Proceedings of the 6th International Conference on Civil Engineering for Sustainable Development (ICCESD 2022), 10~12 February 2022, KUET, Khulna, Bangladesh (ISBN-978-984-35-1972-6)

LOAD-SLIP BEHAVIOR OF REBAR SHEAR CONNECTOR IN COMPOSITE `BEAMS WITH SOLID CONCRETE SLAB

First Fahmida Mahjabin1*, second Mahbuba Begum2 and third Mehedi Hasan3

[1] *first, Bangladesh University of Engineering and Technology, Bangladesh, e-mail: mehjabineva.ce@gmail.com*
[2] *second, Bangladesh University of Engineering and Technology, Bangladesh,e-mail:mahbubabegum.ce.buet.ac.bd*
[3] *third, Bangladesh University of Engineering and Technology, Bangladesh, e-mail: mehedi564662@gmail.com*

***Fahmida Mahjabin**

ABSTRACT

In composite structure,at the interface between steel beam and concrete slab, shear connectors are provided to resist the horizontal shear between the two components and to prevent vertical separation or uplift of the concrete slab. There are various types of shear connectors, in this research the study is focused on investigating the load-slip behavior of the rebar type shear connector in composite beams with solid concrete slab. Eight push out test specimens were designed with variable connector strength, connector diameter and connector length. The diameter of connectors used were 16 mm and 20 mm. For both diameter connectors the height was kept fixed at 100 mm whereas the length of L-shape connector was varied between 50 mm to zero mm. Two type of concrete strength (20MPa and 30 MPa) were used in the test of specimens. All of the Specimen were tested under axial compression. The applied load and vertical slip of steel section with respect to the concrete slab was recorded during the test. The effect of varying parameters such as connector length, diameter and concrete strength of slab were investigated on the ultimate shear capacity. It is observed that with the increase of connector diameter from 16mm to 20 mm for straight bar rebar connector the shear capacity increased 47%. With the increase of compressive strength from 22Mpa to 27MPa with other constant properties the increase of shear capacity was 40%. Two shapes of rebar bar were used as connector. One was a straight bar of 100mm long and the other was L-shape of 100mm length and 50mm height. Shear capacity increases from straight bar to L shape 44% for 16mm diameter connector and 14% for 20mm diameter connector. Two types of failure behavior were observed in the push-out test one was crushing of concrete and another was shearing failure of connector.with lower compressive strength of concrete crushing of concrete failure is observed and with smaller diameter shearing of connector failure is observed. In the experiment it was investigated the effect of shear connector on failure mode and load-slip behavior.

Keywords: *composite beam, shear connector, push-out, load-slip, shear capacity*

1. INTRODUCTION

Steel-concrete composite beams have been used for a considerable time in bridge and building construction (Raguvaran Balasubramanian & Baskar, 2018)A composite beam consists of a steel section and a reinforced concrete slab interconnected by shear connectors (Subramani & Periasamy, 2018). It is common knowledge that concrete is strong in compression but weak when subjected to tension, while steel is strong in tension but slender steel members are susceptible to buckling while under compressive forces (Raguvaran Balasubramanian & Baskar, 2018). The fact that each material is used to take advantage of its positive attributes makes composite steel-concrete construction very efficient and economical (Subramani & Periasamy, 2018). In this kind of structural system concrete provides stability, stiffness; whereas steel provides tensile strength and ductility (Johnson & Anderson, 2001). In figure 1 a I-shape steel beam is connected with a concrete slab with a stud shear connector. The behaviour of shear connector is important in understanding the load-slip behaviour and the composite action at the interface of steel and concrete. Shear connector resist the uplift of concrete slab from steel beam (Mazoz et al., 2013). The design strength and behaviour of C-shape, L-shape & I-shape connectors and headed stud connectors are studied by several researchers through experimental and numerical investigations (Mazoz et al., 2013),(Pashan, 2006) Current design codes such a Eurocode 4 (Johnson & Anderson, 2001) and AISC (Hoffman et al., 1996) only include the design equations and design values for headed stud and channel shear connectors (Kabir & Begum, n.d.)

In this research, a study has been conducted on experimental investigations to determine the failure mechanism and load-slip behaviour of L-shape and zero head length rebar shear connectors in steel-concrete composite beams. In this test experiment there are eight specimens with varying concrete compressive strength when the other parameters are constant and varying diameter while keeping other parameters constant and changing L-shape to zero head length straight rebar connector, so that the test include all the relevant cases into consideration.

