INTERNATIONAL JOURNAL OF RESEARCH IN COMPUTER APPLICATIONS AND ROBOTICS
ISSN 2320-7345

BEHAVIOUR OF SHEAR CONNECTORS IN COMPOSITE CONSTRUCTION

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Abstract: - This project presents a study on the behavior of shear connectors used in steel and concrete composite structures. The investigation is based on an experimental program conducted on a series of prisms, with embedment of steel plates employing various kinds of shear connectors.

Pull out tests were performed on these prisms using a strain controlled UTM and the modes of failures were observed along with the failure loads. The parameters studied under the program were the load Vs. slip behavior load carrying capacity and failure modes. Tests were also conducted on the companion specimen of the materials to ascertain their strength properties.

Comparison was made among the shear connectors with respect to loads at initial slip, ultimate load and occurrences of ultimate slippage.

INTRODUCTION

The present day demands in construction parameters such as strength, safety, serviceability, satisfactory and reliable performance expected of a structure apart from economical solution has made it imperative to use Steel and Concrete Composite Construction Techniques. This has become more relevant to the present scenario of the need for increased ductility of structures, especially so after the revisions of the seismic maps in various parts of the globe. Study on the collapse pattern of structures which failed in earthquake indicates the necessity for the distribution of plastic deformation more uniformly throughout the structure this can be achieved by adapting to Steel and Concrete composite beams.

The most important and frequently encountered combination of construction materials is that of steel and concrete, with application in multi-story commercial buildings and car parks, factories as well as bridges. These materials can be used as composite structures so that they act compositely. These complementary to each other. Cold formed steel sheeting has been used successfully throughout the world. It provides permanently positive reinforcement for the slab and beams and therefore minimizes the need for additional reinforcement. In bridges and buildings concrete deck and floor slabs are the most common load distributing medium, transferring load superimposed on them to a supporting systems are therefore important , accounting for the considerable proportion of the annual construction output . Attempts to improve the efficiency of these will have clear economy advantages and indeed these can be demonstrated.

BENEFITS

Steel and concrete have almost the same thermal expansion apart from ideal combination of strengths with the concrete efficient in compression and the steel in tension. Most of the methods used for tee composite beams have been encased in concrete before erection; the encasement contributes little to beam but requires little gauge reinforcement to control the width of the cracks and to hold it in place during a fire. It is clear from recent practice that composite construction is particularly competitive in medium or long span structures and where there is a premium rapid construction. The complete understanding of all aspects of seismic behavior of all types of composite structures requires years of research efforts. The use of steel sheet have been found to offer economic design solution and included reduced construction time, materials savings and labor cost etc.,

CONCEPT OF COMPOSITE

INTRODUCTION

The steel concrete compositing beams comprises of thin walled cold formed sheets encasing a concrete core. The se side sheets acts as a permanent work as well as positive reinforcement after the concrete hardens. The steel sheeting can have thickness ranging between 0.8 to 1.5 mm. Shear connectors are provided at the soft it and sides of the beam throughout the length to transfer the horizontal shear between steel and concrete, thus limiting the slip at the interface so that the beam system acts as a unit to resist longitudinal bending and also to prevent the relative movement between steel and concrete.

CONCEPT

The concept of a composite construction is to utilize the merits of the different material in a structural system and thus exploit the strength and overcome the weakness of the constituent material. The steel-concrete composite construction is based on this philosophy and thus combines the merits of steel, thus as its higher strength to cost ratio concrete in compression. Composite constructions are strongly advocated for structure, which requires higher ductility aspects.

COMPOSITE ACTION

For a concrete slab, simply rested on a steel beam, phenomenon known as slippage occurs. As loads were placed on top of the slab, the top of the slab and beams are in the compression and bottom of the slab and beam are tension. In a sense, both elements respond like a beam independently. Since bottom of the slab would be in tension, (pushing outwards towards the end of the beam) and top of the beam is in compression (pushing inwards towards center of the beam), the resulting effect is slab extending out over the ends of the beam.

If the slab and beam, were somehow integrated then both will resist load as a single unit. This integration would result, when the member is under loads, in the slab-beam acting as a unit with the top of the beam in compression and bottom of the beam in tension and no slippage in between. The integration is accomplished through incorporation of a shear connector between the slab and beam, the shear connector is generally a metal element, which extends vertically from the top flange of the supporting beam and is embedded into the slab.

