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THE USAGE OF SMOOTH OPEN-SHAPED PROFILED SHEET IN A COMPOSITE STEEL-CONCRETE SLAB

A. Hrušovská[*], Š. Gramblička[**]

Abstract: *The steel-concrete composite slabs are often used as an alternative to monolithic concrete slabs due to the time and money savings. The trapezoidal sheets are used not only as a permanent shuttering, but can also constitute a tension reinforcement for positive bending. Design of composite slabs is regulated in Eurocode 4. The calculation of longitudinal shear resistance is very complex and can be determined only by testing on large scale samples to establish coefficients describing specific type of profiled sheeting. The usage of a smooth open-shaped profiled steel sheet is not involved in the Eurocode 4 although those sheet kinds are widely sold steel sheets worldwide. The research of smooth sheets, their interaction with concrete and a combination with end anchorages are therefore necessary. In this article we will describe the design of composite slabs with smooth open-shaped trapezoidal sheets and end anchorages, and the experimental verification on three large scale samples.*

Keywords: Composite, Slab, Sheet, Smooth, Anchorage

1. Introduction

The composite slab consists of a monolithic concrete slab and a cold-formed steel sheet. The main advantage of composite slab is in the absence of the additional shuttering. Frequent requirement of designers is to use steel sheet as a tension reinforcement for a positive bending in the critical cross-section.

The resistance of composite slab in the longitudinal shear is influenced by plenty of factors such as: the sheet thickness, shape and spacing of the embossments, the load distribution, length of the shear span, thickness of the concrete layer, the steel sheet tension, friction in the supports, the torsional displacement and many others. The connection between concrete and steel is provided by three factors: the physical-chemical adhesion (is influenced by surface properties during the casting and can be removed with higher levels of cyclic loading), the friction (is activated after the establishment of the first slip and do not depend on the size of the contact surface) and the mechanical wedge (is dependent on shape characteristics of contact surfaces and the extra connectors). Last two factors activate after appearance of first micro-cracks. When the slip between steel and concrete is completely prevented, we can speak about complete interaction, however most shear connectors have to undergo some deformation before they can supply any force. In this case the interaction is incomplete (partial), which is the most common class of the composite slab stiffness.

A composite action may be ensured by variable types of connectors (studs, perforated strips, block connectors, angle irons, different type of anchors etc.) or by shaping of the sheet ribs and flanges. According to the connection strength we know full or partial shear connection. The full shear connection is formed when the shear connection is so strong that the ultimate load is determinate by the bending moment resistance. This means, that the application of additional connectors cannot increase total resistance of composite slab. In the case of partial shear connection the failure of composite slab occurs after reaching longitudinal shear resistance value and the ultimate load depends on the number and type of shear connectors that can be also flexible or rigid.

[*] Ing. Andrea Hrušovská: Department of Concrete Structures and Bridges, Faculty of Civil Engineering, Slovak University of Technology, Radlinského 11; 810 05, Bratislava; SK, andrea.halabrinova@stuba.sk

[**] Doc. Ing. Štefan Gramblička, PhD.: Department of Concrete Structures and Bridges, Faculty of Civil Engineering, Slovak University of Technology, Radlinského 11; 810 05, Bratislava; SK, stefan.gramblicka@stuba.sk

According to deformation capacity flexible and rigid connection can be divided into: ductile and brittle (non-ductile) connection. The composite slabs with open-shaped sheets tent to act brittle while those with re-entrant shaped sheets ductile. Ductile behavior can be achieved by embossments, indentations or by adding connectors.

Design of composite slabs is regulated in the Eurocode 4 (EN 1994-1-1, 2004) The bond between concrete slab and the profiled sheet must be made in one of four ways or their combination: by adjustments on flanges or ribs of the sheets (embossments or indentations), by the re-entrant shape on the ribs creating a bond by friction, by anchorages (welds or other connectors) situated at the end of the slab only in combination with sheets described above or by end deformation of the re-entrant shaped ribs. The smooth open-shaped sheets composite slabs are not involved in the Eurocode 4.

2. The composite slab consisting of smooth open-shaped sheet and end anchorages

The design of slab with end anchorages is described in Eurocode 4 in chapter 9.7.4. The issue of longitudinal shear is defined as follows. If the test don´t prove enlargement of the longitudinal shear resistance by other shear equipment, end anchorages have to be designed to the full ultimate state tensile force. This applies only on slabs connected by adjustments on flanges or ribs of the sheets or by the re-entrant shape on the ribs. The longitudinal shear resistance can be calculated also by a partial shear connection method, when the shear resistance of sheet is enlarged by the shear resistance of additive connectors.

In case of sheets with smooth and open-shaped ribs the adhesion as a part of composite action must be neglected, so the whole longitudinal shear force must be supplied by shear connectors.

2.1. The design of composite slab consisting of smooth open-shaped sheet and end anchorages

Fig. 1: Installation of HILTI end anchorages.