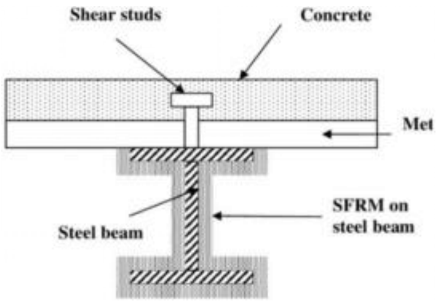

Figure. 1: Composite beam with shear connector(Beitel et al., 2007)

2. EXPERIMENTAL PROGRAM

The push-out test specimens were fabricated from six meter long hot rolled standard (S-shape) compact steel beam I- section (100 by 200 mm) cut into pieces of 350mm length in the Mechanical shop of BUET. The rebar short cut pieces were extracted to appropriate lengths from long deformed reinforcing bar as shear connectors are deformed L-shape (50mm by 100mm) and straight bar of 100mm height. The rebar connectors were then welded to the flanges of steel section according to AWS (American Welding Society) specification by a certified welder at Steel –metal and Welding Shop at BUET. The I shape steel beam and the welded 100mm straight rebar connector is shown in figure 2(a). The wooden box frame-work for slab and 3inch cement block for clear cover is shown in figure 2(b).

Figure. 2(a): Straight rebar connector

Figure. 2(b): Shuttering of specimen

For all test specimens, the position of the connector was kept constant at 212.5mm as end distance i.e distance from the center-line of the connector to the bottom of reinforced concrete slab. Surface welding was applied around the rebar connector so that the connector would not fail due to weld failure during testing.

Table 1: General properties of push-out test specimens

Specimen	Connector diameter (mm)	Connector Length (mm)	Connector height (mm)	Concrete Strength (MPa)
A1	16	50	100	22
A2	20	50	100	22
A3	16	50	100	27
A4	20	50	100	27
B1	16	-	100	22
B2	20	-	100	22
B3	16	-	100	27
B4	20	-	100	27

2.1 Description of Push-out Specimen

In the experiment two push-out text series (series-A and series-B) are categorize with different shear connector shape. There are eight push-out text specimens in which each push-out specimen consists of steel beam section of 100 by 200 mm rectangular beam which is made of hot rolled short standard (S shape) compact steel beam. The beam was held in a vertical position by two identical reinforced concrete slabs having width of 250, length of 350 mm and thickness of 130 mm. A typical test specimen is shown below in Figure 3. In this test specimen, the concrete slabs are attached to the beam flange by rebar shear connectors where some connectors are straight bar and some are L-shape. The connectors are welded at the I-section beam flange.

In current study, the geometry of beam and slab were constant for all with a varying connector geometry and concrete compressive strength. Concrete strength was varied keeping in a low compressive strength for both series of specimens. Series A has shear connector of 100mm length to 50 mm head length of L-shape rebar connector whereas series B has 100 mm length without any head length of straight bar connector. Each test series consists of four push-out test specimens with variable size of rebar connectors of 16mm diameter and 20mm diameter. The slabs are cast vertically followed by (mazoz,2013) procedure. All slabs of same concrete strength are cast from same batch to reduce the variation of concrete strength. Axial compression was applied in downward direction on top of the steel beam. In the interface between steel beam and concrete slab, shear load is produced when subjected to vertical load.

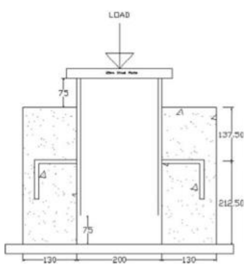

Figure 3(a): front view

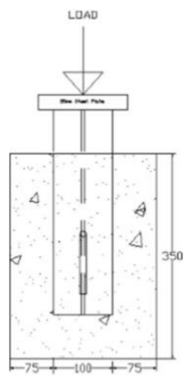

Figure 3(b): side view

Figure. 3: Push-Out test specimen with rebar connector (units in mm) (Kabir & Begum, n.d.)

2.2 Material Properties

Test on steel, concrete and shear connector were carried out using appropriate test procedure to determine the experimental shear strength capacity of rebar shear connector obtained by applying the compressive load on push- out test specimens.

Table 2: Mechanical properties of steel material

Specimen	Yield Strength, fy (MPa)	Ultimate Strength, fu (MPa)	Elongation (%)
Steel section	307	424	22
Rebar Connector			
16mm	408	638	17
20mm	500	668	15

2.3 Test Set-up and Instrumentation

Universal Testing Machine (UTM) having the capacity of 2000KN was used for axial compression of push-out text specimens. The specimens were placed over the flat platform of the UTM. At the upper end of steel beam axial compression was applied by a hydraulic jack through a 25mm thick of rigid steel plate. In order to ensure proper distribution of applied load and uniform contact a rubber pad was placed over the steel plate. The vertical and horizontal slip between reinforced concrete slab and steel beam was measured by two 50 mm capacity dial gauges during loading which were located at the level of shear connectors. One dial gauge was attached at the flange of the beam and the another one was attached at the web of the beam with help of a bracket. The test setup is shown below in Figure 4. The net slip of connector is calculated by the average of two slip values. The load was applied at a rate of 0.5 mm/min using displacement-controlled method. The slip was measured by means of the gauges between the steel beam and the concrete slab during each loading step, after the dial had stabilized.

