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SOLUTION OF CONNECTION IN STEEL-CONCRETE COMPOSITE ELEMENTS USING A U-TYPE CONNECTOR

This paper presents a proposal for a connection for steel-concrete composite elements. It is realized using a U-shaped steel connector fastened with shot-in nails. Experimental tests were conducted, which confirmed the suitability of this solution for use in composite elements. The load-bearing capacity of the connector and its scope of application were determined. A numerical model of the analyzed connection was prepared, showing the compliance of the experimental results with the results of FEM calculations. Analytical calculations were performed, on the basis of which the required number of connectors was determined for different variants of steel-concrete composite beams. The proposed solution can be a supplement to the previously used methods of connection in steel-concrete elements, especially in building ceilings, where solutions eliminating the welding process are preferred for various reasons.

Keywords: Shear connectors; steel-concrete composite beams; non-welding methods; slip

1. Introduction

Composites are increasingly used in construction, constituting an interesting alternative to traditional materials. Thanks to the appropriate selection of individual ingredients, it is possible to influence their physical and strength properties in a specific way, aiming to obtain better parameters than in the case of their traditional counterparts. A special case of composites used in building structures are composite structures, in which, thanks to the appropriate connection of the component materials, we obtain better strength properties (bending load capacity, stiffness) than in the case of traditional reinforced concrete or steel elements. Research is being carried out on composites such as wood-concrete [1], bamboo-concrete [2,3], steel-wood [4,5] and polymer-concrete [6]. However, steel-concrete composites are most commonly used in construction as bridge girders [7,8] or ceiling beams.

The key issue in this type of solutions is to ensure an appropriate connection of the steel and concrete components. It is implemented using special connectors, the most popular of which are headed stud connectors [9,10]. They are characterized by relatively high load-bearing capacity and short assembly time, and are attached to a steel element by welding. Another type of connectors are sections of steel sections of various shapes [11] and perfobond shear connectors [12,13]. The connection of concrete and steel elements of a composite cross-section can also be achieved by appropriately shaping (cutting out) the web of the T-sections [14]. Non-welded connectors include various types of screws [15,16] also combined with epoxy resin [17] and Hilti X-HVB connectors [18]. This work presents a proposed solution in which the connection was made using a U-shaped steel connector, which may be an alternative to previously used solutions.

2. U-type connector

To connect the steel and concrete parts of the cross-section, a cold-formed U-shaped connector was used. It is connected to the steel section using shot-in nails and anchored in the concrete of the ceiling slab. Shear Connectors used in composite structures are usually attached by welding. The proposed solution is one of the few in which the connector is attached without welding. Additionally, in the case of ceiling slabs made on profiled steel sheets, the attachment of the connector and the sheet occurs simultaneously within the same assembly operation. The connector geometry is shown in Fig. 1.

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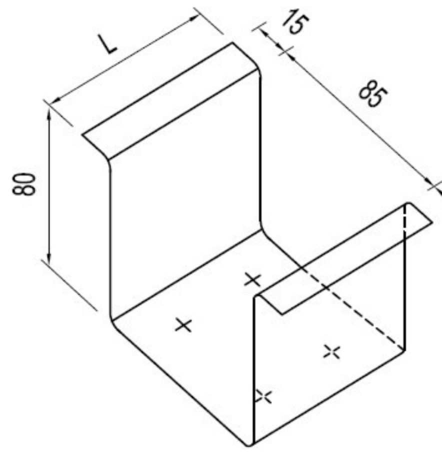

Fig. 1. U-shaped connector geometry

The shape of the connector was selected in such a way that it could transfer the stresses resulting from the separating force acting at the concrete-steel interface. The bending of the upper walls of the connector prevents the slab from detaching from the steel section as a result of vertical loads. The width of the connector base was designed so that it could be attached with four shot-in nails. The length of the connector is a variable value and its height allows it to be used in slabs with a minimum thickness of 10 cm.

3. Push-out test

In order to verify the adopted solution, experimental tests were carried out in accordance with the procedure contained in the standard [19]. Shear connection models were made in which the HEA 160 I-section made of S235 steel was used as the steel cross-section. Slabs with dimensions of 105 × 400 × 550 mm made of C25/30 class concrete were made on a T55 × 188 profiled steel sheet. The reinforcement consisted of a mesh of bars with a diameter of 10 mm and a spacing of 100 mm. Two variants of connectors were used: 60 mm long (the shortest length at which fastening with four shot-in nails is possible) and 100 mm. The wall thickness of each connector was 3 mm and the steel from which they were made was S235. Each fastener was attached using four Hilti ENP 2 shot-in nails. A sample for the standard push-out test is shown in Fig. 2.

