Post + Panel: Next Generation Point Supported CLT Floors

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ABSTRACT

This study provides an overview of the ongoing Post+Panel research program on point-supported Cross-laminated Timber (CLT) floors. Recent studies on rolling shear and punching shear have found that the capacity of CLT in shear may be higher than those specified in the standards. However, while there is a compelling case for higher point supported strengths, most tests have been completed outside of North America, and limited tests have been completed on point supported CLT panels. The work presented herein addresses this critical research need, and consists of CLT rolling shear testing, CLT punching shear testing, and full-scale point-supported CLT floor testing. Rolling shear values are based on both short- and long-term testing including testing using both bend and inclined tests. Rolling shear strength amplification factors and typical stress distributions around columns are presented from previous research in various column configurations. The rolling shear strength was determined for CLT with lamellas of different species, grades, and aspect ratios. The results show that the mean rolling shear strength of CLT was between 0.9 MPa to 1.8 MPa.

INTRODUCTION

The building industry has become increasingly interested in the use of mass timber products, especially CLT and Glued Laminated Timber (glulam). These products consist of sawn lumber combined with glue into a larger structural element. While glulam is composed of layers in the same direction, primarily used for beams and trusses, CLT is composed of layers that alternate in direction and is mostly used for floors and walls. Currently, CLT is often combined with glulam in gravity systems, spanning one direction where the panels are line-supported between glulam beams.

Point-supported CLT refers to CLT panels supported directly on columns, without any supporting beams. This configuration is appealing because of the reduced volume of wood saved from the use of beams, ease of mechanical and electrical distribution, and reduction of floor assembly depth. Figure 1 shows the 18 storeys 53 m tall UBC Tall Wood located at Vancouver, Canada, the prototypical example of a point supported CLT building. While there are many advantages to using point-supported CLT, the high shear stresses near supports result in the design of point-supported CLT floors often being governed by the CLT shear strength, which is controlled by the rolling shear strength of the base material. Rolling shear strength values adopted in Canadian and American material standards (CSA 086, ANSI/APA PGR 320, NDS 2018) are much lower than corresponding longitudinal shear strength values.

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Figure 1. UBC Brock Commons (left); point supported floors (right) (Photos courtesy of Fast + Epp)

ROLLING SHEAR IN CLT

Wood is an anisotropic material with three major axes: longitudinal, tangential, and radial. Rolling shear in wood is represented on the tangential-radial plane perpendicular to grain direction; failure occurs with the longitudinal fibers rolling over each other. The rolling shear strength (f_s) is lower than shear strength parallel to grain (f_v), and "taken as approximately one-third" (CSA O86). The specified rolling shear strength in Canadian Code (CSA O86) ranges from 0.43 to 0.63 MPa, and the allowable stress design values in American Standard (ANSI/APA PRG 320) is between 0.24 to 0.41 MPa depending on the base material stress grade. Eurocode 5 (EN 1995-1-1) suggests a characteristic rolling shear value of 1.0 MPa independent from CLT species and class. Research has been conducted on the rolling shear strength of CLT with the results suggesting strengths of up to 6 MPa (Aicher et al 2015). Most of the previous research is based on samples from North American species (SPF, Hemlock, Southern Yellow Pine etc.), European species (Norway Spruce, Black Spruce, Irish Sitka Spruce, European Beech, Popler etc.), Australian and New Zealand species (Radiata Pine and Eucalyptus Nitens) and Japanese species (Hinoki cypress and Japanese cedar).

Universal standardized test configurations and methods are not yet available for determining the rolling shear properties of CLT, therefore researchers have investigated various test configurations with short-span bending tests and in-plane shear being the most common test methods. The European CLT standard (EN 16351) adopts both methods and the North American CLT standard (PRG 320) references primarily short-span bending tests. In the in-plane shear test, the load is applied on the specimen either using two side plates or on the outer lamella (s) of CLT at a 14° angle similar to EN408 standard. The four-point bending test is most commonly used for short-span shear tests on CLT to determine rolling shear strength. Kumar et al. (2021) reported that the in-plane shear test resulted in 10-20% higher strength compared to rolling shear estimated from bending tests.

Ehrhart and Brandner (2018) conducted a comprehensive rolling shear testing program on six different European species and found the mean rolling shear was between 1.5 MPa to 5.6 MPa.

The mean rolling shear strength observed for various European wood species ranged from 0.9 MPa to 6.0 MPa. The mean rolling shear strength observed in North American species ranged from 1.3 MPa to 2.3 MPa. From Australian/New Zealand wood species, the rolling shear strength was found between 2.0 MPa to 3.6 MPa. Other major factors that appear to influence the rolling shear properties are the density of wood, annual ring orientation, the lamella aspect ratio (width to thickness of lamella), knots, and edge gluing or edge gaps.

