Recent Research in Seismic-Resilient Wood Buildings

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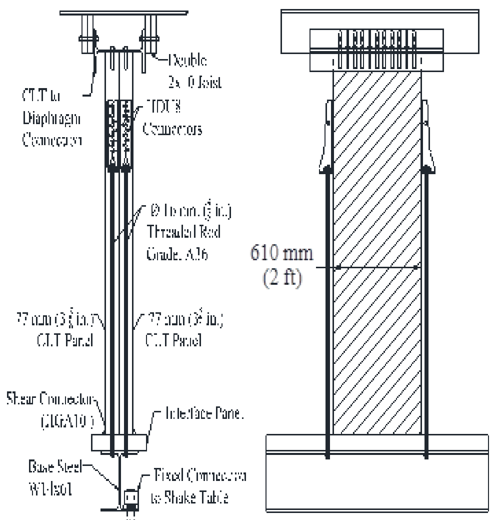
Research Projects:

- Seismic Risk Reduction of Soft-Story Buildings (NEES-Soft)
- Seismic Resilient Tall Wood Buildings (NHERI Tall Wood)
- CLT-Light Frame System Hybrid Buildings (CLT-LiFS)
- Performance Factor (R-Factor) for CLT Shear Wall Systems
- Post-tensioned Timber (Pres-Lam) Systems

NEES-Soft: CLT Retrofit



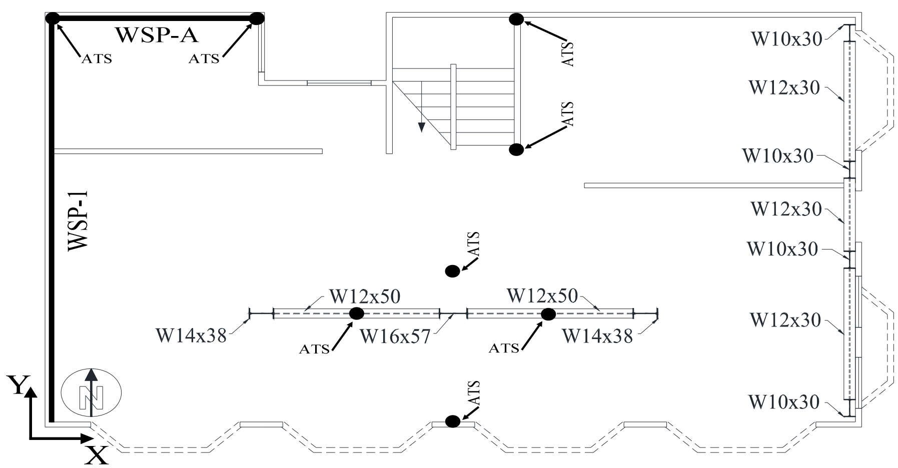
Seismic Evaluation and Retrofit of Multi-Unit Wood-Frame Buildings With Weak First Stories

