The Real Behaviour of Timber Concrete Composite Floors

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Executive Summary

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1.0 Introduction

Timber concrete composite (TCC) floors are a low-carbon form of construction which comprises thin concrete slabs shear connected to timber joists. TCCs are half the weights of reinforced concrete floors, leading to cheaper foundations, and they surpass all-timber floors in thermal mass, stiffness (hence vibration serviceability), strength and fire resistance.

To date only a few TCC floors have been constructed worldwide, in iconic buildings such as the new (2018) Anna Freud Centre in London (UK), the Dr Chau Chak Wing Building in Australia and the free floating staircase of the UBC's Earth Sciences building in Vancouver, Canada [1]. One reason for the limited use has been the lack of guidance in official structural design codes. This situation is changing, with a new section dedicated to TCC design being incorporated into Eurocode 5 due for release in 2020 [2].

Despite these code updates, one issue which still needs addressing is the transverse distribution of live load between adjacent T-sections in a TCC floor where the slab is continuous across the timber joists. The TCCs investigated to date have often shown a failure behaviour that is dominated by brittle fracture of the timber joists. Hence the lower bound theorem of plasticity cannot as a general rule be used to enable safe design of such floors by proceeding with a simple, uncracked analysis of one T-section member based on a convenient transverse distribution of load. This means that a true representation of transverse distribution in TCCs is needed, but to date there have been few works (e.g. [3]) in this field. Moreover by necessity, this prior work has taken an initial look at the problem focusing on low load behaviour, before nonlinearities due to cracking and connector action have become prominent.

The study reported in this summary builds on that prior work by reporting on experimentally-deduced transverse distributions of external load effects in a multi-joist TCC specimen. The crux of this study has been not only the use of load cells to measure transverse distribution of reactions between the joists at each end support, but also the use of a comprehensive network of strain gauges to enable inference of the moment sharing between adjacent TCC T-sections at midspan. In what follows it is shown that, based on the test data, the midspan moment distribution does not always mimic the support reaction distribution, and that the transverse distribution factor on moments is a nonlinear function of load.

2.0 Specimen Details and Testing

The TCC specimen fabricated and tested in this study was of a 4.8 m simply supported single span, 2.1 m slab width, and comprised three hardwood laminated veneer lumber (LVL) joists fastened via bonded-in steel mesh connectors to a 70 mm thick concrete slab. An A393 steel reinforcing mesh was used as anti-crack reinforcement in the slab. LVL planks of 19 mm thickness were used as permanent formwork, because the concrete was cast in-situ. Fig. 1 shows the specimen before and after casting the concrete. Grade C32/40 ready-mix concrete was used and allowed a month to cure before the specimen was tested.

Fig. 1 – Specimen at Different Stages of Fabrication

Instrumentation comprised load cells placed under all joists at the supports, a load cell to measure the applied load, linear voltage displacement transducers (LVDTs) to record vertical deflection at the quarter- and mid- span locations of the joists, along with linear potentiometers to record slip at the ends of the joists.

In addition, and very importantly, longitudinally oriented strain gauges were placed at midspan on the top surface of the slab and at three levels through the depth of each joist. By invoking compatibility, constitutive behaviour and equilibrium requirements the data from these strain gauges were used as the basis for determining the midspan moments developed by the three adjacent TCC T-sections.

The failure test was conducted using a concentrated load at the middle in plan of the slab, directly above midspan of the central joist of the specimen. The test progressed in displacement control while data from the load cells, strain gauges, LVDTs and potentiometers were recorded continuously into a single acquisition system. In the approach to failure the rate of loading was reduced to permit visual capture of emerging failure modes. This test on the main specimen was supported by multiple longitudinal shear tests on connection specimens fabricated (including the formwork interlayer) for this purpose.

Fig. 2 shows that the specimen failed by fracture of the middle joist at midspan. Note that there was also extensive cracking of the slab, which further exhibited large deflections and consequently developed peripheral cracking associated possibly with tensile membrane action at these large deflections. The specimen carried a peak load of 200 kN.

