Wood Products & Mass Timber Research

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Presentation Outline

- Mass Timber Workshop
- Structural Design
- Fire Performance
- Building Monitoring
- Additional Research

Mass Timber Research Workshop

- November 2015 at USDA Forest Products Laboratory
  - Coordinated and Discuss Mass Timber Research Efforts in North America
  - 125+ participates
    - Industry
    - Academia
    - Practitioners
    - Government Officials
- Four broad areas of discussion
  - Structural Performance
  - Serviceability
  - Fire Performance
  - Materials Resources and other Research Areas

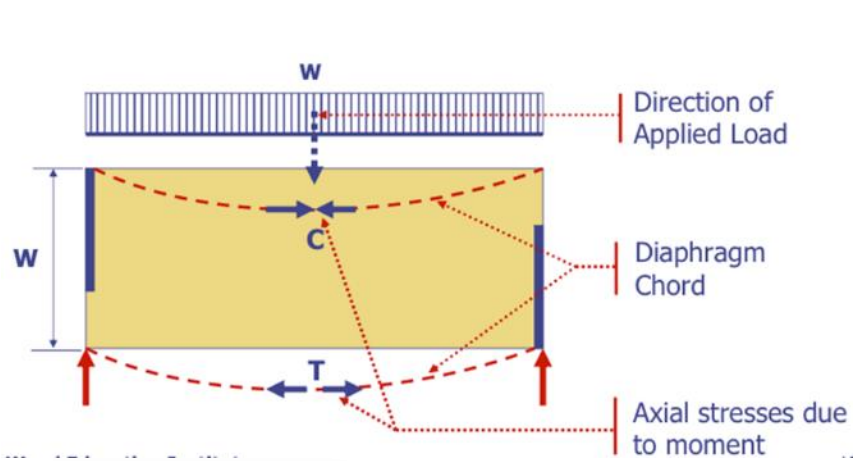
Structural and Building Performance

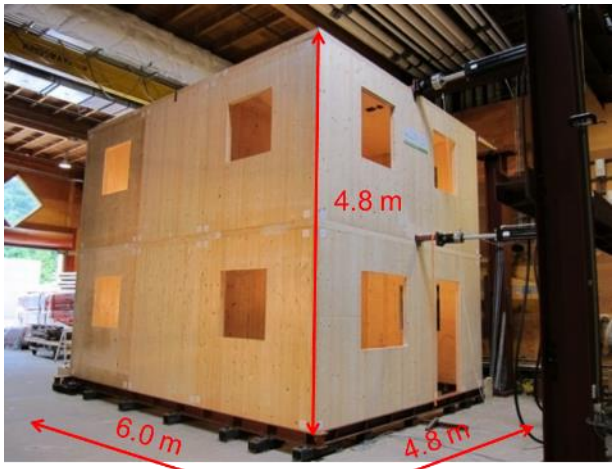
- Structural
  - Seismic design factors
  - Diaphragm design
  - Resilient Systems
    - Rocking Wall
    - BRB
  - Connection
    - Details
    - Improved capacity
- Building
  - Impacts of water and level of protection during construction
  - Long term building performance data
  - Stiffness focused performance based design guidelines for mass timber floors
  - Wind induced vibration for tall buildings
  - Coupling of vibration and acoustic research

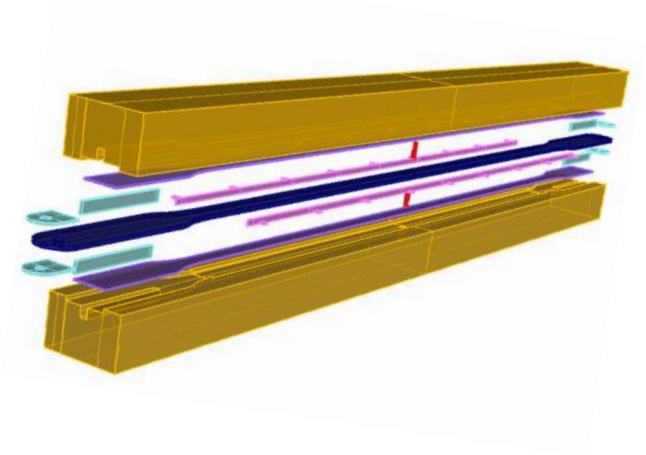
Fire Safety and Other Topics

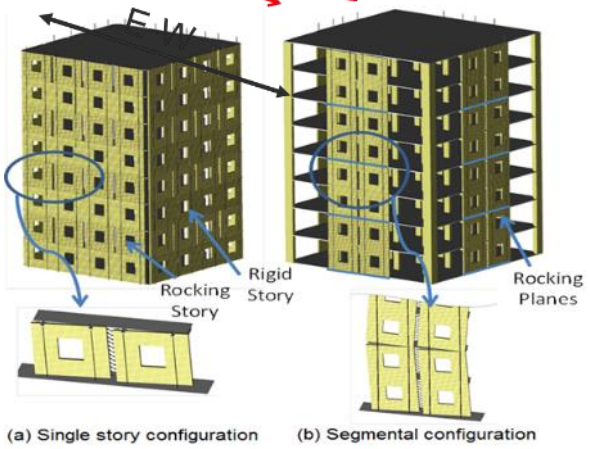
- Fire Performance
  - Communication and Education
    - Share what is known
    - Document fire performance data
  - Industry should standardize
    - Performance testing
    - Data presentations
  - Connection testing and rating with varying concealment levels
  - Adhesives
  - Numerical modeling of mass building fire performance and risk analysis
- Material Resources & Other
  - Data Driven Research on costing aspects
  - Knowledge gap potential sources
    - Beetle kill
    - Forest fire thinning materials

