Experimental Studies on Innovative Shear Connections Between Steel and Concrete for Steel Concrete Composite Structures

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Abstract— This paper shows the results of an experimental investigation carried out on a connection element of steel and concrete composite structures, through double-sided push-out shear tests. The connection system was composed of embossed steel plates with welding. The test configuration follows the EC4 recommendations. The experimental study involves tests on stud with diameter of 16 mm, T connector produced from laminated steel profiles and Embossed steel plate connector. With these tests it is possible to characterize different types of connection and evaluate load and deformation capacity. Nine specimens were made and tested under shear forces. The mechanical and durability properties of steel concrete composite beam with embossed steel plate connector, stud connector and T flange connector were investigated for M30 grade concrete as per IS10262- 2009.

Key words: Steel–concrete joints; Shear strength; Push-out; Embossed steel plates; Load-Slip; Experimental evaluation; mechanical and durability properties

I. Introduction

In steel and concrete composite construction, the two materials are integrated in structural members to combine their advantages of high tensile strength of steel and high compressive strength of concrete. In conventional composite construction, concrete slabs rest over steel beams and are supported by them. Under load these two components act independently and a relative slip occurs at the interface if there is no connection between them. With the help of a deliberate and appropriate connection provided between the beam and the concrete slab, the slip between them can be eliminated. In this case the steel beam and the slab act as a "composite beam" and their action is similar to that of a monolithic Tee beam. Composite structural members provide a cost-effective alternative to traditional structural steel or reinforced concrete beams, slabs, columns, and walls. Generally composite beam consists of 3 components such as steel girder, deck slab and connector. A new type of connection by friction and interlocking is introduced. A pair of longitudinal steel plates welded together and is also welded longitudinally to the upper flange of the steel girder. The bearing behaviour of a new connector – embossed steel plate – was analysed in detail by FEA and experimental tests. And the test results were compared with the results of conventional stud and T flange connectors. Investigations about the shear transmission of different types of shear connectors have been done by push - out test. The main objective of these tests is to describe the connection behaviour and to analyse the components such as load capacity, slip at the interface between steel and concrete. The innovative nature of the problems required complex research methodologies with experimental and theoretical studies, with a definite purpose of practical application of results. The push out test was conducted according to EC4, CEN (1994).

II. Experimental Set-up

A. Push-Out Test

Push-out tests were divided into three groups, and each group had three specimens. Table 1 shows the parameters of push-out specimens. The detailed specifications of each component are listed below.

1) Steel beam: The rolled I-section ISMB150 steel beams were used with a size of 150 mm × 80 mm × 7.6 mm × 4.8 mm. The material type was Fe250 with yield strength of 250 MPa.
2) Concrete slab: The size of the concrete slab was 390 mm ×350 mm × 120 mm. The grade of concrete was M30 of mix ratio 1:1.7:27.
3) The type of studs was Grade 4.6, with ultimate tensile strength of 400 MPa and yield strength of 240 MPa. Three diameters, 16 mm (M16), 19 mm (M19) and 22 mm (M22), were used and the heights of the stud were 75 mm. The thickness of three embossed steel plates are 8mm, 10mm and 12mm and the yield strength of plate is 270MPa. The pattern is DIN 59220:2000 teardrop pattern as shown in Fig 1. And the T connectors are of Fe250 grade and are varied in the width of flange as 50mm, 60mm and 70mm.
4) The diameter of reinforced bar was 10mm, and its yield strength was 415 MPa.
5) The dimensions of the specimens are shown in Fig 2, 3 and 4. Connectors are always welded to the steel profile and later embedded on the concrete slab after concreting.

