

Shear Connection between Steel and Concrete in Composite Structure

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Abstract— For the past few decades, the construction field has been moving towards the usage of steel-concrete composite structural elements in most of its construction. Various research works are carried out to increase the structural aspects of such composite construction. Shear connector between concrete and steel elements in composite construction plays an important role in developing the composite action by ensuring proper shear transfer between the steel profile and the concrete element. The connections between the steel and concrete sections are mostly done using welding, given the durability and strength of welding. For the current study, the shear connectors, connecting the concrete slabs and steel beam, are welded to the flanges of the beam. Given the flexible nature of the shear connectors, they can be available in various shapes and sizes. The performance of each connector was evaluated and compared. The main comparison between the specimens was carried out by comparing the load slip behavior of the specimens.

Keywords— Shear connector, Composite action, Channel connector, Welded connection, Load slip behavior.

I. INTRODUCTION

In a structural member when two or more materials are used in constructing a single element the connection between those elements plays a major role in all the aspects. The main objective of providing the connection between the different materials in a single element is to make than element to act as a single monolithic element. Then comes the transfer of loads, resisting the loads and other structural properties. These types of construction are in use from the past decades. Started with concrete- iron composites various combinations of composites emerge. Among the types, the mostly used one is concrete-steel composites for the many similar properties between them. To increase the monolithic action and to increase the bond between steel beam and concrete slab, a steel projection named as shear connector have been used. Resistance offered in compression and tension by Concrete and Steel respectively is completely utilized by connecting them properly through Shear connectors. The objective of providing this shear connector is to transfer the loads and to resist the force caused during heavy wind, seismic forces and other shear forces. Since the study on connectors is in progress from past few decades, various types of connectors emerge. Some of them are stud connector, perfobond connector, t-rib connector, channel connector, oscillating connector, I section connector, angle connector etc. These shear connectors are usually welded to the flanges of the beam. Based on the purpose of use,

quality, strength and deformation shear connectors are broadly classified into rigid and flexible shear connectors.

II. MATERIAL COLLECTION AND TESTING

The materials required for the project are cement, M sand and coarse aggregates to produce concrete. The preliminary testing on these materials is done.

A. Properties

- Grade of cement = OPC (53 grade)
- Specific gravity of cement = 3.15
- Normal consistency of cement = 32%
- Initial setting time = 35 minutes
- Final setting time = 450 minutes
- Fineness of cement = 6%
- Specific gravity of M. Sand = 2.68
- Fineness modulus of M. Sand = 3.07
- Specific gravity of coarse aggregate = 2.68

B. Mix ratio

The grade of concrete chosen is M-30. The mix ratio for M-30 grade is designed as per IS10262:1982. The mix is designed as normal mix without using any plasticizers or admixtures. The mix ratio is given as

Cement: Fine Aggregate: Coarse Aggregate:
w/c = **1: 1.726: 2.70/ 0.45**

C. Fresh concrete test:

- Slump value: 54 mm
- Compaction factor : 0.911
- Flow table value: 38.9 %

D. Mechanical properties of concrete

Table I Mechanical Properties

Sl. No.	Property	Result
1	Ultrasonic pulse velocity	5056 m/s
2	Compressive strength	42.71 MPa
3	Flexural strength	5.46 MPa
4	Split tensile strength	5.06 MPa

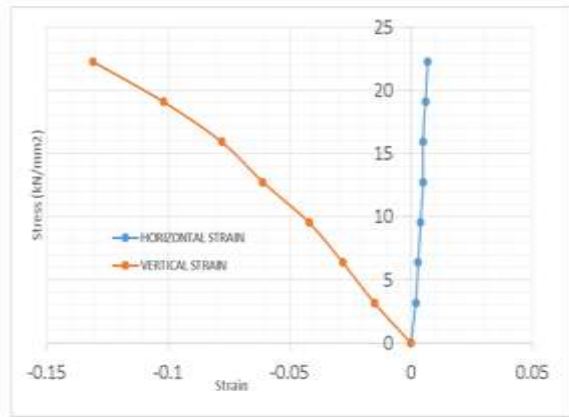
Note: The above values are average of 3 tests of specimens.

