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Connections for Timber-Concrete-Composite Structures

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Summary

This paper presents information on the load-deformation behaviour and the manufacture of different types of timber-concrete connection. The failure modes of four different connections and their influence on the load-deformation behaviour and the failure modes of timber-concrete composite beams is outlined. The design of timber-concrete connections with dowel-type fasteners is summarised and the effect of load sharing between fasteners on the load-carrying capacity of the composite beam is emphasised.

1. Introduction

Timber-concrete-composite structures, used as bending members in floor systems, mostly consist of timber members in the tensile zone, a thin concrete layer in the compression zone and the connection between timber and concrete. The main advantages of this type of composite structure are:

- increased strength and stiffness compared to timber floors,
- improved sound insulation,
- increased fire resistance,
- easy method to reinforce existing timber floors.

The load-carrying behaviour of timber-concrete-composite structures is essentially influenced by the strength and stiffness of the connection between timber and concrete. This is valid for both, the short and long-term behaviour of the composite members. Apart from a large load-carrying capacity, connections for timber-concrete-composite structures should exhibit a high stiffness under service loads as well as distinct plastic deformations before failure. In addition, for economic reasons they should be easy to install.

2. Types of Connection

During a co-operative research project carried out at Delft University of Technology in the Netherlands and Karlsruhe University in Germany (Blaß et al. 1995), timber-concrete-composite structures with four different types of connection were studied:

- especially designed screws driven into the timber without pre-drilling under an angle of ± 45°,
- punched metal plate fasteners,
- grooved holes in timber beams filled with concrete and combined with a dowel, and
- grooved holes in laminated veneer lumber filled with concrete.

2.1 Screws

The screws used in the study were specifically developed for timber-concrete connections. They are driven into the timber without pre-drilling, resulting in low labour costs for the manufacture of the connections. Connections with different screw arrangements were investigated by Timmermann and Meierhofer (1993). Instead of placing the screw perpendicular to the joint between timber and concrete, they placed the screws under an angle of ± 45°, resulting in a truss-like loading of the connections, where the screws are loaded in tension and compression rather than in bending. This fact leads to a much stiffer connection compared to an arrangement perpendicular to the timber surface. The screw has two heads, the lower pressing the concrete formwork onto the timber beams. The upper head together with a part of the shank is encased in concrete.

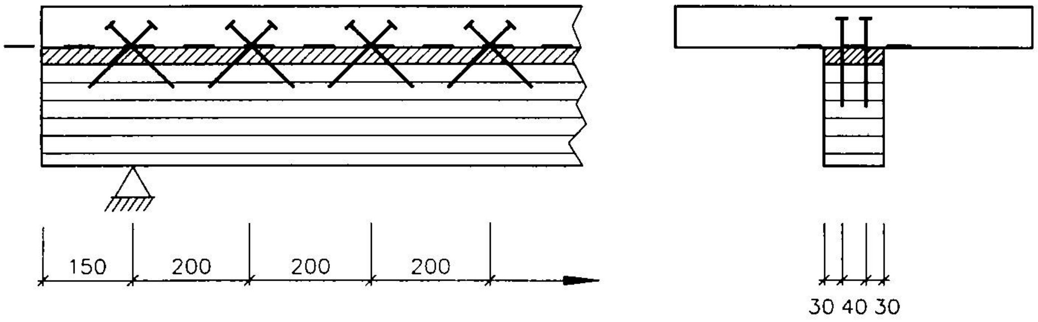

Fig. 1 Timber-concrete connection with crossed screws.

2.2 Punched metal plate fasteners

The punched metal plate fasteners, which are very common as connectors in timber trusses, were first bent about their longitudinal axis to form a right angle. The nails on the plate part later encased in the concrete layer were cut off in order to prevent voids in the concrete close to the plate. The other half was then pressed into the timber beam. This type of connection has to be prefabricated before shipping the beams to the building site.

