NHERI REU Program
Summer 2019

FABRICATION OF A SEMI-ACTIVE FRICTION DAMPING DEVICE

MITCHELL STILES

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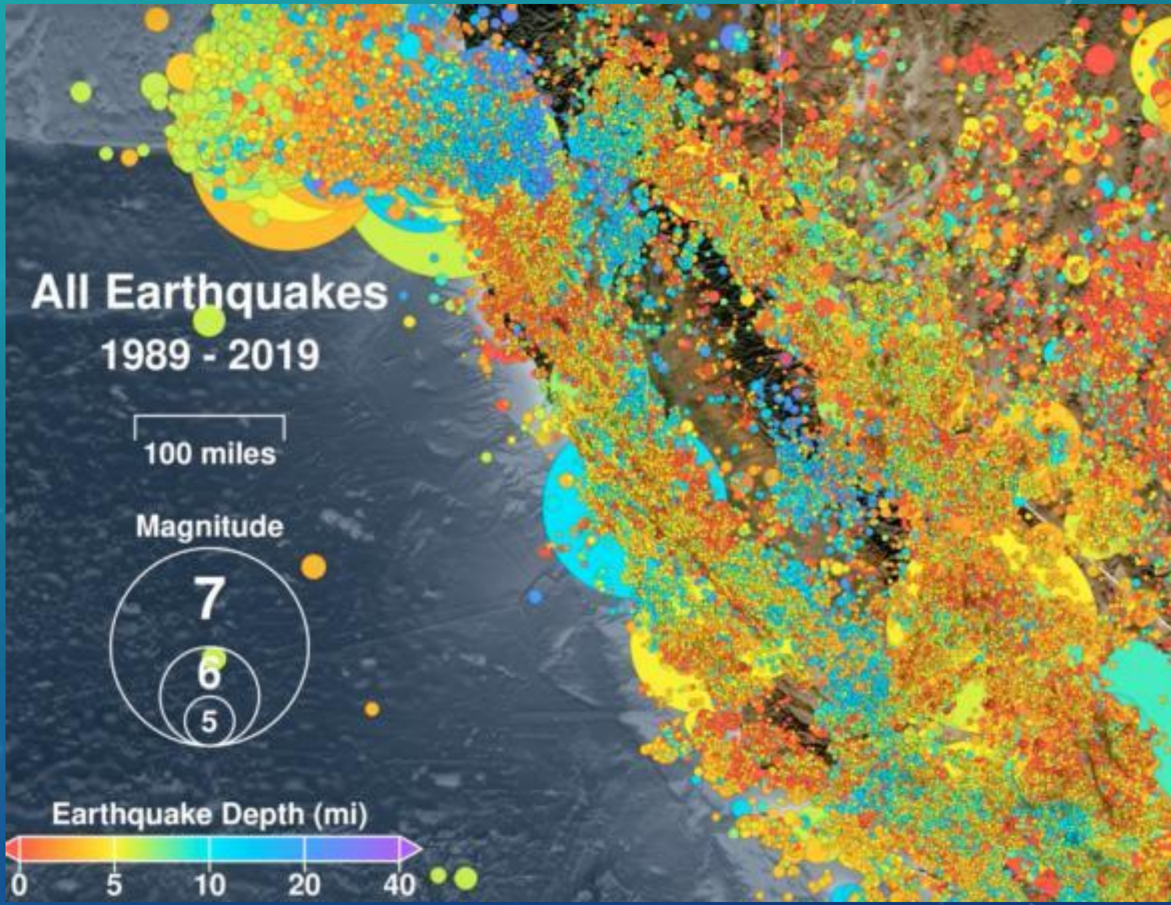
NATURAL DISASTERS IN 2017

- The year 2017 brought about a world insured catastrophe losses of $143 billion between weather, man-made, and earthquake disasters
- Earthquakes alone in 2017 had damages costing about $1.615 billion
- Researchers strive to create new projects and ideas to mitigate effects, collect post-disaster data, and predict different aspects of these events
- My project's goal is to mitigate these effects and lessen civil infrastructure damages caused by earthquakes (in turns saves money from damages)

Data from Insurance Information Institute
https://www.iii.org/fact-statistic/facts-statistics-earthquakes-and-tsunamis

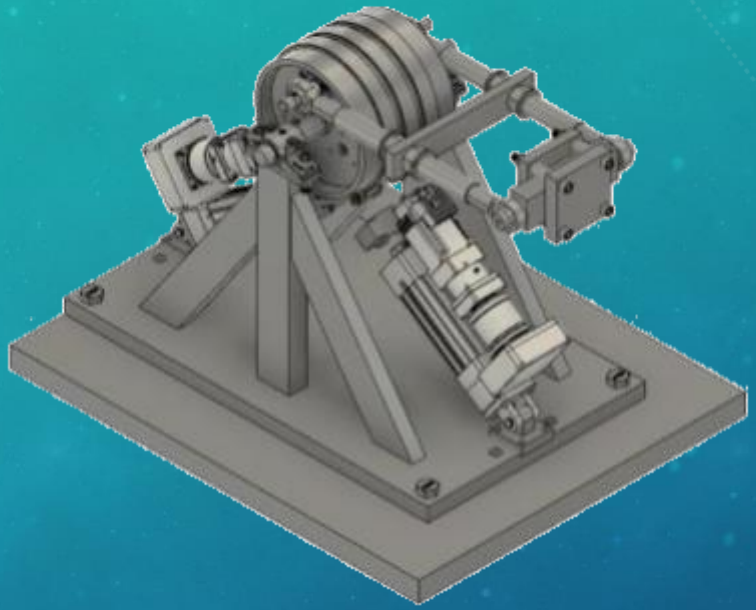


Pictured: Thirty years of quakes in the southwestern United States.