PUNCHING SHEAR IN CLT FLOORS

While the rolling shear strength determined from testing is appropriate for one-way action, research suggests it cannot predict the shear strength of CLT in point supported conditions. When CLT is used in this application, the stresses around columns are generally much higher, and the load path is bidirectional. The rolling shear strength of CLT near support is often termed "punching shear" strength (f_p), with higher strength values than the base rolling shear strength of CLT (f_s).

Verifying the punching shear strength of CLT is more involved than rolling shear, and requires testing a panel section. Verifying failure stress is similarly challenging, and requires predicting the internal stresses within the panel at failure load. The challenges and additional costs associated with point supported CLT tests have resulted in fewer existing studies to date. Three significant studies were identified that studied point supported CLT: Mestek (2011; Mestek & Dietsch, 2014), Bogensperger et al (2016), and Muster (2020). For full-scale panel tests, only one published study has been completed by FPInnovations and Fast + Epp (Fast et al., 2016) in support of the design process for the UBC Tall Wood building. The large-scale FPInnovations tests did not evaluate panel shear strength, as such are not discussed here.

Mestek (2011) completed point supported CLT tests on 189mm thick 7-ply CLT panels in two configurations: one simulating panel with support in its center, and one simulating panel supported on its edge by columns. Three repetitions were used for each test. The stress predicted by 3D FEM models corresponding to the observed failure loads from these tests was higher than those determined in four-point bending tests by up to 70%. This increase in strength was posited to happen due to a combination of compression near the column support, and redistribution of stress to lamella layers perpendicular to loading. To better evaluate the impact of compressions, Mestek (2011) also evaluated completed inclined shear tests with compression force/clamping applied to the CLT. Based on the results of these tests, Mestek proposed a regression equation but bounded the increase in strength at 20% for design purposes.

Bogensperger et al. (2016) studied small-scale 5- and 7-ply CLT panels with columns supported in the center of each panel. Three repetitions were completed for each panel. Similar to Mestek's research, it was found that the failure strength was significantly higher than characteristic rolling shear values predicted by code, with maximum strength 75% higher than code-specified values with the difference attributed to non-linear stress redistribution in the CLT.

Muster (2020) completed studies using both small-scale panel tests and modified inclined shear tests. For the inclined shear tests, CLT billets were studied with wider transverse layers than the longitudinal layers, simulating the effect of stress redistribution in the cross layers. It was found that there was up to a 20% increase in strength when these wider cross layers were used. For small-scale panel tests, Muster (2020) examined center-supported CLT panels that had openings to accommodate the column support connection. Openings size not appear to have a large impact on strength, but the relationship is difficult to say with certainty with only one instance of each test completed and no repetitions.

In all of the experimental studies discussed, it was found that the punching shear capacity of CLT was higher than its expected rolling shear strength. To account for this increase in strength, a punching shear factor, k_p, was introduced by Dietch et al (2018), such that $f_p = k_p f_r$. Here it was proposed that the punching shear strength of CLT was increased by a factor of 1.6 when compared to the rolling shear. Similarly, Muster (2020) proposed a k_p factor of 1.6 for column faces in the center of a panel, and 1.3 for column faces at the edge of a panel. Currently, no long-term studies have been conducted that consider the effect of load duration on punching shear strength.

TESTING PROGRAM

To address current gaps in knowledge about point supported CLT, the Post+Panel research program was initiated by Fast+Epp. The following sections describe the phases of the research program and its initial findings.

Rolling shear tests

Small-scale in-plane shear tests were conducted to determine the rolling shear and failure mechanisms of CLT specimens. 3-ply of 89 mm and 105 mm thick, and 5-ply of 175 mm thick panels from SPF, D-Fir, and Hemlock species from multiple suppliers are tested in strong and weak axes orientations. The specimens are 100 mm × 300 mm and were tested at an angle of 14^0 as shown in Figure 2. A total of 180 specimens, 20 replicates of each category were prepared and subsequently tested at the University of Northern British Columbia Wood Innovation and Research Lab (WIRL).