Specimens	Concrete strength grade	Size of connector
PS1	M30	Diameter of stud 16mm
PS2	M30	Diameter of stud 19mm
PS3	M30	Diameter of stud 22mm
PS4	M30	Size of T flange b_f=50mm, D=70mm
PS5	M30	Size of T flange b_f=60mm, D=70mm
PS6	M30	Size of T flange b_f=70mm, D=70mm
PS7	M30	Thickness of embossed steel plate 8mm
PS8	M30	Thickness of embossed steel plate 10mm
PS9	M30	Thickness of embossed steel plate 12mm

Table 1. The Parameters of Push-Out Specimens

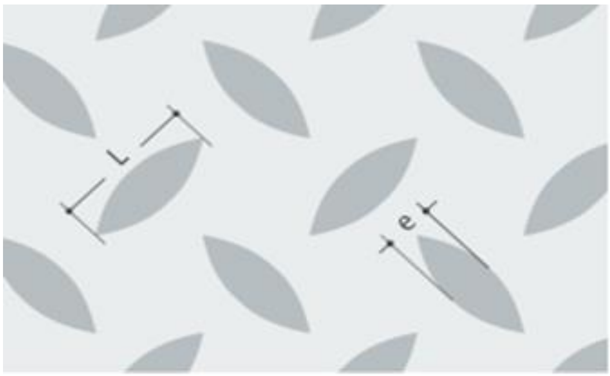


Fig. 1: DIN 59220:2000 teardrop pattern
L: approximately 30 mm
e: approximately 10 mm

B. *Casting of Specimens*

All push-out specimens were constructed using plywood forms. Each specimen consisted of two concrete slabs, each of which was connected to a 450mm long structural I section by welded headed shear studs, T flange and embossed steel plate connector. Steel reinforcement was the same for all tests. After the concrete was placed in the forms, it was vibrated with a mechanical vibrator. The specimens were covered and moist-cured for seven days, at which time the forms were removed. The specimens were tested around 28 days after being cast. Casting of specimens is shown in Fig 5

