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Performance evaluation of triangular and circular bulged perforated headed stud shear connector in composite junction

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Abstract

Composite construction is widely increasing in today's construction practice. Shear connections are essential components for ensuring the composite action in composite structures made of steel and concrete elements. Headed studs and channel shear connectors have been widely used in recent composite construction. In the present study, two new variations of headed stud shear connectors are developed using volumetric alterations: circular and triangular bulged perforated head stud shear connectors (CBPHS & TBPHS). For making these alterations, the headed stud shear connector is divided into three zones with reference to bending height. The bulge in the shank of the headed studs has a perforation to allow the reinforcement to pass through it. The performance of the proposed CBPHS and TBPHS studs was evaluated experimentally. The performance of CBPHS and TBPHS shear connectors was evaluated using six experimental and ten numerical specimens. Results show that CBPHS and TBPHS shear connectors have 29–33 % more ultimate shear carrying capacity with more ductility and stiffness than conventional headed stud shear connectors with almost the same material volumetric consumption. The reinforcement passing through the perforation helped CBPHS and TBPHS connectors attain higher ultimate strength, ductility, and stiffness than specimens without reinforcement passing through perforations. Based on results and comparisons made with other codal provisions, two new equations were developed to evaluate the strength of CBPHS and TBPHS shear connectors with and without reinforcement passing through the perforation.

Introduction

Composite construction practices started in the early 1900s. During the early development period, rigid shear connectors and bond strength between steel and concrete elements mainly ensured the composite action between steel and concrete elements. Various new shear connectors, such as headed stud shear connectors (HSSC) and channel shear connectors were later developed after 1950 as a result of investigations carried out by Viest [1]. HSSC and channel shear connectors are the most commonly used shear connectors in recent composite construction practices. HSSC and channel-shaped shear connectors are considered ductile shear connectors as they undergo higher deformation than rigid shear connectors [2]. Various other types of shear connectors were developed to make construction practice easier and to achieve higher ultimate shear strength. Some of the later-developed shear connectors are perfobond shear connectors [[3], [4], [5], [6]], angle shaped shear connectors [[3], [4], [5], [6]], angle shaped shear connectors [[7], [8], [9], [10]]. Xue et. al. [11] studied the shear behavior of the PBL shear connectors. The study concluded that increasing the number of welded studs and perforated holes and setting end-bearing concrete improves shear behavior. In recent years few innovative shapes of shear connectors have been developed. Omega-shaped shear connector [12] was developed to overcome the drawbacks of conventional channel shear connectors. Results show that the omega-shaped shear connector shows higher shear strength and uplift resistance. Concave shape shear connector [13] was developed to fasten the construction procedure of the composite structures. Results show that the concave shear connectors consume 27% less material to contribute equal strength. Coconut palm shaped shear connector [14] was developed with equal volume consumption with respect to conventional headed stud shear connectors. Results show that the coconut palm stem shaped shear connector made of an equal volume as 16 mm HSSC has 37–47% higher shear capacity. Wing plate-headed stud [15] was designed by stiffening the head stud shear connector's initial and final bending height. results show that with the addition of 4–23% additional volume, the strength of the headed stud shear connector increases by 23–74%. Yan et. al.[16] developed a novel channel shape shear connector to enhance the shear carrying capacity of conventional channel shape shear connectors. the enhanced channel shear connector consists of a conventional channel shape shear connector with externally connected bolts to enhance their interfacial surface resistance. The results show that enhanced channel shear connectors have 30–40% more shear carrying capacity than conventional channel-shaped shear connectors. Vijayakumar et. al.[17] proposed a steel embossed plate connector to replace the conventional headed stud shear connectors. The results show that embossed shear connectors show higher stiffness and ultimate load carrying capacity than conventional headed stud shear connectors. For preexisting structures constructed without shear connectors, demountable type of shear connectors were developed [[18], [19], [20], [21]]. The performance of demountable shear connector with profile steel sheeting was studied by Feyissa et. al.[22]. The study showed that with an increase in the height of the profile sheet, the shear carrying capacity of the demountable shear connector is increased. During the past years, researchers have studied the effect of various other factors affecting the shear capacity of the shear connectors. These factors can be divided into two different types, concrete and stud properties. Concrete properties such as compressive strength and modulus of elasticity are important factors affecting the shear carrying capacity of the shear connector [[12], [23], [24], [25]]. Effect of different concrete variations such as engineered cementitious concrete (ECC)[[26], [27], [28]], ultra-high-performance concrete (UPHC)[[25], [29], [30]], lightweight concrete (LWC)[[27], [31], [32]] and steel fiber reinforced cementitious composite (SFRCC)[6] has also been studied by the researchers. With the change in concrete type, the modulus of elasticity changes for the same compressive strength. Apart from concrete properties, shear connector properties also play an essential role in evaluating the ultimate shear carrying capacity of the shear connector [1]. Shear connector properties, such as the tensile strength and dimension of the connector, are the critical factors affecting the strength of the shear connectors. Key dimension parameters vary with connector type. In the case of HSSC, the bottom diameter and height of the shear connector affect the ultimate shear carrying capacity of connectors [[33], [34]]. In the case of channel shear connector, the connector's length and height and the web's thickness play a key role in resisting the upcoming forces, hence increasing the ultimate shear carrying capacity of the connector [[35], [36], [37]]. The thickness, length of arms, and angle of the angle shear connector affect the angle connector's capacity. [[7], [10]]. Various other parameters, such as the presence of reinforcement, also affect the capacity of HSSC. the study shows that the presence of confinement reinforcement enhanced the strength of the shear connector by

