An Experimental Investigation on Performance of Headed Stud Connectors in Steel-Concrete Composite Beams

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Abstract **- Headed stud connectors are mostly used for effective interaction between steel and concrete in steel-concrete composite beams. This interaction is important because maximum longitudinal shear and vertical separation occurs at the interface. Headed stud connectors which is a type of flexible shear connectors can be easily welded to the steel by using gun welding, the construction is convenient and it is very ductile so that there is large deformation before failure. This is the reason for using flexible shear connectors instead of rigid and anchorage type shear connectors. This paper presents the experimental investigation on the performance of headed stud shear connectors embedded in solid concrete slabs by conducting modified push-out test. This setup consists of loading fixture, test specimen and channel section which acts both as formwork and spreader beam during testing. The varying parameters are number of connectors and clear cover for shear connectors. Load-slip characteristics at the steel-concrete interface and shear capacity of connectors can be found from this test. The failure occurred during testing were stud yielding, ripping and shear failure in concrete. In this paper, the behavior of stud connectors in composite beams has been examined.**

Keywords - Composite beams, flexible shear connectors, headed stud connectors, push-out test, stud connectors

I. INTRODUCTION

Steel concrete composite structures is popular in advanced countries like USA and UK and is fast catching up in developing countries like India now-a-days. In order to avoid gigantic structure, thereby reducing the self-weight, most of the buildings and bridges were constructed with steel concrete composite beams, slabs and columns. In case of steel structure they need bracing and also the steel floor is not acceptable for the general applications. This leads to the arrival of steel concrete composite structures. Steel Concrete Composite structures are widely used for construction of many bridges and buildings all over the world. In this type of construction, the most effective utilization of steel and concrete properties is achieved. Composite construction mostly used for flexural members which is formed by concrete slabs rest over the steel beams. A composite flexural member will have greater stiffness and strength than the bare steel member resulting in reduced deflection and floor vibration in the structure. But the strength of composites depends on the connection between steel and concrete. If there is no connection between steel and concrete, then the two components act independently and slip occurs between them. To maintain compatibility, the interaction between the steel and concrete plays a major role in steel concrete composites. Mechanism of Composite interaction can be achieved through mechanical connection between steel and concrete members. Typically, mechanical shear connection is accomplished with flexible connectors. Flexible connectors derive their resistance through bending and undergo large deformation before failure. By using these connectors, the interaction between steel and concrete increased, so that load carrying capacity is increased. These connectors resists both longitudinal shear and vertical uplift. Headed studs are most widely used flexible shear connectors. In headed studs, shank resists horizontal shear and head resists vertical separation. These studs may be arranged in pairs or singly at regular intervals along length of the beam. Because of various advantages in flexible shear connectors, it is widely used in steel concrete composite structures. This study also deals with flexible shear connectors.

A. Previous Research

Dennis Lam and Ehab EI –Lobody(2005)[5] proposes an effective numerical model using FEM to simulate the push-off test. They observed three modes of failure from the push-off test. The first mode of failure is the concrete cone failure where no stud failure is observed. For this mode of failure, the concrete around the stud started to fail in compression before the stud was yielded, the compression failure progresses through the thickness of the concrete forming a conical shape around the stud. The second mode of failure is that the stud connector was fully yielded and no concrete failure is observed. This mode of failure is identified as the stud failure mode where the yield stress is reached by the stud element while maximum concrete stress of the concrete element is not reached. Finally, the third mode of failure is the combined failure of the stud and concrete slab when maximum stresses are reached in the stud and concrete elements.

Luis Pallares, Jerome F. Hajjar (2009)[3] reviews 391 monotonic and cyclic tests from the literature on experiments of headed stud anchors and proposes formulas for the limit states of steel failure and concrete failure of headed stud anchors subjected to shear force without the use of metal deck. This work also reviews proposals from several authors and provides recommended shear strength values for seismic behavior of headed studs.

