Advanced Materials Research Vols. 133-134 (2010) pp 1095-1100

doi:10.4028/www.scientific.net/AMR.133-134.1095

Retrofitting of Timber Beam Ceilings with the Timber-Concrete Composite Construction

HOLSCHEMACHER Klaus[1,a] and KIESLICH Hubertus[1,b]

[1]Leipzig University of Applied Sciences (HTWK Leipzig), Leipzig, Germany

[a]holschem@fbb.htwk-leipzig.de, [b]hkieslic@fbb.htwk-leipzig.de

Abstract Regarding the redevelopment of existing residential buildings the timber-concrete-composite (TCC) construction is an innovative possibility to toughen up timber beam ceilings. Thereby a concrete slab is added to the timber beams. Both parts of the construction are connected by using special shear connectors. In this case timber is mainly loaded in tension and concrete is generally loaded in compression. The bearing capacity as well as the serviceability of the ceiling can be improved by this composite construction. The idea of combining the construction materials timber and concrete in the way that they both can take and carry on loads is not new. In Germany it was mentioned in 1939 for the first time. The cityscape of Central European towns is mainly characterized by buildings constructed before the 50th of the last century. The protection of the historical main structure of these buildings is getting more important today. Floors built up till that time were primarily made of timber. Research in Germany has been intensified during the last decade. This paper will show the specific properties of timber-concrete composite floors. Several metallic combing agents exist currently. Type and distance of the connection members influence the load bearing behavior of the composite construction. The main types used in Germany will be presented in this paper. The possible ways of calculating timber-concrete composite ceilings will be given and the design basis will be explained.

Keywords: Timber-concrete composite construction, timber beam ceilings, retrofitting

Introduction

Composite constructions are often used in the field of the Construction Engineering. The most famous examples for flexibly connected sections are the combination of steel and concrete or laminated safety glass. The Timber-Concrete Composite (TCC) construction is of particular interest especially in the field of retrofitting existing buildings. In Europe research has been intensified during the last 25 years. But since the late 1930th the combination of timber and concrete has been known. At that time the rare recourses may have been the motivation for this idea. Nowadays we are in a quite similar situation. There is a decrease in natural resources whereas the worldwide population is increasing pursuing a high level of prosperity. That is why the focus is more and more concentrated on sustainability. Often the replacement of the existing infrastructure is not the only way. The retrofitting of existing buildings is getting more and more important against this background. Currently the TCC structures are mainly used in the field of retrofitting timber beam ceilings. The application area is just beginning to change at the moment. TCC constructions are also used in new buildings even if this kind of construction is quite new. In Europe there are also some examples for using it in bridge building. A good introduction to the topic TCC construction can be found in the reference (König, Holschemacher and Dehn 2004).

In the following the focus will be concentrated on the retrofitting of existing buildings. Often today's requirements concerning bearing capacity, serviceability (deformation, vibration behavior and sound insulation) but also fire protection cannot be achieved. The reasons for it are manifold. They reach from the change of use to the biological damage of supporting wooden structures. Often a combination of several reasons is the causation for a required rehabilitation. Among various ways of reconstructing which differ in complexity and effect the TCC construction method can be an alternative. Thereby a concrete slab is added to the timber beams as shown in Fig. 1. Both parts of the construction are connected by using special shear connectors. By using this type of reconstruction

main parts of the ceiling can be left. This fact has a big influence on the economic view of the redevelopment measure. Several advantages but also disadvantages are connected with the use of TCC ceilings. The stiffness and the load bearing capacity of the construction can be increased; fire protection and sound insulation can be enhanced. Furthermore the bottom view of the construction can be conserved, which is often of special importance in the field of reconstruction. On the other hand it is disadvantageous that different assembly sections have to work together on the building site. The height of the rooms will be reduces which also reduced the height of doors and parapet. This may cause additional expenditures.

