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Bending tests on timber-concrete composite members made of beech laminated veneer lumber with notched connection

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ABSTRACT

This paper describes experimental investigations on timber-concrete composite members made of beech laminated veneer lumber (LVL) with notched connection. Timber-concrete composite slabs represent interesting building solutions, and can substitute conventional reinforced concrete slabs and timber slabs. LVL based materials have controllable and homogeneous properties, and allow to exploit the potential of some hardwood species (e.g. beech). The purpose of this experimental work was to validate an analytical model for ductile design of the composite member based on the fact that a plastic compressive failure of LVL within the notches shall be the governing failure mode. The test setup simulated a uniformly distributed vertical load, the specimens were made of beech LVL panels, and the most significant parameters varied in the experiments were the presence and the amount of vertical reinforcement. The test results allowed to validate the design model and showed that the structural behavior of the composite member can be governed by a plastic compressive failure of LVL, and that vertical reinforcement is indispensable to allow development of plasticity. Thanks to the elevated mechanical properties of beech wood, the specimens tested exhibited high strength and stiffness.

1. Introduction

This paper describes a series of full-scale bending tests on timber-concrete composite members made of European beech (Fagus sylvatica) laminated veneer lumber (LVL) with notched connections. This experimental series was conducted in the framework of a research project of ETH Zurich on innovative applications of beech LVL in structural engineering. The idea of this project was to use beech LVL panels as formwork and tensile reinforcement of timber-concrete composite slabs [1]. Although beech LVL is a performing material with consistent mechanical properties, its use in structural engineering began only in recent times. Nowadays, in Europe, beech wood is available in large quantities, but typically used for non-structural applications (e.g. furniture) [2]. Beech LVL is an efficient structural material because it combines the high strength and stiffness of beech wood with the controllable and homogeneous properties of the LVL configuration [3].

Beech LVL panels are innovative and performing structural elements, but have never been used in timber-concrete composites, and no research exists about this topic. Timber-concrete composite members usually consist of a timber member in the tensile zone, a concrete layer in the compression zone, and a connection between the timber and concrete [4–6]. Nowadays, these composite structures are usually made of softwood, and several connection systems have been developed, e.g. screws and notches [7–18]. In general, timber-concrete composite slabs represent interesting systems because they offer several structural, economic and ecological advantages compared to reinforced concrete slabs and timber slabs [19].

The composite slabs developed in this research project have a span between 5 and 8 m, a total thickness of 160–220 mm, and are suitable to be installed in office and residential buildings (Fig. 1). The LVL and concrete are connected by means of 15 mm deep notches cut in the LVL panel, which transfer the shear force necessary for composite action through compressive contact of the two materials. These slabs carry the load only in one direction; consequently, the veneers of the beech LVL plate are oriented mostly in the longitudinal direction of the slab. At the beginning of this project, Boccadoro and Frangi [20] conducted a series of

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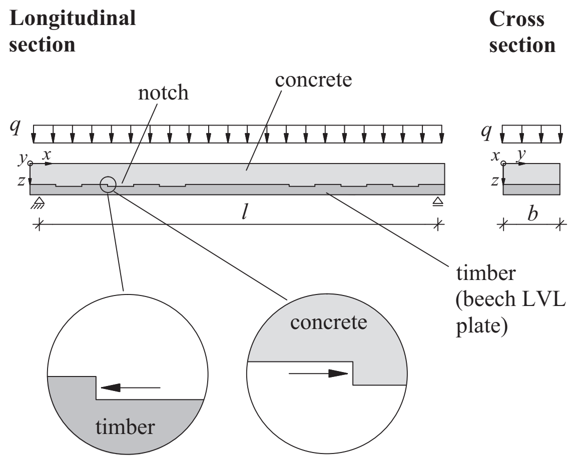

Fig. 1. Timber-concrete composite member made of beech LVL.

four-point bending tests to evaluate feasibility of timber-concrete composite slabs made of beech LVL with a notched connection. These experiments represented the first study on the use of beech wood in timber-concrete composite slabs and provided initial information about the structural behavior of this system. The specimens tested exhibited high load-carrying capacity and stiffness, but their failure mechanism was brittle.