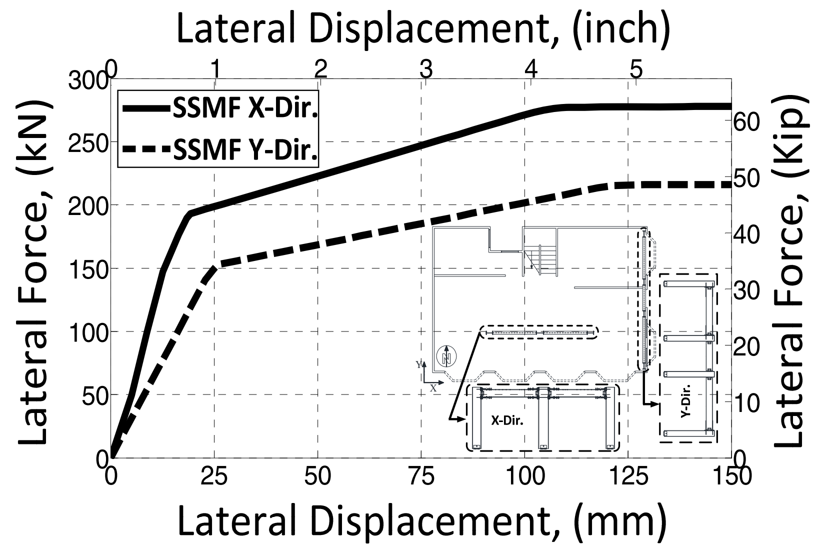
FEMA P-807 / May 2012

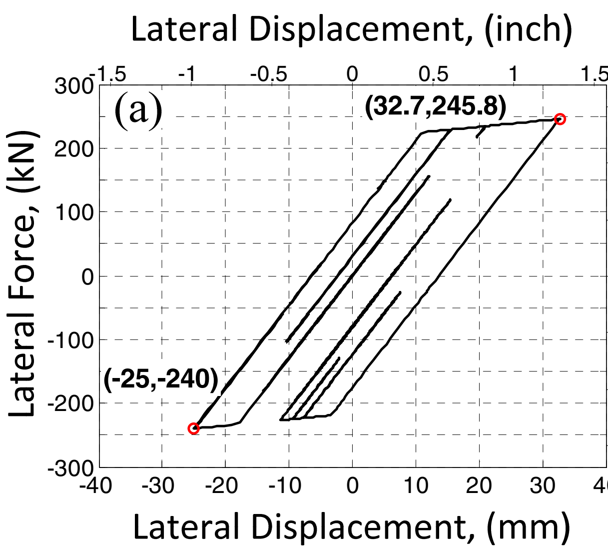
FEMA

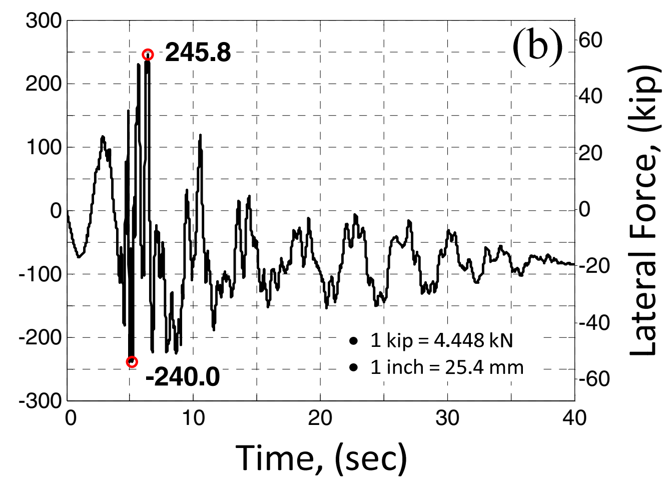
nehrp

NEES-Soft: PBSR

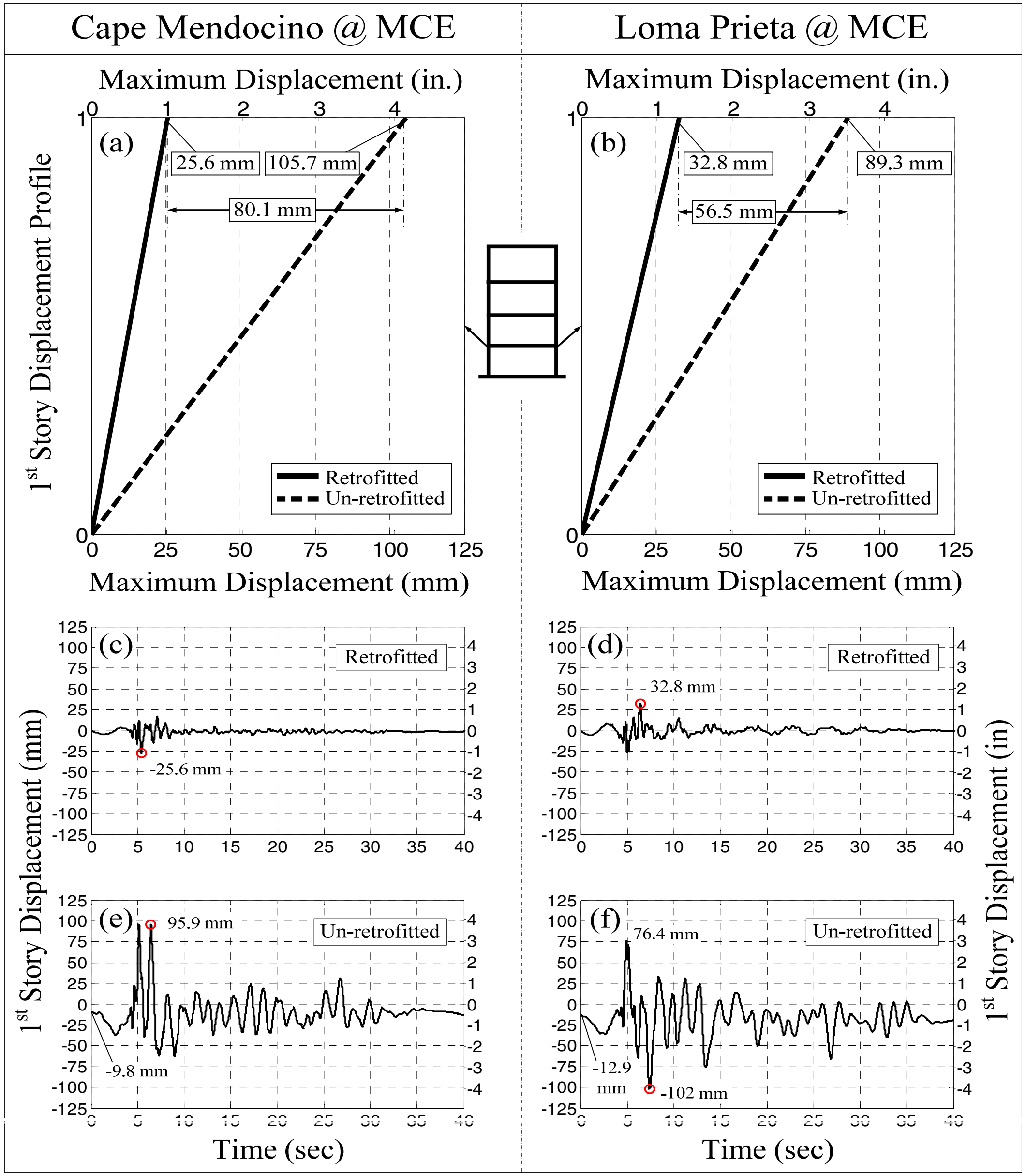




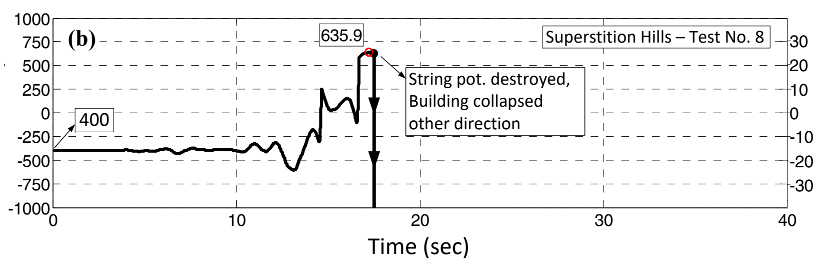




NEES-Soft: Retrofitted (PBSR) and Un-retrofitted Comparison



NEES-Soft: Collapse Test



NHERI TALLWOOD PROJECT

NHERI

- Objective: Develop and validate a Resilience-based seismic design methodology for tall wood buildings
- Website: nheritallwood.mines.edu

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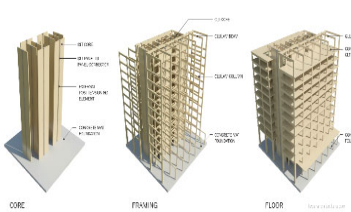
GAME PLAN

