Shear Analysis of Perforated Steel Strip

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Abstract: The paper presented contains of analytical, experimental as well as numerical study of perforated steel strip – often referred to as perfobond connector developed at Technical University of Kosice. New geometrical option for such type of shear connector is presented and analyzed, with focus on shear connection – and therefore the push-out tests are the main topic of the article below.

Keywords: composite bridges; shear connector; steel strip; perfobond; push-out test.

1 Introduction

One of the first studies on of the perfobond strips done was performed by Oguejiofor and Husain. They used the steel strip, 127 mm of height, which included one row of 50 mm in diameter holes, located 45 mm axially from the top of the wall. By comparing this shear connector to the shear stud, which was and still is used as main provider of the shear connection in steel concrete composite bridges, the suitability of such a connection was proven [1, 2].

Vianna et al. did a deep study of layout of holes in perfobond strips. They used strips with zero, two and four holes, which also included two options of either passing reinforcement or no reinforcement. With this study they checked the relevancy of the formula used in Eurocode, which concluded positively [3].

Ahn et. al. compared a use of single or twin perfobond connector and development of the cracks regarding its use. They proved the twin connector to be 1.5 to 2 times as strong and it had a ratio of 0.60 of crack to ultimate load [4].

2 Geometrical attributes

The steel strip contains two rows of holes – which are its main geometrical attribute. After filled with concrete, they serve as concrete studs – and therefore strengthen the shear resistance of the strip. As depicted in the Fig. 1, the second row of holes was cut open. Both rows of holes were of 16 mm radius, with the top (open) row 10 mm axial distance from the top of the wall and the second (closed) row 25 mm distant. Both rows were shifted about 15 mm from each other in horizontal direction (vertical in Fig. 1 as for the push-out tests).

For the push out tests, the steel strip was made out of I-beam (specifically IPE200), which was cut in longitudinal direction into two strips.

Through several holes, reinforcement bars were put in order to secure the concrete blocks of the specimen in push-out test layout. In total, 8 reinforcing bars were used, each of 12 mm diameter.

3 Analytical study

Before conducting the experimental study, the presumed results were counted. Using formula (see Eq. 1) originally developed by Oguejiofor and Husain [2, 5], the expected results from experimental study were to be 735 kN. However, this equation does not consider the special characteristic of this continuous shear connector – the fact that the second, outside, row of the holes is cut open. For this reason the formula was adjusted into the form of Eq. 2, which substitute the diameter of the holes of the outside rows in the way that the areas equal.

$$P_{U,teor} = 4.50htf_c + 3.31nd^2\sqrt{f_c} + 0.91A_{tr}f_{yr}, \tag{1}$$

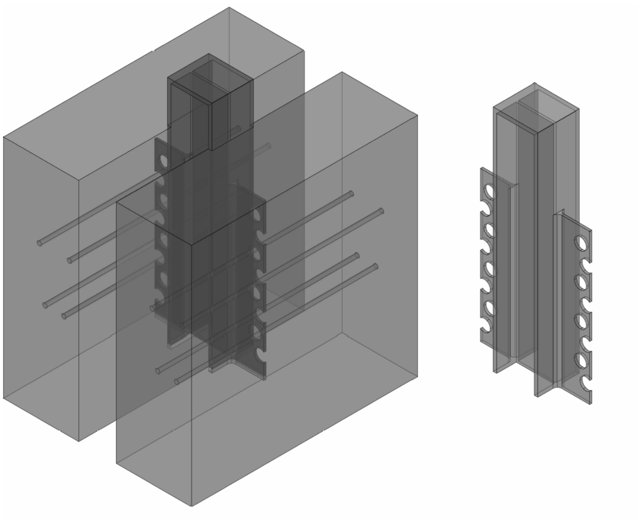


Figure 1: The layout of the perforated steel strip with two rows of holes in the push-out tests.

$$P_{U,teor} = 4.50htf_c + 3.31(n_1 d_1^2 + n_2 d_2^2)\sqrt{f_c} + 0.91 A_{tr} f_{yr}, \tag{2}$$

where *P* represents the expected shear resistance of the specimens; *f* represents strength of each material (with indexes *c* and *yr* representing concrete and reinforced steel, respectively); *A* represents the area of the reinforcing bars that cross the connectors holes; *h* and *t* represent height and thickness of the steel wall, respectively; and *n* and *d* represent number of holes as well as their diameter, respectively.

