

Design Considerations: Beam-Column Connections and Steel Buckling-Restrained Braced Frames

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Senior Engineering Manager, Timberlab



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Steel-Timber Conference



DESIGN CONSIDERATIONS: BEAM-COLUMN CONNECTIONS AND TIMBER BUCKLING RESTRAINED BRACED FRAMES

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TIMBER BRACED FRAMES: CLASSIFICATION

Shear Walls



SARA CULTURAL CENTRE HOTEL, SKELLEFTEÅ, SWEDEN

Braced Frames



MJOSTARNET, NORWAY

Moment Frames



U OF CANTERBURY, NZ

TIMBER BRACED FRAMES: CLASSIFICATION

Code/Design

USA

- 1997 UBC Provisions Removed from 2000 IBC
- Not defined (ASCE 7)
- Not defined (NDS)
- Code alternative (IBC 104.11)

Canada

- CBC Part 4 (R_d , R_o & Height Limit)
- Not defined (CSA O86)
- FPIInnovations design guides
- Alternative solution (?)

Other Countries:

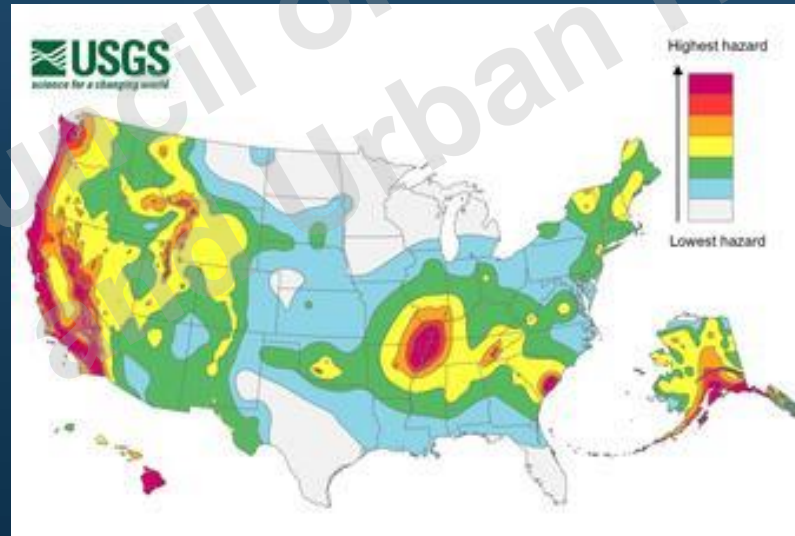
- Europe...
- Australia...
- New Zealand...

Seismic Hazard

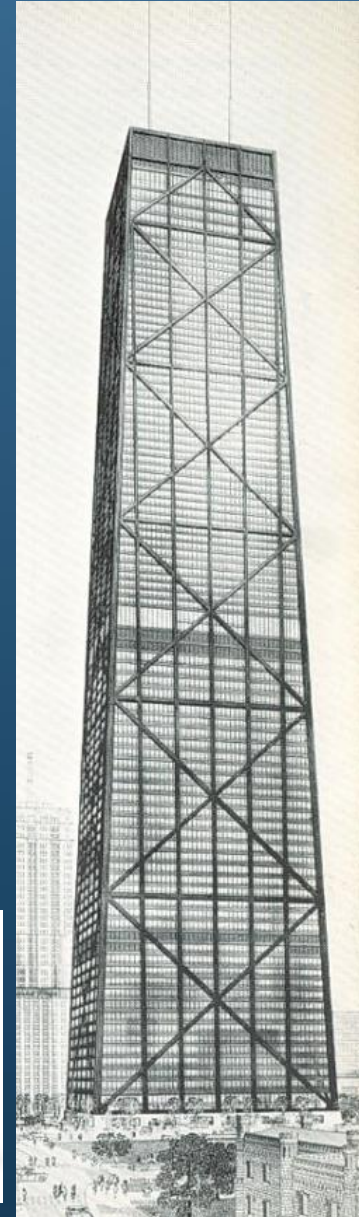
Low (SDC A)

Moderate (SDC B, C)

High (SDC D,E,F)



Building Height/Scale



BRACED FRAMES: TIMBER-TIMBER

California Polytechnic State University: *Simpson Strong Tie Materials Demonstration Laboratory*

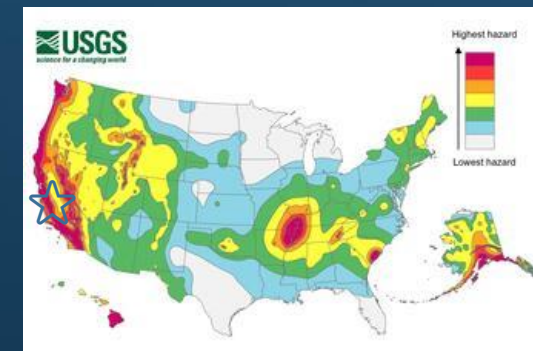
- Date: 2009
- 1-Story
- High Seismic
- IBC
- Code Alternate - Peer Review
- $R \sim 1.0$

Other built projects:

- Jackson Hole Airport, WY



CAL POLY



BRACED FRAMES: TIMBER-TIMBER

Apex Clean Energy, Charlottesville
VA

- Date: 2021
- 6-Story over podium
- **Moderate Seismic**
- IBC
- Code Alt – R=3
- References FPInnovation testing

*Braced Frame + Concrete Shear Walls

Other built projects:

- UMass Amherst MA
- Viega Building, CO
- Wythe II NY
- Bombardier Hangar, QB
- TRCA Toronto ON
- Centennial College, ON
- Beatrice Tinsley, NZ
- UBC ESB, BC