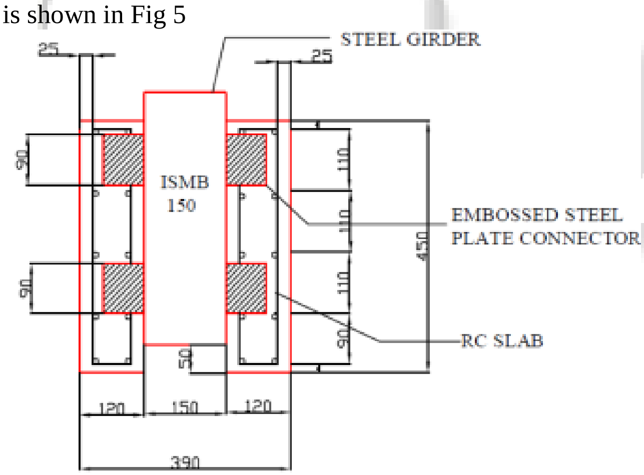


Fig. 2: (a)Front view

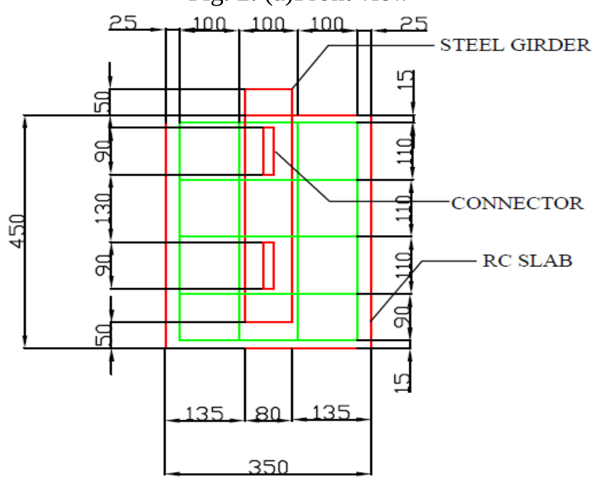
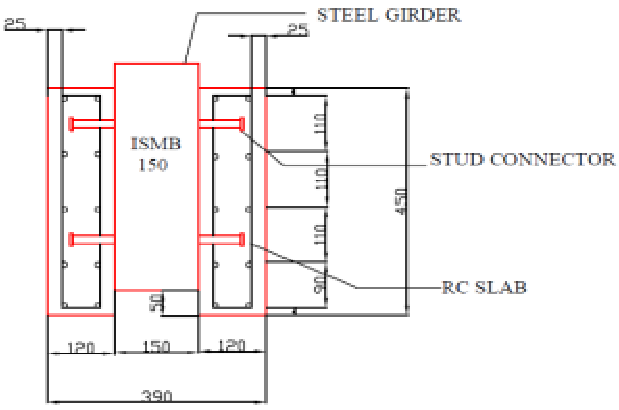
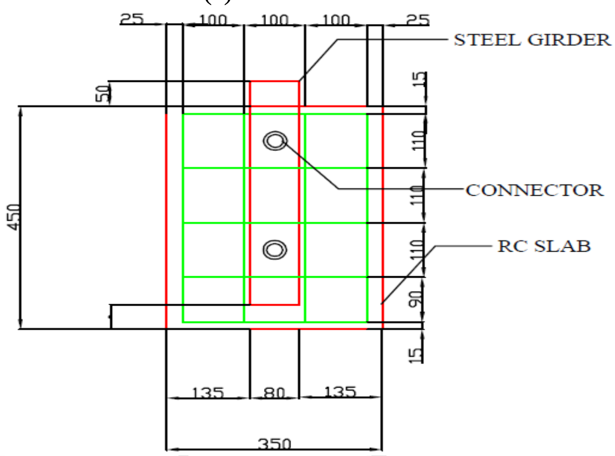


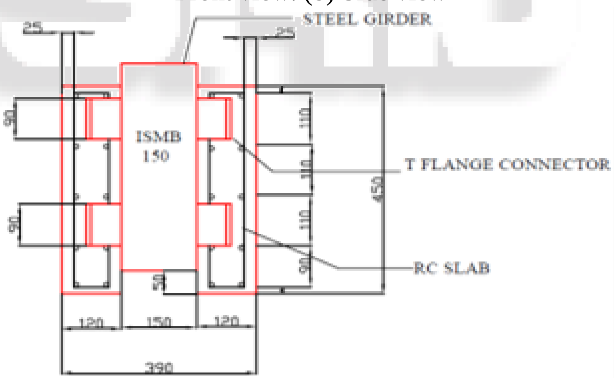
Fig. 3: (b)Side view
Fig. 2: Push-out test specimen (Embossed steel plate) (a) Front view. (b) Side view



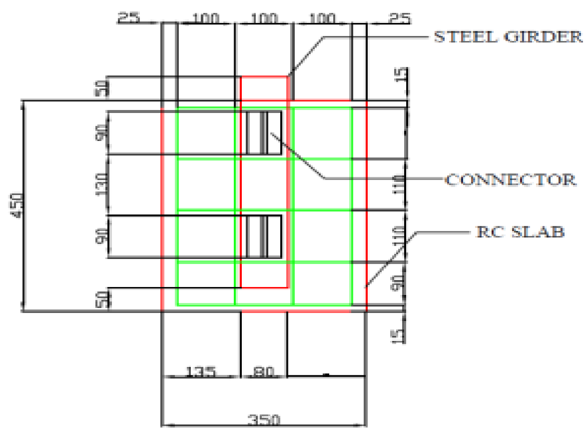
(a) Front view



(b) Side view
Fig. 3: Push-out test specimen (Shear stud connector) (a) Front view. (b) Side view



(a) Front view



(b) Side view
Fig. 4: Push-out test specimen (T flange connector) (a) Front view. (b) Side view

C. Test Setup And Loading Procedure

Specimens were tested in CTM machine with a capacity of 300 tons. The experiment was controlled by displacement result of LVDT. Displacement control was used for the monotonic tests. The monotonic tests were conducted at a displacement rate of 0.005mm/s. The test setup used in the experiments is shown in Fig 6.

