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Modular Testbed Building: Opportunities for Future Research

Chris Pantelides, University of Utah

Joint Researcher Workshop
UC San Diego, Lehigh & SimCenter

December 16-17, 2019
University of California, San Diego

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- Large-scale testbed building is funded as a shared use equipment for use with the Large High Performance Outdoor Shake Table (LHPOST) at UCSD
- Modular Testbed building designed to be reusable
- Enable low-cost testing of components and systems under simulated dynamic 3D loading
- Potential use: seismic protective systems, lateral force resisting systems, nonstructural systems and others

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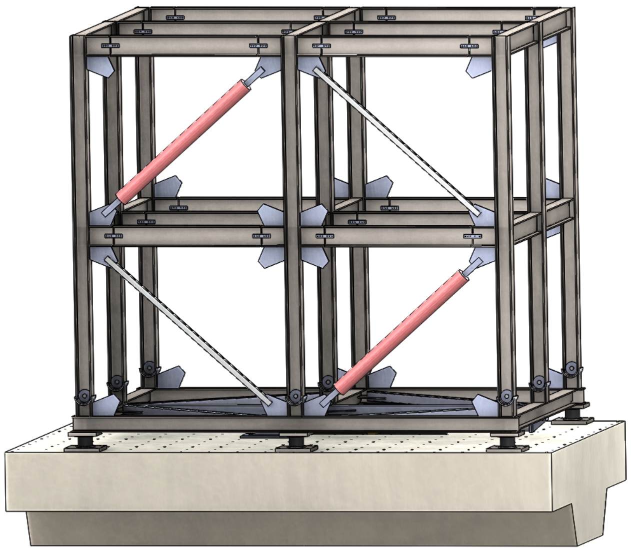

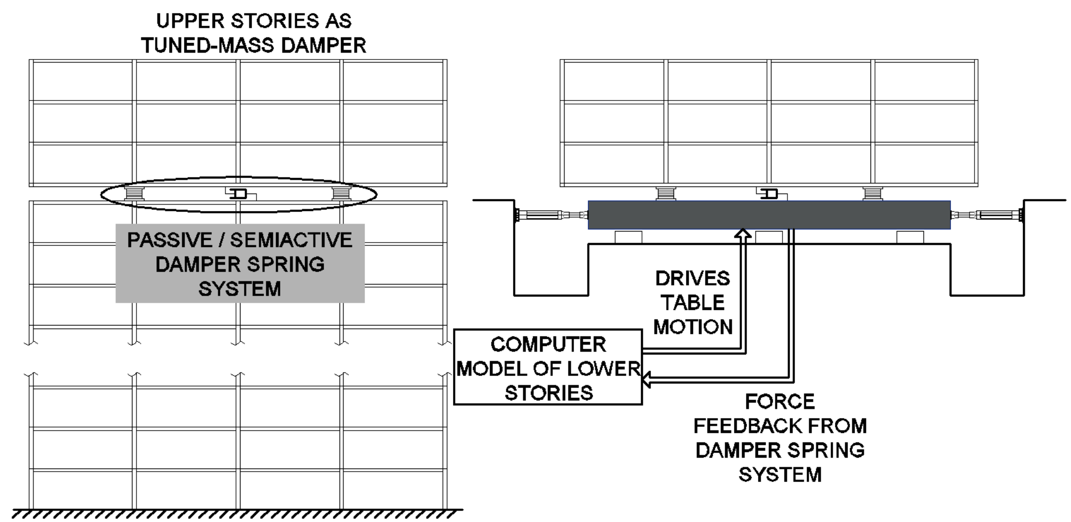

IDEA DEVELOPED FROM COMMUNITY WORKSHOP

Applications of testbed: (left) bracing, damping and seismic isolation systems, and (right) hybrid simulation application with testbed structure representing upper stories of building

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- Unique contribution to the NHERI@UCSDs equipment inventory
- Design, construction and shakedown of a modular test building in parallel to LHPOST upgrade
- Building supports critical need to broaden LHPOST participation
- Customizable "vehicle" for seismic demands to components or subsystems
- Availability of testbed structure saves time and resources in future research projects
- Payload opportunities (sensors, isolation systems, passive and active protective systems, non-structural components)

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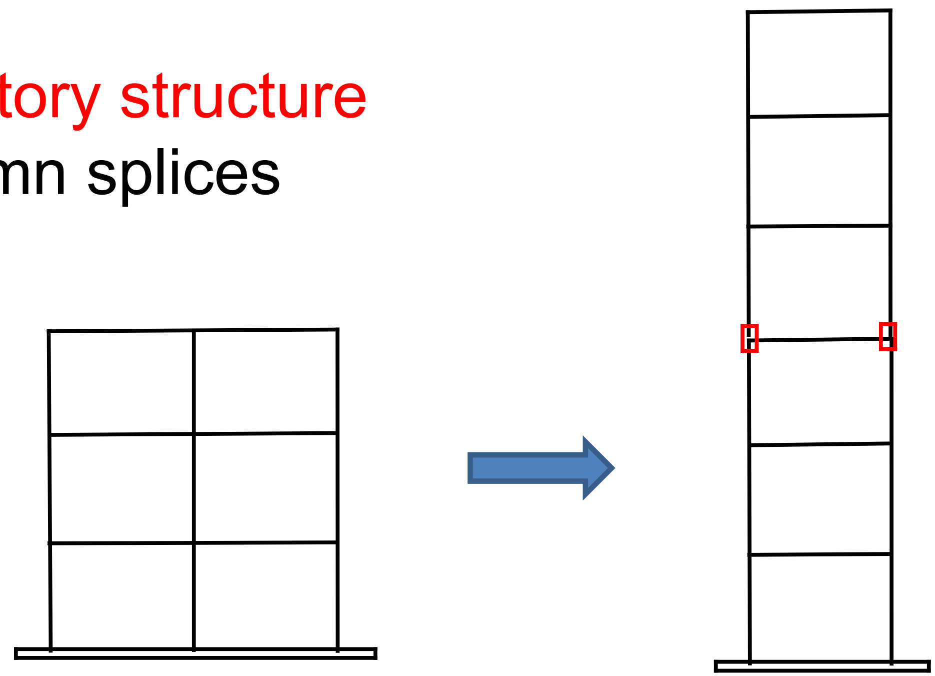
- Main features of proposed testbed structure:
  2-bay by 1-bay 3-story modular structure that can be reconfigured with different story stiffness, strength, and weight
- 1-bay by 1-bay 6-story structure
  is possible w/column splices



