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# Experimental Investigation on Shear Connectors in Steel-concrete Composite Deck Slabs

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## Abstract

**Background/Objectives:** The steel-concrete composite construction has become an effective construction practice in the recent years. The cold form profiled sheet acts a platform for during the construction phase and acts as an external reinforcement after the construction. In steel-concrete composite construction, the shear connectors transfer the longitudinal shear force across the steel flange/concrete interface. The ability to transfer longitudinal shear force by shear connectors mainly depends on the strength of concrete against longitudinal cracking and mechanical properties of the shear connectors. This research investigates shear connector's capacity; the experimental investigation is involved using push-out test for two sets with different shear connectors framing to the profile steel sheet. **Methods/Statistical Analysis**: Set-W consists of three composite slab specimens with welded stud shear connectors, while set-B consists of three composite slab specimens with bolted shear connectors. Trapezoidal profile steel sheet of thickness 1 mm with rectangular embossments is used. Several key parameters of the composite slab are examined and measured, including slippage capacity, load carrying capacity, composite slab ductility and failure mechanism. **Findings**: the welded shear connectors provided a better performance in resisting slippage and providing a welded set higher load carrying capacity, however, the bolted shear connector specimens set showed more ductile behavior as compared to of specimens.

**Keywords:** Bolted Shear Connectors, Composite Slab, Slippage Capacity, Welded Shear Connectors

## 1. Introduction

In the construction industry with the day by day advancement of material properties and state of art technologies has able to create innovation in structural frameworks. In the construction d high rise buildings and bridge, the steel concrete composite construction is being widely used due to its faster, economical and eco-friendly methods. The concrete and steel combine together to form a composite action and it is mainly due to its shear transferring capacity between the steel sheet and concrete. Compared to conventional concrete, better stiffness and strength is provided in the steel-concrete slab. The most popularly used type steel concrete framework is made by providing steel sheet at the bottom and concrete at the top when combine together to form flexural composite member. The behavior of shear connection between the steel beams and composite slabs was analyzed by [1]. Push out tests was

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carried out with three numbers of specimens analyzed in both two and three dimensions. The important parameters studied are effects of inclusion of profiled sheeting, width of slab and types of support conditions. The experimental results were compared with the pull out tests of concrete and studied. The major type of failure was pull out failure and concrete crushing around the studs[2] investigated the behavior of headed stud shear connectors in composite slabs. A three dimensional model was created and was used in the analysis. The test results and finite element analysis was compared with each other. The main aim of the push out tests is to shear connection capacity and load slip behavior of shear connector. The parameters studied in the finite element analysis were sheeting geometries, diameter and height of stud, dimensions of slab, strength of concrete and shear connection capacity. A total of 44 push out specimens were used for the parametric study. Concrete pull out failure and crushing of concrete were major types of failure in the composite slab. The comparison of the experimental and finite element analysis has shown that the capacity of shear connection according to the American and British specifications were overestimated with the maximum value of 27% and 25% respectively. According to Euro Code the shear capacity values were conservative when compared to the other two with maximum value of 11%. Dennis Lam had done experimental research on existing standard push out test arrangement. For a special material like precast hollow core slabs, a new standards push out test procedure was proposed. In the push out tests, the behavior of different types and sizes of shear connectors is analyzed and compared with standard tests. The disadvantages of standard push out tests are that the experimental result cannot be compared with the standard test procedure. The main findings are longitudinal shear transfer by shear connector and slip due to load in the composite slab. From the experimental push out tests three major types of failure were observed. The concrete around the shear stud began to crush during the first mode of failure. In the second mode of failure there is no concrete crushing whereas shear stud starts to yield fully. When both the concrete and shear stud combine together and attains the maximum stress on them the failure is the third stage of failure[3] carried out push out tests to study the different behavior of single stud connector and multi stud connector. The outcome of the experimental results revealed that single stud connector and multi stud connector have similar stiffness but the load carrying capacity of the single stud shear connector was about 10% greater than multi stud shear connector. The spacing type between the shear connector also contributes to the stiffness of multi shear connectors. At the maximum load, the relative slip of single stud shear connector is larger and is about 19% in excess when compared to multi stud shear connector. A new expression between the stud load-slip relationships is proposed based on the test results and is more precise when compared to the existing relationship. The test results of multi stud shear connector agrees well with [4] and single stud test results holds good with AASHTO LRFD and Chinese code for composite slabs.

