



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 9, Issue 12, December 2020

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 7.512

9940 572 462

6381 907 438

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Study on Shear Connectors in Steel - Concrete Composite Construction under Monotonic Loading

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ABSTRACT: Conventional composite construction has flaws of developing a relative slip between structural elements. The use of shear connectors eliminates this shortcoming. In this study, Shear connectors in composite construction should allow a transfer of shear force between two dissimilar materials, prevent the vertical separation between them and gives composite members their unique behavior. The performances of different types of shear connectors based on their shapes such as Headed Stud, Square and Rectangular in steel – concrete composite specimens were evaluated by conducting push-out tests under monotonic loading condition. An ISMB 200 @ 25.4 kg/m Universal Steel beam of length 400mm and reinforced cement concrete slab measuring a length of 300mm with a breadth of 200mm and a thickness of 200mm reinforced with 8mm diameter steel rods were used for this experimental investigation. During this study, the load-slip behavior and failure mechanism of push-out test specimens were observed and attempts have been made to identify the shear connectors which are more relevant to the steel – concrete composite construction.

KEYWORDS: Shear connector; Push-out Test; Shear resistance; Load-Slip curve

1. INTRODUCTION

A structural member composed of two or more divergent materials fastened together to behave structurally as a single unit is called as Composite Structure. The real attraction of having composite construction mainly depends on the efficient interdependence between these two diverse materials. In conventional composite construction, concrete slabs simply rest over the steel beams and are supported by them. Under load, these two components act autonomously and a relative slip occurs at the interface, if there is no proper connection between them. With the help of a deliberate and appropriate connection provided between the steel beam and the concrete slab, the slip between them can be obliterated. The strength and ductility of shear connectors play a vital role in the design of composite structures. Numerous research works have been carried out to evaluate the performances of various types of shear connectors in composite structures. -

Quian Wang *et al.* (2011) worked on Experimental study on Stud shear connectors with large diameter and high strength and reported that (i) The use of studs with large diameter and high strength can simplify the composite structure, save the construction time and make the steel and concrete work together better. (ii) The load-slip curves of specimens under monotonic load and cyclic load in each group have very good repeatability, especially the elastic phase. (iii) The shear resistance and shear rigidity of studs with large diameter and high strength are all higher than the normal studs used in composite structures and can be better used in bridge structures. The Push-out experiments using headed shear studs in group arrangements were carried out by Milan Spremic *et al.* (2013) and concluded that the strength of the concrete is influencing the stiffness and deformation of the connectors and also a group of headed studs with reduced distance may be used instead of a large diameter single headed stud. Mahdi Shariat *et al.* (2011) studied the shear resistance of Channel shear connectors in Plain, Reinforced and Light weight concrete under monotonic loading and found that the increase in length of channel leads to increase in cracking of concrete on the sides of the slab and also increase the ductility of the system. Ali Shariati *et al.* (2014) performed Experimental assessment of angle shear connectors under monotonic and fully reversed cyclic loading in high strength concrete and reported that inadequate ductility behaviour for the angle shear connectors embedded in HSC. Nonetheless, the angle connectors exhibited good behaviour in the case of strength

degradation under cyclic loading. All specimens experienced the angle fracture type of failure and showed a very low strength degradation (0.1%–1.4%) when they were subjected to low cyclic fatigue loading.

II. EXPERIMENTAL DETAILS

1.1 SHEAR CONNECTORS

Three varieties of shear connectors based on shape (Headed stud, Square and Rectangular) were harnessed in this experimental investigation, as shown in Fig.1.