https://www.forbes.com/sites/robinandrews/2019/07/23/watch-30-years-of-earthquakes-rock-california-in-this-remarkable-animation/#5a363eab29ae

BACKGROUND

- The NHERI Lehigh facility was the center for the fabrication of a third generation device, termed the Semi-Active Banded Rotary Friction Device (SABR-FD)
- This new device is being engineered to create a stiffer design and incorporate electric actuators to create a semi-actively controlled friction damping device
- Semi-active mode combines the benefits of passive mode and active mode [4]



Rendering of SABR-FD Design

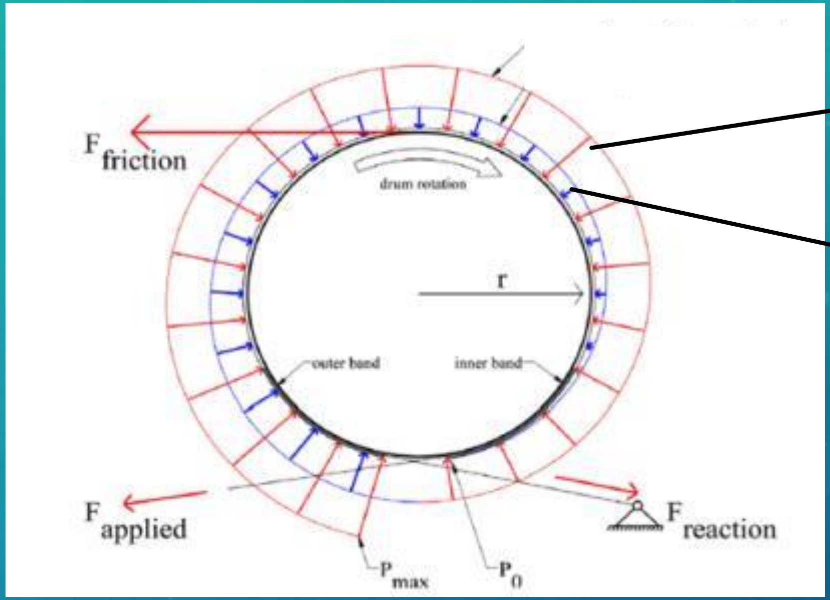
Structure-to-drum connection

BACKGROUND (CONT.)

- The device uses band brake technology to create friction around the outside of the drum. Simple relation exists between the applied, damper, and reaction force[3]:

$$F_{reaction} = F_{applied} + F_{Damper}$$

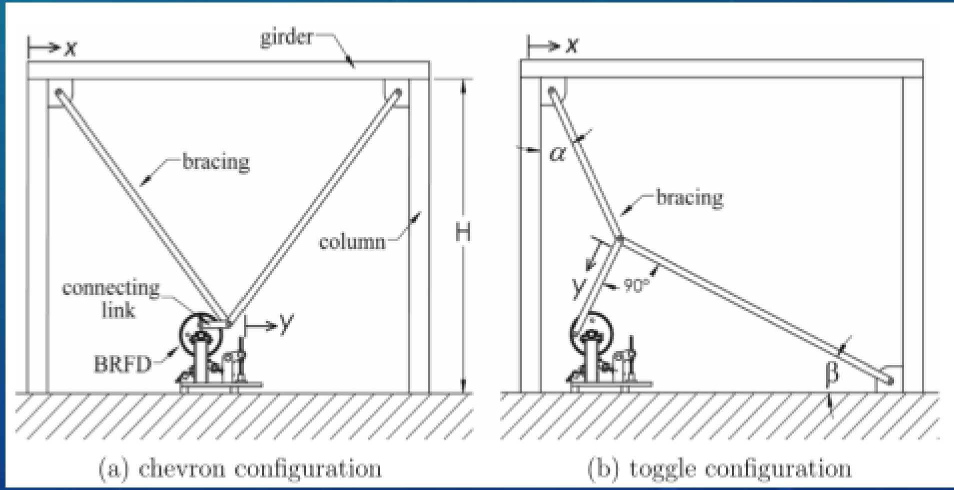
- Variable friction devices provide high energy dissipation by using a friction force that is controlled by an actuator to vary the normal force [1]



