Push-Out Test and FEM Analysis of Continuous Shear Connector

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Abstract. Composite steel concrete bridges with embedded continuous shear connectors are one of the newer popular options for short span (up to 20 m) bridges. They can be used for both road and railway bridges and due to their low structural height, nowadays, they are also a welcome alternative for bridge reconstructions – the concrete part serves as the bridge deck as well as the main structure. Unfortunately, In the Slovak Republic, no such bridges have been built as of yet (2020). At Technical University of Kosice, Department of Steel and Timber Structures, an extensive research regarding the steel shear connectors have been launched. Its goals are to bring new, easier for construction (due to prefabrication process), more resistant with even lower structural height, and more economical (due to lesser usage of materials and quick construction) geometrical solutions for composite steel concrete bridges as well as to open and popularize this solution for developers in the Slovak Republic. In this article, one of the new types is presented. It has a cross-section in a shape of a trapezoid, with holes in all its sides, except the bottom flange. Their purpose is to create concrete studs and secure full shear transmission with higher shear resistance, but they also serve to create space for transverse reinforcing bars. Its geometrical and material characteristics are closely specified. Results and process of push-out tests performed in Laboratory of Excellent Research onto three specimens are described and compared to results of finite element analysis simulation performed in Abaqus software.

1. Introduction
Among the first ones to study the continuous shear connectors were Oguejiofor and Hosain – firstly they compared a simple perfobond rib with 50 mm holes with the shear studs and proved the suitability of this shear component due to its similar resistance. The advantage of this type of shear connection was mainly easier construction (as shear studs are usually welded onto top flange of the I-beam). They also did one of the first numerical study of this component, performed in ANSYS software, where they modelled one quarter of a push-out test specimen. [1][2]

Zhang et. al in their research compared different hole diameters (40, 50 and 60 mm) – and therefore different diameters of concrete studs. The strongest was proved to be the rib with 16 mm thick walls including three 50 mm diameter holes 135 mm apart. [3]

The continuous shear connector described in this article is similar – although it is of trapezoid cross-section, it has similarly based holes – more closely described in the following chapter.
2. Shape of a shear connector
The connector described in this article is of trapezoid shape (see Figure 1). The bottom of the trapezoid is formed from the beam flange, with total width of 200 mm. Two sides of trapezoid are narrowed in 75° degree to 100 mm wide top metal sheet. Both sides as well as the top include holes to provide the shear connection via concrete studs and to ensure possibility of concreting inside of the trapezoidly shaped connector. They are of 50 mm diameter and 100 m apart, with top row shifted about 50 mm in contrast with the sides.

![Figure 1. Continuous shear connector with trapezoid cross-section in push-out tests’ layout.](image)

3. Push-out tests
Four push-out tests were performed onto the connector. The specimens, in the form as depicted in Figure 1, were poured into two concrete blocks, 600 x 600 x 200 mm big each and were put onto 1 cm heigh polystyrene, in order to be able to prevent pushing of steel directly onto the concrete and instead to measure only the shear resistance of the connector. The entire layout is visible in the Figure 2. After the concrete blocks got it strength, the specimens were put into the hydraulic press. [4]

![Figure 2. Push-out tests’ layout](image)
The experiments were performed via loading conditions and the slip of the specimen was measured with two inductive displacement sensors measuring the bottom of the steel parts in between the concrete blocks from both sides. At the 1/3 value of the expected shear resistance the cycle was performed to prove the elastic behavior of the specimens. [5]

![Figure 3. Results of the push-out test experiments](image)

The results of the experiments performed are shown in the Figure 3., from which it is clearly visible that each experiment had remarkably different results. This phenomenon occurred due to the buckling of the middle steel part (see Figure 4)– which was not supposed to move. After each experiment, the additional metal sheet plate was welded onto the middle steel part, however due to the extreme shear resistance of the trapezoid connector only one experiment was performed correctly – PT1c.

![Figure 4. Buckling of the specimen.](image)
4. FEM Analysis

Finite element analysis was created using Abaqus software. Material properties were measured experimentally first – tensile tests of steel; compressive tests of concrete – and were put into the software via diagrams with Yield Point of steel equal 315.3 MPa and compressive strength of concrete equal to 57.89 MPa. Material characteristics of concrete were considered normative. Dynamic, explicit step was chosen to perform the simulation. For interaction general contact was chosen. No additional setting between steel and concrete were set, as the results were already satisfactory. Loading in the Abaqus software exactly copied the real experiment – 166 loading conditions were put in via amplitude with step time 0.1 and with maximum single force of 2130 kN. In mesh module, C3D4 elements were chosen for steel and concrete parts and C3D8R for reinforcement bars. [6][7]

![Figure 5. Results of FEM Analysis](image)

In the Figure 5 the results of the FEM analysis are presented. As visible from the graph the numerical analysis showed lower slip during the first, linear, part of the diagram. However, in both cases the elastic behavior ended in similar loading conditions – 1450 kN in experimental analysis and 1250 kN in software analysis. If we were to consider any possible unevenness on the pad of the hydraulic press and put both graphs at to the same slip during the cycling loading, then the difference in the slip would be considerably lower.

5. Conclusion

Due to the buckling of the middle steel part during experimental research, the results of the research done of the trapezoid shear connector are insufficient. At least three specimens need to be correctly tested in order to prove the real shear resistance of the connector.

However, thanks to the numerical study, we can better predict the expect results – as it seems like the specimen marked PT1C was tested without any problems.
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