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Transverse distribution of internal forces in timber–concrete floors under external point and line loads

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HIGHLIGHTS

- Transversal distribution of concentrated loads in timber–concrete slabs was studied.
- Experimental tests in five composite floor specimens were performed.
- Effects of different parameters in the load distribution were investigated.
- Experimental results were compared with a developed numerical model.
- Distribution of load showed to be significantly affected by the span.

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ABSTRACT

Some aspects of the structural behaviour timber–concrete floors are still not fully known. This is the case of transverse load distribution for point and line loads. This article presents a study on timber–concrete floors subjected to point and line loads.

A set of composite floors, each comprising five beams, was tested in order to evaluate how some parameters might affect the load distribution. These results were compared to those obtained with a numerical model developed by the authors.

Typically, the beam underneath the load takes the highest percentage of the applied load and the distribution for the remaining beams is significantly affected by the span. For composite slabs with medium spans (L = 4.00 m), when the load is applied at the central beam midspan only 37% of the load is received by this beam, with 69% of the load being carried by the composite T-beams adjacent to the middle one and the remaining share (about −6%) resulting from the relieving in the load received by the outer beams.

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1. Introduction

The use of timber–concrete composite structures is relatively new. Some factors make them very attractive: the performance of these composite structures when compared with structures composed solely of one of its component materials, the overall economy relative to concrete structures and the ecological aspect. This timber–concrete option needs to be supported by a good knowledge on its mechanical behaviour, which pushes forward the research on these structures.

In the last four decades, several studies were performed in order to better understand the behaviour of such structures, to develop technical solutions or to make them adequate for their construction purposes [23,25,26,30,34,37,40,41,43]. The aims of these studies are very wide, comprising experimental and theoretical based analyses of several kinds [7,22,27,29,39,42]. Among them, there are several research targets focusing not only in the overall behaviour of the composite element, but also in specific areas as: connections, long-term behaviour, second order effects, geometry, loading type among others [5,6,8,11,19–21,24,31,33,38]. The distribution of load in the transverse direction, though is a little-studied but important research subject, justifying the need to investigate it.

Timber–concrete floors are more and more used as construction solutions, either in new buildings or in the rehabilitation of existing ones. Composed by a thin concrete slab adequately connected to a set of timber beams, using sometimes a timber floorboard interlayer, these systems have proven their suitability. Compared with solutions made solely by timber, these composite floors provide less vibrations and lower noise transmission, lower deformations and higher load carrying capacity. Relatively to concrete floors, the composite solution is more aesthetically pleasing and lighter, which results in savings in the overall construction [1,8].

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Considering the action of a point or line load, the addition of a concrete layer to the timber floor and/or beams enhances the overall capacity of the whole structure to distribute load. By taking advantage of the neighbouring beams capacity to receive part of the load, even for relatively thin layers [10,12], the composite system may allow using beams with a smaller section. This results in an improved design solution, avoiding the sections oversizing as consequence of assuming the loaded beam as the receiver of 100% of the applied load, and therefore using less resources.

Despite the importance in considering the capability of transverse transmission of loads, technical information is scarce either in research articles or in structural codes of practice or standards. This becomes even more noticeable, when the structure is subjected to specific load conditions, as point loads, due to heavy equipment, for instance, or line loads parallel to the timber beams, as a consequence of the dead-weight of a wall.

Most of the researches on timber–concrete floors behaviour consider only the longitudinal direction, reducing the analysis to a "T" shaped beam, neglecting the contribution of the rest of the structure. This simplification, associated with the consideration that the load is applied to the whole width may induce some errors [28].

Nevertheless, the European code for timber structures, Eurocode 5 [17,18], recommends the use of a factor that should affect the strength properties of the timber member when they are part of a system capable of distribute loads. The "system strength factor" (k_{sys}) is proposed associated with the Ultimate Limit States considerations and allows increasing the strength properties of the timber members when they were similar to each other, equally spaced and laterally connected by a continuous system, guaranteeing the load distribution.

For composite structures, such as the steel–concrete ones, the available information is scarce [3], but for timber–concrete structures the available information is even less. It is, therefore a matter of interest to better understand and characterise the distribution of the concerned loads in such structures. This is the purpose of a broader research performed by the authors, in which the current article is enclosed.