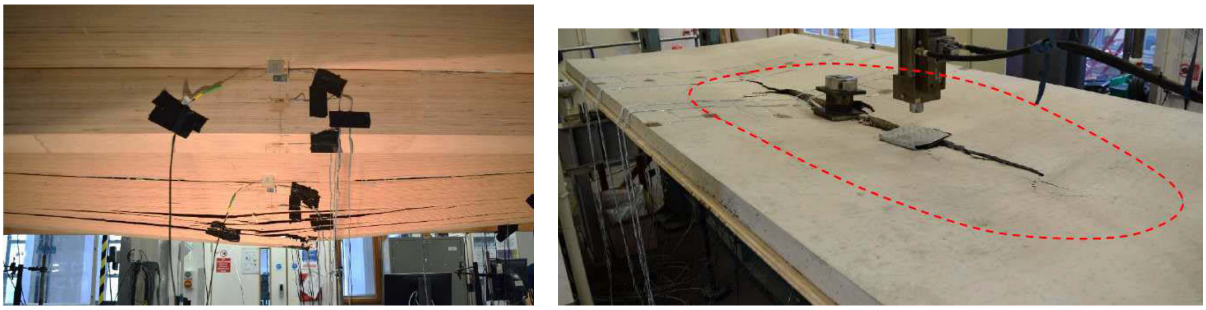

Fig. 2 – Failure Modes of Specimen

3.0 Key Conclusions on Transverse Distribution From Tests

Fig. 3 plots the midspan moment share and also the end support reaction share taken up by each of the three adjacent TCC T-sections as a function of applied load. The labelling system used is such that Rn and MnM refer to the support reaction share and midspan moment share taken up by TCC T-section number n. The TCC T-sections were transversely numbered 1, 2 and 3 from one edge T-section, across the middle T-section and to the other edge T-section respectively. Hence M2M and R2 describe the midspan moment and support reaction shares, respectively, for the middle TCC T-section.

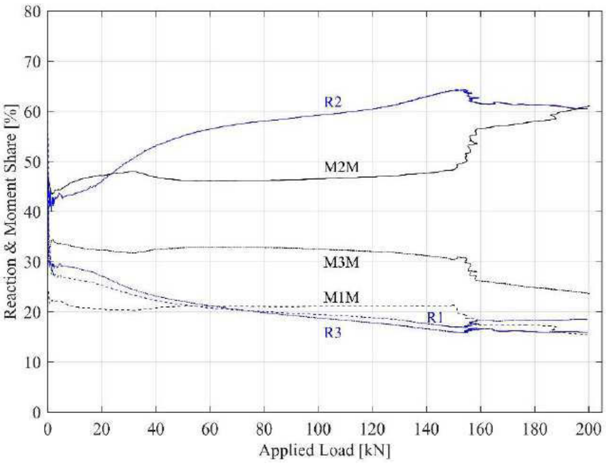

Fig. 3 – Support Reaction and Midspan Moment Sharing

Three key points which readily emerge from Fig. 3 are as follows, namely :

- For the middle T-section, which is clearly the most heavily loaded, both the support reaction and the midspan moment shares vary in a distinctly nonlinear manner with load. This nonlinearity is pronounced both at low load loads and in the approach to failure.
- Indeed it is seen that for this middle T-section the midspan moment share varied from 44% at lower loads to 60% near failure, with the corresponding figures for the support reaction having been 42% at quite low loads to 63% near failure.
- Despite the similar minimum and maximum share percentages for the reaction and moment, the R2 and M2M curves are very distinct from each other over quite wide load ranges on their respective trajectories towards failure, with the moment share lying below its reaction counterpart by up to 15%.

Since it is midspan moment which is used to perform stress design checks on the TCC member, these highlighted points clearly show that basing moment shares on support reaction shares can be quite conservative. This issue should be further investigated to ensure economic design of TCCs, thereby improving their competitiveness in the construction arena.

4.0 Acknowledgements

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5.0 References

[1] Sebastian WM, Lawrence A, Smith A. Commentary : The potential for multi-span continuous timber-concrete composite floors. ICE Journal of Structures and Buildings, 171(9), 661-2.

[2] Dias A. Timber-concrete composites : A new part in Eurocode 5. Proc. WCTE, 2016, Vienna.

[3] H. Kieslich, K. Holschemacher, Lateral load bearing behavior of timber concrete composite constructions, Adv. Mat. Res. 778 (2013) 665–672.