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BENDING PERFORMANCE OF TIMBER-TIMBER COMPOSITE FLOORS

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Abstract: Experimental investigations on Timber-Timber Composite (TTC) floor systems composed of Cross-Laminated Timber (CLT)-glulam are presented in this paper. The floor system was designed as part of two projects in Vancouver, the Sir Matthew Begbie Elementary School and the Bayview Elementary School. Quasi-static monotonic tests were conducted on full-scale 9.1 m long and 1.2 m wide double T-shaped ribbed composite floor segments. The TTC floors consisted of 3-ply CLT panels and two glulam beams connected by three different means: i) screws installed at 90º, ii) screws installed at 45º, and ii) screws installed at 90º with an additional adhesive bond. Six monotonic tests were conducted with two replicates from each type. While all three-floor types reached similar average load-carrying capacities, the TTC floors combining screws with glue exhibited the highest stiffness.

1 INTRODUCTION

With an increase in pollution and climate change, the global demand is increasingly moving towards sustainable construction. Therefore, the construction industry has begun to utilize sustainable materials such as timber that has a low-carbon footprint in their life cycle. Cross-laminated timber (CLT) and Glue-laminated Timber (glulam) have become the most well-known engineered mass timber products, are gaining popularity, and taking over from steel and concrete as the wonder material of the 21st century due to the availability of innovative materials, connections, components, and composite systems (Dias et al. 2016). CLT is a mass timber product, consisting of sawn lumbers laid-up on-flat in alternating directions and glued together; creating panels that have high in-plane strength and stiffness (Shahnewaz et al. 2017, 2018, Gagnon and Pirvu 2020). Timber construction is advancing in North America and the 2020 version of the National Building Code of Canada (NBCC 2020) allowed mass timber structures up to 12 storeys tall.

This paper investigates Timber-Timber Composite (TTC) floor systems made with CLT and glulam under quasi-static monotonic tests including various shear connections for the TTC floors are also investigated. The Vancouver School Board (VSB 2020) commissioned two new buildings to replace the existing Begbie and Bayview elementary schools. The two-storey school buildings include learning spaces with exposed CLT walls, floors, and roofs. Both projects include long span systems in either the roof or the floor, with varying spans.

Timber Concrete Composite (TCC) systems have been extensively studied in recent years using mechanical connectors, adhesive bonds, or a combination (Tannert et al. 2019). Fewer studies have reported experimental, numerical, and analytical investigations on TTC systems, particularly with mechanical fasteners. The objective of the research presented herein is to investigate the flexural performance of double-T shaped TTC floor systems using various connections.

2 SPECIMENS DESCRIPTION

The CLT panels and glulam beams were fabricated by Structurlam in accordance with ANSI/APA/PRG 320 (2018) and CSA O122 (2016); some relevant material properties are provided in Table 1.

Table 1: Material Properties

	CLT	Glulam
Species	S-P-F	Douglas-Fir
Grade	105V, grade V2M1.1	Grade 24f-E
Size	1.162 m x 105 mm	215 mm x 380 mm
Length	9.144m	8.944 m
Avg. density	441 kg/m^3	545 kg/m^3
Avg. moisture content	11%	12%

A total of six (double T cross-section) specimens composed of a CLT panel and two glulam beams were assembled and tested in the Wood Innovation Research Lab at the University of Northern British. The CLT panels were 105 mm thick [35/35/35], 9,144 mm long and 1,162 mm wide with an average density of 441 kg/m^3 at a moisture content of 11%. The 8,944 mm long glulam beams had a cross-section of 215 mm x 380 mm. Their average density and moisture content were 545 kg/m^3 and 12%, respectively. Two types of self-tapping screws (STS): i) 10Ø×200 mm ASSY SK partially threaded washer head screws; and i) 8Ø×300 mm ASSY VG cylinder head fully threaded screws, and one-component polyurethane adhesive (Lepage Premium PL) were used to connect the CLT panel to the glulam beams. The cross-section of the test specimens is illustrated in Figure 1.

