National Science Foundation

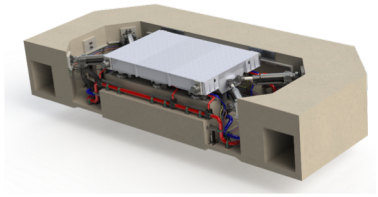
University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

Modular TestBed Building (MTB^2): A Reconfigurable Shared-Use Equipment Resource for use by Researchers at LHPOST6

Tara Hutchinson, University of California San Diego

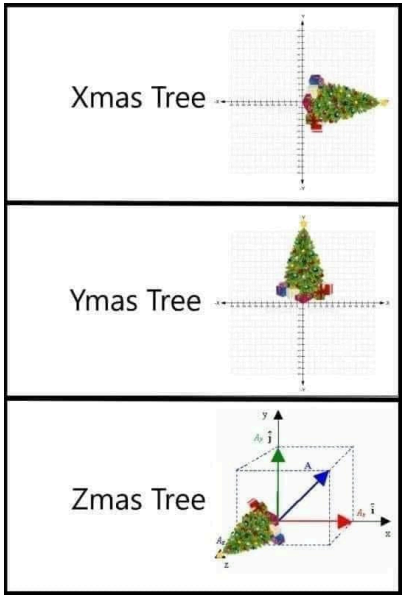
Chris Pantelides, University of Utah



NHERI@UC San Diego User Training Workshop

December 16-17, 2021
University of California, San Diego

"Don't ask what your table can do for you, but ask what you can do for your table" - C. Pantelides

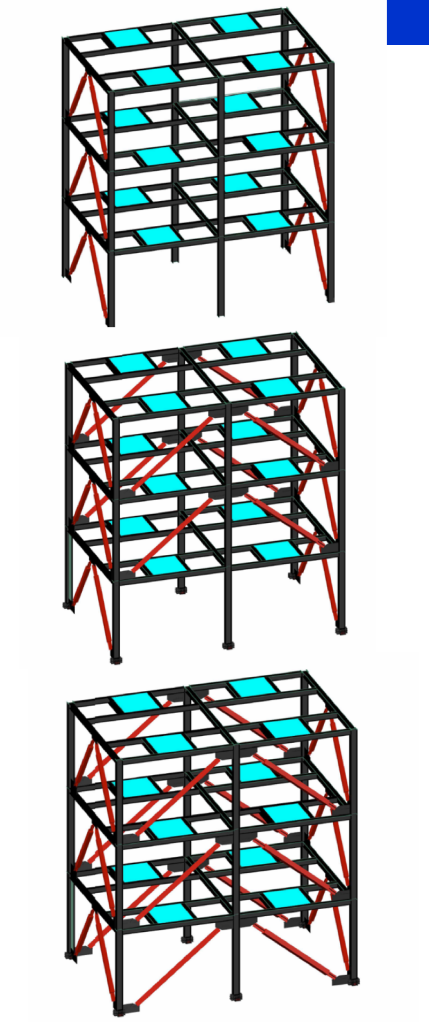


Outline

- Design scope
- Making it happen = Team
- Design Features
  - Pragmatic design decisions
  - Dimensional plans
  - Novel aspects of MTB^2
    - Modular diaphragm
    - Nonlinear components: BRB and moment-frame connections (CP); compliant base
  - Expected performance
    - Dynamic properties
    - NL pushover behavior
- Shake-down: Staging Slab Erection
  - Is MTB^2 truly modular?
- Shake-down Dynamic Testing on LHPOST6 in 2022
- Opportunities for future researchers

Design Scope

- **Community-available building for NHERI users:**
  - New infrastructure to contribute to NHERI@UC San Diego & shared-users of NHERI EF
  - First structure to be tested on newly upgraded LHPOST6
- **Evolution:**
  - Community input via NHERI workshops
  - Inception from prior research & proposals to investigate NCSs
  - Partnership amongst Academe & industry (next slide)
- **Unique features:**
  - Designed to be reconfigurable & reusable with low-cost replaceable nonlinear fuse elements and simple removable floor system
  - Enabling low-cost testing of components & systems under simulated dynamic 3D loading
  - Provide a *vehicle to deliver seismic loads & displacements* to elements of interest



Making it Happen: Team

- University of California San Diego & University of Utah
- Industry Partners


Tara Hutchinson

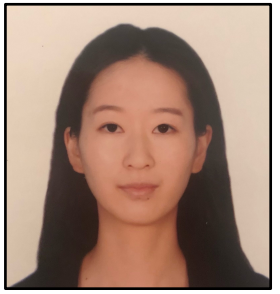

Gilberto Mosqueda


Michael Morano


Louis Lin


Chris Pantelides


Emily Diedrich


Junwei Lui

UC San Diego
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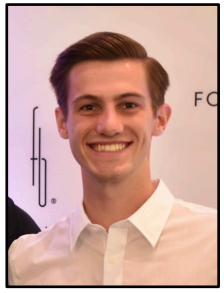
CoreBrace

DURAFUSE FRAMES
THE RESILIENT SEISMIC SOLUTION


Zane Schemmer
(UCB NHERI REU)

http://chei.ucsd.edu/MTB2/index.html

Additional Industry Partners

SME STEEL

ASBURY STEEL

NUCOR®

AMERICAN INSTITUTE OF STEEL CONSTRUCTION
AISC
FOUNDED 1921

HILTI

LeJEUNE BOLT COMPANY

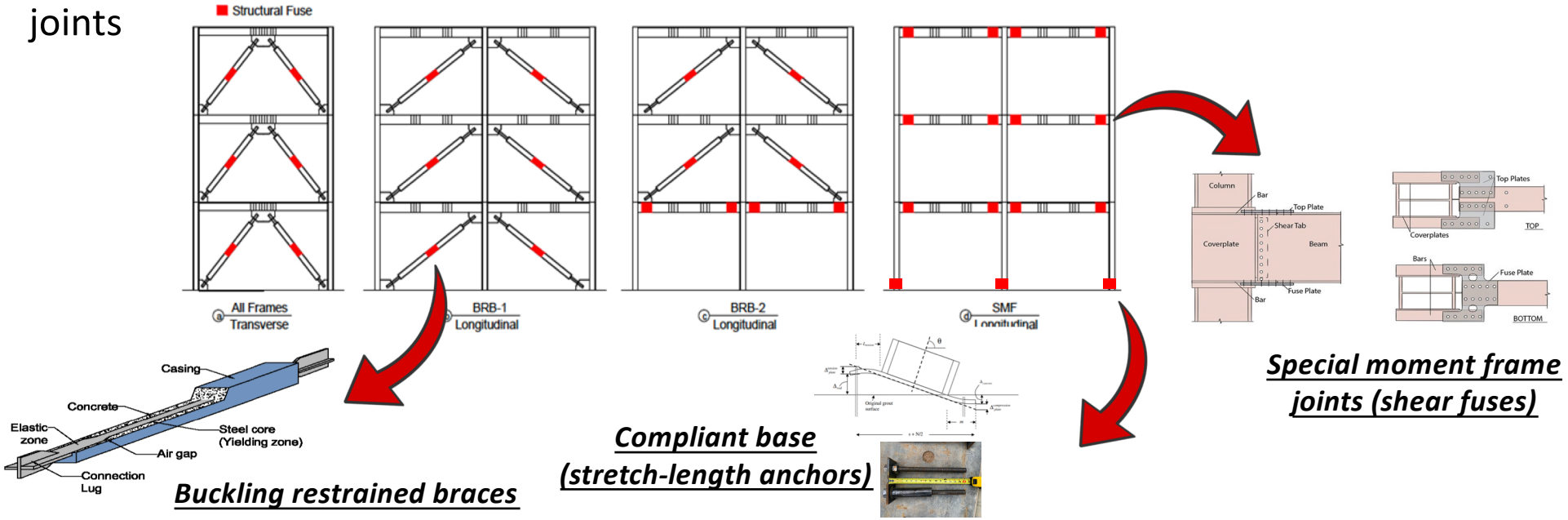
VERCO DECKING, INC.
a NUCOR company

Atlas Tube

Design Features

Reconfigurable 3-D full-scale three-story steel building designed to accommodate a wide range of seismic behavior of buildings:

