PERFORMANCE STUDY OF COMPOSITE TRUSS

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Summary: *The design specifications of composite trusses are only partially included in European standards. However this construction system can be considered as one of the most economical for building and bridge structures. In general, the composite trusses can be used for greater spans up to the 30 m, which allows better use of internal space without restricting columns. They are appropriate also to meet the requirements for building height limitation, the need to run complex installation systems. To create the interaction between steel and concrete, it is necessary to prevent the relative slip at the steel and concrete interface using the shear connectors. But the local effects of a concentrated longitudinal force and the distribution of the shear force between steel section and concrete slab, as special task, should be appropriately examined. The finite element analyse was used to investigate numerically this structural system behaviour, exploiting several computer procedures. Even experimental push-out testing could provide usefull results. The outputs of this research are presented in the paper.*

Keywords: C*omposite truss, shear connection, numerical and experimental study*

1. INTRODUCTION

Composite steel-concrete trusses can be considered as one of the most economical systems for building, especially for greater spans, commonly to the 20 m. The continuous structural elements of this composite type can be used for even greater spans up to the 30 m, which allows better use of internal space without restricting columns. The trusses are appropriate also to meet the requirements for building height limitation as well as the need to run complex electrical, heating, ventilating, and communication systems. Also composite steel bridges, whose carriageway deck is supported on a filigree steel truss structure and slim piers, are particularly preferable especially to ordinary concrete bridges. Primarily considering the technical and architectural aspects as well as compromise between protections of the landscape on the one hand and hard transports necessities on the other. Thus a composite truss bridge, with its speedy assembly engineering can be a structural type which is both economically and aesthetically attractive. To create the interaction between steel parts and concrete, it is necessary to prevent the relative slip at the steel-concrete interface using the shear connectors. But the

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local effects of a concentrated longitudinal force and the distribution of the shear force between steel section and concrete slab, as special task, should be appropriately examined. The finite element analyses can be used to investigate numerically this structural system behaviour, exploiting several computer procedures. Nowadays, different types of shear connectors are used. In our investigation, shear connection is developed using the welded headed studs. The outputs of this research are presented in the paper.

2. LONGITUDINAL SHEAR TRANSFER

2.1. Truss shear connection peculiarity

In Eurocode, there is no particular recommendation for the design of composite truss, except the formulas in EC 4 [1], clause 6.6.2.3 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 the case of a composite truss, the longitudinal forces are introduced into the concrete slab similarly only locally in the nodes, where the web members are connected to the compressed chord. In this study the influence of the degree of connection, represented by the connector diameter, the impact of the top chord section and the material characteristics of steel and concrete are analysed pondering over the stiffness and the resistance of the beams and the shear forces in the connectors.

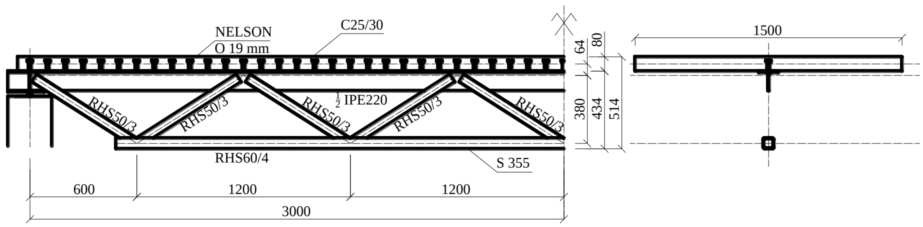


Figure 1. Structural geometry and acting loads

Figure 1 shows a typical portion of a reference composite sample, taken from the investigation [2], consisting of a concrete deck 1500.80 mm and a steel truss beam, whose the top chord was designed as ½ IPE 220, the bottom chord a rectangular hollow section 60.60.4 and the web members were from RHS 50.50.3. During the analytical phase of this composite truss, the finite-element-based software Castem [5] was used to evaluate the structural integrity of the system. Serious considerations had to be given to proper representation of the geometric characteristics. To ensure a full composite action, shear headed studs connectors 19 mm in diameter were welded at the interface between the concrete slab and the truss top chord to resist interface shear. Therefore, it was important during the initial modelling stages to take into account the node positions as key locations of interest. Thus the model with a higher degree of refinement could be assembled such that important results could be obtained at these zones. Proper type and shape of the elements had also to be considered since different mesh size could sometimes cause significant variations in results. The resulting computer model was

used to evaluate the structure system for actions, represented by a series of load cases applied to the structural model. An example of application of the loads is presented also in Fig.1.
The analysis was performed with the characteristic values of material properties and obvious aassumptions on elastic-plastic stress-strain diagrams of steel S355 and concrete class C25/30, commonly used in practice. 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. The analytical expression of the evolution of the load Pi and slip si curve is given by equation

