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Experimental and analytical study on dynamic performance of timber-concrete composite beams

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HIGHLIGHTS

- Experimental and analytical dynamic investigation of four full-scale TCC beams.
- Performed impact hammer tests on the TCC beams with three different connections.
- The fundamental frequency of all tested beams was above 8 Hz, which is acceptable.
- Analytical models predicted frequency of all beams within acceptable range of ±8%.
- Beam-3 with six bird-mouth notches showed best dynamic performance.

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ABSTRACT

Timber-concrete composite (TCC) construction provides an effective and efficient solution for long-span floors in multi-storey buildings. Because of the light-weight and long-span of the floors, the design of these floors are normally governed by serviceability criteria such as deflection, vibration, acoustic, etc and design for strength limits are generally not an issue. Floor vibration caused by dynamic actions such as people walking on the floor, machinery or any similar repetitive actions may not only cause discomfort to occupants but may also result in structural failure as a result of resonance. However, limited design guidance is available in the design codes to address the vibration behaviour of TCC floors owing to a lack of reliable performance data and as such, there is a need to undertake further research into the behaviour of TCC floors. This paper reports on the tests performed on four identical TCC beams, which represent part of a floor system, with different shear connector arrangements, to assess their dynamic performance under the application of impact action using modal parameters (natural frequencies, damping ratios and mode shapes). Five analytical models are used to predict natural frequency of the beams and their reliability is checked.

1. Introduction

The design of long-span and light-weight floor construction is often governed by serviceability rather than strength requirements and dynamic performance is one of these requirements. Therefore, there is a growing need for measurement of dynamic characteristics such as natural frequencies, damping ratios and mode shapes of floor systems to investigate their behaviour. The serviceability design of a flooring system requires an assessment of the fundamental frequency (or first natural frequency) in order to check the vibration behaviour of the floor and occupant comfort. The following frequency ranges are normally avoided for the following vibration modes:

- Frequency below about 3 Hz to prevent walking resonance [1].
- Frequency range of 5–8 Hz to prevent human discomfort [1].

For residential/office floors, a natural frequency greater than 10 Hz shall be targeted [1]. A special investigation is needed if the predicted fundamental frequency of the floors is less than 8 Hz. Hence the prediction of natural frequency, especially fundamental frequency, becomes important for the dynamic assessment of floor systems.

Timber is the only truly renewable and environmentally friendly natural building material. Additionally, high strength to weight ratio, ease of workmanship and handling, good fire resistance are some of the properties that make timber attractive

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for use in construction. However, due to the light-weight nature of timber, timber floors tend to have poor vibration and low impact sound insulation characteristics.

Timber-concrete composites, referred to as TCC from here onwards, is a structural system where timber joists and a concrete slab are combined to act compositely such that the timber joist resists the tensile stresses while the concrete slab mainly resists the compressive stresses. The shear connection between timber and concrete can be achieved through various means such as concrete notches, dowel type shear connectors, nail plates and glued joints. TCC floors have better sound insulation, vibration and thermal insulation properties compared to timber only floors and have a higher strength to weight ratio compared to concrete floors.

Although TCC floor construction techniques were originally used to refurbish/renovate old timber structures after World War II due to lack of steel, its use in new construction has gained popularity in the last 20–30 years due to the several benefits it has over timber only and concrete only floors. The first attempts, to combine the wood and concrete, were done in the 1920s and 1930s. Otto Schaub was the first inventor in Germany to apply for a patent that consisted of a TCC element in 1939. Hotel "Zum guten Hirten" was the first project to use TCC systems in 1960, where concrete was cast on top of the existing timber floor to enhance its performance [2]. The technology has become more acceptable with more successful applications since the 1980s [3]. The first design models were introduced based on research tests in 1984. The outcomes of the tests showed that the composite action increases the overall capacity of wood concrete composite floors over timber floors by a factor of 2.5 [2].

