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STUDY ON SHEAR CONNECTION BETWEEN BRIDGE STEEL TRUSS AND CONCRETE SLAB

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Abstract: *Behaviour of shear connection between steel and concrete parts of steel and concrete composite truss bridges from elastic phase up to plastic collapse is presented. The primary interest concerns the elastic and elastic-plastic distribution of longitudinal shear flow along the connection corresponding to design level of bridge loading. Results of 3D materially non-linear analysis using ANSYS software package is demonstrated together with approximate 2D elastic frame modelling of the shear connection used by designers. Results of both models are mutually compared and confronted with provisions of Eurocode 4 for composite bridges. The non-uniform distribution of the longitudinal shear required for design of shear connection of composite steel and concrete bridges (in both ultimate limit state including fatigue and serviceability limit state) significantly depends on rigidities of the shear connection, steel/concrete parts and concentration of the shear connectors above truss nodes. The most important results from parametric studies are presented and recommendations for practical design suggested.*

Keywords: Steel and concrete composite, Truss girder, Longitudinal shear, Shear connection.

1. Introduction

Composite steel and concrete trusses are used both in buildings as primary or secondary beams and in bridge structures. In ninetieth the comprehensive research (Skidmore et al., 1992) resulted in design recommendations showing wide range of design aspects. In accordance with these recommendations the plastic design can be performed correspondingly to the one of a common plate girder, including the design of a steel-concrete shear connection, provided the shear connectors are ductile.

The elastic design however, is necessary for class 3 and 4 cross sections, rigid shear connectors and generally in bridges (in both ultimate and serviceability limit states). In consequence the highly non-uniform distribution of longitudinal shear along steel truss/concrete slab interface caused by transmitting truss node forces into the concrete slab needs to be taken into account. Local effects of the concentrated longitudinal force introduced into concrete slab of a composite continuous girder due to prestressing were investigated by Johnson & Ivanov (2001) and introduced into Eurocode 4 for bridges (Johnson, 1997). Designers of bridges commonly use shear (vertical) force to calculate longitudinal shear, to which roughly add local effects due to differences of chord forces in truss nodes along estimated length. The detailed experimental and theoretical analysis of composite trusses behaviour both in elastic and plastic region was presented by Machacek & Cudejko (2009). The numerical model using ANSYS software and described briefly below proved to correspond excellently with the tests results.

In this paper the distribution of the shear flow along concrete-steel interface of composite truss bridge girders is analysed by 3D nonlinear analysis (MNA) using ANSYS software and simplified 2D elastic analysis (LA) by SCIA Engineer software. Results of vast parametric studies are shown and discussed.

2. Theoretical Analysis (3D MNA and 2D LA)

Several real bridges were studied, e.g. in city of Pilsen, Fig. 1. First the 3D MNA (materially non-linear analysis) using ANSYS software was applied, Fig. 1. The 3D reinforced concrete elements (SOLID65)

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were used for concrete slab, while beam (BEAM24) and shell (SHELL43) elements for steel parts of the truss. Shear connection using the load-slip stud connector diagram given by Oehlers & Coughlan (1986) was modelled by non-linear springs (COMBIN39) located at a suitable spot between the anticipated shear connector and concrete slab (no uplift effects were considered, see Machacek & Cudejko (2009) for more details). The model was applied to experimental trusses employing real steel and concrete properties and load-slip diagram of used shear connector. Both numerical and experimental central deflections and slips between steel truss and concrete parts were nearly identical and therefore the model may be considered as a benchmark for other models.

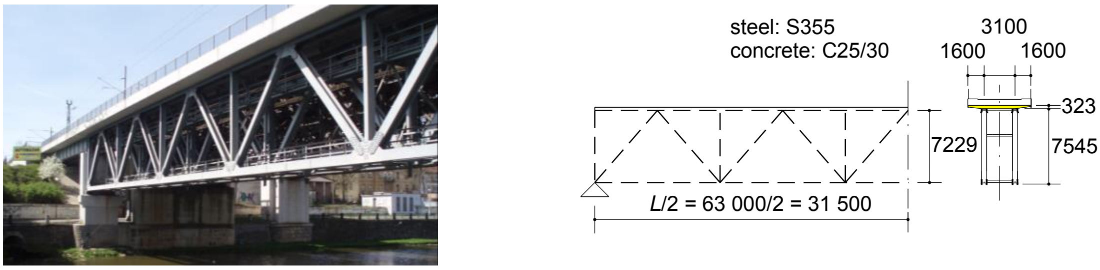

Fig. 1: View of the composite railway bridge and basic data.

