International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 17 (2015) pp 38463-38467

Experimental investigation of headed stud shear connector in composite beam

B. Raguvaran,
Ph.D Scholar,
Department of Civil and Structural Engineering,
Annamalai University, Annamalai Nagar,
Tamil Nadu, India
raghugbs@gmail.com

R. Baskar,
Associate Professor,
Department of Civil and Structural Engineering,
Annamalai University, Annamalai Nagar,
Tamil Nadu, India
rajaram_baskar@rediffmail.com

Abstract- In this study, an experimental study of the behaviour of headed stud shear connector is presented. Six push-out tests on headed stud shear connector with different diameters were investigated. The shear resistance and shear stiffness with small to large diameter of studs and normal concrete strength were predicted. The experimental results were also compared with standard design code formula and recommended values of design codes. The available experimental procedure for the determination of the shear force-slip behaviour of shear connector under static loading was adopted.

Keywords: Steel-concrete composite beam, Headed stud shear connector, Load-slip curve of shear connector, Shear resistance.

Introduction

Shear connector act as an essential element in steel-concrete composite beam. It transfer shear force at steel- concrete interface to steel beam. The transfer of maximum shear force dictates choose of suitable shear connectors in the composite structures. There is increase of variety of forms of shear connectors and it is available for practical use. Headed studs are commonly used in steel-concrete composite structures. Headed studs have a shank and a head this shape creates bond between steel and concrete. Headed studs are embedded in concrete before it welded over the steel flanges. The performance of a shear connector depends on the numerous factors governing the mutually interactive response of the connector and the surrounding concrete. The design strength of shear connector acts as an important factor in the design of composite member. The design equations and design value are available in standard codes.

However, there is a demand on design strength assessment for large diameter headed studs and different concrete strength. The design strength of shear connector is obtained through experiment on push-out test specimen. Most the research confirm that the capacity of shear connectors and load-slip behaviour of shear connector be as equal importance. Some important investigations are discussed.Gattesco and Giuliani [4] reported four stud connector push-out tests, two for monotonic loading, and two for cyclic loading. The main arm of this test was to get the information on the shape of the load-slip curves and the damage accumulation at the end of each cycle for shear. In order to measure the incremental slips of stud shear connectors under repeated loading. Valente [8] conducted 2 static and 4 cyclic standard push-out tests with headed studs in high strength lightweight concrete solid slabs. The studs had 13 mm diameter and 50 mm height. And the ultimate tensile strength, fu, and yielding tensile strength, fy, were 501 MPa and 596 MPa, respectively. The maximum induced slip values and corresponding number of cycles to failure were illustrated. Prakash et al.[8] investigated modified conventional push-out test specimens by increasing the concrete confinement around the studs using hoop type transverse reinforcement to test the effect of shear strength and stiffness of high strength steel (HSS) stud connectors. The HSS studs used in this study had ultimate tensile and yield strengths of 900 MPa and 680 MPa respectively. The studs had a 20 mm shank diameter and 30 mm head diameter. During loading the specimens had cracks that extended parallel to the shear stud position on the top of the slab at almost 30% of the ultimate load.

The resistance of shear connectors can be determined from the push- out test. Push- out specimens is cast to compute the forces of different connectors. The test specimen is purely in compression. The different connectors used are headed studs, angle connector and channel connector. The present study headed stud shear connectors are investigated through push-out test. In this study, the behaviour and effects of headed shear connectors under static loading are investigated and results are presented.

Experiment program

A. Description of Push-out specimen

The push out test consists of a short steel beam section held in a vertical position by two identical reinforced concrete slabs. The concrete slabs attached to the beam flange by shear connectors. The connection subjected to a vertical load produces shear load along the interface between the concrete slab and the steel section.
The present study six push -out specimens were cast and tested. Three different diameter studs as headed shear connectors used for shear connections. The specimen geometry was kept similar with variation provided in the connector type and positioning of shear connector and reinforcements. Slabs have dimensions of 600 mm by 650 mm with thickness of 150 mm. Shear connector was welded on the steel section prior to casting of slabs. Specimen designation denotes the type of connector. HS as Headed

stud; the first two or three digits represent the diameter of headed shear connector embedded in the concrete slabs and the number after the period denoted the reference number of the specimen example HS19.1 where, HS refers Headed studs; 19 refers diameter in mm; 1 denotes trial specimen number.

i. Material properties

A feasible test on steel, concrete and shear connector were conducted using appropriate test specimen. Results obtained from concrete are shown in Table 1. Steel section and shear connector specimens were tested according to the procedure recommended in ASTM standard. Steel coupons were machined from headed studs and steel section results obtained are shown in Table 2, Fig.2 shows steel coupon dimension.

