Modular TestBed Building (MTB²): A Reconfigurable Shared-Use Equipment Resource for use by Researchers at LHPOST6

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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 MTB²
    • 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 MTB² 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

Zane Schemmer (UCB NHERI REU)

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

<table>
<thead>
<tr>
<th>Item</th>
<th>BRB-1</th>
<th>SMF/SMF+CB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse LFRS [k]</td>
<td>13.2</td>
<td>13.2</td>
</tr>
<tr>
<td>Longitudinal LFRS [k]</td>
<td>20.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Steel Plate [k]</td>
<td>113.2</td>
<td>113.2</td>
</tr>
<tr>
<td>Modular Deck [k]</td>
<td>38.4</td>
<td>38.4</td>
</tr>
<tr>
<td>Columns + BP [k]</td>
<td>28.2</td>
<td>28.2</td>
</tr>
<tr>
<td>Beams [k]</td>
<td>17.9</td>
<td>17.9</td>
</tr>
<tr>
<td><strong>Structural System [k]</strong></td>
<td><strong>231.4</strong></td>
<td><strong>213.4</strong></td>
</tr>
<tr>
<td>Footings [k]</td>
<td>81.6</td>
<td>81.6</td>
</tr>
<tr>
<td><strong>Total Weight [k]</strong></td>
<td>313</td>
<td>295</td>
</tr>
</tbody>
</table>

Modular diaphragm: steel plate + concrete deck
Design Features: Dimensional Plans LFRS + Gravity (NS)

NS Direction: 20’ bay
Design Features: Dimensional Plans LFRS (EW)

BRB-1

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

Construction Phase

Stacked Decks

Steel plate (4x floor) 9.4 kips each

Modular concrete deck (2x floor) 6.5 kips each

W4xW4 at 4”x4”

HILTI Powder Actuated Fasteners

8’-3”

15’-11”

Weight = 6.5 kips
Nonlinear Components of MTB$^2$

- 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)**

**Summary of Modal Periods**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Mode1</th>
<th>Mode2</th>
<th>Mode3</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRB-1</td>
<td>0.24s (T)</td>
<td>0.218s (L)</td>
<td>0.145s (Tor)</td>
</tr>
<tr>
<td>SMF</td>
<td>0.487s (L)</td>
<td>0.24s (T)</td>
<td>0.169s (Tor)</td>
</tr>
<tr>
<td>SMF+CB</td>
<td>0.492s (L)</td>
<td>0.24s (T)</td>
<td>0.17s (Tor)</td>
</tr>
</tbody>
</table>
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% $\varepsilon_a$)
• ~4% roof drift capacity (@SMF PL = 0.05$r$)
• Gradual fuse-fuse (floor-floor) progression of yielding (CP discussion)
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:
  • ~2 days for erection
  • ~1.5 days for de-erection
  • (one) problematic BRB gusset – refabricated

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Is MTB$^2$ Truly Modular?

**NHERI@UC San Diego Shared-Use Modular Testbed Building (MTB$^2$)**

First Erection onto Staging Slab (Configuration BRB-1)
October 19-20, 2021

**NHERI@UC San Diego Shared-Use Modular Testbed Building (MTB$^2$)**

De-erection on Staging Slab (Configuration BRB-1)
November 18-19, 2021

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Shock (Tire) Tests

Shock (Tire tap) Locations

Typical Floor Accelerometer Layout

ETabs

T=0.225s  T=0.204  T=0.137s

System Identification

T=0.279s  T=0.229s  T=0.160s
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)

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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 MTB$^2$

- Test alternative LFRS
  - Conventional walls, integrated with fuse elements
  - Isolation systems (elevate MTB$^2$)
  - Alternative BRBs, alternative SMF
Thank you!

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