For uniformly distributed loading and uniformly distributed shear connectors (headed studs of 19 mm dia, ultimate strength f_u = 450 MPa, located in 4 parallel rows and longitudinally in distance of 400 mm) the distribution of shear forces per connector is shown in Fig. 2 (left). After commencing plasticity in the bottom chord of the truss (approx. loading q = 270 kN/m) and following plastification of shear connectors (at approx. 82 kN) a rapid plastic shear flow redistribution yields into truss collapse at q = 325 kN/m.

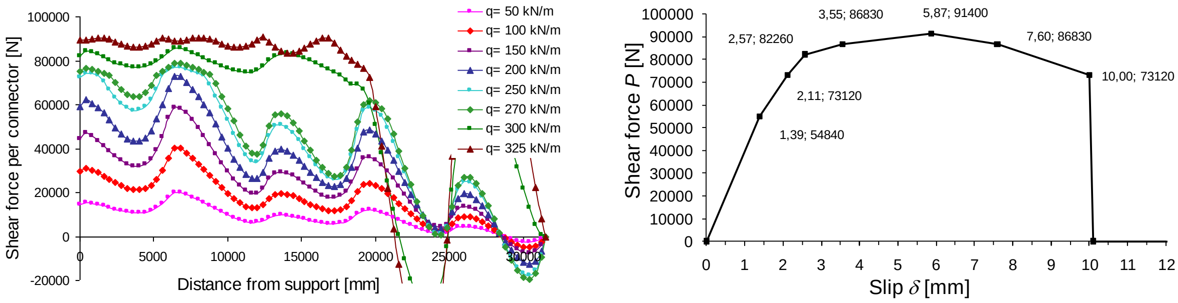

Fig. 2: Shear forces per connector and load-slip diagram of one stud.

Due to rather demanding 3D MNA another study using simplified elastic 2D LA with help of SCIA Engineer common frame software modelling shear connection as short cantilevers between steel truss and concrete slab was performed, which is considered convenient for bridge shear connection design. Only first linear parts of the relationships for both steel and concrete (Young's modulus E, E_{cm}) and linear substitution representing 4 studs at parallel position in accordance with first branch of diagram in Fig. 2 (right) were employed. The shear connectors were modelled as cantilevers of due stiffness sticking out from steel flange axis and pin connected at mid-plane of concrete slab represented by a concrete strut (neglecting slab tension zone) see Fig. 3 (left). Such approach relates to study of longitudinal shear only.

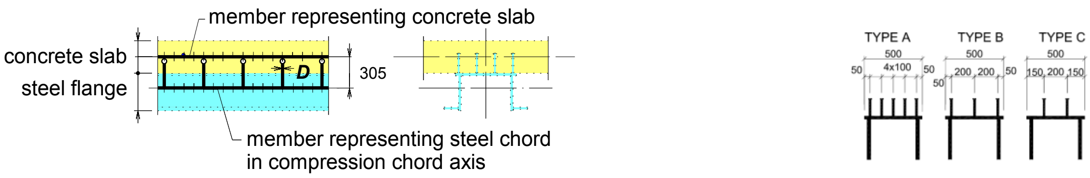

Fig. 3: Left: 2D model of shear connection. Right: Arrangement of studs in parametric study (Chapter 3).

Comparison of shear forces per connector resulting from simplified 2D LA under loading 200 kN/m (which is near to design bridge loading) and non-linear 3D MNA is shown in Fig. 4 (left). The simplified analysis reasonably imitates the ANSYS analysis, while conservativeness (higher values in shear peaks) of simplified elastic solution is obvious. Nevertheless, the simplified analysis seems to be appropriate for both practical design and parametrical studies. Eurocode 4 (EN 1994-2) distribution of the shear flow for loading 200 kN/m is also shown for both non-ductile shear connectors (inclined, trapezoidal distribution) and ductile ones (rectangular distribution) in Fig. 4 (right). Enormous conservativeness of the Eurocode is evident. Eurocode approach is based on brilliant 3D elastic studies by Johnson & Ivanov (2001), but apparently after abnormal simplification.

