MODULAR AND OFFSITE CONSTRUCTION
MAY 21-24 2019 FAIRMONT BANFF SPRINGS HOTEL BANFF, AB, CANADA

Serviceability Performance of Timber Concrete Composite Floors

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ABSTRACT

There is much potential for engineered wood products to be used beyond low-rise residential construction when incorporating the notion of hybrid systems like timber-concrete-composites (TCC). TCC systems are comprised of a timber element connected to a concrete slab through a shear connection. By combining the complimentary properties of timber and concrete, the performance of timber floors can be enhanced, including bending stiffness, load-bearing capacity, dynamic response, airborne sound transmission, structural fire rating, and thermal mass. A large number of T-beam TCC systems existed for decades; however, the growing availability of panel-type products in North America offers designers greater versatility in terms of structural and building physics performance. While stiffness and strength design of TCC systems is straight-forward, there is little design guidance available in terms of vibration and long-term performance. The bending, vibration and long-term performance for a range of TCC systems in several EWPs were validated on small-scale shear tests, floor panels subjected to serviceability loads for 2.5 years, and subsequent full-size bending tests. The tests confirmed that calculations according to the γ-method can predict the basic stiffness and dynamic properties of TCC floors within a reasonable degree of accuracy.

KEYWORDS

Floor systems; Hybrid structures; Bending, vibration and long-term performance

INTRODUCTION

Timber-concrete composite (TCC) systems are generally comprised of a timber plate or beam plate connected to a topping of concrete. TCC offer improvements over both conventional reinforced concrete and light-frame wood flooring systems in regard to strength, section depth, stiffness, and vibration performance (Dias et al. 2016). The availability of panel-type engineered wood products (EWPs) offers designers and engineers greater versatility in terms of architectural expression and structural and building physics performance. EWPs are created by bonding graded strands, veneers or lumber into structural elements resulting in dimensionally stable products with uniform strength properties. Such products include Laminated Strand Lumber (LSL), Laminated Veneer Lumber (LVL) and Cross-Laminated Timber (CLT). The efficiency of TCCs depends largely on the properties of the shear connection between them. Connectors range from low-stiffness, where partial composite behaviour is achieved, to rigid connectors.

The serviceability limit state is often the governing design factor for TCC floors (Tannert et al. 2016). Specific complexities arise since deflections also increase over time due to thermo-hygrometric variations of the environment and concrete creep and drying shrinkage, timber creep, mechano-sorptive creep and shrinking/swelling and connector performance change over time may.

Preceding research at the University of British Columbia focused on performance of different TCC configurations in small-scale shear and full-scale bending tests (Gerber et al. 2016). Nine TCC configurations were selected and designed according to the γ-method to achieve similar composite efficiencies in the range of 90%. The results showed that calculations according to the γ-method predict capacity, stiffness and dynamic properties within a reasonable degree of accuracy

EXPERIMENTAL INVESTIGATION

Objective

The objectives of the research presented herein were to experimentally investigate the long-term and vibration performance of multiple TCC systems. For this purpose, nine full-size specimens were subjected to typical climate yearly variations for approximately 2.5 years.

Materials

Three EWP (LVL, LSL and CLT) and commercial ready-mix concrete were combined with different connectors (self-tapping screws (STS), (10mm diameter ASSY STS with Canadian approval (CCMC (2013), the proprietary glued-in steel connector Holz-Beton-Verbund (HBV) (Clouston and Schreyer 2008), and a combination of STS and adhesive bond using epoxy adhesive, see Table 1. Acoustic insulation is sometimes desired for enhanced performance of TCC floors; herein, Foamular® C-200 polystyrene rigid insulation with a compression strength of 140kPa was utilized. For the TCC systems using adhesive, Sikadur®32 Hi-Mod with a shear strength of 41MPa and a pot life of approx. 30 minutes was used. A plastic separation layer, cut from rolls of clear 6mil polyethylene sheeting, was placed between the timber and concrete elements.