Structural Design



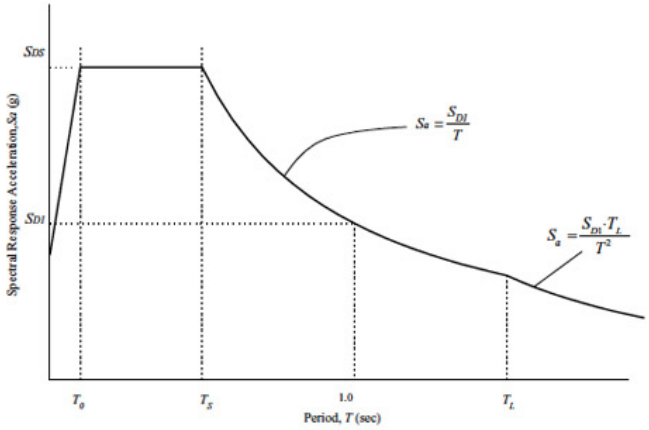


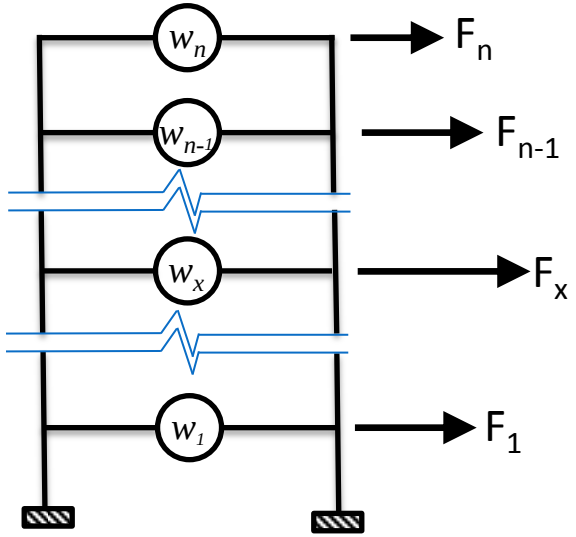




Structural Design - Seismic

– Equivalent Lateral Force Design





$$V = C_s W$$

$$C_s = \frac{S_{DS}}{R/I}$$

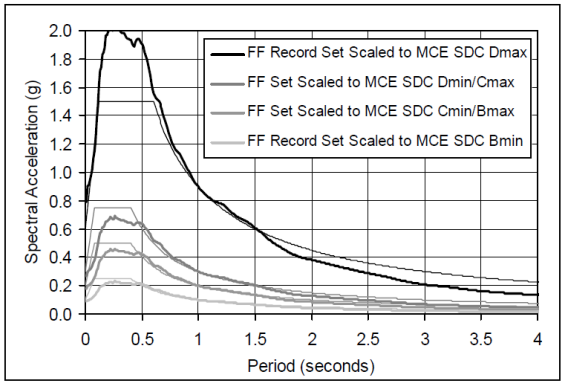
R, Ω_o, C_d

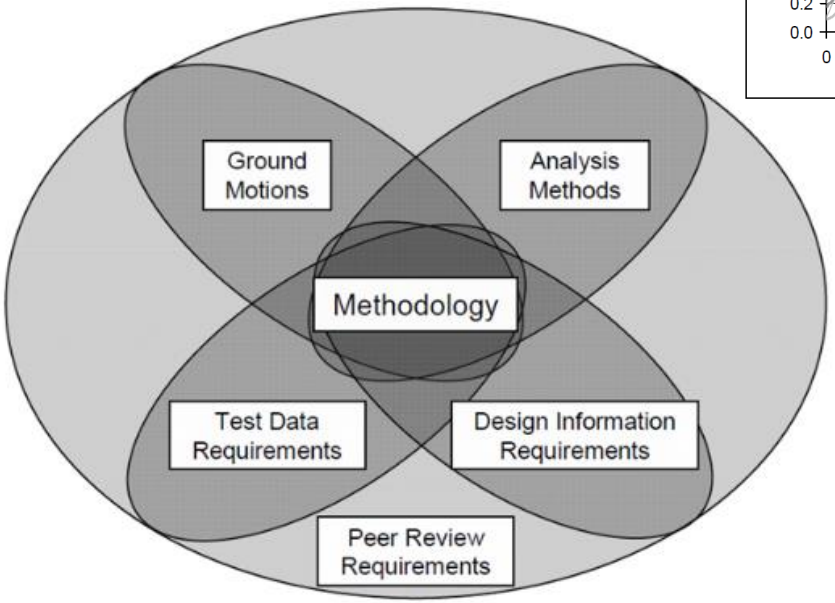
Must be determine via FEMA P695 procedure for new building systems - CLT is considered new

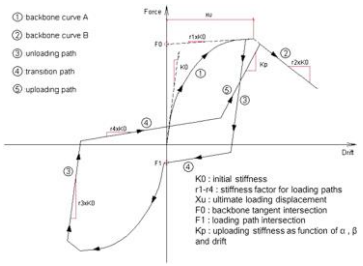
$$F_x = \frac{w_x h^k}{\sum_{i=1}^{n} w_i h_i^k} V$$

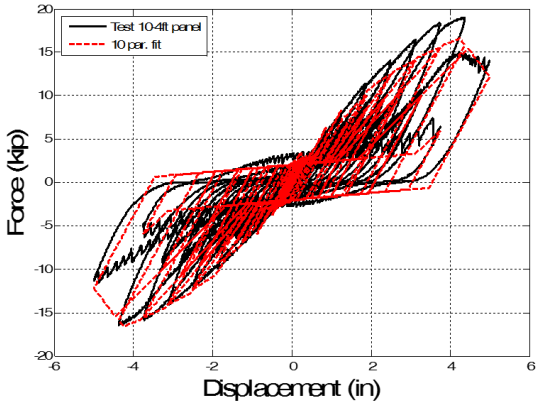
Structural Design – P695

- FEMA P695

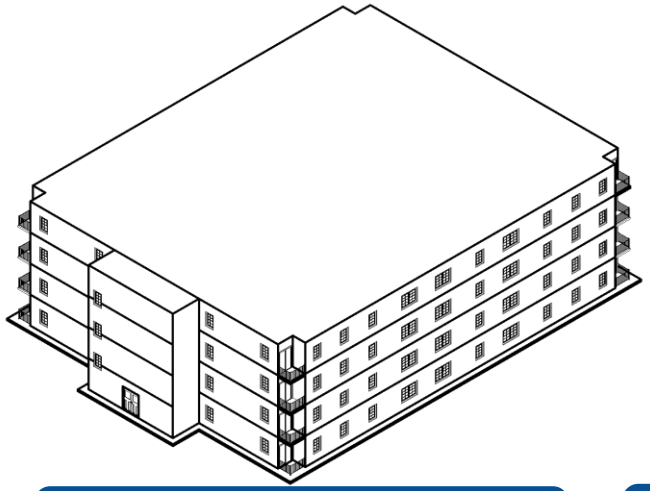


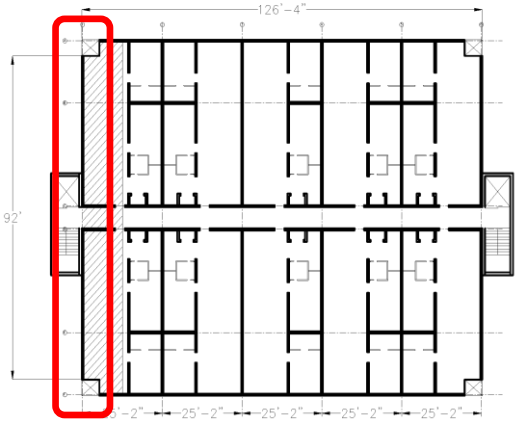


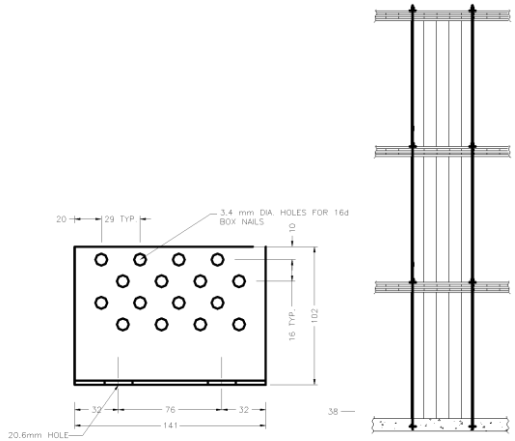




Structural Design – P695







ELF

Obtain shear forces for the archetype model

Design Methodology

Design the archetype model using the design methodology

Modeling

Obtain parameters for the walls and model the building using SAPWood

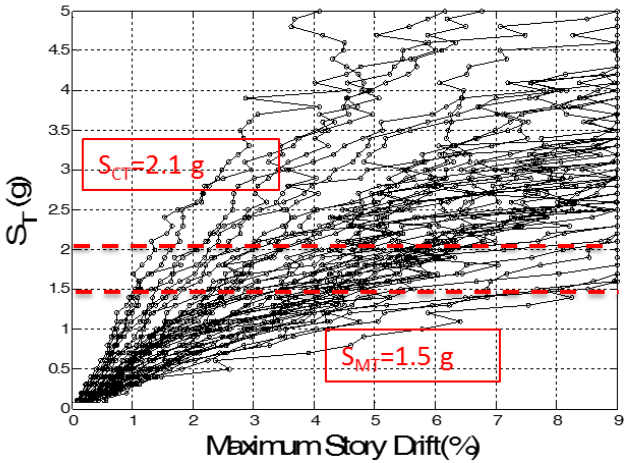
Nonlinear Analysis

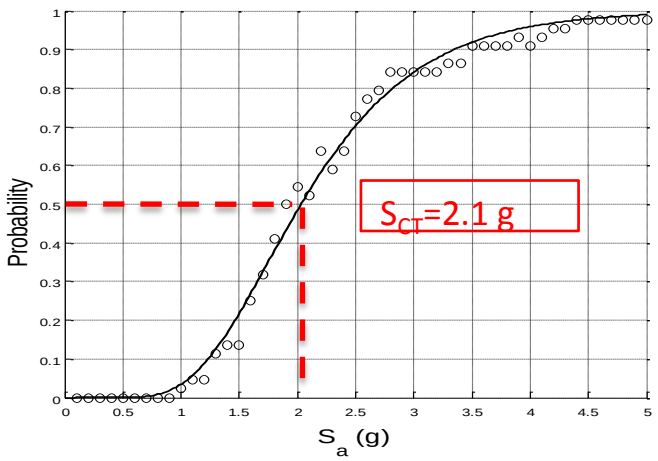
Static pushover and dynamic analysis

Performance evaluation

CMR and ACMR

Structural Design – P695





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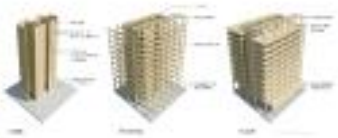
Structural Design – Rocking Walls

