# Behaviour of Steel-Concrete Composite Truss Beams

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**Abstracts:** The design specifications of composite truss are included in the American standard (ASCE), however, in the European standards (Eurocodes), these construction systems are not covered. A finite element model was developed using the software CAST3M to investigate the behavior of the composite trusses. The influence of various parameters on the behavior of the composite truss and the shear connectors were analyzed. Further experimental study to verify the real behavior of these structures is described.

## 1. Introduction

Composite steel-concrete structures can be considered as one of the most economical systems for building and bridge structures, especially for greater spans. To create the interaction between steel and concrete it is necessary to prevent the relative slip between them using the shear connectors. Nowadays, different types of shear connectors are used. This concerns the welded headed studs, the Hilti brackets and the welded perforated shear connectors [Machacek & Cudejko 2009] [Machacek & Cudejko 2010]. In some situations, such as with precast concrete slab or to develop composite action in non-composite structures, shear connection is developed using bolts [Schaap 2004] [Hungerford 2004].

In general, composite systems give the possibility to get spans to the 20 m. The composite trusses can be used for even greater spans up to the 30 m, which allows better use of internal space without restricting columns. Composite trusses are appropriate also to meet the requirements for building height limitation, the need to run complex electrical, heating, ventilating, and communication systems.

Since the mid of 1960's, many investigations have been made in testing composite trusses mainly in USA and Canada, summarized in references [Machacek & Cudejko 2010] and [Samuelson 2002]. The experimental results led to design recommendations and specification of the American Society of Civil Engineers (ASCE) [ASCE 1996].

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In Eurocode, there is no particular recommendation for the design of composite truss, except the formulas in EN 1994-2: 6.6.2.3 [Eurocode 4 2005] for the local effect of a concentrated longitudinal force and the distribution of the longitudinal shear force into local shear flow between steel section and concrete slab. In fact, the longitudinal forces are introduced into the concrete slab only locally at points of the increase of the axial force in the chord, i.e. where the web members are connected to the compressed chord (nodes).

Longitudinal shear flow in composite trusses was analyzed by Machacek and Cudejko [Machacek & Cudejko 2009] [Machacek & Cudejko 2010]. Odrobinak [Odrobinak & Jutila 2002] dealt with the shear flow in a plate girder in the vicinity of support area.

In this study the influence of the degree of connection, represented by the connector diameter, the influence of the top chord section and the material characteristics of steel and concrete are analyzed pondering over the stiffness and the resistance of the beams and the shear forces in the connectors. The analysis is based on the finite element modeling. The specimens for further experimental analysis are prepared.

## 2. FEM Model

To simulate the behavior of composite truss, the software CASTEM was used. The geometry of primary model (Fig. 1) was chosen from the references [Machacek & Cudejko 2009] [Machacek & Cudejko 2010]. The top chord of the steel truss is designed as ½ IPE 220, the bottom chord is a rectangular hollow section RHS 60×60×4 and the web members are from RHS 50×50×3. The top chord of the truss is connected to the concrete slab (1500×80 mm) with headed studs connectors ($\Phi$ = 19 mm). All the components of the composite beam are modeled using beam elements with appropriate cross section. The web member elements are considered pin-ended but the chords are continuous.

The analysis was performed using the characteristic values of material properties. Simplified stress-strain diagrams of steel (S355) and concrete (C25/30) are shown in Fig. 2. The non-linear behavior of the shear connection was modeled using beam elements uniformly distributed with a regular spacing equal to 100 mm along the span and located between the neutral axis of the top chord and the concrete slab [Bujnak 2007]. In the model, virtual elastic-plastic material is used for the beam element in bending to represent the behavior of the connection in shear. The uplift effects between the concrete slab and the beam element, prevented by the axial stiffness of the beam element representing the connector, are neglected in the model.