1) Moment frame behavior with **shear fuse** type plastic hinges
2) **Compliant base** to alleviate moment demands at beam joints (coupled with 1)
3) Braced frame behavior with **buckling restrained braces** (BRBs) at built-in gusset plates at joints



Buckling restrained braces

Compliant base (stretch-length anchors)

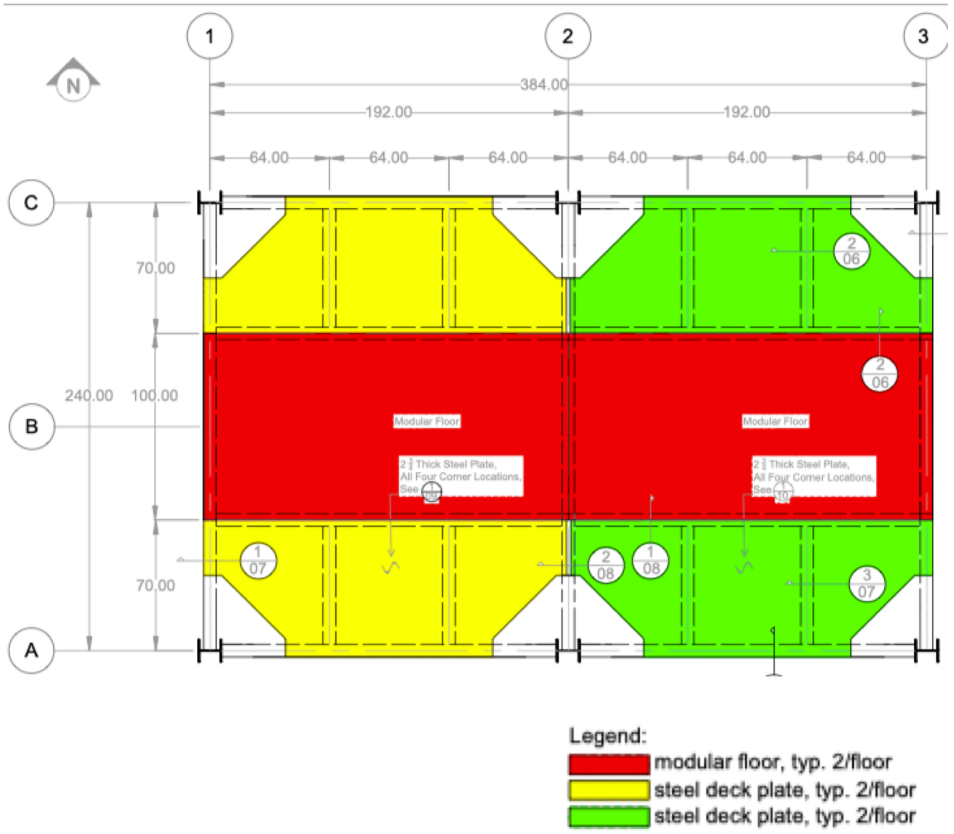
Special moment frame joints (shear fuses)

Design Features: Pragmatic Decisions We Made

- All-hot rolled steel framing system
- Simple floor plan, accommodate geometry directly atop LHPOST
- Simple foundation footprint, straight-forward tie-down to LHPOST6
- Modular nonlinear fuse components
- 3-stories (not too tall; not too short; allows for tuning of dynamic properties)
- Modular diaphragm (attach to; remove and adapt)
- Readily de-erected and stored

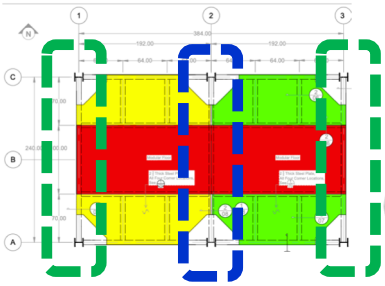
Weight Distribution

	Longitudinal LFRS	
Item	**BRB-1**	**SMF/SMF+CB**
Transverse LFRS [k]	13.2	13.2
Longitudinal LFRS [k]	20.5	2.5
Steel Plate [k]	113.2	113.2
Modular Deck [k]	38.4	38.4
Columns + BP [k]	28.2	28.2
Beams [k]	17.9	17.9
Structural System [k]	**231.4**	**213.4**
Footings [k]	81.6	81.6
Total Weight [k]	**313**	**295**