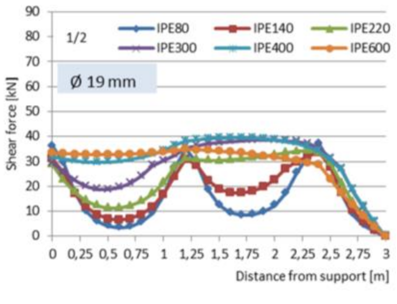
$$P_i = P_{max}\left(1 - e^{-0.709 s_i}\right)^{0.4} \qquad (1)$$

with the Ollgaard´ formula for stud shear capacity [3]

$$P_{max} = 0.336 A_d \sqrt{(f_{ck} E_{cm})} \qquad (2)$$

2.2. Shear connection properties

First of all the influence of the connectors size considering numerous theoretical values of shank diameter varying from 0.1 to 100 mm on truss beam stiffness was analysed. These values represent the progression of the degree of shear stud connection in the truss from no connection to full interaction. It was recognized that the usual diameter of 19 mm is quite sufficient to obtain a full connection. Moreover, the composite effect obtained by the shear connector diameter variation can increase even twice the stiffness of the truss with no connection in comparison to the composite truss beam with full connection.



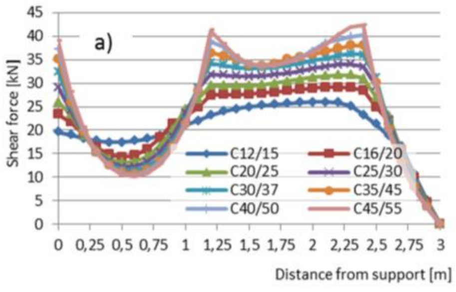


Figure 2. Influence of the top chord section and concrete strength on the shear force distributions

The results of the next investigation focused on the effect of the top chord section on distribution of the shear forces in the frequently used 19 mm diameter connectors along the beams are shown in Fig. 2a for different top chord sections. 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 portion of shear forces in comparison to the obvious zones on the chord between the nodes.
The influence of the material characteristics of concrete and structural steel on the distribution of shear forces in the connectors was analysed 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 (2). 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 as shown in Fig. 2b. Impact of steel strength of truss material on the shear force distribution in the connectors is small and can be neglected.

3. EXPERIMENTAL INVESTIGATION

3.1. Push-out testing

The shear capacity and the load-slip relation are the most important characteristics for the design of the composite structure. The standard push-out tests may be obviously used for finding approximately this relation. To investigate behaviour of connection with different configuration and spacing of the headed stud connectors, five sets labelled as SP1, SP2, SP3, SP4 and SP5, each comprising tree push-out specimens, shown in Fig. 3, were prepared.

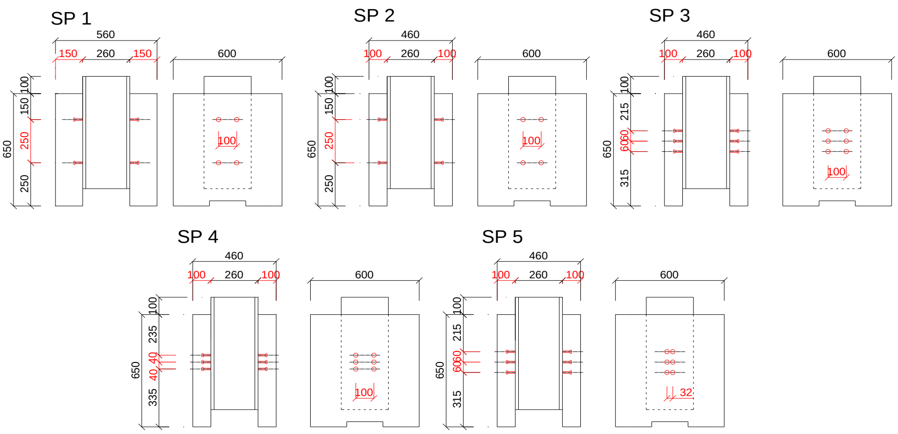


Figure 3. Details of push-out test specimens

Thus fifteen standard tests have been carried out. They consisted of a steel beam HEB 260, two concrete slabs attached to the flanges of the steel beam and stud connectors of steel S235J2 with a shank diameter of 10 mm and 50 mm in height. Slabs of concrete class C25/30 were 620 mm long, 600 mm wide. Only in the case of the first specimen