Pressure imparted from outer band

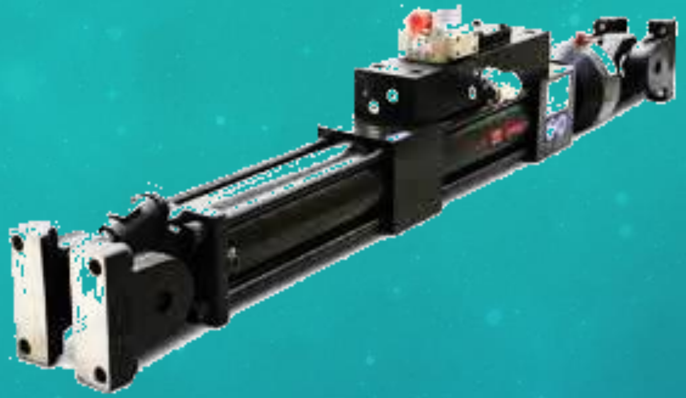
Pressure imparted from inner band

Forces Acting on the SABR-FD [1]



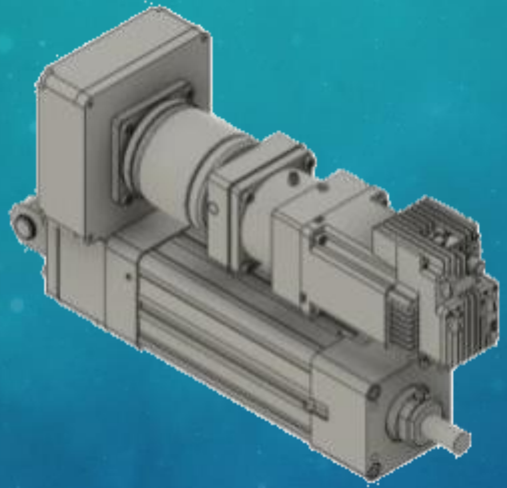
Two possible configurations for the SABR-FD installed within a building's lateral load resisting structural system [1]

MATERIALS, INSTRUMENTATION, AND SOFTWARE



MTS DuraGlide™ 244.22 Hydraulic Actuator

Transducer Techniques load cells

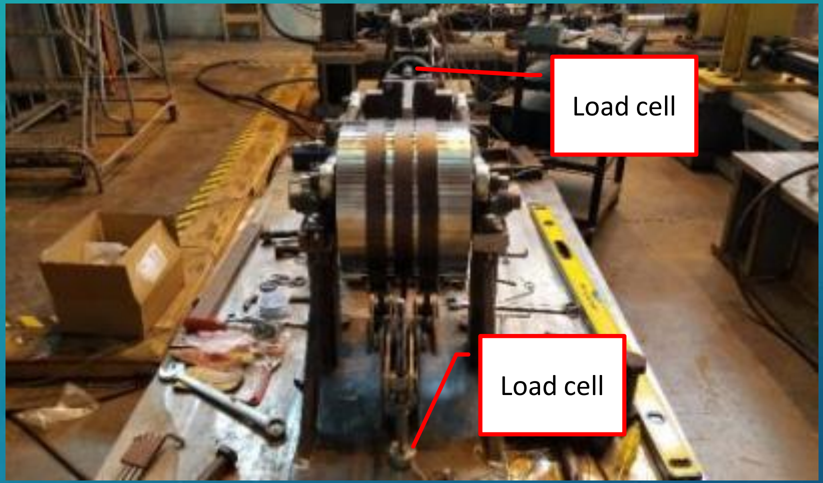


TOLOMATIC_RSA50 BN02 SK3.5 RP2 HT1 AMI3D1B1 MET PCD CR56 with PNII-034-025 GRHD

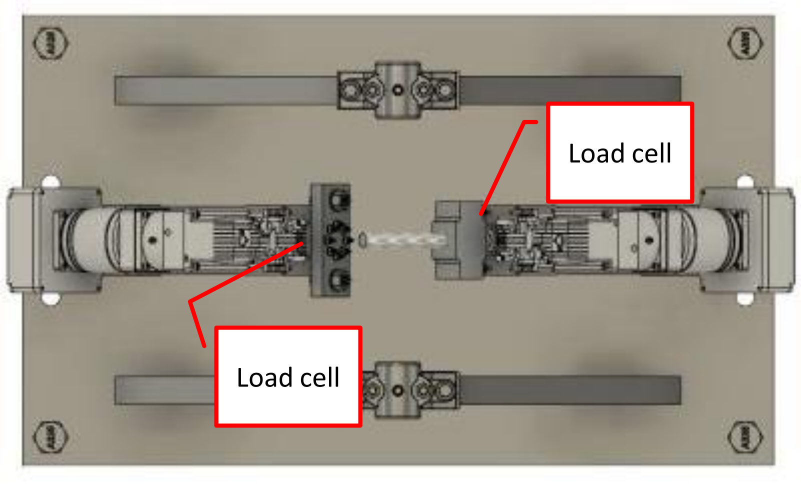
- MTS DuraGlide™ 244.22 Hydraulic Actuator
- Transducer Techniques load cells
- Tolomatic electronic actuators provided by PennAir
- Modeling and simulation in AutoCAD Fusion 360 and SolidWorks
- Pulsar runs the characterization testing

INSTRUMENTATION IMPLEMENTATION

- Load cells are currently located under the screw jack threaded rod
- MTS DuraGlide™ 244.22 Hydraulic Actuator load cell is used to measure damper force F_{Damper}
- Electric actuators can adjust to different applied and reaction forces $F_{reaction}$ and $F_{applied}$
- Electric actuator load cells will measure tension forces $F_{reaction}$ and $F_{applied}$ developed in the damper