10% [34]. The effect of spacing between the confinement reinforcement and the steel beam on the shear capacity of the concrete was studied by Kumar et. al.[38]. The study shows that with the increase in the distance between the confinement reinforcement and the steel beam, the connector's shear capacity reduces, whereas the connector's ductility increases.

Studies in the HSSC were mainly limited to concrete and steel parameters. As a result, very less emphasis was given on the changing the geometry of the HSSC. The variation in the shear connector can be brought with respect to varying stress concentration in the HSSC.

In the present study, the variation in the HSSC was made as per the varying bending length studied by Xue et. al.[34]. According to studies, the deformed height of the HSSC varied with variations in concrete grade. The bending length of the HSSC was observed between 18 and 33% of the overall height of the HSSC. With the increase in concrete strength, the bending length reduces. Based on the variation in bending length of HSSC, the connector was distributed in 3 different zones, as shown in Fig. 1. Zone 1 of the HSSC consists of the head region of the shear connector. Zone 1 of HSSC mainly contributes to resisting the structure's oncoming uplift. Zone 2 of the shear connector consists of the non-bending region of the shank of the HSSC. Zone 3 of the HSSC consists of the bottom shank of the HSSC, where maximum shear concentration on the HSSC occurs. The height of zone 3 can be varied between 0.18 and 0.33 times the height measured from the bottom of the HSSC. The reduction in the volume of the HSSC was made in zone 1 of the HSSC. The volumetric reduction in zone 1 of the HSSC implies that the addition of volume should be done in such a way that the added volume must help the stud to resist the uplift coming on the HSSC due to reduced volume from the head (zone 1) of the stud. Hence considering all the parameters, the volume is added in the bottom region of zone 2 and throughout zone 3. The addition in zone 3 is done in an incremental manner from bottom to top. This incremental addition of volume helps achieve maximum diameter at the bottom of the studs, increasing the effective shear area. The addition in zone 2 should be done in a way such that it enhances the uplift carrying capacity by increasing the surface area along zone 2 of the studs. It is recommended that the volumetric addition for resisting the uplift should be done in zone 2 so that alterations made in the sections get enough cover to provide the compromised uplift resistance capacity. In the present case, the volumetric addition is done in the form of a circular and triangular bulge with a perforation of 10 mm diameter. This perforation hole allows a reinforcement bar of 10 mm diameter to pass through it. This perforation helps the stud to resist additional shear force and uplift pressure acting on the stud.