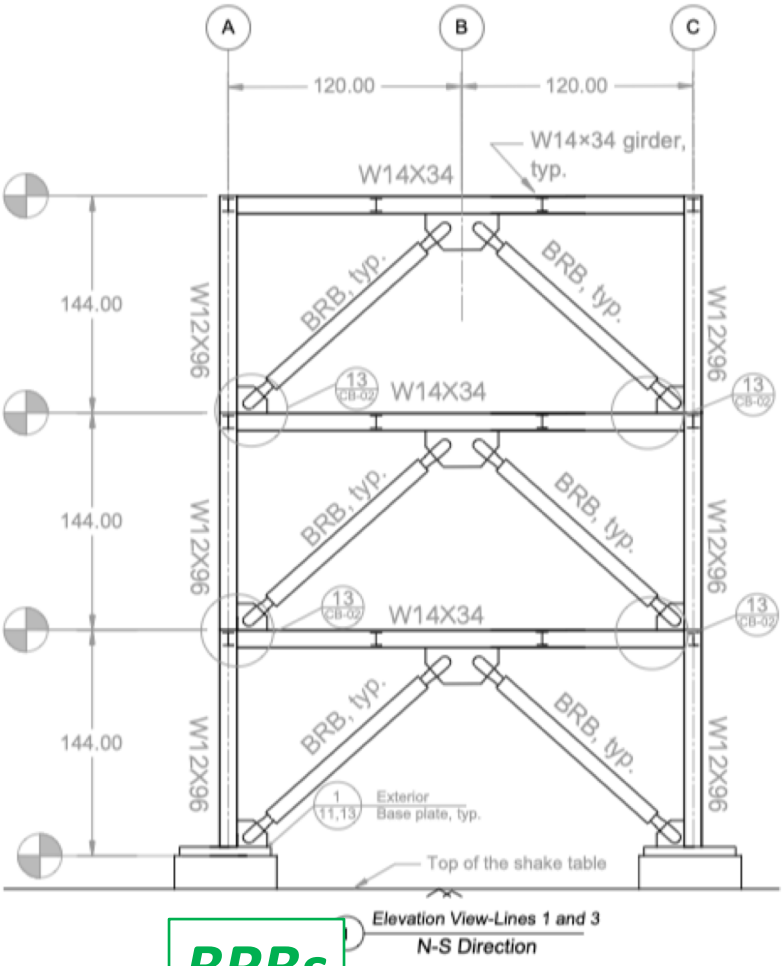


Modular diaphragm: steel plate + concrete deck

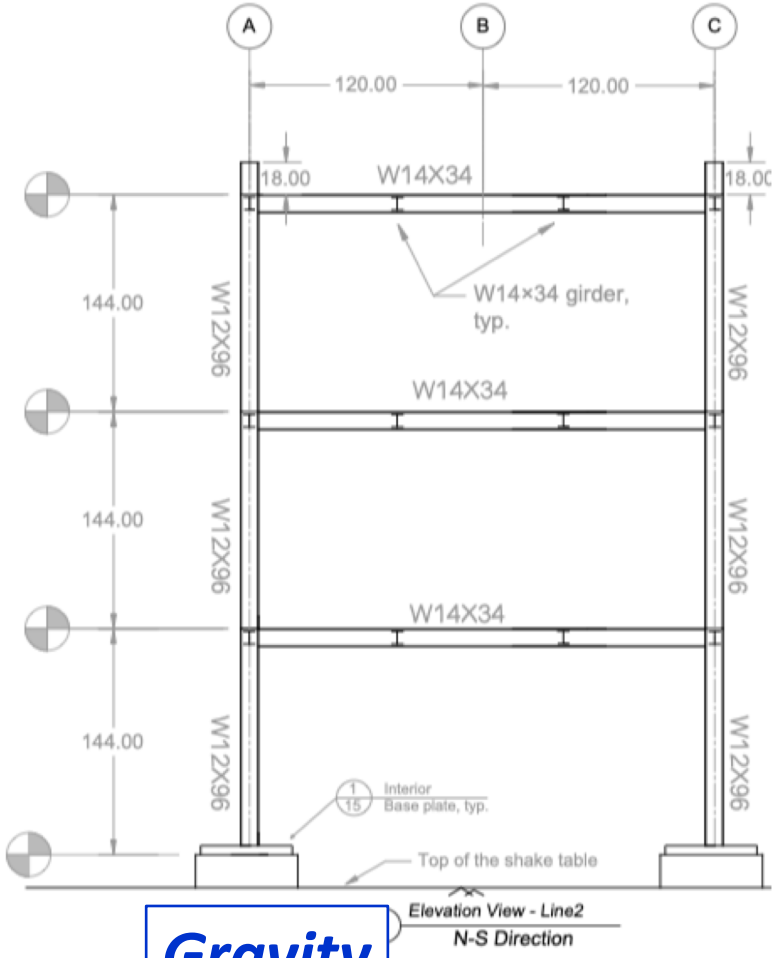
Design Features: Dimensional Plans LFRS + Gravity (NS)



NS Direction: 20’ bay

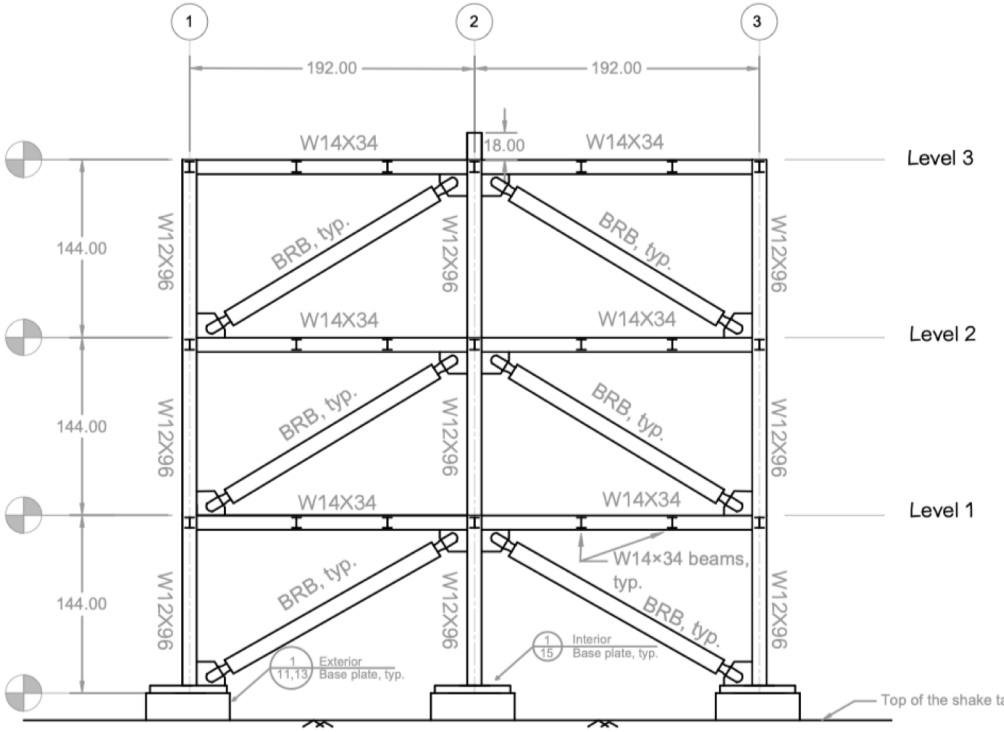


BRBs



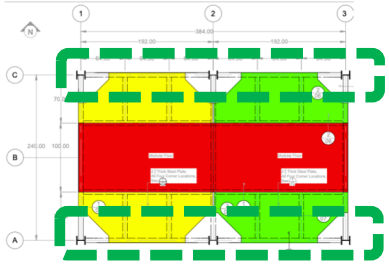
Gravity

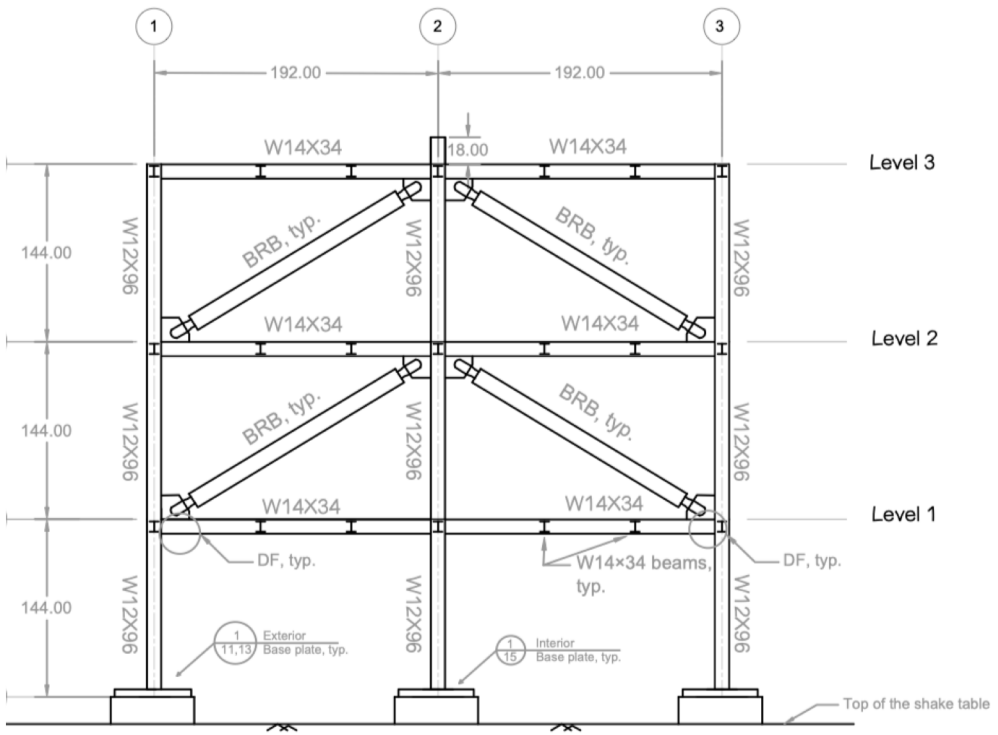
Design Features: Dimensional Plans LFRS (EW)



1 Elevation View-Line A and C
E-W Direction, Conf.1

BRB-1





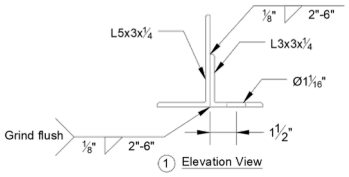
1 Elevation View-Line A and C
E-W Direction,Conf.2