Load cell locations for current setup



Location of load cells and actuators in the semi-active mode

ORIGINAL CONNECTION AND DRUM

Old drum with previous connection

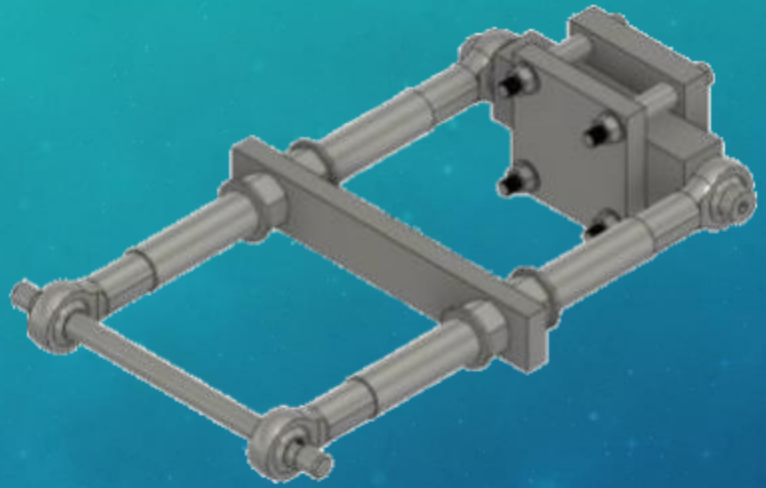
New steel drum

- Original connection had slop
- More moving parts than needed
- The original drum was completely hollow with plates on the outer edges
    - New drum has three plates (one in middle, and two at the outer edges, but about 1.25 inches in from the edge)
- New drum allows for the use of bearings to help hold connecting rod in place from the new structure-to-drum connection

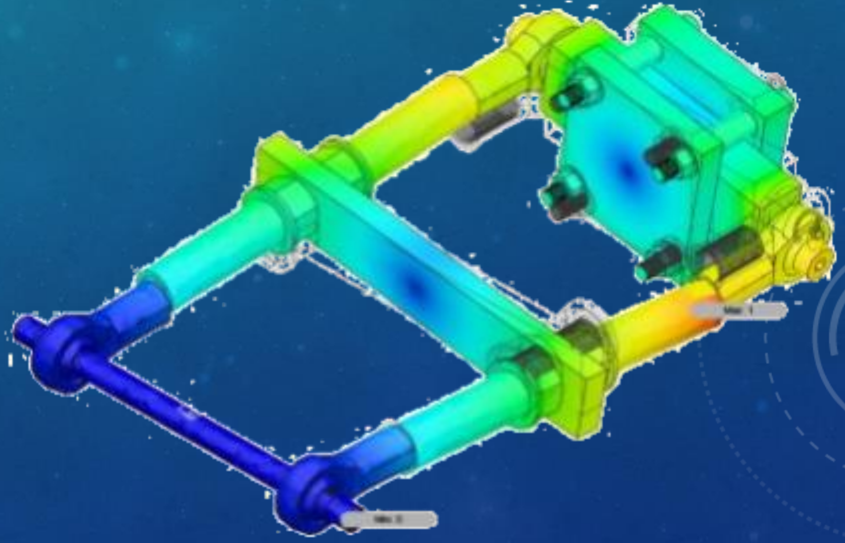
METHODOLOGY (DRAWINGS AND SIMULATION)

- This third-generation friction device takes a lot of the second-generation device (BRFD) ideas and improves upon them
- New structure-to-drum connection
  - Involves threaded rods and rod ends to transfer force from MTS actuator
  - Improves stiffness of connection
- Modal analysis gives the different modes of vibration; i.e. different shape that can be taken up by the structure during vibration. Mode shapes have corresponding mode frequencies