Specimen description

Full-scale specimens were designed to exhibit composite efficiencies in the range of 85-95% to allow comparing the connector requirements for similar performance. Calculations based on the γ-method were performed (EN 1995 2004a). Table 1 summarizes the panel configurations, including the connector spacing. The parameters $\boldsymbol{t}_c$, $\boldsymbol{t}_t$, and $\boldsymbol{t}_i$ refer to concrete, timber and interlayer thickness respectively, while rows refers to the number of rows of fasteners across the width of the panel and $\boldsymbol{s}_1$ and $\boldsymbol{s}_2$ refer to fastener spacing in the high and low shear zones of the panel respectively, see Figure 1.

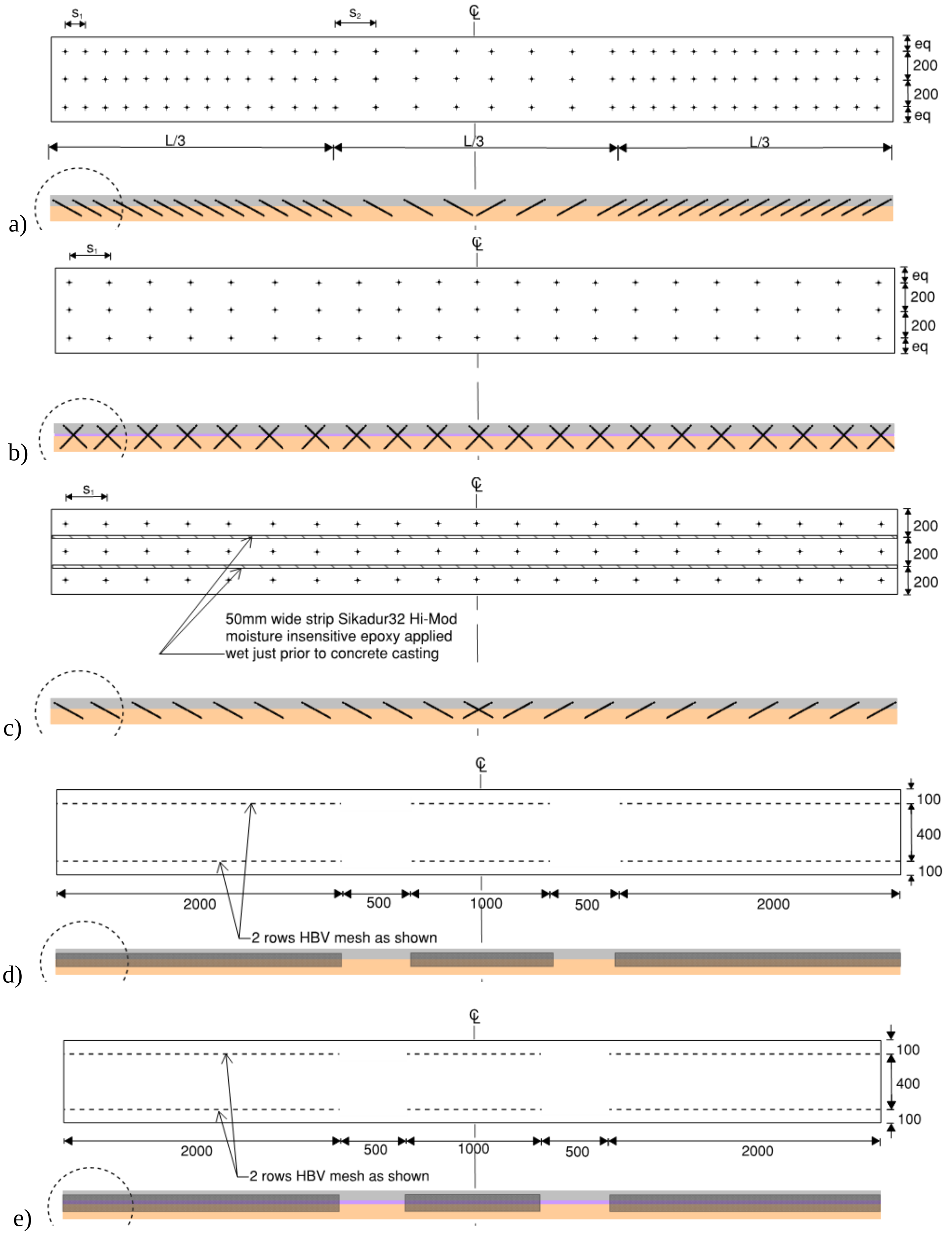


Figure 1. Panel layout (a) STS at 30◦ [S1-S3], (b) STS at 45◦ through insulation [S4], (c) STS at 30◦ plus SikaDur 32 adhesive [S5], (d) HBV mesh [S6-S8], (e) HBV mesh through insulation [S9]

Table 1. Test series and parameter overview.

Series	EWP	Description	t_i (mm)	s_1 (mm)	s_2 (mm)	rows	Figure
S1	LSL	STS 10x240 installed at 30° angle to grain (l_{eff} =140mm)	--	150	300	3	1 (a)
S3	CLT		--	150	300	3	1 (a)
S4	LSL	STS 10x240 at 45° through 25mm insulation (l_{eff}=90mm)	25	300	--	3	1 (b)
S5	LVL	STS 10x240 installed at 30° (l_{eff} =140mm) plus epoxy	--	300	--	3	1 (c)
S6	LSL	HBV mesh (90x1000), installed with 2C PU adhesive	--	--	--	2	1 (d)
S7	LVL		--	--	--	2	1 (d)
S8	CLT		--	--	--	2	1 (d)