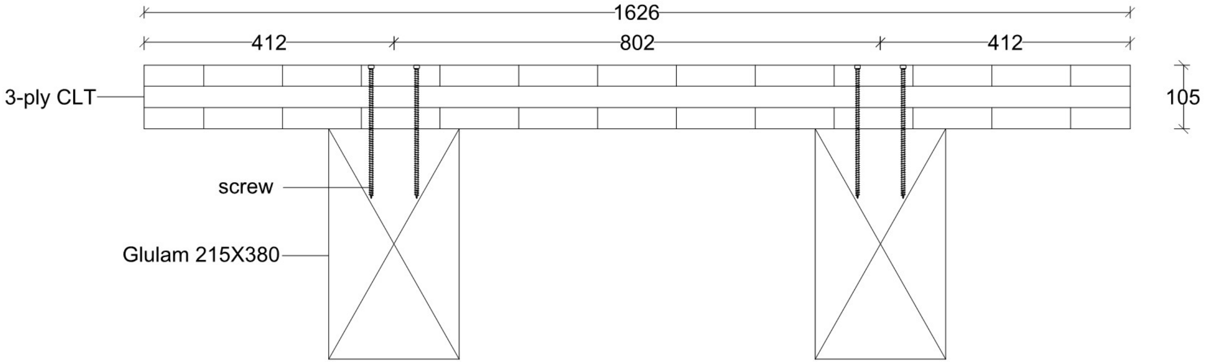

Figure 1: Cross-section of test specimens [mm]

Three connections between CLT and Glulam were investigated:

a) Type A: 2 rows of 10Ø×200 mm ASSY SK STS at 75 mm on centre installed at 90°, c.f. Figure 2a.

b) Type B: 2 rows of 8Ø×300 mm ASSY VG CYL STS at 150 mm on centre installed at 45°, c.f. Figure 2b.

c) Type C: 2 rows of 10Ø×200 mm ASSY SK STS at 300 mm on centre installed at 90°, in combination with an adhesive bond (one-component polyurethane adhesive - Lepage Premium PL), c.f. Figure 2c.

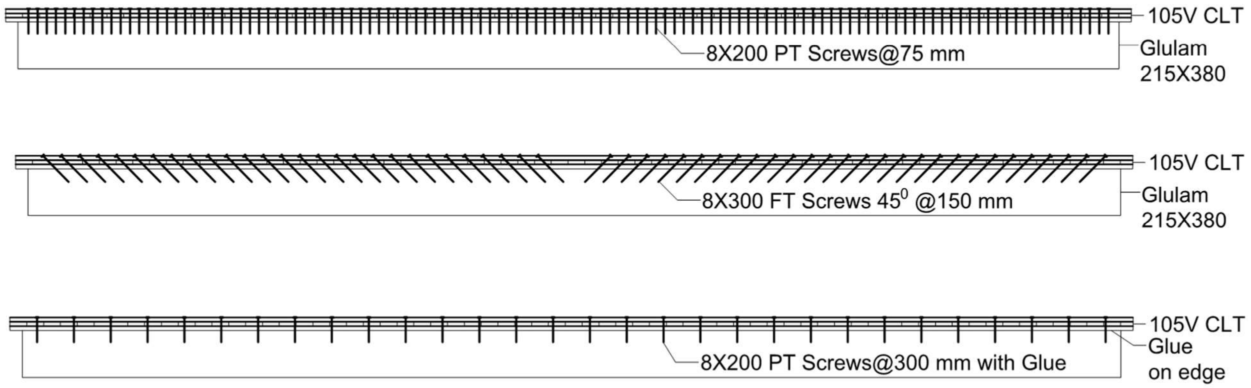

Figure 2: Connections: (a) Type A; (b) Type B; (c) Type C

3 METHODS

Destructive 4-point bending tests were conducted. The test set-up consisted of two 500 kN actuators positioned as shown in Figure 3. Six string pots, labelled S1 to S6 and eight linear variable differential transducers (LVDTs) labelled L7 to L14 were installed to measure the vertical deflections and the relative horizontal displacements between CLT and Glulam, respectively, c.f. Figure 4. The floors were subjected to quasi-static monotonic loading with equal load applied to each actuator. The load was applied at a constant rate of 10 mm/min with an initial pre-load cycle to 40% of the anticipated ultimate load-carrying capacity, unloaded, and re-loaded to failure, where failure is defined as a drop in the applied load by more than 20%. The maximum force, F_{max}, and its corresponding mid-span deflection, $d_{m,Fmax}$, were determined based on the actuator load, and the average of string pots S3 and S4 respectively. The elastic stiffness, k_{dm} , was determined for the range of 10% - 40% of F_{max}.