Six test models were made, three for each connector length. The models were placed in a testing machine and subjected to loading. The loading procedure – according to [19] – consisted of repeatedly applying and reducing the load applied to the upper edge of the steel profile, which forced a shear force acting in the plane of the beam-plate contact. At each increase and decrease in force, the values of vertical displacements (slip) were read. Loads were applied starting from 10 kN, every 2 minutes the load value was increased by another 10 kN until 100 kN was reached. Then the model was unloaded to 10 kN, after which the load value was increased to 100 kN. This operation was repeated cyclically 25 times at 90 second intervals, measuring the slip values for

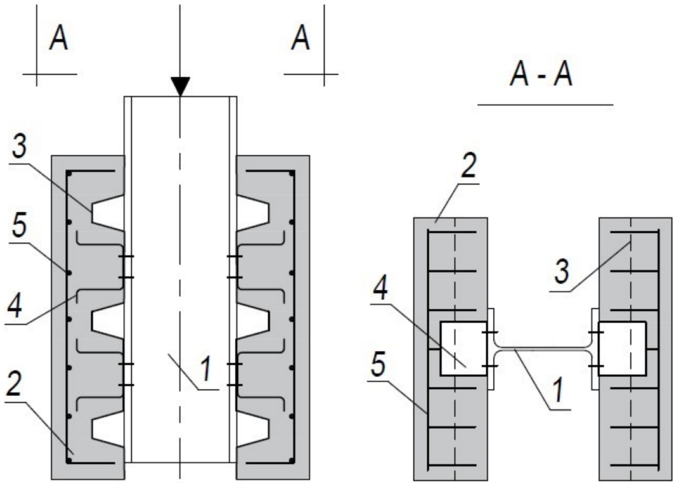

Fig. 2. Test specimen for standard push-out test: 1 – I-beam, 2 – concrete slab, 3 – profiled steel sheeting, 4 – U-shaped connector, 5 – reinforcing bars

each increase and decrease in load. After 25 full cycles, the load value was increased by 10 kN at 90 second intervals, continuously measuring displacements, until the model was destroyed. The maximum shear force for a single connector was: from 80.00 kN to 83.75 kN (for 60 mm connector) and from 86.25 kN to 87.50 kN (for 100 mm connector). In all cases, the same form of destruction was observed – the plate separated from the steel profile. One of the models after the tests is shown in Fig. 3.

Fig. 3. Tested model

Based on the results obtained, load/slip charts were prepared, on the basis of which the load-bearing capacity of the tested connectors was determined. The slip chart for a 100 m long connector is shown in Fig. 4, and for a 60 mm long connector in Fig. 5.

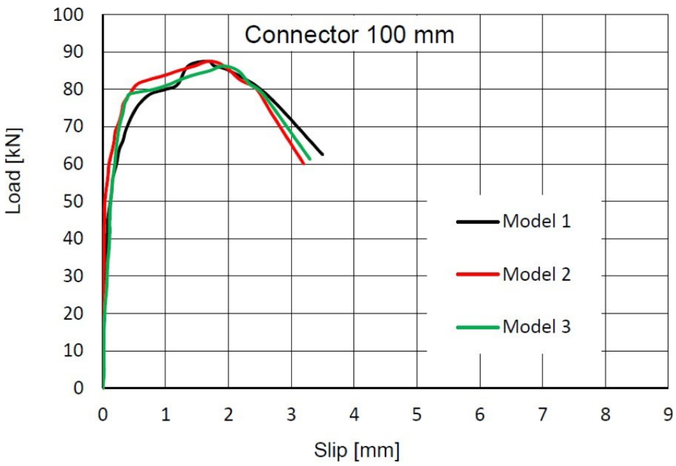

Fig. 4. Load/slip diagram – connector 100 mm

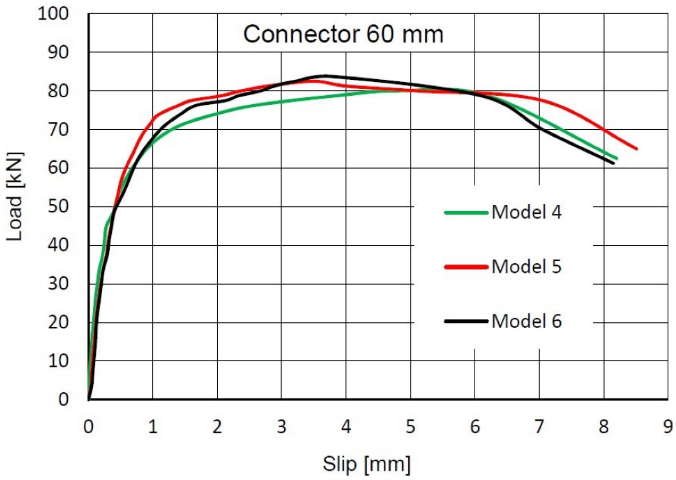

Fig. 5. Load/slip diagram – connector 60 mm

The design load-bearing capacities of the connectors calculated in accordance with [20] were, respectively: 54.7 kN for a length of 60 mm and 59.0 kN for a length of 100 mm.

