COMAT

The 9th International Conference on Advanced Composite Materials Engineering

Transilvania University of Brasov
FACULTY OF MECHANICAL ENGINEERING

17-18October 2022

DESIGN OF CONCRETE SLABS IN TIMBER CONCRETE-COMPOSITE STRUCTURES

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Abstract: *Timber-concrete composite (TCC) slabs consist of timber beams, connected by shear connectors with a concrete slab. Typical dowel type shear connectors may provide only a flexible bond between the timber beams and the concrete slab. Therefore, in single span systems, the concrete slab is predominantly under compressive stresses, but usually a small tensile zone may not be avoided. The paper discusses the optimal arrangement of reinforcement in the concrete slab and the possibilities of verification of the concrete slab. It is found that fibre-reinforced polymer (FRP)-based textile reinforcement or the application of fibre-reinforced concrete is the optimal solution for the concrete slab in TCC structures. In the result, the depth of the concrete slab may be reduced to an optimal and resource-saving value.*

Keywords: *Timber-concrete composite, flexible bond, concrete properties, design optimization*

1. INTRODUCTION

Basically, timber-concrete composite (TCC) slabs consist of timber beams, shear connectors and a concrete slab. The shear connectors provide the bond between timber beams and the concrete slab resulting in a composite member. Additionally, a non-load-bearing boarding may be arranged between the timber beams and the concrete slab. The timber beams may be arranged separately with a spacing (T-beam section) or without any gap between them (board stack elements). Typical position of the concrete slab is above the timber beams, but in special situations the location between or at least partially between the timber beams may be preferred [1]. Typical sections of TCC slabs are shown in Figure 1.

