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EXPERIMENTAL INVESTIGATIONS OF REINFORCED CROSS-LAMINATED TIMBER-CONCRETE COMPOSITE SYSTEMS

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ABSTRACT: This paper presents experimental investigations on Timber concrete composite (TCC) systems as a part of the design of "The Arbour", a mass timber building for George Brown College, located in Toronto, Canada. The objective is to determine the out-of-plane shear capacity, ultimate capacity and vibration performance of TCC systems in addition to the properties of shear connectors. The TCC system is comprised of a 245mm thick, 7-ply cross-laminated timber (CLT) with 150 mm concrete topping joined with shear connectors. A total of 18-half scale and 12-full scale TCC slabs with a span of 4.6 m and 9.2 m, respectively, will be tested until failure using three-point bending. The efficiency of three types of shear connectors: self-tapping screws, steel kerf plates, and proprietary glued-in Holz-Beton-Verbund (HBV) connectors will be evaluated. Currently, there are no test results available on steel kerf plates shear connectors in CLT, therefore, small scale tests will be conducted with three different embedded depth in CLT varied from 35 to 90 mm. Six series of TCC floor systems comprised of unreinforced/raw, half-reinforced and full-reinforced CLT will be tested. To simulate an extreme loading case when the live load of a typical slab band is applied near the panel edges, one test series will be tested by applying eccentric point loading near the edge – inducing torsional behaviour. The results from this research will be utilized to make design decisions for low-cost and efficient TCC composite systems for use in tall timber buildings.

KEYWORDS: Timber floors, composite systems, cross-laminated timber, shear capacity, vibration, connections

1 INTRODUCTION

Timber concrete composite (TCC) systems are generally comprised of a timber element connected to concrete topping and can be an efficient hybrid system for timber buildings. Deflection and vibration often govern the design of wood floors, whereas reinforced concrete floors do not use the material efficiently where 60% of the gross cracked concrete section does not contribute to the total load resistance (Gutkowski et al. 2008).
Previous studies showed that TCC can overcome the weaknesses of traditional reinforced concrete or light wood frame floors with regard to strength, section depth, stiffness, and vibration performance (Yeoh et al. 2011, Gerber 2016). The availability of panel-type engineered wood products (EWPs) such as cross-laminated timber (CLT) offers designers greater versatility in terms of architectural expression and structural performance. The efficiency of TCCs depends largely on the cross-sectional properties of timber and concrete as well as the shear connections between them. Currently, connectors ranging from low-to-high stiffness are available and some examples are a) self-tapping screws, b) dowel shear key, c) proprietary HBV, d) steel kerf plate, e) transverse notch connection.

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2 PROJECT OVERVIEW

"The Arbour" building for George Brown College is a 10-storey educational building located at 185 Queens Quay East in the East Bayfront district of Toronto, ON, Canada. This building will facilitate classrooms, lecture halls, and host The Tall Wood Institute. To reflect the purpose of the building and to develop economical and environmental structural solutions, timber was chosen as the primary structural material. Each mass timber floor will be exposed from the underside and structural concrete topping will be added to achieve 9.2 m span conducive to institutional programming. These floors will be supported on glulam columns from the ground floor all the way to the upper roof.

2.1 TYPICAL FLOOR

CLT panels are used as the primary floor system. To eliminate the use of beams and create more head clearance as well as the space for mechanical and electrical components, 7-ply CLT panels span 9.2 m in north-south direction (Figure 1) and act as slab bands on which thinner 7-ply CLT panels bear in the perpendicular direction. The typical 430×1178 mm columns or "wallumns" supporting the main CLT "bands" are designed to provide additional distribution area for shear stresses, and reduce the weak-axis bending in the panels.
As shown in Figure 1, 50 mm non-structural and 150mm structural concrete topping is added on top of the infill and slab band panels, respectively. The 150mm structural topping allows for a TCC section to be formed. The engagement of the concrete topping with the timber will be facilitated by the use of shear connectors.

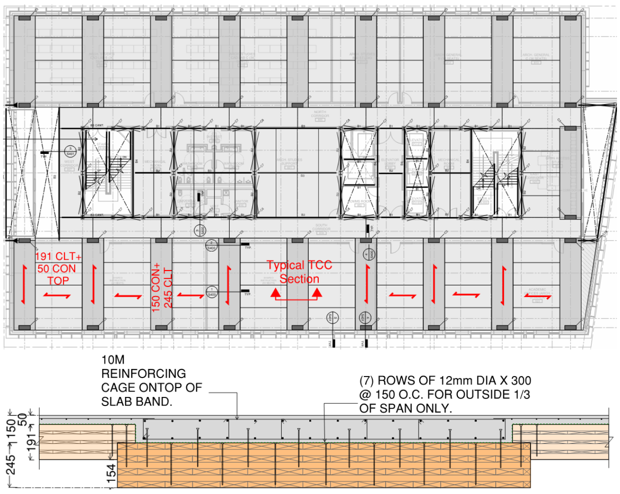

Figure 1: *Typical floor plan and cross-section of a slab band*

3 EXPERIMENTAL PROGRAM

3.1 OBJECTIVES

A test program is designed to investigate the parameters for the successful implementation of a low-cost and efficient TCC system. The goals are to investigate a) out-of-plane shear capacity between wood and concrete, b) properties of shear connectors, c) ultimate capacity of TCC floor systems, and d) vibration performance.