## 2. Experimental Program

### 2.1 Material Properties of Cold Form Profiled Sheet

Cold form steel sheet is a light weight material which many advantages such as high durability, structural performance and structural economy. In this experiment, 1 mm thickness of profiled sheet with rectangular type embossments were used. The dimension of profiled sheets is 450 mm x 430 mm (length and weight) respectively. From the test results, it was noted the yield stress and

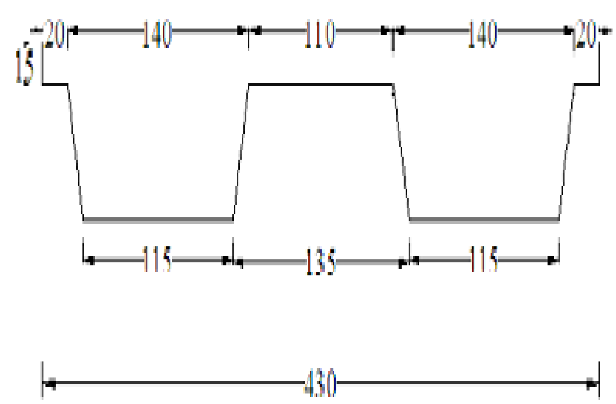


**Figure 1.** Geometry of profiled steel sheet.

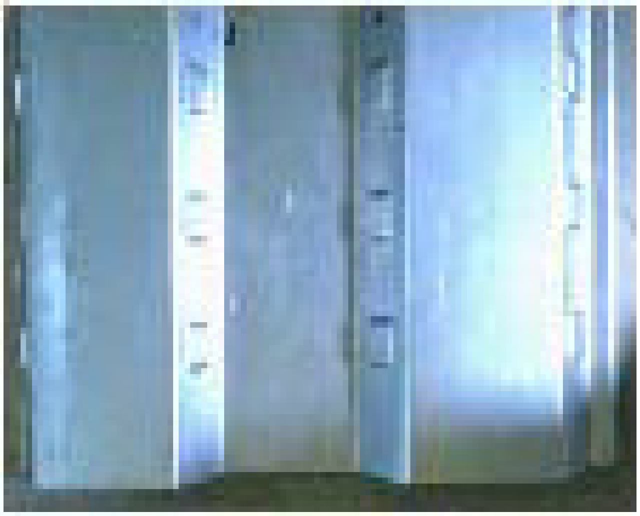

**Figure 2.** Embossed profile steel sheet.

modules of elasticity was 300 MPa and 2 x $10^5$ N/$mm^2$ respectively. The details of the profiled sheet are shown in Figure 1. The embossed profiled sheet is shown in Figure 2.

## 2.2 Beam Section

As per the recommendations in [5], the beam section was designed. Hot rolled beam section [I-Beam specimen: 100 x 200 x 6 mm (ISMB 200)] as shown in Figure 3 was used in this project. The properties of the beam section are Yield stress and Young's modulus is 288 MPa and 189 GPa respectively.

## 2.3 Reinforcement Steel

In the specimen, 6 mm diameter bars with 200 mm spacing in both directions were used to reinforce the structure. The main function of steel is to arrest the cracks that occur due to shrinkage and temperature.

## 2.4 Shear Connectors

The composite action in the steel-concrete sections is achieved by the shear connectors. The load transfer from the concrete slab to the steel beam in composite slab to the steel beam is composite construction depends on the shear connector behavior. Reinforcement area, positions in shear connector, strength and dimensions of shear connector (Table1), geometries and direction of steel sheeting, compressive strength of concrete and location of shear connector are the factors that influence the behavior of shear connector. In this project, Headed stud shear connectors and Bolted shear connectors as shown in Figures 4 and 5 were used with the following particulars.

**Figure 3.** I-Beam specimen.

**Figure 4.** Headed stud shear connectors.

**Table 1.** Dimensions of shear connector

| Head Diameter (mm) | Head Thickness (mm) | Shaft diameter (mm) | Height of shaft above base of sheeting (mm) | Spacing (direction of force) (mm) | Spacing (direction transverse to force) (mm) |
|---|---|---|---|---|---|
| 20 | 6.5 | 13 | 57.15 | 250 | 70 |