Figure. 4: Test setup and instrumentation(Kabir & Begum, n.d.)

3. TEST RESULTS

3.1 Load-Slip behaviour

In this section, the experimental results related to the Push-out specimens are presented, along with a description of observed failure mechanisms. The main test results are shown in the form of load-slip curves. The relation between the axial compressive load and the vertical slip of steel section with respect to concrete slab is presented in the table 3.

Table 3: Test results of push-out test specimen

Specimen	Connector diameter	Connector Height	Compressive Strength	Ultimate Load	Capacity Increase	Slip at ultimate	Occurance of Failure
	(mm)	(mm)	(MPa)	(KN)	%	(mm)	
A1	16	50	22	172	-	7.2	Shearing of connector
A2	20	50	22	164	-4.6	5	Cracking of Concrete
A3	16	50	27	242	-	6	Shearing of connector
A4	20	50	27	240	-0.8	4.2	Cracking of Concrete
B1	16	-	22	163	-	5.2	Shearing of connector
B2	20	-	22	240	47.2	4.8	Cracking of Concrete
B3	16	-	27	168	-	3.8	Shearing of connector
B4	20	-	27	210	25	4.5	Cracking of Concrete

3.2 Failure Mechanisms

Two types of failure were observed in the text specimen. One is shear failure of rebar connector and the another is concrete cracking followed by crushing. The failure patterns are shown below in Figures. Concrete crushing around the connector is illustrated in Figure 5(b) and shearing of connector failure shown in figure 5(a). In the specimens having smaller diameter of connectors 16mm (i.e., A-1, A-3, B1 and B-3), failure occurred by shearing of the rebar connectors. No cracking or splitting of concrete was observed in these specimens. On the other hand, in specimens A-2, A-4, B-2 and B4 failure was initiated by cracking and crushing of concrete followed by shear failure of the connector.

Figure. 5(a) Shearing of connector

Figure. 5(b) Crushing of Concrete

Figure 5: Failure of concrete slab

3.3 Parametric Study

3.3.1 Effect of compressive strength of concrete

Compressive strength has a significant effect on the shear resistance of rebar shear connector and failure mode. In this study eight specimens are divided into two series (series A and series B). Two different type of compressive strength of concrete were used 22MPa and 27 MPa. The four sets were

16 mm diameter with 50 mm connector length (A1&A3), 20 mm diameter with 50mm connector length (A3&A4) and 16 mm, 20 mm connector diameter without connector length (B1, B2, B3&B4).

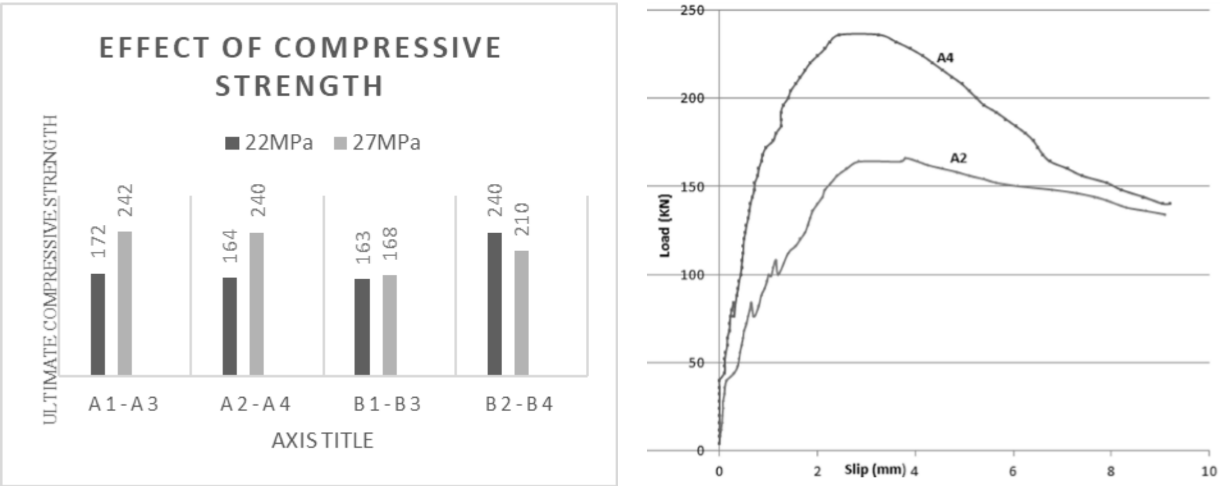

Figure.6: Effect of compressive strength of concrete for two different diameter connectors