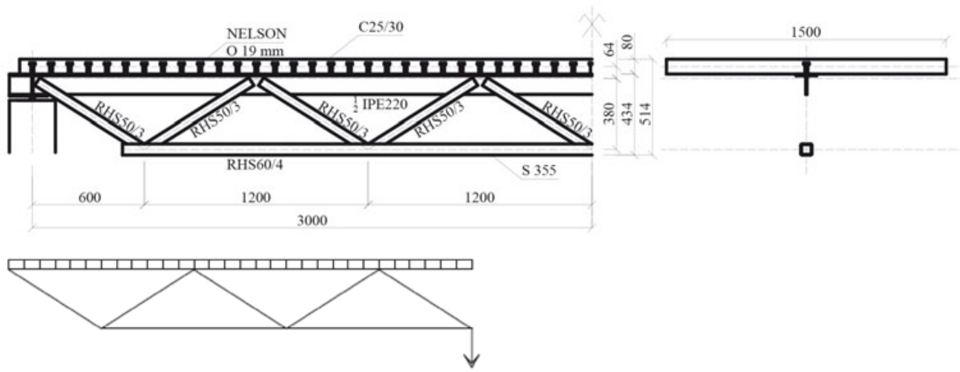


**Figure 1:** Geometric characteristics of the composite truss and the FEM model

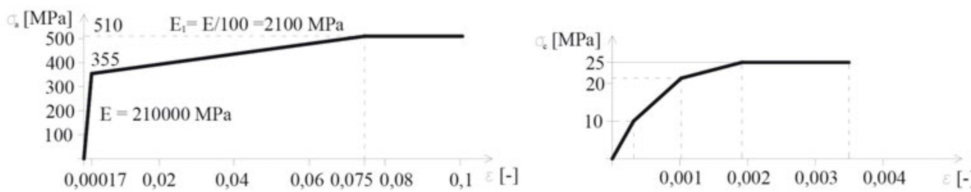


**Figure 2:** Stress-strain curves of the steel and the concrete used in the FEM model

As the results of the push-out test of shear connectors were not available, the following formula of Ollgaard for stud shear capacity [Ollgaard et al. 1971], based on the results of the push-out tests, was used:

$$P_{\max} = 0.336 A_d \sqrt{(f_{ck} E_{cm})} \tag{1}$$

The analytical expression of the evolution of the load – slip ($P_i - s_i$) curve is given by equation (2):

$$P_i = P_{\max} \left(1 - e^{-0.709 s_i}\right)^{0.4} \tag{2}$$

Loading of the truss was imposed at the central node of the bottom chord (Fig. 1). For elastic analysis, a load of 10 kN is applied and for plastic analysis the load is applied with a displacement control with a maximum value equal to 100 mm.

## 3. Results

In elastic analysis, the influence of the connectors is analyzed considering 360 theoretical values of diameter in the range 0.1 mm to 100 mm. These values represent the progression of the degree of shear connection in the truss from no connection to full connection. Their influence on the stiffness of the composite truss is shown in Fig. 3. It can be observed that the usual diameter of 19 mm is enough to obtain a full connection in the truss. Fig. 3 shows that the composite effect obtained by the shear connector diameter variation can increase even twice the stiffness of the truss with no connection and the truss composite beam with full connection.

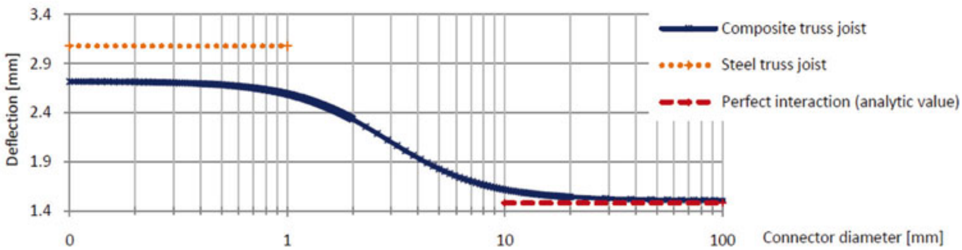


**Figure 3:** Influence of the connector diameter on the deflection of the composite truss

The next investigation of the effect of the top chord section on the composite truss, included primarily its area *A* and the moment of inertia *I*. The chord varied from ½ IPE80 to ½ IPE600 (18 different sections). In this analysis a full connection is considered and the distance between the top chord and the bottom chord centroids remains constant. The value of the distance between the centroid of the top chord and that of the whole truss, when the top chord parameters *A* and *I* increase, becomes greater in the elastic analysis and decreases in the plastic analysis (Fig. 4). For the top chord section with $A< 6.7\times10^{-3}$ m$^2$ ($I< 4.6\times10^{-5}$ m$^4$) this distance and the contribution of the top chord to the resistance of the whole section are greater in plastic analysis than in elastic analysis. For the analyzed truss configuration, the contribution of the top chord on the resistance of the whole section is 7 % in elastic analysis and 10 % in plastic analysis. Therefore, in accordance with these results, the ASCE [6] neglects the global contribution of the top chord to the resistance of the whole section.

In Fig. 5, it can be seen that the influence of the top chord section on the stiffness of the truss damps down with the increase of the degree of connection for all types of the degrees of connection. This influence is more significant for lower degrees of connections (no connection or partial connection) with small chord sections (lower than $1.5\times10^{-3}$ m$^2$). However for the real (and full) connection, the top chord section does not influence the stiffness of the composite truss significantly. The curves in Fig. 5 are drawn on the basis of the results of Fig. 3 where the full connection is represented by connector diameter of 50 mm, the real connection represented by the diameter 19 mm and the partial connection by the diameter 3 mm.