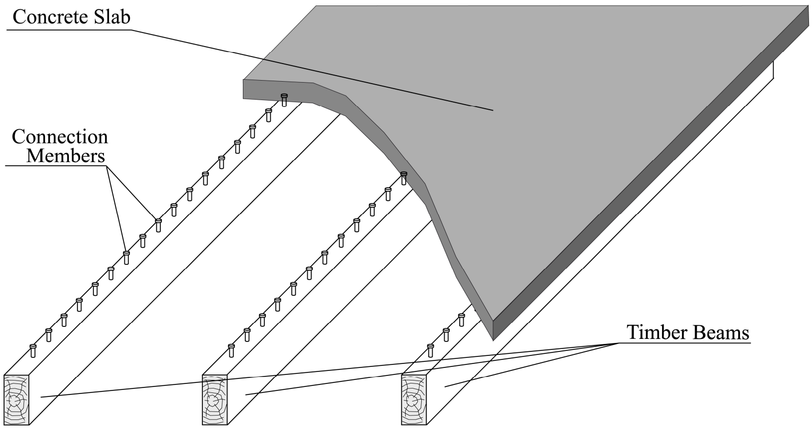


Figure 1: Principle structure of a TCC ceiling

Load-Dearing Behavior and Design of Timber-Concrete-Composite Constructions

Fig. 1 has already described the principle structure of a TCC ceiling and represents a special case of flexibly connected bending beam. In Germany the use of common fasteners like nails or screws is only allowed in bonding timber or timber with steel. To use them in order to connect timber and concrete it is necessary to apply for an approval in individual case or a national technical approval. The properties of the structure are influenced by the components of the composite construction as well as by the properties of the connection itself. The connection properties can be described by the maximum load (F_u) and the sliding modulus (k_S). In Fig. 2 the distribution of stress in the composite cross-section is shown qualitatively. If there is no connection between timber and concrete both parts of the cross-section are loaded in bending, they can move against each other. The increasing stiffness of the connection causes an increasing part of normal forces in the composite construction. In a rigid connection no movements are possible any more. The value and proportion of normal stress also depends on external forces, the span of the ceiling and geometrical values like the area, the plane-area moment and material properties like the modulus of elasticity.

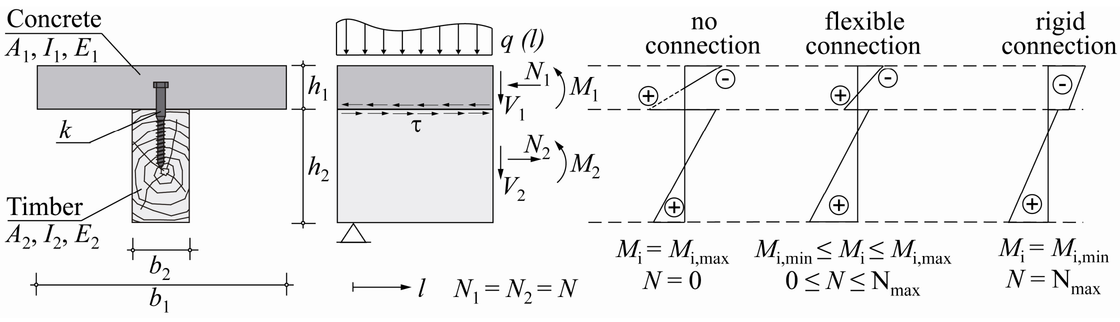
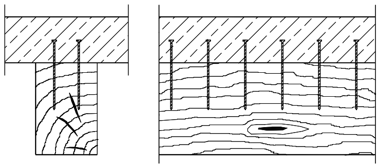
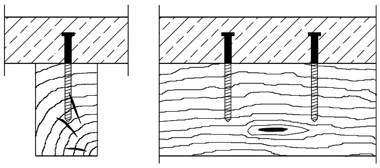
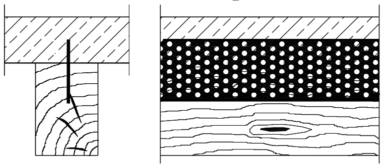
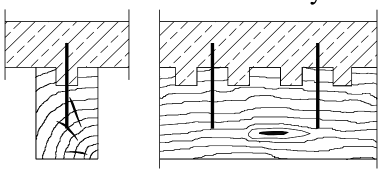
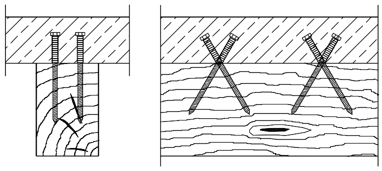


