Engineering Structures 175 (2018) 231–244

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Forward and Reverse shear transfer in beech LVL-concrete composites with singly inclined coach screw connectors

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ARTICLE INFO

Keywords:
Timber-concrete composites
Connections
LVL
Testing
Slip modulus
Ductility

ABSTRACT

Double-shear tests are reported on beech LVL-concrete composite connections based on coach screw connectors singly inclined at either 45° or 90°. On different specimens with the same screw orientation the longitudinal shear force was applied either in forward or reverse, because in practice concrete shrinkage, moisture-induced timber expansion and oscillatory (e.g. seismic) or moving loads can induce reversal of the force on the connection. The test data show that relative to the 90° screw connections, sloping the screws to 45° in tension only marginally affected longitudinal shear strength but led to a fivefold increase of slip modulus and to a significant drop in ductility, while sloping the screws the other way to 45° in compression only marginally affected slip modulus but led to an almost fourfold drop in longitudinal shear strength and to a substantial increase in ductility. The specimens tested within each group showed good consistency of shear strength and (except the 45° tension screw specimens, despite their consistent strengths) of failure mode, but high variability of slip modulus. Comparisons with previously tested timber-concrete composite (TCC) connections based on other screw types and layouts suggest good performance of the present connections. The gamma method applied to a given TCC T-section under load shows that the present alternate connections lead to quite different depths of uncracked concrete and so to significant variation of midspan deflection. In closing, it is recommended that both forward and reverse shear testing becomes a protocol for singly inclined coach screw-based TCC connections.

1. Introduction

1.1. Literature review

The slip modulus, longitudinal shear strength and ductility of timber-concrete connections often strongly influence the deflections, vibration characteristics, load capacity and stress redistribution capabilities of timber-concrete composite (TCC) floors, an example of which is shown in Fig. 1. It is thus important to quantify these connection properties. To that end multiple studies [1–5] show that, by comparison with test data, existing standards predict these properties to quite variable degrees of accuracy. Thus, into the foreseeable future, testing will be the primary means of characterising connection behaviour.

TCC connections based on mechanical connectors have been extensively characterised in experimental studies to date. These include nails or nail-plates [1,5–7], vertical or inclined screws [6,8–12], dowels [4,13,14], perforated steel plates or steel meshes bonded into the timber [3,15–17], and notches [3,6,18–22]. The tests have considered both normal and lightweight concretes, short-term and long-term behaviours, and the presence or absence of a formwork interlayer. In one study [21], rectangular notched connections reinforced with coach screws were found to outperform toothed metal plate connections under fatigue loading for application to road bridges. Other forms of mechanical connector include a "flowering" steel cylinder installed using a cartridge-operated gun [23], others which performed as well with prefabricated slabs as with cast in-situ slabs [24], and a hybrid cylindrical connector comprising an ultra-high performance fibre reinforced concrete (UHPFRC) annulus surrounding a solid circular steel core [25].

Adhesive (hence chemical) connections have also been investigated [26–30] as a means to avoid drilling into the timber, and to improve TCC connection (and so member) stiffness by reducing interface slip. Both dry slab-on-wet adhesive and wet concrete-on-wet adhesive options have been studied. Key fabrication variables (e.g. the pouring height for the concrete in the wet-on-wet option), connection performance under combined hygrothermal and mechanical loads, and long-term behaviour (up to 4.5 years) have all been experimentally verified in these studies.

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https://doi.org/10.1016/j.engstruct.2018.06.070
Received 20 January 2018; Received in revised form 2 May 2018; Accepted 19 June 2018
Available online 20 August 2018

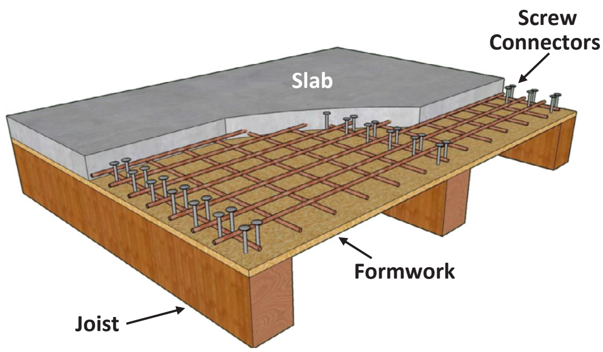

Fig. 1. Timber-concrete composite floor.

A review [31] of relevant experimental research concluded that adhesive connections and connections comprising long notches with dowels are of superior slip stiffness and strength but are also brittle, while metal plate connectors and connections comprising short notches with dowels give excellent stiffness, excellent strength and moderate ductility. Finally, the review highlighted that dowel type connectors can combine good stiffness and strength with excellent ductility.