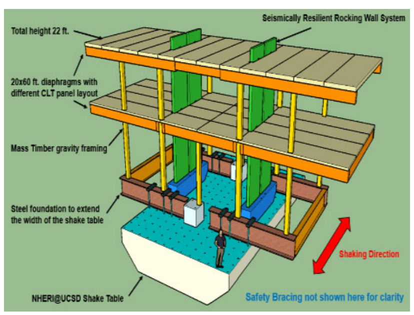
nheritallwood.mines.edu

Project duration: 2016~2020

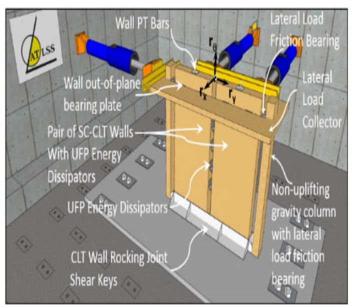


Define Tall Wood Archetypes

Investigative testing at system level

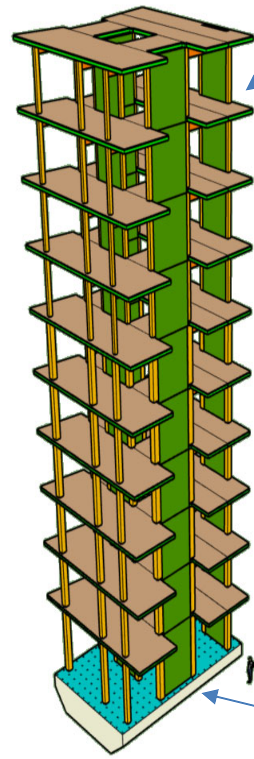


Two-story test at NHERI@UCSD 2017 Summer

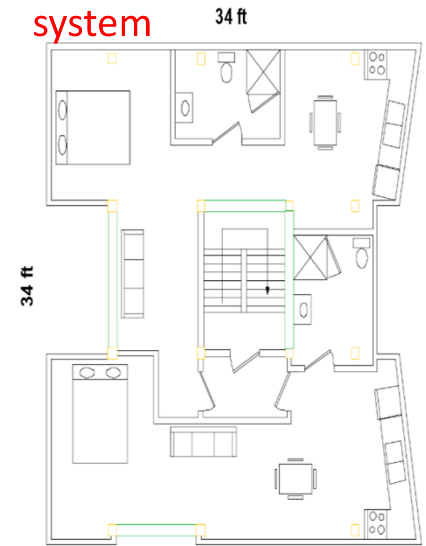


Assembly test at NHERI@Lehigh 2018~2019

Full-scale 10-story validation



Mixed-Use building w/ CLT rocking wall lateral system



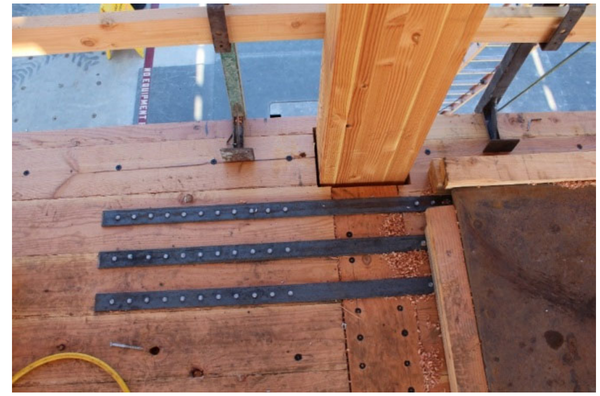
UCSD Shake Table

Tons of R & D

(2018~2019)

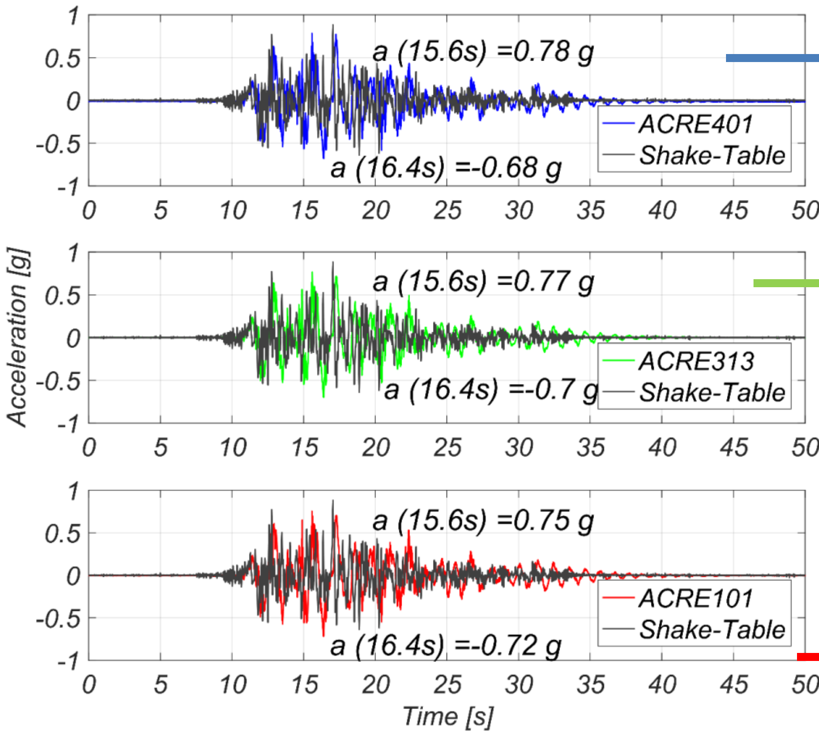
Shake-table Diaphragm Testing

- Two Diaphragm Designs for all Three Wall Systems
  - Roof – CLT Panels + Concrete Topping (Composite slab)
  - **Floor level – 3-ply CLT Panels**