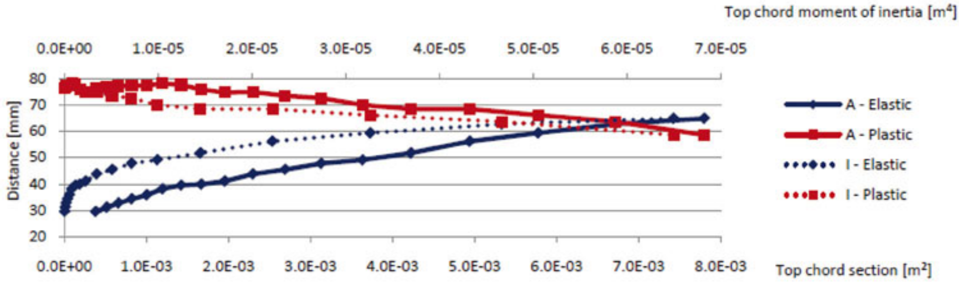


**Figure 4:** Distance between the top chord and the composite truss centroids (ϕ 19 mm connectors)

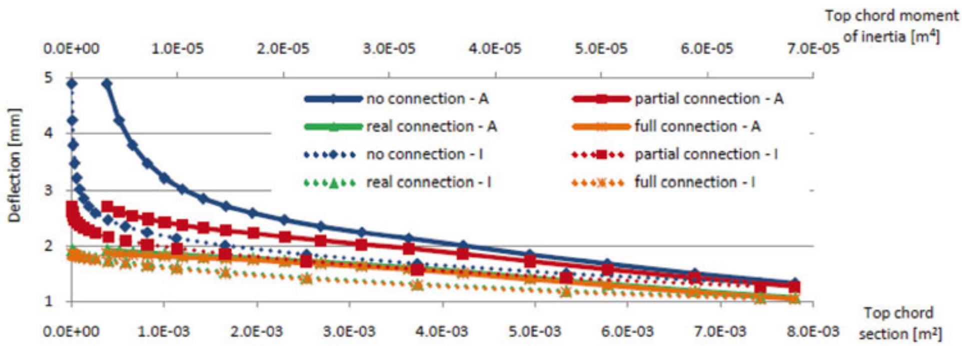


**Figure 5:** Influence of the degree of connection on the stiffness of the truss

The distribution of the shear forces in the connectors along the beams, provided by plastic analysis and for the displacement equal to 100 mm is shown in Fig. 6 for different top chord sections. It can be observed that the plastic deformation of the connectors gives uniform distribution of shear forces along the beam. This phenomenon is influenced by the ratio of geometry and resistance between the connector and the top chord section. Thus, it is necessary to optimize this ratio. Otherwise, the connectors in the panel area would transfer the predominant part of shear forces in comparison to the obvious zones on the chord between the nodes.

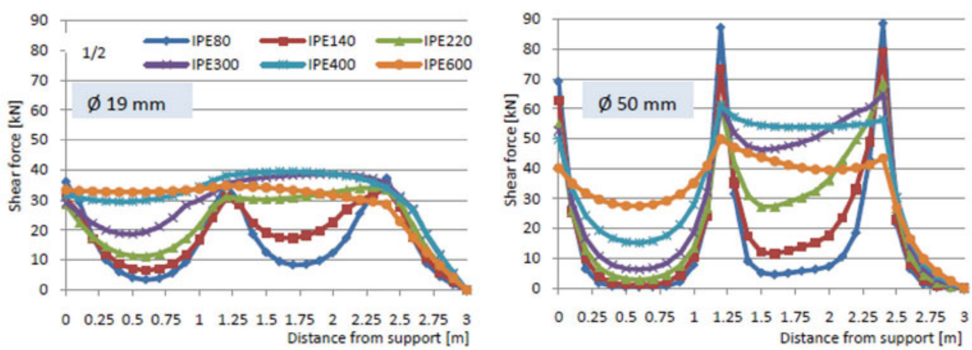


**Figure 6:** Influence of the top chord section on the shear forces in the connectors

The influence of the material characteristics of concrete and structural steel on the distribution of shear forces in the connectors was analyzed in the additional parametrical study. The concrete strength is an input value in one of the formulae used to calculate the shear resistance of headed studs (1). Therefore, the greater value of concrete strength can provide a better shear force transfer in the connection. However the concrete strength does not affect significantly the shape of stress distribution by connectors (Fig. 7a). Impact of steel strength of truss material on the shear force distribution in the connectors (Fig.7b) is small and can be neglected. However its influence on the resistance of the whole structure has to be considered.