Fig.1. Headed studs

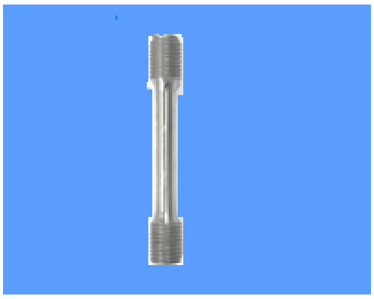

Fig.2. Steel coupon

TABLE.1. Mechanical properties of concrete

Charactestic compressive strength of concrete (fc) (N/mm^2)	**Elastic modulus(Ec)** (N/mm^2)	**Average tensile strength (fcr)** (N/mm^2)
31.74	25850	3.45

TABLE.2. Mechanical properties of Steel

Specimen	**Characteristic yield strength of steel(fy)** (N/mm^2)	**Elastic modulus** (N/mm^2)	**Elongation** (%)
Steel beam	260	2x10^5	18
Headed studs	374	2x10^5	21
Reinforcement			
10 mm	496	2x10^5	14
12 mm	424	2x10^5	13.8

ii. Push- out Specimen construction

Slabs were cast in the horizontal position in a leveled platform using appropriate formwork. The slabs were allowed to cure under uncontrolled natural condition. Consequently slab connected steel sections were positioned vertically and welded. Fig.3 presents configuration and geometry of specimen.

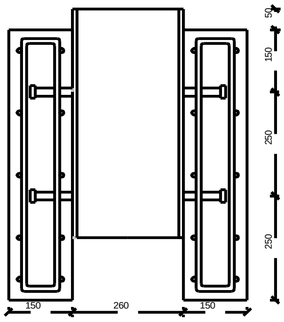

Fig.3. Front view (Unit mm)

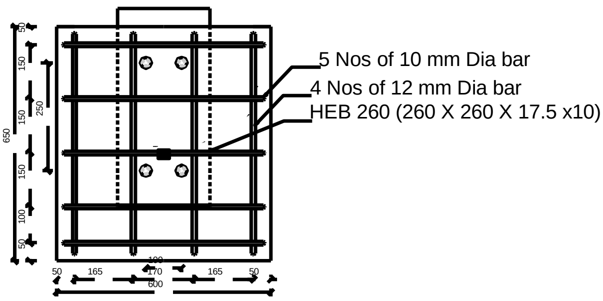

Fig.4. Side view of push-out specimen

Fig.5 Full-scale push – out specimen after welding

Instrumentation and test setup

All specimens were tested on a loading frame of 300t capacity. The specimen was placed over the frame platform. To achieve a uniform contact, a layer of Neoprene sheet and Teflon sheet was applied between the concrete slab and the frame platform. The load was applied at the upper end of the steel beam by the loading head of hydraulic jack on the frame through proving ring and a steel distributing plate.

The slip between the slab and the beam was measured by four dial gages located at the level mid row of shear connectors. Each dial gages was firmly attached to the beam with a bracket welded on the beam. Slip readings were taken at the mid level of steel beam with dial gage attached to the beam with the brackets where welded. Fig.5 presents the test setup used for the push-out specimens. All the specimens were tested statically with the load increasing in steps. The load was applied in 20 KN increments for all specimens throughout the test. Slip readings were taken for each load increment after the dial had stabilized. The cracks on the slab were highlighted and labeled as it occurred.

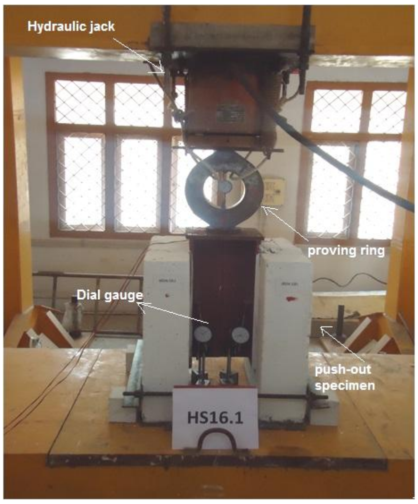

Fig.5 Test setup and instrumentation

Results and discussion

A. Failure mechanism

The failure modes observed in the push-out tests were shear deformation of studs and concrete crushing. The concrete around the connectors have no obvious cracks. Some cracks and local crushing were found in the slabs of specimen with 19 mm headed stud. Shear deformation of headed studs was found in the specimen with 22 mm headed studs. The headed stud connectors remained intact at the concrete slab cracks occurred in the vicinity of the end of steel beam in the slab. Fig.6 shows the failure shape of the headed studs after the slabs was removed.

