Effect of No, and size of shear connectors in shear transfer between concrete – steel in composite beam (push off test)

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1. Abstract

In this paper, an attempt has been made to review the effect of the number and size of shear connectors in shear transfer between concrete – steel in composite beams (push off test). This review aims to identify the most important shear connections for composite structures and reviews representative journal papers on the topic. It makes an attempt to cover the number and size of shear connections. The article concludes with a discussion of recent shear connector uses in composite structures. Comparative studies, which have been conducted by several researchers, were covered to address the applicability and the efficiency of various shear connectors. The scope of this review to improve the effect of numbers and size of shear connectors in composite beam. A guide line are limited to design of shear connectors, No equation is currently available for the design of shear connectors embedded in concrete slab. The results of monotonic push-off test are used to calibrate a proposed nonlinear finite element model were used to evaluate the accuracy of available equations for the prediction of shear connectors in concrete slab. This review tries to identify the shear connector that are the most relevant to composite structures and reviews their representative journal publications that related to this topic.

Keywords: Shear connector, composite beam, push-off test, shear bearing capacity, shear strength

2. Introduction

Composite structures made of normal weight concrete have been utilized since 1920, and as a consequence of the study, composite structures have been used widely for bridge construction since 1950. The basic design provisions published in the 1961 American Institute of Steel Construction (AISC) standard were the main development in constructing structures in the last decade. In research, the growth of these provisions was found. Shear connectors between concrete slabs and steel beams in composite construction can play an important role in the seismic response of a structure. They provide the necessary shear connection for composite action in flexure, and can be used to distribute the large horizontal inertial forces in the slab to the main lateral load resisting elements of the structure. During an earthquake, such shear connectors are subjected to reverse cyclic loading [1]. The strength of a stud is determined by the stud details (height, diameter, and strength) as well as the concrete environment (concrete property, reinforcement detailing, and so on). The current design methods in the codes for calculating stud shear strength are based on studs embedded in normal strength concrete test results. The behavior and shear strength of studs in high strength concrete are of interest as the usage of high strength concrete becomes more common [2]. The Stud connector is the most extensively used and known shear connector, having the advantage of being automatically welded. Other widely used connectors may also be referred, like the Channel connector, the C connector, or the Hilti connector fixed with an automatic specific device. Some other alternative shear connector's account for the contribution of the mechanical interlock formed in holes or other indentations drilled in plates that are welded to the beam flange. This is the case of the Perfobond connector, studied in the present work. Another type of connector, recently proposed is the T-Perfobond connector, associating the Perfobond connector to the T connector in this innovative connector the holes are drilled not into a single plate but into the T-stub web plate. Several authors studied in [3]. By connecting the steel girder to the concrete slab, it allows to transmission of shear forces at the steel concrete interface, thus, enabling the benefits of composite actions to be achieved. Prior to casting of the concrete slab, shear connectors are welded to the top of the steel girder in order to develop composite action in the construction of new bridges. To achieve the behavior of angle shear connectors in composite beam with high strength concrete slab, primary experimental push-off test on these connectors have been conducted. The results of these in case of shear capacity and ductility were compared and discussed [4].

2.1Standard push-off test:

The ability of the shear connector to transfer longitudinal shear force and the amount of slip at the