Mode Number	Frequency (Hz)
1	60.64
2	71.9
3	275.6
4	285.6
5	367.6

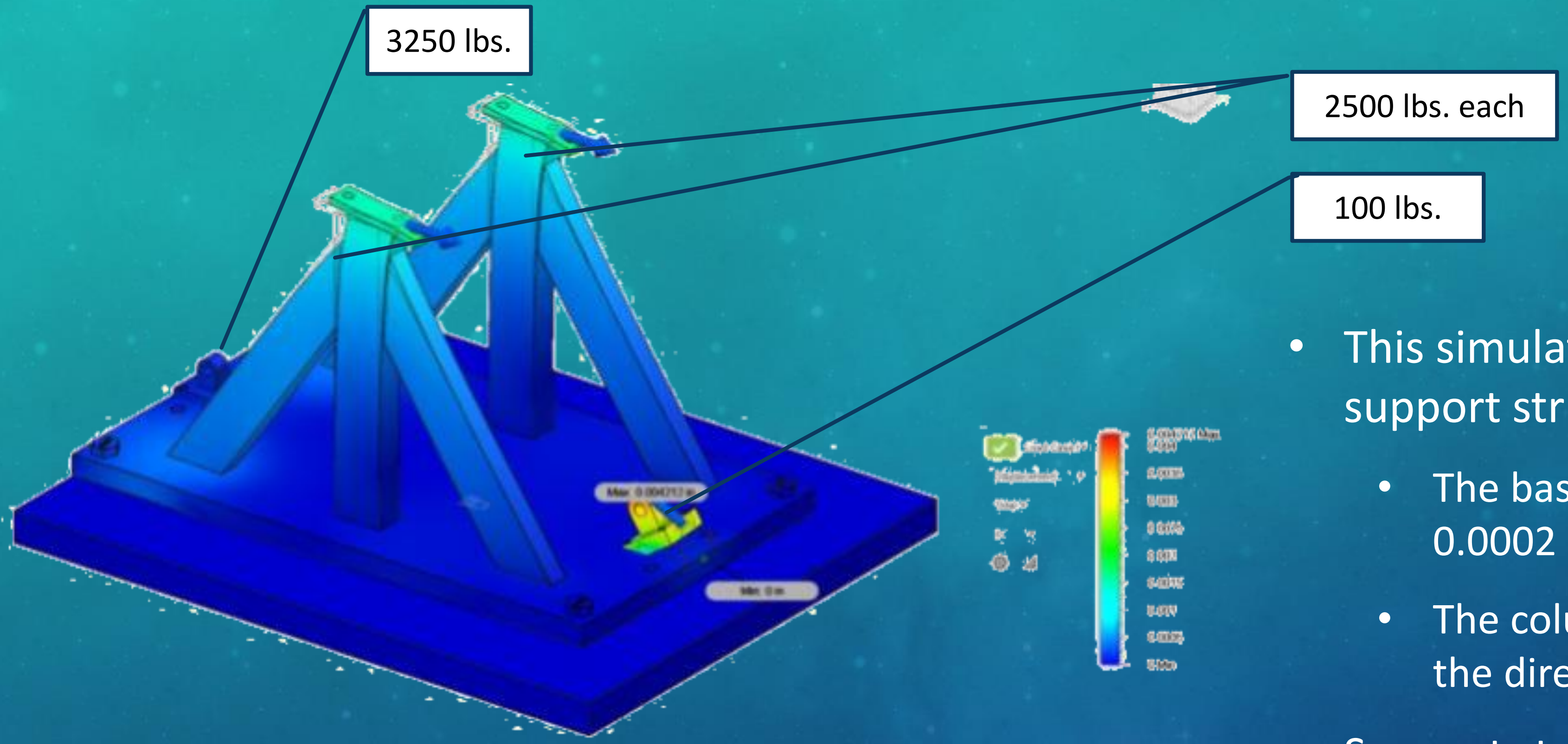


New structure to drum connection



Modal analysis of connection rendition

METHODOLOGY, STATIC ANALYSIS



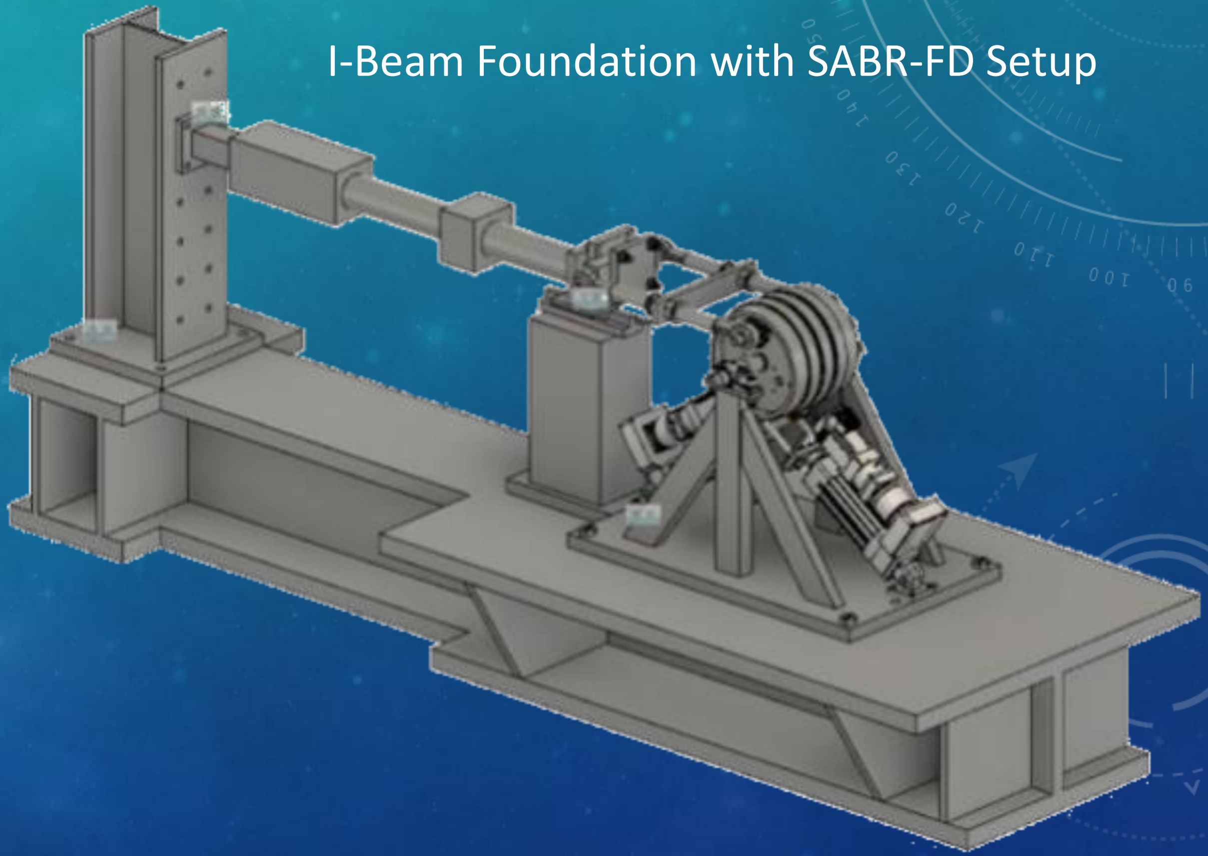
Input Force	Displacement
2500 lbs. (right support)	0.00198 in.
2500 lbs. (left support)	0.00203 in.
100 lbs. (front clevis)	0.00421 in.
3250 lbs. (rear clevis)	0.05 in.