Ghafar et al. [4] conducted a series of dynamic tests to investigate dynamic performance of the LVL-concrete composite beams using their natural frequencies and modal properties and found that the beam span is the most significant parameter affecting the natural frequencies and the portion of critical damping. Ghafar et al. [5] investigated the dynamic performance of timber-concrete composite (TCC) flooring systems both experimentally and using finite element models. The investigation was conducted based on the natural period, mode shapes and effective damping of the flooring systems. Fragiacomo and Lukaszewska [6] assessed vibration performance of the TCC flooring systems, where the concrete slab was prefabricated off-site with connectors and connected to the timber joists on site, using the natural frequencies and damping ratios of the flooring systems.

This paper presents the results from dynamic experimental investigations on four TCC beams with identical geometry and with different connection systems. The beam represents part of a flooring system. An instrumented modal hammer was used to excite the beams and free vibration response was recorded. Five existing analytical prediction models were used to predict the fundamental frequency of the beams which are then correlated with experimental results.

2. Experimental investigation

Tests were conducted on four identical TCC beams, Beams-1–4, with three different shear connections. The type of shear connection system used in the Beams-1 and 2 were SFS screw (Type VB-4.8–7.5 × 165) and normal screw (Type 17 with gauge 14), respectively. Beams-3 and 4 had six and four bird-mouth notches, respectively, and each notch had coach screw. The beams were tested with pin supports at one end while the other end was roller supported. Free vibration was initiated using a modal hammer. Impacts were applied at mid and 1/3rd span of the beams to excite at least their first three flexural modes.

2.1. Geometry of the beams

The overall length of the beams was 6 m while the clear span between the supports was 5.8 m. The timber joists constructed using laminated veneer lumber (LVL), were 250 mm deep and had a thickness of 48 mm, while the concrete slab,

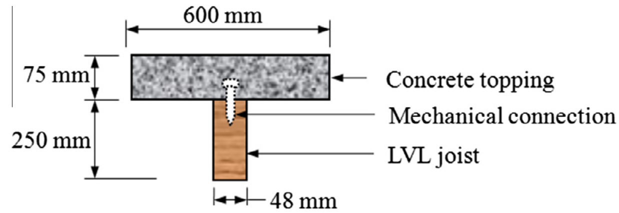

Fig. 1. Geometry of TCC beams.

which was cast on the top of LVL joist, had a depth of 75 mm and a width of 600 mm (see Fig. 1). The types of shear connectors used are discussed in Section 2.2.

2.2. Shear connectors

Three different types of shear connectors were used in the four beams, namely, SFS screws, normal screws and bird-mouth notches combined with coach screws. These types of mechanical connectors used for the shear connection systems are shown in Fig. 2. The details of the screws and their arrangement on each beam before pouring concrete are depicted in Figs. 3–5.

In Beam-1, SFS screws (Type VB-4.8–7.5 × 165), which were 220 mm long and 6 mm in diameter, as shown in Fig. 3(a), were used as shear connectors. Two screws were inserted at each location on the LVL joist inclined at 45° as shown in Fig. 3(b) with an embedment length in the LVL joist of 140 mm. The spacing between the screws was 300 mm for one-third of the beam span from each support owing to higher shear forces, while spacing at middle third span was 600 mm as shown in Fig. 3(d).

In Beam-2, the normal wood screws (100 mm long, 5 mm diameter and Type 17 gauge 14), were inserted vertically into the LVL joist at an equal spacing of 500 mm, as shown in Fig. 4, to form the shear connector. The embedment length of each screw in the LVL joist was 65 mm.

Bird-mouth (or triangular) notch connectors, each with a 16 mm diameter coach screw were used as shear connectors in Beams-3 and 4 (see Fig. 5). Beam-3 had six notches spaced at 500 mm and Beam-4 had four notches spaced at 600 mm apart as shown in Fig. 5(d) and (e), respectively.

2.3. Fabrication of beams

Each specimen had three components – an LVL joist, the concrete slab and shear connectors. The concrete used for the slab had a characteristic strength of 32 MPa. A standard reinforcement mesh with 7 mm diameter bars at 200 mm spacing in both directions was used in the concrete slab to constrain shrinkage cracks.

2.4. Material properties

2.4.1. LVL

The characteristic properties of the LVL joists as provided by the manufacturer are summarised in Table 1. Four point bending test was carried out on individual

Fig. 2. Detail of the mechanical connectors.