NHERI TALLWOOD

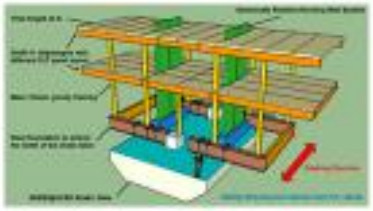
Project duration: 2016~2020

Project Website: Nheritallwood.mines.edu



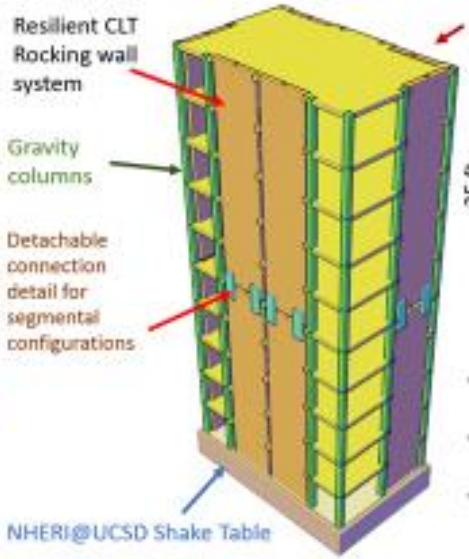
Archetype Meeting at Portland OR 11/2016

Investigative Testing



- A full-scaled 2-story mass timber building with CLT rocking walls (July 2017 NHERI@UCSD)
- Floor and non-structural assembly test at Lehigh Univ. (2017~2018)

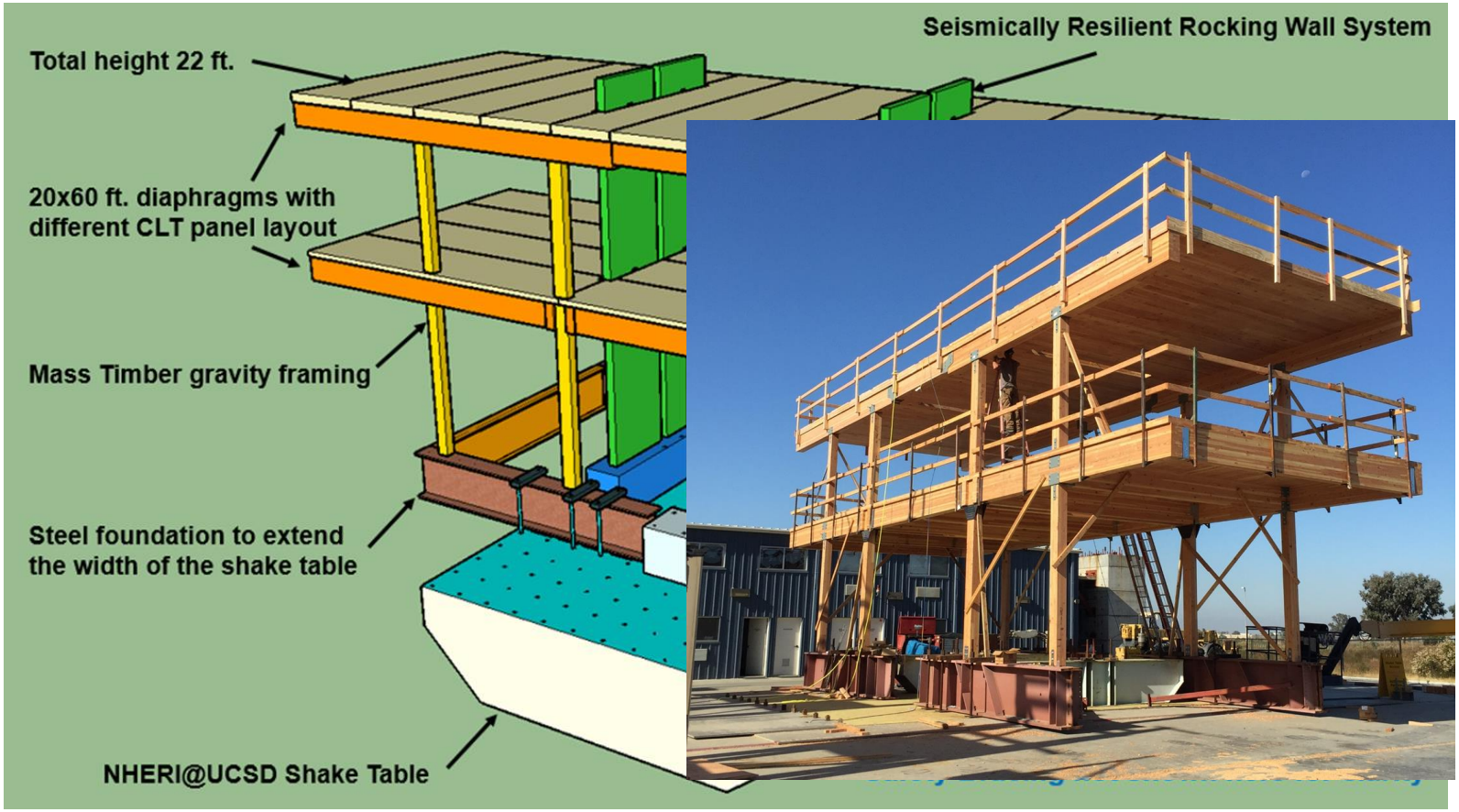
Validation Test



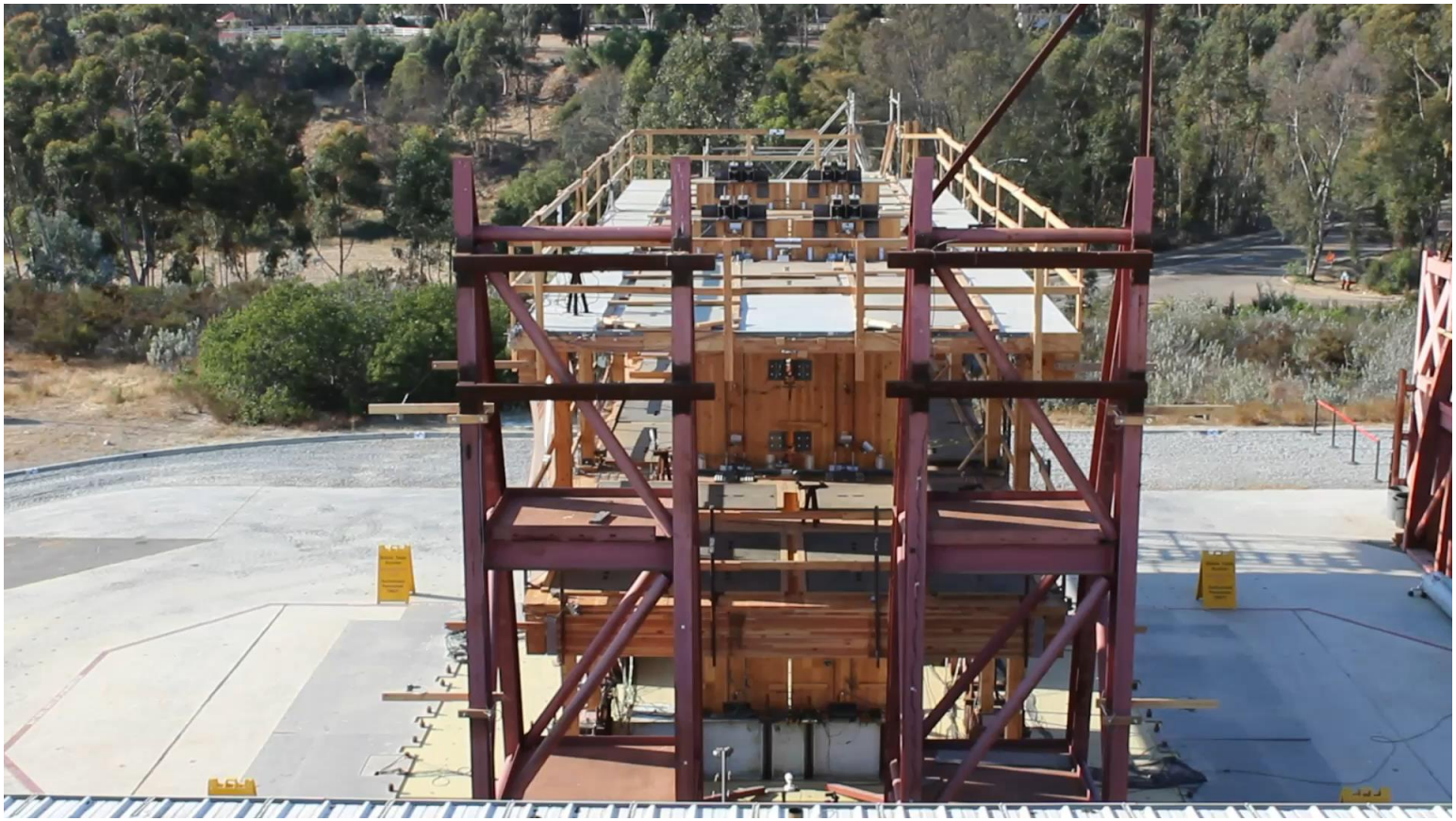
- Both individual and coupled rocking walls included
- Intentional un-symmetric design to induce torsion
- Include two configurations: Monolithic and Segmental

