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INVESTIGATION OF CROSS LAMINATED TIMBER'S LONG-TERM PERFORMANCE (CREEP)

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ABSTRACT: Cross laminated timber (CLT) and its use as a structural wood product is relatively new compared to other engineered wood products. While current design standards for CLT subjected to long term deflection or creep provide a value for the time dependent deformation factor (creep factor), direct validation of such a value has not been conducted. The 2018 version of the National Design Specification (NDS) recommends a creep factor of 2.0 be used for CLT. Eurocode recommends a value equivalent to 1.8 for normal moisture and temperature conditions. To provide a point of comparison to the design values suggested in US standards, full scale long-term deflection testing of CLT panels is being conducted under a variety of load levels. The increasing deflections over time give an indication of the creep factor. This paper describes the short-term destructive tests and the first 3 months of progress of the long-term tests. Preliminary results indicate creep factors approaching values glue-laminated timber and solid sawn lumber in the NDS after the first 3 months.

KEYWORDS: Cross laminated timber, CLT, Creep, deflection, wood design

1 INTRODUCTION

With increased use of CLT as a construction material in larger buildings, including midrise and high-rise buildings, the work to fully understand CLT grows in importance. Larger structures, especially commercial use cases require larger spans for gather spaces. This includes meeting rooms, open concept office spaces, recreational spaces and auditoriums. Creep in CLT is of concern for these designs due to wood's low stiffness relative to other building materials such as concrete and steel. As seen in fundamental mechanics lower stiffnesses result in greater deflections for the same spans and strengths. Wood structures, utilizing CLT or not, are therefore more likely to be controlled by deflection limit states rather than strength design.

Current understanding of CLT's performance under creep is lacking. The American Wood Council (AWC) currently group CLT with other panelised products in the 2018 edition of the National Design Specification (NDS) for wood construction [1]. Current provisions from the AWC prescribe equation 1 for calculating long term deflection.

$$\Delta_T = K_{cr}\Delta_{LT} + \Delta_{ST} \tag{1}$$

Where Δ_T is the total deflection of the member, K_{cr} is the time dependent deformation factor also known as the creep factor, Δ_{LT} is the immediate deflection due to the long-term component of the design load, and Δ_{ST} is the deflection due to short term or normal component of design load. [1]. These deflections are calculated using the modified effective bending stiffness shown in equation 2.

$$(EI)'_{eff} = (EI)_{eff} C_M C_t \tag{2}$$

Where $(EI)'_{eff}$ is the adjusted effective bending stiffness, $(EI)_{eff}$ is the effective bending stiffness, C_M is the wet service factor, and C_t is the temperature factor.[1]. The NDS specifies a creep factor of 1.5 to most wood products and lumber in dry service conditions and 2.0 in wet service conditions. CLT is assigned a 2.0 creep factor for both wet and dry service conditions like plywood. Service conditions are based upon expected moisture contents in the structural member. Internal moisture contents above 19% are considered in a wet service condition except for laminar products like CLT and CLT where exceeding 16% is considered wet service. The assignment of the creep factor and the categorization of CLT was made on the recommendation of a study done on European CLT for adoption in Eurocode[4].

Eurocode deals with creep similarly to the NDS though uses a single modification factor, k_{def}, for both the reduction in young's modulus and the magnification of instantaneous deflections where the NDS utilise three different terms, C_M, $C_{.t}$, and K_{cr}. The modification factor in Eurocode differs by product and service class. The service classes are labelled numerically one to three and are based on escalating moisture content within the material, denotated by averaged ambient temperature and the average relative humidity of the air [4]. Additional discussion on the service classes notes that softwoods in each service class typically stay under certain moisture contents. For service class one softwood moisture content stays below 12%, softwoods in service class two remain below 20% moisture content, and service class three exists for conditions where softwoods are above 20%

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moisture content [4]. This system is analogous to the NDS's wet and dry service conditions. Service class one to dry service and service class two and three to wet service. Both deflection magnifications and reductions in member stiffness differ based upon the expected environmental conditions under Eurocode 5. CLT is not explicitly included in the later version as a product though associated standards assign the same values as Type EN 636-2 Plywood for all service classes [5]. For service classes one and two k_{def} is 0.8 and 1.0 respectively. CLT does not have a creep deformation factor for service class three. When these terms are applied, they produce an 80% and 100% magnification in deflections due to long term loads. The NDS only provide one magnification level for long term loads on CLT, a 100% magnification.