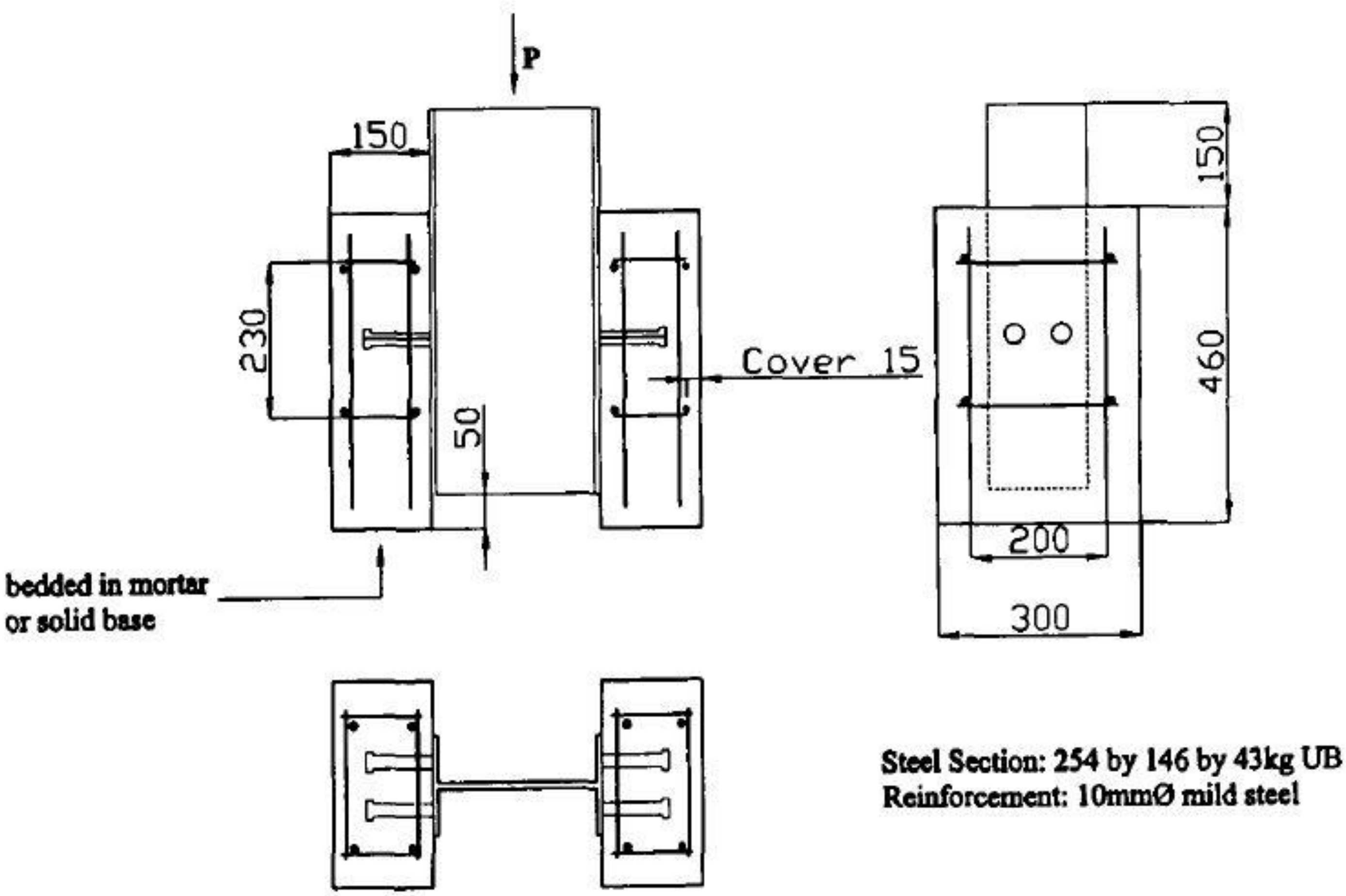

Fig.1. push off test specimen to CP117 & BS 5400 [6]

Objective

1- The overall aim of this study is to investigate the behavior and ultimate strength of various shear connectors used in composite beams.

2- The effects of No. and size of connection, as well as differences in its characteristics, on the behavior of composite beams.