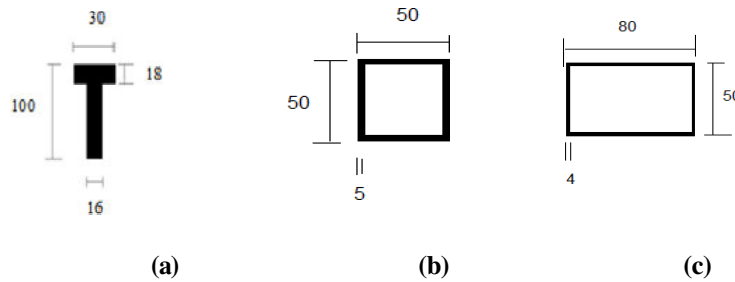


Fig.1. New varieties of shear connectors: (a) Headed stud (b) Square (c) Rectangular (All dimensions are in mm)

1.1. LINE SKETCH OF PUSH – OUT SPECIMENS WITH VARIETIES OF SHEAR CONNECTORS

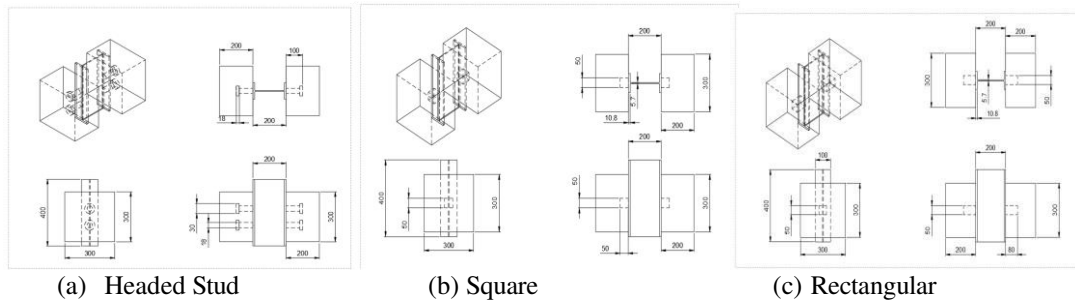


Fig.2. Line sketch of Push-out specimens with shear connectors (All dimensions are in mm)

1.2. MATERIAL PROPERTIES

Tensile tests were carried out on several test specimens (I section) formulated from ISMB200. The average value of yield stress, ultimate stress, % elongation in length and young's modulus obtained from the coupon test for ISMB200. Similarly, tensile tests were conducted on 8mm diameter mild steel rod. The values are given in Table 2.1.

Fe 250 and Fe 415 grade of steel were utilised for shear connectors. Ordinary Portland Cement of 53 grade was used. The fine and coarse aggregates were selected as per IS 383-1970 (Reaffirmed 2002), The Indian Standard Specification for Coarse and Fine Aggregates from Natural Sources for Concrete (Second Revision) for the preparation of concrete. The physical properties of cement, fine and coarse aggregates were found by conducting test in a laboratory environment and the values are given in Table 2.2.

All the concreting work was carried out in a laboratory according to ISI0262:2009, The Indian Standard Concrete Mix Proportioning – Guidelines (First Revision). The concrete mix was designed for M20 grade and the procedure for casting of cubes and cylinders was done as per Indian Standards. The mix proportions with the water-to-cement ratio obtained for the M20 grade of concrete are given in Table 2.3. A standard cylinder of 150mm diameter and 300mm height and a cube of 150 mm x 150 mm x 150 mm in size were simultaneously cast, in order to determine the

cylindrical compressive strength, cube compressive strength and split tensile strength of concrete. In total, 9 cubes and 18 cylindrical specimens (3 specimens per connector) were cast and tested after a curing period of 28 days and the values are given in Table 2.4.