S9	LSL	HBV mesh (120x1000), plus insulation interlayer	25	--	--	2	1 (e)

Vibration tests

The dynamic performance of each TCC floor was predicted based on methods of mechanics using the effective bending stiffness determined by the γ-method. The panels were subjected to dynamic excitation from a heel strike impact and accelerations were recorded using an accelerometer (Figure 2a) with a resolution of 50 μg and sampling rate of 2000 Hz. From these acceleration time histories, the fundamental frequency was obtained using a Fast Fourier Transform. Before signal processing, the recorded acceleration was pre-processed (removing the offset and down-sampling).

Long-term tests

Nine TCC floor segments (one replicate from Series S1, S3, S4, S6-S9 and two replicates from series S5) were exposed to serviceability loads for approximately 2.5 years. The panels were located outside in a vertical position, applying a uniform load on all nine floors by means of four pre-stressed rods, see Figure 2b. The environmental conditions, the applied load and the resulting deflections were monitored with one recording every 30 minutes. Over the course of the long-term loading, the rods were re-tightened six times, allowing for comparisons of the change of the effective bending stiffness over time. After completion of the long-term loading, the panels were subjected to vibration and quasi-static monotonic destructive bending tests.

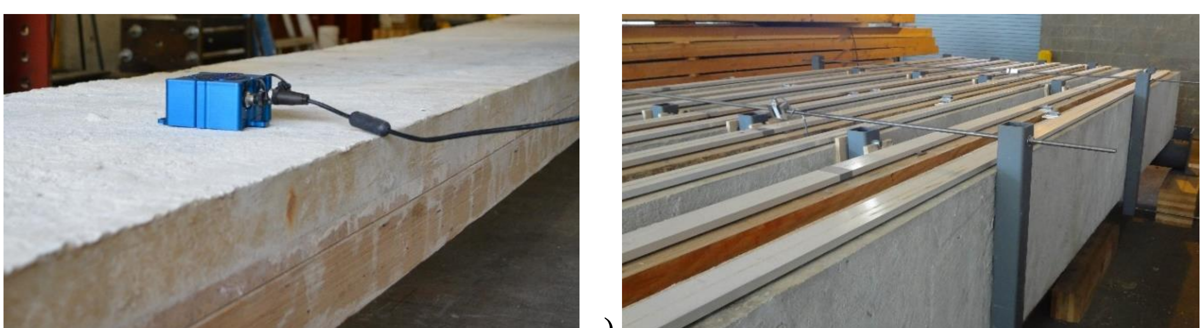
a) )