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E. Stress strain behavior of M-30 Grade Concrete



III. EXPERIMENTAL PROGRAM:

A. Properties of beam:

- Beam : ISMB100
- Weight per m : 8.0 kg
- Sectional area : 10.21 cm²
- Depth of section : 100 mm
- Width of flange : 50 mm
- Thickness of flange : 6.4 mm
- Thickness of web : 4 mm

B. Properties of shear connector

In this project, channel section is used as shear connector.

- Connector : ISMC 75
- Weight per m : 6.8 kg
- Sectional area : 8.67 cm²
- Depth of section : 75 mm
- Width of flange : 40 mm
- Thickness of flange : 7.3 mm
- Thickness of web : 4.4 mm

C. Properties of slab:

- Length : 300 mm
- Thickness : 100 mm
- Height : 360 mm
- Cover : 20 mm

8 mm diameter rod is provided at 80 mm center to center spacing is provided as Nominal reinforcement. The longitudinal bars are bended towards the connector.



Fig. 2: Reinforcement cage

D. Fabrication, casting and curing

In this structural element, the steel shear connector is welded to the flanges of the steel beam at the specified position. There are two types of specimens. One specimen is cast with a single shear connector and the other specimen is

cast with two shear connector. And then the reinforced slab is casted on the side of the flanges. While casting the beam is raised 40mm above the base of the slab. It is so because while applying load, it should not directly applied on the slab. The specimen is cast using M30 grade concrete. The hand mix concrete is made and is poured in the mould and compacted using tamping rod. The wet gunny bag curing was adopted. In the specimen with single connector, the connector is welded at the center of the beam. In specimen with double connector, the connector is welded at 60mm offset from the center. One connector is placed at 60mm above the center and another one 60mm below the center. The fabrication details are given in Fig.2 & Fig.3.

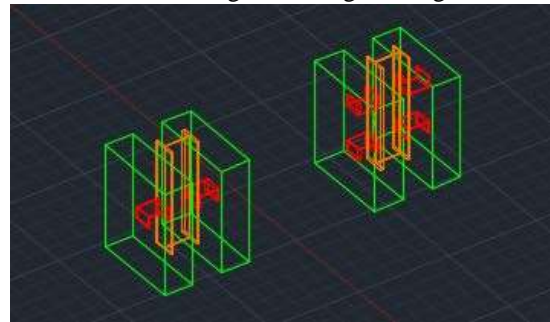


Fig. 3: Fabrication diagram



Fig. 4 Beam with Connectors



Fig. 5: Casting and Curing



Fig. 6: Finished specimen after curing

E. Specimen

Two type specimens (each two) are cast by placing

connectors at different position on the flange of the beam. In one specimen static loading is given and in another dynamic loading is given. The specimen description is given in Table 6.

F. Test Procedure

While testing, the compressive load is applied on the web of the beam using UTM. The vertical strain in the beam is measured using an electrical strain gauge pasted on the edge mid of the web. The vertical strain, horizontal strain at middle and top of the slab is measured using a demec gauge. The stain is measured only on one side of the slab. UPV test is conducted on the top of the slab, to measure the micro cracks. The slip is measured using dial gauge with 0.01 mm least count for each corresponding load. The overall experimental setup is given in Fig.7 and the position of demec gauge pellets in slab and electrical strain gauge in beam is given in Fig.8.



Fig. 7: Experimental Set-up



Fig. 8: Position of demec gauge pellets in slab and electrical strain gauge in beam

IV. TEST OBSERVATIONS & RESULTS

A. Specimen ID: SCA1 Observation

First crack started at 225KN. The Crack developed near the I-section and slowly propagated to the edge of the slab (top surface). The failure of shear connector occurred at the load of 275KN. The failure occurred at the welded portion (one side). Fig.14 shows that, after 275 kN, the load starts released and the slip value goes on increasing. Crack width increase slowly at the inner surface of the both slab. Symmetrical crack develop on both slab. The crack pattern is shown in Fig.9. The connector, lifted upwards by 8mm and at the ultimate load, the connector failed at the welded portion. From Fig.20, it is obtained that for the same load,

the horizontal strain is small in middle when compared to top in the slab. This is because of the presence of the shear connector near the mid of the slab. From Fig.16 and Fig.18 it is obtained that the vertical strain is slab and beam increases linearly with load.