Full-scale 10-story building test at NHERI@UCSD shake table (expected 2019~2020)

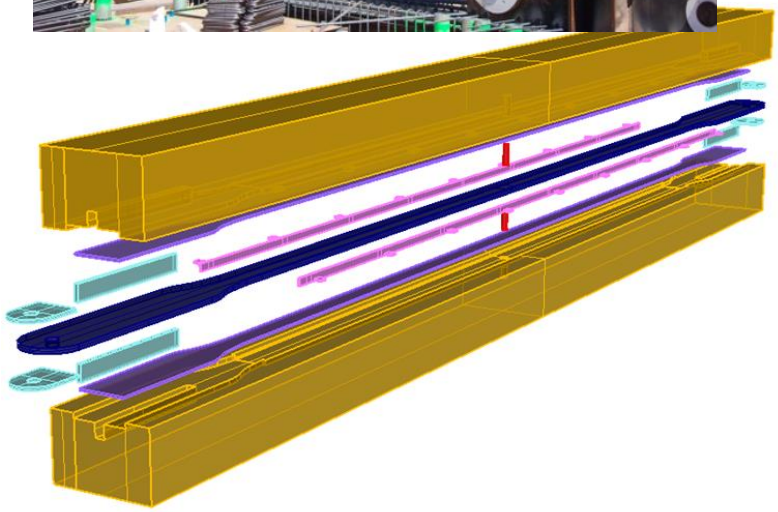
Structural Design – Rocking Wall

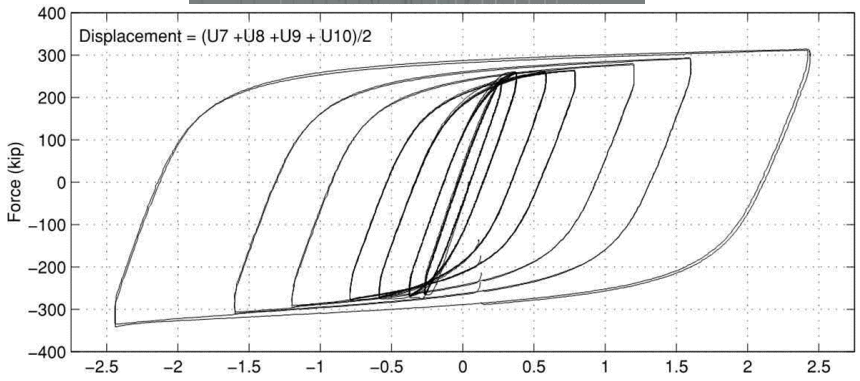


Structural Design – Rocking Walls

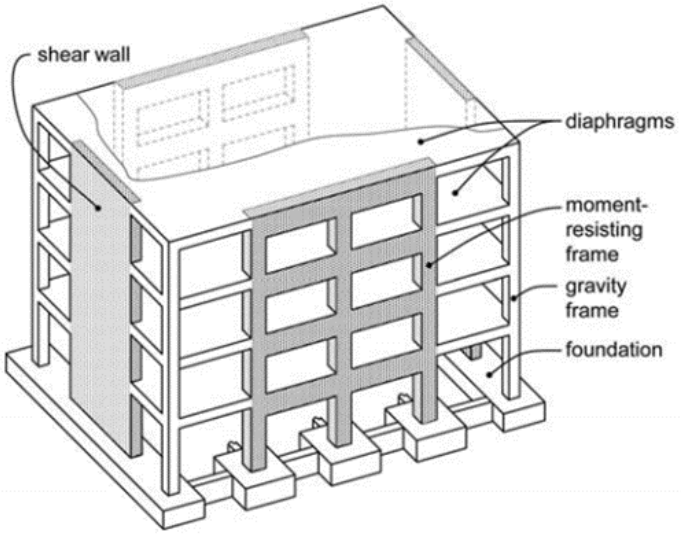


Structural Design - BRB





Structural Design - Diaphragms



CROSS LAMINATED TIMBER

Horizontal Diaphragm Design Example

Our aim for this white paper is to provide a practical design method to determine the strength of a Cross Laminated Timber horizontal diaphragm and deflection due to lateral wind or seismic loads.

CLT HORIZONTAL DIAPHRAGM DESIGN

The design approach is based on compliance with engineered design of CLT in accordance with the 2015 International Building Code, reference standards, and other published information including manufacturer's literature.

Applicable Building Code, reference standards, and other information sources:

- *ICC, 2015 International Building Code*
- *ANSI/AWC NDS-2015 National Design Specification (NDS) for Wood Construction with Commentary*
- *AWC SDPWS-2015 Special Design Provisions for Wind and Seismic*
- *ANSI/APA PRG 320 – 2012 Standard for Performance-rated Cross-laminated Timber*
- *FP Innovations, US CLT (Cross-Laminated Timber) Handbook 2013*
- *ASCE 7-10 Minimum Design Loads for Buildings and Other Structures*
- *AISC 360-10 Specification for Structural Steel Buildings*
- *APA Product Report PR-L314 - CrossLam by Structurlam Products LP, February 20, 2014*
- *ICC-ES Evaluation Report ESR-3179 – ASSY Screws by MyTiCon Timber Connectors, October 2014*
- *Structurlam CrossLam Design Guide Imperial Version 11*
- *MyTiCon, CLT Connection Design Guide NDS*

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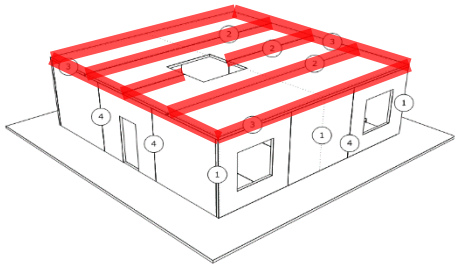
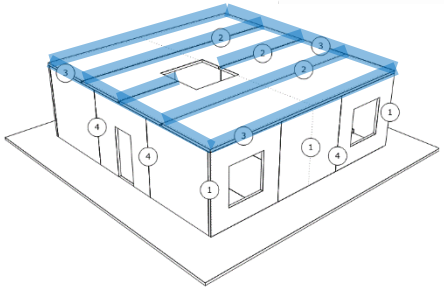
***Disclaimer** – This white paper is intended for guidance only. The design professional of record should exercise good engineering judgement in the application of these guidance materials in a specific project.*