3. Literature review

The concrete strength significantly affected the shear resistance of stud connectors. The increase of the maximum shear load was about 34% when the cylinder compressive strength of the concrete increased from 30 to 81 MPa. The test showed that the amount of slip at the maximum load was on the same level for both NSC and HSC specimens. However, ductile behavior of the studs was observed for the NSC specimens after the maximum load. The descending branch of the load-slip curves for the high strength concrete was short and steep [2]. It was discovered that increasing the number of holes in the connection increases the resistance, with a mean resistance gain of around 5% for each additional hole. When compared to other contributions, such as plate bearing or slab reinforcement, it was also concluded that the contribution of the concrete cylinders created through the perforations does not have a significant impact on strength. However, it is reasonable to conclude that at least one hole is required to ensure proper behavior and prevent an undesired uplift. For all of the perforated connections, the uplift was found to be regulated and of equal size. In terms of rigidity, it was shown that all the isolated perforated connectors without rebar present approximately the same stiffness up to their maximum load [3]. The experimental test exhibited brittle failure mechanism of the connections in order to evaluate behavior of concrete dowel shear connectors for longitudinal shear in shallow-hollow composite beams. The behavior of concrete dowel in shallow-hollow composite beams is not under pure shear stress, as evidenced by specimen failure and ultimate failure load values in push-out tests. As a result, the stress in the shear connections included not only shear stress down the length of the steel beam, but also potentially compression stress in the slab. Future research might be adequately planned as a result of this study [5]. To determine the shear capacity of the connector in the composite beam with precast concrete hollow cored floor slabs, a new horizontal push off test is proposed. The new test is compatible with the existing vertical push off tests, according to the findings. A series of push off tests are now being conducted to establish the shear capacity of the headed stud in composite beams with precast hollow core slabs as a result of this research [6]. The results and interpretations of push tests on shear connector devices for steel-concrete composite structures/bridges carried out. Different concrete grades and types have been used, like ordinary concrete, lightweight concrete, high strength concrete and lightweight high strength concrete, as well with as without steel fibers. The devices under investigation were headed studs, perfobondstrips, oscillating perfobondstrips, waveform strips and T-connectors. The tests have been done as specified in EuroCode 4 for standard push test. Sometimes unexpected behavior has been observed during testing, like brittle splitting failure in case of the (oscillating) perfobondstrip in normal concrete. A direct comparison for a specific shear connector device in combination with a certain concrete grade/type is possible [7].

Research has been carried out extensively to determine the behavior of various types of shear connectors. The purpose of this study is to go through the various types of shear connectors that may be found in composite systems.

HEADED STUDS

To resist horizontal shear and vertical uplift forces in composite steel-concrete structures, the most commonly used type of shear connector is the head stud. Also referred to as the Nelson stud (Figure 2), this type of connector contributes to the shear transfer and prevents uplift, as it is designed to work as an arc welding electrode, and, simultaneously, after the welding, acts as the resisting connector with a suitable head. As a result of the high degree of automation in the workshop or on site, this type of connector is commonly used worldwide. However, in structures submitted to fatigue, the use of this type of connector has some restrictions, the requirement for specific welding equipment and a high power generator on site for its use limits the utilization of such connectors. Another drawback is that the strength for concrete grades higher than C30/37 is normally governed by the strength of the steel cross section of the stud. Hence, higher concrete grades will not be advantageous for this connector device. Furthermore, it is practically impossible to automate the welding of headed studs. Much research has been carried out on headed stud shear connectors and various equations have been proposed to estimate the strength of studs

The AISC (2005b), CSA (2001) and Eurocode (2004) standards currently provide design equations for the calculation of the resistance of a stud shear connector.

$$\mathbf{Q_k = Kr\, Ø_s\, A_s\, (f_c\, E_c)^{0.5} \leq Ø_s\, A_s\, f_u}$$

Where:

$\mathbf{Q_k}$ stud connection capacity, **K and r** are the empirical factors of connection resistance and the reduction factor for slabs the factor K is 0.46 in Eurocode 4 (BSI, 1992) and 0.5 in the American code (Highway). The factor r depends on the shape and orientation of the connector as well as the geometry of the steel deck, $\mathbf{Ø_s}$ is the performance factor of the stud (engaged as 0.8), $\mathbf{A_s}$ is the cross-sectional area of the stud; $\mathbf{f_c}$ is the compression of the concrete; $\mathbf{E_c}$ is the modulus of elasticity for the concrete; $\mathbf{f_u}$ is the ultimate tensile strength of the stud.

According to previous researchers, there are several parameters that influence stud connectors. Among the most important are the shank diameter, the height of the stud and its tensile strength, as well as the compressive strength and modulus of elasticity of the concrete and direction of concrete casting. While evaluating the structural performance of the shear connection of the stud in precast deck bridges, the bedding height and the material properties of the filling material must also be taken into account

Due to the small space on the top flange, a dense distribution of shear connectors might create safety concerns for field workers. Thus, in composite bridges, various advantages and convenience can be obtained from the use of large studs, which are larger than 25 mm in diameter [8].