Many shear connectors are placed along the beam to prevent slippage, which is caused by the compression in the beam and the slab-beam interface shear. The most known from of shear connector composite (concrete/slab) connection being stud shear connectors. The shear studs installation is made faster with the use of automatic welding gun, which would reduce the cost of shear connectors thus increasing their popularity in composite construction. This same concept can be used for profiled beam as well.

TYPES OF COMPOSITE CONSTRUCTION

The following are different types of composite construction in practice:

1. Propped/Shored construction
2. Un propped/Un shored construction
3. Participating formwork
4. Non-participating formwork

Propped / shored construction

If the beam is supported while concrete is attaining its characteristic strength, it is called shored / propped construction. Only after concrete attaining compressive strength, the slab and beam can be considered to respond together in resisting the loads, in this form, the beam would sustain its own self weight and the supports would be remove after the concrete attaining its characteristic strength and thus the self-weight of the slab, other superimposed dead load and live load are resisted by through the composite action.

Unpropped / Unshored construction

In many areas, it may not be possible or practicable to support the structural steel beam while concrete attains its characteristic strength and form of construction is called unpropped / unshored construction. In this case, the self-weight of beam and the self-weight of concrete is sustained by the beam element itself and composite action comes into effect only for the imposed loads.

Participating Formwork

Profiled sheeting and partial thickness precast concrete slab is used as structurally participating form work. In this form of construction the strength of the form work used is also considered in the design appropriately.

Non-participating Formwork

Fiber reinforced plastic or cement sheeting, if used as form work, is referred to as structurally non-participating, because once the concrete slab has been hardened, the strength of the sheeting is ignored in the design.

MODES OF FAILURE

The failure of the beam may be due to the following aspects:

[1] Shear bond failure from loss of composite action because of inadequate shear transfer at the interface between the concrete and steel sheet.
[2] Formation of a major diagonal crack in the beam at approximately one-quarter to one-third span.
[3] Vertical separation between the concrete and steel sheet.

ADVANTAGES

The most obvious and apparent advantages are:-

[1] The side sheets serves as a form for the wet concrete and remains permanently in place. Obviously this eliminates the forming operation hence cost saving benefits can be gained.
[2] Since the side sheets are manufactured of thin-walled cold formed sheets they are light in weight. This leads to saving of time and labor during installation.
[3] The beams can be installed rapidly and easily.
[4] Reduced beam depth reduces the storey height and consequently the cost of cladding in a building and lowers the cost of embankment in a flyover (due to lower of embankment).
[5] Reduced depth allows provision of lower cost for fire proofing of beams exposed faces.
[6] Composite sections have higher stiffness than the corresponding steel sections (in a steel structure). And thus deflection is lesser.
[7] Reduction in overall weight of structure and there by reduction in foundation cost.
[8] Better seismic resistance (i.e.) best suited repeated earthquake loadings, which require a high amount of resistance and ductility.
[9] Faster construction for maximum utilization of rolled and / or fabricated components (structural steel members) and hence quick returns of the invested capital.
[10] Composite beam structures possess overload capacity and toughness substantially in excess of the overload capacity and toughness of non-composite structures.

DISADVANTAGES

[1] Immediately prior to concreting the steel sheet must be cleaned of all dirt, oil water and all foreign matter.
[2] As the steel sheet is exposed, which may be subjected to corrosion and fire, it requires additional protective measures.

DESIGN METHODOLOGY FOR COMPOSITE BEAMS

DESIGN APPROACH

(For steel encased concrete composite beams)

Linear elastic analysis can be applied at working or service load to control both serviceability limit states such as deflection and crack widths and the ultimate limit state of fatigue. However in order to determine the maximum possible strength of a composite beam, we have to revert to non-linear techniques such as rigid plastic analysis.

Rigid plastic analysis assumes that the material are either not stressed at all or are fully yielded with an infinite deformation capacity at the yield stress or plastic plateau as shown in figure

The rigid plastic is therefore an upper bound to the strength of a composite beam and requires that not all other modes of failure occur prior to this strength being achieved. It is therefore necessary to ensure that

Premature failure through the following modes does not occurs:

1. Fracture of shear connectors
2. Failure of concrete due to concentrated dowel loads imposed in it.

It is also necessary to ensure that the composite beam has sufficient rotational capacity to attain ultimate strength.