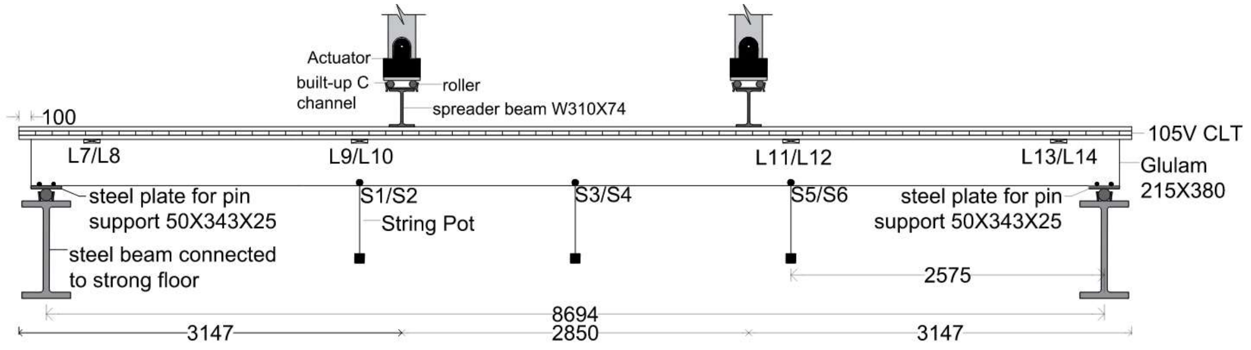

Figure 3: Schematic of 4-point bending setup and location of sensors

Figure 4: Photo of a 4-point bending test

4 RESULTS AND DISCUSSION

4.1 Load-Deflection Curves

The test results are listed in Table 2 and the load-deflection curves are illustrated in Figure 5. The observed initial stiffness (0-10% F_{max}) observed for each specimen showed little variation regardless of connection type. Comparatively, variation in the load-carrying capacities was observed across all specimens, and variation in elastic stiffnesses was observed between specimen types. The average capacity of composite floors with Type B connectors was the highest (438 kN), 15% higher compared to the average capacity of floors with Type A connectors. However, the floors with Type C connectors had a similar capacity like floors with Type B connectors. The applications glue in the composite floors with Type C connectors transformed into a very stiff system. The average stiffness of floors with Type C connectors was found 23% and 16% higher compared to floors with Type A and B, respectively.

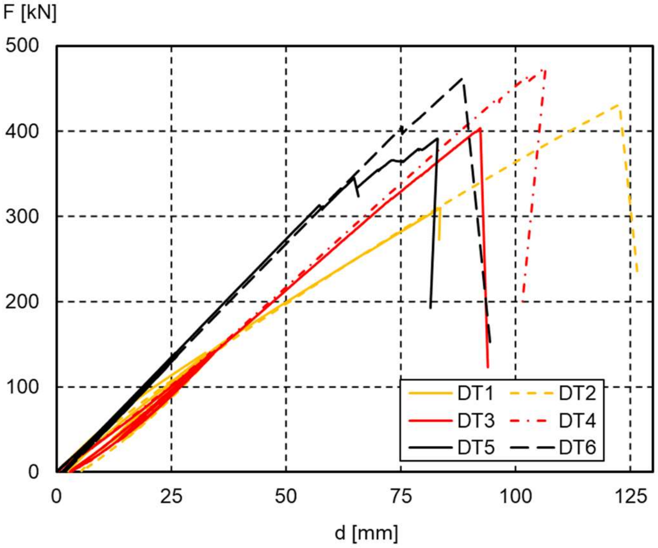

Figure 5: Load-deflection curves from full-scale bending tests at mid-span

Table 2: Test results

Test ID	Connector Type	F_{max} [kN]	$d_{m,Fmax}$ [mm]	k_{dm} [kN/mm]
DT-1	Type A	310	84	4.3
DT-2		431	123	4.3
DT-3	Type B	403	92	4.6
DT-4		473	102	4.7
DT-5	Type C	391	83	5.6
DT-6		462	95	5.5

4.2 Failure Modes

All 6 specimens failed in brittle tension failure of one of the two glulam beams at a location close to the mid-span of the specimen. A typical failure is shown in Figure 6 for a Type A specimen. The right glulam in specimen DT1 (specimen type A) initiated earlier failure than other specimens; the glulam beam on the right side of the specimen had a finger joint near mid-span which experienced a sudden tension failure, resulting in earlier failure of DT1 compared to DT2 (e.g., DT1 shows at 28% lower ultimate load compared to DT2) and all other specimens. In addition to typical tension failure of one glulam, some CLT rolling shear failure was observed at the left CLT-glulam interface in specimen DT6. No special failure mechanisms, and joint failures were observed in any of the other specimens.

Figure 6: Typical failure in Type A floor specimen

5 CONCLUSIONS

Six glulam and CLT double-T shaped full-scale timber-timber composite floors were tested for flexural performance. The composite systems were constructed using 3-ply CLT slabs with two glulam beams (double-T formation) connected by Type A-partially threaded screws installed at 90°, Type B- fully threaded screws at 45^{o}, and Type C-partially threaded screws with glue at 90°. The load-deformation behaviour observed in the full-scale testing was linear up to failure. Type B and C connectors had the strongest capacity and stiffness compared to both Type A. The deformation capacity and ductility of Type A connector were found the highest among three types. The failure mechanism in all specimens was observed brittle tension failure at mid-span initiated at one of the two glulam beams.

ACKNOWLEDGEMENTS

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