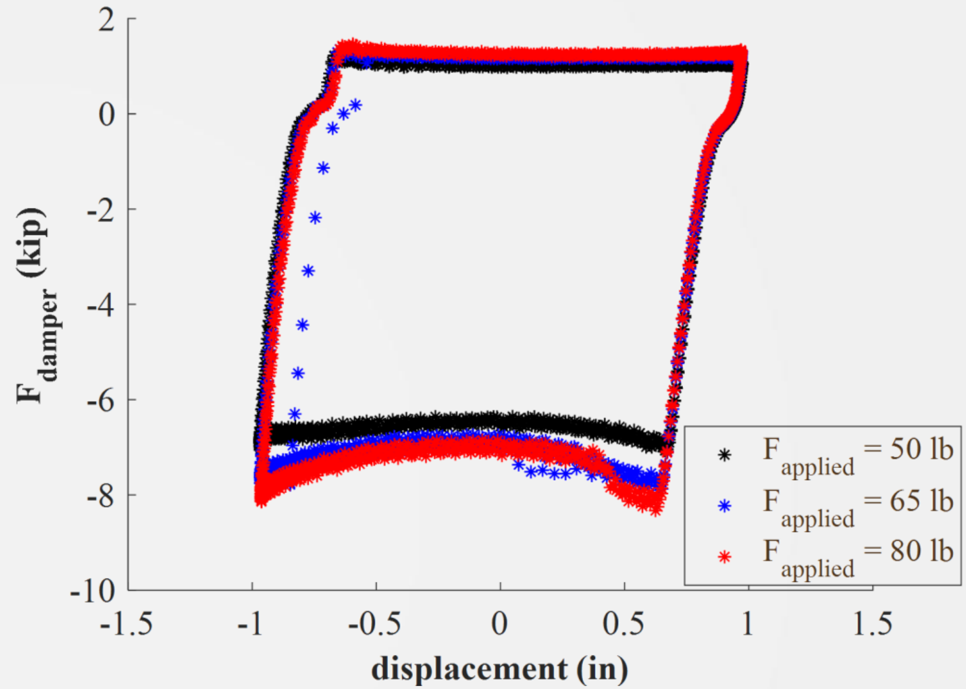
Characterization Test of BRFD – Test Setup



Dynamic Test Results



(a) f = 0.1 Hz



(b) f = 0.5 Hz

Harmonic displacement input:

- Amplitude : 1 inch
- Frequency : 0.1 Hz and 0.5 Hz
- Applied force, $F_{applied}$: 50, 65 and 80 lb