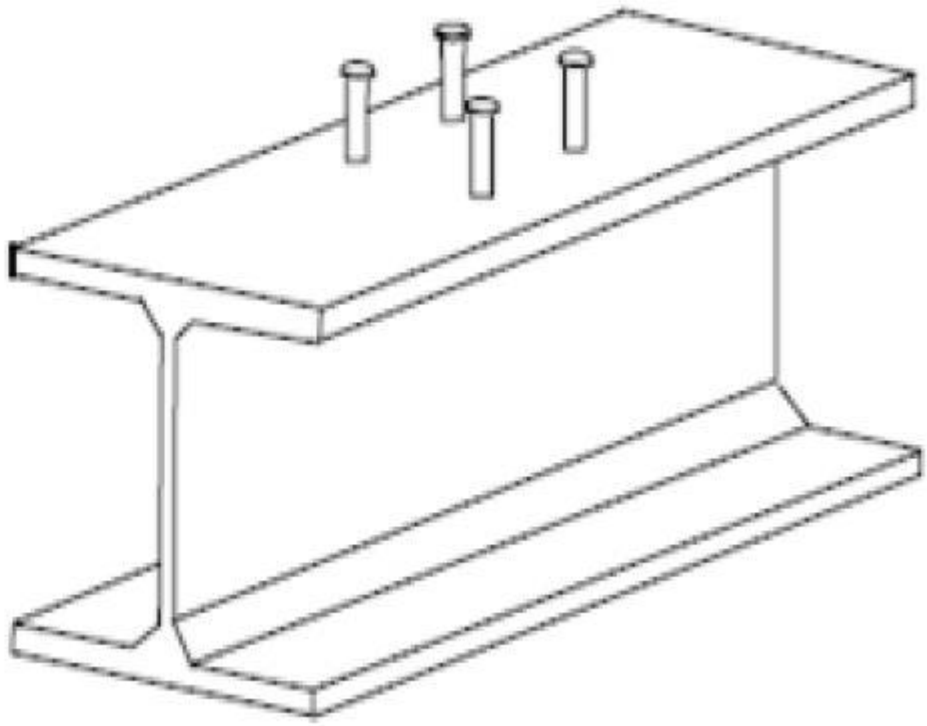

Figure 2. Head stud shear connector [2].

PERFOBOND RIBS

This connector includes a welded steel plate, with a number of holes (Figure 3). The flow of concrete through the rib holes formed dowels that provide resistance in both the vertical and horizontal directions. The fact that it not only ensures the concrete steel bond, but also enables a better anchorage of the internal columns hogging moment has encouraged its adoption. A study indicated that a one meter length of perfobond connector is comparable to eighteen 22 mm diameter studs disposed in two lines or twenty four 19 mm diameter studs disposed in three lines. Specifying some reinforcing bars in the hogging moment region is common in order to avoid concrete cracking, design of the connection does not normally take into consideration the extra resistance provided by its use. This connector aims to transfer the forces of the reinforcing bar directly to the column flange from the hogging moment region. The seated and double web angles are the other elements that exist in the internal and external connections the shear-capacity equations of perfobond ribs are expressed [9].

$$q_u = 0.590tA_c\sqrt{f_c'} + 1.233\,A_{tr}f_y + 2.871\,nd^2\sqrt{f_c'}$$

Where $f_{c'}$ is the compressive strength of concrete; f_y is the yield strength of steel; A_c is the shear area of concrete; A_{tr} is the area of transversal reinforcement that passes through the holes; **d** is the diameter of the perfobond rib holes; **n** is the quantity of perfobondrib holes.