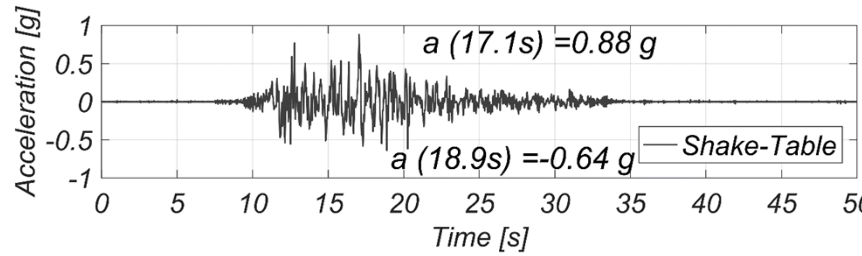


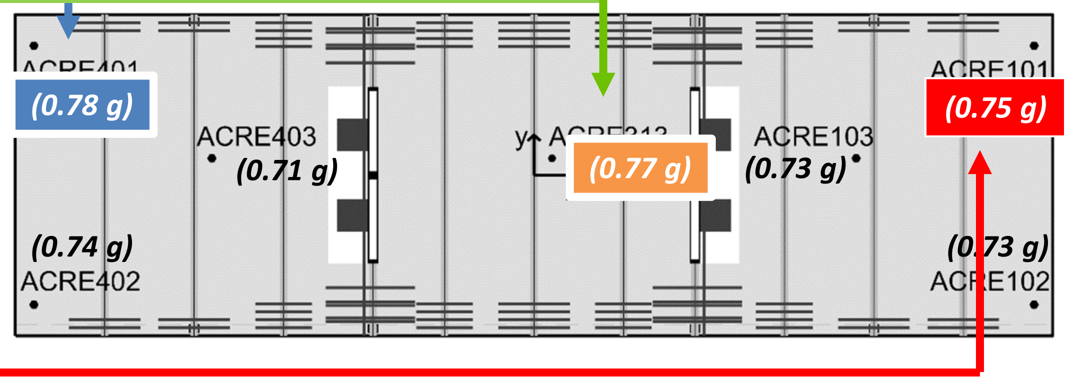
Shake-table Diaphragm Testing

Average accelerations at diaphragm levels



Northridge (MCE) – Scale Factor 1.2

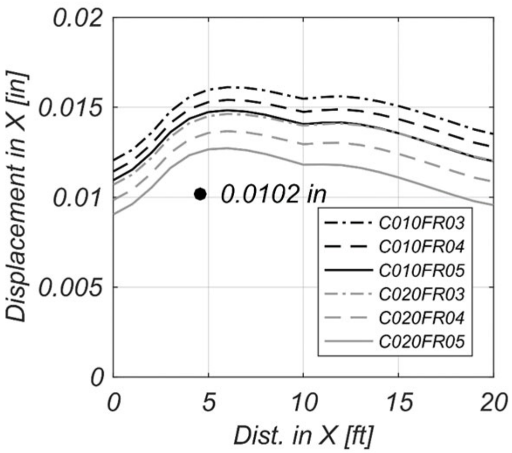


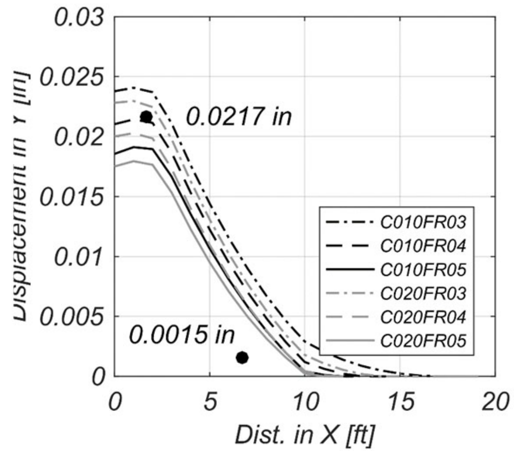


Uniform accelerations at the roof level

Shake-table Diaphragm Testing

Accelerations for Northridge (MCE) (Scale Factor 1.2 : Avg. Peak Floor Accel. (g) = 0.873)