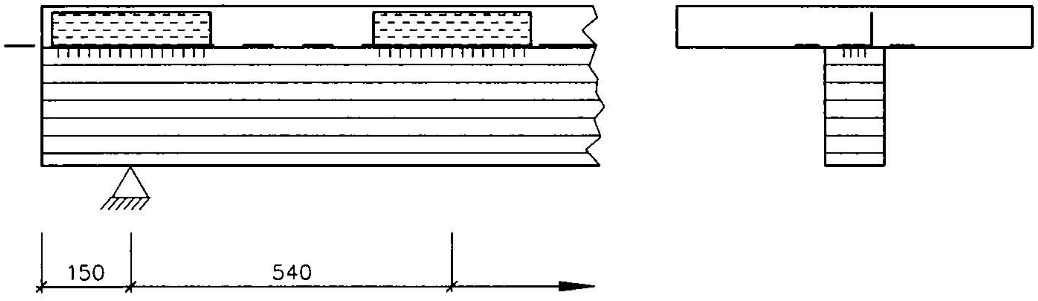

Fig. 2 Timber-concrete connection with punched metal plate fasteners

2.3 Grooved connections with dowels

In order to manufacture this type of cleat joint, first grooves with a diameter of 70 mm are routed 30 mm deep into the timber beam surface. Within this indentation, a hole with a diameter of 20 mm is drilled to take the steel dowel. The steel dowels - short pieces of concrete reinforcement bars - are then driven into the 20 mm holes. Concrete finally covers the upper part of the dowels and fills the remaining space in the grooves.

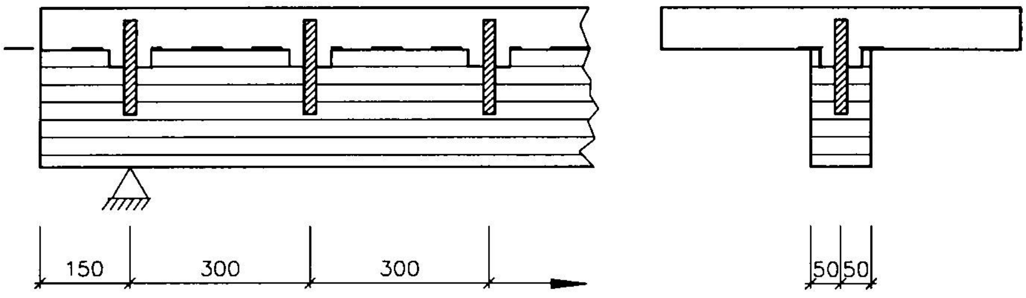

Fig. 3 Timber-concrete connection with grooved holes and dowels

2.4 Grooved connections in LVL

This type of timber-concrete connection is used for composite plate structures, where instead of timber beams laminated veneer lumber (LVL) as sheet material is used in the tensile zone. The joints are manufactured by grooving circular holes with a diameter of 115 mm and a depth of 15 mm into the LVL surface. The holes are conical in vertical direction in order to prevent a separation between timber and concrete. The concrete filling the flat holes forms a type of cleat which is able to transfer shear forces. In order to avoid a brittle failure of the concrete cleats, they are reinforced. The manufacture of the indentations is carried out with computer-controlled routing machines resulting in very economical connections.