SP1, the slab thickness was 150 mm. The other specimens had slabs just 100 mm thick. In the specimens SP1 and SP2, the steel and concrete elements were attached by four stud connectors at each flange using automatic welding procedure. Six studs were welded at each flange of steel members SP3, SP4 and SP5. The longitudinal distances between the connectors differed, too. In SP1 and SP2, these spacing parallel to the loading direction was 250 mm, only 60 mm in SP3 and SP4, then 40 mm in SP5. Transversal spacing was160 mm, with exception of SP5 reduced at 32 mm. According to standard procedure of EC 4 [1], the load was applied in increments of 20 kN from 0 to 100 kN (40% of the expected failure load), then returned to 12 kN (5% of the expected failure load). Later loading was repeated 25 times between 12 kN and 200 kN. At each load increment, readings of the slip between the steel beam and the concrete were recorded. During this cycling loading the specimens remained in good condition, the slabs and the steel beam worked well together, the cracks had not yet been developed at that time. At the end of the 25th cycle, loading was changed from load control to slip control. The slip controlled load continued up to the failure at the speed of 1mm/2 min. At the load of 300 kN, the interface between steel and concrete was delaminated and the slip of 1 mm was achieved. Beyond the load of 300 kN, the cracks began to appear in the slabs. The test ended with the shear of the connectors at the load of 300 kN. The failure of the specimens occurred by shear of the connectors at the loads per one stud given in Table 1. Value *Pu,min* means minimum ultimate load carried by one connector and $P_{Rk,exp} = 0.9P_{u,min}$ equivalent experimental design value. Corresponding slip amounts are also listed in Table 1.

Table 1. Carrying capacity of single stud [kN] and slip value [mm]

specimen	$P_{u,min}$	$P_{Rk,exp}$	δ_{uk}
SP1	31,91	28,71	4,5
SP2	29,48	26,53	4,4
SP3	33,29	29,96	4,7
SP4	29,64	26,67	4,1
SP5	34,09	30,68	5,9

3.2. Numerical modelling

However, the full-scale push-out test remains also the time-consuming and costly option. Therefore the numerical analysis is adopted, once the verification of the numerical model with experimental results was established. For finite element modelling, nonlinear analysis software ATENA [6] was selected. It is capable to simulate a real behaviour of concrete structures including concrete cracking, crushing and reinforcement yielding. The three-dimensional linear four-node tetrahedral isoparametric elements were used to model the entire specimen. Because of symmetry, only a quarter of the push-out configuration was modelled. Fig. 4 shows the mesh used to represent a quarter of the push-out test specimen. The element size was 0.05 m for the elements of concrete slab and steel beam and 0.005 m for a head and a shank of the shear connectors. The head and the stud of the connectors were approximated by a hexagon. For the application of the support conditions, all the nodes of the concrete slab in the direction transverse to loading were restricted from moving in the Z direction to resist the compression load. All the nodes along the middle of the steel beam web and the bearing plate were restricted due to symmetry from moving in the X direction. All the concrete nodes, steel beam flange nodes, and steel beam web nodes, that lie on the opposite symmetry surface, were restricted from moving in the Y direction. The deformation controlled load was applied at the center of the steel web, as shown in Fig. 4b.

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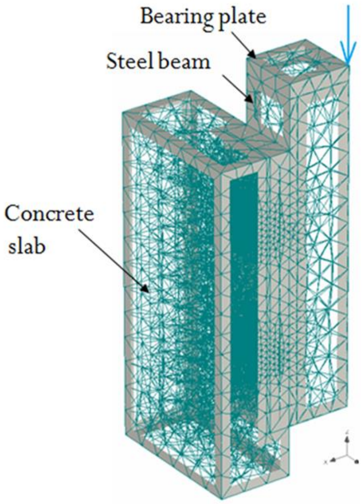
a)



b)

Figure 4. Real specimen and its finite element model

Load could be applied using the arc length method. An initial increment of displacement was given on the data line and the initial load proportionality factor was assigned to this initial increment using the automatic incremental scheme. This initial increment would be adjusted if the increment fails to converge. From then on the value of load after each increment was computed automatically. Concrete behaviour of slab in the push-out specimens was treated as an elastic-plastic material that was offered by the software. Only the average measured value of fcm = 28 MPa was set-up and entered as only one known input concrete property and the other values have been calculated by ATENA. The headed stud model has behaved like linear elastic material with modulus E = 210000 MPa up to the yield stress fy = 360 MPa. After reaching this value, the steel becomes fully plastic. The steel beam was modelled in this study with yield stress fy = 235 MPa using the analogous bilinear curve.