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- Frame system designed to allow for full scale 3D testing including torsion
- Superstructure design allows for testing of structural and nonstructural components in the lateral, transverse, and vertical directions
- Servo-hydraulic actuator attached to the frame enables active or semi-active control as well as hybrid simulation with shake table
- Steel testbed structure has gravity and floor framing system that supports attachable mass blocks to deliver inertial loads

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- Building design includes two concepts for lateral load resisting systems:

i) flexible moment frame behavior achieved with **shear fuse** type plastic hinge zones at beam ends for repeatable nonlinear behavior

ii) stiffer braced frame behavior achieved by installing **buckling-restrained braces** (BRBs) at the built-in gusset plates at joints

- Users must provide braces and/or fuse connections
  Could be coupled w/other new lateral force resisting systems
  Could convert to a base-isolated building through a basemat

- **Building supports/modularity**:

- Modular testbed building has a framing system that is fixed in the transverse direction

- For enhanced transverse modularity integrate a different detail in that direction so as to increase the building's modularity

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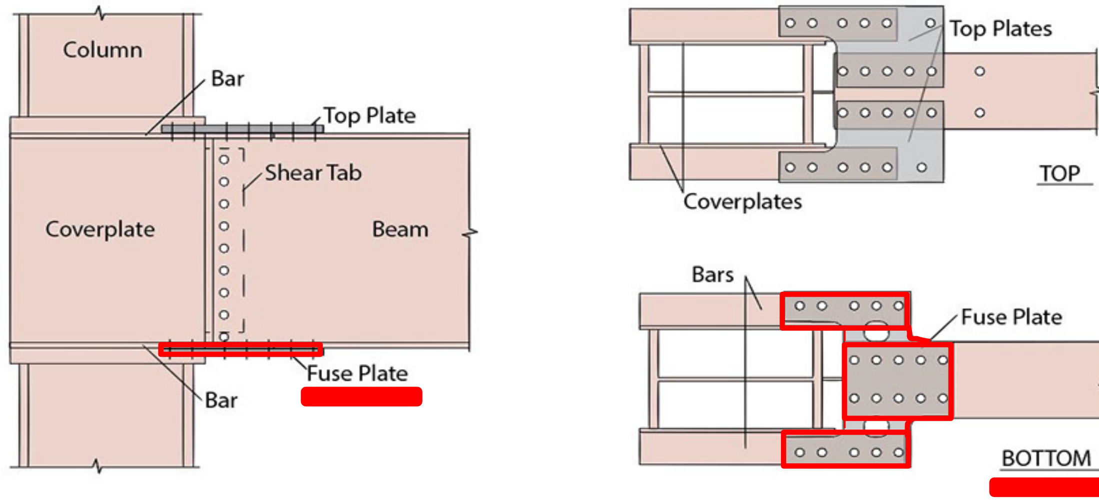
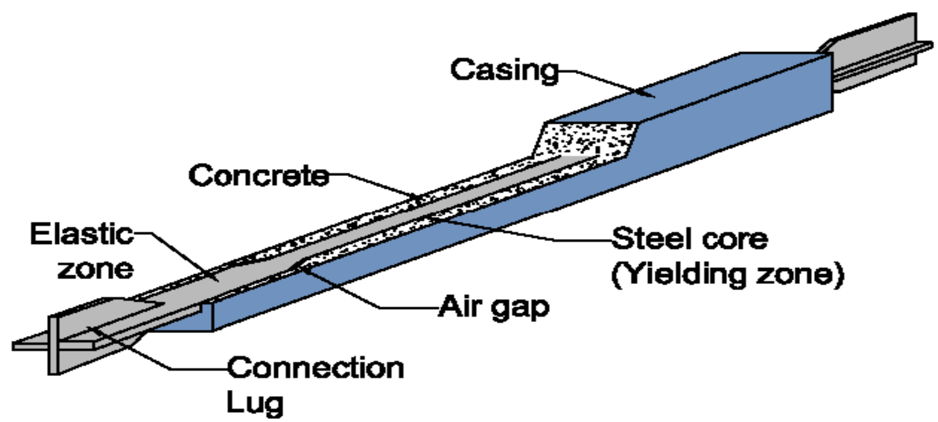
SHEAR FUSE



BUCKLING RESTRAINED BRACE (BRB)



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- Innovative devices such as semi-active dampers can be tested
- Bracing replaced by a servo-hydraulic actuator to test active devices or mimic behavior of different systems through hybrid simulation
- Frame supported on a base isolation system (4-6 bearings) user provides bearings and basemat to support structure
- Basemat can be used to test various isolation systems
- In base isolated configuration structure can be modified for tuned mass dampers in upper stories of buildings

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Design of Testbed Building: Reconfigurable 3-D full-scale three-story steel building designed to accommodate general behavioral modes of buildings during seismic shaking

- Three configurations will be evaluated to demonstrate a range of common modes during earthquakes:

(1) buckling restrained braced frame (BRBF) with BRBs on every floor (BRB-1);

(1) BRBF with BRBs on the 2nd and 3rd floor to induce a first floor soft-story response (BRB-2); and

(2) a flexible special moment resisting steel frame with shear fuses (BRB-3)

