Institute for Working Forest Landscapes
National Center for Advanced Wood Products Manufacturing and Design
College of Forestry, Oregon State University

A. Cover Page

1. Project Title

Behavior of CLT Diaphragm Panel-to-Panel Connections with Self-Tapping Screws

2. List of PIs and other key personnel names/affiliations

Role	Name (Last, First)	Affiliation
Lead PI	Miller, Thomas	Civil Engr, CoE
CoPI	Rakesh Gupta	WSE, CoF

3. Project starting and ending date

Start Date	3/1/16
End Date	2/28/18
Duration (months)	24

4. Total Project Costs

Year 1	Year 2	Year 3	Total
$ 47,883	$ 50,641	---	$ 98,524

5. Summary Abstract

The goal of this project is to contribute to the development of design methods for cross-laminated timber (CLT) diaphragms (floors and roofs) as critical elements of the seismic load-resisting system for buildings. The long, 8’ connection joints of this study are close to full-scale, and are of great interest to practicing engineers and academics working on the structural development of CLT in the United States. The objectives of this study are to examine the following: 1) Determine strengths/stiffnesses of common self-tapping screwed connections with fastener spacings that will be used in practice, and 2) find the ductility/energy dissipation of the connections to more accurately model structural performance characteristics in seismic design. ASTM E455 will be the standard used for the static loading of the diaphragms while ASTM E2126-11 and the CUREE testing protocol will be used for cyclic loading. Looking at how CLT floor diaphragm connections transfer lateral loads will lead to design provisions in the National Design Specification for Wood Construction and the International Building Code that will help structural engineers to confidently use CLT in designing lateral-force-resisting systems. This information is important because the structural strengths and stiffnesses of CLT will enable it to be a choice structural system for taller wooden buildings. These buildings, made with renewable materials, will then be much more competitive with construction from materials which are more energy intensive to produce.

B. Project Description

B1. Introduction and justification

Cross-laminated timber, or CLT, is a promising solution for taller wood buildings. As a majority of residential (and some low-rise) buildings are light-frame wood construction, taller buildings is the next sector where wood can make a positive impact on sustainable construction. The strengths and stiffnesses of CLT panels can resist greater vertical and lateral loads than light-frame walls and floor and roof diaphragms, and thus provide CLT with the ability to build taller wood buildings.

A main motivating factor behind CLT research in North America is the fact that there are much higher levels of seismic activity in the US and the West Coast especially, compared to Europe. Floor and roof diaphragms, the horizontal components of the lateral force resisting system (LFRS) of a building, are designed to resist earthquake ground motions and wind loading. Screw fasteners or other in-plane connections between panels provide much of the ductility (beneficial energy dissipation) in the diaphragm system and the panels themselves are very stiff due to their thickness. A practical question for structural engineers is whether or not the diaphragms should be considered flexible or rigid for design. This determines how the vertical shear walls share the lateral forces from the earthquake. Moreover, research into developing optimal connection systems and spacing requirements for fasteners is necessary if there is to be efficient design of CLT buildings in seismic regions.

The objectives of this study are to examine the following: 1) determine strengths/stiffnesses of common self-tapping screw connections with fastener spacing that will be used in practice, and 2) find the ductility/energy dissipation of the connections so as to contribute to more accurate structural performance characteristics for use in seismic design.

Thomas Tannert at the University of British Columbia has led two separate projects involving CLT panel-to-panel shear connections, although at a smaller scale than proposed here. In early 2015, he looked at both one and two shear plane specimens with 0.4 m in joint length. Self-tapping screws were used with single surface splines, half-lap connections, and butt joint connections. They found that having screws in tension (45º angle) and shear (90º) provided an improvement in both strength and ductility (beneficial energy dissipation) of the connection. This combination was used only in the half-lap connection (Closen 2015). The continuation of this UBC project will be completed in collaboration with the project described in this proposal. The second effort (Danzig, Closen, and Tannert 2014) tested six larger specimens 500 mm (1.6’) wide and 1500 mm (4.9’) tall with only butt joint connections. The panel-to-panel shear connections used screws in tension and compression. They found the cyclic ductility ratio of 4.1 (substantial deformation before failure) and the cyclic yield strength of 68 kN/m to be encouraging. However, even though butt joints seem like a good connection choice due to the lack of necessary milling, they had difficulty with the installation of a screw at an angle to the face. For this reason, the UBC group has indicated that they will likely not pursue additional butt joint testing.

B2. Research location and methods

All of the research will be conducted on the OSU campus (in WSE Dept.).

<u>Test Specimens</u>

Each test specimen consists of three (3) Douglas-fir, 3-ply, 2.44 m X 0.61 m CLT panels. The three panels will be arranged such that two shear planes will exist in each test specimen (Figure 2). Half-lap joints and a single surface splines will be tested (Figure 1). Both connections will feature a combination of self-tapping screws that are installed at 45º and 90º angles to the face of the panel. All screws will be installed parallel to the joint plane. Spacing and screw angle combinations will be determined in collaboration with Thomas Tannert at the University of British Columbia and Max Closen from MyTiCon Timber Connectors.