4. Numerical analysis

The numerical model of the tested connection was prepared in the Ansys program based on the finite element method. All model components were declared as 10-node Solid type. It was assumed that the material and geometric data of individual elements of the model are identical to the results of experimental tests. For all steel elements of the model, an elastic-plastic material model, a volumetric density of 7850 kg/m^3 and a Poisson's ratio of 0.3 were assumed. Other material parameters are presented in TABLE 1.

For concrete, an elastic-plastic material model was assumed, as well as a volumetric density of 2500 kg/m^3, Poisson's ratio of 0.2, Young's modulus of 31 GPa and compression strength of 16.09 MPa.

A high convergence with the experimental results was obtained, both in terms of the nature of deformations and the size of displacements. Stress concentration zones in profiled steel sheet and connector are shown in Fig. 6.

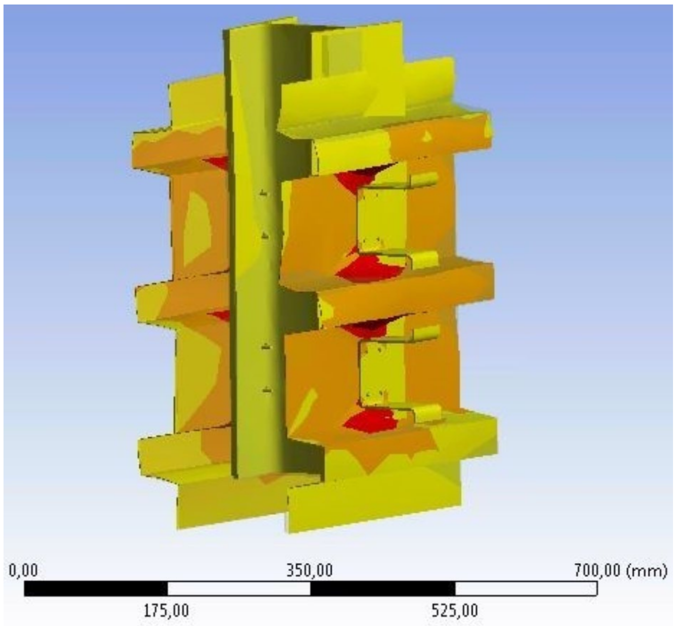

Fig. 6. Stress concentration zones in profiled steel sheeting and connector

The slip curve from the experimental model was compared (assuming its average value from all tests performed) with the slip curve obtained on the basis of numerical calculations. A high degree of convergence of the results for both curves was observed, which proves the correctness of the numerical model. A comparison of slip curves for the numerical model and the experimental model (for a 60 mm joint) is shown in Fig. 7.

The obtained convergence of numerical and experimental test results will be maintained also in the case of changing the material parameters of individual model components (e.g. changing the steel type). Changing the geometric dimensions of concrete slabs and their structure (e.g. slabs without profiled steel sheet) will result in the need to verify and validate the numerical model.

TABLE 1

Material parameters of the steel elements of the model

Parameter	Model element				
	I-beam	U-shaped connector	Profiled steel sheet	Shot-in nails	Reinforcement bars
Young's modulus [GPa]	210.00	210.00	210.00	210.00	200.00
Yield limit [MPa]	292.25	332.20	277.25	350.00	305.00
Ultimate tensile strength [MPa]	405.15	415.25	350.10	650.00	490.00