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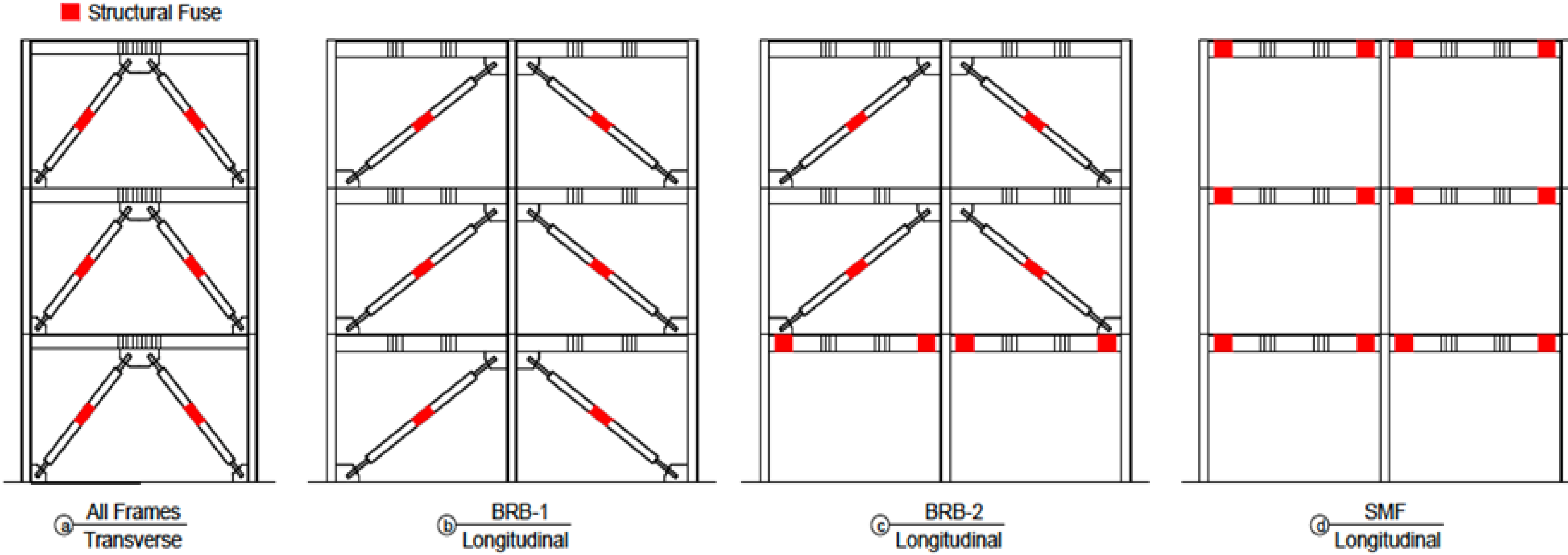

BRB-1: nearly uniform distributed inelastic displacement profile with replaceable BRBs

BRB-2: targeted soft story responses

SMF: capture inelasticity at beam ends

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Archetype Building and Expected Response Definition

- Archetype model proposed is a 3-story building
- Building designed using response spectrum analysis
  MCE motion spectrum for Site Class D (stiff) soil conditions
  Short-period spectral acceleration SMS = 2.1g
  One-second spectral acceleration SM1 = 1.4g
- Dead load 50psf (32kips/floor)+weight of steel frame (60kips)
  Total weight estimated as 156kips
- Tune modular building's dynamic properties
  addition of masses at the floor levels - moveable concrete blocks and/or steel (trench) plates at floor levels

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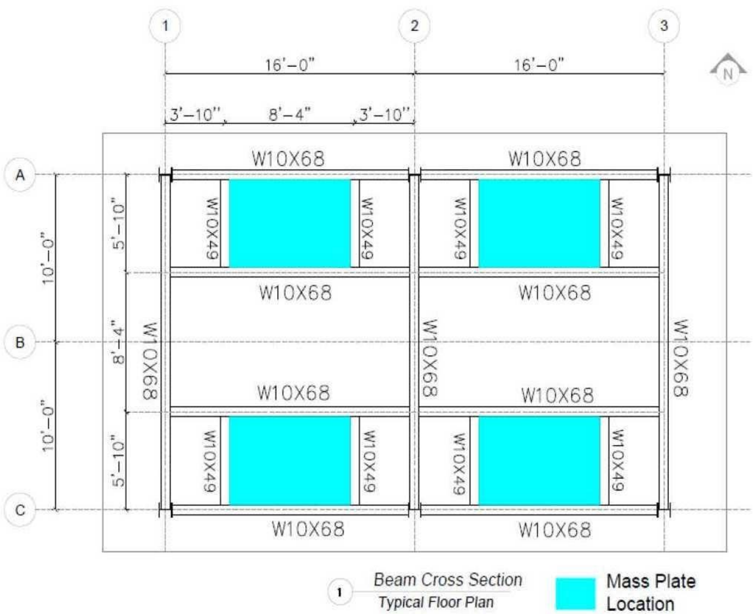

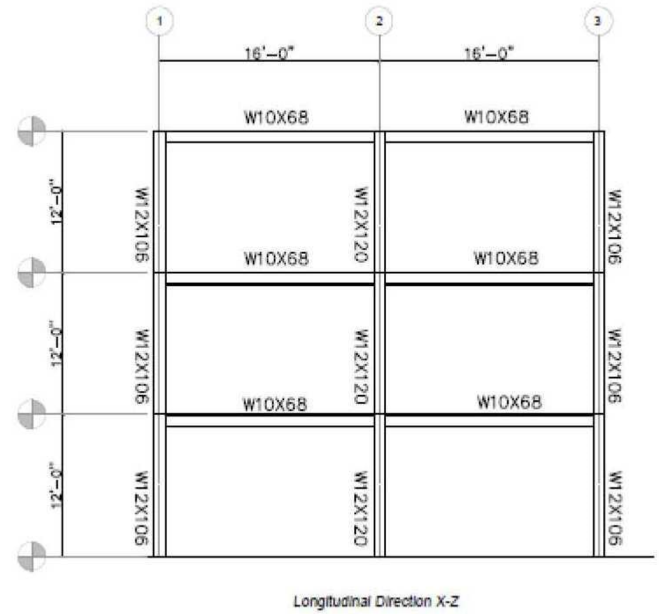

Archetype building: (left) plan view and (right) elevation
[Preliminary member sizes]