Table 2.1 Material properties of steel beam and reinforcement

Material	Yield stress (MPa)	Ultimate Stress (MPa)	Elongation (%)	Young's Modulus (MPa)
I-Steel Beam	275	505	21	208
Reinforcement (8mm diameter)	225	370	23	210

Table 2.2 Material properties of cement, fine aggregate and coarse aggregate

Material Property	Cement	Fine Aggregate	Coarse Aggregate
Specific Gravity	3.10	2.55	2.66
Fineness Modulus	4%	2.33	6.35

Table 2.3 Mix proportions for M20 grade concrete

Water	Cement	Fine aggregate	Coarse aggregate
161.181 Litres	358.18 kg/m ³	748.23 kg/m ³	1114.6 kg/m ³
0.45	1	1.89	3.10

Table 2.4. Material properties of Compressive strength and Tensile strength of concrete

Connector	Cylindrical Compressive Strength in MPa	Cube Compressive Strength in MPa	Split tensile strength in MPa
Headed Stud	24.27	30.36	6.07
Square	23.81	29.81	5.66
Rectangular	24.03	29.80	5.61

2.4 FABRICATION OF PUSH-OUT SPECIMENS

The steel-concrete composite push-out specimens comprised of universal steel beam, shear connectors and reinforced cement concrete slab. The reinforced cement concrete slabs were connected to the steel beam by means of the shear connectors welded to both the flanges of the steel beam. Push out tests specimens were fabricated using four headed stud connectors two per each side and two square and rectangular connectors one connector per each side welded to the steel beam. It was fixed at the centre of the concrete slab. Welding was done strong enough to prevent failure of welding before the connector while loading. The shear connectors of almost same weight of 0.9 kg and almost same bearing width of 50 mm have been used in this investigation. The varieties of shear connectors welded to the Universal steel beams of ISMB200 are shown in Figure 3. (a to c).

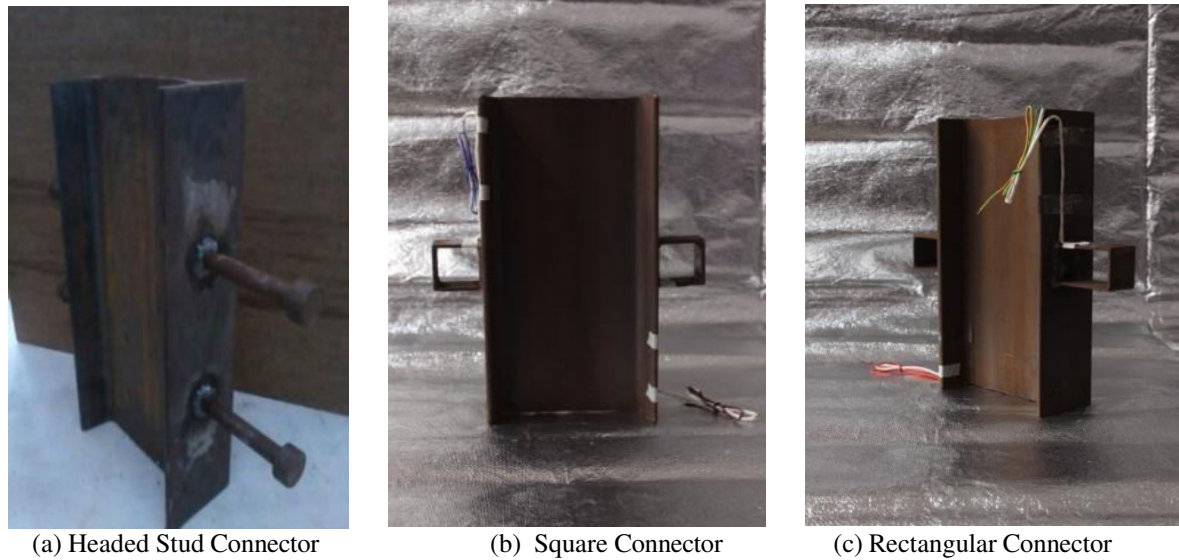


Fig.3.Fabrication of connectors with Steel beam

The Push-out test specimens were formulated by placing reinforcements in the specially fabricated concrete casting steel mould as shown in Figure 4 and then freshly mixed cement concrete was placed and compacted well and it was allowed for hardening for a day and the mould was removed and then the specimens were allowed for curing for 28 next days. The curing of concrete slabs attached to the flanges of steel beam was done by using jute bags. Figure 5 shows the typical push out test specimen after the curing period. After the curing period of 28 days, the specimens were made ready for push out test.