SMF

EW Direction: 12' stories; 16' bays

Modular Concrete Deck (2x Floor Level)

5ksi Concrete Reinforced with W4xW4 at 4”x4”

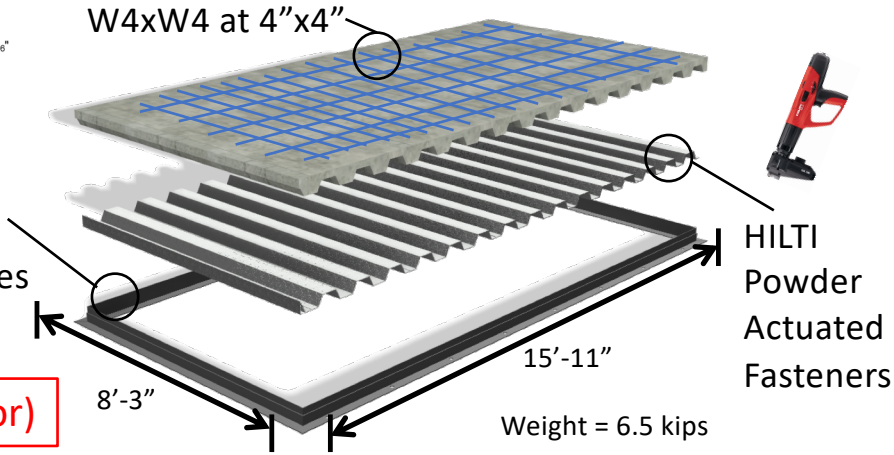


VERCO 18 ga. PLW3-36 FormLok Metal Decking

- Connected to angles via HILTI Powder Actuated Fasteners

Frame is made from welded back-to-back L5x3x1/4 and L3x3x1/4 angles

- Bolted to beam using (16) 7/8” A325 Bolts



Steel plate (4x floor)

9.4 kips each

Modular concrete deck (2x floor)

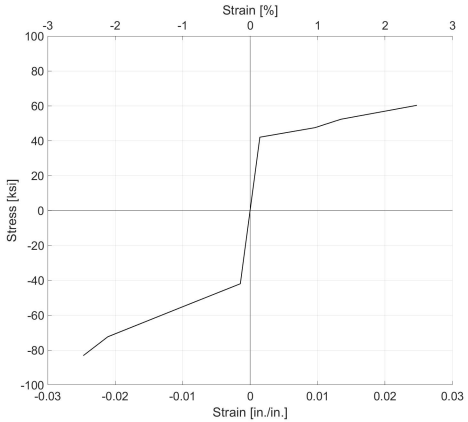
6.5 kips each

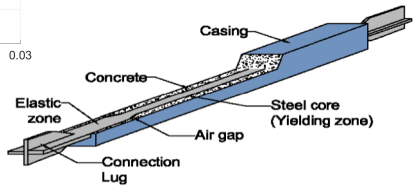
Construction Phase

Stacked Decks

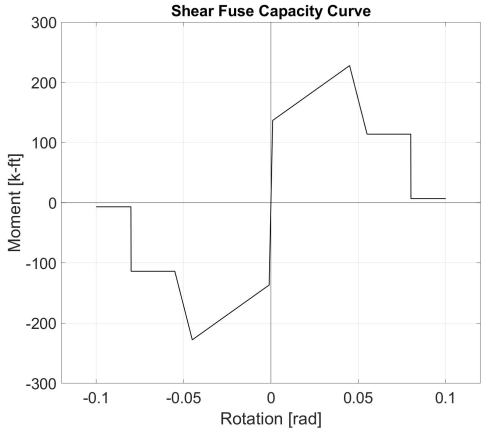
Nonlinear Components of MTB²

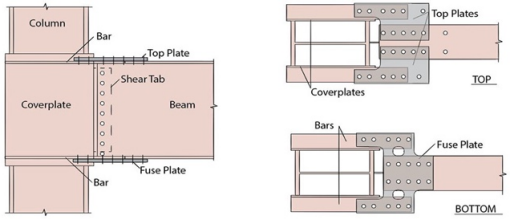
- Replaceable, strategically placed
  - Buckling Restrained Brace (BRB)
  - Special Moment Frame (SMF)
  - Compliant Base (CB)





Buckling restrained braces
(yielding core)

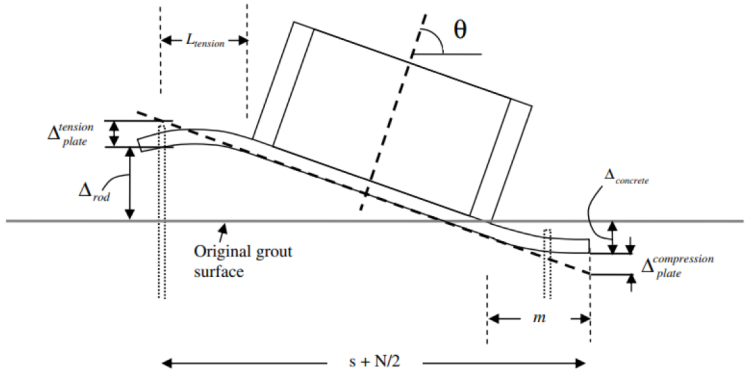


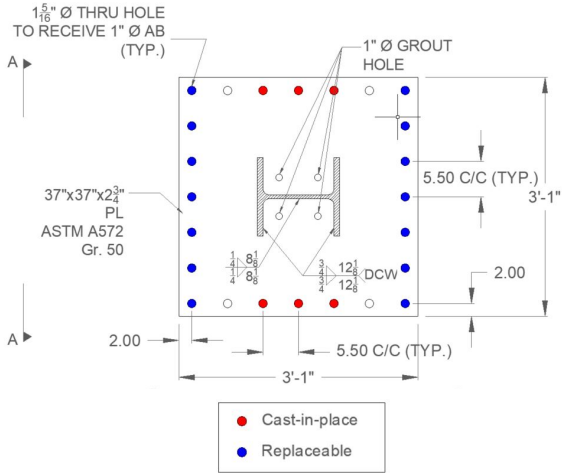


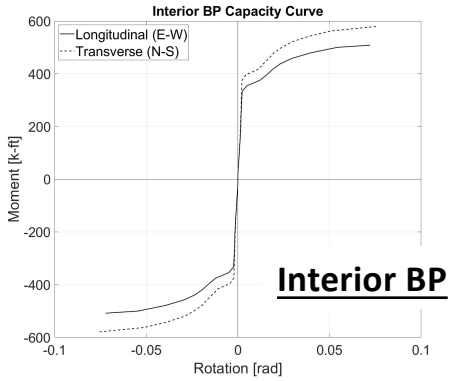
Special moment frame joints (shear fuses)
(yielding shear plates)

Compliant Base

- Fixed base (fully restrained 'complete' anchor) vs compliant base (stretch length anchors)