APEX CLEAN ENERGY



BRACED FRAMES: TIMBER-TIMBER

Mjøstårnet, Norway

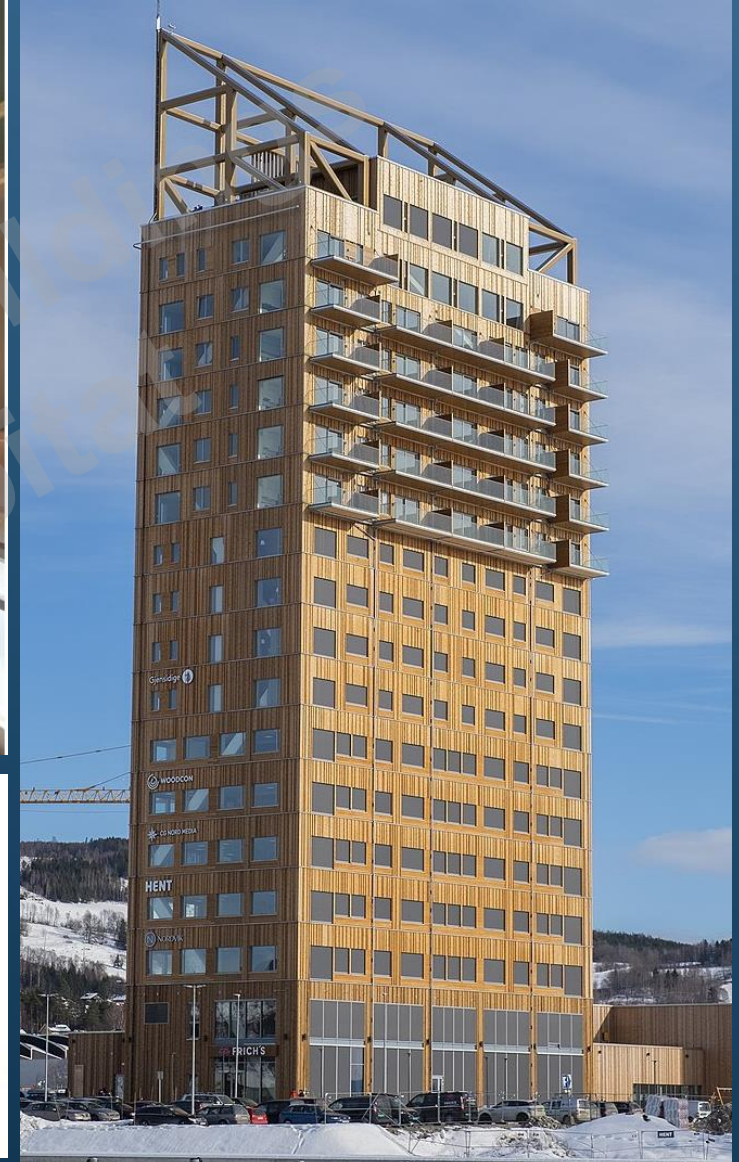
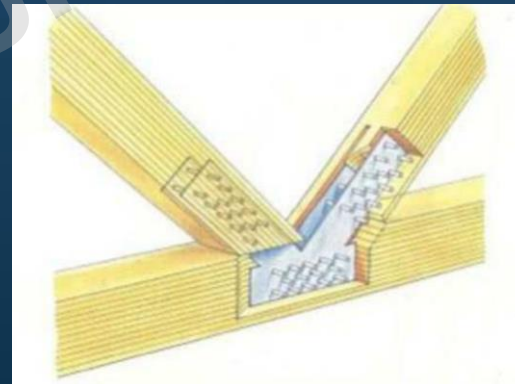
- Date: 2019
- 18-Story
- Low Seismic
- Eurocode

Other built projects:

- TREET Tower, Norway
- 25 King St. Australia



MOELVEN



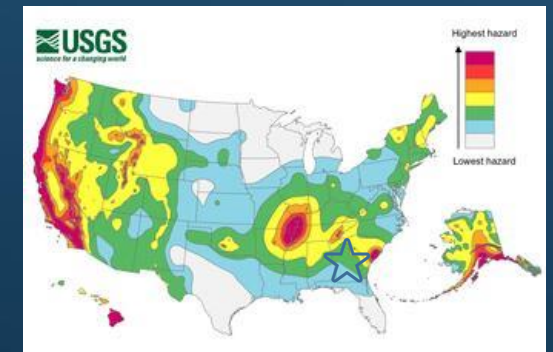
BRACED FRAMES: STEEL/TIMBER-TIMBER

T3, Atlanta Georgia

- Date: 2018
- 5-Story over podium
- Low Seismic
- IBC
- ASCE 7 - R=3 (Steel)
- Code Alternate (?)



HINES



BRACED FRAMES: STEEL BRBF-TIMBER

First Tech Credit Union, Hillsboro OR

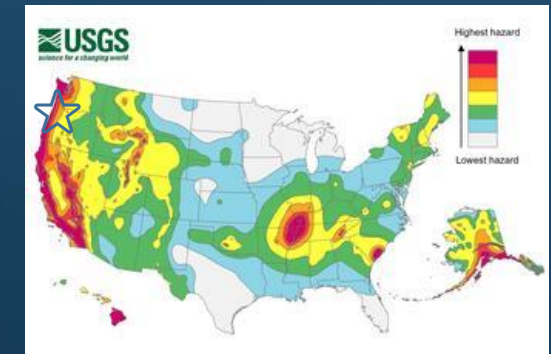
- Date: 2016
- 5-Story
- High Seismic
- IBC
- AISC 341 – BRBF

Other built projects:

- Carbon 12, Portland OR
- Heartwood, Seattle WA
- County Office Building, Redwood City CA
- 843 N Spring St., Los Angeles CA
- District 56 Tallwood 1, BC *ECBF
- 80M, Washington DC *OCBF



SWINERTON BUILDERS



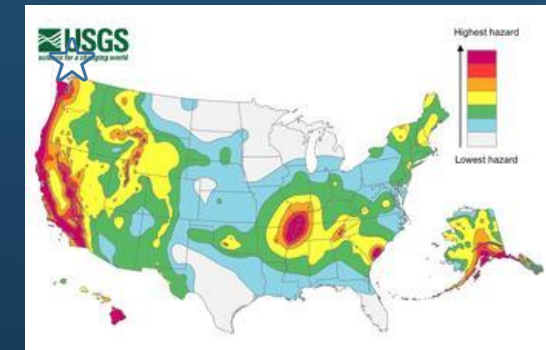
BRACED FRAMES: STEEL BRB-TIMBER

Terminus 56, BC

- Date: 2021
- 5-Story
- High Seismic
- CBC
- UC Canterbury Research
- Based on capacity-based design principles
- Alternative Solution (?)