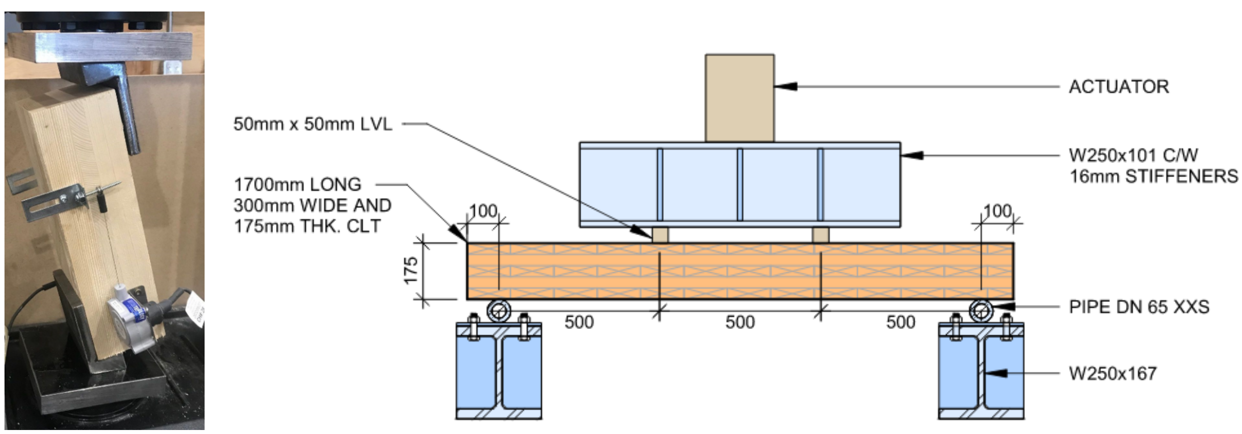

Figure 2. In-plane shear tests (left: photo courtesy of UNBC); 4-point bending test (right)

Additional four-point bending specimens were conducted with specimens 1700 mm long and 300 mm wide, prepared from 175 mm thick 5-ply SPF CLT. Tested in both strong and weak axes directions is planned. Initially, a total of 40 samples (20 replicates of each configuration) are planned for short-term loading (Figure 3). The rolling shear properties will also be determined for a long-term loading setup under four-point. The long-term loads will be applied at a specified percentage of short-term ultimate loads e.g., $0.35F_u$, $0.55F_u$, and at a load corresponding to 0.3 MPa rolling shear stress. A total of 36 samples will be tested for long-term loading for up to 12 months.

Punching shear tests

A number of panels punching shear tests will be completed at Fast + Epp's Concept Lab. The effect of five main variables will be considered in four series of tests during this phase of testing: CLT thickness and support location, CLT material type, column support geometry, and screw reinforcing. For all tests in the experimental program, a total of six repetitions will be completed.

The first test series studied both the effect of CLT thickness depth and column location on CLT capacity using two different thicknesses of E-rated SPF panels: 175mm CLT (5-ply of 35 mm lamella), and 245mm CLT (7-ply of 35 mm lamella). Four different column configurations are also examined in this series, with the support types considered shown in **Figure** .