Fig 4. View of concrete casting mould with



Fig 5. View of composite specimen after curing reinforcement

2.5 PUSH-OUT TEST ARRANGEMENT AND TEST

Push-out testing on steel concrete composite specimens was carried out to understand the behaviour of the new varieties of shear connectors under monotonic loading condition. The typical experimental setup for push-out testing is shown in Figure 6. The tests were conducted by using a hydraulic jack of capacity 5000 kN. The specimen was kept on a bearing support. Soft wooden boards were placed between the concrete slab and the base of the test frame, in order to avoid the undesirable bearing stress concentration. The hydraulic actuator of capacity 35T, stroke length of 500 mm and

the test floor of 800 mm thick was used for testing. Two displacement transducers were instrumented on either side of the I-section, in order to measure the vertical slip of the Universal steel beam of I-section from the concrete slabs.

In this experimental analysis, DEWE Soft 7 Software was used to record the values of loads, displacements and load-slip curve. The loading cell and displacement transducers with high precision were connected to the data logger which was connected to a monitor. The model was symmetrical, with the load being carried out in the axis of symmetry, and hence it was assumed that the shear load per connector was equal to the total load applied divided by the number of connectors; in plotting the results, the mean value of the slips was used.

A monotonic load was applied using a hydraulic actuator attached to the loading frame. The loading on the Universal steel beam of I-section creates heavy shear and makes it to shear off or slip from the concrete slab. Loading was continued till cracking of slab or fracture of the connectors took place. The load applied was measured using a load cell and the displacements were recorded for each increment of the loading. Push-out testing of a typical steel concrete composite specimen is shown in Figure 7.

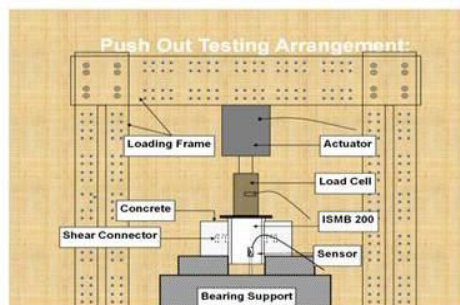


Fig 6. Typical arrangement of push-out test



Fig 7. push-out test specimen during testing

III. OBSERVATIONS AND RESULTS

3.1 Load – Slip behaviour of new varieties of shear connectors

Three push-out test specimens were cast for each type of shear connector. Totally 15 push-out test specimens were prepared. The specimens were loaded till severe cracking of concrete slabs or a fracture of the shear connectors occurred. The value of applied load and each measured slip is given in Table 5.

Table 5. Applied load and each measured slip

Load (kN)	Slip (mm)		
	Headed Stud	Square	Rectangular
0	0	0	0
10	0.479	0.153	0.19
30	0.995	0.669	0.479
60	1.727	1.408	0.792
90	2.391	2.197	1.153
120	3.304	2.978	1.525
150	3.994	3.494	2.029
180	4.672	4.018	2.808
210	5.087	4.672	3.699 at a load of 181.4kN
240	5.587	5.432	
270	6.001	6.221	
273	6.096	7.462	

283	6.228		
300	6.453		
330	6.85		
355	7.581		

Fig 8 shows the graphical representation of load –slip curve of new varieties of shear connectors.