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Fabrication and Shake-Down:

- Verify readiness for future applications
  fabricate & erect on LHPOST and evaluate dynamic performance under a range of motion intensities: low amplitude white noise, low->strong intensity earthquake
- Tested in the three longitudinal configurations
  under actual earthquake records: yielding of structural fuses - high level of drift for severe shaking - two sets of fuse connections to replace as necessary (BRBs replaced as needed)
- Various mass options to assist with model validation and motion response prediction

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- System identification to compute system's dynamic properties and define performance of three configurations for future tests, including tests with nonstructural elements
- First set of shake table tests for BRB frames with bi-directional loading and they provide an opportunity for payload projects from community to further evaluate frame behavior
- Data from these experiments including design documentation and a user's manual will be published through *DataDepot* in *DesignSafe*

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Proposed schedule for design, construction & shakedown of testbed structure

Task	Dates
Project start date	Oct 1, 2019
Design of Testbed Structure	Oct 2019–Jan 2020
Purchase of materials and request for donations	Jan 2020-Mar 2020
Construction of testbed structure on staging facility	Apr 2020- Jun 2020
Ambient vibration and low-level dynamic testing	Jul 2020-Aug 2020
Shakedown of testbed structure on LHPOST	Feb 2021- Mar 2021

*** Opportunities for Payload**

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Opportunities for Future Research: STRUCTURAL

BASE ISOLATION: LEAD RUBBER BEARINGS

E-Defense – 2019
Nagae T.,
Nagoya University

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FRICTION-BASE ISOLATOR

E-Defense – 2019
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Nagoya University

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BASE ISOLATION: VISCOUS DAMPERS

E-Defense – 2019
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VISCOUS DAMPER BRACE

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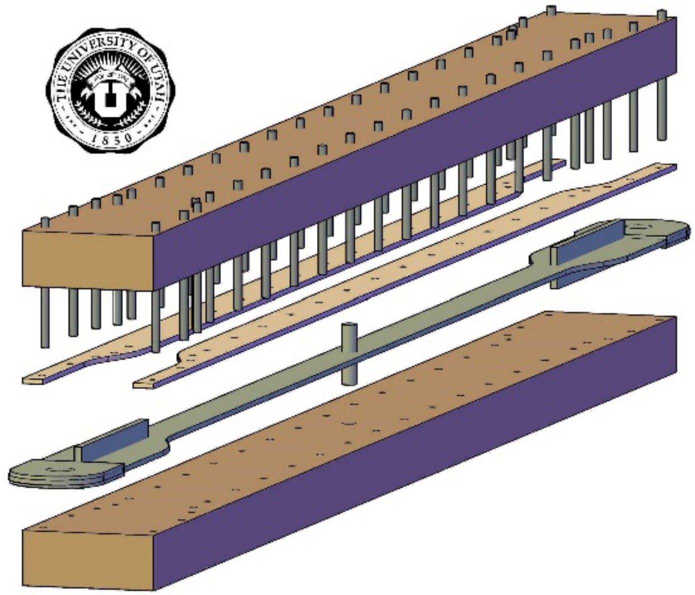
VISCOUS DAMPER BRACE

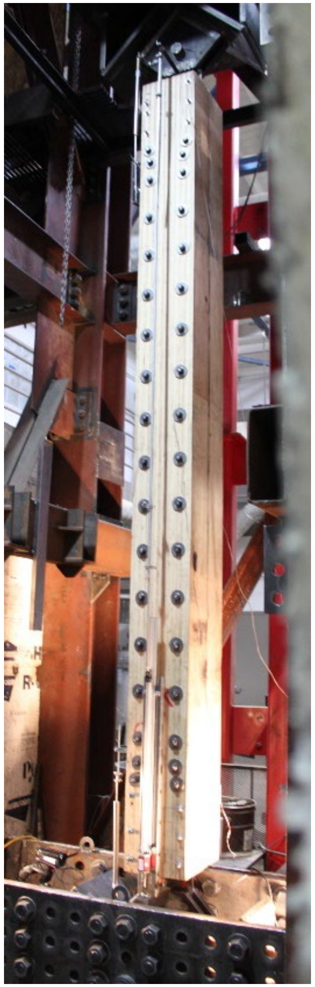
181 Fremont Tower
Ibbi Almufti, Jason Krolicki, and Adrian Crowther, Structure Magazine, June 2016

- Innovative **viscous damping** system provided 8% critical damping from 2% inherent damping