ASPECT ENGINEERS

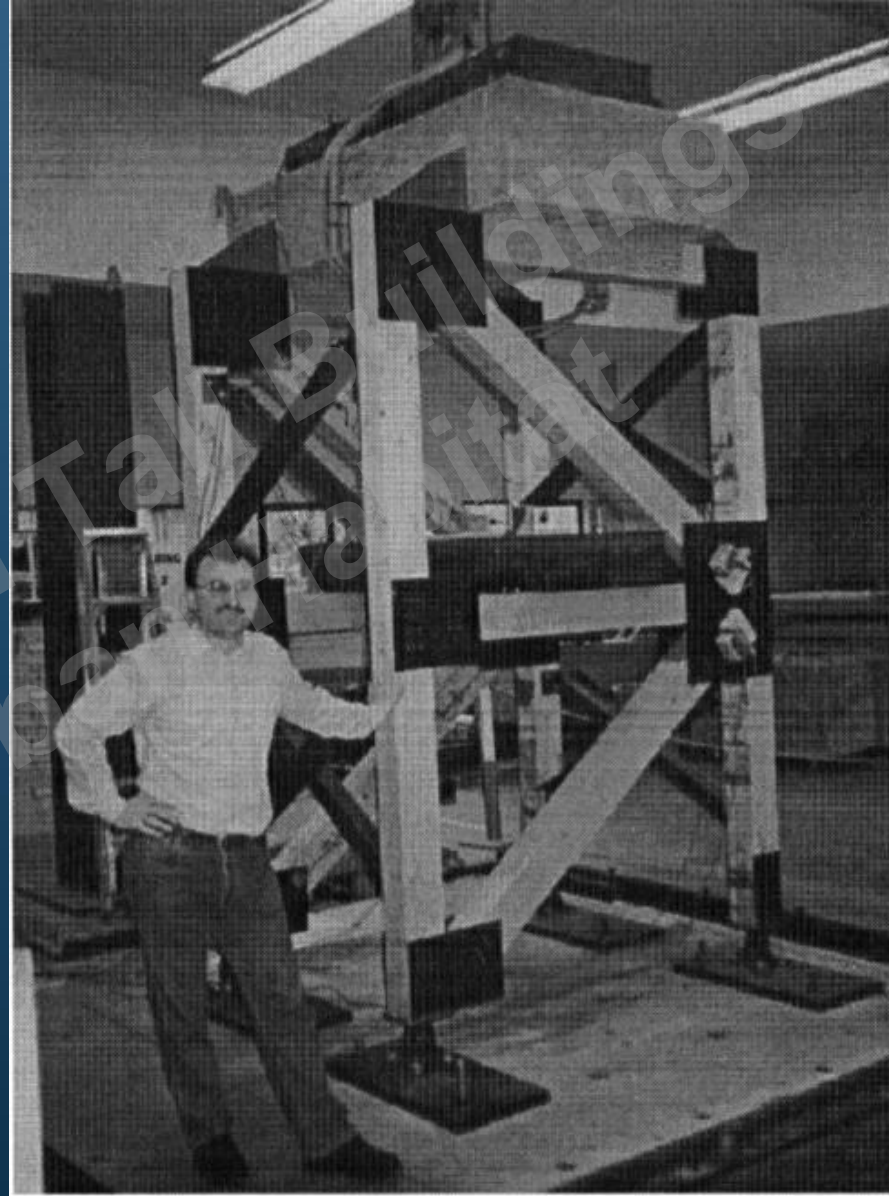


BRACED FRAMES: RESEARCH

UBC Popovich Thesis – 2000

FPIInnovation Reports Yr 1 and 2 – 2019, 2020

- Bolts and timber rivet end connections tested (rivets identified as superior)
- Limited deformation ($< \sim 1.25\%$ Drift)
- Only one end yields, at least initially
- Low cumulative energy dissipation
- Brace end gaps for tension and compression deformation.
- Recommended that columns should be continuous (not spliced) to help distribute brace yielding between stories.