Clamping Force

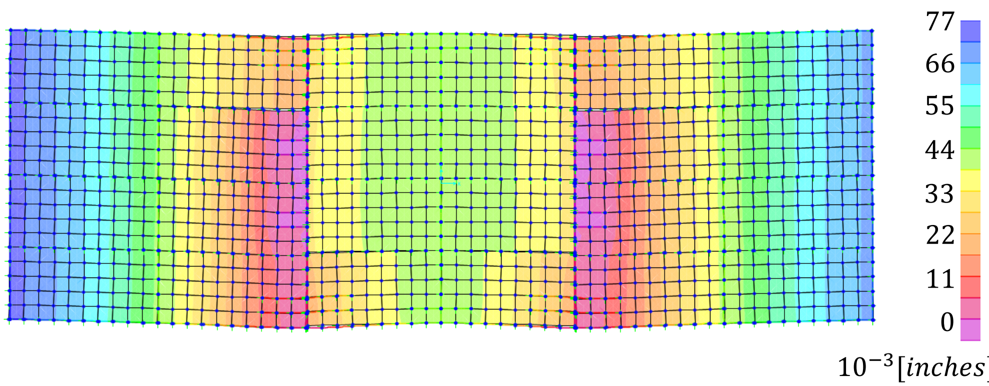
Friction Coefficient

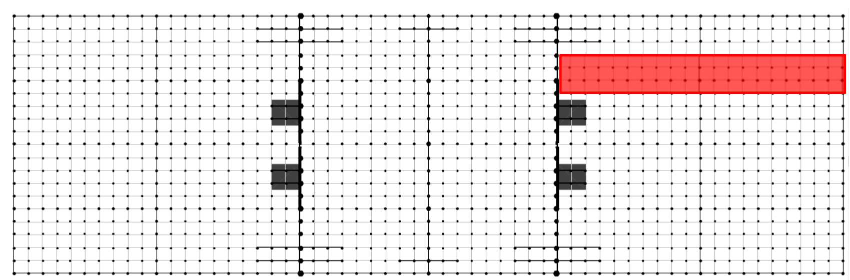
***C010FR04*:**

$F_c = 0.1\ F_y$ to $0.2\ F_y$

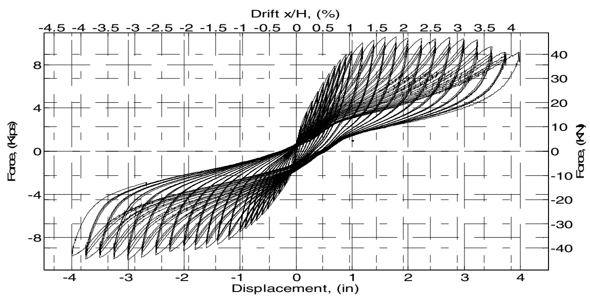
$\mu = 0.3$ to 0.4

The model captures the maximum response, when friction is considered on the numerical model.

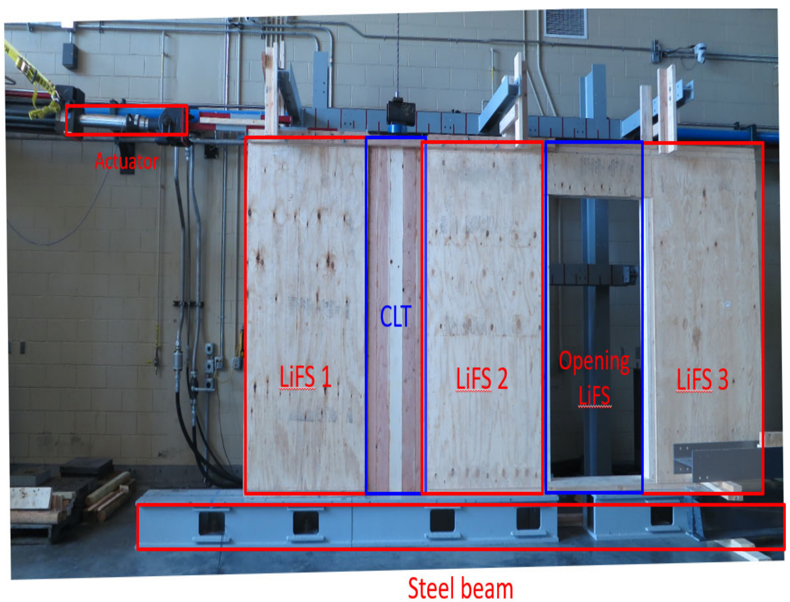




CLT-LiFS Walls



CLT-LiFS wall test



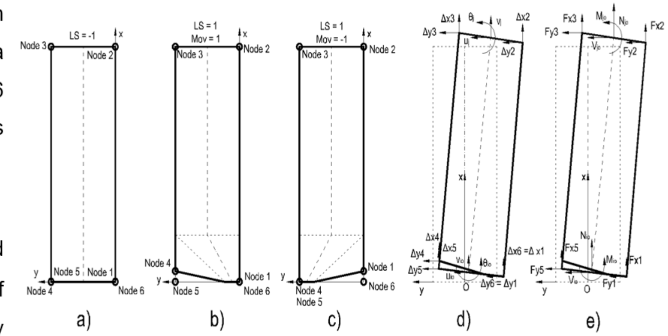
STIFFNESS MATRIX OF 4-NODE ROCKING ELEMENT

Nodal displacements of 2-node element can be expressed by that of 4-node element, via a transformation matrix $[B_2]$ (Node 5 and 6 are virtual nodes not included in stiffness matrix):

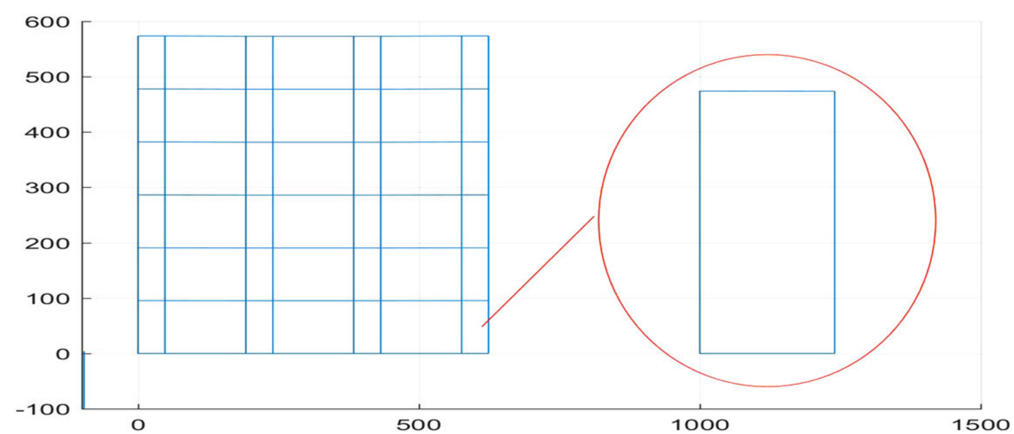
$$[U^{o}_{2-node}] = [B_2][U^{local}_{4-node,8-DOF}]$$

Assume that $\Delta y_1 = \Delta y_4 = \Delta y_5 = \Delta y_6 = u_{io}$ and $\Delta y_2 = \Delta y_3 = u_{jo}$. The nodal displacements of 4-node element can also be expressed by that of 2-node element, via matrix $[B_3]$:

$$[U^{local}_{4-node,8-DOF}] = [B_3][U^{o}_{2-node}]$$



Location of nodes in 4-node element model



MOISTURE DIFFUSION AND CREEP MODELS

Moisture content tests

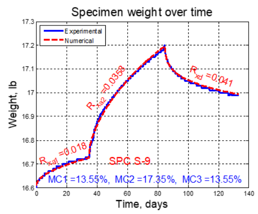
- Three types of specimen.
- Three environmental conditions.