Fig. 9: Specimen ID: SCA1 after testing

Table II Specimen description

Specimen ID	Description	Image
SCA1	Static load test on Specimen with one shear connector	
SCA2	Static load test on Specimen with two shear connector	
SCB1	Cyclic load test on Specimen with one shear connector	
SCB2	Cyclic load test on Specimen with two shear connector	

B. Specimen ID: SCA2 Observation:

Micro crack develops on the top surface. The crack started from inside to outside. It travelled up to center of the slab (on top surface). The crack pattern is shown in Fig.10. The I section starts buckling at 400 kN. Since I section buckled, load not transferred to the slab. The top connector in the left side of the flange lifted upwards by 3mm and in the connector in the right side of the slab lifted upwards by 2mm. The bottom connector in the left side of the flange lifted downwards by 1mm and in the connector in the right side of the slab lifted downwards by 2mm. The connector spacing increased by 4mm on both sides of the flange. The buckled portion of specimen is given Fig.11. From Fig.20, it is obtained that for the same load, the strain is maximum in the middle and minimum in the top of the slab. The vertical strain is slab and beam increases linearly

with load. The vertical strain of the specimen is given in Fig.16. From Fig.14, it is obtained that up to 400 kN, the slip increases slowly. After I section starts buckling, the slip value increases by large amount for each successive loading. Initially the strain in beam increases by large value. After I section starts buckling, the strain value increases by small amount.



Fig. 10: Specimen SCA2 after testing



Fig. 11: The buckled portion of SCA2

C. Specimen ID: SCB1 Observation

The ultimate load for the same type of element in static loading condition is 275kN. Therefore the cyclic range is chosen as 0-150kN. After 5 cycles, the load increases up to ultimate.

Crack on the top surface of the slab. In outside surface of the slab 2 cracks starts from bottom and travelled towards top. No crack or bend in the beam. The edge of the channel connector lifted upwards by 5mm on both sides. The tested specimen is given in Fig.12. From Fig.15, it is obtained that the slip value increases in successive cycle.



Fig. 12: Specimen SCB1 after testing

D. Specimen ID: SCB2 Observation

The ultimate load for the same type of element in static loading condition is 500kN. Therefore the cyclic range is chosen as 0-250kN. After 5 cycles, the load increases up to ultimate. Since the same type of specimen in static loading

buckles at the top of the beam, the stiffener is provided on the top of the beam up to 40mm depth.

Crack on top surface. It is a through crack. Slab bends outwards. No crack on outside surface. Beam buckles at 500 KN (ultimate load). The tested specimen is given in Fig.13. From Fig.21, it is obtained that the horizontal strain in the mid of the slab is higher than the strain in the top of the slab. The top connector lifted upwards and the bottom connector bended downwards. The top connector in the left side of the flange lifted upwards by 5mm and in the connector in the right side of the slab deflected upwards by 2mm. The bottom connector in the left side of the flange lifted upwards by 2mm and in the connector in the right side of the flange lifted upwards by 5mm. The connector spacing increased by 3mm on both sides of the flange.

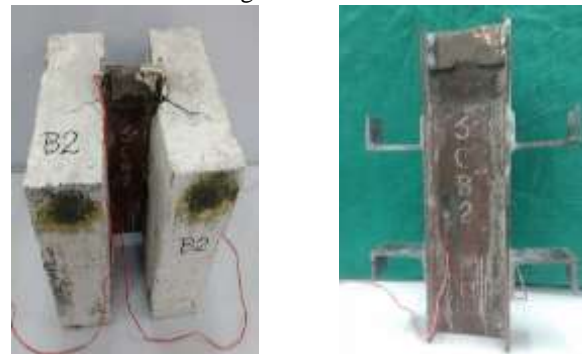


Fig. 13: Specimen SCB2 after testing

V. RESULTS AND DISCUSSIONS

On comparison of specimens SC1 and SC2 the following points are discussed

A. Load slip behavior

The shape of load- slip curve is similar irrespective of number of connector in it. The only difference is the specimen with double connector bears more load than specimen with single connector. The ultimate load for single connector is 275 kN and that for double connector is 500 kN in static loading condition. The result of the load slip is represented in Fig.14 & 15.