For the design example the smooth open-shaped sheet RUUKKI T55-107L-976 with length 2,1m, the end anchorages HILTI X HVB 95 (Fig.1) and the class of concrete C30/35 have been chosen. The thickness of concrete layer is 110mm due to the design recommendations in Eurocode 4. The limiting values of deflection and bending moment of the profiled sheet in construction phase were verified as described in standard. It is necessary to set number of anchorages and their location in sheet ribs before analysis for the ultimate state in service limit phase is taken. If we would like to design slab for full shear connectivity, the number of connectors have to be calculated on full ultimate state tensile force:

$$N_p = A_{eff} \times f_{yd} \cong 270kN \tag{1}$$

The resistance of one anchor is influenced by the direction of anchor against the rib and the initial resistance given by the manufacturer, so the number of anchors will be:

$$\mathrm{n}_t = N_p / P_{Rd} = 270kN/28kN \cong 10 \tag{2}$$

Since the design is made on the slab width of 1 m, this means placement of 10 pieces of anchors into four ribs on each side of the slab. The condition of the minimum distance from the anchor edge to medium rib equal to 40 mm is limiting for our example (Fig.2). It means that only four anchorages on each side can be fitted to the slab with use of the selected sheet. Knowing this it was necessary to recalculate resistance to longitudinal shear and other ultimate resistances of section with partial shear connection method. The full shear connection in this type of slab is practically impossible, but as a partial connection is this solution sufficient and us designed slab can supply design load of 13,6kN/m^2 at 100% utilization in the longitudinal shear.

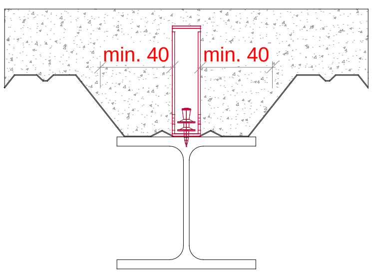

Fig. 2: Installation instruction given by manufacturer.

2.2. The experimental analysis of composite slab consisting of smooth open-shaped sheet and end anchorages

In the experimental program were verified three composite slabs as those described in Section 2.1.. The smooth open-shaped sheet RUUKKI T55-107L-976 with total length 2,2m (2,1 theoretical span), four end anchorages HILTI X HVB 95 on each side of slab and the class of concrete C30/35 were used.

Fig. 3: Composite slabs before casting.

The test was carried out as a four-point bending test (Fig.4). Following values were measured in each slab: deflection on the bottom edge of the slab in two ribs, deflection on the upper edge in the center of the slab and slip of the sheet and the concrete on both sides of the slab. The measured values were evaluated graphically.

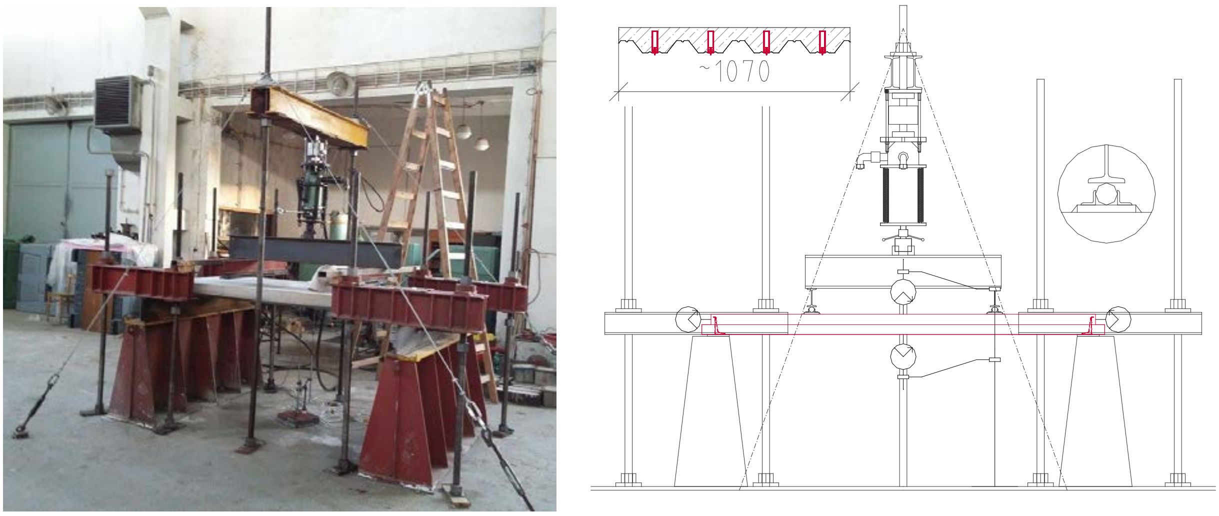

Fig. 4: The experimental set-up.