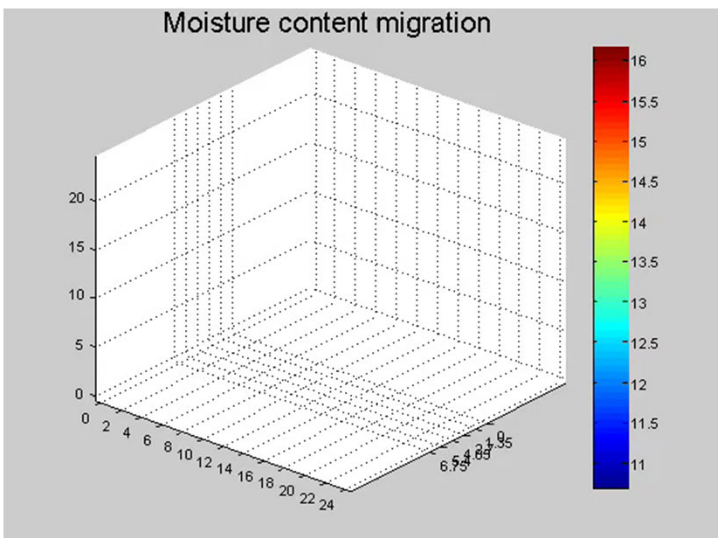
6.6×12×12 in.

Calculate moisture content

$$MC = \frac{W_1 - W_0}{W_0} \times 100 \text{ percent}$$

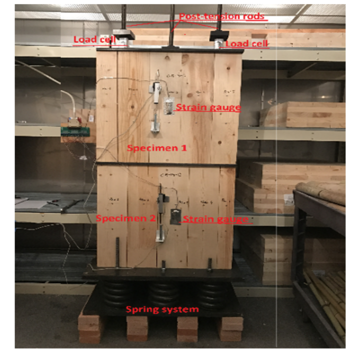
Obtaining diffusion coefficients





Creep tests: Measuring deformations

- Various specimen types.
- Different loading levels.
- Multiple locations.
- Using DEMEC and gauges.

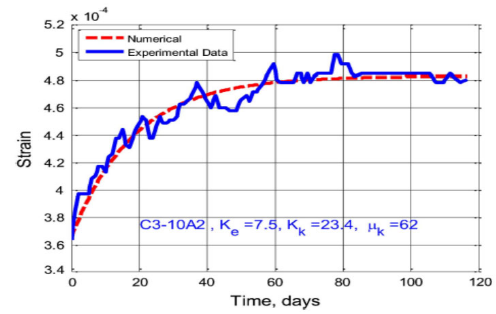


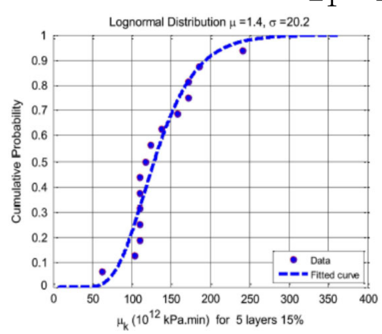
Numerical: Using the four-element model.

$$\varepsilon(t) = \frac{\sigma}{K_e} + \left(\frac{\sigma}{K_k}\right)\left[1 - e^{-\frac{K_k.t}{\mu_k}}\right] + \frac{\sigma}{\mu_\omega}.\Delta MC$$

μ_ω is the mechanosorptive constant.

$$\mu_\omega = \frac{E_1.E_2.(MC_2 - MC_1)}{E_1 - E_2}$$





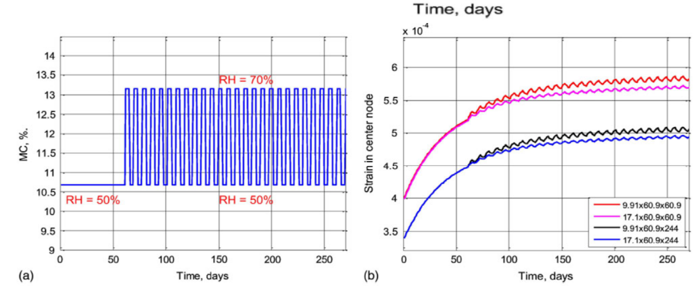


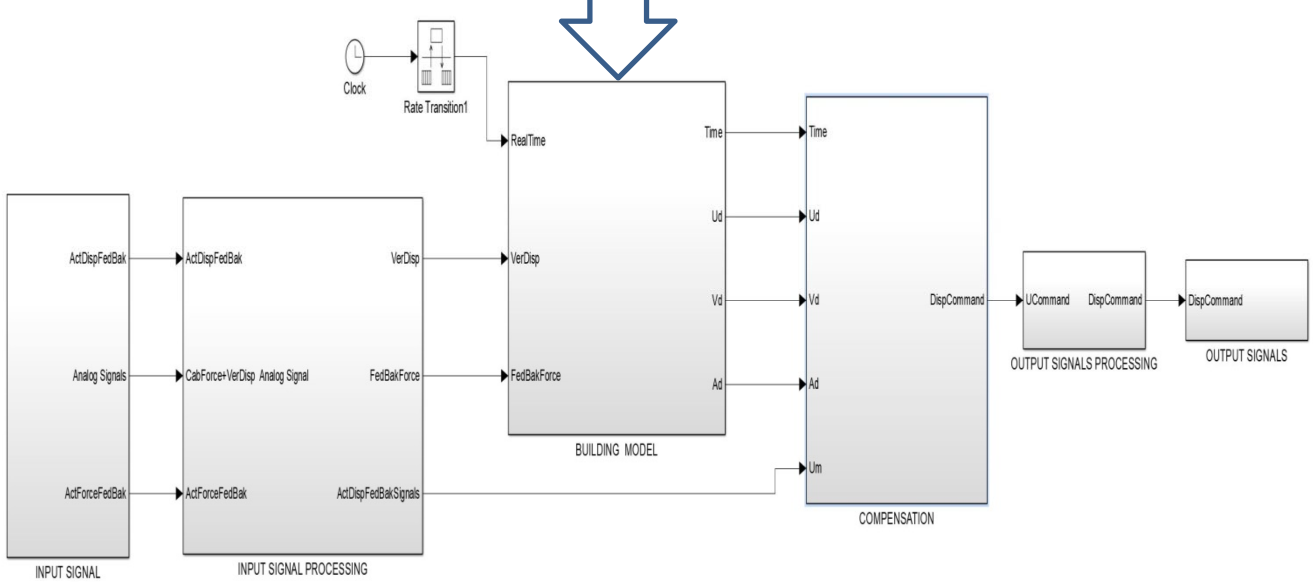
Fig. 15. Axial strain history for different CLT configurations (1 in. = 2.54 cm): (a) moisture content profile; and (b) axial strain.