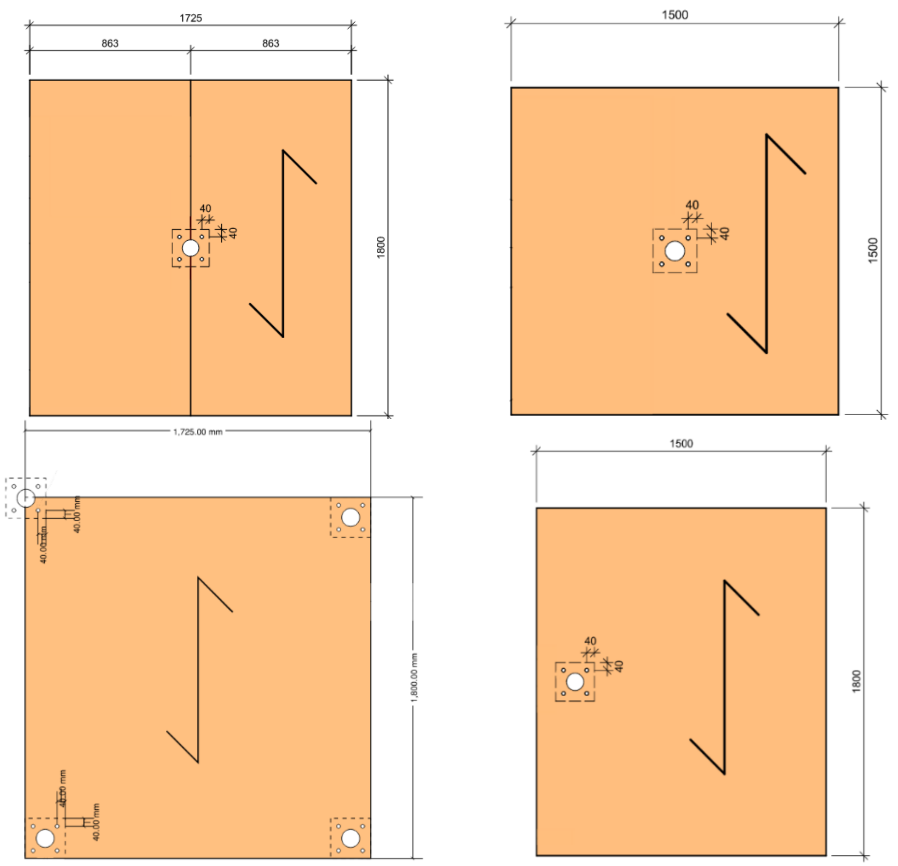

Figure 3. Typical panels for punching shear tests. Interior panel edge condition (top left), interior mid-panel condition (top right), interior panel corner condition (bottom left), building perimeter condition (bottom right)

For the interior and edge columns, the load is applied to a column stub in the center of the support, and the CLT is line supported along all four exterior edges. In the case of corner supports, one of the corners will be supported by only 1/4th of a column stub and the other three will have to be supported by a full column stub. Load is then to the CLT corner with a fourth of the stub on the column, with the intention of failing this column before the other three supports, Finally, in the case of interior edge columns load will be applied to the central column stub, while the CLT pane is line supported along the other three sides.

The second testing condition examines the effect of material grade and species on panel capacity. For this test series, 5ply 175mm V- and E-rated panels from four different manufacturers are compared, using the edge column setup from test series one.

The third test series will examine the effect of support size and shape on CLT strength. Eight different column configurations will be considered, ranging from rectangular columns to square columns with different plate sizes, and a single trial with circular columns. All square and rectangular tests will use the edge column setup from series one, and the circular column will test both interior and edge conditions.

The fourth test series will examine the impact of inclined fully threaded screw reinforcement on the overall shear strength of a CLT panel. Screw reinforcing extent and spacing will be reviewed as well as application of reinforcing on all or some sides of the support.

Full-scale point supported CLT floor tests

Two-span continuous CLT floor panels will be tested under point-supported conditions as shown in Figure 4. The span length of the samples will be 4.5 m and both typical panels of 2.4 m and 3.5 m wide will be tested. The CLT panels consist of 175 mm thick 5-ply from SPF species.

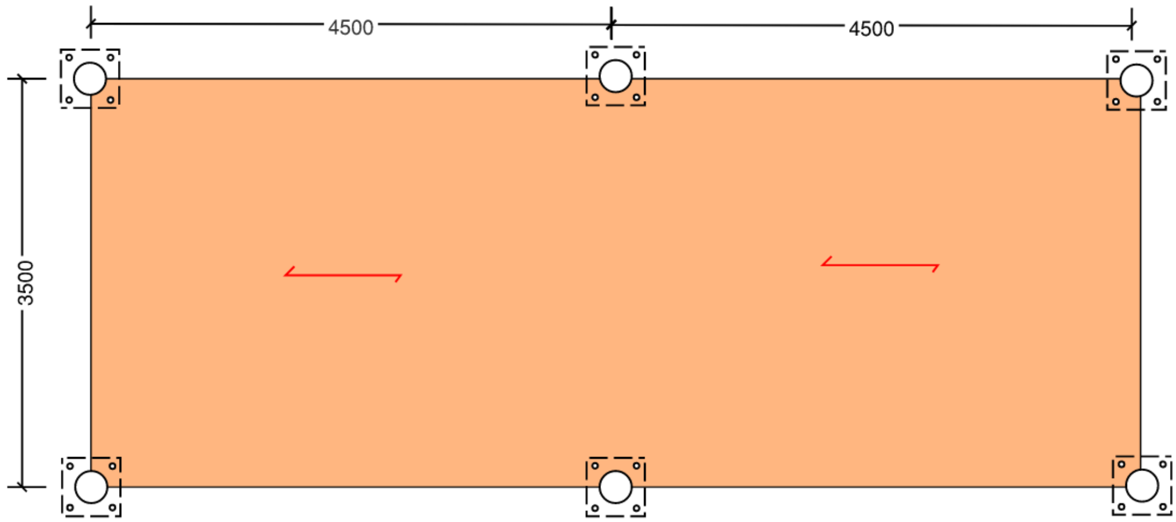

Figure 4. Full-scale continuous CLT panel tests

Preliminary Results of Rolling Shear Tests

At the time of writing, a total of 243 specimens were prepared, conditioned at 20 °C and 65% relative humidity, and subsequently tested at the University of Northern British Columbia Wood Innovation and Research. Table 1 provides the characteristics of the test series. The specimens, sized 100 mm (width) × 300 mm (length), were tested at an angle of 14^0 against the vertical axis, as shown in Figure 5, at a loading rate of 1.0 mm/min until failure. The rolling shear strength (f_r) was calculated by Eq. 1.