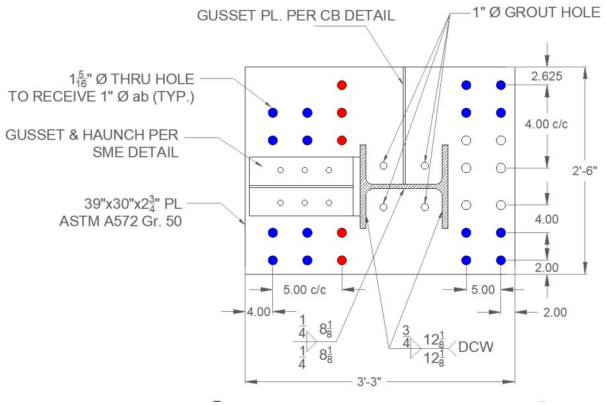


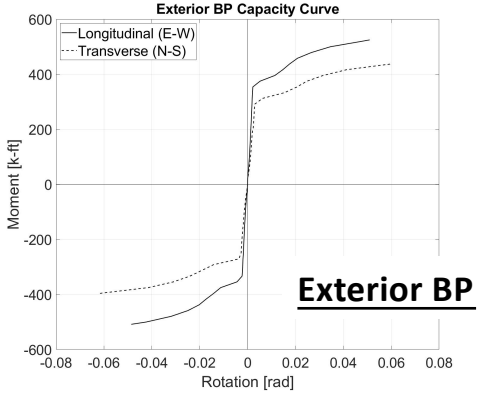




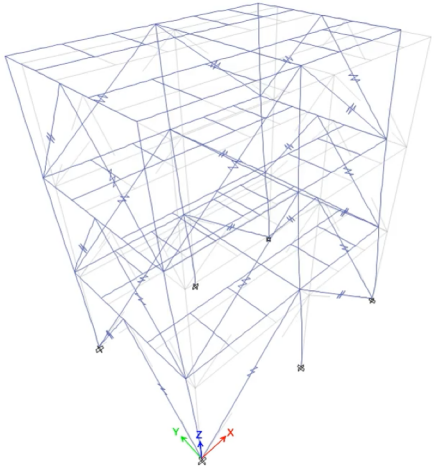
Cast-in ABs

Stretch Length ABs (replaceable)

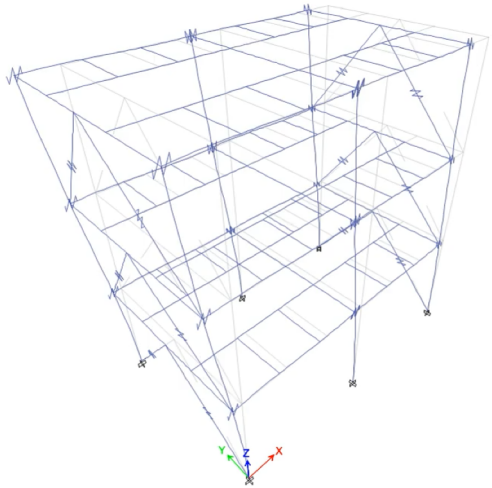




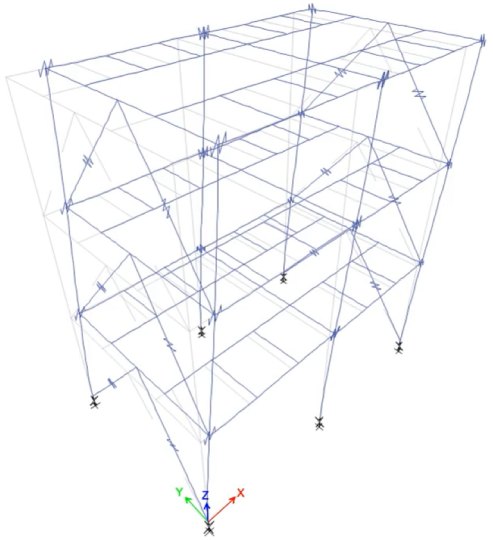
MTB^2 Expected Performance (Dynamic Properties)



BRB-1 (mode1)



SMF (mode1)



SMF +CB (mode1)

Summary of Modal Periods

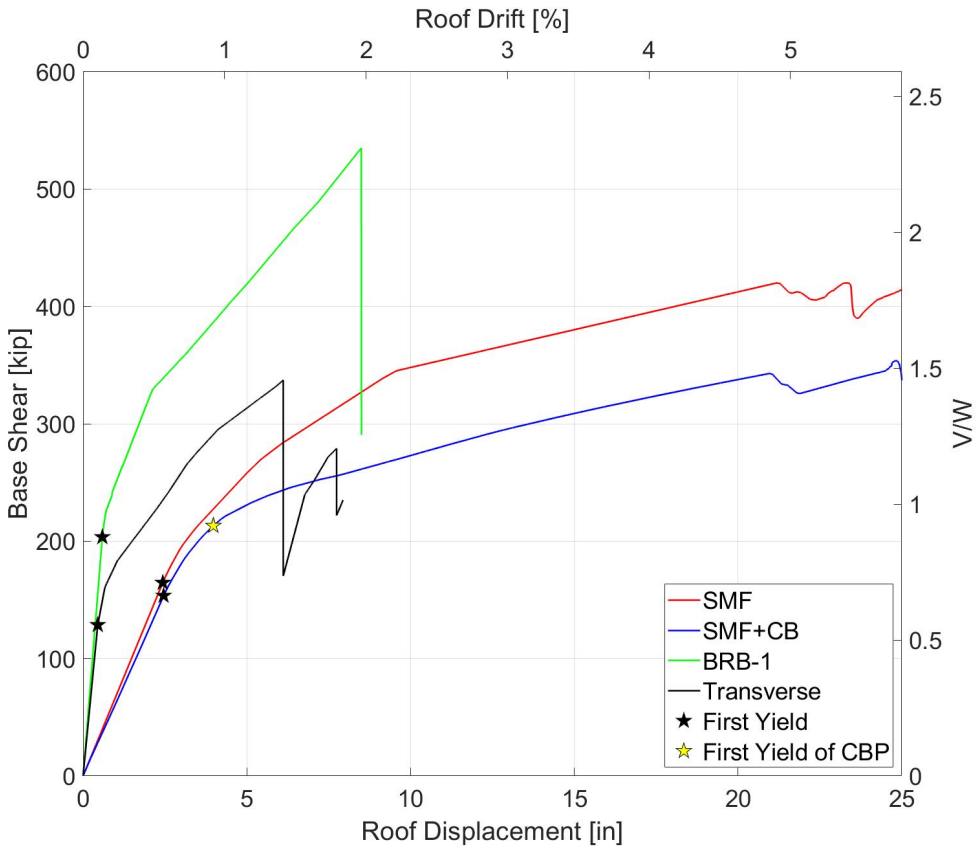
Configuration	Mode1	Mode2	Mode3
BRB-1	0.24s (T)	0.218s (L)	0.145s (Tor)
SMF	0.487s (L)	0.24s (T)	0.169s (Tor)
SMF+CB	0.492s (L)	0.24s (T)	0.17s (Tor)

MTB² Expected Performance (NL Pushover Behavior)

Features of behavior

- Softer, ductile SMF response
- Softer, post-yield SMF+CB response
- Stiffest, strongest configuration BRB-1
- Consistent elastic stiffness in all BRB configurations
- ~2% roof drift capacity (@BRB PL = 2.5% ε_a)
- ~4% roof drift capacity (@SMF PL = 0.05r)

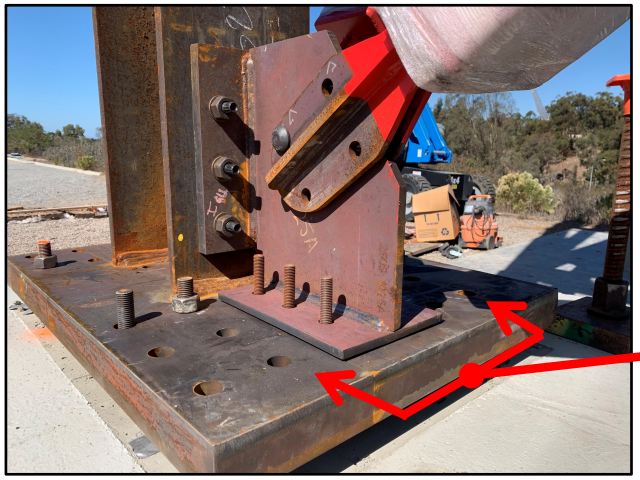
- Gradual fuse-fuse (floor-floor) progression of yielding (CP discussion)