  Three braces in one and BRBs at lower ends to act as fuse in MCE

MASS TIMBER BUCKLING RESTRAINED BRACE





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SOIL–STRUCTURE INTERACTION

Soil Box at E-Defense – 2019
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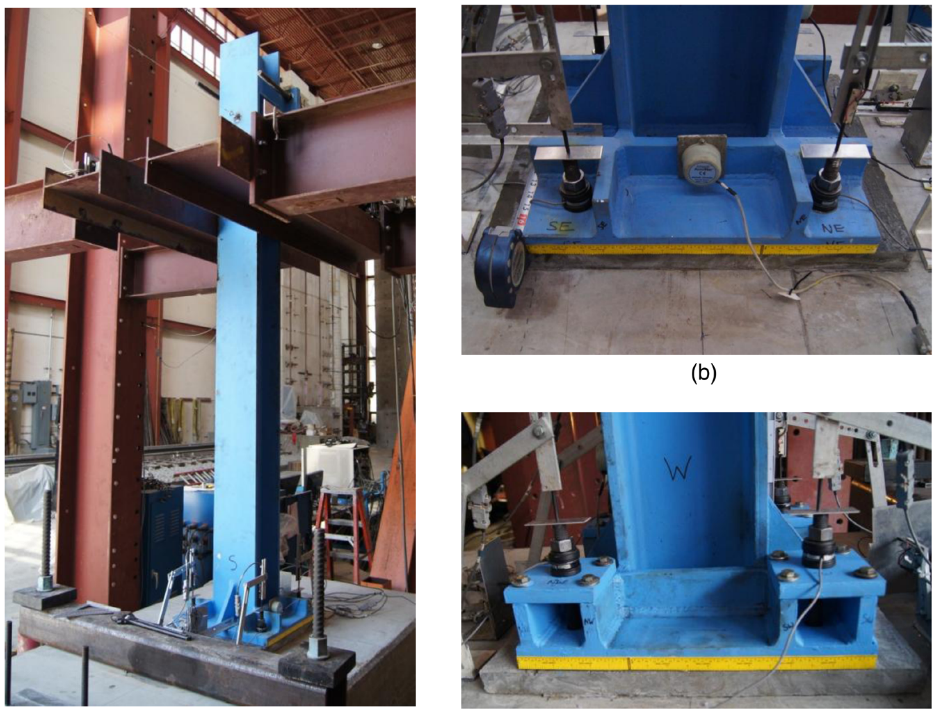
STRETCH LENGTH BOLTS



(a) (b) (c)

Trautner, C.A., Hutchinson, T., Grosser, P.R., Silva, J.F. 2016. "Effects of detailing on the cyclic behavior of steel baseplate connections designed to promote anchor yielding." *J. Structural Engineering*, 142(2),04015117.

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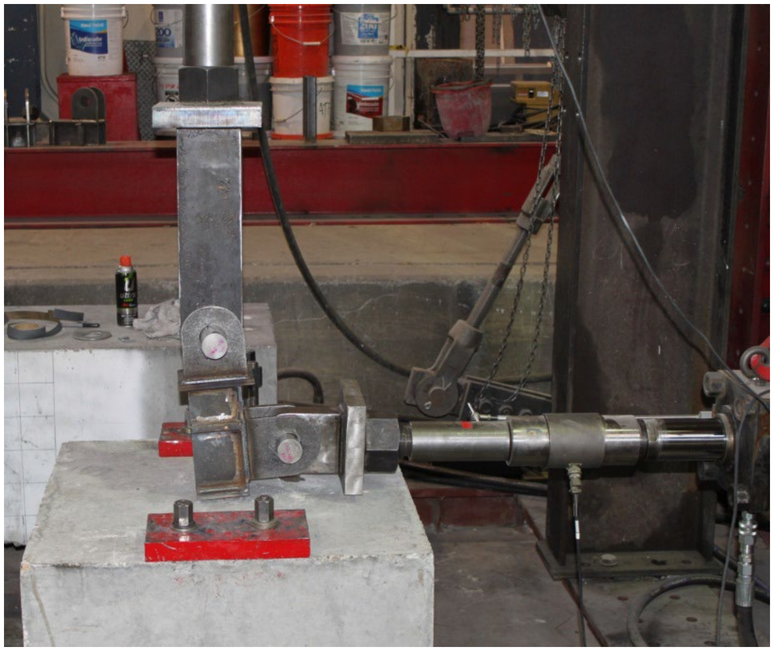

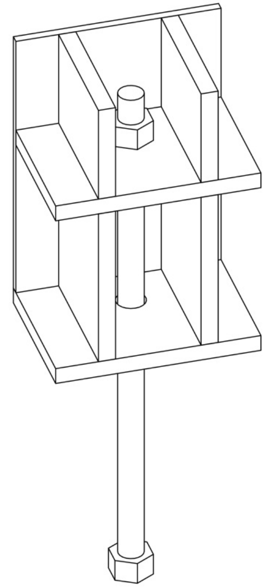

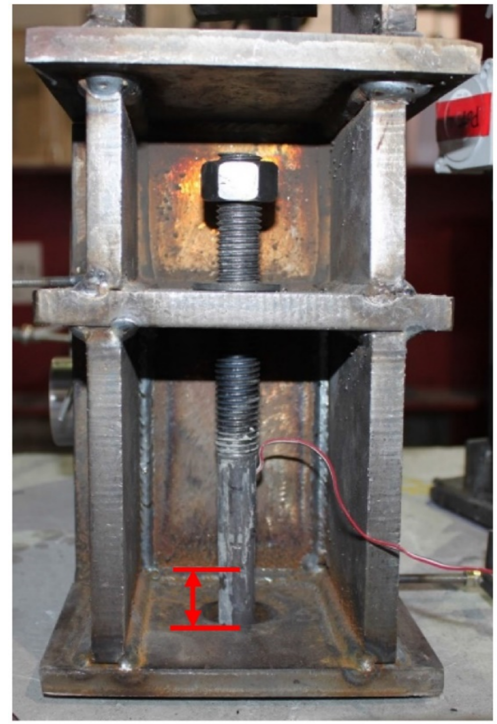

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Opportunities for Future Research: NON-STRUCTURAL

Amherst College Commons: Structural Silicone Glazed Curtain Wall System

Blanchard, A., and Abramson, J., *Structure Magazine*, November 2019.