Figure 2: Distribution of normal stress in the TCC cross-section

Table 1: Typical connection members for TCC constructions

Connection member	*Effectiveness*	*Labor input*
Nails 	Low because of the low stiffness of the nails, depending on the diameter; *k* = 600…3.000 N/mm per connection member (DIN 1052 2008); connection member is mainly loaded in bending	Labor input is also depending on the diameter, at large diameters predrilling becomes necessary, but mostly low
Screws 	Depending on the diameter of the screws; *k* = 1100…8.600 N/mm per connection member (DIN 1052 2008); connection member is mainly loaded in bending	Labor input is also depending on the diameter, at large diameters predrilling becomes necessary
Bonded steel plates 	High; *k* = 825…350 N/mm per mm length of the expanded metal (Z-9.1-557); connection member is mainly loaded in shear	Very high; the steel plates have to be glued into the beam
Combination of pin-shaped connection member and concrete keys 	High; the sliding modulus depends on different parameters and has to be determined experimentally; the stress of the connection member differs depending on the location (console-framework)	Very high; the timber beams have to be prepared carefully, the cut out for the concrete keys have to be milled into the beam
Inclined connection members 	High; *k* = 300…25.000 N/mm per connection member, depending on the angel of inclination (Z-9.1-445 and Z-9.1-342); connection member is mainly loaded in normal forces	High, the hole has to be predrilled, the fitting has to be controlled

Several metallic connection members are used currently. They differ strongly in effectiveness, required labor input and price. The most common of them are compared in the following table (Table 1). At some of them a sliding modulus (*k*) is denoted. These reference values are taken from the DIN-standard (coniferous timber) or the technical approval. But mostly they have to be determined experimentally because the values shown only represent a connection of timber or timber and steel (except of those which are taken from the technical approval). The following Table 1 cannot be complete.

In the following the experimental setup to determine the sliding modulus and the maximum load of a connection of timber and concrete will be described. These characteristic parameters are needed to assess a TCC construction. They depend on the type of connection and the material properties of the concrete slab and the timber used. Fig. 3 shows the experimental set-up of the push-out test and the loading regime according to DIN EN 26891 1991 to determine these dates. Three different experimental set up are possible. The picture shows one of them in detail. Concrete (2) is added on both sides of the timber (1) connected with the fasteners which were chosen for the TCC construction. The maximum load has to be estimated and the loading regime has to be implemented according to the diagram shown in Fig. 3. At first the load has to be increased (force-controlled) by a loading rate of 20 % of the estimated maximum load per minute up to 70 % of the maximum. Within this span the

load is to be kept constantly for 30 sec at 40 % and 10 % of the estimated maximum value. From this point on up to the failure of the specimen or a displacement of 15 mm the force is increased displacement-controlled. For measuring the displacement between the timber beam and the concrete slab 4 LVTD's are applied as shown in the picture (3).