It is obvious that from the figures that as the concrete strength increases the ultimate load carrying capacity also increases. For changing of compressive strength of 22Mpa to 27 MPa for 16mm diameter having 50 mm length the increment of ultimate load was found to be 40.7% (A1&A3). Again for 20 mm diameter connector with 50 mm connector length the increment was observed to be 46.3% (A2&A4). The increment of ultimate load carrying capacity for straight connectors with no head length (B1, B2, B3 and B4) was observed very less compared to connectors with 50 mm head length. The height of all connectors were designed constant as 100 mm. The load vs slip graphs of those specimens mentioned for observation.

3.3.2 Effect of Connector diameter

It is obvious from the test that as the diameter of rebar shear connector increases the ultimate load carrying capacity also increases. For 22 MPa and 27 MPa concrete strength, connectors without head length the ultimate capacity increment was observed to be 47.2% & 25% respectively for variable connector diameter (16 mm & 20 mm). The effect of diameter increment had less effect on ultimate capacity for specimens having connector length as 50 mm. The load vs slip graphs of those specimens are mentioned below for observation.

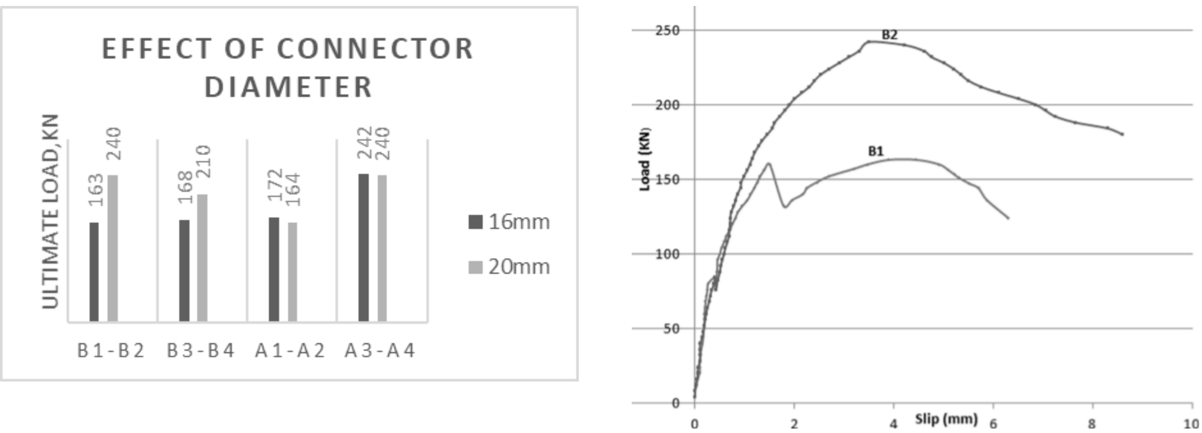

Figure.7: Effect of connector diameter for zero head length connector

3.3.3 Effect of Connector Length

Specimens A1, A2, A3 & A4 were designed as 50 mm length and specimens B1, B2, B3 & B4 were designed as zero mm length. The height was kept constant as 100 mm for all the tested specimens. The effect of such variation on ultimate load carrying capacity are mentioned in the table below. From the above observation it was found that for connector having head length of 50 mm had higher ultimate capacity than connectors with zero head length. The maximum capacity increment was 44% for specimen A3 compared to B3 where connector diameter was 16mm and concrete strength was 27MPa. The capacity increase for 20mm diameter and 27MPa compressive strength of concrete with having variable connector length is 14.2%. So with lower compressive strength of concrete it is observed that the effect of connector length shows decrement in capacity. The relation between axial compressive load and vertical slip of steel section with respect to concrete slab are mentioned below for the effect of rebar shear connector length.