B. Vertical strain in slab

The vertical strain in slab is maximum in the specimen with single connector than double connector. The shape of the curve is similar in both the specimens during both static and cyclic loading. The slab undergoes tension in vertical direction during loading. The result of the vertical strain in slab is represented in Fig.16 & 17.

C. Vertical strain in beam

The vertical strain is a maximum in the specimen with single connector. The shape of the curve is similar in both the specimens in both loading conditions. The result of the vertical strain in beam is represented in Fig.18 & 19.

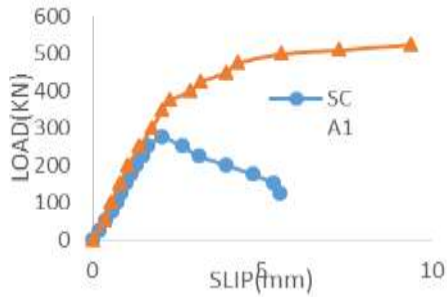


Fig. 14: Load vs slip of SCA1 & SCA2

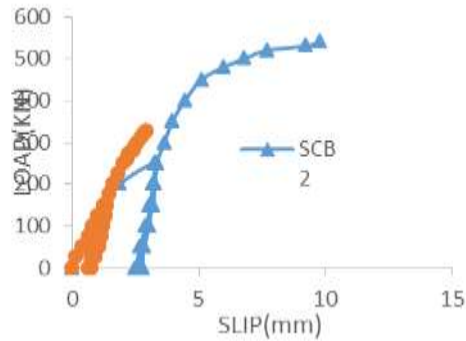


Fig. 15: Load vs slip of SCA1 & SCA2

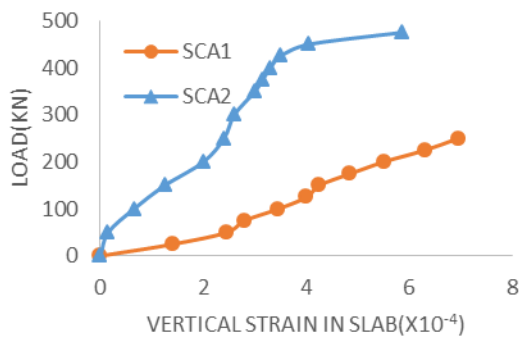


Fig. 16: Load vs. vertical strain of SCA1 & SCA2

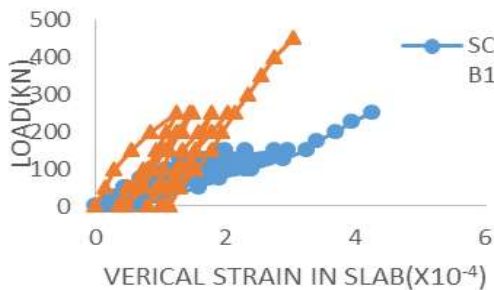


Fig. 17: Load vs. vertical strain of SCB1 & SCB2

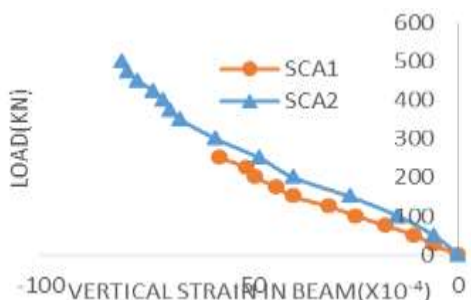


Fig. 18: Load vs vertical strain in beam of SCA1 & SCA2

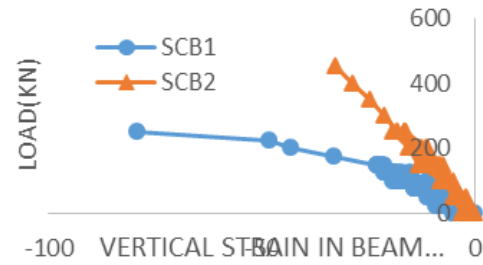


Fig. 19: Load vs vertical strain in beam of SCB1 & SCB2

D. Horizontal strain in slab

The horizontal strain in top of the slab is a maximum in specimen with single connector. This is because of the location of the shear connector. Since one of the connector in SCA2 & SCB2 is placed near the top of the beam, the strain is a minimum in the top of slab. The horizontal strain in middle of the slab is vice versa to the horizontal strain in top of the slab. The horizontal strain in middle of the slab is a maximum in the specimen with two connectors. The result of the horizontal strain in slab is represented in Fig.20 & 21.

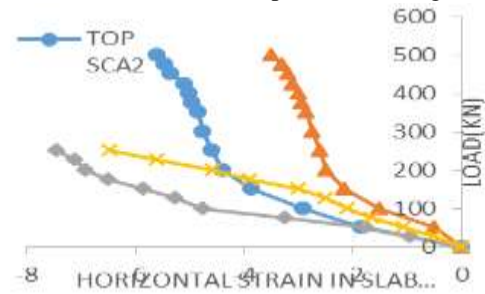


Fig. 20: Load vs horizontal strain of SCA1 & SCA2

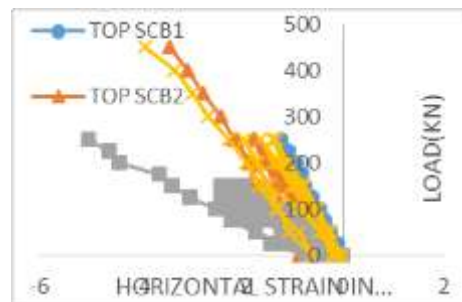


Fig. 21: Load vs. horizontal strain of SCB1 & SCB2
Residual slip at Zero Load

In SCB1 the slip increases in each cycle, this implies that the slip is recovered in each cycle. In SCB2, the slip doesn't recover in each successive cycle.