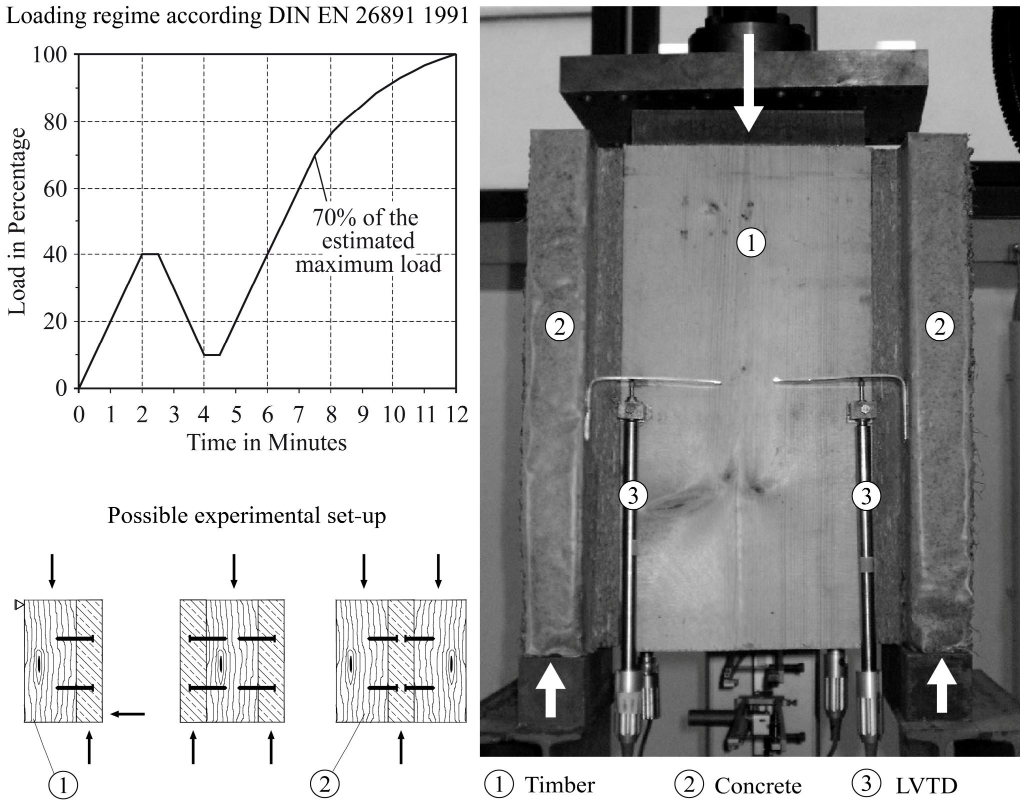


Figure 3: Experimental set-up and loading regime for the push-out test

With the help of different ways it is possible to dimension a TCC construction. Basically it is necessary to differentiate between the short term behavior and the long term behavior of the composite construction. The known determination between the ultimate limit sate (ULS) and the serviceability limit state (SLS) is maintained. For short term behavior the γ-procedure is most common. It was deduced by Möhler for flexibly connected bending or compression members (Möhler 1956) and is used in (DIN 1052 2008). Thereby the Steiner's dues of the plane-area moment are reduced because of the flexibility of the connection members. Strictly this method is only applicable for simple beams under sinusoidal load and constant stiffness of the connection members over the length of the beam (Glaser 2005). According to the German model code (DIN 1052 2008) the effective stiffness is calculated as presented in Eq. 1. It has to be used for all required static verifications at the time $t = 0$. Thereby E_i represents the modulus of elasticity of the partial cross section, A_i the area of the partial cross section, I_i the plane-area moment of the partial cross section and a_i the distance between the center of gravity of the partial cross section and the composite cross section. The quotient K_i / s_i in (Eq. 2) represents the stiffness of the joint and l the equivalent bearing distance.

$$(E \cdot I)_{ef} = \sum_{i=1}^{3} (E_i \cdot I_i + \gamma_i \cdot E_i \cdot A_i \cdot a_i^2) \qquad (1)$$

$$\gamma_i = \frac{1}{1+k_i} \quad with \quad k_i = \frac{\pi^2 \cdot E_i \cdot A_i \cdot s_i}{K_i \cdot l^2} \qquad (2)$$