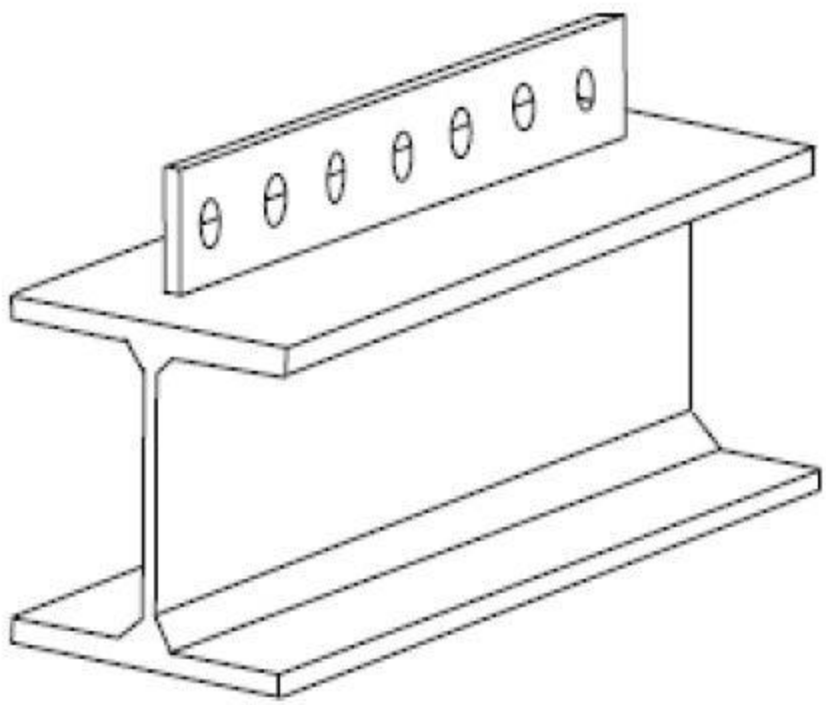

Figure 3. Perfobond ribs shear connector [9].

T-RIB CONNECTOR

In the scope of a study on perfobond connectors, presented an alternative connector for headed studs, called the T-perfobond. By adding a flange to the plate (Fig, 4), which acts as a block, the derivation of this connector from the perfobond connector was created. The need to combine the large strength of a block type connector with some ductility and uplift resistance arising from the holes at the perfobond connector web is a motivating factor for the development of this T-perfobond connector. In order to prevent a premature loss of stiffness in the connection, the T-rib connector detail should minimize the prying action effect. As leftover rolled sections can be used to produce the T-rib connectors, it could reduce cost and minimize welding work. The four steps involved in the fabrication process of the T-rib connectors: (i) initial profile, (ii) web holes, (iii) flange holes, (iv) opposite flange [9].

Figure 4. T-RIB shear connector [9].

OSCILLATING PERFOBONDSTRIPS

As compared to the headed studs and T-shape connectors, this type of connector has larger load capacity. However, due to the fast drop of the load capacity after the peak, the performance of this connector in the case of ordinary strength and normal weight concrete is rather disappointing. Nonetheless, the absence of such behavior when they are in use in lightweight concrete, concrete with fibers or high strength concrete allows the oscillating perfobond strips con-nectors (Figure 5) to perform well. The difference in the failure modes for lower and higher concrete strength for oscillating perfobond strip connectors should be taken into consideration. The addition of steel fibers to the concrete reported a very positive effect [8]

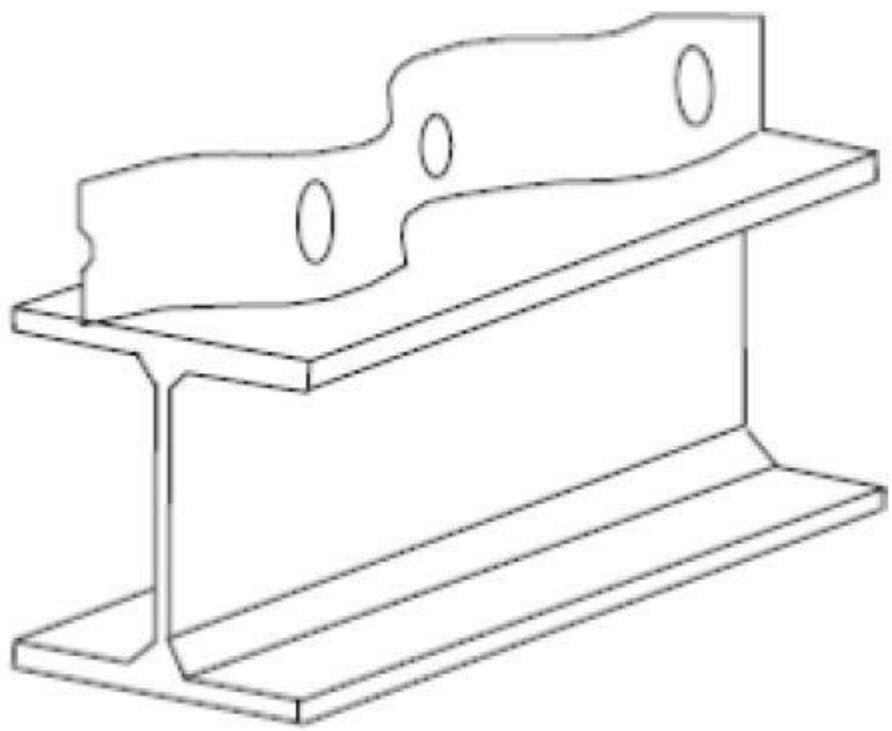

Figure 5. Oscillating-perfobondstrip shear connector [8].