Table III Residual Slip at Zero Load

Cycle	Slip of SCB1(mm)	Slip of SCB2(mm)
1	0	0
2	0.64	2.65
3	0.67	2.5
4	0.69	2.78
5	0.73	2.55
6	0.75	2.54

VI. CONCLUSION

The specimens with two different locations of shear connector were casted and tested. From the test results the following conclusions are arrived. In this experimental programme two different types of failures are observed.

- Failure of the channel connector
- Crushing-spalling of concrete

The specimen SCA1 alone failed due to failure of the channel connector at the extreme load, the channel connector at one side of the slab gets detached from the beam. The failure occurred at the welded portion of the connector. The specimens SCB1, SCA2 & SCB2 undergone crushing splitting of concrete.

- The number of connector decides the load bearing capacity of the specimen. The specimen with two number of connectors bears a large load than a specimen with a single connector.
- The strain in slab is influenced by the position of connector. The middle horizontal strain in slab is minimum in SCA1 & SCB1. This is because the connector is positioned near the mid of the slab.
- The horizontal strain in top of the slab is maximum in SCA1 & SCB1. This is because the strain is measured at a distance away from the connector.
- The maximal and minimal horizontal strain in SCA2 & SCB2 is viceversa of SCA1 & SCB1.
- In the specimens SCA2 & SCB2, the beam gets buckled. This is because, the connector is strong to transfer the load, but the top portion of the beam unable to bear the load. This buckling can be reduced by providing a stiffener.
- Almost in all the specimens the connector lifted upwards or bended downwards to some extent, this can be reduced by providing a stiffener in the connector or by increasing the thickness of the connector.
- From the results obtained, the position of the connector, the number of connector, the thickness of connector, the extra provisions like stiffeners in beam are the factors which influence the load carrying capacity of the specimen.

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