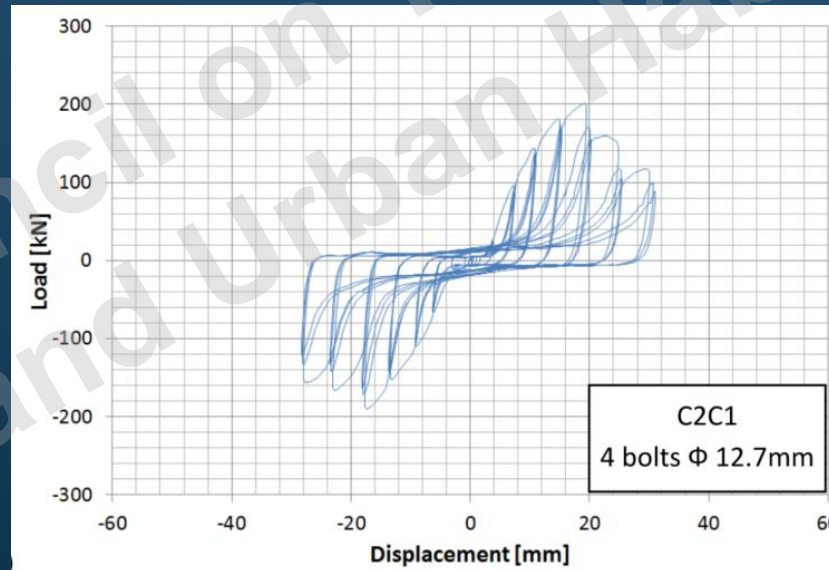


POPOVICH

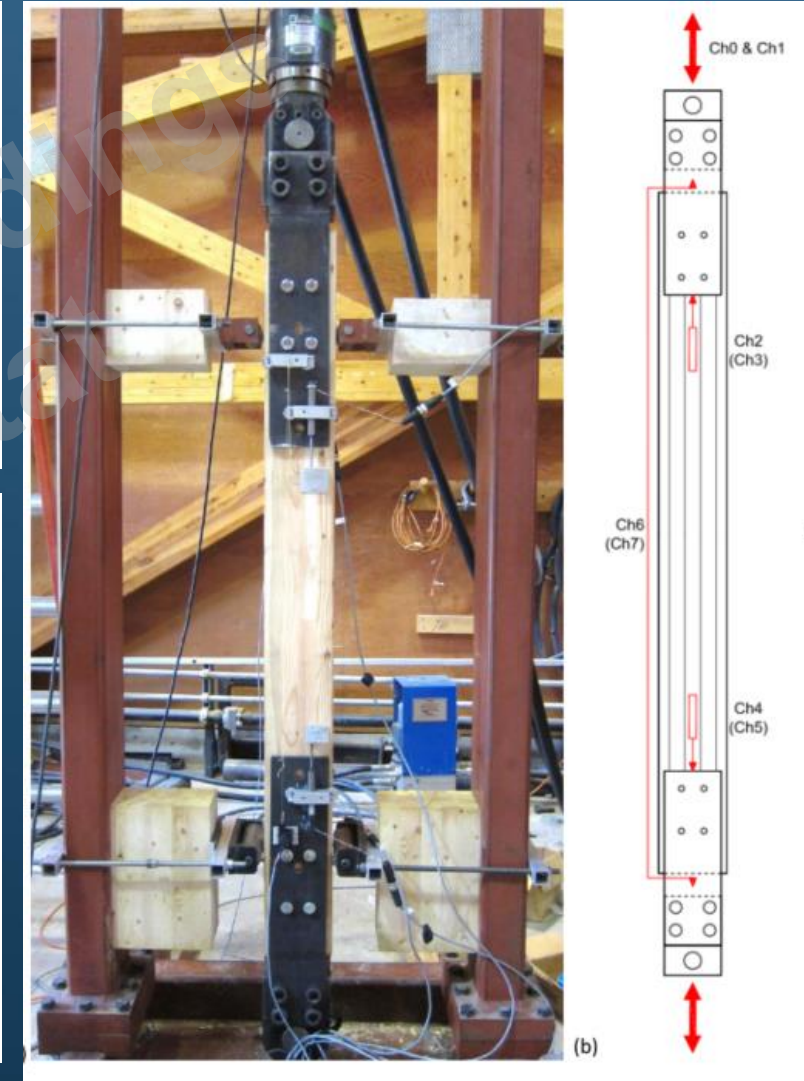
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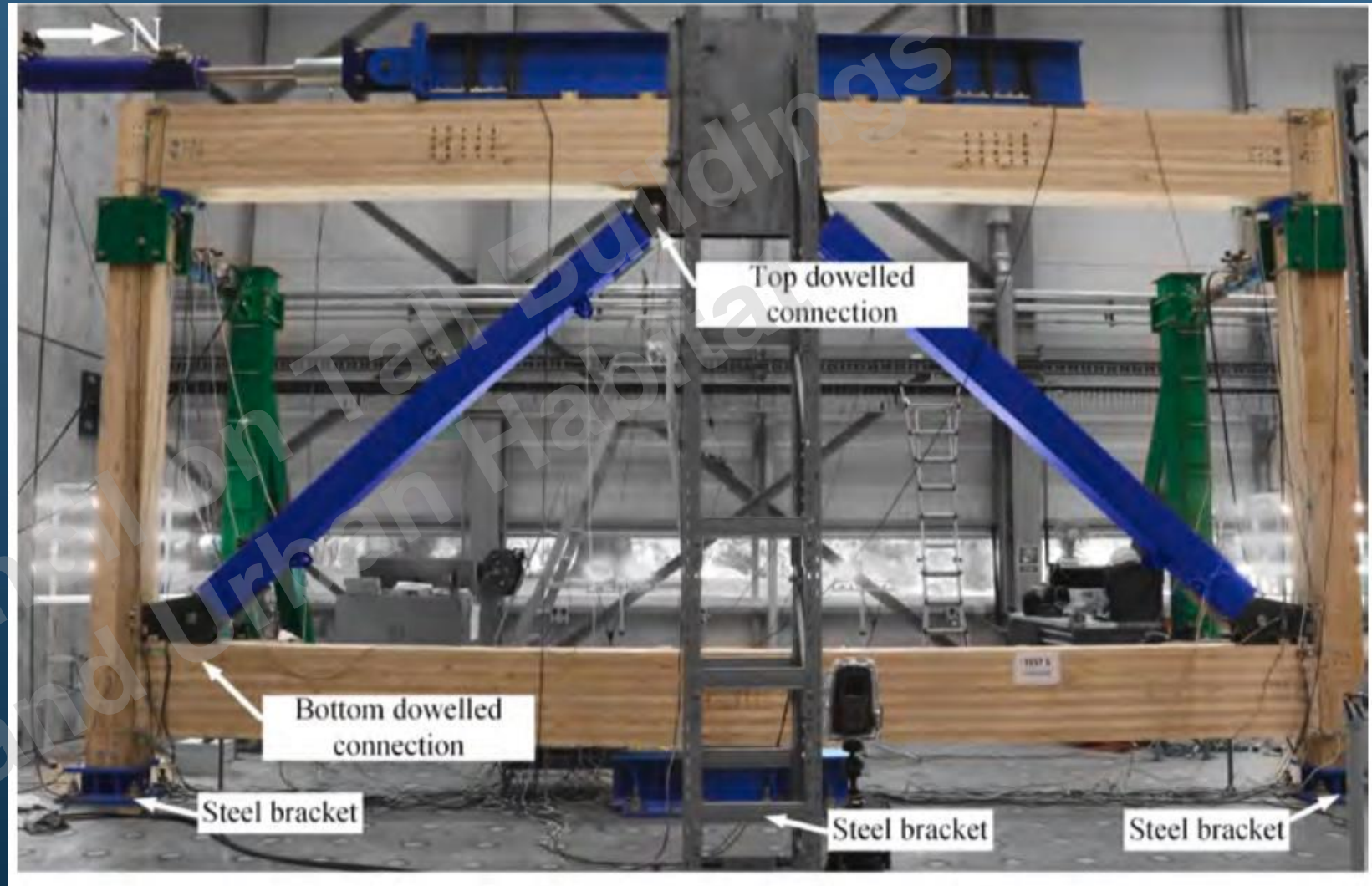
FP INNOVATIONS