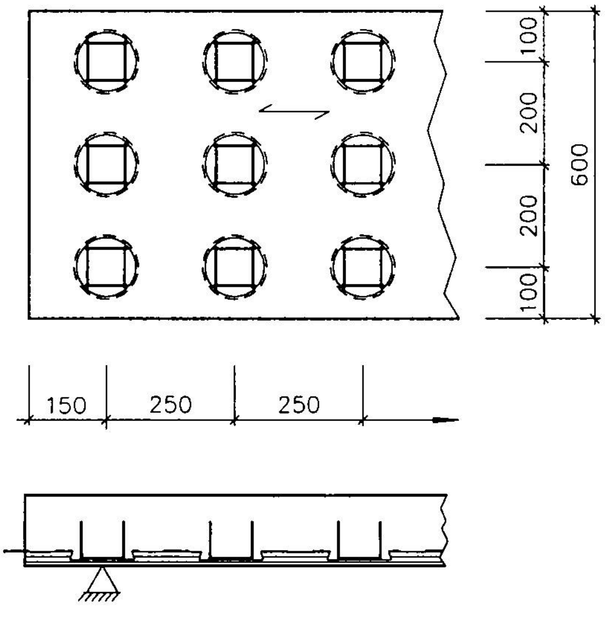

Fig. 4 Timber-concrete connection with grooved indentations in LVL

3. Load-Carrying Behaviour of Connections

In order to acquire sufficient data about the variation of the load-carrying behaviour, about 50 single shear specimens of every type of connection were tested in short-term tests. Although the failure modes of the four types were quite different, all types exhibited a high stiffness at service load level and distinct plastic deformations before failure.

Depending on the thickness of the intermediate layer between timber and concrete, the screws loaded in tension were either pulled out of the timber or failed in tension in the threaded part of the shank. After reaching the maximum load, the load on the connection decreased with increasing withdrawal of the screw (Figure 5 top left). The average maximum load for one pair of screws was about 18 kN at a displacement of about 1 mm.