**Figure 5.** Bolted shear connectors.

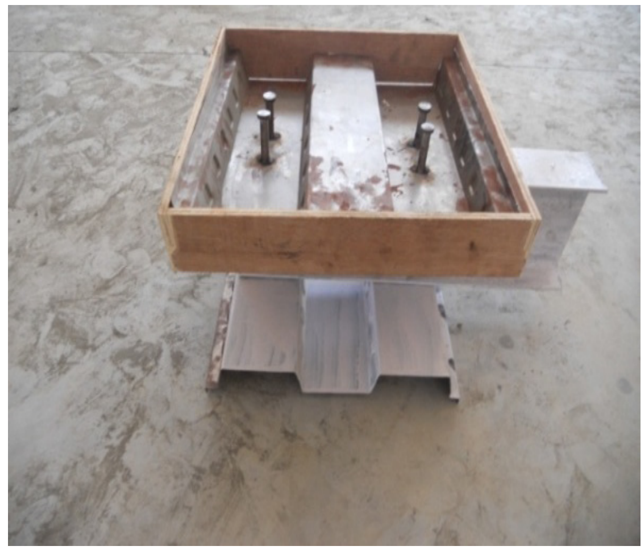

**Figure 6.** Arrangement of shear connectors and formwork.

## 2.5 Fabrication of Specimens

The push-out specimens were fabricated using ISMB 200 steel section. The headed stud shear connectors were welded to the steel flanges of the steel sections whereas bolted shear connectors are driven through the predrilled holes in the steel flanges through embossed profiled steel sheeting. After placing the shear connectors, plywood forms were erected around the flange for casting concrete. Figure 6 shows the typical formwork for push out specimen. The overall thickness of the slabs in all of the specimens was 85 mm. The height and width of the slabs were 430 mm and 450 mm respectively, in all of the specimens. In all specimens, the reinforcement cage was placed on the top of the profiled sheeting followed by pouring of concrete. After pouring, the concrete was properly consolidated and finished. The composite slabs are left for hardening for a day. Then the composite slab on other side of the steel beam is casted. The specimens are cured for 28 days and made ready for testing.

## 2.6 Description of Test

The ISMB steel section is connected on both sides by identical composition slab with the help of shear connector. All three specimens for each connector were similar profile sheet was placed perpendicular to the steel beam. Vertical load was applied to the specimen through the upper part of the steel beam by a hydraulic jack system of 250 kN capacity. Dial gauges were placed at the top of the steel beam to measure the slip between concrete slab and steel beam. The experimental test setup is shown in Figure 7. The increase in vertical load causes the movement of the composite concrete slab relative to the steel

**Figure 7.** Experimental test set-up.

beam leading to failure of specimen. Finally, slip correspondingly to the vertical load is plotted.

## 3. Results and Discussion

### 3.1 Load–slip Behavior

For Bolted shear connector, the initial crack load was found as 180 kN. The maximum slip was found as 27.69 mm. Load-slip behavior is as shown in Figure 8 and the readings are tabulated in Table 2.

For Headed stud shear connector, the initial crack load was found as 200 kN. The maximum slip was found as 30.2 mm. Load-slip behavior is as shown in Figure 8 and the readings are tabulated in Table 2.

**Table 2.** Test results for bolted and stud shear connector

| Load (kN) | Load per bolt (kN) | Slip (mm) | Load (kN) | Load per stud (kN) | Slip (mm) |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 1.25 | 3.25 | 15 | 1.25 | 2.87 |
| 20 | 2.5 | 5.25 | 25 | 2.5 | 4.41 |
| 30 | 3.75 | 7.1 | 35 | 3.75 | 6.91 |
| 40 | 5 | 8.95 | 45 | 5 | 8.3 |
| 50 | 6.25 | 10.38 | 55 | 6.25 | 9.35 |
| 60 | 7.5 | 12.01 | 65 | 7.5 | 11.93 |
| 70 | 8.75 | 13.95 | 75 | 8.75 | 12.75 |
| 80 | 10 | 15.55 | 85 | 10 | 14.49 |
| 90 | 11.25 | 16.97 | 95 | 11.25 | 15.16 |
| 100 | 12.5 | 18.01 | 105 | 12.5 | 16.17 |
| 115 | 14.37 | 19.73 | 115 | 13.75 | 17.38 |

| | | | | | |
|---|---|---|---|---|---|
| 125 | 15.62 | 20.75 | 125 | 15 | 19.11 |
| 135 | 16.87 | 22.16 | 135 | 16.25 | 20.18 |
| 145 | 18.12 | 23.09 | 145 | 17.5 | 21.62 |
| 155 | 19.37 | 24.11 | 155 | 18.75 | 22.9 |
| 162 | 20.25 | 25.2 | 165 | 20 | 23.97 |
| 172 | 21.5 | 26.19 | 180 | 21.25 | 25.5 |
| 180 | 22.5 | 27.69 | 185 | 22.5 | 26.4 |
| | | | 190 | 23.75 | 27.5 |
| | | | 200 | 24.68 | 30.2 |