III. TEST RESULTS

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. In all the load slip graphs shown in this section, the abscissa represents the average slip in mm at the interface of the steel section and the concrete slab.

A. Stud Connector

This type of connection is characterized by a stiffer initial behaviour, with linear evolution, followed by a plastic behaviour, where deformation develops for a slow increasing load value. Based on the results of three push-out tests, all the

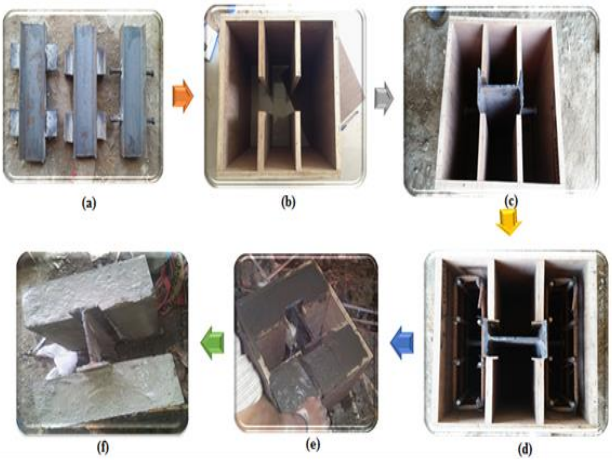


Fig. 5: Casting of Push-out test specimen
(a) Welding, (b)Mould for concreting, (c) Fixing the beam inside the mould, (d)Fixing reinforcement in position, (e) Concreting (f) After removing the mould

Fig. 6:

Fig. 6: Experimental setup

samples were failed by stud shank failure. Load – slip curve for three different diameter studs was shown in Fig 7. The load-slip curve consists of two parts, ascending and descending part. The ascending section can be separated into elastic and plastic parts. In the elastic part, the load-slip curves showed an almost linear relationship. In the plastic part, the slip increased rapidly and the stiffness reduced continuously. Here the ultimate slip was defined as the slip value when loading reached its peak. The failure pattern is shown in fig.10.

B. T Flange Connector

The possible failures modes for T connectors are similar to the ones presented for stud connectors. The connector fracture type of failure was observed. Every tested specimen suffered shear failure, localized near the web basis, right above the welded fillet. The area of failure is showing important deformation on the T web. In the lower part of the connector there is a concentrated zone of crushed concrete and several inclined cracks are rising from there. The type of deformation observed is very similar to the deformation suffered by the stud connectors. Increase in breadth of T flange increases the shear bearing capacity. The load – slip curve for three different T flange connectors was shown in Fig 8. It shows an initial almost linear progression. After this value a constant load level and increasing deformation is observed. Then the load slowly starts to decrease. T connectors show high load and high deformation capacity. The failure pattern is shown in fig.11.

C. Embossed Steel Plate Connector

The type of deformation observed is similar to stud and T connectors. In the lower part of the connector there is a concentrated zone of crushed concrete. These connections exhibit a high resistance to horizontal shear forces and are very rigid compared to traditional connectors (headed studs). However, their ductility is limited. It shows good load and deformation capacity and higher slip values and allows higher load values. The load – slip curve for three different thickness plate connectors was shown in Fig 9. It exhibits a linear domain followed by a non-linear domain with a noticeable ductility. With increasing the thickness of the plate it takes more shear with large deformation. The failure pattern is shown in fig.12.