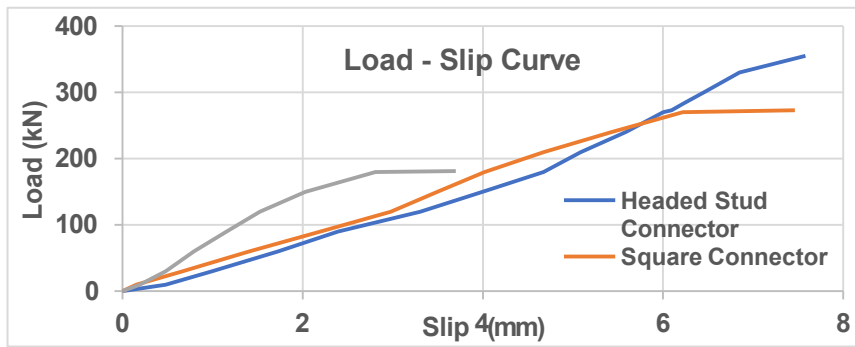


Fig 8. Load – Slip curve for varieties of shear connectors’ specimens

Well defined elastic and plastic region could have been seen in all types of connectors under monotonic loading. The load – slip curve is approximately linear up to 50%, 75% and 83%, in headed stud, square and rectangular connectors respectively.

The value of ultimate shear resistance and corresponding slip is given in Fig 9.

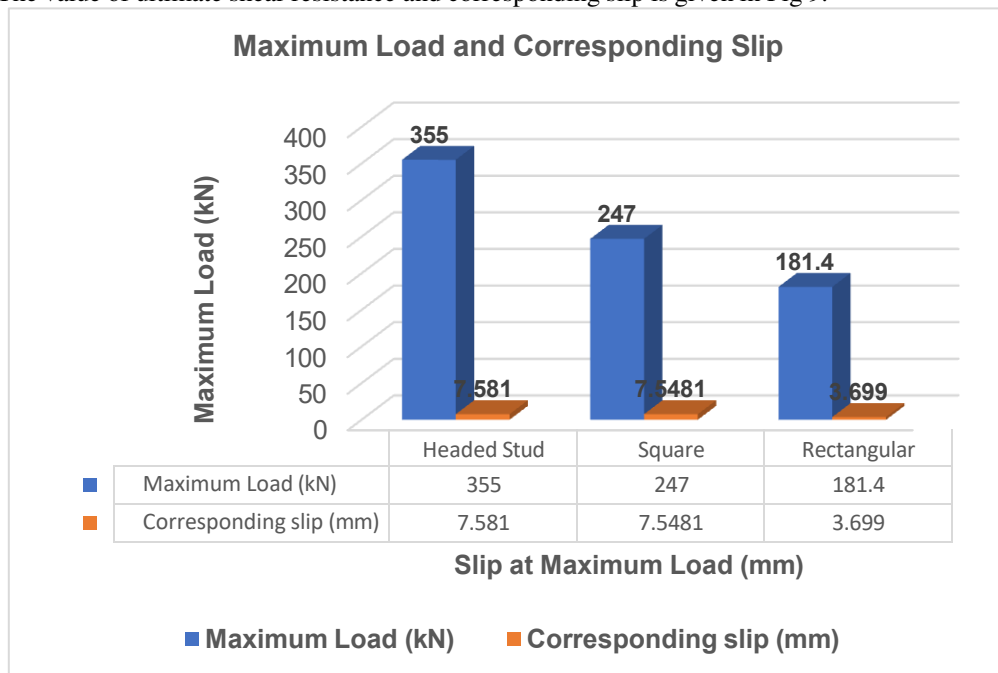


Fig 9. Maximum Load and corresponding slip of push-out specimens

Headed stud connectors specimens withstood an ultimate load of 355kN with the corresponding slip value of 7.581mm. Square connectors specimens withstood an ultimate load of 247 kN whereas the corresponding slip was gauged as 7.5481mm. Rectangular connectors specimens withstood an ultimate load of 181.4 kN with the corresponding slip value of 3.699mm. It means that the square connectors specimens endured an ultimate load of 70% of headed stud connectors specimens, for the same value of slip. The headed stud connectors specimens combated up to the maximum shear resistance than all other type of connectors. The rectangular connectors specimens failed with a maximum slip of 3.699mm which is 50% less than that of square connectors specimens.

It can be seen that the ultimate shear resistance of headed stud connectors specimens is high, succeeding that, square and rectangular connectors specimens resisted 70% and 51% of ultimate shear resistance of headed stud connectors specimens with corresponding slip values of 7.5481mm and 3.699mm respectively under monotonic loading condition.