$$f_r = \frac{P_{max} \times \cos \propto}{L \times w} \quad (1)$$

where, $P_{\max}$ is the peak load, L and w are the length and the width of the specimen' rolling shear plane, and $\propto$ is the angle between the shear plane and the direction of the force (14°).

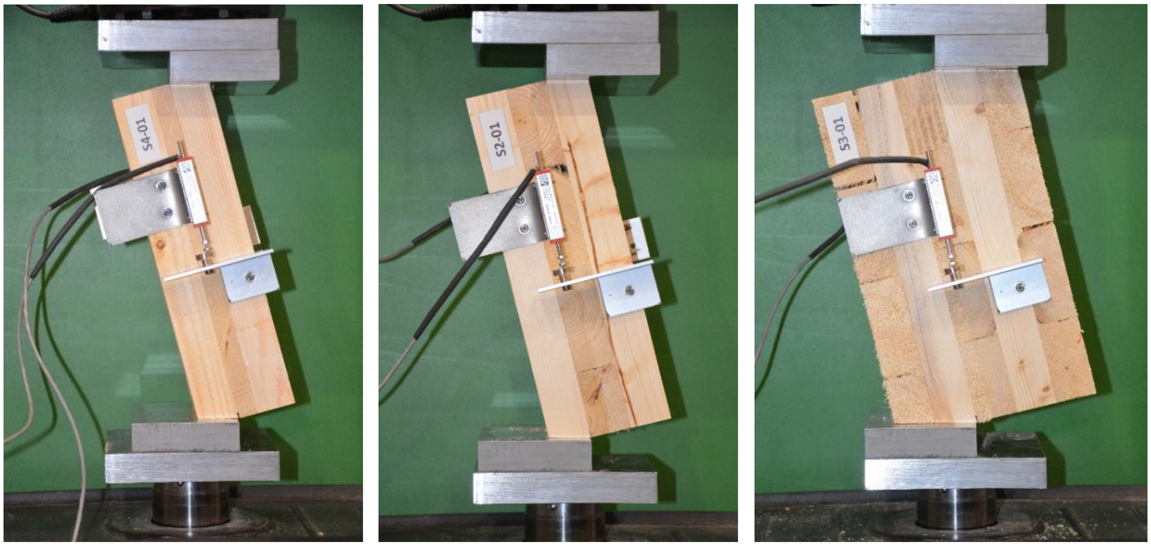

Figure 5. Shear test on 89, 105, and 175 mm thick CLT (left to right) [Photos courtesy of UNBC]

Table 1. Rolling shear strength from tests

Series	Manufacturer	Stress Grade	Layup	Species	Tested layer	Count	f_r (MPa)	COV (%)
S1	A	V2	35x19x35	Black Spruce	Minor	30	1.55	18
S2	A	V2	35x 35 x35	Black Spruce	Minor	30	0.94	21
S3	A	E1	35x35x35x35x35	Black Spruce	Major	30	1.06	21
S4	B	V2	35x19x35	SPF	Minor	18	1.75	23
S5	B	V2	35x35x35	SPF	Minor	15	1.70	22
S6	B	E1	35x35x35x35x35	SPF	Major	15	1.51	15
S7	C	C24	20x20x20x20x20	SPF	Major	15	1.15	15
S8	C	C24	20x20x20x20x20	SPF	Minor	15	1.24	24
S9	D	V2	35x17x35x17x35	SPF	Major	15	0.92	30
S10	D	V2	35x17x35x17x35	SPF	Minor	15	1.55	23
S11	D	V2	35x19x35	SPF	Minor	15	1.54	47
S12	D	V2	35x35x35	SPF	Minor	15	1.15	19
S13	D	E1	35x35x35x35x35	SPF	Major	15	1.57	21

CONCLUSIONS

This paper presents an outline of previous and ongoing research on point supported CLT floors. The critical research needs on rolling shear and punching shear have been addressed. The ongoing structural testing program at Fast + Epp's and the University of Northern British Columbia will provide valuable modelling and design inputs for point supported CLT. This research will no doubt strengthen Fast +Epp's commitment to sustainability.

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