WAVEFORM STRIPS

The objective of the curved form is to improve the transfer of force between the steel and the surrounding concrete as opposed to a straight connector. It is however recognized that it would be more difficult to weld using conventional automated welding equipment. The strips are welded to the HE-section with two fillet welds of 5 mm waveform strip with a width of 50 mm, a thickness of 6 mm and bend in 2 waves with amplitude 110 mm; Figure 6. Although the strip is meant to be welded using point weld equipment, such equipment with sufficient capacity is very scarce, and it is even doubtful whether the connector could be successfully welded using this equipment [8].

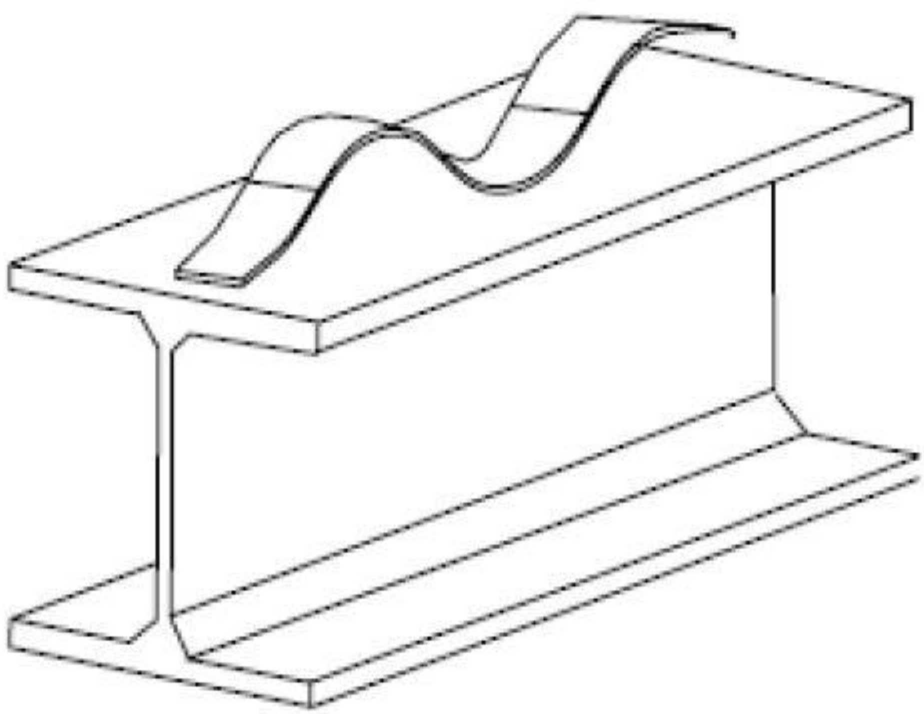

Figure 6. Waveform-strip shear connector [8].

T-CONNECTORS

This connector is a section of a standard T-section welded to the H or I section with two fillet welds. Therefore, a T section, which has a larger cross section than a single strip, and by its shape could prevent vertical separation between the steel section and the concrete, seemed a good alternative. The behavior of the T-connector is very favorable. The beating stress on the front of the T is very high, as a result of the relatively small area. Local concrete crushing occurs, which results in a quasi-plastic performance. The load capacity for Tconnectors is similar to that of the oscillating perfobondstrip, however, the ductility of these connectors is much larger. When used in concrete with fibers, lightweight concrete or a higher strength concrete, there is a notable increase in the load capacity and ductility of this type of connector [9].