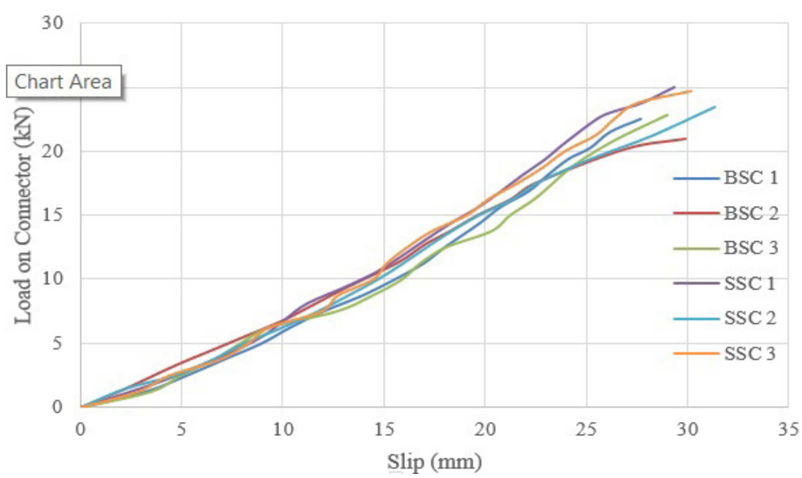


**Figure 8.** Load vs. slip behavior.

Comparison on Load Vs Slip curve for Bolted and Headed stud shear connector was shown in Figure 8. From the graph it is clear that the Headed stud shear connector carry maximum load when compared to Bolted connector. The initial crack occurs in Headed stud shear connector was 140kN while for Bolted connector was 110 kN. This result also shows that the performance of Headed stud shear connector is better.

## 3.2 Failure Modes

Initial crack was found on the horizontal surface of the slab. As the load is increased the cracks extend to the depth of the slab. Vertical cracks were found at the bottom of the specimen after the horizontal crack. The vertical cracks are responsible for the separation between the profiled sheeting and the concrete slab. Finally, combination of concrete crushing and splitting failure followed by the

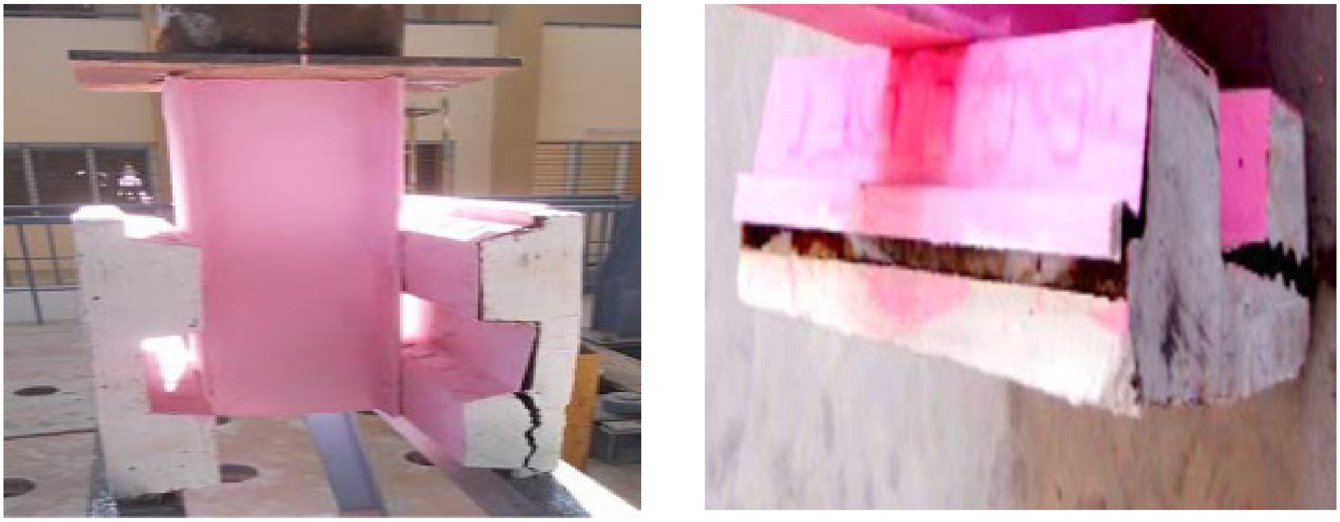

**Figure 9.** Failure pattern in headed stud shear connector.

**Figure 10.** Failure pattern in bolted shear connector.

failure of the stud occurs. Figure 9 shows the failure pattern of Headed stud connector. In this shear connector, the separation between the profiled sheeting and the concrete slab was maximum at the top of the profiled sheeting and the development of crack near the stud is minimum.

Figure 10 shows the failure pattern of Bolted shear connector. In this connector, maximum crack and the separation of the slab from the profiled sheet occurred near the bolts and the width of crack was maximum.

## 4. Conclusion

From the results arrived from the experimental study, the following conclusions were arrived,

- The comparison between the bolted and the headed shear connector was studied. The following parameters such as shear connection capacity, ultimate load carrying capacity and structural performance where discussed.
- The slip obtained from bolted stud shear connector is higher when compared to headed shear connector.
- Three major types of failure were detected. The first failure is crushing of concrete and shear, second type of failure is buckling of shear stud connector and combining of both shear connector and concrete is third type of failure.
- The bond between the sheet and the concrete was increased due to use of embossed profiled sheet.
- The performance of the headed shear connector was greater than bolted shear connector in this study. Thus headed shear connector can be further used in the composite slab construction.

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