BRACED FRAMES: RESEARCH - HYBRID BRBF

U of Canterbury NZ

- Date: 2019
- Timber GLB and GLC
- “Conventional” BRB
- BRB was “home-made” & had some performance issues
- 2D Frame Cyclic Tests
- Two gusset connection types tested
- Tests - limited to 1.5% Story Drift

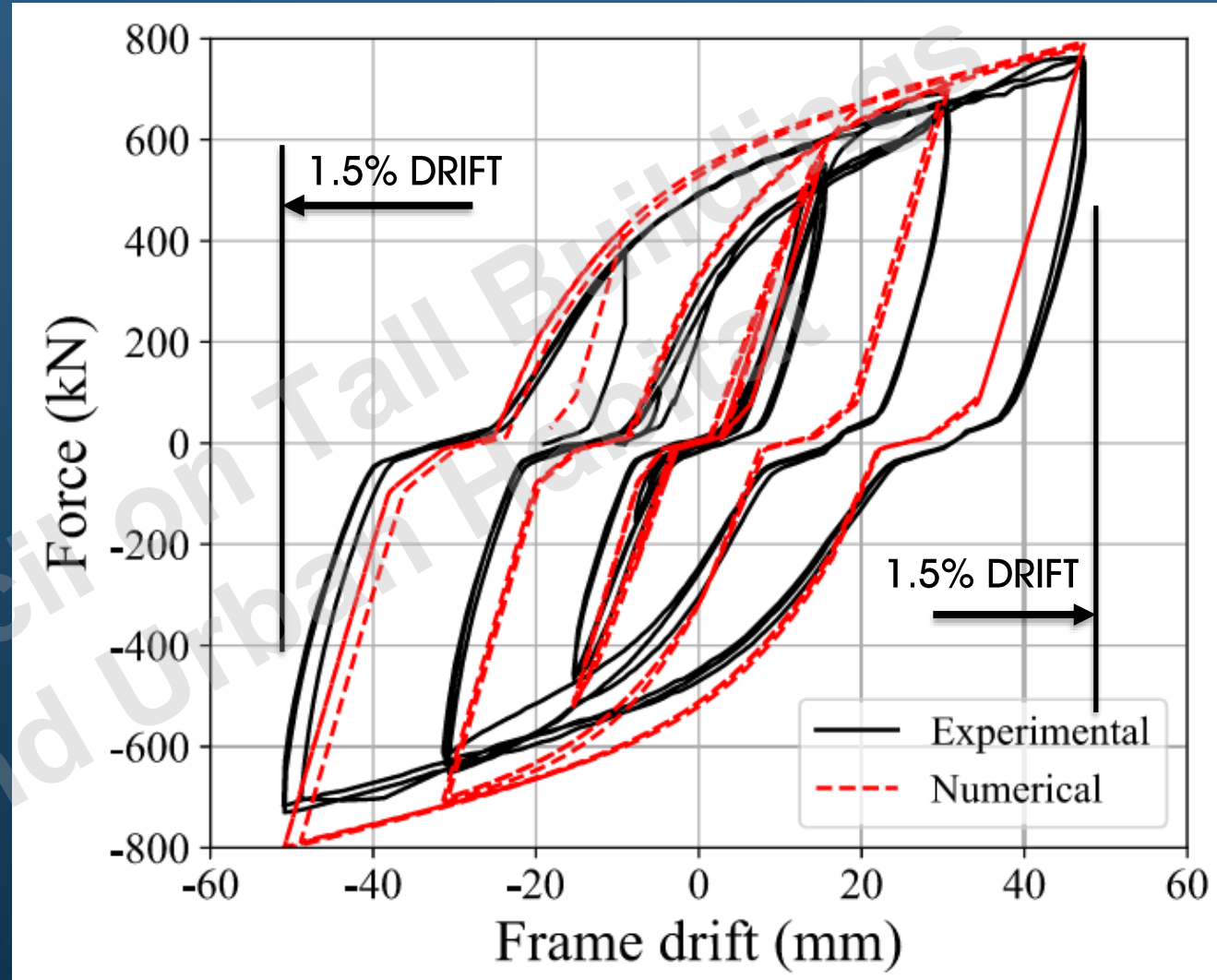


DONG, ET AL

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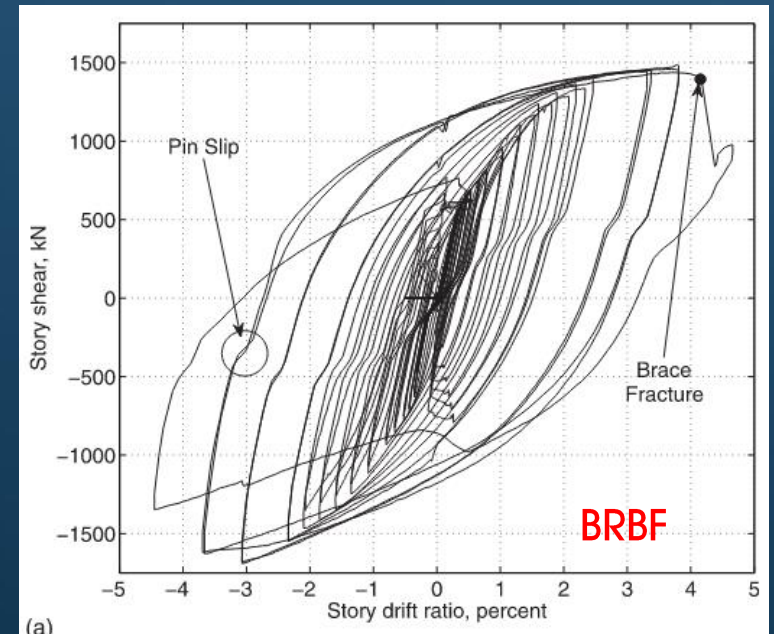
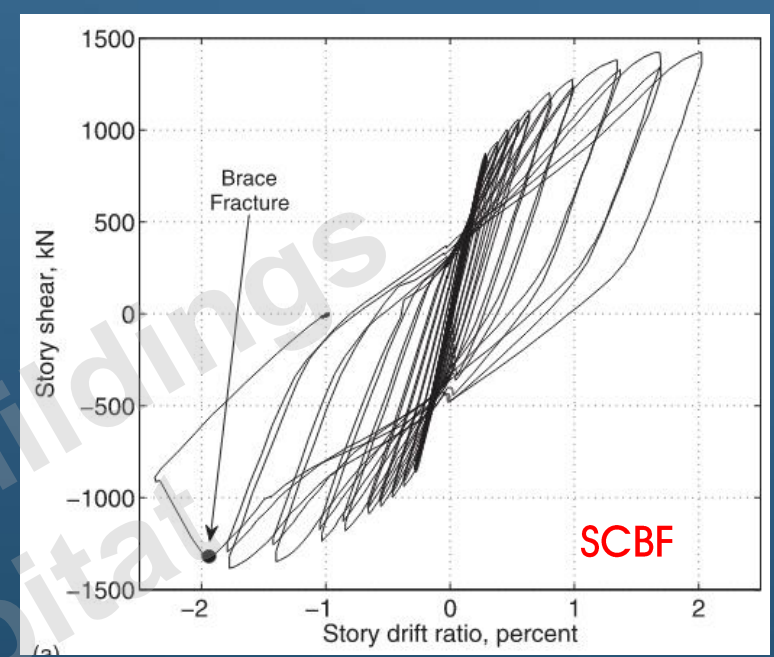
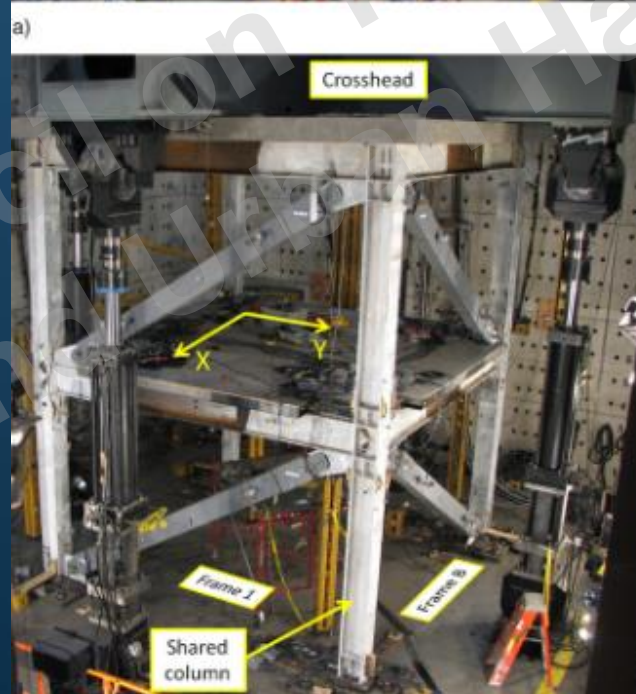