Luis Pallares, Jerome F. Hajjar (2010)[4] reviewed different strength equations to compute the nominal tensile strength of a headed stud and compared to experimental results. The resulting recommendations seek to ensure a ductile failure in the steel shank instead of a brittle failure within the concrete. Several criteria are proposed to ensure that ductile failure controls in composite construction, and, different headed stud configurations and detailing reinforcement recommendations are proposed to improve the ductile behavior of headed stud anchors subjected to tension and combined tension and shear. A distance of 1.5hef to develop the full tensile strength provided by the CCD model of the four-sided pyramid delineating the concrete failure surfaces is necessary to avoid edge conditions reducing the tensile strength of the anchor in composite construction.

A.L.Smith and G.H.Couchman (2010)[6] conducted studies on strength and ductility of headed stud connectors in which the effect of variables such as mesh position, transverse spacing of shear connectors, number of shear connectors per trough and the slab depth on the resistance of headed stud shear connectors were considered. The results agrees with the minimum shear connection rules in BS EN 1994-1-1 for headed stud shear connectors. The observation also suggest that shear connectors in pairs will give an increase in resistance of 16% over using a single shear connector, independent of the spacing and there is no further improvement by using shear connectors in groups of three.

Dongyan Xue, Yuqing Liu, Zhen Yu, Jun He (2012)[7] conducted push-out tests to investigate the different behavior between single-stud and multi-stud connectors. The results show that the single-stud and multi-stud connectors have the similar stiffness, and the spacing of studs has little influence in the stiffness of multi-stud connectors. The ultimate strength of single-stud connector is about 10% larger than multi-stud connectors. When the load reaches its peak, the relative slip of single-stud connector is about 19% larger than that of multi-stud connectors. The multi-stud effect on static behavior of shear connector is negligible.

Most of the researches conducted so-far on studs have focused on performance of single stud connectors in composite beam. Few researches have focused on performance of multi-stud connectors. But practically, there are multi-stud connectors in composite beams. So, research on multi-stud connector is important. In this paper, comparison of failure pattern between the single and double stud connectors in steel-concrete composite specimens have made and effect of clear cover have been discussed..

II. MODIFIED PUSH-OUT TEST

A. Test setup

The test setup consisted of a loading fixture, a test specimen and a spreader beam. For each specimen, a box type steel formwork was prepared. Steel formwork was placed on the three sides while ISLC 200 channel section was placed on the remaining side. This channel section is same for all the specimens having the same height. It is connected to the concrete by using two anchor bolts of 20mm diameter which were placed inside the concrete during casting and connected during loading process. Reinforcing bars of 10mm diameter were placed at the top in both the directions. These bars were located 50 mm from the top. The loading fixture was lifted into position and was connected to the flat plate of the test specimen by four 20 mm diameter bolts. The channel section served as formwork as well as spreader beam during the loading process. Shear studs of 19mm diameter were welded to a flat plate using standard stud installation technique. A plastic sheet was placed over the flat plate to prevent bonding between the steel plate and the concrete. The flat plate was placed on the ground with the studs oriented upwards. After completing all the forms for each test specimen, concrete was cast horizontally inside all the forms and vibrated according to standard construction practices. The specimens has to be tested by making use of a loading fixture which is formed by steel beams.

This modified test setup is due to certain difficulties in standard push-out test. Concrete slabs must be cast horizontally to reflect the actual construction practice. When the two concrete slabs of a specimen were cast at different times, the concrete compressive strength of the two slabs at the time of push-out test differs from each other. Another method, which was used previously by Pashan and Hosain, was to cut the I-beam along the web into two T-sections and weld them back together after casting the two concrete slabs simultaneously. To overcome the difficulties in the standard push-out test, a new horizontal test setup is proposed which consists of constant steel I beam and channel section, individual steel plate for each specimens. It reduces the quantity of steel so that it is cost effective.

Fig 1: Test setup

B. Material Properties

To determine the compressive strength of concrete, three concrete cubes were casted for each mix. The grade of the concrete chosen for the study is M20. The expected compressive strength of concrete is 27 N/mm^2. The compressive strength of concrete obtained from the test is 30.67 N/mm^2. The studs chosen for this study is φ19x100 studs.