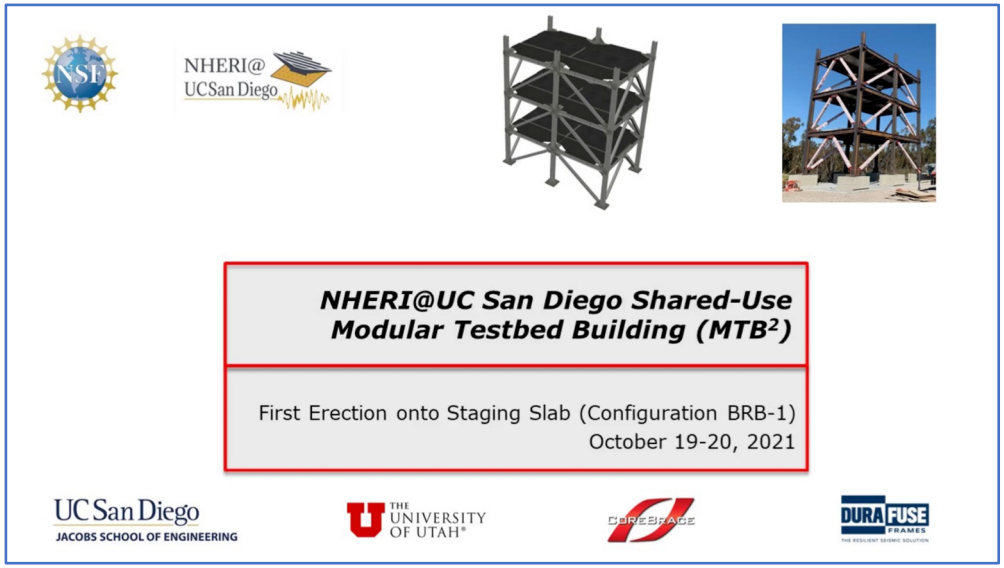
ETabs FE Model NL Pushover results

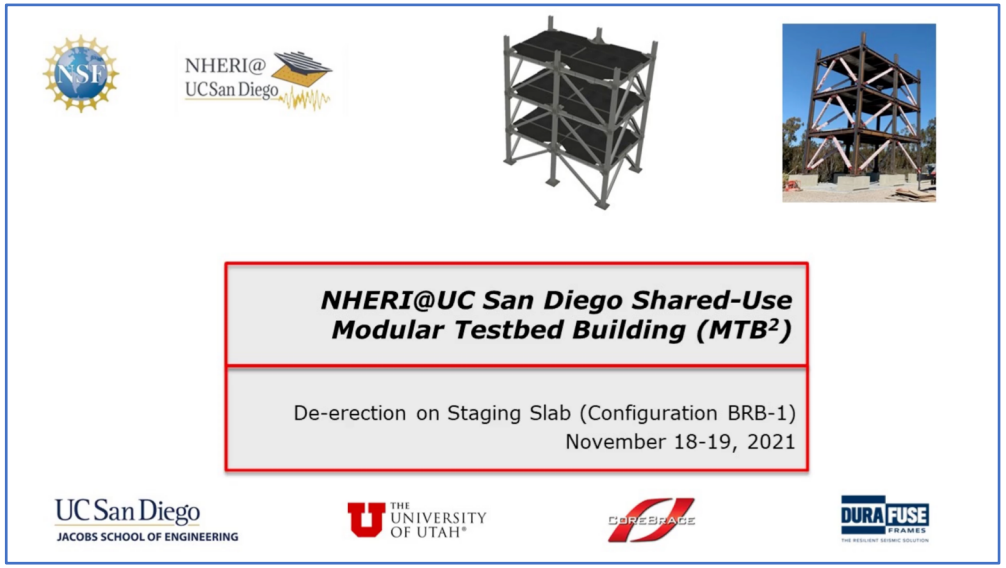
Shake-Down Staging Slab Erection

- Erection of MTB^2 on the UCSD staging slab
  - Oct – Nov 2021 (BRB-1, 50% bolt-up)
  - Evaluate fit-up of all components
  - Conduct shock (tire) tests of MTB^2
- Outcome:
  - ~2days for erection
  - ~1.5days for de-erection
  - (one) problematic BRB gusset – refabricated



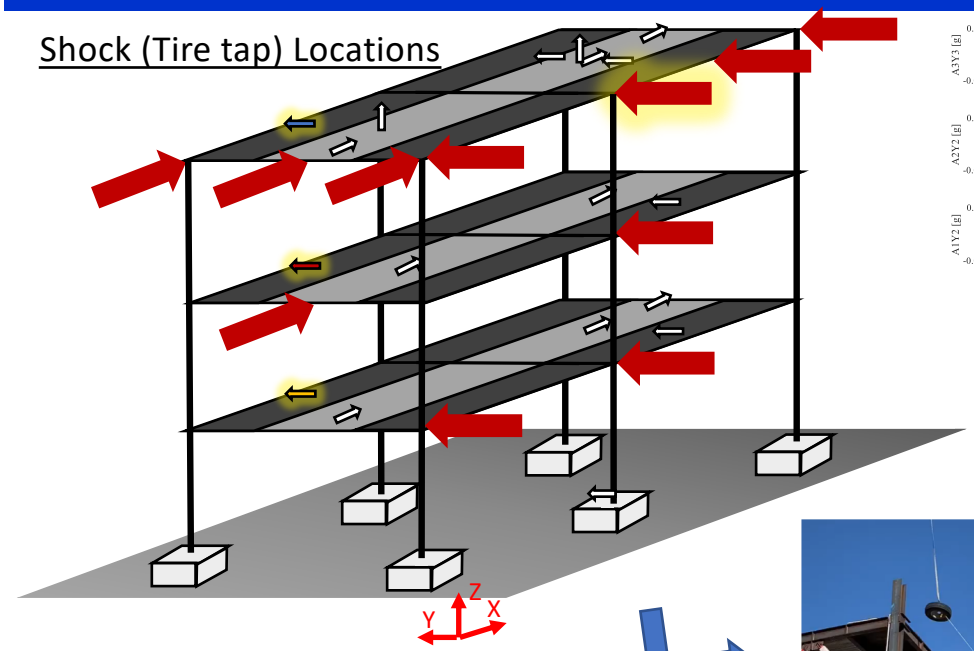
Is MTB² Truly Modular?