To be able to compete with other slab systems, the structures developed in this research project should fulfill some structural requirements. From the structural point of view, a composite slab should be as stiff as possible at the service level, ductile at the ultimate limit state, and must have sufficient load-carrying capacity. Furthermore, vibration, sound insulation and fire resistance requirements have to be fulfilled. In general, at the service level, a notched timber-concrete connection has a high stiffness [6]. Moreover, according to previous research studies, a notch can fail in a ductile way if a compressive failure of the timber is the governing failure mode (e.g [21]). The controllable and homogeneous properties of LVL materials allow predicting the behavior of the timber part of the composite member with high accuracy, and thus a ductile design of the slab becomes feasible. This was demonstrated by Boccadoro and Frangi [22] by means of shear tests on notches. The basic concept of the composite slab developed was to ensure that yielding of the notches governs the global structural behavior of the composite members.

To study the structural behavior of the composite members, Boccadoro [1] presented an analytical model for ductile design of timber-concrete composite members made of LVL with notched connections. According to the model, a correct design of the notch dimensions and the installation of vertical reinforcement allow achieving a ductile structural behavior induced by notch yielding followed by a compressive failure of the concrete on the top of the cross section. Vertical reinforcement is indispensable to make sure that no premature brittle failure occurs and notch plasticity can develop. This reinforcement shall:

- keep the timber and concrete vertically together
- carry the vertical tension stresses in the concrete
- allow plastic compressive deformations in the LVL layer

Thus, in theory, this reinforcement shall carry only vertical forces. In contrast, the horizontal shear forces necessary for composite action shall be carried exclusively by the notches. However, when vertical reinforcement is installed in a composite member, depending on the layout, it may carry not only vertical forces as assumed in the model, but also forces parallel to the interface, which may induce restraints influencing the LVL behavior. This makes design of the test specimens challenging. The most important aspects of the model are presented by Boccadoro et al. [23] in another publication focused on the modeling of LVL-concrete composite members with ductile notched connections.

The bending tests described in this paper were performed to validate the analytical model developed by Boccadoro [1]. This paper presents the most important results of the experiments. A complete description of the tests is summarized in a test report [24] and the results are compared to the model calculations by Boccadoro et al. [23]. Thanks to the high mechanical properties of beech LVL, the LVL plates used in the tests have a small thickness (40 mm). This implies a thicker concrete layer in comparison to current timber-concrete composite systems, which automatically leads to the concrete being subjected to high tensile stresses. The topic of tensile stress in the concrete has been analyzed in depth in the paper about the model [23]. The most relevant parameter studied during these bending tests was the vertical reinforcement of the composite member. The amount and the type of reinforcement was varied. Some specimens lacked of any reinforcement at all. The vertical reinforcement of specimens 2.2, 7.1, 7.2 and 8.2 was of special layout. It was designed to fulfill the previously mentioned structural requirements as well as possible.

2. Materials and methods

2.1. Test specimens

Ten composite specimens with 15-mm-deep notches were tested. The specimens were 6 m long, 530 mm wide and 200 mm deep. Beech LVL panels and concrete layers were 40 mm and 160 mm deep, respectively. The notch dimensions of all specimens except specimen 1 were chosen according to the analytical model presented by Boccadoro [1] so that a compressive failure in the timber should govern the structural behavior. Since the width of the notches was proportional to the shear force resulting from a uniformly distributed vertical load, all notches should yield simultaneously. The beech LVL panels were made of 14 veneers (12 veneers in longitudinal direction and 2 veneers in the cross direction to ensure the dimensional stability) (Fig. 2). In contrast to the preliminary bending tests [20], to prevent rolling shearing-off failures, the beech LVL panels investigated in this test series did not contain a cross layer in the middle. As shown in Fig. 2, the LVL panels of specimen 8.2 came from a different production series and showed a small difference in the veneer configuration. The mechanical properties of the beech LVL panel product "BauBuche" were determined by van de Kuilen and Knorz [25,26] in preparation of a European Technical Approval. Some of these properties are reported in Table 1 as an example. The concrete that was tested was of strength class C50/60 according to the Swiss Standard SIA 262 [27], had a maximum aggregate diameter of 16 mm, and contained a liquid admixture to reduce the drying shrinkage and a steel mesh to prevent shrinkage cracks (the diameter of the bars was 6 mm and the spacing was 150 mm). The mechanical properties of the concrete tested are summarized in Table 2. Table 3 clas-

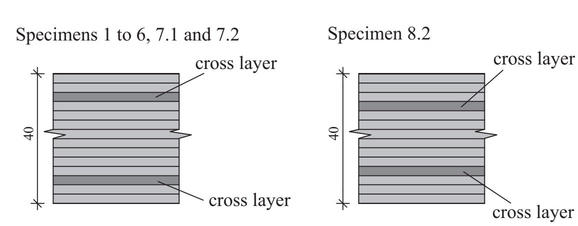

Fig. 2. Layer composition of the investigated beech LVL panels.