C. Test Specimens

Three concrete specimens were casted. Concrete slab size is 900x600 mm. The height of the specimen is 200 mm for two specimens with clear cover 100 mm, in that one specimen with single stud at the center and other specimen with double stud placed at the center with transverse spacing of 100 mm. The third specimen height is changed to 150 mm with clear cover 50 mm having single stud at the center.

D. Loading Procedure

After the concrete specimens were flipped, loading fixture was placed over the plate by fastening with four bolts. The channel section was placed in front of the concrete for uniform distribution of loads. Hydraulic jack with capacity 500 KN, load cell and spacer blocks were placed between the loading fixture and channel section. The slip between the concrete and steel was measured by using three LVDTs. Load and slip has been monitored by 16 Channel Data Logger. From that, load-slip curve is plotted.

III. RESULTS AND DISCUSSION

A. Modes of failure

When the load is applied to the channel section, it uniformly distributes the load to the concrete. The concrete transvers this load to the stud connector at the interface. Due to this load, the stud resists the shear load initially by deforming, and transfers the load to concrete through bearing. This dispersion of load causes tensile cracks in concrete by ripping, shearing and splitting later slip occurs at the interface and the stud bends locally. The bending of stud increases the compressive stress of concrete around the stud. This also increases the load coming to the stud.

For single stud placed in the steel plate with 100 mm clear cover, the failure observed is the stud shank failure and no concrete failure which means that the stud reaches its yield point whereas concrete has not attained the maximum stress. The stud bends and breaks at the bottom of the shank. This is because the bearing stress on the shank is concentrated near the base. The failure of stud is shown in fig. 3 & 4.

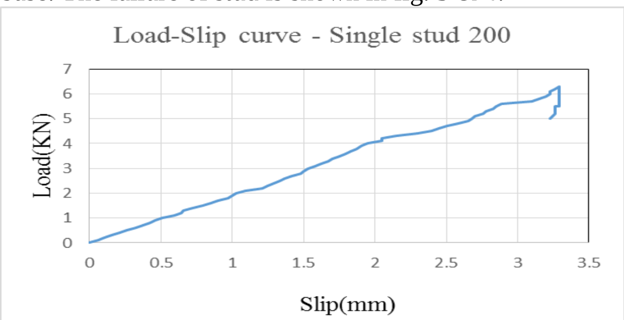

Fig.2: Load-Slip Curve for Single stud at the center (200mm)

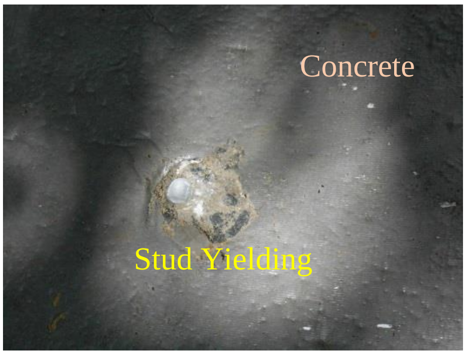

Fig.3: Stud yielding in concrete

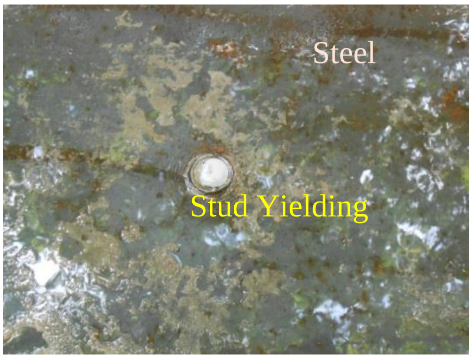

Fig.4: Stud yielding in steel

For double studs placed in the steel plate with transverse spacing 100 mm and clear cover 100 mm, the failure observed is the concrete failure (Ripping and shear failure) and no failure is observed in the stud but the stud bends which means that the concrete reaches its maximum capacity before the studs and the stud capacity increases due to the presence of two studs in the specimen. The concrete failure is shown in fig. 6 and stud bending is shown in fig. 7.