With the second, adjusted, equation (see Eq. 2), the expected shear resistance was lowered to 725 kN.

4 Experimental study

The normative push-out tests were performed. Two 600 mm long strips were welded vertically onto 100 mm wide middle steel part that served for transforming the pushing force from the hydraulic press into the steel strips, which were lying onto the 10 mm thick polystyrene, in order not to push directly to the concrete – as they were poured into the 600×600×200 mm blocks each. That way, only the shear resistance of the perforated steel strip tested would be measured [6].

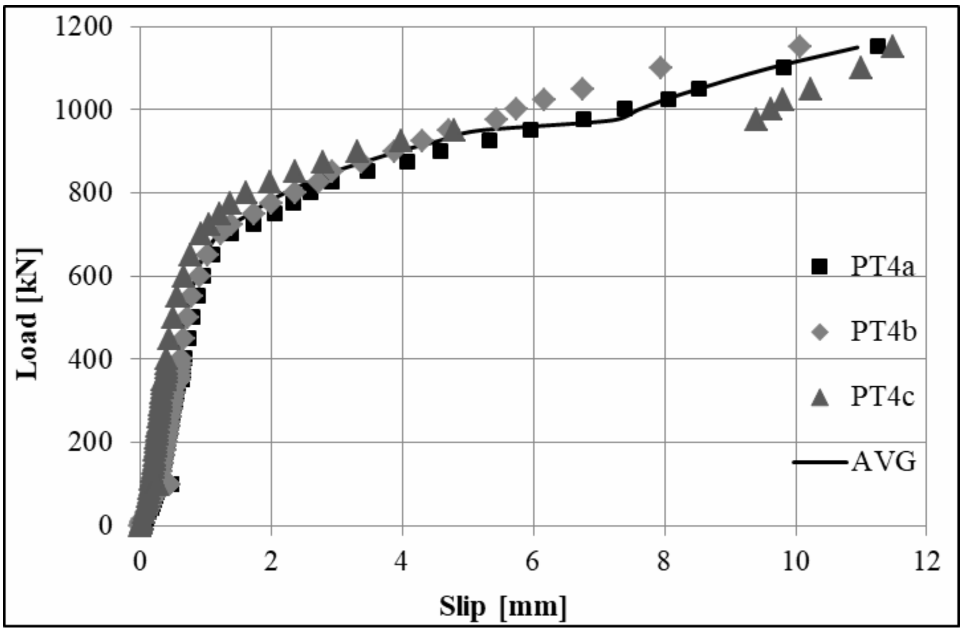


Figure 2: The push-out tests results.

All the specimens were loaded exactly the same by loading cycles. The maxim reached loading cycle included the force of 1150 kN from hydraulic press after the 10 mm polystyrene was compressed and the specimens developed plastic fractures.

The shear resistance of this type perforated steel strip was set at the point where the specimens stopped acting elastically – at the point of the graph (see Fig. 2) where the vertical part turns into horizontal part – which happened after the loading cycle equal to 700 kN.