Each of the key structural properties of TCC connections has come under scrutiny in targeted studies. For example, longitudinal shear strength was found [14] to be palpably higher for the concrete-timber-concrete double shear test configuration than for the timber-concrete-timber alternative. Moreover, high ductility of the connections was shown [32,33] to lead to user-friendly analysis approaches for TCC members at ultimate, and also in one case [34] to enable up to 87% and 144% increases in ultimate load and midspan deflection, respectively. Finally, the slip modulus deduced from testing of TCC connections was found [35] to need a 60% reduction in cracked concrete zones of a FE model, to enable reliable prediction of deflection for the associated TCC member.

1.2. Aims and objectives of the present study

The aim of the study reported in this paper was to characterise the quasi-static behaviours of TCC connections based on beech LVL, a recent advance in engineered timber. The objectives were to:

- Understand the fabrication issues arising from driving large diameter coach screw connectors parallel to each other into beech (a hardwood) LVL, so that all screws are at a single inclination.
- Experimentally determine, separately under forward and reverse longitudinal shear, the constitutive behaviours of the TCC connections based on these singly inclined coach screws.

This study builds significantly on the above discussed and other experimental investigations into TCC connections, for the following key reasons, namely:

- Hardwood LVL is a recent innovation which represents engineered timber with the best possible structural timber properties, best consistency of those properties and highest efficiency (double that of glulam) of use of original wood. Indeed in all three senses LVL is superior to glulam, owing to the circumferential peeling of the very thin LVL layers off the original log, giving little waste and minimising the influence of defects on overall section properties, as opposed to the longitudinal machining of the same log to give the much thicker, more defect-sensitive layers and more waste for glulam. Given this recency of hardwood LVL, it is not surprising that only very few studies, including two [36,37] on beech LVL-concrete composite slabs and one [38] on beech LVL-concrete composite beams, have been reported using this advance in engineered timber. Hence the study presented in this paper advances previous work because that earlier work by necessity could only employ hardwood or softwood original logs or glulam, or softwood LVL, but not hardwood LVL. Given the high and consistent strength of beech LVL, the use of large section coach screws is highly advisable, in order to draw out as much capacity as possible from this connection.
- Coach screws are installation-friendly fasteners which lead to connections with good structural properties. Now if the dominant design load for any given TCC floor is a UDL, it is prudent to use these screws in a singly inclined layout symmetrically about midspan, with the screw-heads pointing towards the supports, because that layout endows the resulting connections with high slip stiffness and strength. It must then be recognised that in service, the connections may well experience longitudinal shear reversal due to shrinkage of the concrete (if it is cast wet around the connectors), also due to moisture-induced expansion of the timber, possibly due to oscillatory seismic loading or to lorries moving along a TCC bridge deck, etc. Given the asymmetry of this connection about the vertical, such reversal induces a different constitutive behaviour of the connection. For that reason, it is strongly advisable to test singly inclined screw TCC connections alternately under longitudinal shear in opposite directions. This has influenced the testing regime adopted in the present study.

In what follows the hardwood LVL-concrete connection specimens and the reverse shear tests to which they were subjected are described, the resulting constitutive behaviours are quantified using the recorded test data, and the connections are compared. The paper then closes with some suggestions for further work.

2. Test specimens

2.1. Local details

Twelve double-shear beech LVL-concrete connection specimens, each with a central LVL stub flanked by concrete slabs, were fabricated and tested in this study. All connection specimens included the following features, namely:

- 400 mm deep × 200 mm wide sections of GL70 Baubuche beech LVL joists.
- M12 coach screws of 180 mm length.
- Concrete of a specified C32/40 nominal grade although, as seen later, the actual concrete was stronger.

Within the twelve specimens three screw inclination angles to the slab-joist interface were employed, namely 90°, 45° with the screws in tension and 45° with the screws in compression. For each inclination angle, four specimens were used to check the extent of repeatability of results. Henceforth, the specimens are identified according to inclination angle and to the nature of the axial force (Tension, Compression) in the screw as set out in Table 1.

Figs. 2–4 show details of the C90, C45T and C45C specimens. Some points to note are:

- In all specimens, four screws were driven into the LVL stub at 120 mm spacing along a single line on each side, and in a plane

Table 1
Nomenclature used for connection specimens.

Connection name	Description
C90	Screws at 90° inclination angle
C45C	Screws which develop compression at 45° inclination
C45T	Screws which develop tension at 45° inclination