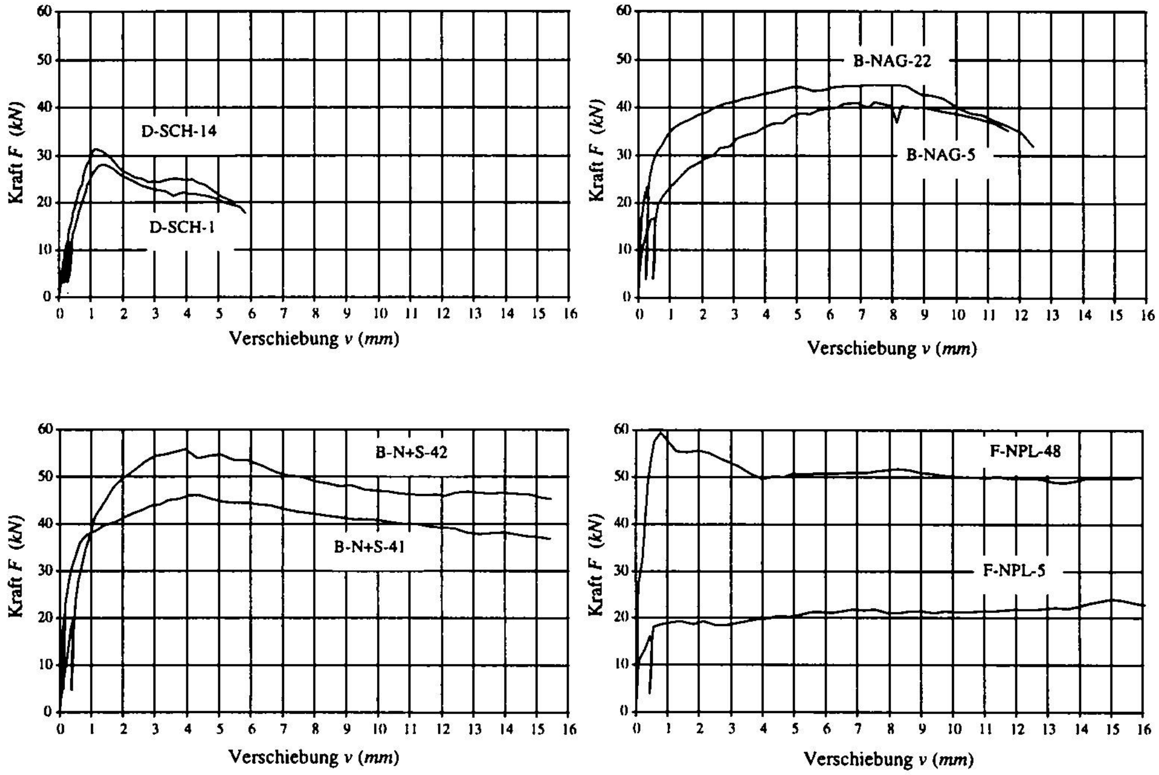

Fig. 5 Load-deformation-diagrams with maximum and minimum stiffness of four different connections. Screws (top left), punched metal plate fasteners (top right), grooved connections with dowels (bottom left), and grooved connections in LVL (bottom right)

The connections with punched metal plate fasteners failed due to bending and subsequent withdrawal of the punched out nails out of the timber. In some cases, nails failed in tension at the metal plate. The mean maximum load for one plate was about 48 kN, the stiffness modulus at service load level about 50 kN/mm.

Grooved connections exhibited a particular plastic deformation capability. The tests were stopped after a relative displacement of 15 mm between timber and concrete was reached. The failure for grooved connections with dowels was caused by dowel bending combined with concrete cracking in the vicinity of the dowel. The maximum load for one connector unit (indentation plus dowel) was about 50 kN, the stiffness modulus at service load level about 75 kN/mm. Grooved connections in LVL acted as large concrete connectors. In some cases, the load was still increasing when a displacement of 15 mm was reached. Failure was caused by reaching the embedding strength of the laminated veneer lumber. The average maximum load was about 50 kN per indentation, the corresponding stiffness modulus 120 kN/mm.

4. Load-carrying Behaviour of Timber-Concrete-Composite Beams

For each type of connection, ten timber-concrete composite beams were tested in short-term tests. For the composite beams with screws, punched metal plate fasteners and grooved connections with dowels, the span of the beams with a T-type cross-section was 5,40 m (Fig. 6 top), for the beams with grooved connections in LVL, the span was 4,50 m (Fig. 6 bottom).

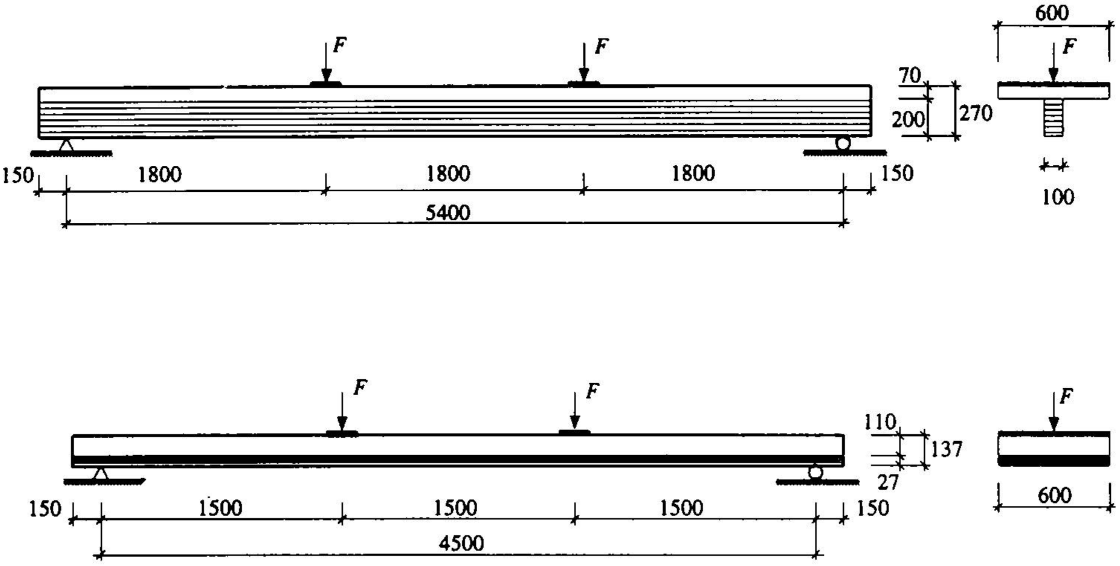

Fig. 6 Test specimens for timber-concrete composite beams. Connections are screws, punched metal plate fasteners, grooved connections with dowels (top), and grooved connections in LVL (bottom)