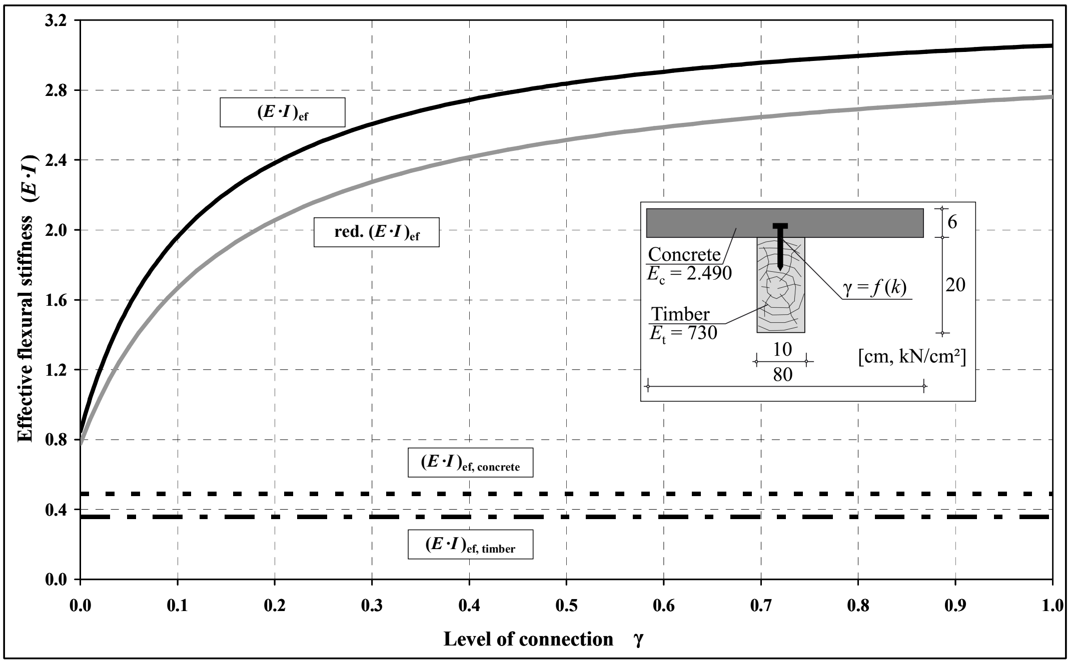


Figure 4: Influence of the level of connection on the effective stiffness of the TCC construction

The Fig. 4 shows the influence of the level of connection on the effective stiffness of the composite construction at the time $t = 0$. The level of connection reaches between 0 (no connection) and 1 (rigid connection). The graph shows that the stiffness of the TCC construction depends strongly on the level of connection. The gray graph represents the effective stiffness of the composite construction by attenuation of the stiffness of the concrete slab by 20 % caused by the formation of cracking (Möller 2003). This is true for simple beams. But especially in the point of support of continuous beams the reduction of the stiffness of the concrete slab should be higher. The diagram shows that the stiffness of a TCC construction compared with the timber beam could be increased by 6.25 times ($(E{\cdot}I)_{ef}$) and respectively by 5.75 times (red. $(E{\cdot}I)_{ef}$). The γ-value can also be explained as the relation between the strain in the center of gravity at flexibly and rigidly connected partial cross sections due to same curvature of the cross sections (Schänzlin 2003). The load bearing behavior of a TCC construction is also influenced by creep and shrinkage of the timber and the concrete used. The shrinkage of concrete causes an increase of deflection and of bending moments in the partial cross section but also a decrease of the normal forces in the partial cross sections, the maximum shear forces and load at the connection members. To take the long term behavior into account a modified analysis was presented in (Kuhlmann 2004). Thereby a modified effective stiffness, fictitious forces and a modified modulus of elasticity is provided. Another way of calculation was introduced by Natterer and Hoeft (Natterer, Hoeft 1987). There differential equations for a TCC ceiling had been derived and were solved for special loadings and boundary conditions (jointed supported simple beams).

For calculating a TCC ceiling by computer it is also possible to use framework models. Thereby the system is divided into two parts connected by the use of some truss bars representing the properties of connection members. The properties of the concrete slab are assigned to the layer on the top and those of the timber beams to the bottom layer. Both parts are equally deformed. Furthermore the use of FEM programs is possible. But therefore the material properties of the construction members as well as the properties of the connection have to be well known and the required time for calculating is high.