The investigation of creep factors for CLT is necessary to provide experimental evidence to support the creep factors suggested in the NDS or propose changes if necessary. To evaluate the long-term performance of CLT panels a series of tests have been conducted. Short term testing to establish the strength and stiffness characteristics of the CLT specimens followed by a long-term creep test. The experimental test setup and current results will be presented and discussed.

2 EXPERIMENTAL TESTING

2.1 SHORT TERM TEST

Two specimens out of the available CLT panels were randomly selected for short term testing. The specimens used throughout the experiment were 5-ply CLT panels with a cross-sectional area of 14.5 cm x 30.5 cm and 5.5 m in length (6.75 in x 12 in x 18 ft). Each panel is a V3 CLT panel per PRG 320 [3] and was tested using four-point loading as shown in Figure 1.

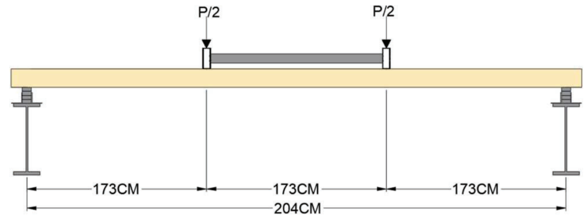

Figure 1: *Loading configuration for short-term testing.*

Four-point loading used for this experiment aligns with previous work for ease of comparison. [4] The load is transferred to the specimen through steel hollow structural sections 7.62 cm (3 in) wide and 20.32 cm (8 in) tall. The specimen rests on top of wood blocks placed on top of steel W-sections as supports spaced at 204 cm (17 ft) center-to-center. Specimens showed no visible signs of crushing at the bearing locations after short term tests.

Specimen subjected to the short-term loading produced moment failure, pictured in figure 2, by fiber rupture in the tension side of the panel. The resulting load displacement graphs are shown in Figure 3.

Figure 2: *Moment failure of specimen in destructive test*

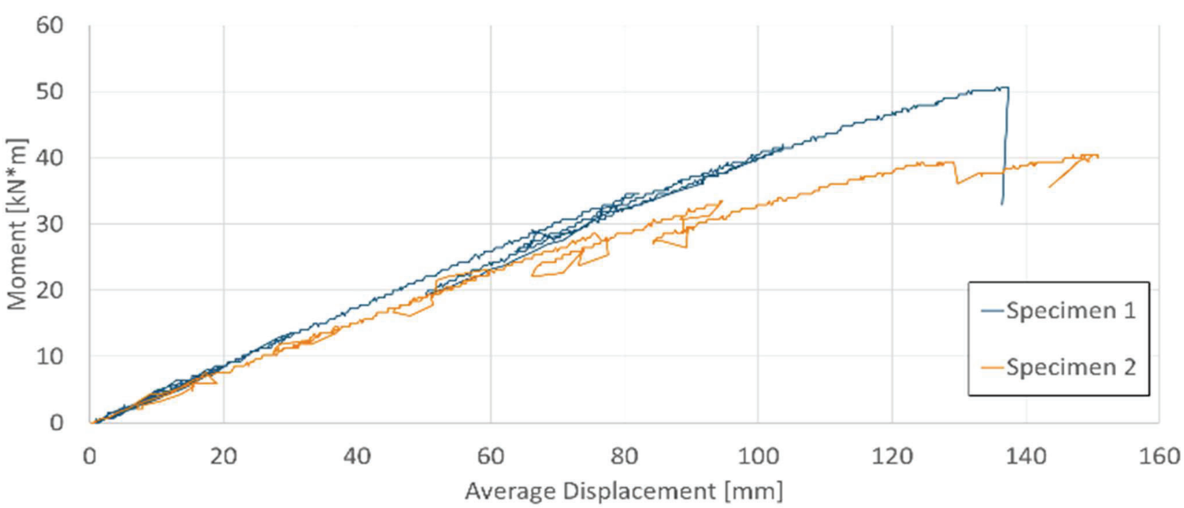

Figure 3: *Short-term test Load-Displacement curves*

The average experimental moment capacity of the CLT specimens was calculated from the following relationship:

$$M = \frac{P}{2}a \quad (3)$$

Where M is the moment capacity, a is the distance from center of bearing to the center of load application (173 cm, 68 in.), and P is the total load applied to the specimen. The load P is split and by a spreader beam and applied evenly according to Figure 1. The moment capacity for each specimen is reported in Table 2 along with the associated peak load and deflection at the peak load. Peak load is reported as total force applied to the specimen. Table 2 also reports the average moment capacity based on the two experimental tests shown in the last row of the table.