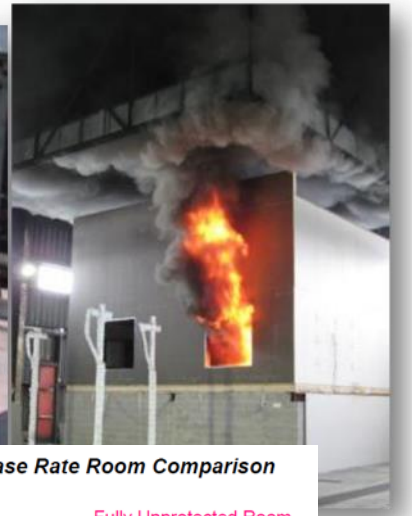


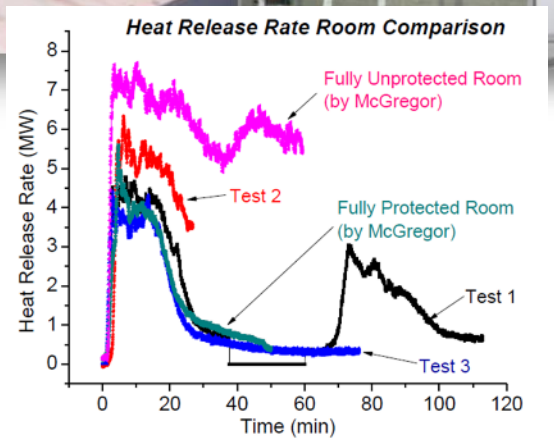


Yielding Connections

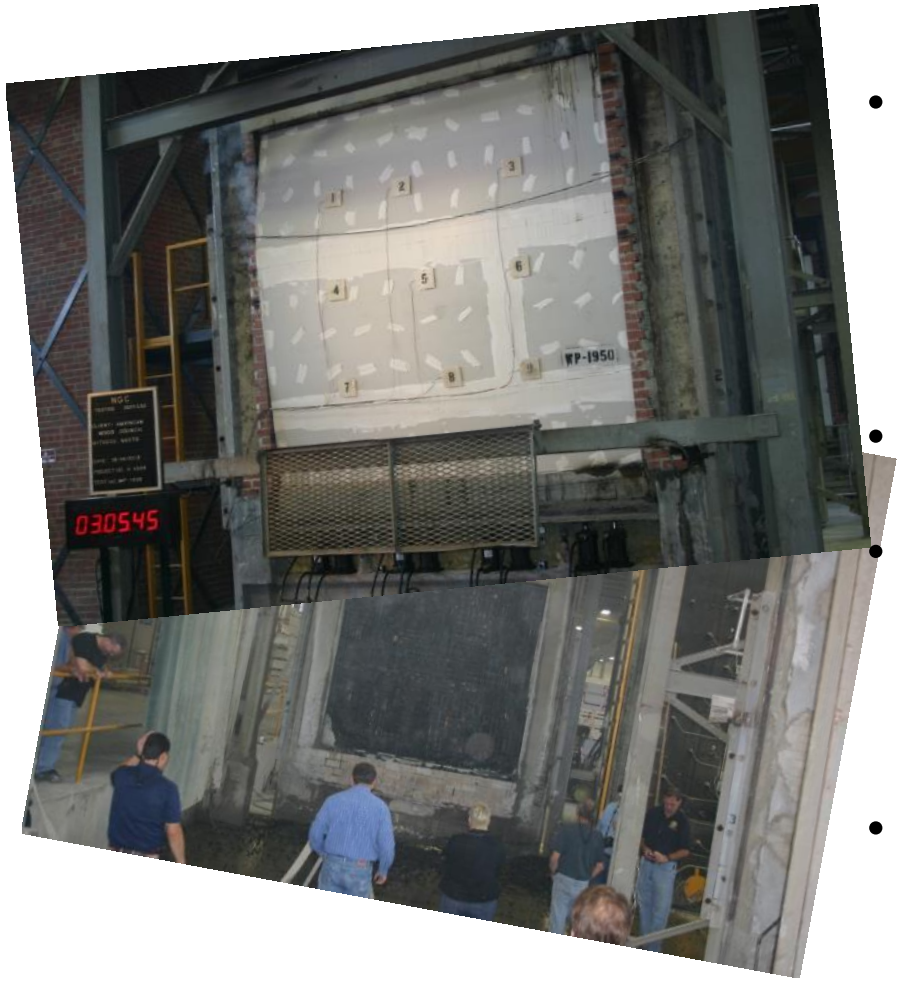
Non Yielding Connections

Fire Performance



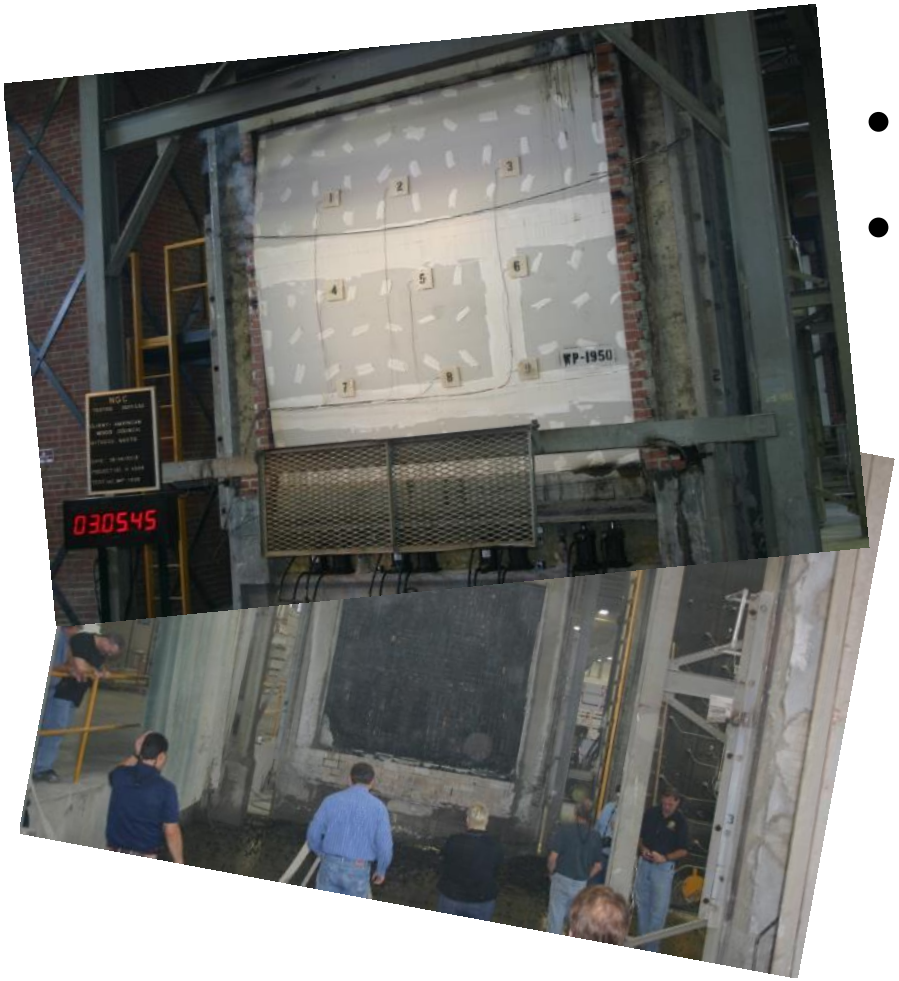


Fire Performance



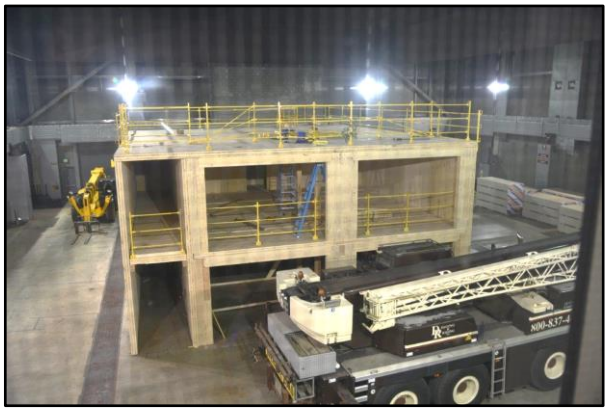
- In 2012, AWC sponsored E119 fire endurance test
  - 5 ply CLT
  - 5/8-in (16mm) Type X Gypsum on both side
  - Maximum load of test frame
- Additional supporting FPInnovations tests
- CLT is recognize for using in Type IV Construction in 2015 IBC
  - No concealed spaces
  - Maximum building height of 65ft (21.3 m)
- Chapter 16 of NDS