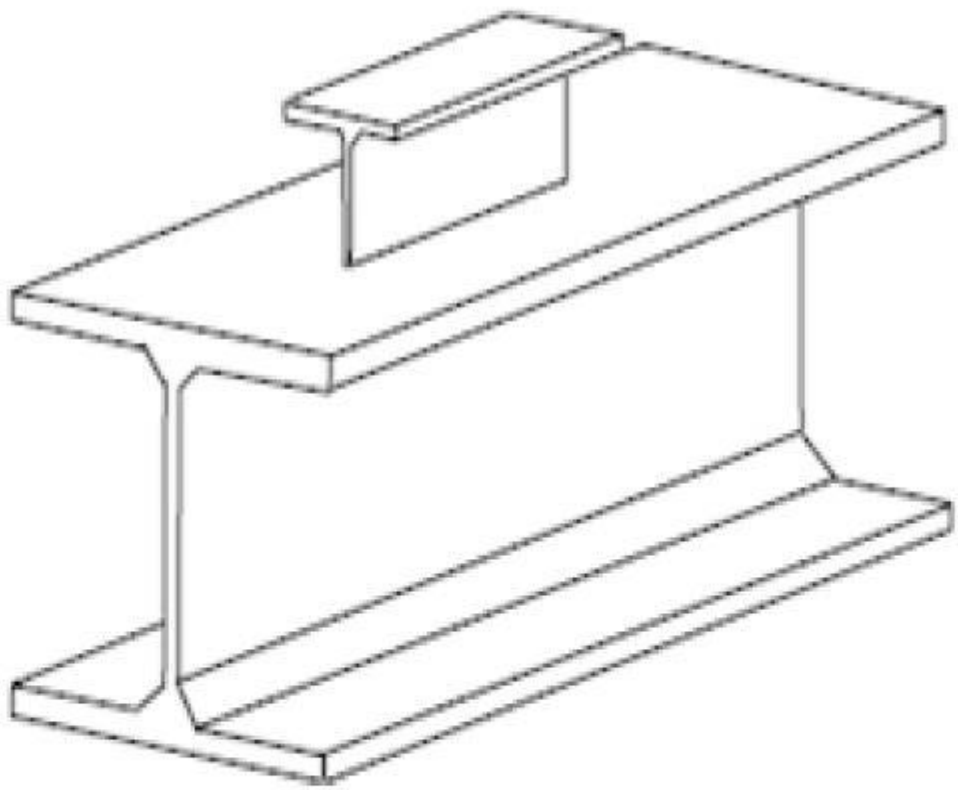

Figure 7. T shear connector [9].

CHANNEL CONNECTOR

Channel connectors might not need inspection procedures, such as bending test of headed studs, due to the highly reliable conventional welding system used in the welding of these connectors. The load carrying capacity of a channel shear connector is higher than that of a stud shear connector. This enables replacement of a large number of headed studs with a few channel connectors. Reported on the test results of full size and push-out specimens. test was carried out on push-out specimens made of plain concrete, reinforced concrete (RC), fiber reinforced concrete (FRC) and engineered cementations composite (ECC). Based on the results, the reversed cyclic shear strength of most specimens is lower than their monotonic strength by about 10 to 23%. The results also indicated that the shear strength and load-displacement behavior of the specimens is slightly affected by the use the polypropylene fibers (FRC specimens)the following equation for the calculation of the strength of a channel shear connector embedded in a solid concrete slab [9].

$$Q_n = 36.5(t_f + 0.5t_w)L_c\sqrt{f_c}$$

$\mathbf{Q_n}$ is the nominal strength of one channel shear connector (N); $\mathbf{t_f}$ is the flange thickness of the channel shear connector (mm); $\mathbf{t_w}$ is the web thickness of the channel shear connector (mm); $\mathbf{L_c}$ is the length of the channel shear connector (mm); $\mathbf{f_c}$ is the specified compressive strength of the concrete (MPa).