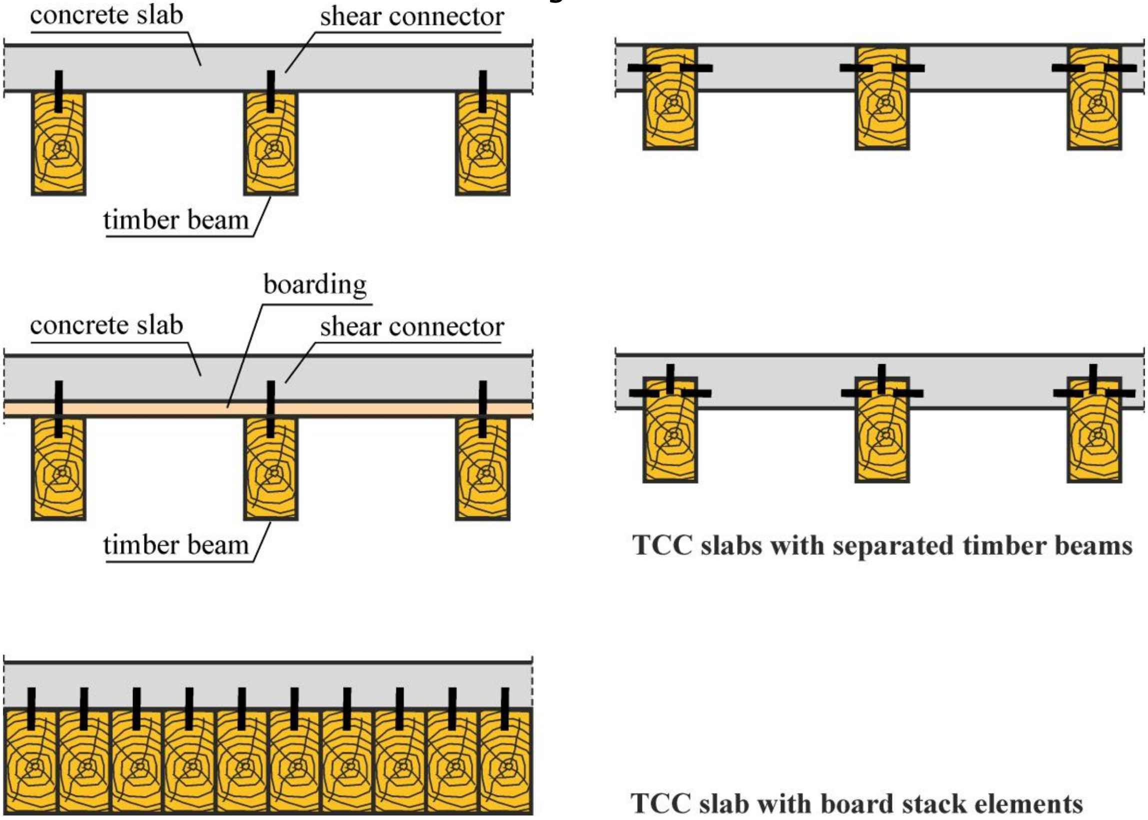

Figure 1: Typical sections of TCC slabs

Shear connectors applied in TCC structures may be classified in dowel type steel fasteners, notches, combinations of steel fasteners and notches, and special types, e.g. glued connections. It is possible to incline the steel fasteners or arrange them in two rows if necessary, see Figure 2. Furthermore, the spacing of shear connectors may be changed in accordance to the shear force distribution along the longitudinal axis of the TCC structure.

Apart from glued connections, shear connectors provide only flexible bond between timber beams and concrete slab. This fact causes a jump in the strain distribution as well as a slip in the interface between timber beams and concrete slab. As presented in Figure 3, the concrete slab is in single span systems predominant but not complete under compression [2].

In today's construction practice, TCC is mainly applied for strengthening of existing timber beam ceilings. Older timber beam ceilings do often not satisfy recent serviceability (e.g. deflection, vibration sensitivity) and building physics (e.g. fire and sound protection) demands. Strengthening of timber beam ceilings by TCC technique is a time saving and economic procedure. In most cases, the boarding may stay in place and it is easy to install the shear connectors at the top of the timber beams, and subsequently to cast the concrete slab. There is no change of the appearance of the bottom side of the timber beam ceilings. This is a huge

advantage of TCC technology in comparison to other possible strengthening methods in the context of heritage protection [3].
Besides, TCC slabs are increasingly applied in construction of new buildings. Main reason is the reduced environmental impact of TCC systems in comparison to reinforced concrete slabs of similar load-bearing capacity.

