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Study on Behaviour of Angle Shear Connector in Steel-concrete Composite Structures

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Abstract

In this study an experimental study of the behaviour of angle shear connector is presented. Six push-out tests on angle shear connector with two varied length angles were investigated. The shear resistance and shear stiffness with angles embedded in a 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 structure, Angle shears connector, load-slip of shear connector, shear resistance

1. Introduction

Shear connector is an essential element in steel-concrete composite member. Presence of shear connector limits the shear flow of steel-concrete interface. 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.

The angle connector is one of the shear connectors. The angle shear connector is easier compared to the other connectors, since in most steel shops, commercial standard sizes for hot rolled steel profiles of C-shaped shear connectors are available. Moreover, by simply cutting in their long steel profiles, these types of connectors can be easily prepared. 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. The design code is currently providing the equation and values only for headed stud shear connectors and some type of shear connectors. 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. Kiyomiya *et al*. (1986) studied the behaviour of the L shape steel shear connector by means of push-out test method. Tensile fracture of shear connector, concrete crush, and shear failure of concrete were observed in their study. Consequently an equation to predict the load-carrying capacity of the angle, T-shape steel and channel shear connector was developed by selecting lower limit maximum shear force obtained from experimental results. Choi *et al*. (2008) investigated the fatigue strength of welded joints between angle shear connectors and the bottom plate in steel-concrete composite slabs through fatigue tests. Shariati *et al*. (2014) investigated the shear behaviour of angle shear connector under monotonic loading and reverse cyclic loading. The resistance of shear connectors can be determined from the push- out test. Push- out specimens are 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 angle shear connectors are investigated through push-out test. In this study, the behaviour and effects of angle shear connectors under static loading are investigated and results are presented.

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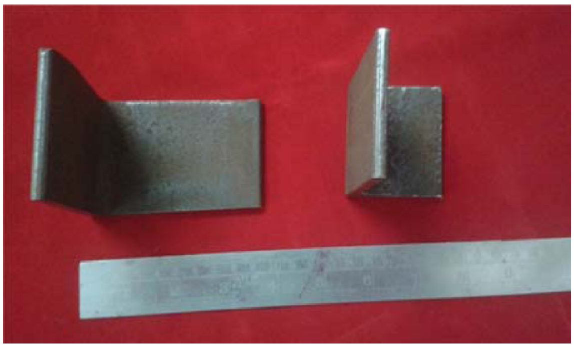


Figure 1. Angle connector.

Figure 2. Steel coupons.

2. Experiment Program

2.1. 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 four push- out specimens were cast and tested. Two different angle sections as angle 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 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 A as angle; the first two or three digits represent the height of the angle shear connector embedded in the concrete slabs while its length is indicated by the last two digits, the number after the period denoted the reference number of the specimen example A9050.1 where, A refers angle; 90 refers outstanding leg in mm; 50 refers connected leg in mm; 1 denotes trial specimen number.

Table 1. Mechanical properties of concrete

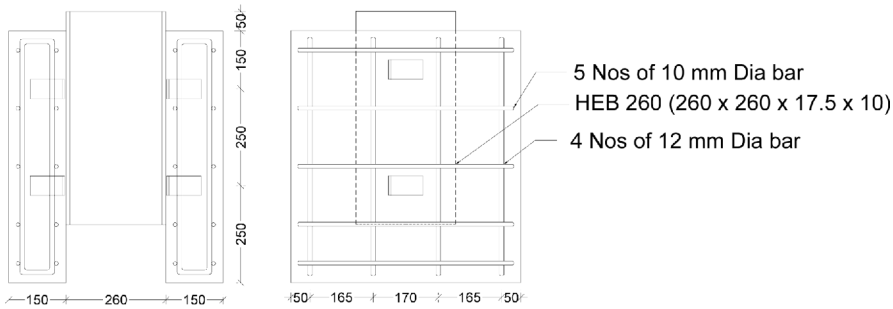
Charactestic compressive strength of concrete (f_c) (N/mm^2)	Elastic modulus (E_c) (N/mm^2)	Average tensile strength (f_{cr}) (N/mm^2)
31. 74	25850	3.45