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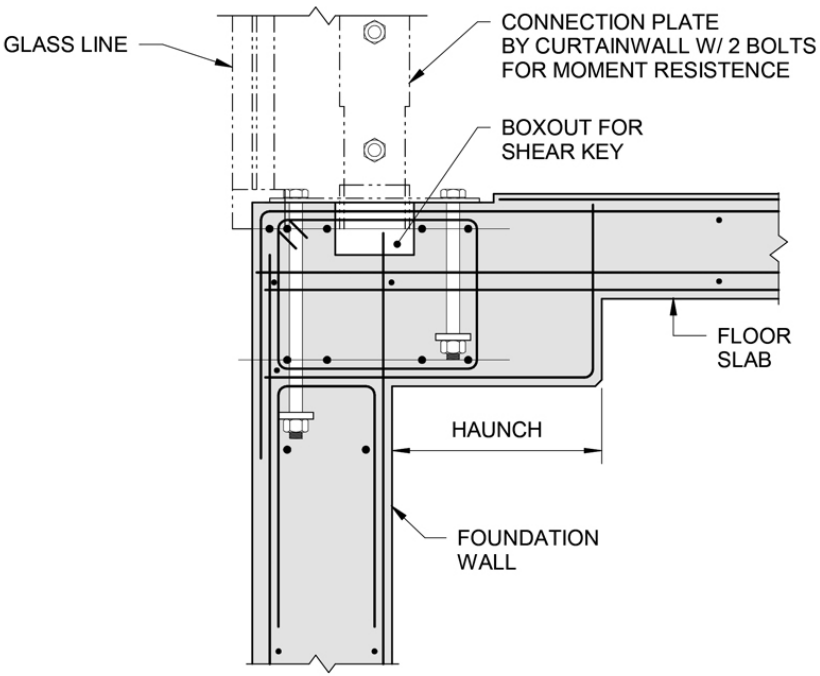

Structural detail at base of glass wall and connection to concrete wall and slab

Mullions in tension and connected through two vertically slotted holes to resist bending moment

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181 Fremont Tower: Almufti, I., Krolicki, J., and Crowther, A., *Structure Magazine*, June 2016.

- **One elevator** functions after the 475-year event
  Guide rails and support brackets upgraded to hospital requirements - 1st elevator to utilize elevator as a designated evacuation route
- **Emergency back-up systems** designed to keep essential function of building including elevators running for 8 hours after earthquake
- **Stairs** designed to accommodate more movement and less damage than ASCE 7, Ch.13 - Min. horizontal bearing seat is 1.5 x mean MCE displacement - Stairs required to carry dead and live loads under MCE level demands with minimal damage
- **Façade** was designed and tested to remain air- and weather-tight after 475 year earthquake up to 2% drift ratio
- **Anchorage** design of **non-structural components** and **distribution systems** remain elastic under 475-year event

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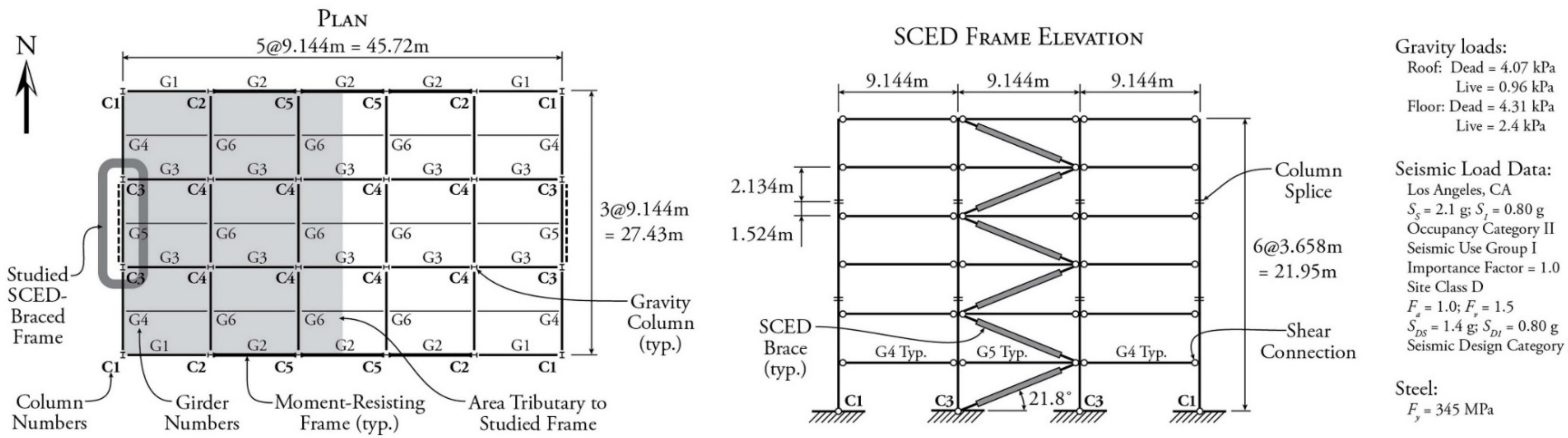
Opportunities for Future Research: COMPUTATIONAL SIMULATION

OpenSees



Erochko, J., Christopoulos, C. 2014. “Seismic response of six-story steel frame building with self-centering energy-dissipative (SCED) braces combined with linear viscous dampers.” NCEE 2014 - 10th *U.S. National Conference on Earthquake Engineering*: Frontiers of Earthquake Engineering.