Fire Performance



- Limited by 65ft (21.3 m)
- ICC Tall Wood Ad-hoc Committee formed
  - Evaluate fire related code changes
  - Evaluate structural changes
  - Targeting 2018 Group Cycle A for code changes

Fire Performance - Compartment



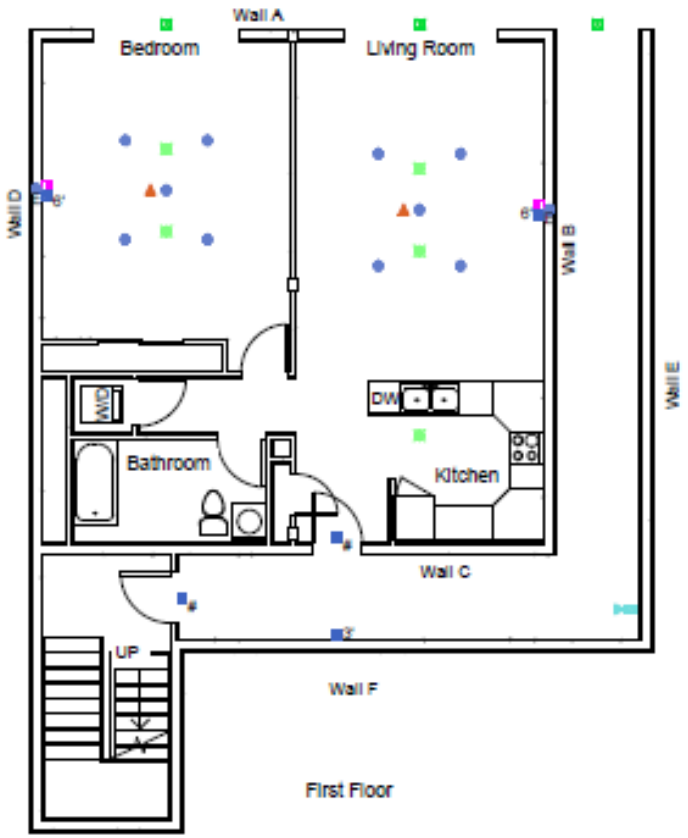


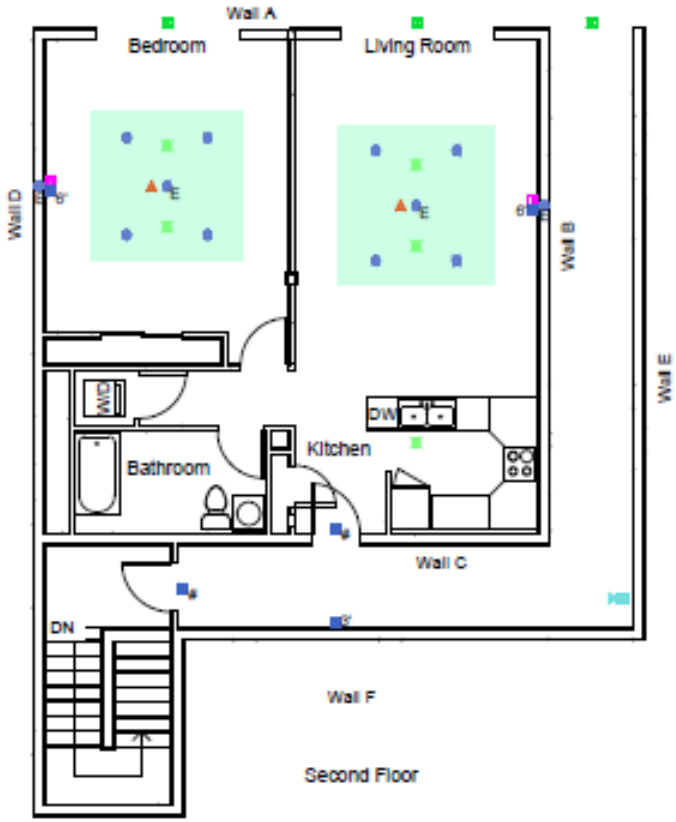

Fire Performance - Compartment






Fire Performance - Compartment





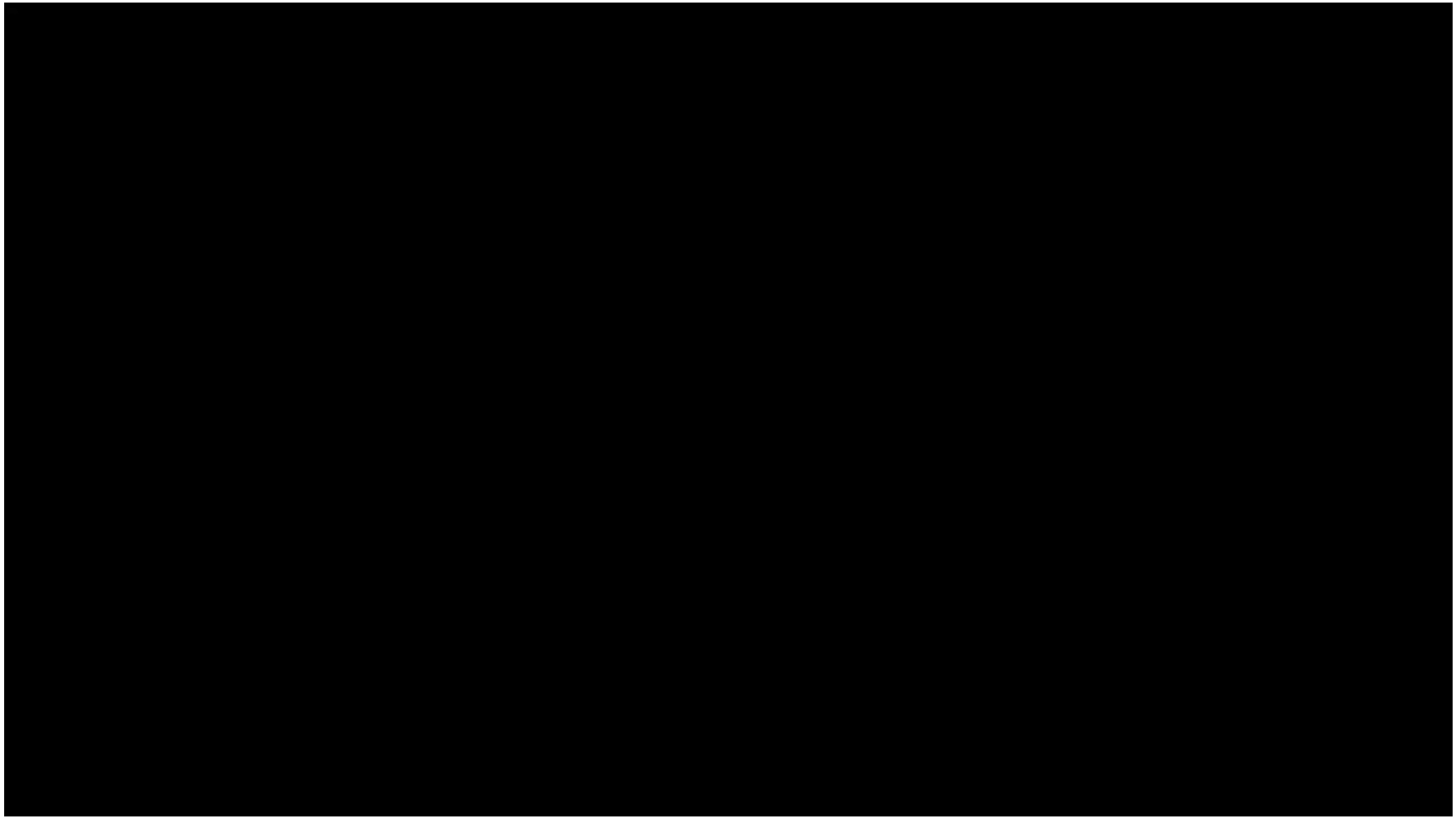
Fire Performance - Compartment

No.	Test Floor / Construction Type	Wall A	Wall B	Wall C	Wall D	Floor/Ceiling	Interior Partition	Active Protection
1	1st / IV-A	60% openings with 2 layers Type X GWB elsewhere	2 Layers Type X GWB	2 Layers Type X GWB	2 Layers Type X GWB	Floor: 2 layers cement board Ceiling: 2 layers GWB	Non-fire rated ½" GWB on each side	None
2	2nd / IV-B		2 Layers Type X GWB	2 Layers Type X GWB	2 Layers Type X GWB	Floor: 2 layers cement board Ceiling: 2 layers GWB with 30% in LR & BR		
3	2nd / IV-B		Livingroom: Exposed CLT Kitchen: 2 Layers GWB	2 Layers Type X GWB	Bedroom: Exposed CLT Bathroom: 2 Layers Type X GWB	Floor: 2 layers cement board Ceiling: 2 layers GWB		
4	1st / IV-C	60% openings with glazing with exposed CLT elsewhere	Exposed CLT			Floor: 2 layers cement board Ceiling: Exposed CLT		NFPA 13, (Density = 0.05)