Table 2: *Destructive test results and specimen characteristics*

Specimen Number	Peak Load [kN]	Deflection at peak load[mm]	Peak Applied Moment [kN*m]
1	58.7	135.6	50.8
2	46.8	147.1	40.5
Average	52.8	141.5	45.6

2.2 LONG TERM TEST

The primary goal of long-term testing was to measure the creep in a series of CLT specimens. Loading towers were used to maximize the space which was available. Figure 4 shows a representation of the loading towers.

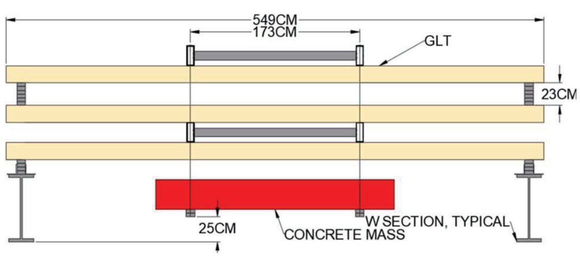

Figure 4: *Schematic view of loading tower for the long-term testing*

Deflection characteristics of the specimen as found during the short-term tests were used to inform the design of the towers such as clearances between specimens within the load towers and the required height of the pedestals to allow sufficient space for the hanging mass. Each tower consists of two CLT panels and a flat-wise glulam beam acting as a transfer member. The load is transferred from the hanging concrete mass below the bottom specimen to the glue laminated timber(GLT) beam using steel threaded rod The GLM beam bends in positive bending and transfers the load to the CLT specimen below at the bearing locations on each end of the beam. The next CLT specimen in the load path will be in negative bending under this load. In total three loading towers have been constructed testing six CLT panels and three GLT beams. Using loading towers introduces variation in the loading due to the accumulation of load due to specimens and equipment self-weights. This additional load was accounted for in all calculations based on an assumed specific gravity for Southern Pine of 0.55, the self-weight of the CLT members were calculated to be 1.57 kN (354 lb). Similarly, the self-weight of the GLT members were calculated to be 1.88 kN (422 lb). LRFD and ASD moment capacities were calculated in accordance with Table 10.3.1 of the 2018 NDS for wood construction. [1] The resulting moment capacities and self-weights of the specimens were used to find the most appropriate load levels to use for the long-term test. The load levels used for the creep test are shown in Table 3. The load levels are reported as a percentage of the average peak moment reported in Table 2 and includes the mass above the specimens and self-weight.

Table 3: *load level information*

Load [kN]	Applied Moment [kN*m]	% Ultimate
P	M	---
8.7	15.1	17
10.6	18.4	20
11.6	20.0	22
13.5	23.3	26
14.7	25.4	28
16.6	28.7	32

The load levels used for this experiment ensure the CLT specimens remained within the linear elastic region ensuring no change in stiffness throughout the creep test. Because the load displacement curves in Figure 1 show no obvious yield point, the 40% rule was used to determine the elastic region of the beam. With this method young's modulus is determined using the load-displacement data associated with 0% to 40% of the failure load. Appendix X2.5-6 of ASTM D198 permits the use of this method when visual inspection of the data is insufficient to identify the yield point.

The creep factors will be back calculated by rearranging equation (1) from the NDS shown as equation (4):

$$K_{cr} = \frac{\Delta_T - \Delta_{ST}}{\Delta_{LT}} \quad (4)$$

Where Δ_T =total deflection, Δ_{LT} =instantaneous deflection due to long-term loadings, Δ_{ST} =instantaneous deflection due to short-term loadings, and k_{cr} = creep factor. For this test there is no short-term loading as all load is applied for the duration of the experiment, therefore equation 4 simplifies to the ratio of total deflection to instantaneous deflection as shown in Equation 5:

$$k_{cr} = \frac{\Delta_T}{\Delta_{LT}} \quad (5)$$

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The application of the load for the six CLT specimens and three GLT specimen in three separate stacks was applied on December 20, 2022. The stacks are shown in Figure 5.

***Figure 5:** Loading setup of long-term deflection testing.*

3 PRELIMINARY LONG-TERM DEFLECTION RESULTS

The following discussion presents the first 12 weeks of experimental data for the long-term testing. Midspan deflections of each of the six CLT panels and three GLT beams have been collected every minute. Figure 6 reports the daily average deflections for three specimens loaded between two different towers. Daily averages are reported for clarity. Deflection characteristics for the various specimens agree with expected behaviour. Lower load levels produce smaller displacements. Discontinuities in the data are missing data caused by battery and power outages. The instantaneous deflection due to long term loadings were recorded within 3 min of initial loading as per the recommendation of ASTM D6815 [6]. Equation 4 was applied to subsequent readings using this initial deflection to produce the plot in Figure 7.