- This simulation is of the new frame and support struts
  - The base plate deflects a maximum of 0.0002 inches (upwards)
  - The columns will displace 0.0019 inches in the direction of force acting on the support
- Support struts were originally plates of steel, but would have increased the weight significantly
- Electric actuators mount to the base from the clevis receivers

FULL SETUP MODELING

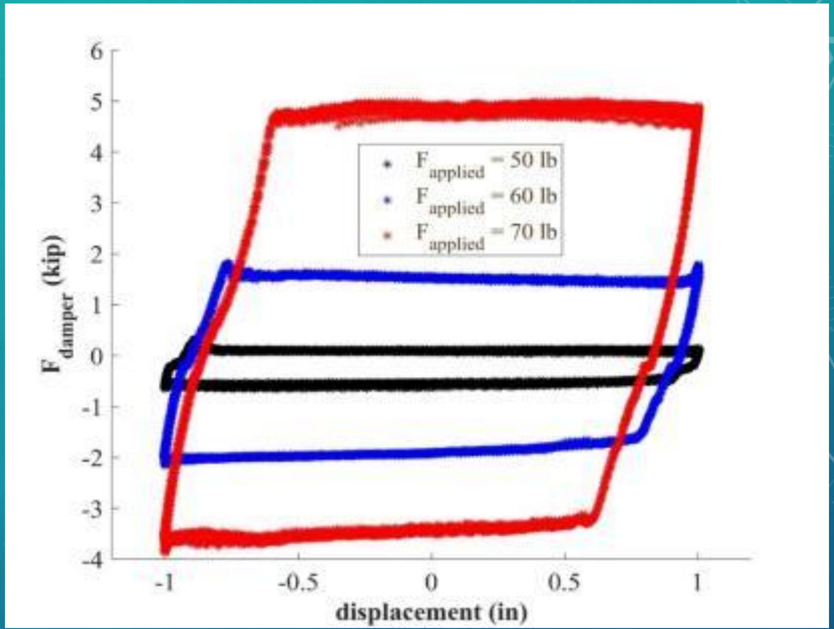
- This is the foundation beam the SABR-FD is being mounted to with a 22 kip actuator
- New sliding bearing block