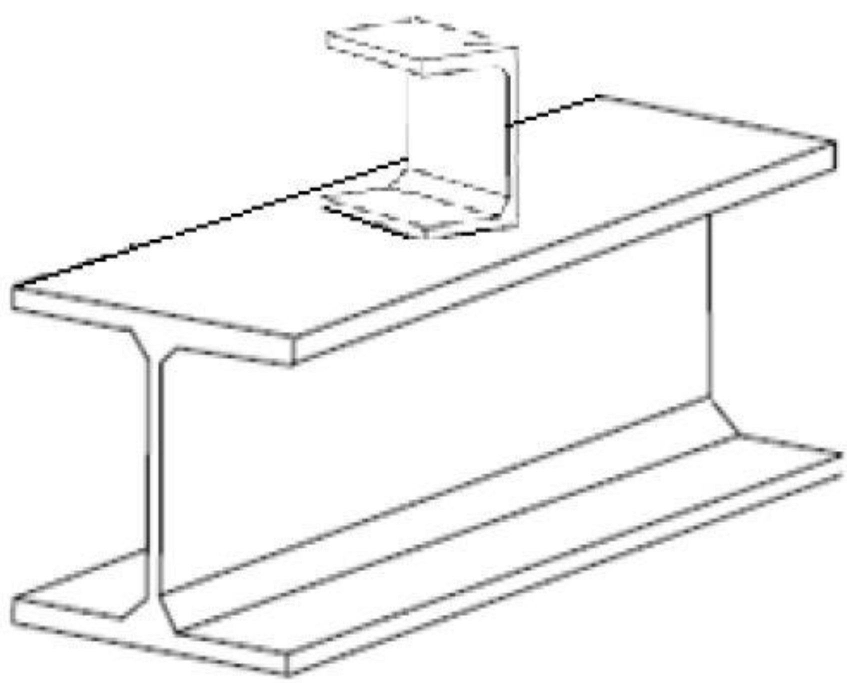

Figure 8. Channel shear connector.

4. Results and Discussions

The strength of the stud connectors is shown to be significantly affected by the concrete compressive strength. When high strength concrete is used, increasing the transverse reinforcement in the concrete slabs has little impact, and when regular concrete is used, it has some effect [2].

Concrete dowel connections for longitudinal shear in shallow-hollow composite beams are described, as well as their behavior and push-out test. The theoretical prediction used in this study for concrete dowel connections without tie-bars was based on EN 1992-1-1 and EN 1994-1-1. Three specimens were subjected to push-out tests, and the findings were compared to theory predictions and existing formulas to determine longitudinal shear resistance. The behavior of concrete dowel in shallow-hollow composite beams was not under pure shear stress, as evidenced by the failure of specimens and the ultimate failure load values of the push-out test [3].

Static strength is necessary for shear connector design and ductility is an essential assumption in the design which is confirmed throughout ultimate slip. The load-slip curve for one shear connector is used to exact the mechanical properties of the shear connector. The slip occurs between steel beam and the concrete bloc. The static curve is used to see if there is sufficient ductility for shear connectors as well [4].

The shear strength and stiffness of the connection is not only dependent on the strength of the connector itself, but also on the resistance of the concrete slab to longitudinal cracking caused by the high concentration of shear force at each connector [5].

The results and interpretations of push tests on shear connector devices for steel-concrete composite structures/bridges carried out in the Stevin laboratory are presented. Different concrete grades and types have been used, like ordinary concrete, lightweight concrete, high strength concrete and lightweight high strength concrete, as well with as without steel fibers. The devices under investigation were headed studs, perfobondstrips, oscillating perfobondstrips, waveform strips and T-connectors.

The tests have been done as specified in EuroCode 4 for standard push test. Sometimes unexpected behavior has been observed during testing, like brittle splitting failure in case of the (oscillating) perfobondstrip in normal concrete. A direct comparison for a specific shear connector device in combination with a certain concrete grade/type is possible. Although the number of samples in a test series was limited, it is still realistic to draw conclusions with respect to their expected strength/ductility based on EuroCode 4 [7 – 9].

5. Conclusion

A series of push off tests are currently carried out to determine the shear capacity of the connectors in composite beams with concrete slabs.

A review of several forms of shear connectors in composite structures has been attempted. The review comes to a close with a discussion of recent shear connector uses in composite structures. Despite its widespread application for transferring longitudinal shear forces across the steel-concrete interface, headed stud shear connectors have some disadvantages and difficulties in composite beams.

The strength and ductility of the shear connectors under investigation were given specific consideration. In reality, the geometry used for the connectors ductility requirement of a 6 mm minimum slip capacity has been confirmed in the most of testing. The two connectors side by side layout was an exception to this standard. This configuration, on the other hand, significantly increases the connector load carrying capacity. One of the primary benefits of this type of connector is its high capacity, as a single connector may replace a large number of standard studs.

When two identical connectors are used side by side, some interaction between them prevents this configuration from reaching twice the resistance of the single connector configuration. Furthermore, the twin connector detailing has a much smaller ductility than the single connector connection.

6. References

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