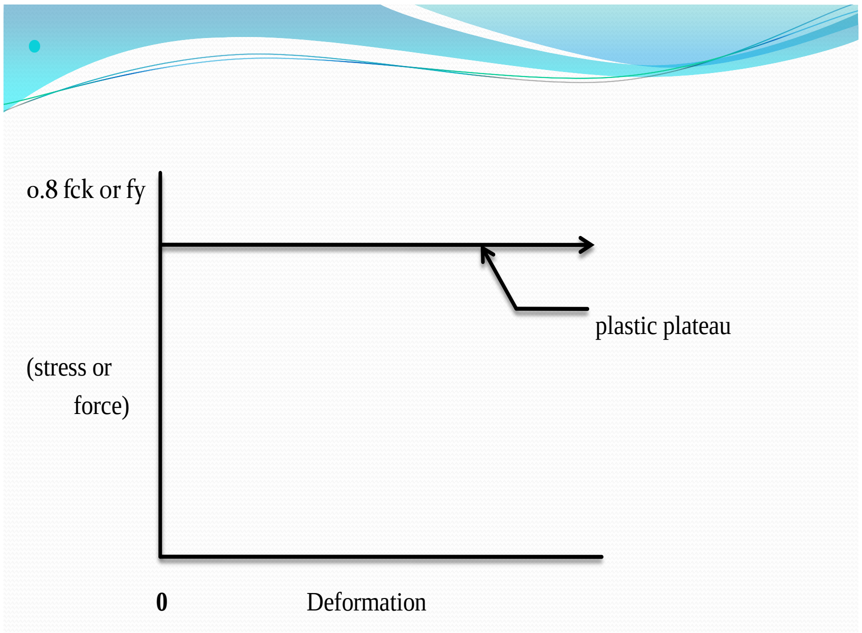


Fig.1. Idealized material properties

ULTIMATE STRENGTH RIGID PLASTIC ANALYSIS

The steel encased concrete composite beam is analyzed using the rigid plastic analysis assuming partial shear connection. Partial shear connection is synonymous with partial interaction, so that the neutral axis in these beams can be determined by ensuring that each element is in equilibrium with shear connection, the beam has partial interaction. The strain profiles in the reinforced concrete element and steel element separate due to loss of interaction.

The strain profiles are parallel because the curvatures are the same in both the elements, and hence the slip strain and therefore the slip between elements, and the hence the slip between elements is the same throughout the depth of the beam.

CALCULATION OF MOMENT OF RESISTANCE

The analysis for calculating the Moment of Resistance of the Composite Section is done on the idealized or the Transformed Section. Transformed Section is the section having same area of concrete as that of original section but without connectors. An example of calculation for Moment of Resistance of Steel encased concrete composite beam is given below.

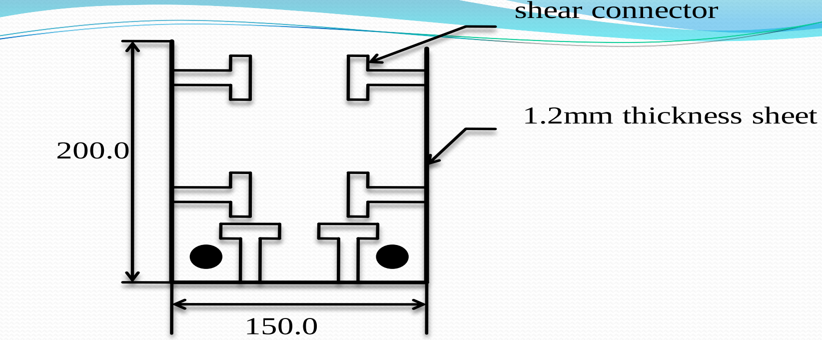
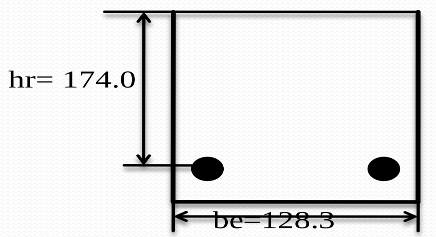


fig.3 original cross section



(fig.4 transformed section)

EXPERIMENTAL WORK

CASTING OF SPECIMEN

Materials used

Cement

Cement used for all beams and companion specimens was ordinary portland cement of 53 grades, conforming to IS: 269-1976

Fine aggregate

The fine aggregate used for specimens was conforming to IS: 383-1970. It was sieved through 4.75mm sieve and used.

Coarse aggregate

The coarse aggregate conforming to IS:383-1970 used is hard broken granite stone obtained from quarries in and around Salem. The size of aggregate used was 12mm to 20mm.

Water

Portable water used for mixing concrete and for curing the specimen.

Cold formed steel

Cold formed steel sheet of 1.25mm thickness conforming to IS:1079-1968 was used as beam through for composite beam. The sheet played a dual role as formwork and as a tensile reinforcement.