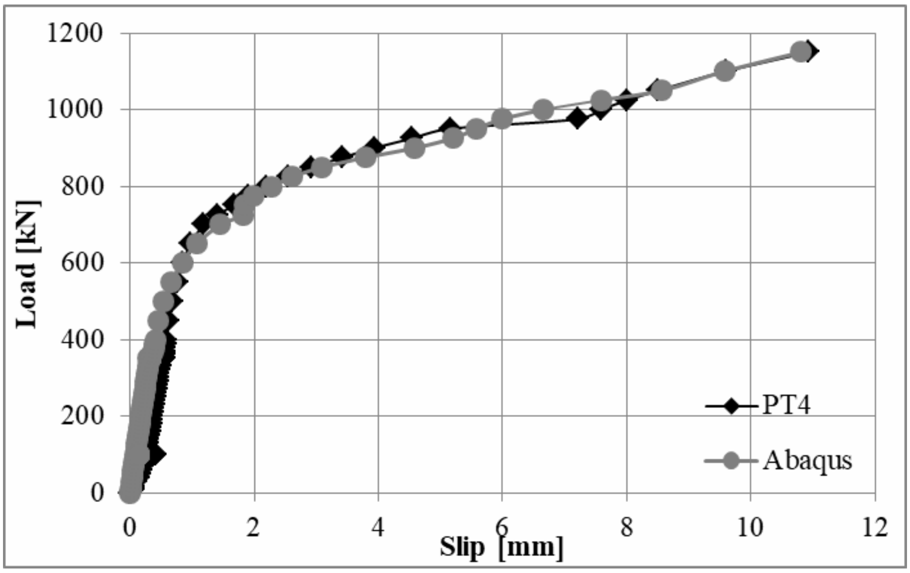
5 Numerical study

Finite element model was created using Abaqus/CAE software. The model created was the replica of the entire tested specimens, with its idealized geometrical measurements. It consist of around 1 million elements [7].

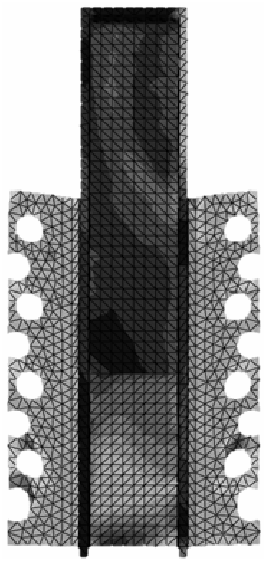
Material properties set in the Abaqus software were based on the experimental results of materials used. Compressive and tensile strength of concrete at the time of the push-out tests was 58 MPa and 7 MPa, respectively. Its Young Modulus was approximately 33.5 GPa. Yield strength of steel was measured by Faculty of Metalurgy, Technical University of Kosice, who determined it to be 315.3 MPa. Young Modulus of steel was not measured and therefore the normative value of 210 GPa was considered in the numerical study. Reinforcing bars used in the specimens were not tested, therefore only the normative values of their material characteristics were put into the software [7–11].

Dynamic, explicit step performed the analysis in the time of 0.1 s. Nonlinear geometry option was set on ON to take into consideration all the possible geometrical nonlinearities of the specimens during push-out tests [7].

One of the most important aspects of analysis of the push-out tests is the interaction between the two main materials – concrete and steel. In the Interaction Module the General Contact option chosen. To specify the connection, in this option the additional characteristic was added – the fraction coefficient between the touching surfaces of concrete and steel. Its value was 0.25 [7].



(a) the comparison between software analysis results and experimental results



(b) the deformated stressed perforated steel strip during the maximum loading cycle

Figure 3: The software analysis of the specimens during push-out tests.

As visible in the Fig. 3a the curve of the graph representing the numerical study from Abaqus software copied the curve representing the average experimental results sufficiently. The end of the linear section of the software curve was equal to the end of the linear section of the experimental curve with its value of 700 kN.

6 Conclusion

In conclusion, the value of 700 kN for shear resistance of the perforated steel strip is sufficient to secure full shear connection for future use in bridges. However, for use in bridges, flexural tests as well as fatigue tests need to be analyzed.

By adjusting the formula, the ratio between experimental study versus the analytical study was risen from 0.95 to 0.97, however for future use new regression analysis would be required.

The numerical study proved to be satisfactory and therefore can be used for future parametric study.

Acknowledgement

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