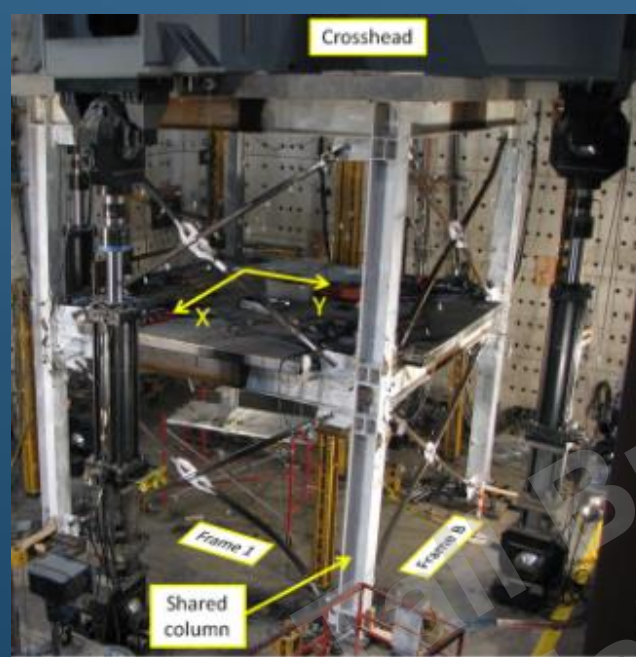


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BRACED FRAMES: RESEARCH - STEEL BRBRF

U of Washington, USA

- Date: 2009
- AISC 341 - SCBF and BRBF
- 3D Frame Cyclic Tests
- SCBF attained 2% Story Drift
- BRBF attained 4% Story Drift
- Beam/Column/Gusset Failure Modes Studied
- Frame vs. Brace story shear measured



PALMER, ET AL

BRACED FRAMES: RESEARCH - STEEL BRBRF

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(a)



(b)



(c)