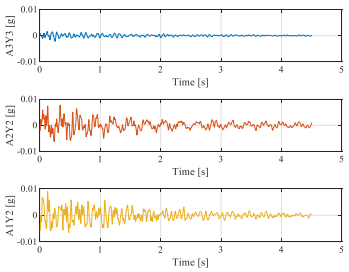


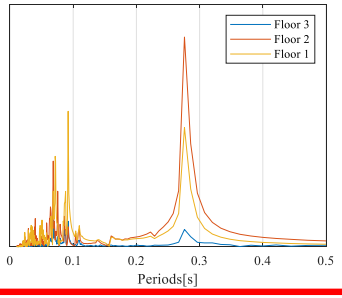


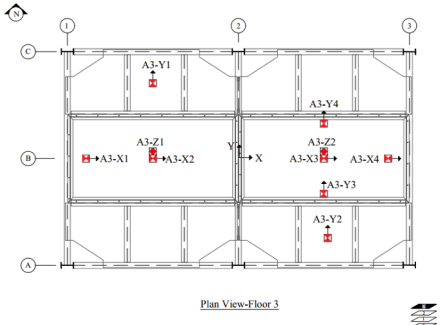
Shock (Tire) Tests

Shock (Tire tap) Locations



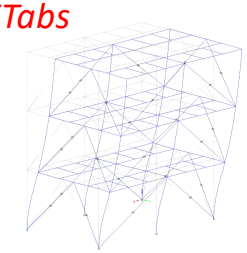






Typical Floor Accelerometer Layout

ETabs



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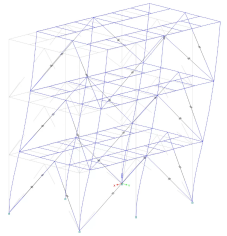

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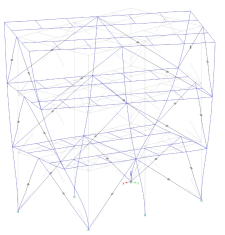

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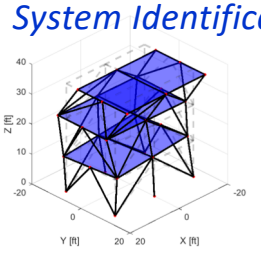
System Identification



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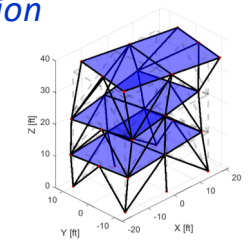

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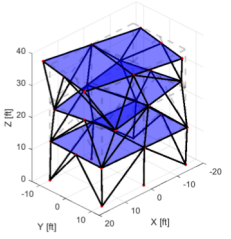

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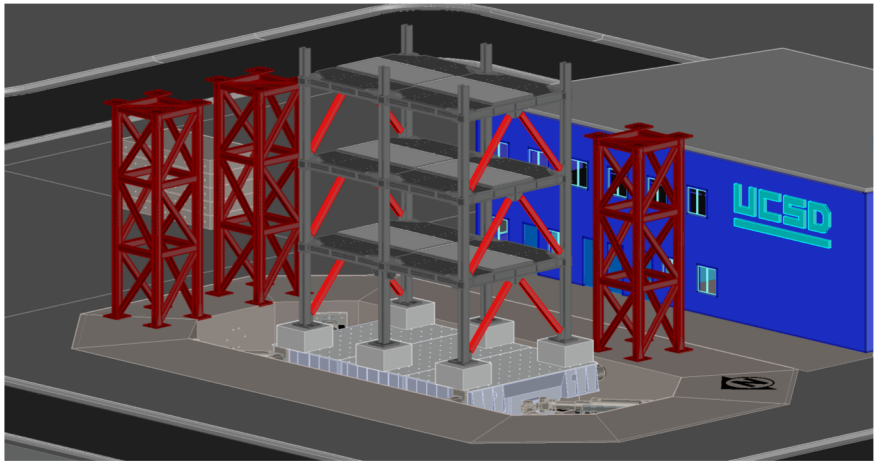
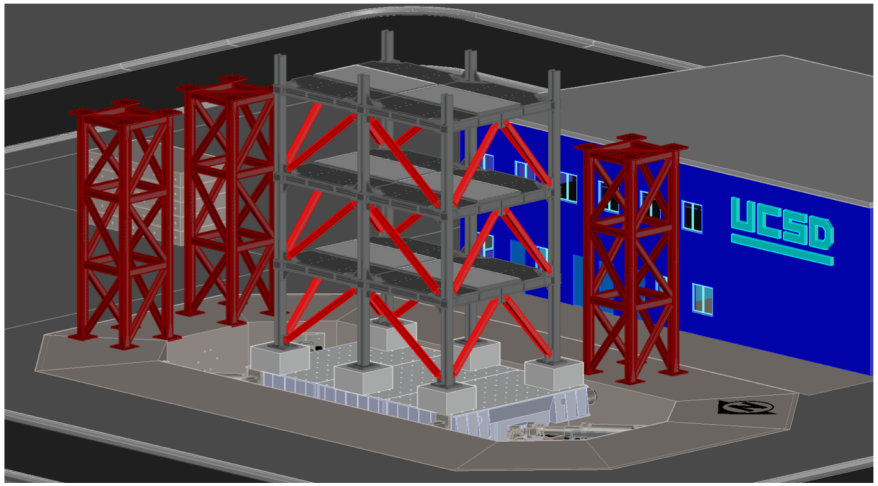
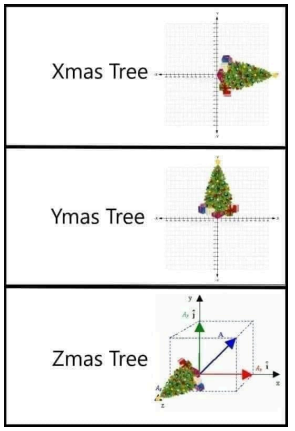
Shake-down Dynamic Testing on LHPOST6 in 2022