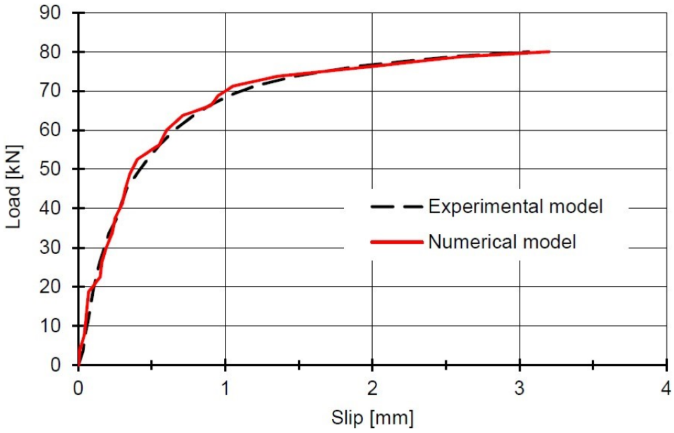

Fig. 7. Load/slip diagram – experimental and numerical model

5. Results of analytical calculations

In order for the steel-concrete composite to be treated as one cross-section, the key issue is to ensure adequate load-bearing capacity of the connection between the steel and concrete components, which is achieved using connectors. This load-bearing capacity should be not less than the value of the separating force acting in the plane of contact between the slab and the steel section. The discussed connecting method can be successfully used in steel-concrete ceiling beams. In order to assess its effectiveness, analytical calculations were carried out to determine the required load-bearing capacity of the composite corresponding to the separating force $V_{l.Ed}$ acting at the beam-slab contact and the required number of connectors n for different material and construction variants of steel-concrete composite beams.

The analysis adopted the scheme of a simply supported beam, with a spacing of 2.0 m, consisting of a regular I-section, combined with a concrete slab (concrete class C25/30), made on a T55 × 188 profiled steel sheet. The range of slab thicknesses considered was from 105 mm (minimum thickness of the ceiling slab for the T×55 × 188 profiled steel sheet) to 150 mm. Calculations were made for the material and geometric parameters of the connector identical to those in the experimental tests, for two connector lengths: 60 mm and 100 mm.

In order to compare the proposed solution with those used so far, comparative calculations were made for two other types of connectors, assuming the same height or as close as possible to the analyzed connector. The first is the Hilti X-HVB with a height of 80 mm and the same method of fastening as the U-type connector (using shot-in nails). The second is the Nelson stud welding connector (the most commonly used connector in composite structures) with a diameter of 16 mm and a height of 100 mm. The results are presented in TABLE 2.

The value of the separating force and, therefore, the required load-bearing capacity of the connection varies depending on the size of the steel section and the type of steel from which it was made. Changing the steel grade (from S235 to S275) with the same I-beam size increases the separating force by 15-17%. The difference in the value of the separating force between the smallest and the largest I-beam considered is 62.75% for S235 steel and 65.23% for S275 steel, which each time translates into an increase in the required number of connectors.

The smaller number of 100 mm long connectors (compared to 60 mm long connectors) results from their higher shear load capacity (approx. 8%).

Changing the thickness of the concrete slab in the considered range (105 mm - 150 mm) does not affect the value of the separating force.

The load-bearing capacity of the analyzed connector is higher in comparison to the Hilti X-HVB connector and to the Nelson connector, which in each case translates into a smaller number of U-type connectors necessary to transfer the separating force.

6. Conclusion

The value of the separating force $V_{.l.Ed}$ depends primarily on the cross-sectional size of the steel beam and the type of steel from which it is made. Increasing its dimensions and the steel yield strength causes an increase in the resultant value of tensile stresses in the steel element of the composite cross-section. This is accompanied by a shift of the neutral axis of the composite cross-section towards the slab/I-beam contact plane, which re-

TABLE 2

Required number of connectors n to transfer the separating force $V_{l.Ed}$

Beam span [m]	Slab thickness [mm]	Steel	I-beam	$V_{l.Ed}$ [kN]	n			
					Type of Connector			
					U-type 60 mm [pcs.]	U-type 100 mm [pcs.]	X_HVB [pcs.]	Nelson [pcs.]
7.5	105÷150	S235	I 180	665.65	24	23	97	28
			I 200	784.90	29	27	116	33
			I 220	928.25	34	32	138	39
			I 240	1083.35	40	37	161	46
9.0	105÷150	S275	I 180	767.25	29	27	114	33
			I 200	918.50	35	32	136	39
			I 220	1086.25	40	37	161	46
			I 240	1267.75	47	43	188	53

sults in an increase in the height of the slab's compression zone and a more complete use of the concrete's compressive load-bearing capacity. As a consequence, the bending load-bearing capacity of the beam increases, which is accompanied by an increase in the value of the separating force acting in the plane of the joint, which translates into a larger required number of connectors needed to transfer it.

As long as the neutral axis of the composite cross-section remains within the concrete slab (this was the case in the analyzed example), a change in the slab thickness does not affect the value of the separating force or the number of connectors. The calculated numbers of connectors for all considered variants allow for ensuring the required load-bearing capacity of the connection between the steel and concrete components and for their rational arrangement along the length of the beam.

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