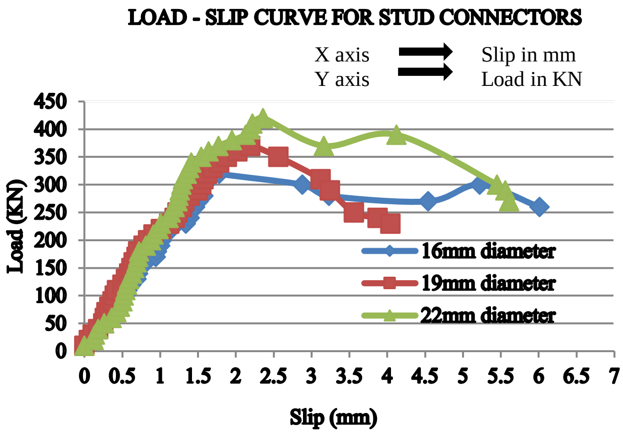


Fig. 7: Load –slip curve for different diameter studs

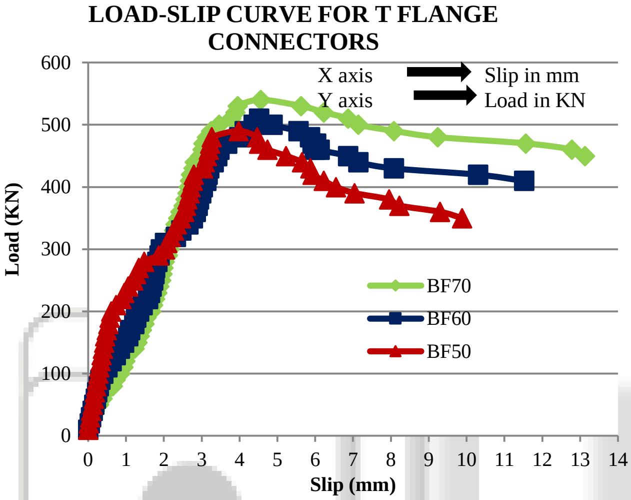


Fig. 8: Load –slip curve for different sized T flange connectors

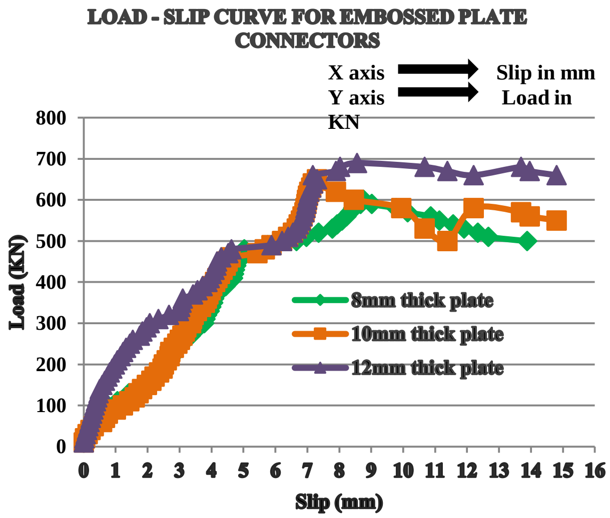


Fig. 9: Load –slip curve for different thickness of embossed steel plate connectors

IV. CONCLUSIONS

The work developed here aims to characterize different shear connection typologies. Numbers of standard Push-out tests were performed with headed studs, T connectors and Embossed steel plate connectors. In every tested specimen, the load and deformation values were observed and compared with the embossed steel plate connector.

Fig. 10: Failure pattern of stud connectors

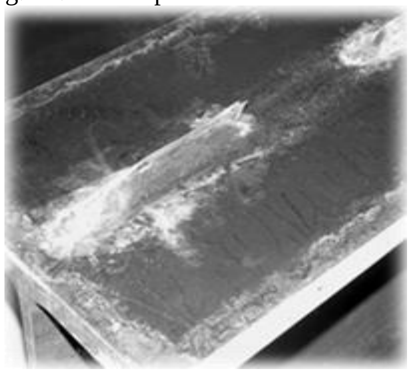


Fig. 11: Failure pattern of T connectors

Fig. 12: Failure pattern of Embossed plate connectors

In general, the load capacity of embossed plate connector is more than the ones verified for stud and T flange connectors. And the deformation values are higher, which is a good result if a better ductility is intended.

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