Force amplification ($F_{damper}/F_{applied}$) = 112

Computational Model for BRFD

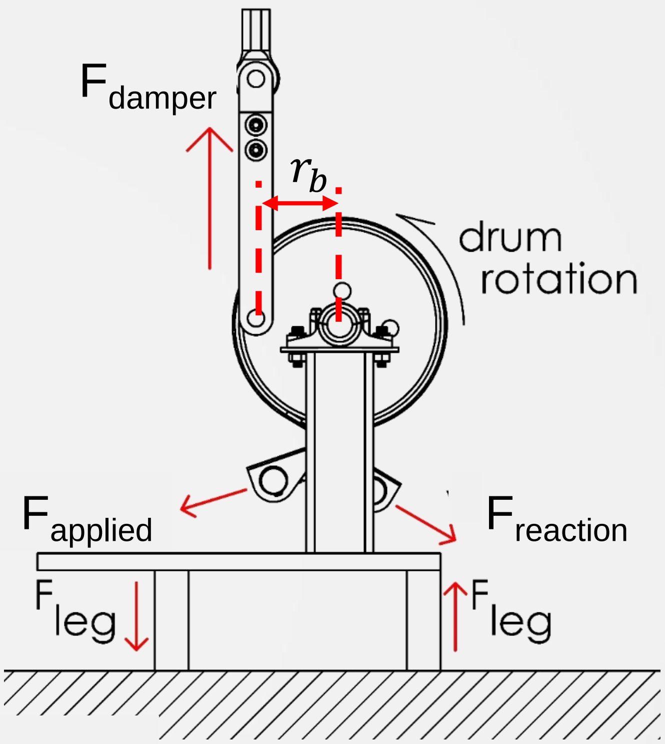
- **LuGre friction model**

$$F_{friction} = \sigma_0 z + \sigma_1 \dot{z} + \sigma_2 \dot{x}$$

$$\dot{z} = \dot{x} - \sigma_0 \frac{|\dot{x}|}{g(\dot{x})} z$$

$$g(\dot{x}) = F_C + (F_S - F_C)e^{-\left(\frac{\dot{x}}{\dot{x}_S}\right)^2}$$

  - σ_0, σ_1 and σ_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



$$F_{damper} = \frac{F_{friction} r}{r_b}$$

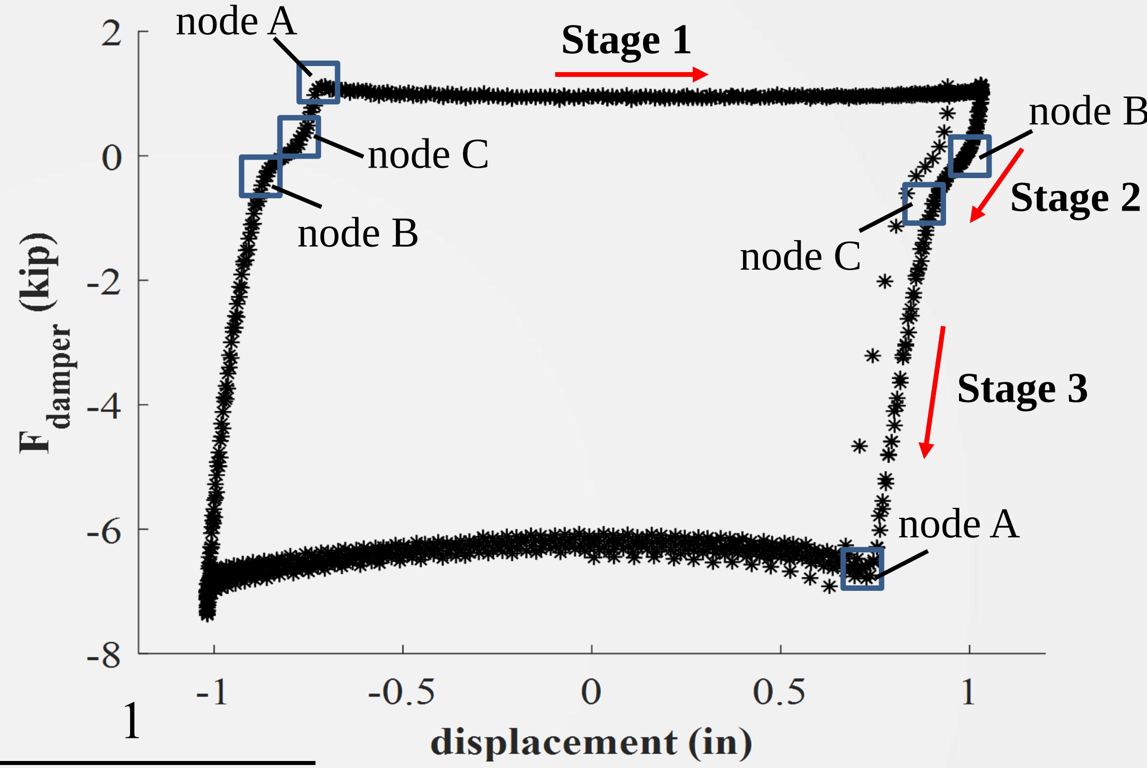
where r_b is the distance from the center of the drum to the brace and r is the drum radius

Cao, L., Downey, A., Laflamme, S., Taylor, D. and Ricles, J., (2015). Variable friction device for structural control based on duo-servo vehicle brake: Modeling and experimental validation, Journal of Sound and Vibration 348 41-56 doi:10.1016/j.jsv.2015.03.011.