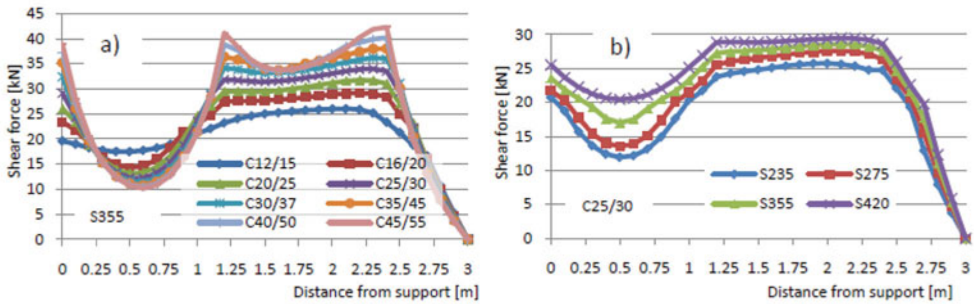


**Figure 7:** Influence of material strength on the shear force distribution in the connectors: a) influence of the concrete strength of the slab, b) influence of the steel strength of the truss

## 4. Experimental study

To analyze the real behavior of steel-concrete composite trusses, experimental program is prepared. Four same steel-concrete composite truss beams of span 3.75 m were produced (see Fig.8). Shear connection is provided by headed stud shear of diameter 10 mm and height 50 mm only just above the nodes (see Fig. 9). For this configuration, the hypothesis, that the longitudinal forces are introduced into the concrete slab only locally in the nodes, was followed.

Steel truss components were made from the steel S235. Upper chord of the beam was made from ½ IPE 160, bottom chord from two welded UPE 120, outside web members from square hollow section SHS 70x70x6.3 and the internal web members from the square hollow section SHS 40x40x3.

Concrete slab of size 800x100 mm was made with demand on concrete grade C25/30. Transversal and longitudinal reinforcement was formed from the bars ϕR10 (see Fig. 9).

Loading will be applied in the thirds of span (above internal nodes). During the testing the end slips, deflections of steel truss and concrete slab and strains on steel and concrete parts will be measured.

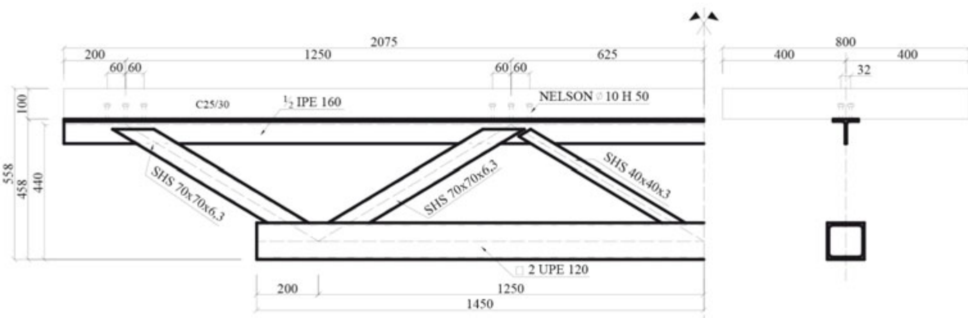


**Figure 8:** Configuration of steel-concrete composite trusses

**Figure 9:** Composite truss before concrete casting and the detail of the connection above the node

# 5. Conclusion

The influence of different parameters of the steel-concrete composite truss on its behavior was investigated by elastic and plastic analysis. The parametric studies showed that the top chord sections have no significant effect on the flexural stiffness and load carrying capacity of the composite trusses, because they are usually located very near to the neutral axis of the composite member. However, the top chord section has an important influence on values of the shear forces in the connectors. In fact, the ratio between the characteristics of the shear connector and the top chord section governs the distribution of shear force along the beam. It is necessary to optimize this ratio and to develop the rules for predicting the distribution of shear forces in the connectors for various ratios of shear connectors and top chord sections. In this way more efficient use of the connectors can be achieved.

The influence of material characteristics of the structure components presented the next subject of our study. It was found that concrete strength affect the connector resistance, but has no significant effect on the redistribution of shear forces in the connectors. Similarly, the steel strength of the truss has little influence on the shear forces in connection.

The improvement of this promising model is in progress on the basis of 3D model using solid elements and local damage evolution of concrete. The aim is to take account of the local phenomena such as the plastic deformation between the connectors and the top chord on all the length of the chord including the panel points.

The experimental program of bending test of composite truss beam would test the finite model and investigate real behavior of the composite truss with connection only above the nodes.

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