3.3. Result of push-out testing

Fig. 5 shows a comparison between the load-slip curves obtained experimentally and numerically using the finite element method. The load per stud was recorded from fifteen specimen tests, starting SP1 to SP5, illustrated by corresponding group of lines I-1 to V-3, respectively. Theoretical results from numerical analyses of the specimen set

SP1 are characterised by line FEM. Minimal values indicated in the picture are also in Table 1. Theoretical and experimental values of forces as well as slip confirm a good agreement between the test and the theory in the range of practically applied loading. The supplementary comparison of results can be judged also as rather good, if the extremely complex of material grouping and welding procedure are considered. The current move towards generating design data by using numerical models in place of experiments calls for careful attention to random variables. By considering experiments, random variables are usually represented implicitly, leading to a scatter in the results.

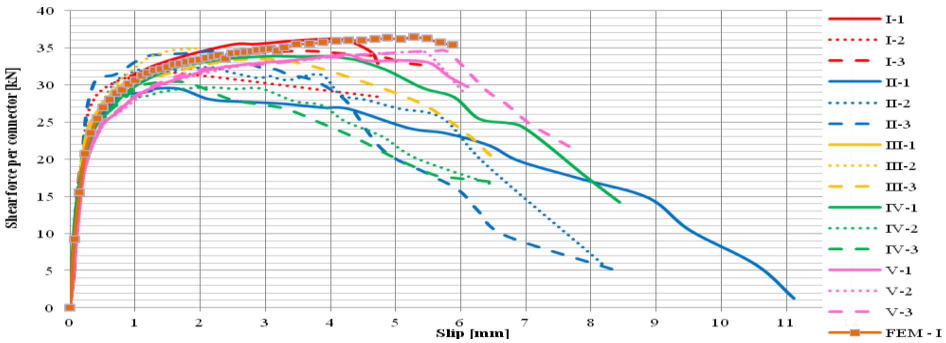


Figure 5. Comparison test and numerical results

Therefore, there is a need to further review the use of numerical model for producing reliable design data. Since local connection in truss beams is sensitive to choice of the stud location and properties as well as geometric characteristics in these composite structural elements, it would be particularly important to ensure that the variation of input parameters is accounted for.

4. CONCLUDING REMARKS

The improvement of this promising model is in progress on the basis of space analyses using solid elements and local damage evolution of concrete. The aim is to take into 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. Moreover, the experimental program of bending test of full-scale composite truss beams as the most suitable method to investigate real behavior would validate also the finite model of these slim, elegant and above all light and transparent composite elements, but with connection only above the nodes.

ACKNOWLEDGMENT

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STUDIJA PERFORMANSI KOMPOZITNIH REŠETKI

***Rezime**: Specifikacije projektovanja kompozitnih greda su samo delimično uključene u evropske standarde. Ovaj konstrukcijski sistem se, medjutim, može smatrati kao jedan od najekonomičnijih za strukture zgrada i mostova. Uopšte uzev, kompozitne rešetke se mogu koristiti za veće raspone, do 30 m, što omogućava bolje korišćenje unutrašnjeg prostora, bez ograničenja stubova. One su adekvatne i za ispunjenje zahteva u pogledu ograničenja visine gradjenja, kao i za potrebu sprovodjenja složenih instalacionih sistema. Da bi se ostvarila interakcija izmedju čelika i betona, neophodno je da se spreči relativno klizanje na njihovom interfejsu korišćenjem smičućih veznih elemenata. Medjutim, lokalni uticaji koncentrisane uzdužne sile i raspodela smičuće sile izmedju čeličnog dela i betonske ploče se moraju ispravno razmotriti, kao poseban zadatak. Analiza metodom konačnih elemenata je korišćena za numeričko ispitivanje ponašanja ovog strukturnog sistema, uz upotrebu nekoliko kompjuterskih postupaka. Čak i eksperimentalno testiranje istiskivanjem može da da korisne rezultate. Ishodi ovih istraživanja su prikazani u ovom radu.*

***Ključne reči:** Kompozitna rešetka, smičući vezni elementi, numerička i eksperimentalna studija*