Downey, A., Cao, L., Laflamme, S., Taylor, D. and Ricles, J., (2016). High capacity variable friction damper based on band brake technology. Engineering Structures, 113, pp.287-298. doi:10.1016/j.engstruct.2016.01.035

3 Stage Dynamic Model for BRFD

- Stage 1 (node A → node B)
  F_1 = 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 γ_1, γ_2 are constants

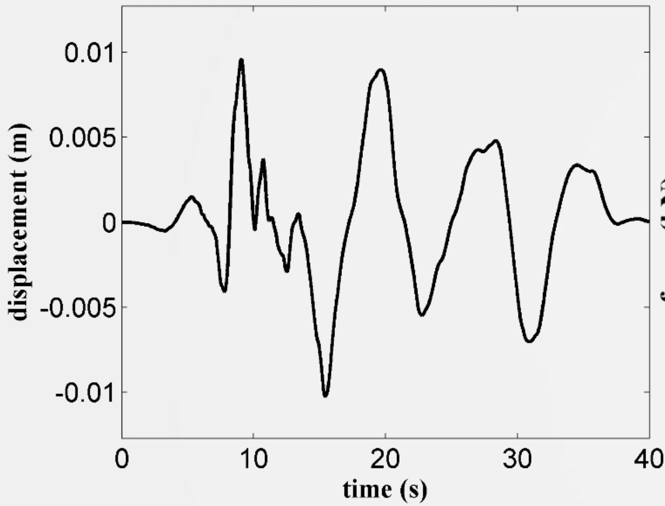
- Stage i ⟶ Stage j

$$F_{\text{friction}} = (1\text{-m(x)}) \times F_i + \text{m(x)} \times F_j$$

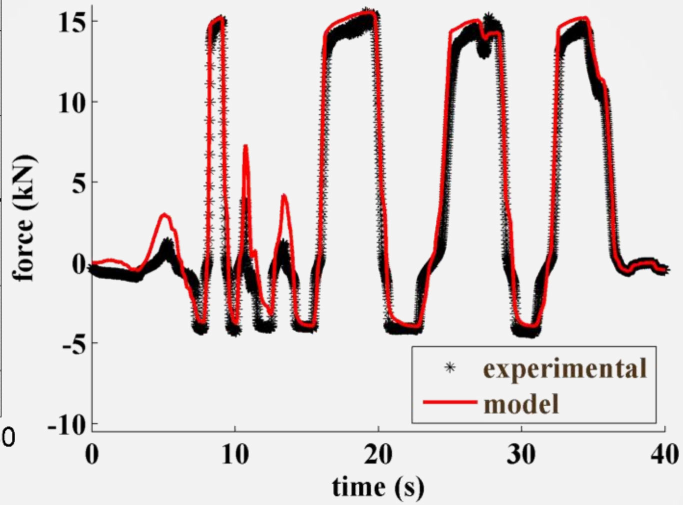
Cao, L., Downey, A., Laflamme, S., Taylor, D. and Ricles, J., (2015). Variable friction device for structural control based on duo-servo vehicle brake: Modeling and experimental validation, Journal of Sound and Vibration 348 41-56 doi:10.1016/j.jsv.2015.03.011.

Damper Characterization Results

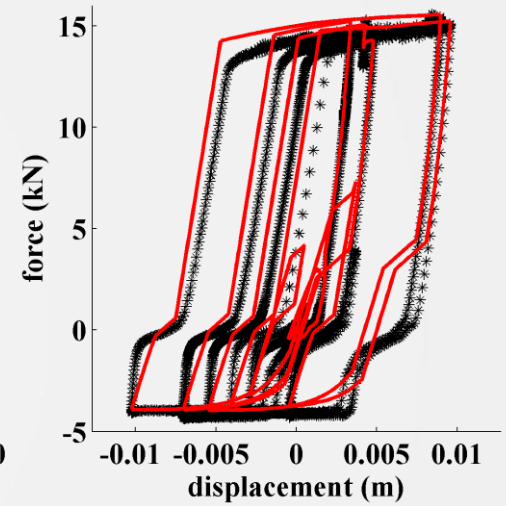
- Imperial Valley earthquake with $F_{applied}$= 30 lb



(a) time history of damper displacement



(b) time history of damping force F_{damper}



(c) force-displacement hysteretic response

Downey, A., Cao, L., Laflamme, S., Taylor, D. and Ricles, J., (2016). High capacity variable friction damper based on band brake technology. Engineering Structures, 113, pp.287-298. doi:10.1016/j.engstruct.2016.01.035