Figure 2. Vibration tests of TCC test specimens (a) and long-term loading (b)

RESULTS AND DISCUSSION

Long-term performance

The applied loads for the full period of long-term loading are shown in Figure 3, while Figure 4 illustrates the measure average deflections for the full period of long-term loading. The applied load mirrored the yearly fluctuations in ambient climate conditions with higher temperature and lower relative humidity in summer compared to winter this behaviour. While there was a significant loss in load (cause by relaxation) in winter when the EWPs absorbed moisture, there was a gain of load during the summer months when the EWPs were drying out.

The effective bending stiffness (EI_{eff}), determined during the subsequent destructive testing, was on average 16% lower than that of specimens that were not exposed to long-term testing, varying between 3% for series S5 (adhesive bond in addition to STS) and around 28% for series S3 and S8 (specimens using CLT).

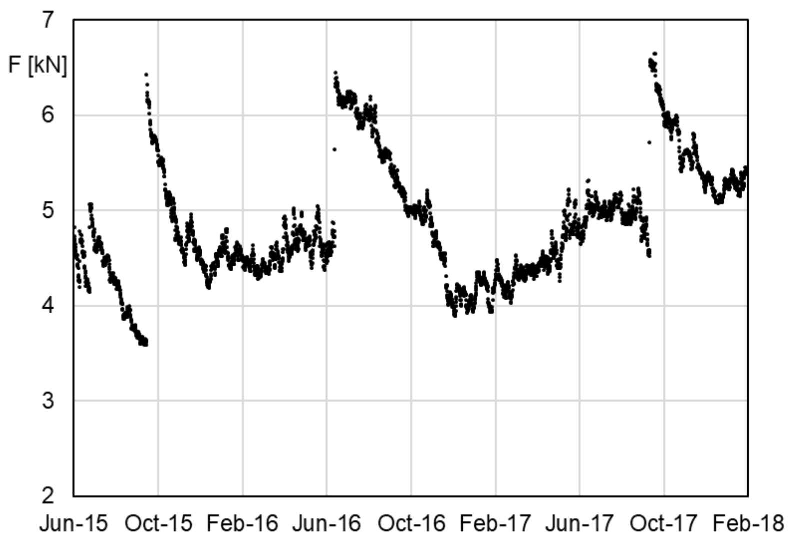


Figure 3. Applied load as average over four hours for duration of long-term loading

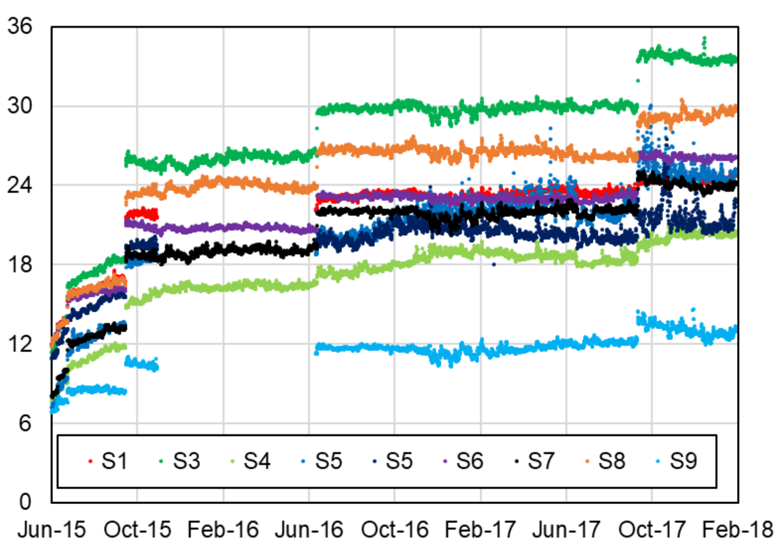


Figure 4. Panel deflections as average over four hours for duration of long-term loading