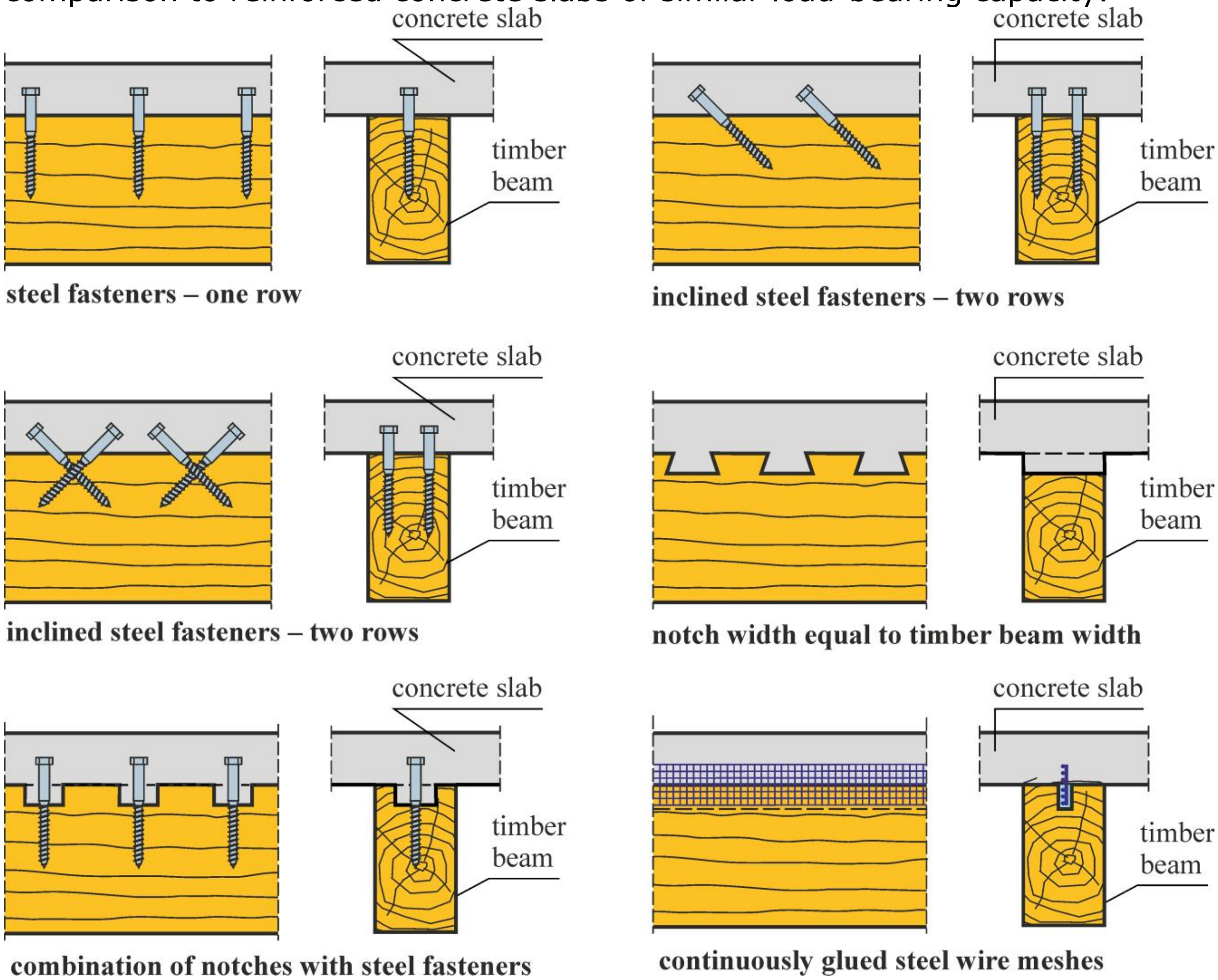

Figure 2: Typical shear connectors in TCC slabs

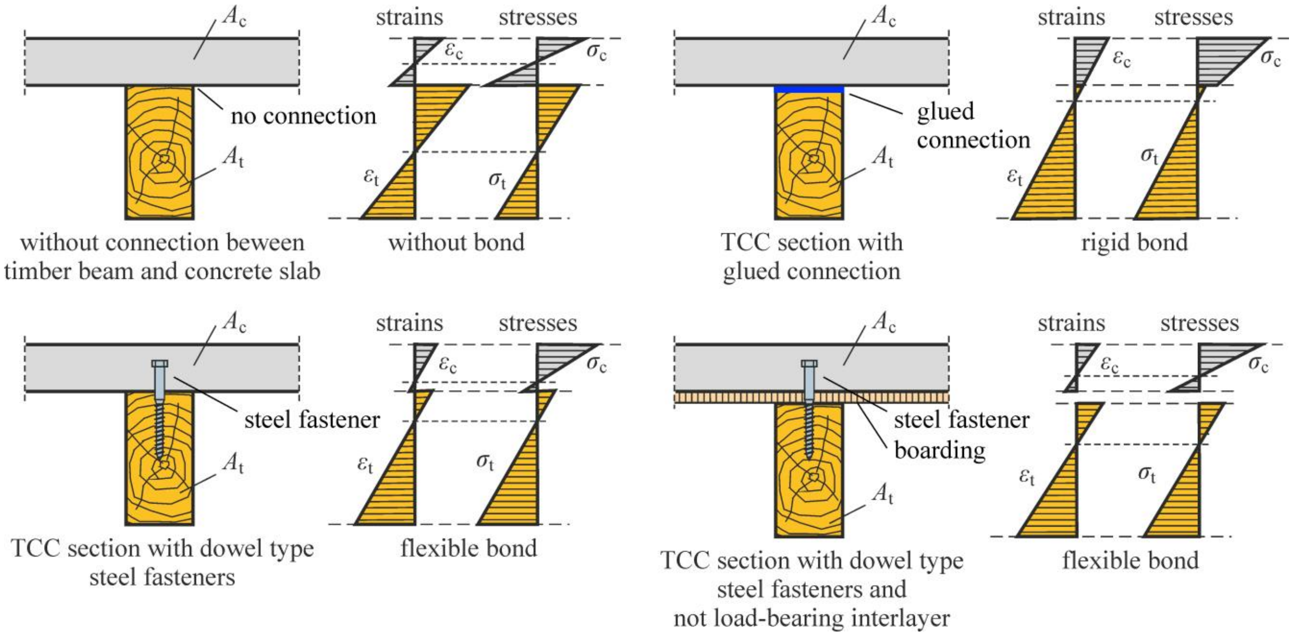

Figure 3: Stress and strain distribution for systems without, with rigid, and with flexible bond

2. DESIGN OF THE CONCRETE SLAB IN TCC STRUCTURES

In TCC systems with flexible bond, the depth of the tensile zone in the concrete slab is normally very low in parallel to the timber axis, see Figure 3. Therefore, the possibilities for the verification of the tensile stresses in the concrete slab as well as the suitable type of reinforcement must be discussed. In this context, the application of a steel bar or mesh reinforcement or the usage of plain concrete are traditional solutions in construction practice.