Table 2. Mechanical properties of steel

Specimen	Characteristic yield strength of steel (f_y) (N/mm^2)	Elastic modulus (N/mm^2)	Elongation (%)
Steel beam	260	2×10^5	21
Angle shear connector	332	2×10^5	22
Reinforcement			
10 mm	496	2×10^5	14
12 mm	424	2×10^5	13.8

2.2.1. 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 angle connector and steel section results obtained are shown in Table 2, Fig. 2 shows steel coupon dimension.



(a) (b)

Figure 4. (a) Front view (b) Side view dimensions of push-out specimen (unit mm).

Figure 5. Construction of concrete formwork.

2.2.2. Push-out Specimen construction

Slabs were cast in the horizontal position in a levelled platform using appropriate formwork. The slabs were allowed to cure under uncontrolled natural condition. Consequently slab connected steel sections were positioned vertically and welded. Figure 4 presents configuration and geometry of specimen.

2.3. Instrumentation and test setup

All specimens were tested in a compression-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. Figure 6 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 labelled as it occurred.

3. Test Results

3.1. Failure mechanism

The failure modes observed in the push-out tests were shear like deformation of connectors and crushing of concrete near the bottom of slab. The concrete around the connectors have no obvious cracks. In the specimen with 50 mm length angle connector, the angle connectors remained intact at the concrete slab simple cracks occurred near the end of steel beam in the slab. Figure 8 shows the failure shape of the angle connector after the slabs was removed.

Figure 6. Test setup and instrumentation.

Figure 7. Concrete crushing and separation of slab.

Figure 8. Shear failures of angle connectors in A9090.

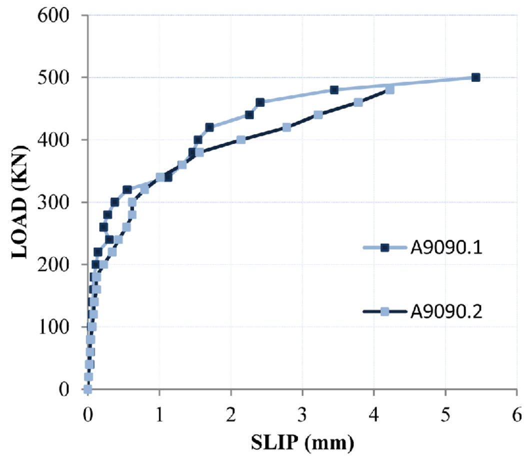


Figure 9. Load versus Slip.

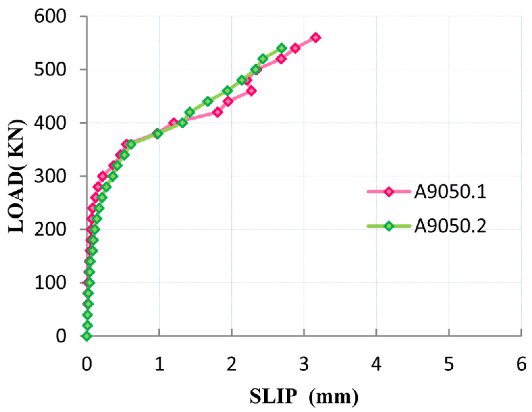


Figure 10. Load versus Slip.

3.2. Load-slip behaviour

Figures 9, 10, and 11 present the load-slip curves of the push-out specimens. The load-slip curve shows that in all specimens, the load capacity decreased quickly beyond the ultimate load. It can be seen that the specimens with longer length showed yield plateau and higher slip increases when the load reached its ultimate compared to short length angle. The eurocode 4 suggests that a connector may be considered ductile if the characteristic slip is at least 6 mm. Based on the static curve of the angle shear connectors embedded in normal strength concrete, it can be concluded that sufficient ductility can be achieved with angle shear connectors. Maximum slip occurred was 5.42 mm.