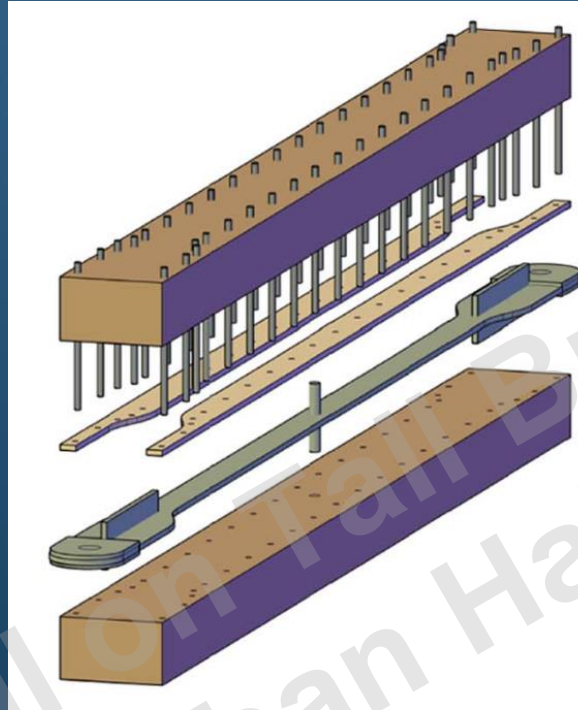


(d)

BRACED FRAMES: RESEARCH – TIMBER BRB

U of Utah, USA

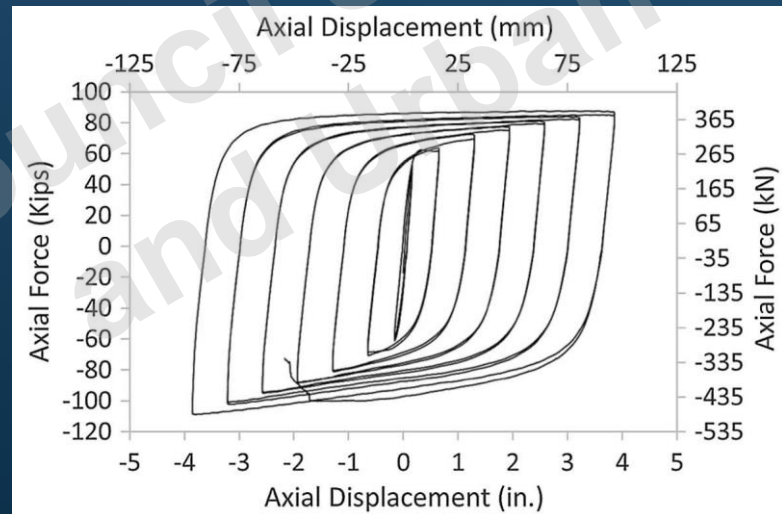
- Date: 2015-2019
- Steel Core – timber casing
- Cyclic component test
- Six tested specimens
- AISC 341 qualification procedure
- Max core strains: 3.9% (~4% Story Drift)
- CIDs: up to 1500 (>> 200)
- Failure modes observed



BRACED FRAMES: RESEARCH – TIMBER BRB

U of Utah, USA

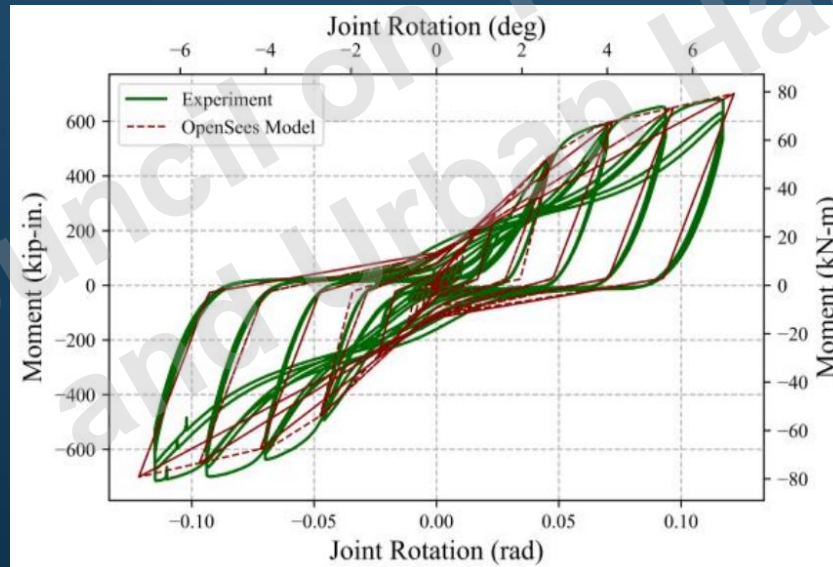
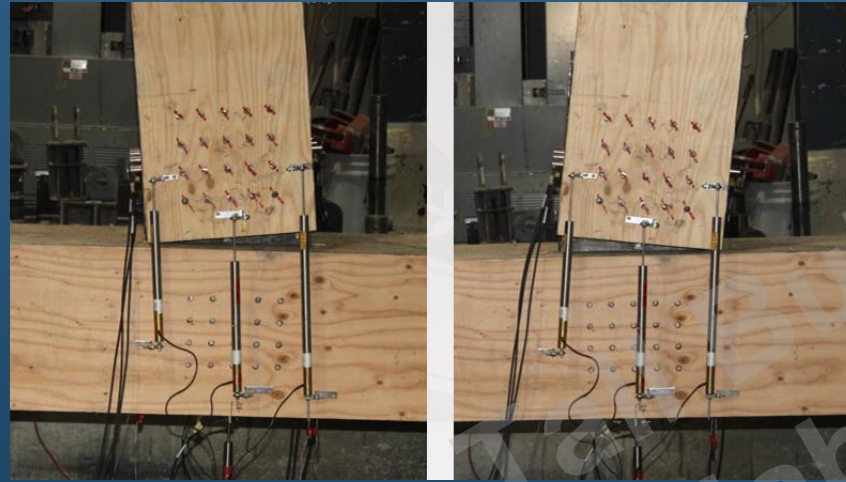
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BRACED FRAMES: RESEARCH – TIMBER-BRBF PHASE 1