At time, arrangement of steel mesh reinforcement is the preferred option. However, it must be considered a concrete cover of 2 cm or more in this case. The cover is needed to ensure the bond between reinforcing bars and concrete, to prevent corrosion of steel reinforcement, and for reasons of fire resistance. Because the slab height in usual TCC systems amounts 6 to 16 cm, the reinforcement position is very close to neutral axis or even in compression zone, see Figure 4. Thus, there is a compressive strain or only low tensile strain in the reinforcement and the reinforcement is not or only partially activated. Following, the steel bar or mesh reinforcement is not suitable to bear the tensile stresses in the concrete slab in parallel to the timber beam axis.

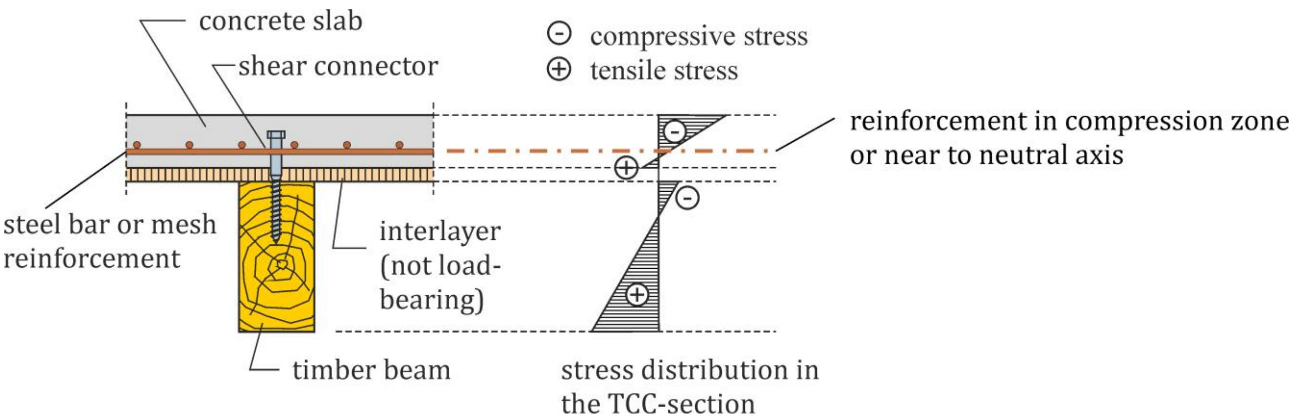

Figure 4: Activity of steel bar or mesh reinforcement in TCC slabs

The verification of the concrete slab as a plain concrete member seems to be the most promising way. Indeed, the stresses in the concrete slab can be easily transferred into inner forces, namely the axial force N_c and the bending moment M_c, see Figure 5. According to Eurocode 2, Chapter 12, the axial force N_c must be limited to [4]

$$N_c \leq N_{Ed} = \eta \cdot f_{cd,pl} \cdot b_c \cdot h_c \cdot (1 - 2 \cdot e/h_c) \qquad (1)$$

where $\eta \cdot f_{cd,pl}$ = design effective compressive strength of concrete, b_c =overall width of the concrete slab, h_c = overall height of the concrete slab, and e = eccentricity ($e = M_c/N_c$). In some National Annexes, e.g. in Germany [5], there is an additional demand to limit the eccentricity to $e/h_c < 0.4$.

Another possibility is the consideration of the tensile zone of the concrete slab as a non-load-bearing layer [6], see Figure 6. This kind of verification results in an iterative procedure and is well suitable for software-based calculations.