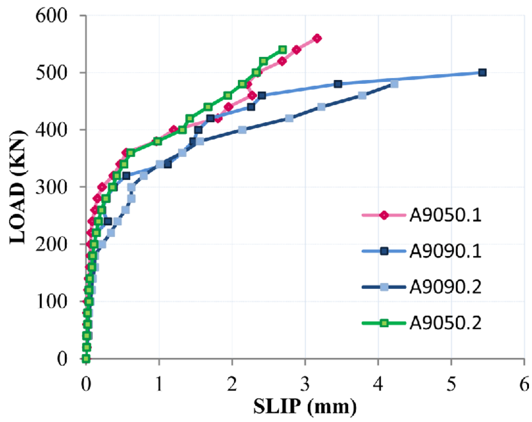


Figure 11. Comparison Load versus Slip.

3.3. Shear resistance and stiffness

The ultimate resistance and stiffness of angle 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 considering the elastic phase of load-slip curves; corresponding slip obtained by dividing the loads at 50% of ultimate loads by the slip value. Table 6 presents the shear resistance and stiffness of connectors.

3.4. Effect of angle length

The length of the connectors varied from 50 to 90 mm. The load-slip curves of static loading for specimens with the angle length of 50 mm were considered. The specimen with 50 mm length angle connectors were having slightly higher load of 137.5 kN compared to 122.5 kN for the specimen with 90 mm length angle connectors. This corresponding increase of load carrying capacity of 12.24%. Slip was found; it was low value of 3.29 mm compared to 5.42 mm for the specimen with 90 mm length angle connectors. Corresponding decrease of 39.37%. From the results, this was found 50 mm length angle connectors have higher shear resistance than compared to 90 mm length angle connectors.

3.5. Design code strength comparison

Angle connectors were investigated by the Eurocode design formula based on French studies given by

Table 3. Test results

S.No	Specimen Designation	Shear resistance of shear connector (*Qu*) (kN)	Stiffness of Shear connection (K_s) (kN/mm)	Slip at 50% of Max. Load. (mm)	Max slip (mm)	Failure mode
1	A9090.1	125	240.38	0.26	5.42	Shear failure
2	A9090.1	120	157.89	0.38	4.21	Shear faliure
3	A9050.1	135	259.61	0.26	2.69	Concrete crushing
4	A9090.1	140	318.18	0.22	3.12	Concrete crushing

Table 4. Design strength comparison

Specimen designation	Max Shear resistance (Qu) (kN)	Design resistance (Qud) (kN)	Design Resistance Eurocode design formula (Qud) (kN)
A9050	137.5	110	107.32
A9090	122.5	98	107.32

$$Qu = 10\ \text{ba}\ \text{hac}^{3/4} f_c^{2/3} \quad (1)$$

Where, ba and hac are the length and the height of the outstanding leg of the connector. The design resistance Qud is then obtained by applying to qu a partial safety factor equal to 1.25.

4. Conclusion

Push-out tests were performed to study the behaviour of angle shear connector embedded in a concrete slab subjected to static loading. Main conclusions of this study are as follows:

(1) The maximum shear resistance has been observed -the 90 mm length angle connector and 50 mm length angle connector had slight difference of its strength resistance against shear.

(2) The load-slip curves of specimens under static loading were observed linear similar trend in elastic phase with accompanied exhibit nonlinear when reaches ultimate load.

(3) Maximum slip obtained is in the range of 3-5.5 mm. The slips were found with the allowable limits of 6 mm according to eurocode 4. Performances of shear connectors were considered as flexible.

(4) Shear resistance and shear stiffness of the connectors with two different length angles were obtained and this shows good prediction compared with other connectors.

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