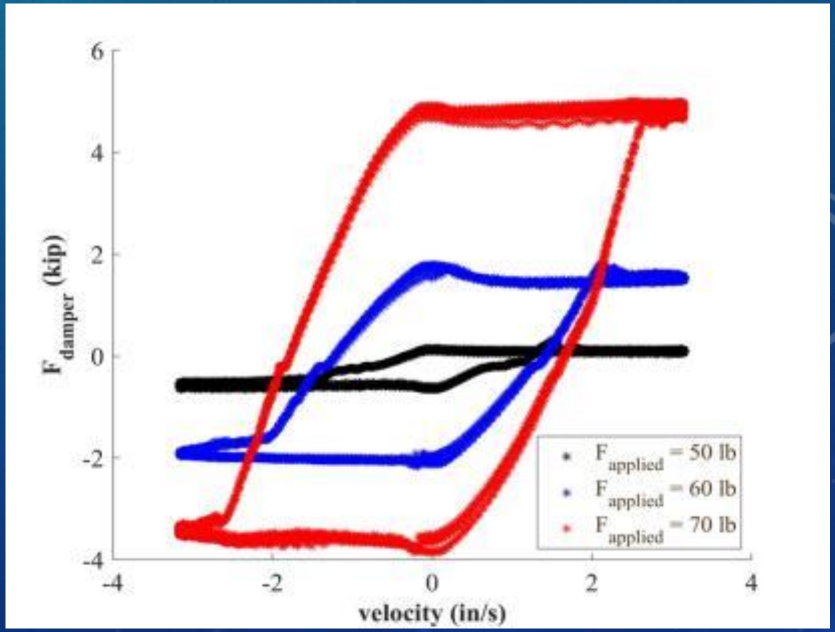
I-Beam Foundation with SABR-FD Setup



PRELIMINARY RESULTS

BRFD_EQmotion_small_.mp4





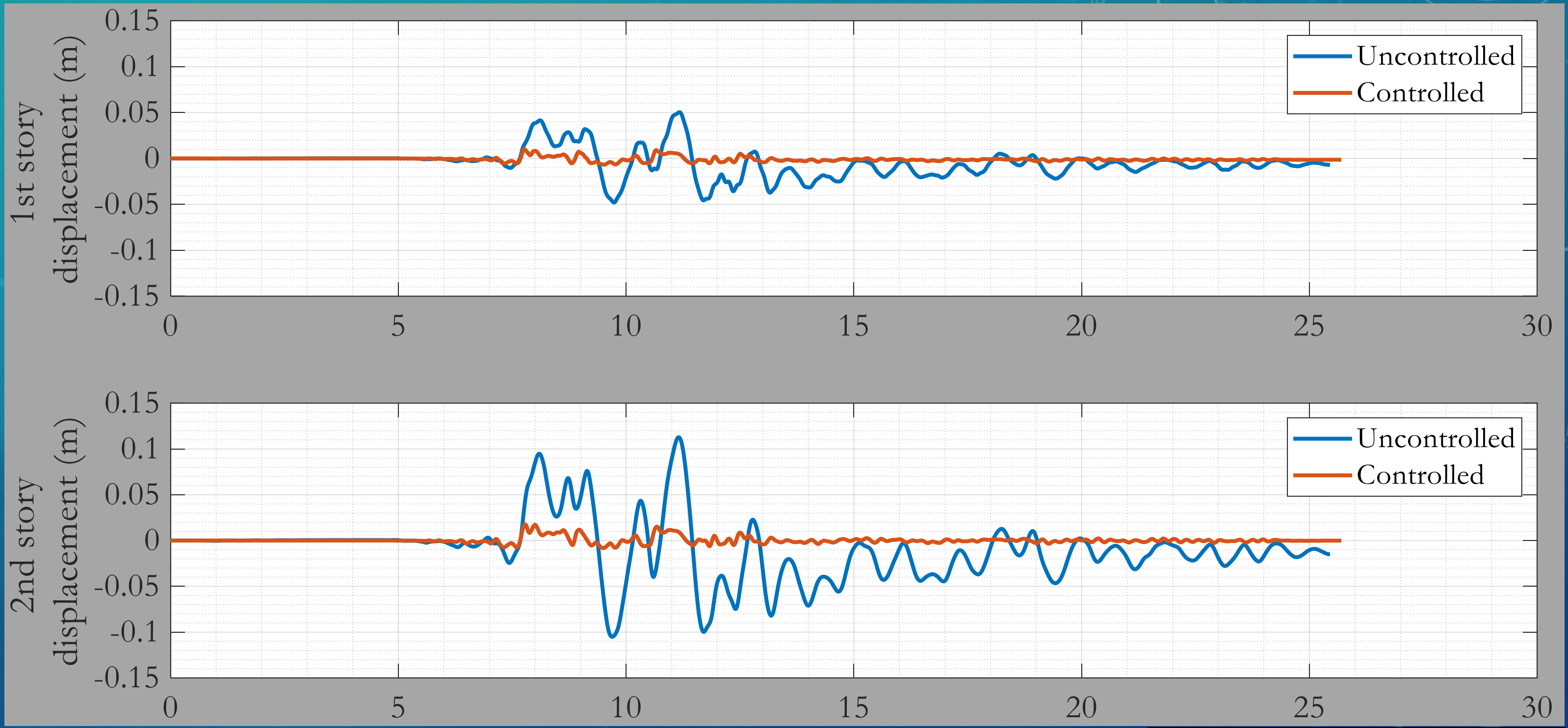
Force vs. displacement and Force vs. velocity graphs

PRELIMINARY RESULTS

- Six tests were run
  - RSN1602_DUZCE_BOL090, DBE
  - RSN1602_DUZCE_BOL090, MCE
  - RSN1176_KOCAELI_YPT150, DBE
  - RSN1176_KOCAELI_YPT150, MCE
  - RSN182_IMPVALL_H_H-E07230, DBE
  - RSN182_IMPVALL_H_H-E07230, MCE
- DBE: Design Based Earthquake with 10% probability of exceedance in 50 years;
- MCE: Maximum Considered Earthquake with 2% Probability of exceedance in 50 years.

RSN1176_KOCAELI_YPT150, MCE EQ file (provided by Safwan Al-Subaihawi)

First story reduction = -80%



Second story reduction = -84%

Reduction = (peak floor displacement with the damper - peak floor displacement without the damper) * 100 / (peak floor displacement without the damper)

Discussions

- The drum was tested at different frequencies of 0.2, 0.5, 1.0, 2.0, and 3.0 Hz with a constant amplitude of 1 inch
- The drum experienced 50-70 lbs.. of applied force and a maximum damping force of 5 kips
    - These are the boundary conditions for the SABR-FD
    - Electric actuators will be able to supply the necessary holding force of 3250 lbs.., distributed by PennAir from Tolomatic
- New setup with 22 kip actuator will be setup in the fall (semi-active control)