Summary

The TCC construction is a practicable possibility to toughen up existing timber beam ceilings. There is an enormous potential on the market of retrofitting. Even for new buildings it is an interesting opportunity especially regarding ecological aspects because significant parts of the construction are

renewable and can easily be recycled. In the past various researches to develop this kind of construction method were executed. Nevertheless experimental investigations are still needed to design a TCC ceiling. By connecting timber and concrete it is possible to use the typical advantages of both construction materials sensibly. The load carrying behavior of timber beam ceilings can be improved as well as the vibration behavior. In addition to that, clear advantages occur regarding fire protection and sound insulation. All in all, the TCC construction represents a competitive system in the field of reconstruction.

Acknowledgement

At the end of this paper the authors want to thank our colleagues Yvette Klug, Stefan Käseberg and Torsten Müller for supporting our work at the Institute of Concrete Construction at the University of Applied Science Leipzig.

References

[1] Deutsches Institut für Bautechnik (DIBt) Z-9.1-342 "SFS-Verbundschrauben VB-48-7,5x100 al Verbindungsmittel für das SFS Holz-Beton-Verbundsystem" (in German).
[2] Deutsches Institut für Bautechnik (DIBt) Z-9.1-445 "Timco II Schrauben als Verbindungsmittel für das Timco-Holz-Beton-Verbundsystem" (in German).
[3] Deutsches Institut für Bautechnik (DIBt) Z-9.1-557 "Holz-Beton-Verbundsystem mit eingeklebten HBV-Schubverbindern" (in German).
[4] DIN 1052 (2008) "*Entwurf, Berechnung und Bemessung von Holzbauwerken – Allgemeine Bemessungsregeln und Bemessungsregeln für den Hochbau (Design of timber structures – General rules and rules for buildings)*" Berlin, Germany, Beuth Verlag (in German).
[5] DIN EN 26891 (1991) "*Holzbauwerke – Verbindungen mit mechanischen Verbindungsmitteln (Timber structures – Joints made with mechanical fasteners)*" Berlin, Germany, Beuth Verlag (in German).
[6] Glaser, R (2005) "*Zum Kurz- und Langzeitverhalten von Holz-Beton-Verbunddecken*" Dissertation, Brandenburg University of Technologie Cottbus, Germany (in German).
[7] König, G.; Holschemacher, K., and Dehn, F (2004) "*Holz-Beton-Verbund*" Berlin, Germany: Bauwerk Verlag (in German).
[8] Kuhlmann, U, Schänzlin, J, and Michelfelder, B (2004) "Berechnung von Holz-Beton-Verbunddecken (Evaluation of Timber Concrete Composite Slabs)." *Beton- und Stahlbetonbau* 99 H 4, 262-271.
[9] Möhler, K (1956) "*Über das Tragverhalten von Biegeträgern und Druckstäben mit zusammengesetzten Querschnitten und nachgiebigen Verbindungsmitteln*" University lecturing qualification, TH Karlsruhe, Germany (in German).
[10] Möller, G (2003) "Betrachtungen zur Bemessung nachgiebig zusammengesetzter Querschnitte." *Bautechnik,* 80 H 11, 786-795.
[11] Natterer, J, and Hoeft, M (1987) "Zum Tragverhalten von Holz-Beton-Verbundkonstruktionen. "Ecole Polytechnique Federal de Lausanne, Forschungsbericht CERS Nr. 1345, März 1987.
[12] Rautenstrauch, K (2004) "Entwicklung der Holz-Beton-Verbundbauweise" in König, G.; Holschemacher, K., Dehn, F. (2004) "*Holz-Beton-Verbund*" Berlin, Germany: Bauwerk Verlag (in German), 1-22.
[13] Schänzlin, J (2003) "*Zum Langzeitverhalten von Brettstapel-Beton-Verbunddecken.*" Dissertation, University Stuttgart, Germany (in German).