Heavy Timber Buckling-Restrained Braced Frames

*A proposed solution for buildings in regions of high seismicity*

EERI 68th Annual Meeting, April 8, 2016
San Francisco, CA
Heavy Timber Braced Frame Precedents
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Braced Frames – Norway (Source: Sweco)
Heavy Timber Braced Frame Precedents
Representative Load vs. Slip Relationship for Wood Fasteners

- Glued joints
- Notched joints
- Circular notch with dowel
- Axially loaded screws
- Nailplates
- Dowel type fasteners

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Attributes of Timber/Dowel Braces

a) 9.5 mm Bolts

b) 12.7 mm Bolts

continues

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Attributes of Timber Dowel Braces
# Current Code Definitions

## IBC 2012 (ASCE 7-10)

<table>
<thead>
<tr>
<th>R</th>
<th>$\Omega_0$</th>
<th>$C_d$</th>
<th>Height Limits (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance or steel sheets</td>
<td>14.1 and 14.5</td>
<td>6 1/2</td>
<td>3</td>
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<table>
<thead>
<tr>
<th>Rd</th>
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<tr>
<td></td>
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<td>Timber Structures Designed and Detailed According to CSA 086</td>
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<tr>
<td></td>
<td></td>
<td>Shear walls</td>
</tr>
<tr>
<td>Nailed shear walls: wood-based panel</td>
<td>3.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Shear walls: wood-based and gypsum panels in combination</td>
<td>2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Braced or moment-resisting frames with ductile connections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderately ductile</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Limited ductility</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Other wood- or gypsum-based SFRS(s) not listed above</td>
<td>1.0</td>
<td>1.0</td>
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</tbody>
</table>
Attributes of Timber/Dowel Braces

Advantages
- High strength/weight ratio (low inertial mass)
- High short term load strength

Disadvantages
- Brittle failure modes exist
- Localized damage at post-yield (pinched hysteresis)
- Concentrated locations of limited ductility (fasteners)
- Ductile connections = low stiffness
The BRB - Primer
Buckling-Restrained Braced Frame Primer
Buckling Restrained Brace Primer
Buckling Restrained Brace Primer

BRB Observed Failure Modes

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Buckling-Restrained Braced Frame Primer

Current Code Definition:

25. Steel buckling-restrained braced frames

- AISC 341-10
  - Section F4 – Design Provisions
    - Capacity based philosophy
  - Section K3 – Testing Qualifications
    - Component
    - Subassembly

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<tr>
<td>25</td>
<td>14.1</td>
<td>8</td>
<td>2(\frac{1}{2})</td>
<td>5</td>
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The HTBRB
Heavy Timber Buckling-Restrained Braced Frames

ARUP

Braced Frames – Heavy Timber BRB Research
HTBRB Component Level Test Requirements

2% DRIFT

W 13.75ft

U 3.34"

ΔL 2.36"

H 13.75ft

L 19.45ft

Brace Pin to Pin L’ = 16’-11"

θ 45deg
HTBRB Component Level Test Requirements

4c. Loading Sequence

Loads shall be applied to the test specimen to produce the following deformations, where the deformation is the steel core axial deformation for the test specimen and the rotational deformation demand for the subassemblage test specimen brace:

(1) 2 cycles of loading at the deformation corresponding to $\Delta_b = \Delta_{by}$.
(2) 2 cycles of loading at the deformation corresponding to $\Delta_b = 0.50\Delta_{bm}$.
(3) 2 cycles of loading at the deformation corresponding to $\Delta_b = 1\Delta_{bm}$.
(4) 2 cycles of loading at the deformation corresponding to $\Delta_b = 1.5\Delta_{bm}$.
(5) 2 cycles of loading at the deformation corresponding to $\Delta_b = 2.0\Delta_{bm}$.
(6) Additional complete cycles of loading at the deformation corresponding to $\Delta_b = 1.5\Delta_{bm}$ as required for the brace test specimen to achieve a cumulative inelastic axial deformation of at least 200 times the yield deformation (not required for the subassemblage test specimen).
3. ACCEPTANCE CRITERIA:

A. THE HYSTERETIC BEHAVIOR SHALL DISPLAY NO POST-YIELD LOSS OF STRENGTH, DEGRADATION, OR PINCHING.

B. FRACTURE OF ANY PORTION OF THE BRB SHALL NOT OCCUR.

C. A CUMULATIVE INELASTIC DUCTILITY VALUE OF 200 SHALL BE ATTAINED.

D. THE COMPRESSION STRENGTH ADJUSTMENT FACTOR $\beta$ SHALL BE NO GREATER THAN 1.15.
Specimen B

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Braced Frames – Heavy Timber BRB Research
Specimen B

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Braced Frames – Heavy Timber BRB Research
Conclusion

• There is a need for code-defined heavy timber seismic systems
• The HTBRBF has merits b/c:
  • An extension of codified AISC 341 steel BRBF system
  • Straightforward to analyze
  • High strength, stiffness, & ductility (win-win-win)
  • Limited irrecoverable timber damage
  • Potential for rapid application near-term (PBD – ASCE 41-13)
• Sub-assembly (frame) test needed
• Economic/constructible frame details needed
• Start USA code definition
  • FEMA P-695