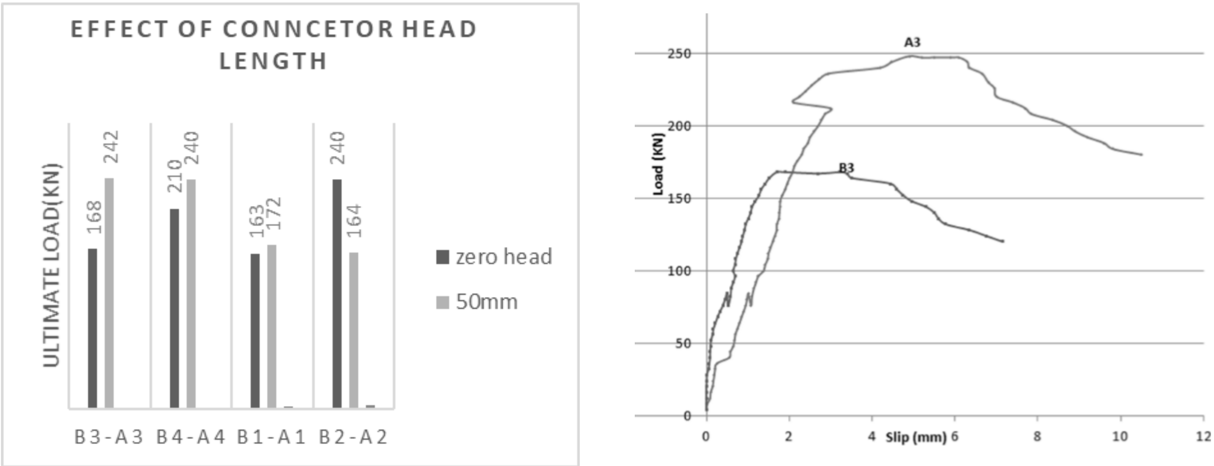

Figure 8: Effect of connector length for A3 and B3

4. CONCLUSIONS

This research presented the results of tests performed on 8 push-out specimens to investigate the feasibility of using rebars as shear connectors in composite beam with solid concrete slab. The following conclusions are drawn concerning the failure modes, the ductility and the ultimate load capacity of the test specimens.

1. The failure modes observed from the push-out tests can be generally classified into two types: Shearing of the connector and Crushing-cracking of the concrete slab. The shearing of the connector was occurred, especially in the specimen with connectors of lower diameter connector 16mm. However, in specimens with 20mm connectors failure was caused by cracking and crushing of the concrete surrounding the connector.
2. The slip values at failure obtained from the push-out tests, were found greater than 6 mm. Therefore, the connector can be considered as ductile, according to Eurocode 4 (2005).
3. When the failure mode is concrete cracking-crushing, the ultimate load capacity decreased gradually and the maximum slip value was observed higher than the specimens of shearing of connector failure. So concrete crushing specimen showed more ductility than shearing of connector failure.
4. The ultimate load capacity increased significantly with the increase of connector diameter. With the increase of connector diameter from 16mm to 20mm the load carrying capacity increased 47.2% for 22MPa concrete strength and without connector length.
5. The ultimate load capacity increases with the increase of compressive strength of concrete. For 20mm diameter connector with 50mm connector length the capacity increased 46.3% with the increase of compressive strength from 22MPa to 27MPa.

6. The ultimate load capacity increases significantly with the increase of connector length. For 20mm diameter connector with no headed length capacity decreases 44% than 50mm connector length.

REFERENCES

Hoffman, E. S., Gouwens, A. S., Gustafson, D. P., & Rice, P. F. (1996). Structural Design Guide. In *Structural Design Guide*. https://doi.org/10.1007/978-1-4613-1171-3

Johnson, R. P., & Anderson, D. (2001). EN1994 Eurocode 4: Design of composite steel and concrete structures. *Proceedings of the Institution of Civil Engineers - Civil Engineering*, *144*(6), 33–38. https://doi.org/10.1680/cien.2001.144.6.33

Kabir, M. H., & Begum, M. (n.d.). *Load-slip Behaviour of L-shape Rebar Shear Connectors in Steel-Concrete Composite Members*. 1–6.

Mazoz, A., Benanane, A., & Titoum, M. (2013). Push-out tests on a new shear connector of I-shape. *International Journal of Steel Structures*, *13*(3), 519–528. https://doi.org/10.1007/s13296-013-3011-4

Pashan, A. (2006). *Behaviour of Channel Shear Connectors : Push-Out Tests* (Issue March).

Raguvaran Balasubramanian, B., & Baskar, R. (2018). Performance study of steel-concrete composite beam involving flexible shear connector. *International Journal of Structural Engineering*, *9*(1), 70–80. https://doi.org/10.1504/IJSTRUCTE.2018.090751

Subramani, T., & Periasamy, A. (2018). Study on behaviour of stud type shear connector in composite beam using ANSYS. *International Journal of Engineering and Technology(UAE)*, *7*(3), 54–58. https://doi.org/10.14419/ijet.v7i3.10.15629