3.2 MATERIALS

The TCC floors in the test program are comprised of 7-ply, 245 mm CLT with 150 mm concrete topping. The CLT panels are made of 245E MSR lumber in the major axis and SPF No. 1/2 in the minor axis. The floors are supported on 430×1178 mm glulam columns. Three types of shear connectors will be used (Table 1): Type I- 10 mm diameter and 300 mm long fully threaded self-tapping screws, Type II- 90 mm deep steel kerf plates and Type III- 90 mm deep proprietary glued-in HBV. Ready-mix concrete of 35 MPa will be used for the TCC floors.

3.3 TCC FLOOR TESTS

A total of 7 series will be tested in the laboratory (Table 1). Series 1 represents the small-scale shear tests using Type II TCC connectors. 18 half-scale and 12 full-scale of three different types of TCC floors will be tested. Each series of half-scale TCC floor systems comprised of unreinforced/raw, half-reinforced and full-reinforced CLT. The results from the TCC floor systems will be compared against unreinforced, half-reinforced and full-reinforced CLT floors of control series 2. To simulate an extreme case when the live load of a typical slab band is applied near to edges, series 7 will be tested by applying eccentric point loading. Figure 2 shows test specimens with Type II TCC floors using 2100 mm long and 90 mm deep shear plates are placed at 300 mm for the outer one-third spans and at space of 1000 mm for the middle span.

Table 1: *Test Series*

Series	Description	Connector Type	Test Type	#of tests	L_o [mm]	b_c [mm]	b_t [mm]
	SC Test 1	II	Shear	6	-	300	300
1	SC Test 2	II	Shear	6	-	300	300
	SC Test 3	II	Shear	6	-	300	300
	HS, Raw CLT [control]	-	Bending	4	4170	2200	2400
2	HS, HR CLT Panels [control]	-	Bending	4	4170	2200	2400
	HS, FR CLT Panels [control]	-	Bending	4	4170	2200	2400
	HS, Raw CLT w/ Type I TCC	I	Bending	2	4170	2200	2400
3	HS, HR CLT Panels w/ Type I TCC	I	Bending	2	4170	2200	2400
	HS, FR CLT Panels w/ Type I TCC	I	Bending	2	4170	2200	2400
	HS, Raw CLT w/ Type 2 TCC	II	Bending	2	4170	2200	2400
4	HS, HR CLT Panels w/ Type II TCC	II	Bending	2	4170	2200	2400
	HS, FR CLT Panels w/ Type II TCC	II	Bending	2	4170	2200	2400
	HS, Raw CLT w/ Type III TCC	III	Bending	2	4170	2200	2400
5	HS, HR CLT Panels w/ Type III TCC	III	Bending	2	4170	2200	2400
	HS, FR CLT Panels w/ Type III TCC	III	Bending	2	4170	2200	2400
	FS, HR CLT Panels w/ Type I TCC	I	Bending	3	8770	2200	2400
6	FS, HR CLT Panels w/ Type II TCC	II	Bending	3	8770	2200	2400
	FS, HR CLT Panels w/ Type III TCC	III	Bending	3	8770	2200	2400
	FS, HR CLT Panels w/ Type I TCC	I	Torsion	1	8770	2200	2400
7	FS, HR CLT Panels w/ Type II TCC	II	Torsion	1	8770	2200	2400
	FS, HR CLT Panels w/ Type III TCC	III	Torsion	1	8770	2200	2400

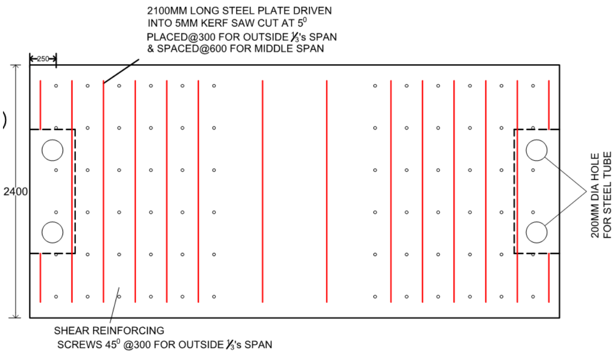

Figure 2: *Plan view of Type II TCC with half reinforced CLT*

4 CONCLUSIONS

It is important to estimate the out-of-plane shear capacity accurately for the design of a low cost and efficient TCC system, which was overlooked in previous research. This research will evaluate the performance and efficiency of various TCC systems by estimating the out-of-plane shear contribution of concrete and wood. Results obtained from this test program will be implemented to develop an efficient TCC system for timber buildings.

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