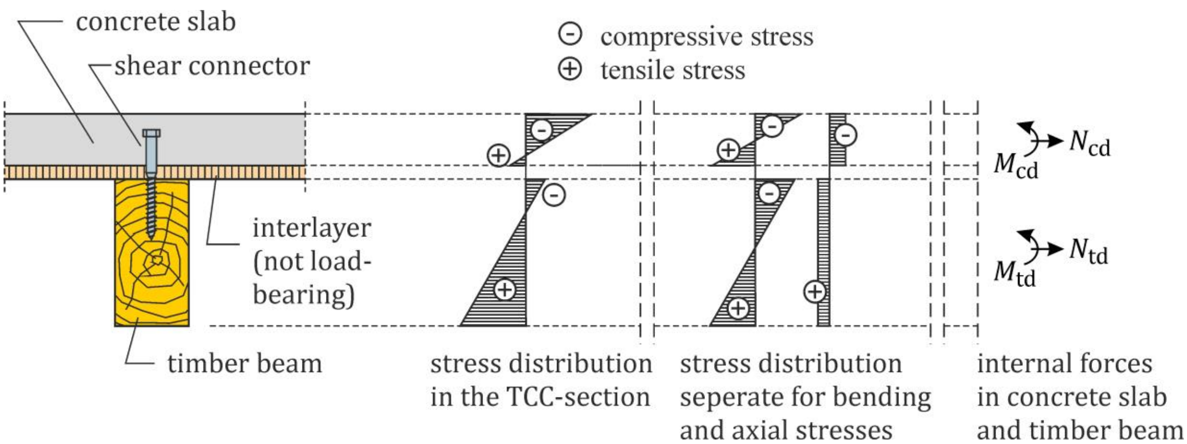

Figure 5: Determination of internal forces for timber beams and concrete slab

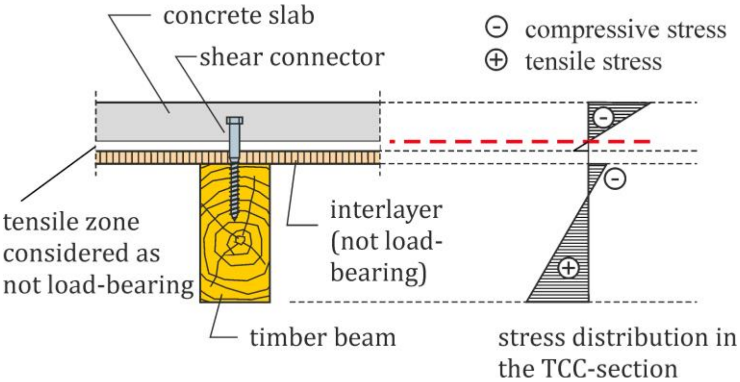

Figure 6: Consideration of the concrete tensile zone as not load-bearing

Based on the previous discussion, the application of plain concrete for the slab in TCC structures seems possible. But, besides the verification in parallel to the timber beam axis, additionally the load-bearing behaviour of the concrete slab in lateral direction must be investigated [7]. There are many possible situations causing bending moments in the concrete slab perpendicular to the timber beam axis, e.g. heavy single loads acting between the timber beams, heavy single loads acting at only one timber beam, varying span of neighbouring timber beams, and application of the TCC slab as part of the bracing system. Therefore, the application of plain concrete in TCC systems is only rarely possible. As mentioned before, also a steel bar or mesh reinforcement is not the ideal solution. Following, there is a need to look for other, more innovative types of reinforcement.

3. INNOVATIVE REINFORCEMENT FOR TCC SLABS

Innovative reinforcement types for TCC slabs must be able to bear tensile stresses in a region near to the slab surface. In this context, fibre reinforced concrete (FRC) and textile reinforced concrete (TRC) are promising materials.

FRC is mostly produced with steel or polymeric fibres. The fibres are able to bridge concrete cracks and to bear tensile forces after cracking of concrete resulting in a post-cracking tensile strength of concrete. There are different design rules for the calculation of FRC, e.g. fib Model Code 2010 [8]. The available design value for post-cracking tensile strength is mainly in a range between 1.00 and 2.00 MPa. This is enough to bear the tensile stresses and to establish FRC as a building material for slabs in TCC structures.

Typical reinforcement for TRC are textile meshes on the basis of glass or carbon fibres. The benefit of the application of TRC is the fact that there is no concrete cover needed to protect the textile reinforcement against corrosion. Therefore, the cover may be reduced to few millimetres resulting in a better position of the textile mesh in the tensile zone.

4. CONCLUSIONS

Steel bar or mesh reinforcement is of limited value for bearing tensile stresses in parallel to the timber beam axis of TCC slabs. Reasons are the low height of the tensile zone and the necessity of a concrete cover of at least 2 cm. In the result, the position of the steel reinforcement is near to neutral axis where only low tensile strains or even compressive strains are occurring.

Promising alternatives are the application of FRC or TRC. FRC is able to bear tensile stresses over the complete height of the tensile zone. When applying TRC, the textile reinforcement must not be protected against corrosion. Thus, very low concrete cover may be realized, resulting in improved position of the textile meshes within the tensile zone of the slab. Based on the mentioned benefits, it is to expect that the application of FRC and TRC will strongly increase in near future.

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