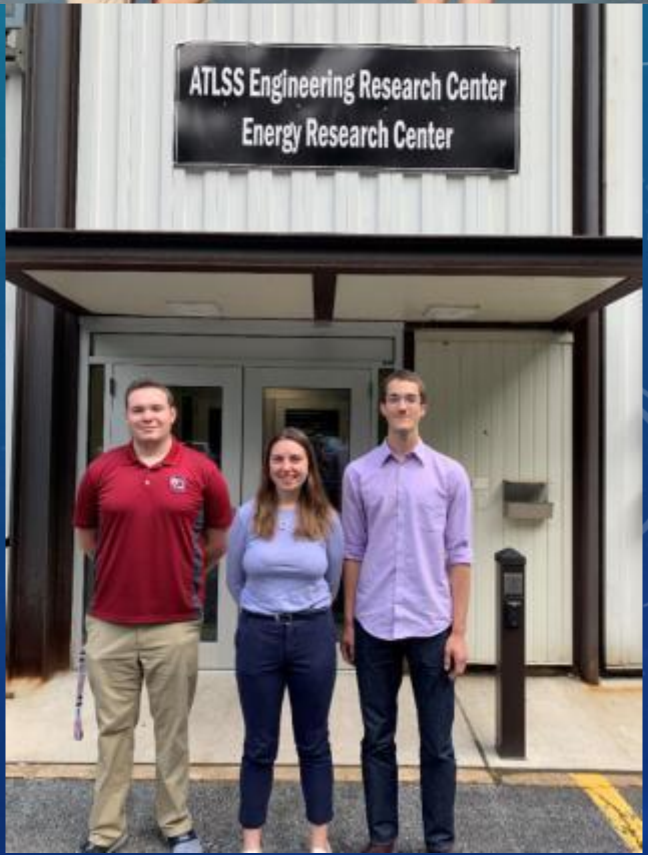
Conclusions

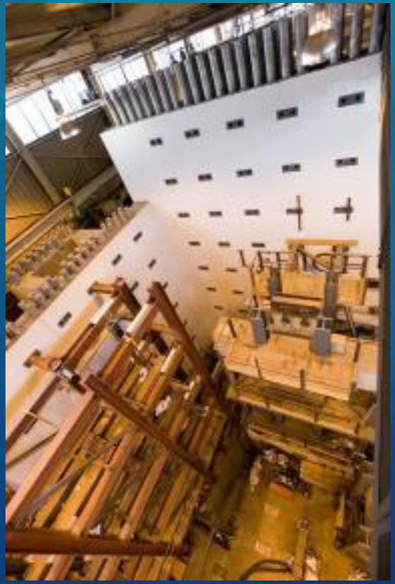
- New damper can enable civil infrastructural systems to achieve a high level of performance, with minimal damage under severe earthquakes
- The high performance leads to resiliency being achieved
- Actuators needed only need 48 VDC to operate, so low power availability should be applicable

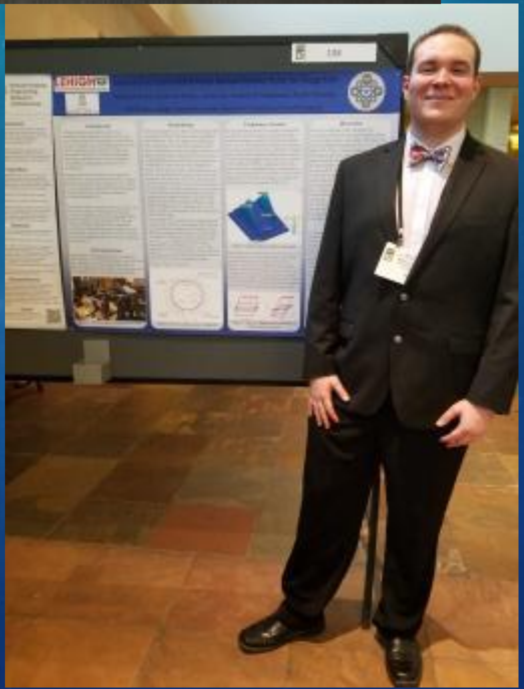
FUTURE RESEARCH

- Fabrication of the new base and frame will be happening in the next few weeks
- Designing a stiff base structure in Fusion 360 ensures the goal to do hybrid simulations with multiple dampers including the new SABR-FD
- The project will continue through the collaboration of the University of South Carolina and Lehigh University.
- Tests on the SABR-FD will be conducted once the electric actuators arrive at Lehigh University
- Once the proof of concept design is validated, additional configurations for different applications will be considered

MY EXPERIENCES AT LEHIGH UNIVERSITY







LEARNING OUTCOMES

- By working at the ATLSS Engineering Research Center at Lehigh University
  - I have learned what goes on behind research
  - I learned about simulations in the real world being implemented into computer analysis
  - I learned more about the applications of damping devices and the different ways they can mitigate earthquakes
- How this research can be used to mitigate earthquakes
  - Larger devices with different configurations can create base isolation
  - Semi-active damping can be implemented in low power situations and be allowed to change the damper force
- After doing this research over the summer, I can say that I would continue towards graduate school at some point and do more research to benefit society

ACKNOWLEDGEMENTS

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- [1] 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, 287-298.
- [2] 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.
- [3] Baker AK. Industrial brake and clutch design. Pentech Press; 1992.
- [4] Saaed TE, Nikolakopoulos G, Jonasson J-E, Hedlund H. A state-of-the-art review of structural control systems. J Vib Control 2015; 21:919-37.