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

Cape Mendocino @ MCE

- Maximum Displacement (in.)
  - 1st Story Displacement Profile
  - Retrofit: [25.6 mm, 105.7 mm]
  - Un-retrofitted: [80.1 mm]

Loma Prieta @ MCE

- Maximum Displacement (in.)
  - 1st Story Displacement Profile
  - Retrofit: [52.8 mm, 56.5 mm]
  - Un-retrofitted: [89.3 mm]

- Time (sec)
  - Retrofit: [95.9 mm]
  - Un-retrofitted: [76.9 mm]
NEES-Soft: Collapse Test

Superstition Hills – Test No. 8
String pot. destroyed, building collapsed other direction
NHERI TALLWOOD PROJECT

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

**Project duration:** 2016~2020

17th U.S.-Japan-New Zealand Workshop on the Improvement of Structural Engineering and Resilience

nheritallwood.mines.edu

**Full-scale 10-story validation**

Mixed-Use building w/ CLT rocking wall lateral system

UCSD Shake Table

Tons of R & D (2018~2019)

- Define Tall Wood Archetypes
- Investigative testing at system level
- Two-story test at NHERI@UCSD 2017 Summer
- Assembly test at NHERI@Lehigh 2018~2019

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

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<th>Time [s]</th>
<th>Acceleration [g]</th>
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- **Shake-table**
  - a (15.6s) = 0.78 g
  - a (16.4s) = 0.68 g
  - a (15.6s) = 0.77 g
  - a (16.4s) = 0.7 g
  - a (15.6s) = 0.75 g
  - a (16.4s) = 0.72 g
  - a (17.1s) = 0.88 g
  - a (18.9s) = 0.64 g

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(0.78 g)  (0.74 g)  (0.71 g)  (0.73 g)  (0.75 g)  (0.77 g)  (0.73 g)  (0.73 g)
```
Shake-table Diaphragm Testing

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

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

Clamping Force

Friction Coefficient

\[ F_c = 0.1 \, F_y \text{ to } 0.2 \, F_y \]
\[ \mu = 0.3 \text{ to } 0.4 \]
CLT-LiFS Walls

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):

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

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

$$[U^{local}_{node, 8-DOF}] = [B_3][U^2_{node}]$$
MOISTURE DIFFUSION AND CREEP MODELS

Moisture content tests
- Three types of specimen.
- Three environmental conditions.

Calculate moisture content
\[ MC = \frac{W_t - W_0}{W_0} \times 100 \text{ percent} \]

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.

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

\[ \mu_\omega \] is the mechanosorptive constant.

\[ \mu_\omega = \frac{E_1 \cdot E_2 \cdot (MC_2 - MC_1)}{E_1 - E_2} \]
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
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
Acknowledgements

Questions?