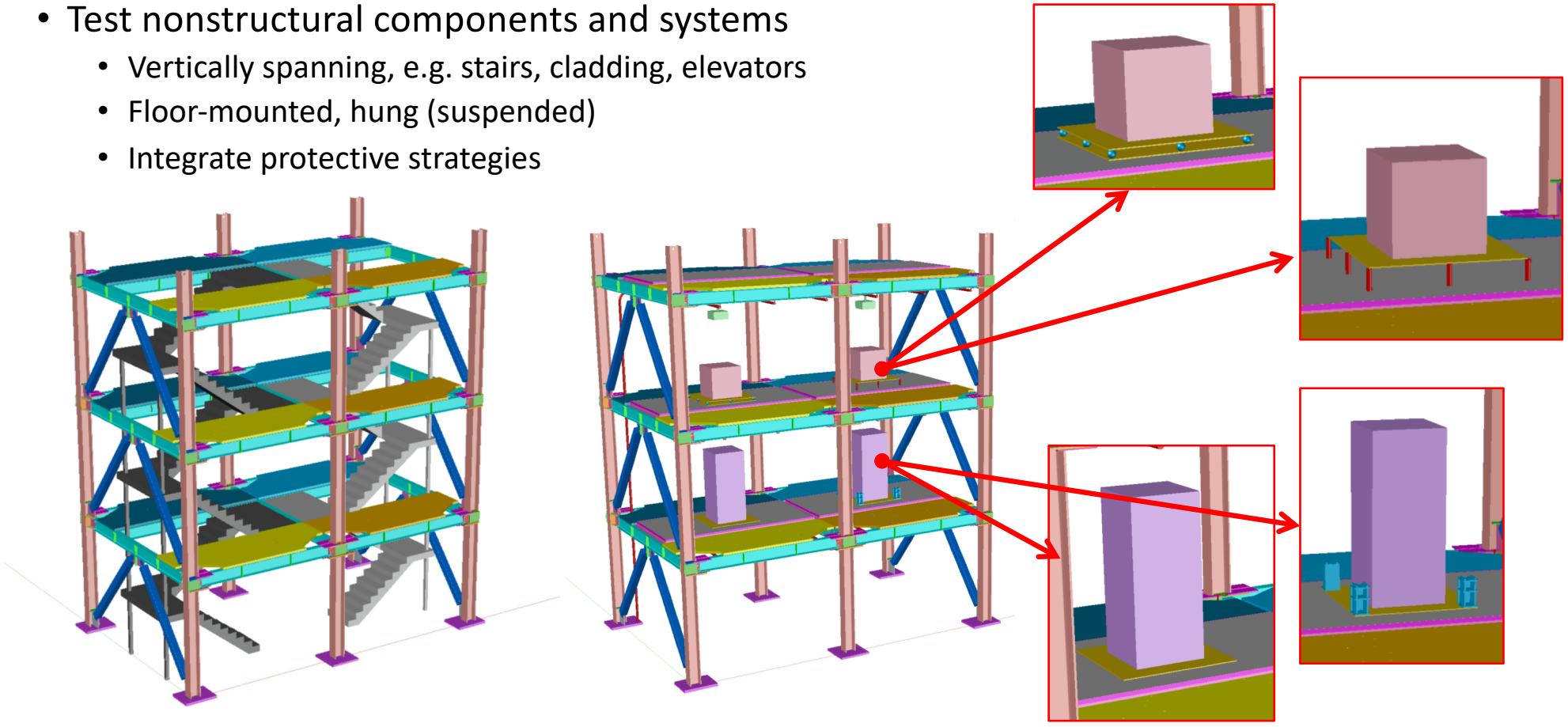


- Test Protocol
  - Three configurations: SMF, SMF+CB, BRB-1
  - One significant (swap) of LFRS (SMF -> BRB)
  - ~180 sensors
  - White noise, sequenced X, XY, XYZ base excitation
  - Motions selected from upgrade (acceptance) tested suite: (Kobe, Takatori & Northridge Rinaldi)
  - Performance limits: service (elastic), service (quasi-elastic), design (near-fuse limit states)



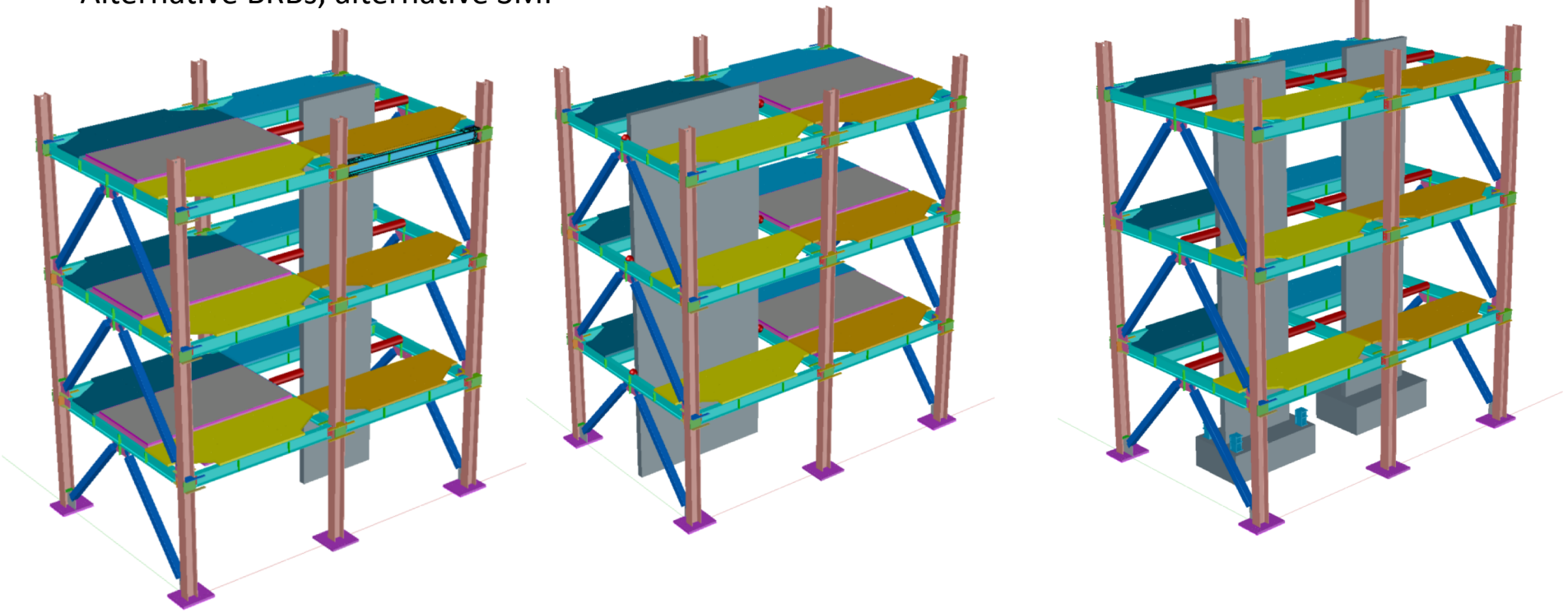
Future Research Opportunities with MTB²

- Test nonstructural components and systems
  - Vertically spanning, e.g. stairs, cladding, elevators
  - Floor-mounted, hung (suspended)
  - Integrate protective strategies

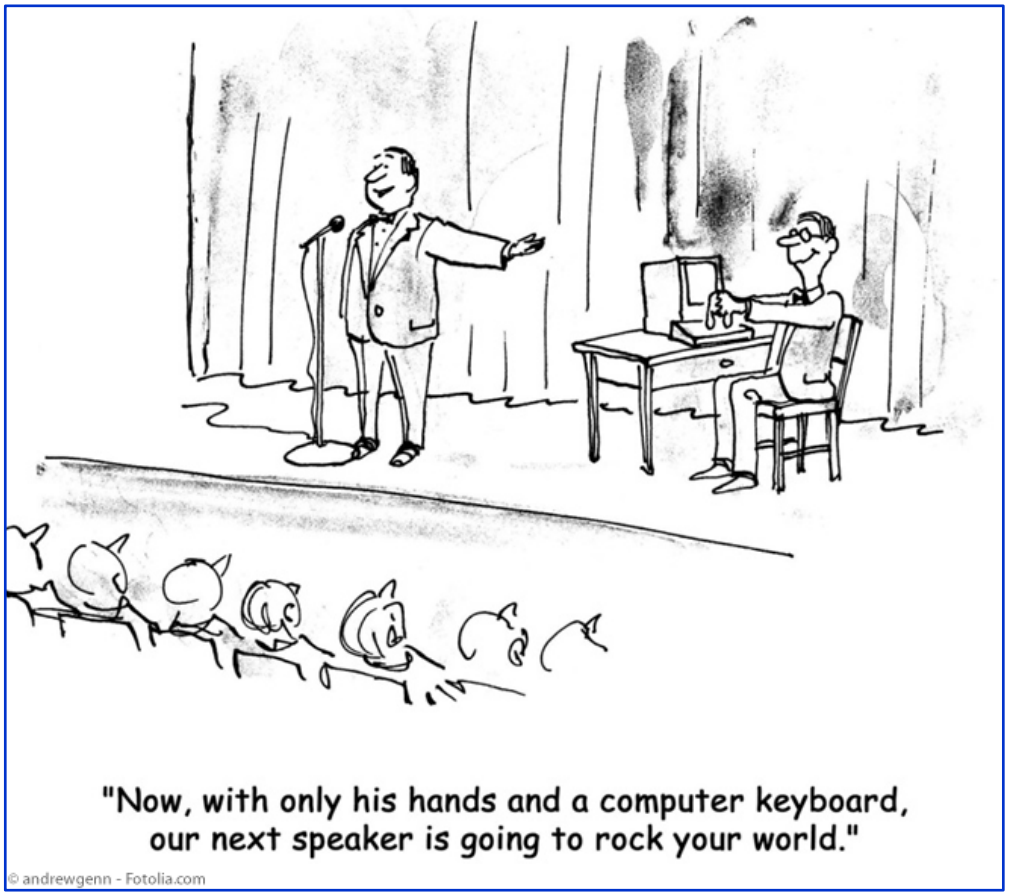


Future Research Opportunities with MTB²

- Test alternative LFRS
  - Conventional walls, integrated with fuse elements
  - Isolation systems (elevate MTB²)
  - Alternative BRBs, alternative SMF



Thank you!



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