5	1st / IV-C					Floor: 2 layers cement board Ceiling: Exposed CLT		NFPA 13, (Density = 0.05) with 23-minute activation delay

Fire Performance - Compartment

- Lower kitchen cabinet along Wall C
- Consists of medical gauze and paper towel wrapped together, soaked in 200 ml of gasoline, and then placed inside of a plastic quart size bag

Fire Performance - Compartment



Fire Performance - Compartment

The following table summarizes the major events that occurred during the tests.

Event	Time to Event after Ignition (mm:ss)				
	Test 1	Test 2	Test 3	Test 4	Test 5
Flashover* – Living Room	13:27	11:42	12:37	N/A	-
Flashover* – Bedroom	17:20	17:20	17:00	N/A	-
Flames in Hallway	26:51	30:38	13:06	N/A	-
Entire 20-minute Door Fails	57:46	63:59	29:42	N/A	-
Sprinkler Activation	N/A	N/A	N/A	2:37	23:00

*Flashover based on the average time that the TC's located at a height of 6 feet above the floor reached 600°C or greater for both TC trees in either the bedroom or the living room.

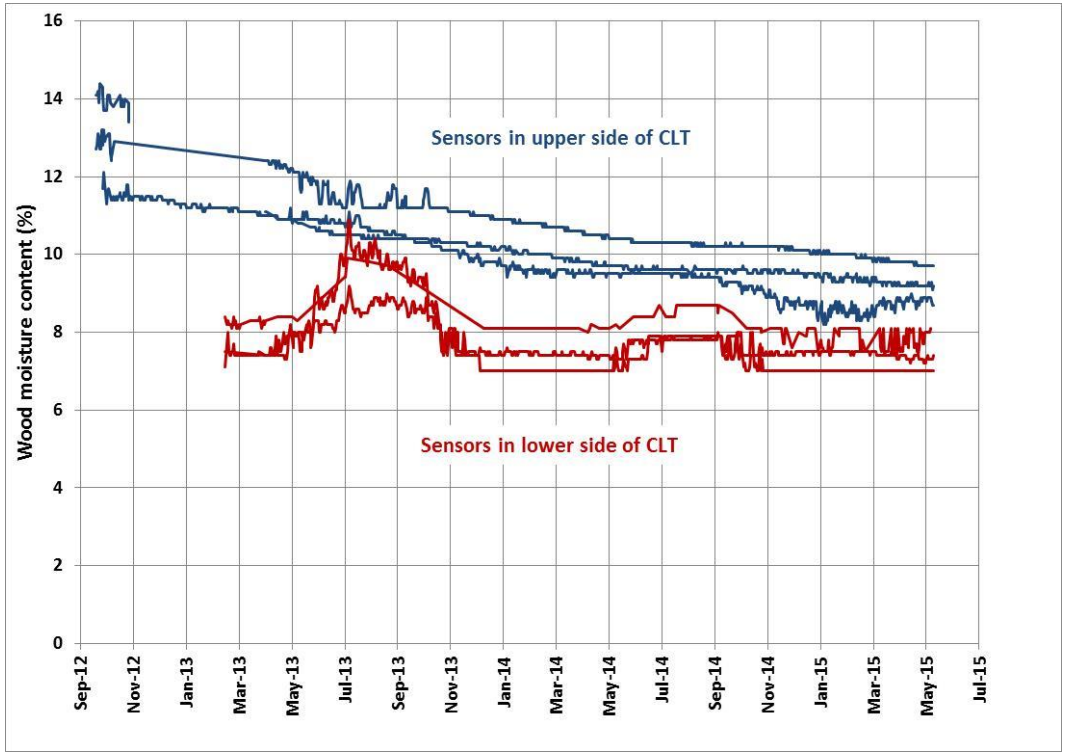
Building Monitoring

Building Monitoring

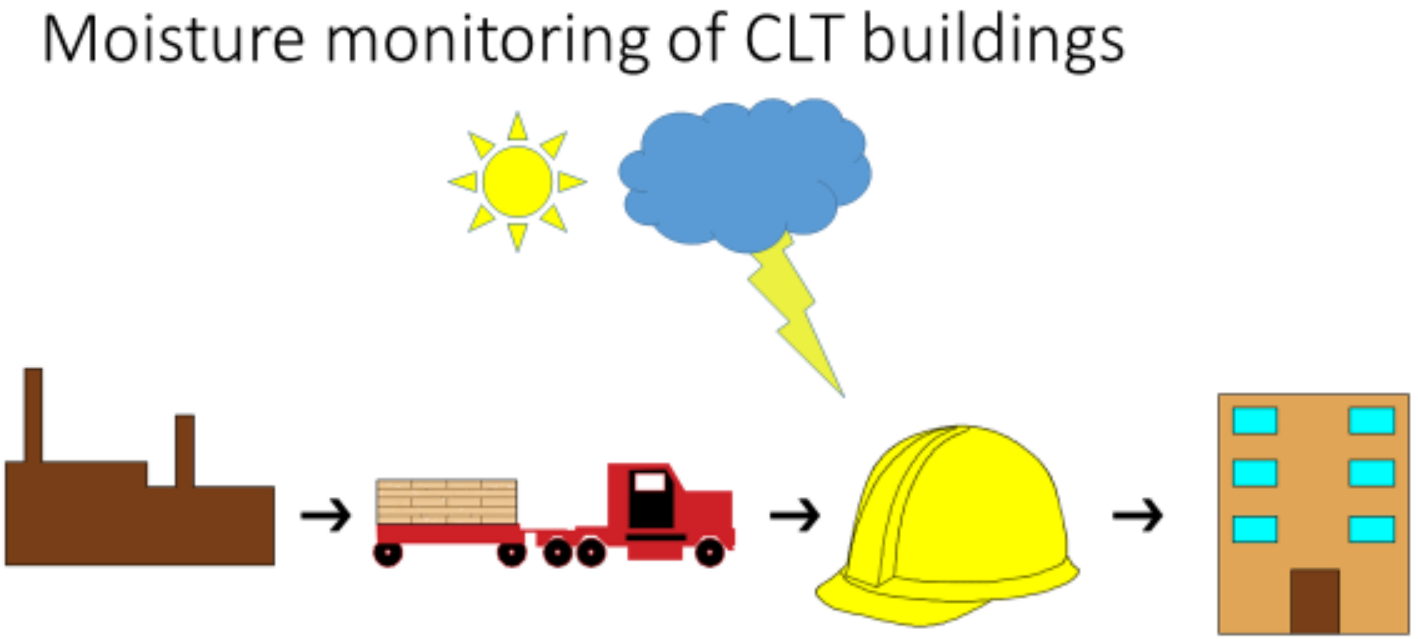
- Moisture monitoring of mass timber buildings
- Solar driven moisture of CLT facades