In this HSSC modification, the volumetric reduction is made in zone 1 of the HSSC. Volumetric addition is done in zone 2 and zone 3. To improve the compromised upcoming uplift on HSSC due to volumetric reduction in zone 1, the volumetric addition is done in the bottom region of zone 2. The addition is done in the form of a circular bulge with a perforation in the center. The perforation gives provision for a 10 mm bar to pass through it. This provision gives additional resistance to uplift by anchoring the bar into concrete. Volumetric addition is done incrementally to achieve maximum diameter at the bottom of the stud in zone 3 of the stud. Fig. 2 (a&b) illustrate the dimensions and pictorial view of CBPHS studs.

Similar to CBPHS the volumetric reduction is done from the zone 1 and added to zone 2 and 3. The volumetric addition in zone 2 is done in the form of triangular bulge with a perforation in the center of the bulge. The volume added in zone 3 is incremental so that maximum diameter is achieved at the bottom of the stud. Fig. 2 (c&d) illustrate the dimensions and pictorial view of TBPHS studs.

Section snippets

Experimental setup

The pushout test is used to assess shear connector performance. The results are in the form of a curve plotted as load vs slip (displacement) curves. The pushout curve illustrates the shear connector's ultimate strength and deformation capability. Eurocode 4 provides guidelines for specific pushout test. With time researchers have developed pushout test with single-shear connectors welded on either side of the flange and later embedded in the concrete [[8], [26], [38], [39]]. In the current…

Steel properties

The tensile strength of the steel beam and HSSC material were evaluated before casting the specimen. The tensile strength of the stud was closely monitored as it is a key specimen for the present study. The yield strength and ultimate strength of the connector material were 425 and 491 MPa, respectively. The stress–strain curve for stud material is shown in Fig. 6. To validate the property of the HSSC with Eurocode 4, the ultimate strength of the shear connector was kept below 500 MPa. The…

Results and discussions (Experimental Study)

The test results are compared with the conventional HSSC based on the specimen's ultimate strength, ultimate displacement, ductility, and stiffness. Ultimate strength is the maximum load carried by the shear connector during the pushout test. The ultimate displacement is calculated at 90% load fall of the ultimate strength of the shear connector. The stiffness of the shear connector is calculated per the guidelines of Eurocode 4. The slope of the load–displacement curve at 70% of the ultimate …

Finite element analysis (FEA)

FEA (Finite element analysis) was carried out using ABAQUS. Several commands play a key role in order to simulate close to the actual experimental simulation of pushout analysis. Various parts from the experimental pushout analysis were modeled for successful simulation of pushout analysis. These parts include concrete slab, rigid base plate, steel beam, stud material, and reinforcements. In order to get close to accurate results assigning proper surface interactions between surfaces, boundary…

FEA modelling validation.

Three models were considered for validating the experimental results using finite element analysis. One specimen of conventional HSSC and one specimen of CBPHS and TBPHS each were taken into consideration for validation. Bending behavior and load–displacement curve were validated using the finite element analysis. Simulation shows close bending behavior of CBPHS and TBPHS studs as shown in Fig. 17.

The load–displacement curve was closely monitored, and results show close to accurate modeling of…

Parametric analysis

Following parameters were considered for parametric analysis of CBPHS and TBPHS shear connectors.…

Result and discussion (experimental+numerical study)

To compare the performance of the parametric specimen, comparison was done based on ultimate strength, ultimate displacement and stiffness of the connector. Obtained results using the finite element analysis are shown in Table 5. Load-displacement curves of the all the specimens considered for finite element analysis is shown in Fig. 19&20.Fig. 20.….

Capacity equation formulation-

The researchers have proposed several formulas for evaluating the ultimate strength of concrete in recent years. Various design codes have recommended these equations based on the results. The proposed CBPHS and TBPHS have a geometric variation that alters the shank and head geometry. With consumption of almost the same volume as the HSSC of 19 mm diameter, the proposed TBPHS and CBPHS shear connector has a bottom diameter of 24.75 mm, slightly higher than the conventional HSSC. These…

Conclusion

The present study aims to alter the geometry of the conventional HSSC shear to increase the shear carrying capacity of the connector. In reference to the bending length of the HSSC was divided into three different zones depending on the stress concentration and the functionality of the zone.

The volumetric alterations were done so that maximum diameter can be attained at the bottom of the shear connector. In order to achieve the maximum diameter at the bottom of zone 3, the volumetric reduction…

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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