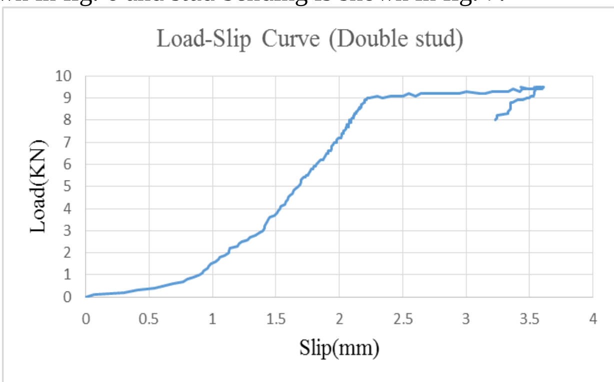

Fig.5: Load-Slip Curve for double stud (200mm)

Fig.6: Ripping and shear failure in concrete

Fig.7: Stud bending

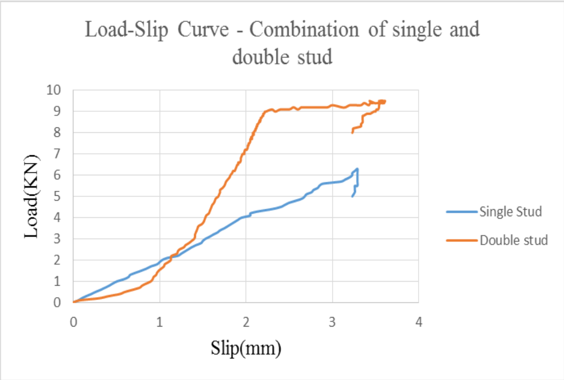

Fig.8: Comparison of load-slip curves of single stud and double stud

For single stud placed in the steel plate with 50 mm clear cover, again the failure is the stud shank failure and no concrete failure which means that the stud reaches its yield point whereas maximum concrete stress has not attained. The stud bends and breaks at the bottom of the shank. The failure of stud is same as the specimen with single stud at the center with height 200mm.

Fig.9: Stud after yielding

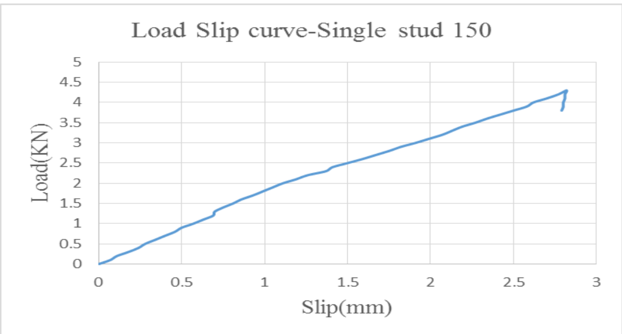

Fig.10: Load-Slip Curve for Single stud at the center (150mm)

B. Load-slip curve

When the load is applied to the concrete, slip occurs between the steel and concrete. The behavior of shear connectors can be explained by load-slip curves. The load-slip curve for single and double stud having height 200mm is shown in fig.2 & 5.From the results, it is seen that load-slip curve consists of elastic, plastic and descending part. The elastic part is almost linear which represents that with increase in load, the slip also increases. In the plastic part, even when the load increases, the slip is uniform up to failure. Once the specimen fails, the load is reversed so that load-slip curve has a descending part.