Building Monitoring - Promega

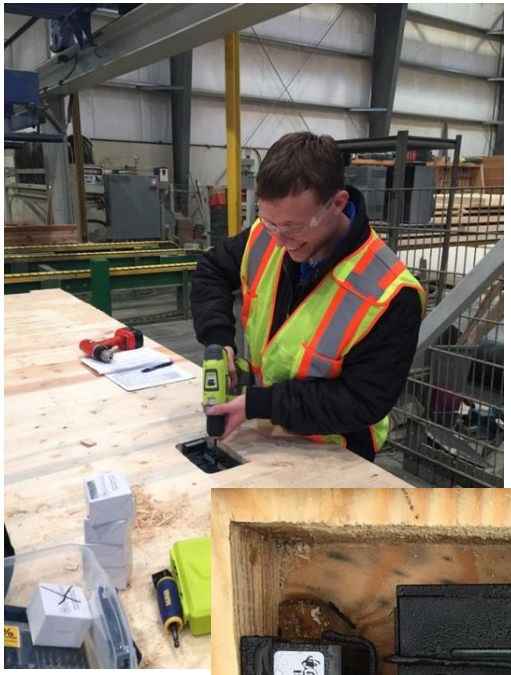
Building Monitoring - Promega

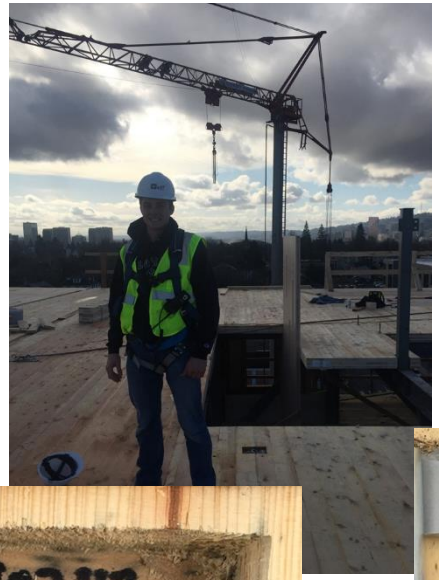


Building Monitoring

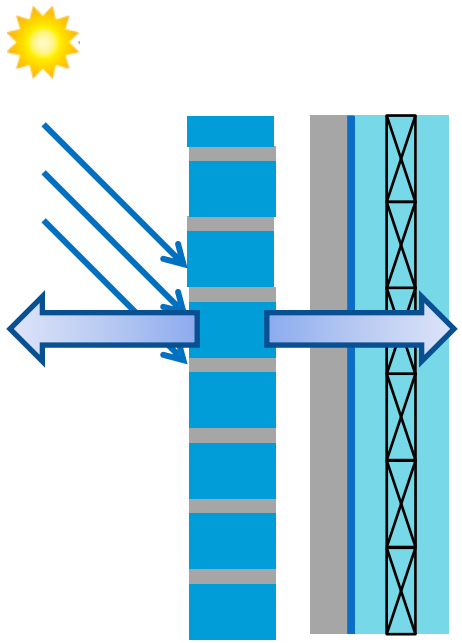


Building Monitoring





Solar-driven inward diffusion



- Reservoir cladding
  - Brick veneer
  - Stone veneer
  - Stucco
  - Cement board, etc.
- Wetted by rain
- Later warmed by solar radiation
- Strong drive for inward vapor diffusion
- Is this a problem with vapor permeable exterior insulation and water-resistive barrier?

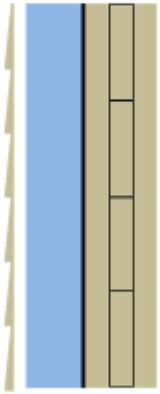
Building Performance - Modeling

Comparing two CLT walls

Vapor-open

Rigid mineral wool

Vapor-tight

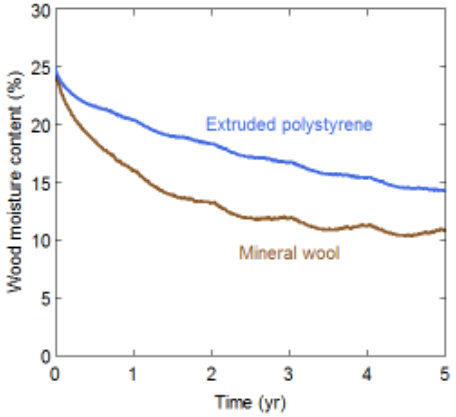


Extruded polystyrene

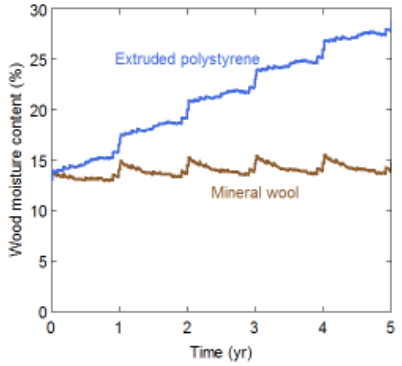
Assemblies:
- Cladding
- Drainage cavity
- R-10 exterior insulati
- Air barrier membrane (vapor permeable)
- 3-ply CLT

Simulations:
- Boston climate
- North-facing wall
- Indoor conditions from ASHRAE 160

Simulated drying capability



Wind-driven rain intrusion



Tall Wood Building Competitions

Additional Research

- USDA Wood Innovation Grants
  - Cross Laminated Timber has a area of emphasis:
    - 2015 – 5 awards related to CLT
    - 2016 – 8 awards focus on Mass Timber or CLT
    - 2017 – 8 awards focus on Mass Timber or CLT

Additional Research – Wood Innovaitons

- **Accelerating the Development of a Cross Laminated Timber Market in Washington State with a Cross-sector Coalition**
- **Building Code Acceptance of Wood Products Under Design Fire Scenarios**
- **Development of Cross Laminated Timber Markets for Hardwood Lumber Producers to Promote Forest Health and Support of Rural Communities**
- **Seismically Resilient Cross Laminated Timber Inverted Pendulum Solutions for Tall Wood Buildings**
- **Expanding Cross Laminated Timber Market through Building Moisture Monitoring and Improved Modeling**
- **Carbon12: An 8-story heavy timber framed building**
- **Utilization of Cross Laminated Timber (CLT) in Low and Mid-rise Buildings for Enhanced Wind Performance**

Additional Research

- USDA ARS – Oregon State
  - SMART-CLT – Structural Health Monitoring and Post-Occupancy Performance of Mass Timber Buildings
  - Cross-Laminated Timber Fastener Solutions for Tall Wood Buildings
  - Behavior of CLT Diaphragm Panel-to-Panel Connections with Self-tapping Screws
  - Fire Performance of Douglas Fir CLT Wall and Floor Assemblies Made in Oregon
  - Seismic Performance of Rocking Wall in Concrete Floor Systems
  - Health Monitoring of Peavy Hall on OSU Campus
- SOM – OSU –SLB
  - Concrete Jointed Timber Frame

Additional Research

- FPL - U.S. Endowment for Forestry & Communities, Inc. Partnership
  - Fund identified research needs for mass timber
    - Risk assessment of CLT adhesives subjected to fire
    - Development of Buckling Restrained Braced Frames
    - Evaluating biological resistance of mass timber to decay
    - Development of a mold-risk model for wood buildings
    - Continued Development and Outreach for the Athena Impact Estimator for Buildings

Take Away

- Mass Timber building are being embraced
- Mass Timber Workshop effort to focused research activities across the nation
- Code acceptance and standardized design methods is still the pressing need
  - Alternative means and methods for seismic design
  - Fire Understanding
  - Monitoring of Buildings
- A comprehensive database for CLT research and performance data will greatly facilitate this effort