Fig.6 Load versus Slip

B. Load – slip behaviour

Fig 7, Fig 8 and Fig 9 presents load - slip curves for each diameter of studs. The load carrying capacity increases with stud diameter as well as deformation for maximum load. The load –slips curves emerges linear progression followed by a plastic behaviour it was noted, as presented, deformation develops for an approximately constant or slow increasing load value. The eurocode 4 [3] suggests that a connector may be considered ductile if the characteristic slip is at least 6 mm. Based on the static curve of the stud shear connectors embedded in normal strength concrete, it can be observed that the specimen with 16 mm and 22 mm diameters can be achieved sufficient ductility other hand specimen with 25 mm cannot be achieved. The maximum slip value is 6.68 mm.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 17 (2015) pp 38463-38467

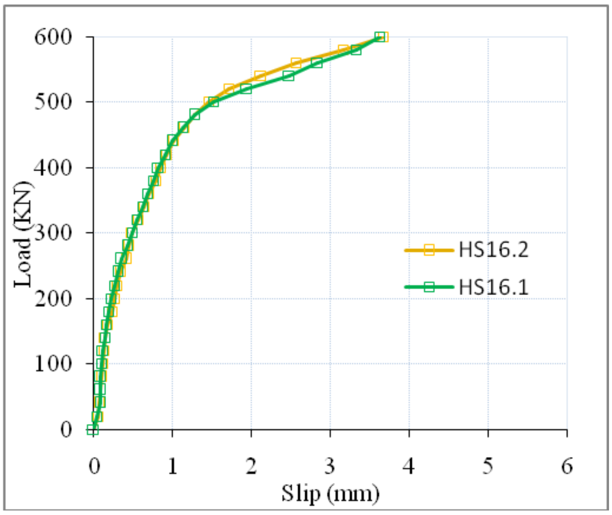

Fig.6 Load versus Slip

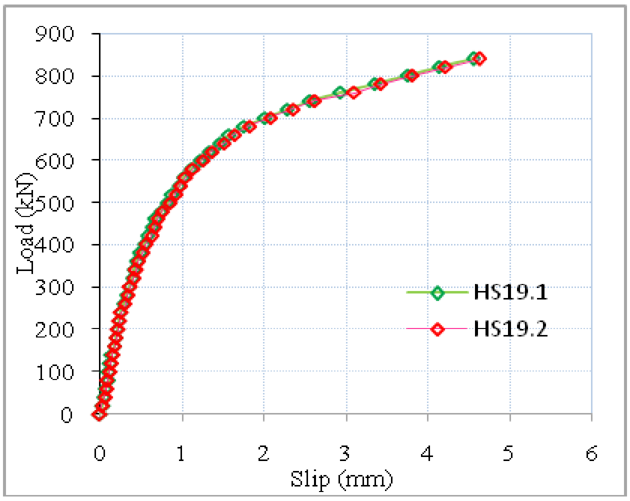

Fig.7 Load versus Slip

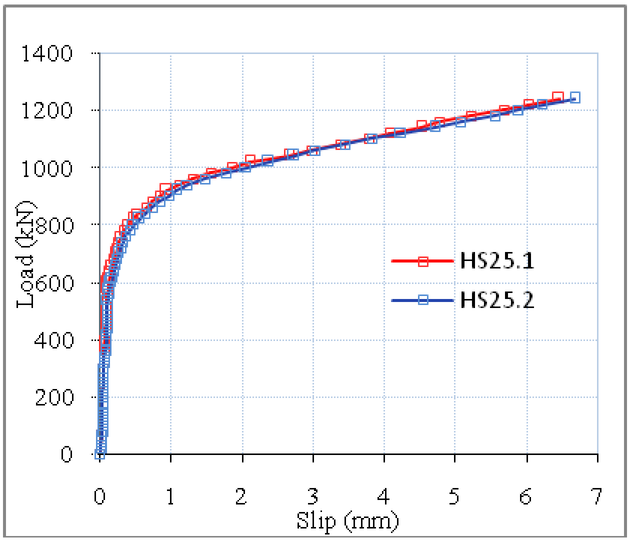

Fig.8 Load versus Slip

C Shear resistance and stiffness

The ultimate resistance and stiffness of stud shear connector were determined. The ultimate resistance per connector has been calculated by dividing the ultimate load achieved in each specimen by the number of connectors used in the specimen. The shear stiffness has been calculated by dividing values of half's of the ultimate loads by the corresponding slip values. Table 3 presents the shear resistance and stiffness of connectors.