CLT-LiFS Building

CLT-LiFS Building test

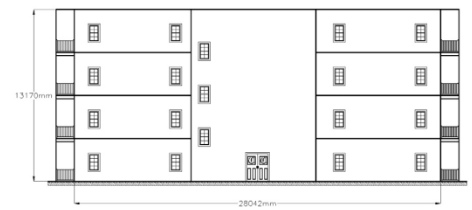
Realtime Hybrid Simulation of CLT-LiFS Building (Under preparation)

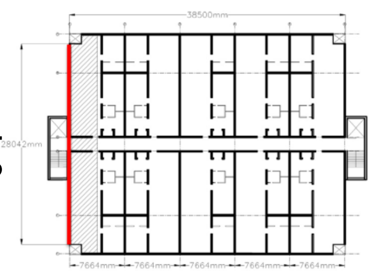
2 physical stories + 4 numerical stories = 6 Stories

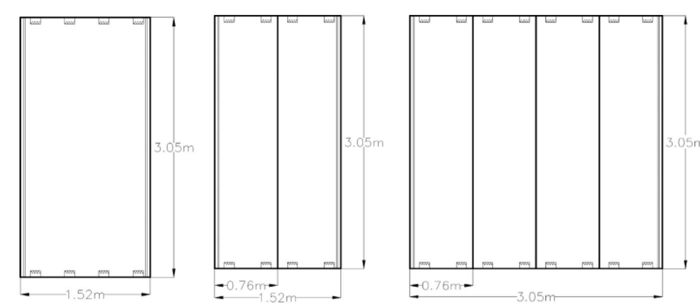


Performance (R) Factors for CLT Shear Wall Systems

- **For ASCE 7-16 ELF Procedure**
- **Follows FEMA P-695 methodology**
- **Involves development of design method**
- **Archetypes developed for shear walls testing**
- **Includes uncertainties**



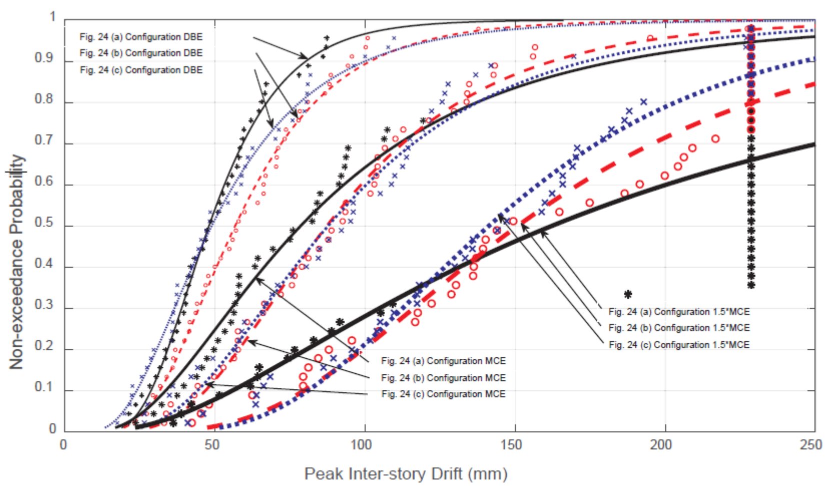


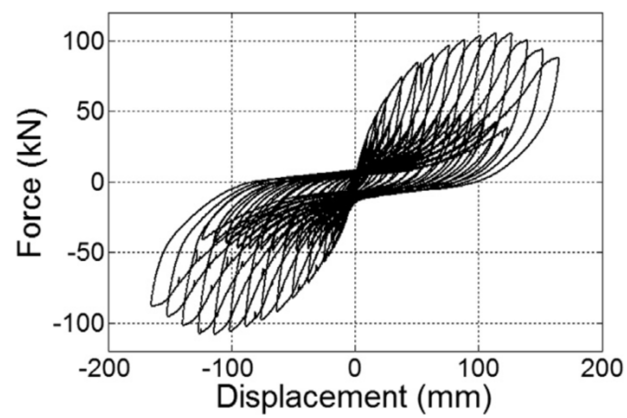


(a) (b) (c)

Performance (R) Factors for CLT Shear Wall Systems

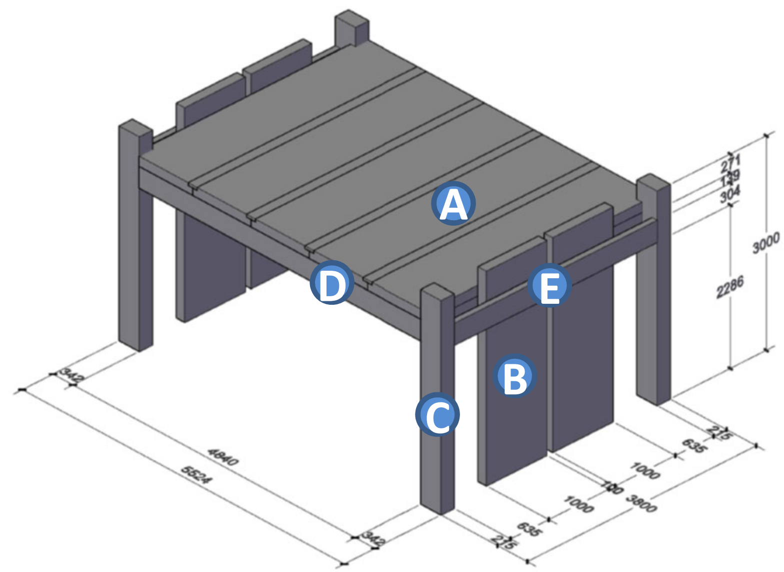
- Different wall configurations tested
- Boundary conditions and gravity load considered
- Nonlinear Time History analysis performed
- Maximum inter-story drift recorded
- Cumulative Density Function (CDF)s plotted