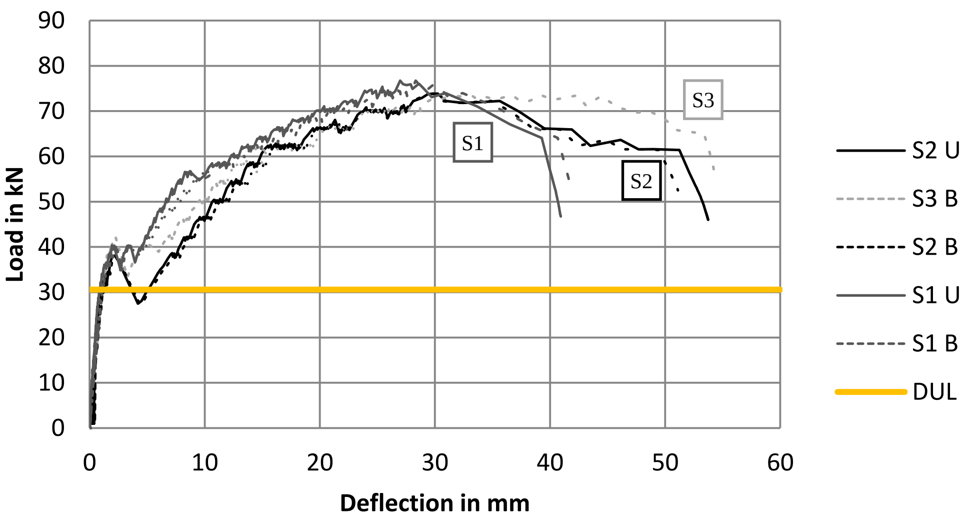

Fig. 5: The measured deflection.

Fig. 5. describes deflection, where S1, S2, S3 labels three slab samples and ending B or U are used for the bottom or upper edge measuring. Line named by shortcut DUL represents design ultimate load calculated in section 2.1.. The deflection capacity of tested slabs is markedly greater than calculated one, which means safety design. The deformation capacity can be classified as a ductile, what is caused by ductile connectors and behavior of these slabs resembles re-entrant slabs.

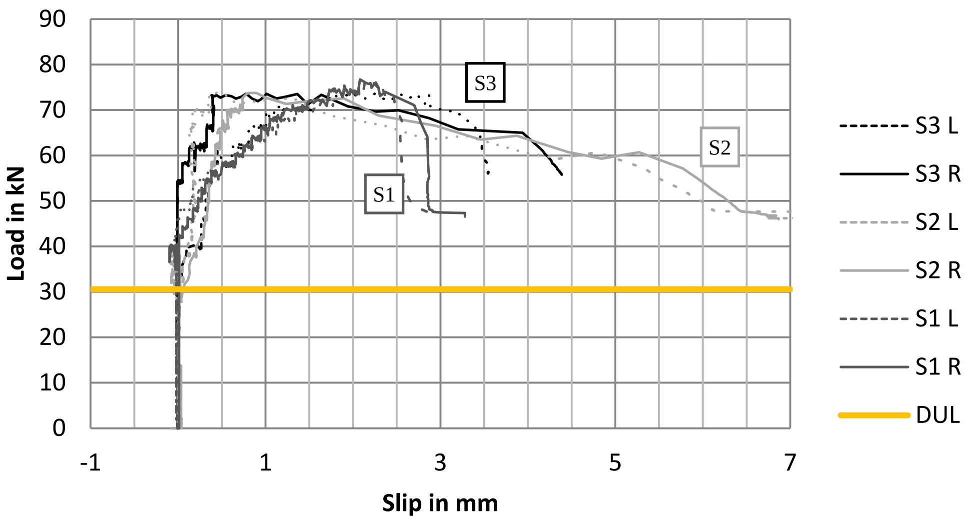

Fig. 6: The measured slip.

Fig. 6. represents slip of concrete layer against steel sheet, where ending L or R are used for left or right slab side measuring. Actually a zero slip was measured until reaching at least 38kN loading level in every case. The adhesion between the steel and the concrete is surprisingly high enough to supply designed load. Of course, composite slab cannot be designed without any anchorages, but added connectors may supply load after adhesion disappearance, which can be caused by higher levels of cyclic load or bad surface conditions during the casting. The course of slip curve is similar to those delineating slabs with profiled sheets with minor embossments although the used sheet has smooth opened ribs (Stark, 1990).

3. Conclusions

In this paper we demonstrated simple direction on how to design the composite slab with smooth open-shaped profiled sheet and end anchorages. The yet done experimental analysis showed satisfying result verification with sufficient reserve on the safe side. The partial shear connection method is an important option for the economic use of composite slabs in building industry, especially when it is practically impossible to place required numbers of connector to ensure full shear connection. We assume that the use of these slabs will have a wider application in the future and therefore future research is needed.

In the near future another three samples will be tested, two with the same proportions and connectivity parameters, but with another way of loading and one with the same dimensions, but without the end anchorages. The first two will be loaded till the first slip will appear and then the loading will start from the zero loading level again. The slab without end anchorages will allow us to do a comparison of adhesion behavior. A numerical analysis is also planned in the future.

Acknowledgement

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