Vibration Performance

All fundamental frequencies for the TCC slabs ranged between 6 and 10 Hz, see Table 2. Floors S4 and S9 had the highest fundamental frequency, due to the presence of isolation layer which increased the moment arm and consequently EI_{eff} of the panel without changing the mass considerably. The fundamental frequency of the floors S5, S6, S7 was higher compared to floors S1 and S3, also because of higher EI_{eff}. The tested panels behaved like shallow floors with lower stiffness and fundamental frequencies compared to floors with ribs and the same mass.

The fundamental frequency of some panels is below 8 Hz. Eurocode 5 (EN 1995 2004b) refers to the need of special investigation for the vibration design of floors with the fundamental frequency below this threshold as such floors might be prone to resonance with one of the walking harmonics. Also, this is the minimum satisfactory natural frequency for lightweight floors (Weckendorf et al. 2016). One advantage of TCC floors is their higher mass compared to lightweight floors which decreases the amplitude of the response. It should be noted that damping plays an important role in the vibration performance of timber floors and that further investigations are required to find the damping ratio of TCC floor systems.

Table 2. Results summary

Series	EI_{eff} (10^{12} N*mm^2)			1st Natural Freq. (Hz)			M_{ult} (kN*m/m)		Failure
	γ-Meth.	Short	Long$^{1)}$	γ-Meth.	Short	Long	Short	Long	mode
S1	3.2	3.4 3.2	2.7	7.1	7.3 7.0	7.2	202 183	178	A
S3	2.8	2.9 3.2	2.4	7.0	6.8 7.0	7.6	118 147	129	C
S4	4.6	4.7 4.3	4.0	8.4	8.2 8.1	9.2	197 167	200	D
S5	3.9	4.2 3.9	3.8 4.0	7.9	7.7 7.9	8.5 8.8	165 140	156 157	E
S6	3.6	3.3 3.1	3.1	7.2	7.2 7.0	8.2	139 137	148	F
S7	3.9	3.9 4.2	3.5	7.9	7.9 8.1	8.4	139 141	152	F
S8	2.9	3.1 2.9	2.3	7.0	7.3 7.1	6.6	134 119	126	C
S9	5.9	5.7 6.1	5.5	9.7	8.9 9.6	9.9	143 141	145	F

CONCLUSIONS

The work presented is an extract of the analytical and experimental work performed of multi-phase program with focus on: the performance of TCC configurations in small-scale shear tests, the performance of eight selected TCC configurations in full-scale bending and vibration tests, and the performance of one specimen from each configuration subjected to long-term loading.

The full-scale test specimens were designed according to the γ-method to achieve composite efficiencies in the range of 90%. Specimens were tested for elastic stiffness under quasi-static bending and dynamic properties were obtained using an accelerometer. The results showed that calculations according to the γ-method predict the stiffness and dynamic properties of the panels within a reasonable degree of accuracy.

The analyses showed that some TCC systems exhibit a fundamental frequency below 8 Hz warranting special attention. Adding a layer of insulation increased the fundamental frequency. Assuming constant mass, the panels with higher effective bending stiffness provide higher fundamental frequency. Further investigation needs to estimate the damping ratio of such floors.

Results from the long-term tests showed an increase in deformation over time. The long-term loading, however, did not cause significant degradation, effective bending stiffness decreased by on average 16% while load-carrying capacity decreased by only 5% on average, and vibration performance remained unchanged.

ACKNOWLEDGEMENTS

The research was supported by BC FII through the Wood First Program and NSERC through the Engage program. Weyerhaeuser, Louisiana Pacific, Brisco Manufacturing; Structurlam Products, MyTiCon Timber Connectors Inc, TiComTec GmbH, Sika Canada, and Lafarge donated material. The help and support of the technicians at FPInnovations and UBC is appreciated.

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