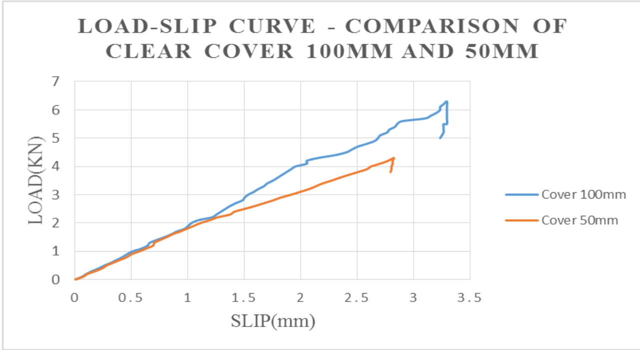

Fig.11: Comparison of load-slip curves of specimen having clear cover of studs 100mm and 50mm

By comparing load-slip curves of single and double stud, it is seen that the slip of the two specimens was almost similar which means that both are having similar stiffness. The load carrying capacity of double stud connectors is greater than single stud connectors. The load-slip curve of combination of single and double studs is shown in fig.8.

By comparing load-slip curves of specimen with clear cover of 100mm and 50mm, it is seen that there is no difference in behavior of headed studs while increasing the cover. The minimum cover as specified by LRFD specification is 50mm. By increasing cover from 50mm to 100mm, the load slip curve is elastic and the behavior of headed stud is same. So, there is no advantage with increasing the cover. The load-slip curve of comparison of specimen having height 200mm and 150mm is shown in fig.11.

C. Load carrying capacity

For the specimen with single stud at the center with 100mm clear cover, the load at the failure is 63 KN with maximum slip of 3.29 mm. In the reinforced concrete section, no cracks occurred. There occurs only stud yielding. For the specimen with double stud placed transversely at the center, the load at failure is 95 KN with maximum slip of 3.61 mm. In this specimen, due to the distribution of loads, tensile cracks formed in the concrete in the form of ripping and shear failure. Due to ripping failure, cracks occur from the stud perpendicular to the direction of load. Due to shear failure, cracks occur at 45° with respect to the stud. These cracks come below the half of the beam and then the load is reversed. Both the cracks occurs from the stud which is farthest from the load direction. This behavior is was explained by Milan Spremic, et al in 2013. The first stud in the column can achieve full shear resistance. The shear failure occurred in this stud. It can be considered that the shear resistance of concrete has been used in a layer which is approximately equal to the diameter of the headed stud, at the first stud. The second headed stud in the row behaves as a headed stud with an inclusion in front of it. The second, third and other studs have the same or slightly lower shear resistance which directly depends in the height of the shank of the headed stud at which the concrete pressure occurs. The failure of the specimen with double stud proves this theory. For the specimen with single stud at the center with 50mm clear cover, the load at failure is 43 KN with maximum slip of 2.82 mm. There is no failure in the concrete, only stud yielding occurs.

IV. COMPARISON WITH THE CODE VALUES

In Indian code, there is no expression for calculating shear capacity of mechanical connectors in steel-concrete composites. In Eurocode 1994-1-1:2004, the design resistance of welded headed studs can be determined by

$$P_{Rd} = \frac{0{,}8\, f_u\, \pi\, d^2 / 4}{\gamma_V}$$

$$P_{Rd} = \frac{0{,}29\, \alpha d^2 \sqrt{f_{ck} E_{cm}}}{\gamma_V}$$

Whichever is smaller. The shear capacity of connectors were found out from this formulae. But the results only matches with the results of specimen with single stud. For multi-stud connectors, there is no standard formulae. So, the expression for multi-stud connectors have to be derived.

V. CONCLUSIONS

- To overcome the difficulties in the standard push-out test, a modified horizontal push-out test setup is employed.
- This setup is cost effective and it effectively replace existing vertical setup.
- Three specimens with single stud at the center having clear cover 100mm and 50mm and double stud with transverse spacing 100 mm were casted and tested.
- The results showed that the single stud and double stud specimens have similar stiffness.
- There is no advantage in increasing the clear cover which leads to reduce in weight and cost.
- With increase in number of studs, the stud capacity enhances so that concrete failure occurs. So, grade of concrete has to be increased when go for more no. of studs.
- The ultimate strength of double stud connectors is higher than the ultimate strength of single stud connectors.
- The expression for calculating shear capacity of connectors in codes have to be introduced.

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