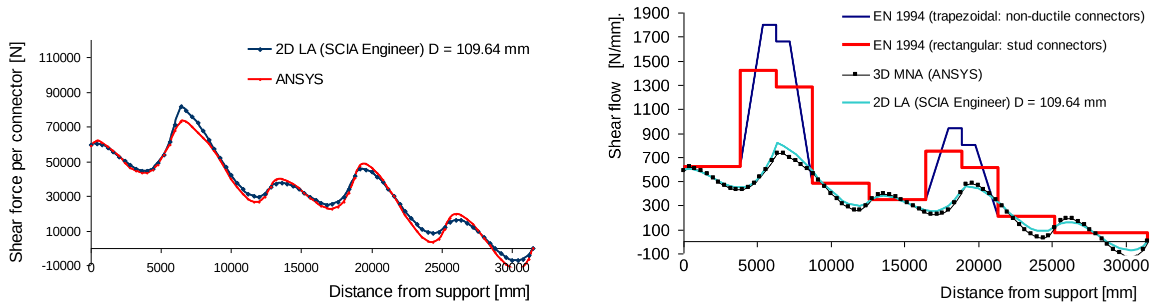

Fig. 4: Left: Shear forces per connector from 2D LA and 3D GMNA, loading 200 kN/m.
Right: Comparison of shear flow from both analyses with Eurocode 4, loading 200 kN/m.

3. Parametrical Studies

Detailed parametrical studies in simplified 2D LA were performed for various real bridge structures. Here only those concerning railway bridge shown in Fig. 5 are presented to show the fundamental significance of relevant parameters. Arrangement of shear connectors placed on upper truss chord is shown in Fig. 3 right). Load-slip relationship of welded studs with characteristic/design strength P = 81.6/65.3 kN was linearized up to 48.9 kN.

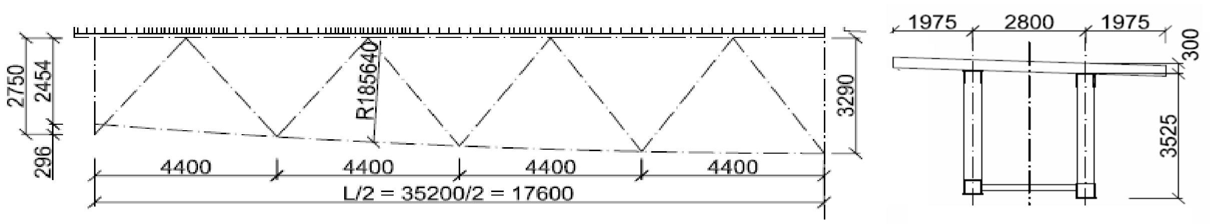

Fig. 5: Layout of the bridge.

This study deals with bridge loading LM71 in central position according to Fig. 6 (left) only, i.e. under unpropped construction and without supplemental dead loadings. Distribution of the shear flow (instead of shear force per connector) for various number of parallel studs uniformly distributed at 200 mm spacing is shown in Fig. 6 (right).

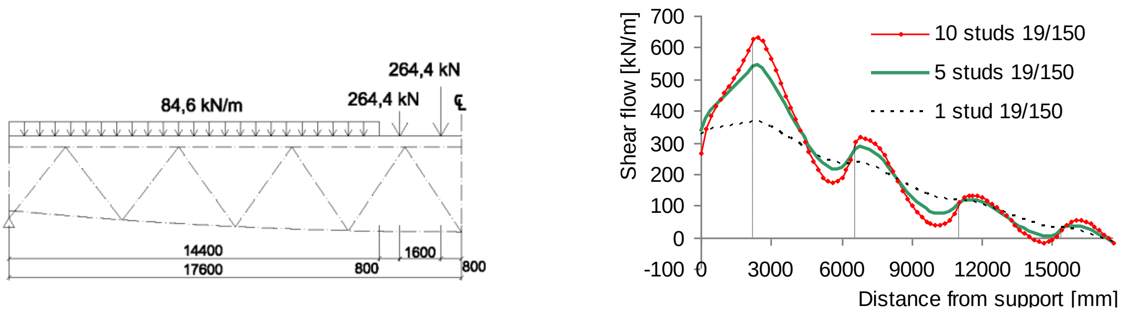

Fig. 6: Left: Relevant design Eurocode bridge loading LM71.
Right: Influence of shear connection stiffness (number of parallel studs).

