Design and Testing Toe-Screwed Cross-Laminated Timber Shear Walls

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MOTIVATION
Cross-Laminated Timber (CLT) is a versatile construction material gaining interest in the U.S. for tall platform construction. Current demand indicates further growth of the CLT market, and readily available connections are needed. Structural wood screws are a good connection choice and European designers have used them for CLT connections for many years. Currently, many CLT structures use surface metal brackets to connect panels, but this system can increase fabrication, on-site labor, and finishing costs. Installing angled screws at wall-to-floor intersections (toe-screwing) is a promising solution. Structural wood screws create a flush structural wall finish and a flexible design method. Toe-screwed connections for low-rise CLT buildings can improve CLT competitiveness with other building systems. However, research is lacking for using structural wood screws in a lateral-force-resisting system, including toe-screws. Toe screws are expected to meet the requirements of structural engineers if significant strength and stiffness can be developed, safe failures can be achieved, and significant connection ductility is present.

OBJECTIVES
The project’s goals are to determine if toe-screwed CLT shear walls can carry significant load, fail predictably, and be seismically viable. The specific objectives are to:
1. Characterize the performance of toe-screwed (TS) CLT shear walls;
2. Determine the effects of changing the TS layout;
3. Identify if consistent and desirable failure modes occur in TS CLT shear walls;
4. Determine the ability of current design methods to appropriately predict wall strength;
5. Develop the equivalent-energy-elastic-plastic (EEEP) curve for future modeling and system comparison;
6. Extract the ASCE/SEI 41-17 modeling parameters needed for non-linear static pushover analysis of buildings with toe-screwed CLT shear wall connections.

METHODS
• 1 monotonic and 3 cyclic tests for 3 different TS wall connections (equally spaced (Fig. 1), grouped, and 2 hold-downs with toe-screws). Walls were 3 ply V2 Douglas-fir wall panels 1.83x3.66 m (6x12 ft). Aspect ratio of 2.
• No additional applied gravity load.
• Tested MyTiCon ASSY SK 6 mm by 200 mm (1/4 by 8 inch) screws.
• Screws installed at 45 degrees for all tests (Fig. 2); spaced 76 mm (3 in.) for the grouped screws, 152 mm (6 in.) for the equally spaced screws.
• ASCE/SEI 41-17 idealized component backbone parameters extracted for use in design and analysis of multistory CLT structures (Fig. 3).
• Screws were counter-sunk with no pilot hole (Fig. 4).

RESULTS
1. Toe-screwed CLT shear walls can provide similar strength, stiffness and ductility compared to light-frame-shear wall systems and other CLT shear wall connectors.
2. The tested toe-screwed connections provided:
   • Strength averaging 2.3 times commonly used light-framed shear walls.
   • Toe-screwed wall strength, stiffness, and energy dissipation were respectively 1.5, 1.4, and 1.3 times 23 other CLT metal bracket and hold-down connection layouts.
3. A simple toe-screw wall design method was developed that can conservatively and accurately predict yield and peak strengths for expected and allowable design loads. (see Table 1 below for comparison)
4. The ASCE/SEI 41-17 idealized backbone curves (Fig. 3) for TS walls can be assembled from the presented parameters based on expected material properties to provide a reasonable finite element non-linear approximation of the toe-screwed walls for non-linear pushover analysis.
5. The hysteresis curves exhibited substantial pinching and trailing cycle strength loss accompanied with large amounts of energy dissipation.
6. TS shear walls fail from washer head pull-through (Fig. 2) similar to single connection tests. The head pull-through failure was observed to be a gradual plastic failure with a low amount of variation within test series. Monotonic and cyclic tests capture the positive envelope well and failures do not appear to change between loading types (Fig. 3). TS shear walls were observed to provide significant drift capacity (Fig. 1).
7. The combined observed wall properties and failure observations indicate that TS walls using washer-headed, partially-threaded self-tapping screws are viable for seismic lateral-force-resisting systems in buildings.

Table 1. Design strength values and comparison to test values

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<thead>
<tr>
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<th>Equally Spaced TS</th>
<th>Grouped TS</th>
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<tr>
<td>Limit State</td>
<td>Design (kN)</td>
<td>Expected (kN)</td>
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<tr>
<td>Peak</td>
<td>19.6</td>
<td>45.7</td>
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<sup>a</sup> average positive peak wall strength divided by either the design yield or peak design strength
<sup>b</sup> average positive peak wall strength divided by either the expected yield or expected peak strength

Fig. 1. A tipped toe-screwed CLT shear at 5% drift, displaying extreme head pull-through failure

Fig. 2. A sample of the characteristic head pull-through failure of the walls. The head of the screw is placed at the point of maximum strength during pull-through.

Fig. 3. Cyclic and monotonic envelopes for equally spaced and grouped toe-screwed walls with the resulting ASCE/SEI 41-17 backbone curve.

Fig. 4. Toe-screw prior to testing.