Test Protocol/Procedure

Table 1: Test Matrix

Joint type	Monotonic	Cyclic
Half-lap joint	3	3
Surface spline	3	3

Figure 1: Half-lap and single surface spline connections (FPInnovations 2013)

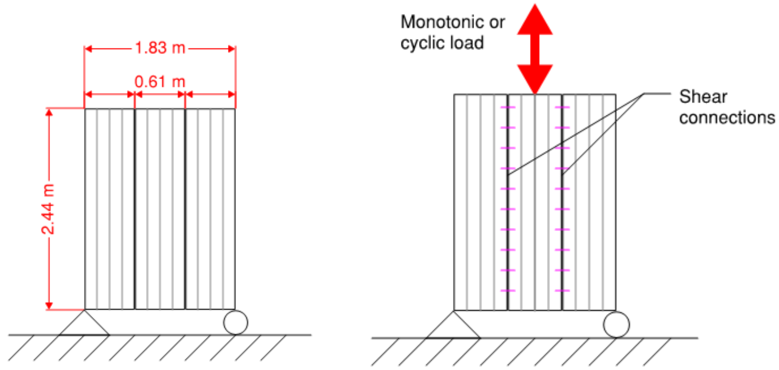

Figure 2 Specimen dimensions and loading

Testing will be based on ASTM E455 – Standard Test Method for Static Load Testing of Framed Floor or Roof Diaphragm Constructions for Buildings (ASTM 2011) the CUREE protocol (Krawinkler et al.), and ASTM E2126-11 – Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of the Lateral Force Resisting Systems for Buildings (ASTM 2002). A total of twelve specimens and two connection types will be tested. Figure 2 depicts the cyclic and monotonic test series.

The first experiment series will be monotonic tests that will include an elastic portion that determines the stiffness of the linearly elastic portion of the stress-strain curve. The second portion will be monotonic loading until failure to determine the ultimate shear strength of the diaphragm system. The second experiment series will be cyclic tests following ASTM E2126 (ASTM 2002). The CUREE cyclic loading protocol for wood structures (Krawinkler et al., 2000) will be used to simulate earthquake loadings.

The testing specifications for the second phase will be developed after the phase 1 testing is completed.

B3. Anticipated outcomes

The proposed research effort provides essential information for the design of cross-laminated timber diaphragms (floors and roofs) that are critical components in resisting seismic loadings. The tests will provide stiffnesses (from elastic tests) and strengths of half-lap joints and single surface spline connections in CLT diaphragms. These values will be compared to design values using the well-established European Yield Model. Ductility and overstrength factors will be examined to further quantify behavior in cyclic loading/earthquake events. Failure modes of the wood and connectors will be observed to optimize the design of the connections. Thus, the project will enable CLT diaphragms to be used with increased confidence in building design, including taller structures in seismic zones. Dr. Gupta will attend the World Conference on Timber Engineering in Austria in August of 2016 to share the results of phase 1.

B4. Timeline

Task description (lead PI)	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1a. Complete testing of phase 1 STS connection project	■	■										
1b. Complete analysis and publication of phase 1 results	■	■										
1c. Present research at WCTC 2016 Austria		■										
2a. Develop testing specifications for phase 2 of project		■	■	■	■							
2b. Acquire materials for phase 2 CLT panels			■	■	■							
2c. Commercial production of panels				■	■							
2d. Structural testing of CLT diaphragm specimens					■	■	■					
2e. Complete analysis and publication of phase 2 results						■	■	■				

B5. Partner linkages and support

<u>OSU, CoE, Civil Engineering Department, Corvallis, OR, USA</u>

The MS students associated with this project will be dual majors in Civil and Construction Engineering (structural engineering) and Wood Science & Engineering. Thomas Miller (PI) is a civil engineering professor. The civil engineering department has already donated funds to this project for commercial manufacturing of the CLT panels. CCE has also provided the MS student with four terms of a GTA.

<u>OSU, CoF, Wood Science & Engineering Department, Corvallis, OR, USA</u>

Rakesh Gupta is the WSE co-PI. The department has already provided the MS student with one term of GRA support as well as use of the Timber Engineering Lab and equipment for testing.

<u>University of British Columbia, Dept. of Wood Science, Vancouver, BC, Canada</u>

This research will be conducted in collaboration with Dr. Thomas Tannert at UBC in Vancouver, BC, Canada. Dr. Tannert has a substantial background in structural timber research and more recently has been forging the way for STS panel-to-panel CLT connections. This collaborative strategy allows both teams to contribute to this body of knowledge and at the same time validate each other's results for use in both Canada and the United States.

<u>Frank Lumber Co, Mill City, OR, USA</u>

Frank Lumber Company is providing the lumber needed for phase 1 of this project. Five units of 8' lumber were donated in the Fall 2015 term.

<u>MyTiCon Timber Connectors, BC, Canada</u>

Max Closen, owner of MyTiCon Timber Connectors in BC, has been the industry PI on the projects Dr. Tannert has completed at UBC with STS fasteners and CLT diaphragms. These fasteners are commonly used in European CLT structures and are being tested for cyclic load performance in their projects and this project to further acceptance of CLT in North America by designers and building officials. They are donating all of the fasteners for this project.

<u>Riddle Laminators (DR Johnson Lumber), Riddle, OR, USA</u>

John Redfield, owner of Riddle Laminators in southern Oregon, has agreed to commercially produce the CLT panels for phase 1 of this project. The CLT product that Riddle Laminators manufactures has been certified by the APA to PRG-320—American National Standard for Performance-Rated Cross-Laminated Timber.

<u>CLT P695 Group</u>

This project is contributing towards the structural design and analysis goals of the FEMA P695 CLT group. This group consists of approximately ten professionals that are focusing on CLT within the FEMA P695 project (Quantification of Building Seismic Performance Factors). Max Closen from MyTiCon Timber Connectors, along with three other industry professionals, have developed a white paper for CLT diaphragm design and are awaiting results of this project's larger scale diaphragm connection tests to both validate and adjust their design values.

C. Bibliography

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