***Figure 6:** Daily average deflection time history for all CLT specimen*

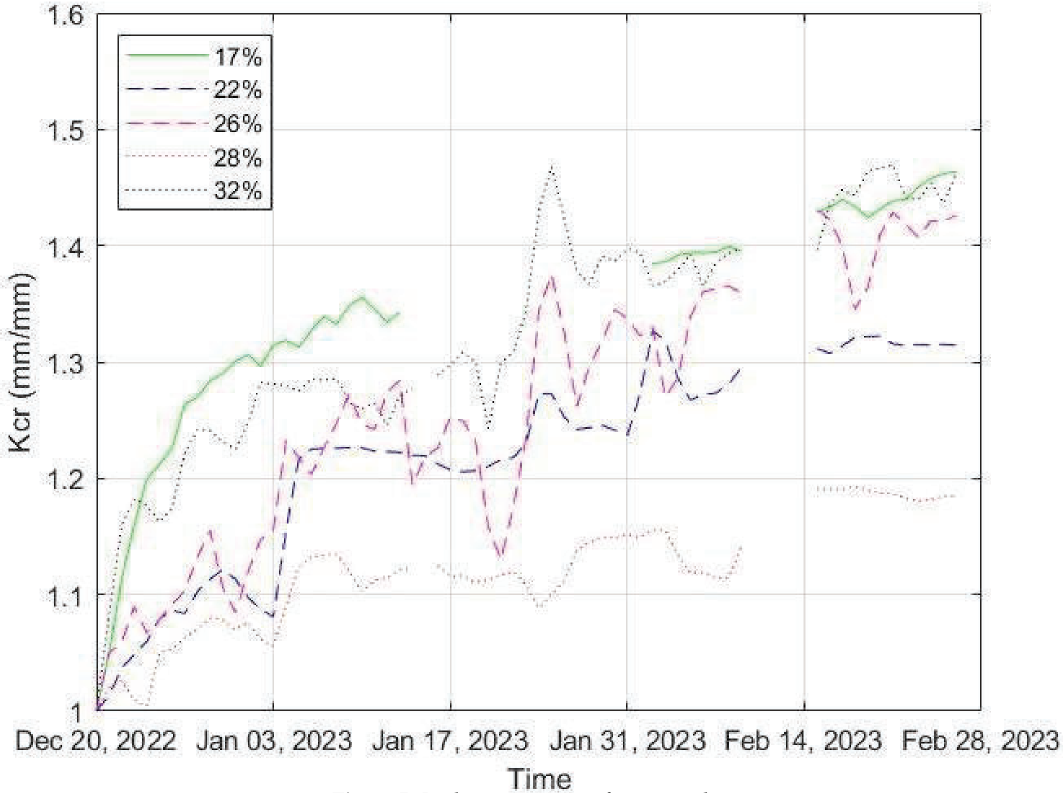

Figure 7: *Daily average creep factor time history*

Figure 6 displays the creep time history for the various specimens at different load levels. Creep factors slowly increase over time as the specimens continue to experience increases in strain. Specimens show a consistent overall creep behaviour, though day-to-day increase in deformation for each specimen differ. The rate of deformation is decreasing over time which is consistent with expected behaviour and previous tests [2]. After three months the CLT specimens experienced 18% to 46% increases in deflection resulting in k_{cr} factors ranging between 1.18 to 1.46. Subjects experienced significant increases in deformation over the first 10 days of the test. The rate of creep then declined significantly and continue to level as the testing period expands. The rate of creep is expected to decline to a level that is considered negligible after 24 months.

4 CONCLUSIONS

An experimental setup was designed to test the long-term deformation (creep) behavior of cross-laminated timber (CLT) to determine the applicability of current design provisions in both the National Design Specification (NDS) and Eurocode. Recommendations for normal temperature and moisture service for NDS recommends amplifying long-term deformations by a factor of 1.5, while Eurocode recommends a factor equivalent to 1.8 for similar conditions. Current time dependent deformation (creep) factors are below the 1.5 recommendation for GLT and solid lumber and below the service class one recommendation under Eurocode, though tests are still ongoing. Past tests indicate that creep continues past the first three months and more time is necessary to obtain an accurate creep factor [2]. Future results will indicate whether the current value prescribed by the NDS is appropriate for CLT or if a lower creep value is appropriate for dry service conditions. Creep factors will continue to be collected and once sufficient data is gathered these values will be evaluated with the currently prescribed values within the NDS.

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