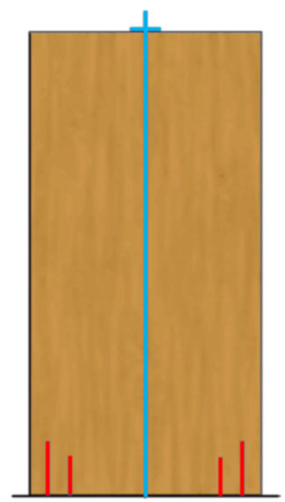


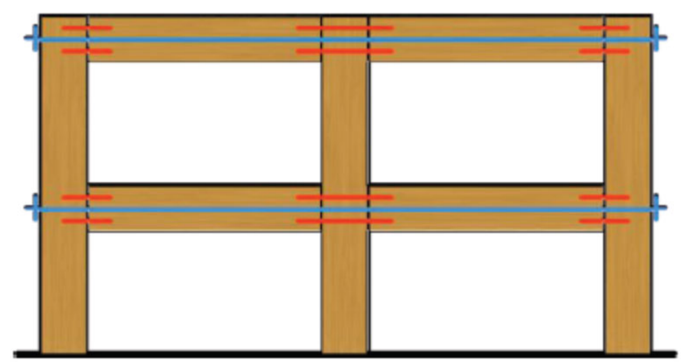


Post-tensioned Timber Systems

- Full scale model
- CLT walls and Glulam frames
- CLT Floor added
- Practical connection details
- Walls testing complete

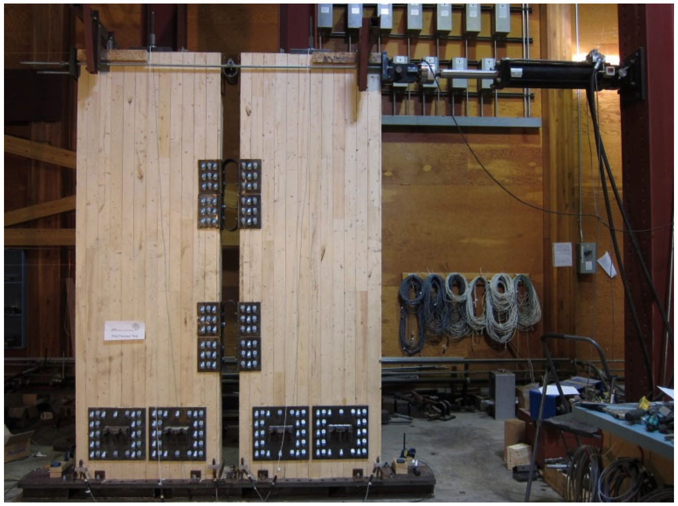


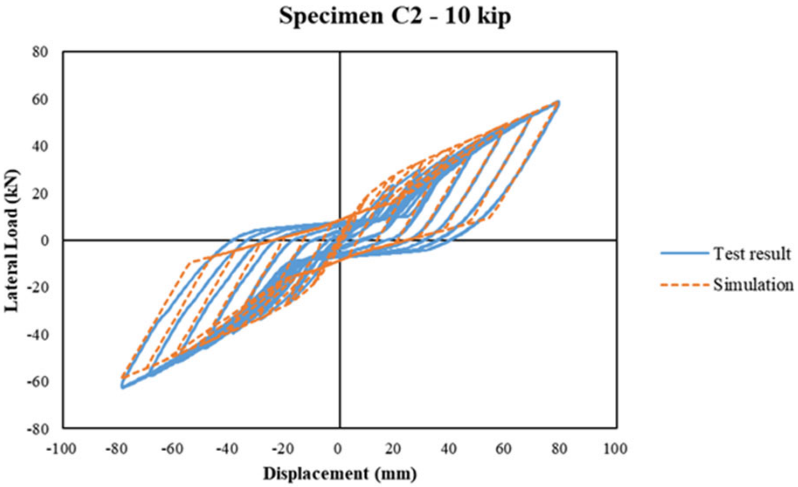


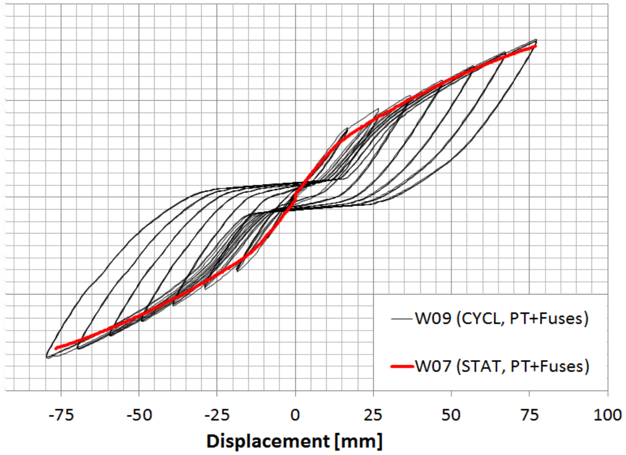


Post-tensioned Timber Systems

- Single and Coupled Walls tested
- Expected performance
- Almost no damage
- Numerical models developed
- Key parameters identified







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Questions?