The influence of the connection behaviour on the load-deformation behaviour of the composite beams depends both on the load-carrying behaviour of the connections and on the load level of the connection loads before the failure of the beam. Since all four types of connection approximately exhibit an elastic-plastic load deformation behaviour, the load-deformation behaviour of the tested composite beams essentially depends on the load level of the fasteners. If the fasteners between timber and concrete govern the design, the highly loaded fasteners close to the supports will approach their load-carrying capacity, deform plastically and a certain amount of plastic deformation of the beams is to be expected before failure. If, on the other hand, the connection loads remain in the elastic range until the beam fails, the beams will basically behave linearly until failure.

Depending on the number and capacity of the connections, the behaviour of the tested beams ranged from linear-elastic until failure until elastic-plastic. The beams with the highest connection capacity (grooved connections in LVL) exhibited a linear load-deformation behaviour until failure. The brittle failure was caused by the failure of the LVL-layer under combined bending and tensile stresses.

The composite T-beams eventually all failed due to the combined bending/tensile failure of the timber beams. The composite beams with screws and those with grooved connections with dowels showed a pronounced plastic deformation before failure due to the plastic deformation in the timber-concrete connections. The failure of the connections close to the supports - withdrawal of the screws or splitting of the timber end cross-section and cracking of concrete, respectively - before the failure of the beams could be clearly observed in the tests. The beams with punched metal plate fasteners displayed a slightly curved load-deformation diagram, indicating the fact that the first connections approached their load-carrying capacity before the failure of the composite beam.

5. Design of Timber-Concrete Connections

Generally, the design of timber-concrete composite structures requires the consideration of the slip occurring in the joint between timber and concrete. A method for the calculation of the fastener loads for mechanically jointed beams or columns is e. g. given in Annex B and C of Eurocode 5 Part 1-1 (ENV 1995-1-1). The design of timber-concrete connections is dealt with in Eurocode 5 Part 2 - Design of timber structures - Part 2: Bridges. In many cases, the load-carrying capacity and the slip modulus of the connection have to be determined by tests. Testing is not required, however, for laterally loaded dowel-type fasteners inserted perpendicular to the shear plane. If there is no intermediate layer between timber and concrete, the strength of the joints with screws, dowels and threaded nails may be assumed 20 % higher than for corresponding timber-to-timber joints according to ENV 1995-1-1. The corresponding stiffness values may be taken 100 % higher than for corresponding timber-to-timber joints.

If the withdrawal strength and stiffness of screws or threaded nails is known, Eurocode 5 Part 2 also provides a method to design inclined fasteners for timber-concrete connections. The analytical model assumes a truss-like behaviour of the components, where for uni-directionally inclined fasteners the shear force is transferred by tensile forces in the fasteners and compression forces between timber and concrete, and for two-directionally inclined fasteners by tensile and compression forces in the fasteners.

If tests to determine the load-carrying capacity and the slip modulus of timber-concrete connections show a distinct plastic behaviour, a redistribution of loads from highly loaded fasteners to less loaded fasteners will occur in composite beams, as soon as the most stressed fasteners deform plastically. If the connection governs the design of the composite beam with a large number of fasteners, the characteristic load-carrying capacity of the beam therefore depends on the characteristic strength of a number of connections loaded in parallel, rather than on the characteristic strength of a single connection. This load-sharing increases the load-carrying capacity of the composite beam and should either be taken into account during the connection design or when determining the characteristic strength of timber-concrete connections.

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