NHERI TallWood:
Dynamic Testing and Analysis of Multi-Story Rocking Cross Laminated Timber Walls

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Los Angeles, CA
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Cross Laminated Timber (CLT)

- Renewable
- Lightweight material
- Fast construction
- Potential for resilience
Project Outline and Scope

Tall CLT Building Archetypes
2016

- Sub Assembly Testing
  - Summer 2017 Two-Story test at NHERI@UCSD
  - 2017-2018 Assembly test at NHERI@Lehigh

Structural Response Modeling
2017 - 2019

- Develop RBSD Methodology
  - 2017 - 2019

Methodology and Model Validation

- Summer 2020 Full-Scale 10-Story Test at NHERI@UCSD
  - Resilient CLT Rocking wall system
  - Gravity columns
  - Detachable connection detail for segmental configurations
  - Non-structural system and building envelop included but not shown
  - Both individual and coupled rocking walls included
  - Intentional un-symmetric design to induce torsion
  - Include two configurations: Monolithic and Segmental
Post-Tensioned Rocking Shear Walls

UFP provides energy dissipation

PT bars strength provide recentering capabilities
Presentation Agenda

1. Experimental Tests at UCSD
2. Test Results
3. Numerical Modeling
NHERI@UCSD Shake Table Testing

CLT ROCKING WALLS

CLT DIAPHRAGMS 20 x 58 FT

10 FT

12 FT

GRAVITY FRAME EXTENDER BEAMS

GLULAM GRAVITY FRAME

SHAKE TABLE

Total height 22 ft.
20 x 4 ft. diaphragm with different CLT panel layout.
Mass Timber gravity framing.
Steel foundation to extend the width of the shake table.
CLT Rocking Walls

Post-Tensioning Saddle

Out-of-Plane Bracing

Wall to Diaphragm Shear Transfer

Rocking Wall Base Beam

UFP Energy Dissipaters
### CLT Rocking Wall Performance Objectives

<table>
<thead>
<tr>
<th>Performance Level</th>
<th>Panel Crushing</th>
<th>PT Yielding</th>
<th>UFP Yielding</th>
<th>Target Drift</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SLE</strong> (50% in 30)</td>
<td>Immediate Occupancy</td>
<td>No Crushing</td>
<td>No Yielding</td>
<td>Minor Yielding</td>
</tr>
<tr>
<td><strong>DBE</strong> (10% in 50)</td>
<td>Limited Repair</td>
<td>Minor Crushing</td>
<td>Minor Yielding</td>
<td>Yielding</td>
</tr>
<tr>
<td><strong>MCE_{R}</strong></td>
<td>Collapse Prevention</td>
<td>Crushing</td>
<td>Yielding</td>
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</tr>
</tbody>
</table>
## Testing Sequence

<table>
<thead>
<tr>
<th>Day</th>
<th>Test</th>
<th>Record Name</th>
<th>Hazard Level</th>
<th>PGA (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>1</td>
<td>Loma Prieta</td>
<td>SLE</td>
<td>0.16</td>
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<tr>
<td></td>
<td>2</td>
<td>Loma Prieta</td>
<td>SLE</td>
<td>0.18</td>
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<tr>
<td></td>
<td>3</td>
<td>Northridge</td>
<td>SLE</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Superstition Hills</td>
<td>SLE</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Northridge</td>
<td>DBE</td>
<td>0.53</td>
</tr>
<tr>
<td>Day 2</td>
<td>6</td>
<td>Northridge</td>
<td>DBE</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Imperial Valley</td>
<td>SLE</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Northridge</td>
<td>DBE</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Loma Prieta</td>
<td>DBE</td>
<td>0.52</td>
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<tr>
<td></td>
<td>10</td>
<td>Superstition Hills</td>
<td>DBE</td>
<td>0.44</td>
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<tr>
<td></td>
<td>11</td>
<td>Loma Prieta</td>
<td>MCE</td>
<td>0.62</td>
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<tr>
<td></td>
<td>12</td>
<td>Northridge</td>
<td>MCE</td>
<td>0.73</td>
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<tr>
<td></td>
<td>13</td>
<td>Superstition Hills</td>
<td>MCE</td>
<td>0.63</td>
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<tr>
<td></td>
<td>14</td>
<td>Northridge</td>
<td>MCEx1.2</td>
<td>0.85</td>
</tr>
</tbody>
</table>

**Location:** Oakland, CA  
**Site Class:** B  

### PGA Levels

- **SLE:** 10% in 30  
- **DBE:** 10% in 50  
- **MCE**  
- **MCE_R**
Presentation Agenda

1. Experimental Tests at UCSD
2. Test Results
3. Numerical Modeling
Test – Northridge MCE x 1.2
Experimental Test Results

**Story Drifts**

![Graph showing story drifts at different hazard levels. The graph includes data points for Roof Drift and Floor Drift across various hazard levels such as SLE, DBE, MCE, and MCEx1.2.]

**Base Shear**

![Graph showing base shear at different hazard levels. The graph includes data points for SLE, DBE, MCE, and MCEx1.2.]

- Roof Drift
- Floor Drift

Hazard Level
Base Shear Hysteresis

SLE: Test 1
Loma Prieta

DBE: Test 8
Northridge

MCE1.2: Test 14
Northridge
Base of CLT Rocking Wall Damage
Test – Northridge MCE x 1.2 – Toe Rocking
Presentation Agenda

1. Experimental Tests at UCSD
2. Test Results
3. Numerical Modeling
Numerical Model

Tension only Material:
MultiSpring Contact Elements

Building Drift Time Histories

DBE: Test 10 – Superstition Hill

MCEx1.2: Test 14 – Northridge
PT Forces

DBE: Test 10 – Superstition Hill

MCEx1.2: Test 14 – Northridge
## Were Performance Objectives Met?

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<td>No Yielding Yielding</td>
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### How would have the Specimen Responded with a Rigid Foundation?

- No Crushing
- No Yielding
- No Yielding
- 0.5% Drift
- 1% Drift
- 1-2% Drift
- 2% Drift
- 2-3% Drift
- 4% Drift
How would the Specimen Responded on a Rigid Diaphragm?

**Roof Drifts**

- SLE
- SLE_rigid
- DBE
- DBE_rigid
- MCE
- MCE_rigid

**Peak PT Force**

- SLE
- SLE_rigid
- DBE
- DBE_rigid
- MCE
- MCE_rigid
How would the Specimen Responded on a Rigid Diaphragm?

**UFP**

**Panel Crushing**

![Graph showing UFP and Panel Crushing](image)
# Updated Performance Objectives with a Rigid Foundation

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Conclusions

• A full scale test of a two-story full timber building with post-tensioned rocking CLT walls was successful and showed promising results for the future 10-story test.

• The rocking wall base beam protected the base of the wall during the tests

• OpenSees modeling can be improved to better match experimental results. Some improvements that could be made include:
  • Diaphragm deformation
  • Accumulation of base beam deformation
  • Torsional effects
Acknowledgements

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Thank You!