U of Utah, USA

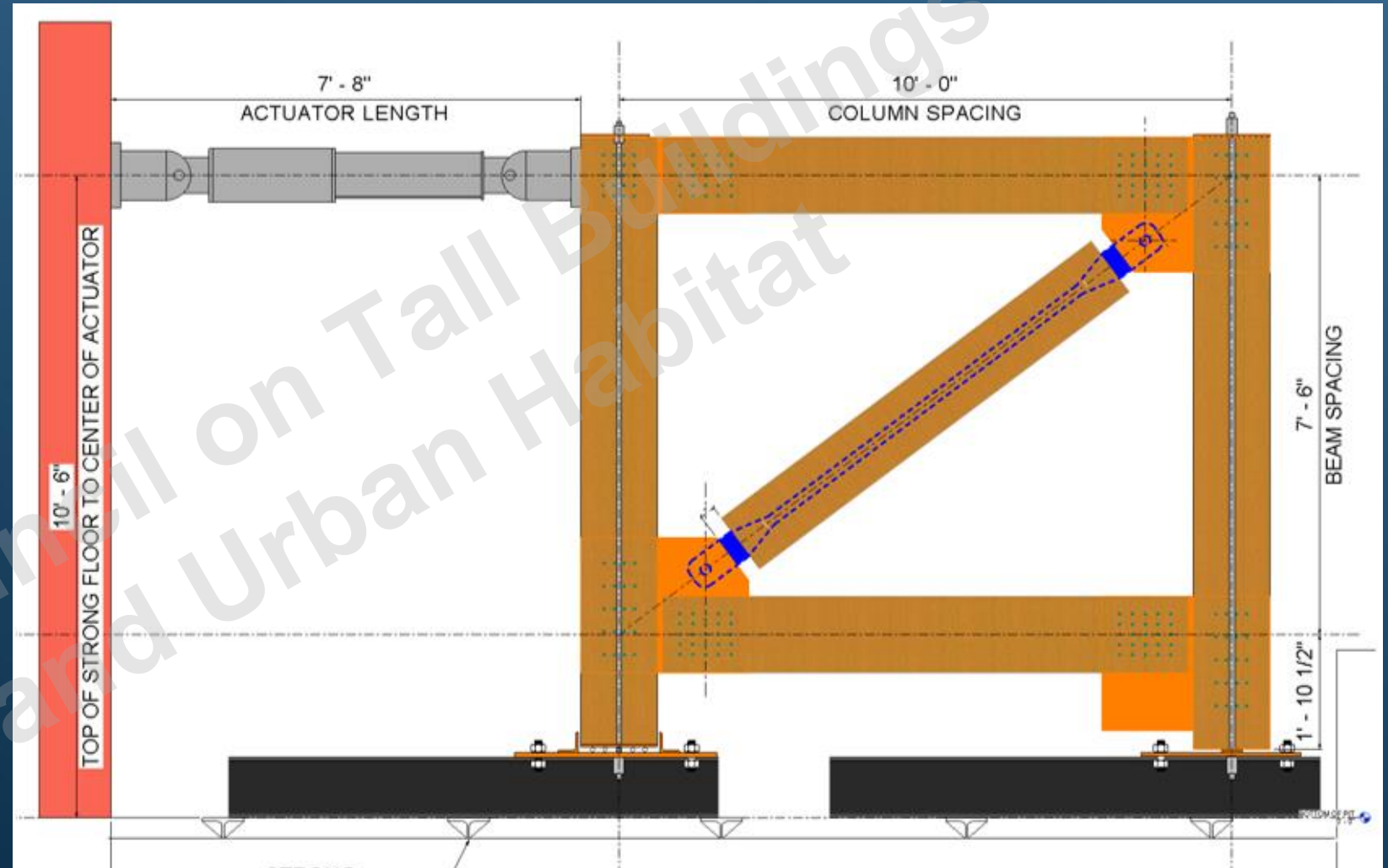
- Date: 2021
- Beam/Column Joint Rotation Testing
- (20), (16), and (12) ½" dia. dowel groups tested
- Group IV dowel failure modes (ductile)
- 0.13 rad (7.4 deg) rotation achieved (Equates to > 10% story drift)



BRACED FRAMES: RESEARCH - TIMBER-BRBF PHASE 2

U of Utah, USA

- Date: 2022 (Ongoing)
- Cyclic 2D subassembly testing
- Cyclic performance validation
- Target 3.5 to 4% drift



RESEARCH TO APPLICATION – TIMBER BRACED FRAMES

ASCE 7-16 – SDC B – F

- Section 12.2.1.1

Current Pathways for Code Compliance:

- FEMA P695 – *Quantification of Building Seismic Performance Factors*

-or-

- ASCE 7-16:
- *Chapter 1 – Performance based design procedures*
- *Chapter 16 – Nonlinear Response History Analysis*
- *Peer Review*

12.2.1.1 Alternative Structural Systems. Use of seismic force-resisting systems not contained in Table 12.2-1 shall be permitted contingent on submittal to and approval by the Authority Having Jurisdiction and independent structural design review of an accompanying set of design criteria and substantiating analytical and test data. The design criteria shall specify any limitations on system use, including Seismic Design Category and height; required procedures for designing the system's components and connections; required detailing; and the values of the response modification coefficient, R ; overstrength factor, Ω_0 ; and deflection amplification factor, C_d . The submitted data shall establish the system's nonlinear dynamic characteristics and demonstrate that the design criteria result in a probability of collapse conditioned on the occurrence of MCE_R shaking not greater than 10% for Risk Category II structures. The conditional probability of collapse shall be determined based on a nonlinear analytical evaluation of the system and shall account for sources of uncertainty in quality of the design criteria, modeling fidelity, laboratory test data, and ground motions. Structural design review shall conform to the criteria of Section 16.5.

THANK YOU