This paper is a development of the findings published at [32], where four theoretical models were used to observe the behaviour of timber–concrete composite floors subjected to point and line loads. It describes the study performed in five real-scale timber–concrete floor specimens and its essential findings. Aiming at studying the load distribution in the transverse direction, the specimens were defined with different characteristics. Based on a previous parametric study, several parameters were chosen to be studied. The aim was to analyse the effects that they may have in the transverse load distribution in each specimen.

The specimens were experimentally subjected to point and line loads, applied in different locations from time to time. A validated Finite Elements (FE) model was used to predict the specimens' behaviour, as well as to compare its results with the experimental ones. Its main purpose was to develop a design tool able to predict the behaviour of the composite slab-type structures in question, when subjected to point and line loads. This model was developed by the authors using a commercial program and validated through numerical and experimental results [32]. The obtained results are presented and discussed, and the conclusions are drawn.

2. Specimens

As mentioned before, the main goal of this experimental study was to understand the transverse load distribution in timber–concrete composite slabs under point and line loads. To do so, it was essential to define a test that would characterise the target composite slabs, guaranteeing at the same time that it would be able to capture the phenomenon in study for different load cases. Based on a preliminary numerical analysis, the parameters with major effects in the composite floors behaviour when subjected to the action of the loading cases under consideration were identified. This analysis included material properties, geometry, support conditions, and loading conditions. By the analysis of its effects on vertical displacements and bending moments at midspan of the beams, and also on the beam support reactions, a set of parameters was established. The parameters comprised the concrete strength, the thickness of the concrete layer (t_c) and the beam span (L). This led to a set of five real-scale specimens to be subjected to point loads, at mid and quarter span, and to line loads over each beam longitudinal axis.

The tests were performed in the structural lab of the Department of Civil Engineering of the University of Coimbra.

2.1. Properties and geometry

The five specimens were numbered and the designation adopted based on it, namely S1–S5. The first specimen, S1, was considered the *Base specimen*. It was defined and designed considering usual dimensions and materials commonly applied in such composite slabs. Table 1 summarizes the characteristics of each specimen and the parameter that is different relative to the *Base specimen*, in bold.

The parameters (namely slab width, beam spacing, timber strength and section) which were found to have minor influences on load distribution were kept constant across all specimens. All the floor specimens were composed of a concrete layer, with different thicknesses and properties, and five glulam beams. The width was fixed at 3.00 m and the beam spacing at 0.60 m. Parameters such as the beam section, connector type or timber interlayer were also intended to be fixed, however there were some cases where it was not possible to guarantee this, consequence of the structural design requirements or for practical feasibility reasons.

The specimens were structurally designed according to EC5 [17], for the loads required by EC1 [15] for building floors. They were simply supported at two opposite ends with a *base span*[1] of 4.00 m (Fig. 1). The *base thickness* of the concrete layer was 0.05 m and was composed of normal strength concrete. For all the specimens but S2, a C25/30 ready-mix concrete was used, according to EC2 [16]. For S2 floor a cork light-weight concrete (LWAC) was used, and since its supply was unable to perform, the mixture was prepared at the laboratory. This kind of concrete was already studied [11], and proved to be a good solution for timber–concrete composite slabs. Associated with an extra ecological component, the use of cork waste material diminishes the self-weight of the slab and improves the thermal insulation relative to a standard timber–concrete solution.

The five specimens were cast, assembled and tested. In order to optimise the ready-mix concrete supply, specimens S1 and S5 were cast separately while S3 and S4 were cast together. Table 2 summarizes the properties of the concrete used in each specimen.

The mean compressive strength was obtained based in the compression tests performed to the cubic specimens, 0.15 m side, according to NP-EN12390 [36]. The mean modulus of elasticity (MOE) was obtained through static tests performed in the prismatic concrete specimens (0.15 × 0.15 × 0.60 m), according to E397 [13]. This specification implies the assumption of a compressive strength for the concrete. The values used correspond to those found for the cube specimens. After the prismatic specimens have been tested to

[1] The span of the *Base specimen* was termed as *base span*. A similar designation is adopted for the characteristics of this specific specimen.

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