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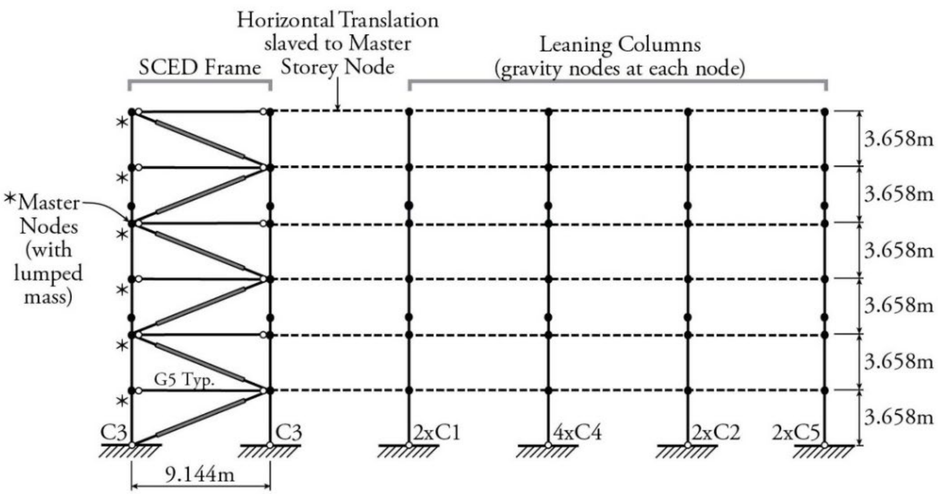
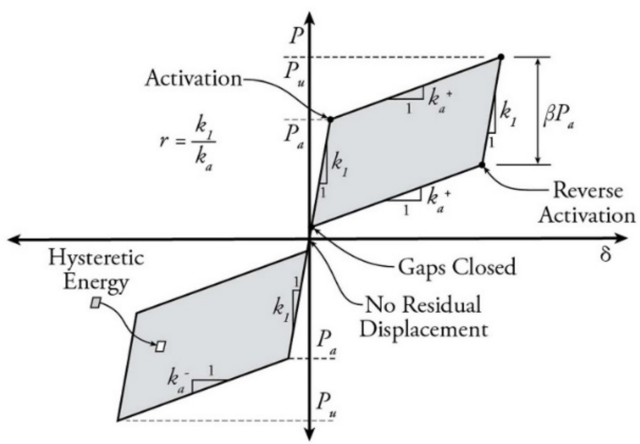
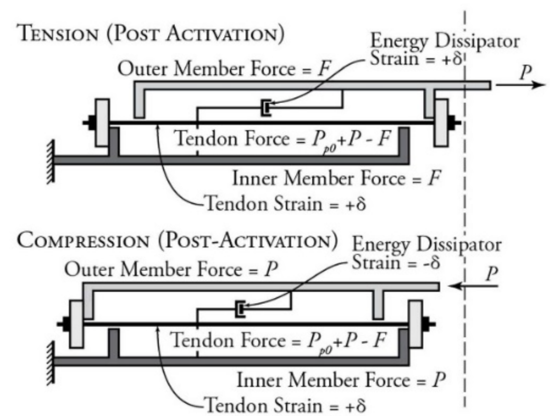


OpenSees





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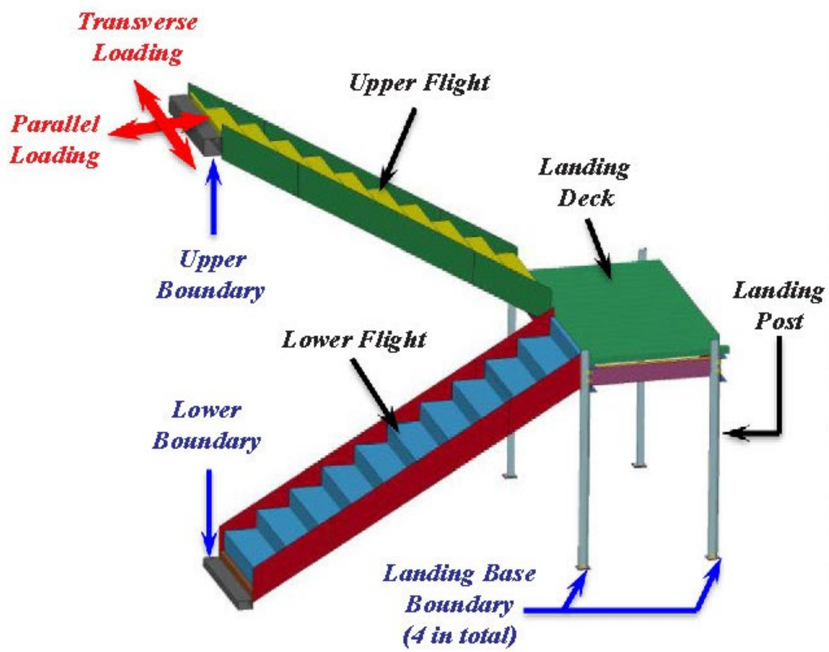
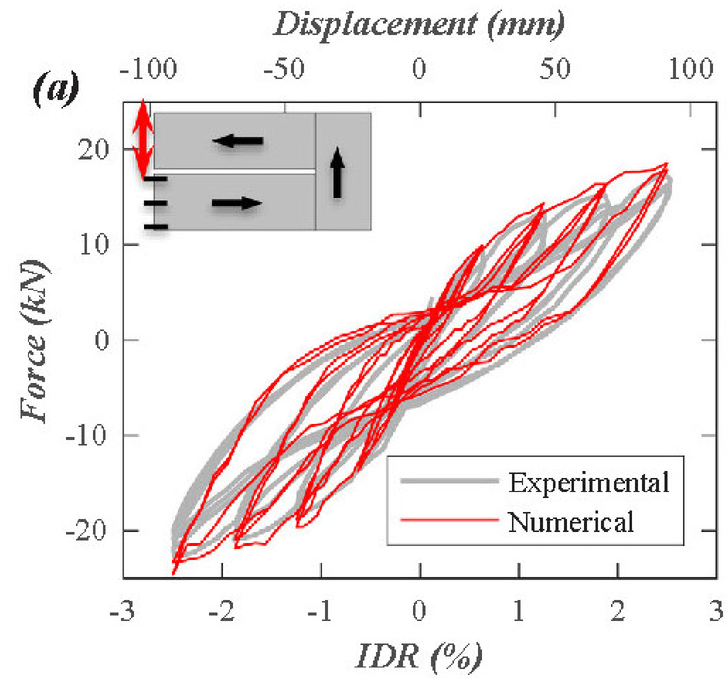
LS-DYNA