The actual shear forces per one stud arranged as Type A (Fig. 3, right) depending on stiffness of the upper steel chord (second moment of area and corresponding area) and effective width of the concrete slab (initially 3375 x 300 mm) which were rearranged into half or doubled are shown in Fig. 7. In practice the shear peaks are covered by concentrated shear connectors. The densification necessary for successful design of shear connection produces considerable redistribution of the shear flow and attracts the shear flow to concentrated (more rigid) areas. Design of an optimum densification requires an iteration process.

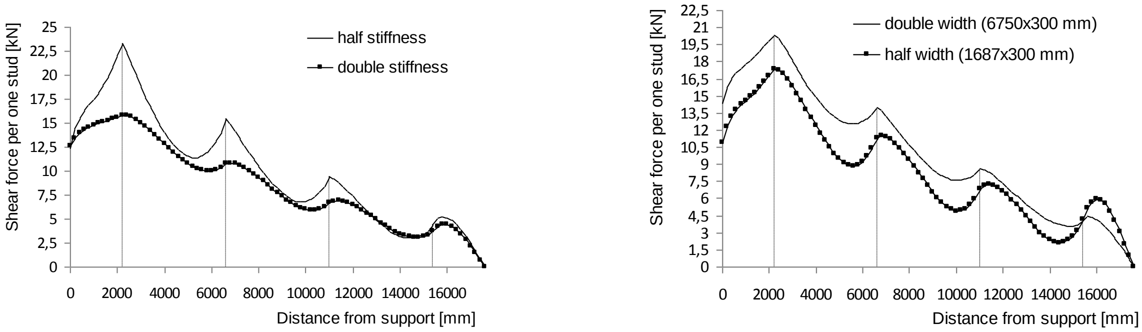

Fig. 7: Left: Influence of stiffness of the upper steel chord. Right: Influence of the slab effective width.

An example of shear forces per one stud, where initial 5 parallel studs in uniform 200 mm distance were densified above the first and second node, is shown in Fig. 8 (left). The concentration of studs within one quarter of node distances (proved to be optimal and marked as densified areas) corresponds to initial ratios of respective shear forces above the first and second node to the force at the third node (2.44 or 1.64, respectively). Obviously the redistribution is not fully optimal and need the second iteration. Other studies were focused on creep and temperature effects. E.g. creep effects on shear forces per connector for uniform supplemental dead loading 94.05 kN/m are illustrated in Fig. 8 (right).

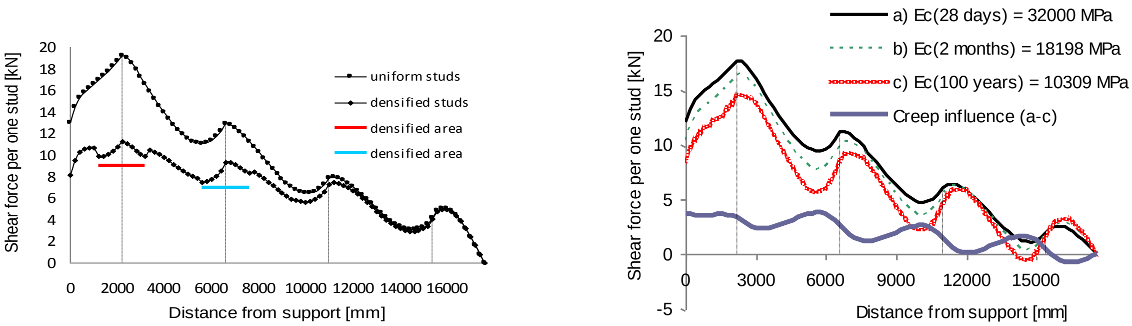

Fig. 8: Left: Shear forces due to densification of studs above the first two truss nodes.
Right: Influence of concrete modulus of elasticity (5 parallel studs 19/150, 200 mm spacing).

4. Conclusions

Proposed 2D LA model proved to be an efficient tool for parametric studies and correct design practice. The studies point to following results: The longitudinal shear peaks are more distinct for higher stiffness of the shear connection, less stiff steel chord and wider/thicker concrete slab. Optimum densification of shear connectors within a quarter of node distances is recommended and requires an iteration process. Effects of temperature and creep are similar as in common plated composite steel and concrete bridges.

Acknowledgement

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