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Review

Time-dependent behaviour of timber–concrete composite members: Numerical verification, sensitivity and influence of material properties

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HIGHLIGHTS

- Long-term analysis of timber–concrete composite structures.
- Influence of material properties on structural response of TCC beams.
- Conducting comprehensive sensitivity analyses for time-dependent behaviour.
- Suggesting long-term input parameters for laminated veneer lumber (LVL).
- The FE model is accurate and efficient enough for design oriented parametric studies.

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ABSTRACT

This paper presents a study that models timber and concrete material properties in order to understand their influence on the structural response of timber–concrete composite (TCC) beams under long-term loads. First, the accuracy of a 1D composite frame (finite element) FE model developed by the authors is verified against available short- and long-term experimental data, which included characterising the material properties. Using the developed formulation and analytical tools, comprehensive sensitivity analyses and parametric studies are conducted to gain better understanding about time and moisture dependant factors that affect long-term behaviour of timber and timber–concrete composite beams. With regard to the results of parametric studies, the required input parameters (not available yet) for long-term analysis of laminated veneer lumber (LVL) are suggested. It is shown that the proposed simple strategy can adequately and efficiently capture the short- and long-term material behaviour of timber, TCC and timber–timber composite (TTC) structures and can be employed for design oriented parametric studies.

Contents

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1. Introduction

Over the last decade, application of timber–concrete composite (TCC) structures has been increasing in the construction industry and many researches have been devoted to understanding the local [1–5] and global [6–10] behaviours of timber and TCC members under short- [11–15] and long-term [16–18] loads. Having a composite T-section with concrete flange and timber web combines the best properties of both materials to be exploited and consequently will be a good motivation for using them. Also, timber is a renewable material and its application in conjunction with other construction materials such as concrete is a viable option for developing efficient structural systems [19] with lower carbon footprint compared with steel and reinforced concrete construction. Amongst different structural characteristics of TCC beams, the time dependant behaviour of the beams under serviceability limit state loading scenarios are the most important design parameters for medium to long span TCC beams subjected to heavy environmental conditions (large variations of ambient relative humidity and temperature) [18,20,21]. Hence investigating the behaviour of such structures under long-term loading is vital and of importance to structural engineers.

All the materials in the TCC beams, i.e. concrete, timber and connection system, display significant time-dependent phenomena [19–21] which causes strain and stress redistribution. When the stresses are less than 35% of the short-term strength, timber can be regarded as a linear-viscoelastic material [22] provided the environment condition is stable, whereas in a variable environment, the viscoelastic behaviour of timber becomes non-linear [23,24]. The time-dependant material behaviour of TCC components is not only affected by the long-term load but also driven by environmental variations (i.e. thermal and relative humidity changes) [20,25] and should be accounted for in long-term design of composite beams, especially when a more accurate estimation of deflection is needed.

Relative humidity changes cause moisture content changes which can affect timber behaviour and subsequently lead to large deformations in timber elements. Creep strains under changing moisture conditions are larger than creep strain under constant wet conditions, which are also larger than creep under constant dry conditions [23,24]. Accordingly, the long-term behaviour of timber is a complex function of both the ambient conditions and the inherent properties of the structure such as wood species, dimensions and coating. Different rheological models have been developed for normal timber such as spruce in the literature [23,24,26,27] to capture the time dependent response; however, to the best of authors' knowledge the long-term input parameters for other types of engineering wood produces like laminated veneer lumber (LVL) is not available in the literature.

In this study, a non-linear flexibility-based frame FE model developed by the authors [28,29] is employed for short- and long-term analysis of TCC floors as well as conducting parametric studies. First the short-term response of TCC beams with different geometries, material properties and types of connections is verified against the test results available in the literature. Then the developed numerical model is used for long-term analysis of three different sets of experimental programs which in one of them timber joists were made of LVL. Different FE models are developed to investigate the long-term response of the beams and a sensitivity analysis is conducted to calibrate the long-term input parameters of LVL. It is shown that the formulation offers superior efficiency compared with continuum-based FE models and accordingly, the developed FE model can be efficiently used for undertaking design oriented parametric studies on timber, TCC and TTC structures.

2. Frame FE model

A 1D frame FE model is employed for further comparative studies and sensitivity analyses. In this model, the reinforced concrete slab and timber joist are coupled together by non-linear lumped connections at both ends to capture the partial interaction between the layers (see Fig. 1).

The 1D frame element is formulated in the framework of total secant approach. The cross sections of concrete and timber are sub-divided into fibres to monitor the behaviour of material points over the section depth and width (see Fig. 1). The maximum size of fibres is limited to 20 mm in this study. The details of the formulation as well as validation of the model can be found in Khorsandnia et al. [28] and Khorsandnia [29].

3. Short-term analysis

The developed 1D frame FE model and analytical tool have been already verified against some experimental data [28]; however, before conducting any parametric studies, further verifications for various types of TCC beams are required to ensure that the proposed formulation can adequately predict the load–deflection and ultimate loading capacity of the TCC beams. Therefore, twelve TCC beams from two different experimental programs undertaken by Yeoh et al. [8] and Clouston et al. [11] are chosen from the literature to validate the accuracy of the 1D frame FE predictions. The TCC beams tested by Yeoh et al. have T-shape cross-section,

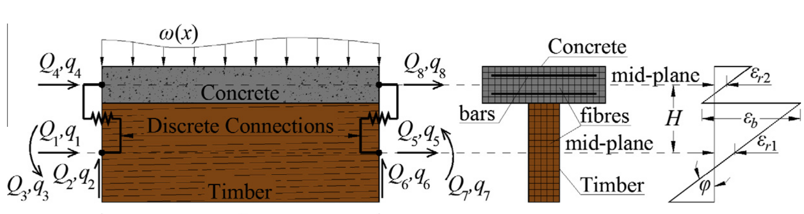

Fig. 1. 1D frame FE model developed by Khorsandnia et al. [28] (q and Q are generalised nodal displacements and forces, respectively; ε_r, φ and ε_b are axial strain at the mid-plane, total curvature and slip strain of the section, respectively).