TABLE 3. Test results

Specimen Designation	**Shear resistance of the connection (qu) (kN)**	**Slip at 50% ultimate load (0.5δh) (mm)**	**Shear stiffness of the connection (Ks) (kN/mm)**	**Maximum slip at ultimate load (δh) (mm)**	**Failure observation**
HS16.1	600	0.48	78.12	3.62	Shear failure
HS 16.2	600	0.49	76.53	3.67	
HS19.1	840	0.63	83.34	4.64	Shear failure
HS 19.2	840	0.58	90.51	4.56	
HS25.1	1240	0.14	553.57	6.46	Concrete crushing
HS 25.2	1240	0.18	430.55	6.68	

D.Effects of stud diameter

Diameters of headed studs deposited were 16 mm, 19 mm, and 25 mm. The specimens in each diameter were tested under static loads. The shear resistance and the shear stiffness increase as the diameter and the tensile strength become larger. The shear resistance of the studs with 19 mm is around 33.34% higher than of the studs with 16 mm. The shear stiffness is around 11.69 % higher. Correspondingly, the shear resistance of the studs with 25 mm is around 38.46% higher than of the studs with 19 mm.

Eurocode 4 [3]

The shear resistance of a headed stud is determined by following

$$PRD = \frac{0.8\ Fu\ d^2}{4} \quad (1)$$

Where, ultimate strength of steel Fu is 519 Mpa, diameter of shank for 19 mm, 25 mm, and γv is 1.25. Because of higher value of tensile strength following equation to be used for calculation of shear resistance

$$PRD = \frac{0.29 d^2 (fck\ Ecm)^{0.5}}{\gamma v} \qquad (2)$$

Where, concrete strength (cube) *fck* is 31.74 N/mm^2 Elastic modulus is 25.8 kN/m^{2}from the table; partial safety factor γv is 1.25.

Considering value 'Fu' from test and substituting values to the equation (2). The characteristic resistance of shear connector was obtained. Some standard design codes have been recommended the characteristic resistance for design concrete strength were straight away used.

TABLE 4 .Comparison stud strength

Stud dimension (mm)	**Max load per connector (P_{max}) (kN)**	**Design Shear resistance Per connector (Pk) (kN)**	**Design Shear resistance Per connector (PRD) - Eurocode 4 (kN)**	**Design Shear resistance Per connector (PRD) - BS:5400-1979 part-5 (kN)**	**Design Shear resistance Per connector (PRD) - Indian Code IS:11384 -1985 (kN)**
16 x 100	75	67.5	53.79	-	
19 x 100	105	94.5	75.86	100	85
25 x 100	155	139.5	131.34	154	101

Conclusions

Push-out test specimen with three varied diameters of headed stud shear connector embedded in a normal concrete were investigated. Results were compared with the standards used design codes. Main conclusions of this study are

- Shear resistance of headed stud shear connector were found. Maximum shear resistance of 139.5 kN was obtained for the specimen with 25 mm diameter studs.
- The load-slip curves of specimens under static loading were observed. The curves exhibited linear progression followed by a plastic behaviour. The curves showed similar trend for each diameter of studs.
- Maximum slip obtained is in the range of 3 mm - 7 mm. The slips were found with the allowable limits of 6 mm according to eurocode 4. Performances of shear connectors that are 16 mm and 19 mm diameter studs were considered as flexible.
- Shear resistance and shear stiffness of the connectors with the shear connectors were obtained and this shows good prediction compared with other type connectors.

References

[1] ASTM E8/E8M-11 (2012). "Standard Test Method for Testing of Metallic Materials". ASTM International, West Conshohocken, PA.

[2] BS: 5400, (1979), Steel, concrete and composite bridges: Part 5: "Code of practice for design of composite bridges," London, British Standards Institution.

[3] DD ENV 1994-1-1, "Design of composite steel and concrete structures- Part 1.1, and EC 4: General rules and rules for building, London", British Standards Institution.

[4] Gattesco N and Giuliani E.(1996) "Experimental study on stud shear connectors subjected to cyclic loading", Journal of Constructional Steel Research. 38 (1), pp.1-21.

[5] IS: 11384-1985, "Code of practice for composite construction in structural steel and concrete", Bureau of Indian Standard, New Delhi.

[6] Johnson, R. P. and Anderson, D., (1993), *Designer's Hand-book to Eurocode 4- part 1.1*, Design of composite steel and concrete structures.

[7] Lam D and EI-Lobody E, (2001), "Finite element modelling of headed stud shear connectors in steel-concrete composite beam", Elsevier science Ltd, p. 401. 2001.

[8] Prakash, A., Anandavalli, N., Madheswaran, C.K., Lakshmanan, N. (2012). "Modified Push-out Tests for Determining Shear Strength and Stiffness of HSS Stud Connector'' International Journal of Composite Materials. **2**(3):22-31.

[9] Ollgaard J, Slutter R, Fisher J, (1971) Shear strength of stud connectors in lightweight and normal- weight concrete, AISC Eng. J., 8: pp55-64.

[10] Valente, I., Cruz, P., (2009), "Experimental analysis of shear connection between steel and lightweight concrete"., J. Struct. *Eng*., 65, pp.1954-1963.