3.2 Failure pattern of varieties of shear connectors

During monotonic loading, slight cracks were formed on the surface of the specimens with headed stud connectors at about 70% of ultimate load. Typical pattern of cracking in the concrete slabs consisted of horizontal and diagonal, whereas the horizontal cracks developed first on the surface of the concrete slab near the location of headed studs. Figure 10 shows the cracks of the concrete slab near the position of the Headed studs shear connectors. After failure of the specimens, the concrete was removed and the failure shape and deformation of connectors were observed. Figure 11 shows the failure of Headed stud connector under monotonic loading.

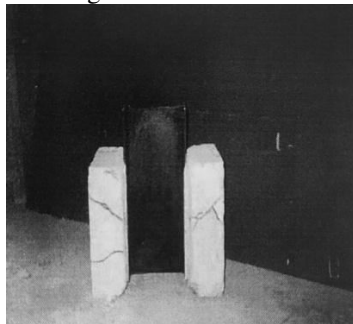


Figure 10 Cracks of the concrete slab near the position of the Headed studs shear connector



Figure 11 Failure of Headed stud connectors under monotonic loading

During monotonic loading, severe cracks were noticed on the surface of the square connectors specimens before failure and the first crack was perceived nearly 81% of ultimate load of the specimen and propagation of cracks were found sternly after unloading. After failure, the concrete was removed and the failure shape and deformation of square connectors were reviewed. Fig 12 and Fig 13 shows failure of square connectors specimen and part of fractured square connector attached to the steel beam.



Fig 12. Failure of square connector specimen



Fig 13. Part of fractured square connector attached to the steel beam

In the case of Rectangular connectors specimens, all the specimens failed by both crushing of concrete and splitting and shearing of connectors from the steel beam and remained embedded in the slab after unloading occurred. Here also acute cracks were observed. Fig14 and Fig 15 shows cracking pattern of the specimen at the connector level and deformation of rectangular connector after failure.



Fig 14. Cracking pattern of Rectangular
Rectangular connector specimen
failure

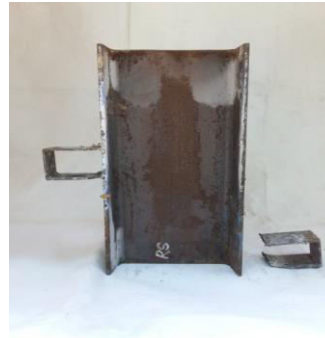


Fig 15. Deformation of
connector after
failure

In this research work, the weight and bearing width of connectors welded to the universal steel beam were almost kept as same as 0.9kg and 50mm respectively. In the case of rectangular connector, the width of the connector was kept as equal to width of the square connector, but the length was increased by 60% more than that of square connector, that led to minimise the development of cracks on the surface of the concrete slab.

IV. CONCLUSIONS

The average results of the experimental investigation including Nine push-out tests are carried out. The results include failure pattern, behavior of load-slip curve and shear resistance of connectors under monotonic loading. From the experimental investigations on three types of shear connectors, the following conclusions were derived:

1. In load – slip curve, well defined elastic and plastic region could have been seen in all types of connectors specimens under monotonic loading.
2. The load – slip curve is approximately linear up to 50%, 75% and 83%, in headed stud, square and rectangular connectors specimens respectively.
3. The ultimate shear resistance of headed stud connectors specimens is high, succeeding those square and rectangular connectors specimens resisted 70% and 51% of ultimate shear resistance of headed stud connectors specimens with corresponding slip values of 7.5481mm and 3.699 mm respectively under monotonic loading condition.
4. Both type of failures such as crushing of concrete slab and failure of connectors were observed in square and rectangular connectors' specimens.
5. The headed stud connectors specimens proved to be most effective in terms of load-carrying capacity and square connectors specimens withstood 70% of ultimate load -carrying capacity of headed stud connectors specimens.

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