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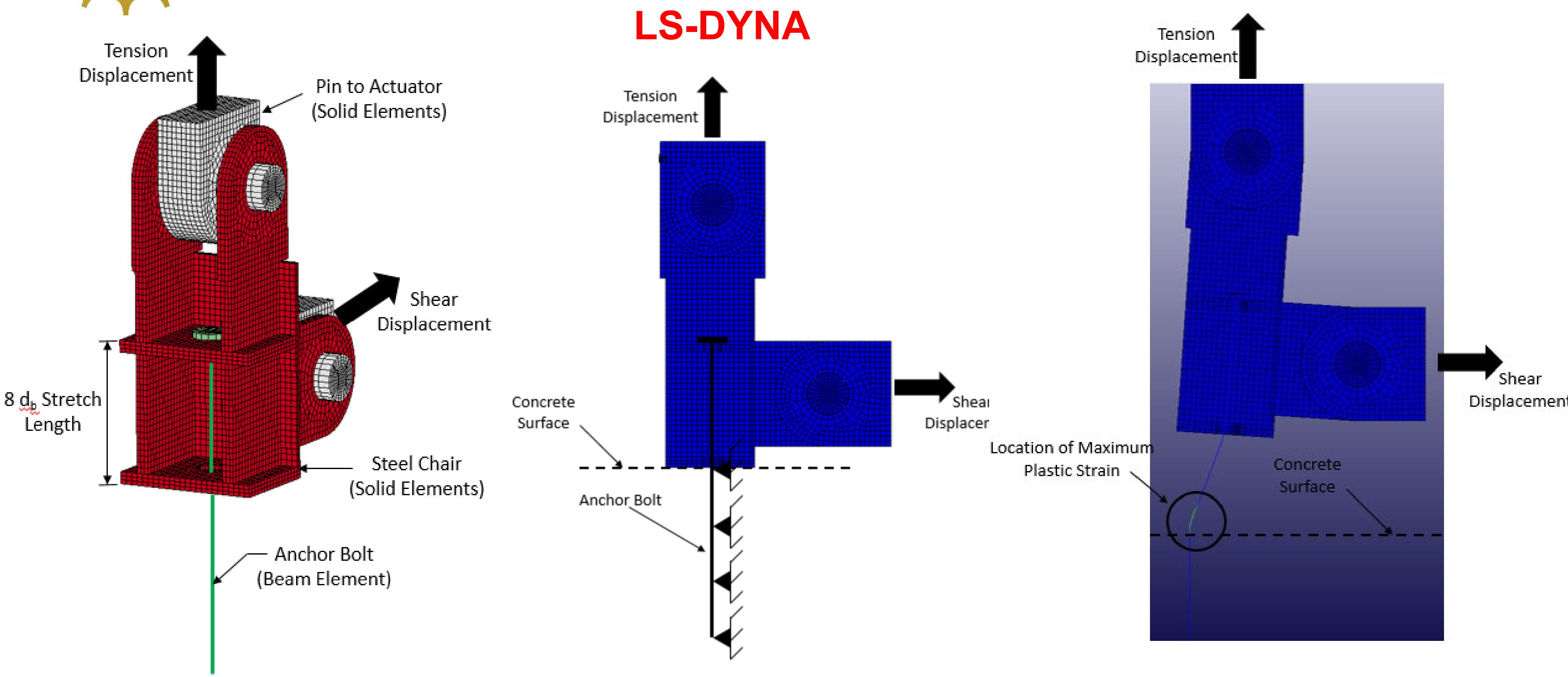

Parks, J., Pantelides, C.P., Ibarra, L., and Sanders, D. 2019. "Cyclic tests and model of stretch length anchor bolt assemblies for dry storage casks." *ACI Structural J.*, (under review).

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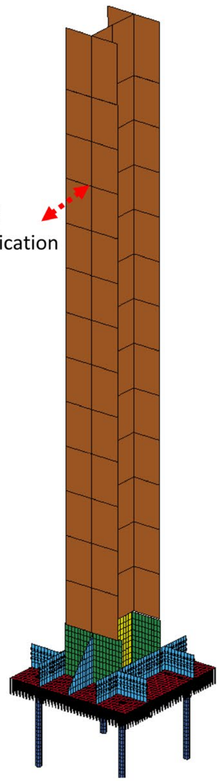

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Summary

- Design of a **reconfigurable testbed** that can replicate a variety of structural behaviors in the current building stock
- Design considers **fuse type members** for inelastic range response **tunable dynamic characteristics** while producing a range of drift ratio and acceleration demands throughout the structure
- Shake down testing and **system identification of the testbed will be made available** to facilitate design for future users
- For **enhanced transverse modularity** there is an option for future users to integrate a different detail in that direction so as to increase the building's modularity
- **What would you like to see achievable with the testbed building?**

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- Modular Testbed Building can be used to test **structural systems** including base isolation with fluid viscous dampers, lead rubber bearings, friction base isolators, friction pendulum isolation system, viscous damper braces, mass timber buckling restrained braces, soil-structure interaction, stretch length bolts and others
- Testbed building can be used to test **non-structural systems** including curtain wall systems, elevators, emergency back-up systems, stairs, anchorage of non-structural components, as well as combinations of **structural and non-structural systems**
- Experimental results from the testbed building can be used to calibrate **computational models** such as OpenSees, LS-DYNA and others
- **What is your idea about future research with the testbed building?**

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SIMCENTER COMPUTATIONAL MODELING AND SIMULATION CENTER

National Science Foundation

University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

ACKNOWLEDGMENTS

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SME Steel

Corebrace

DuraFuse

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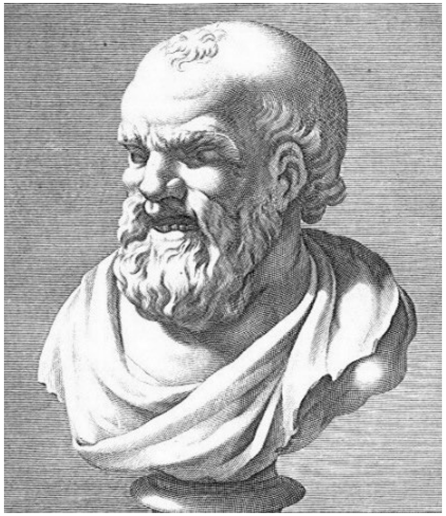
"Everything existing in the universe is the fruit of chance and necessity"



Democritus, 460 BC - 370 BC

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