MIX DESIGN OF CONCRETE

STIPULATIONS FOR PROPORTIONING:

Grade Designation	**M25**
Type of Cement	OPC 53
Maximum Nominal Aggregate Size	20 mm
Minimum Cement Content	300 kg/m3
Maximum Water Cement Ratio	0.50
Workability	75- 100 mm (Slump)
Exposure Condition	Moderate
Degree of Supervision	Good
Type of Aggregate	Crushed Angular
Maximum Cement Content	450 kg/m3

TEST DATA FOR MATERIALS:

Cement Used MAHA GOLD Cement OPC 53 grade

Sp. Gravity of Cement	3.15
Sp. Gravity of Water	1.00
Sp. Gravity of 20 mm Aggregate	2.74
Sp. Gravity of Sand	2.74
Water Absorption of 20 mm Aggregate	0.50%
Water Absorption of Sand	1.0%
Free (Surface) Moisture of 20 mm Aggregate	nil
Free (Surface) Moisture of Sand	2.0%
Sieve Analysis of Coarse Aggregates	Done
Sieve Analysis of Fine Aggregates	Done

TARGET MEAN STRENGTH FOR PROPORTIONING:

F_{ck} = f_{ck}+ 1.65 [s]

F_{ck} = 25 + [1.65 × 4] = 31.6 N/mm^2.

SELECTION OF WATER CEMENT RATIO:

W/C ratio = 0.45

W/c ratio = 0.50 [from table 5 IS 456 2000]

0.45 < 0.50

Hence ok

SELECTION OF WATER CONTENT:

Water content = 186 lit [25 to 50mm slump] table 2 of IS 452000

Increase in water content = 191.6 [75 to 100mm slump]

3% increase in every 25mm slump

CALCULATION OF CEMENT CONTENT:

Water cement ratio = 0.45

Cement content = 191.6 /0.45 = 425.77 kg/m^3.

TABLE 5 OF IS 456 2000

Minimum cement content = 300 kg/m^3.

425.77 < 300 kg/m^3.

CALCULATION OF CEMENT CONTENT:

Water cement ratio = 0.45

Cement content = 191.6 /0.45 = 425.77 kg/m^3.

TABLE 5 OF IS 456 2000

Minimum cement content = 300 kg/m^3.

425.77 < 300 kg/m^3

VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE CONTENT:

Volume of coarse aggregate per unit volume of total aggregate = 0.64 m^3.

From TABLE 3 OF IS 456 2000 for 20mm aggregate

For every 0.05 increase/ decrease in w/c ratio from 0.5 reduce / add 0.01

Therefore add 0.01

Volume of coarse aggregate per unit volume of total aggregate = 0.65m^3

Volume of fine aggregate per unit volume of total aggregate = [1- 0.65]

= 0.35 m^3

MIX CALCULATIONS:

Volume of concrete = 1m^3.

Volume of cement = [Mass of cement/specific gravity of cement]×[1/1000]

Volume of cement = [425.77/3.15] × [1/1000]

Volume of cement = 0.135 m^3

Volume of water = [mass of water/ specific gravity of cement]×[1/1000]
= [191.6/1] × [1/1000]
= 0.1916 m^3.

Total volume of aggregate = [a – (b + c)]
= [1 - [0.135 + 0.1916]] = 0.6734m^3.

Masses of coarse aggregate
= e × [volume of coarse agg] × [specific gravity of coarse agg] × 1000
= 0.6734 × 0.65 × 2.74 × 1000
= 1199.3254 kg

Masses of fine aggregate
= e × [vol of fine agg] × [sp gravity of fine agg] × 1000
= 0.6734 × 0.35 × 2.74 × 1000
= 645.7906 kg

MIX PROPORTION:

Cement = 425.77 kg/m^3
Water = 191.6 kg/m^3
Fine agg = 645.7906 kg/m^3
Coarse agg = 1199.3254 kg/m^3

THEREFORE THE RATIO IS CONCLUDED TO
1 : 1.516 : 2.816.

SLUMP TEST

MIX	SLUMP
Conventional	75mm
Two stud	79mm
Four stud	72mm
Plain sheet	74mm

CASTING OF PRISM

For casting prism specimen, wooden formworks were used. The dimension of the specimen is 300mm x 100mm x 70mm. the CR steel sheet is embedded in the mid section of the concrete portion as shown in the figure. To have a good bond between steel and concrete, shear connector of various kinds were used. The various types of shear connectors are shown in the figure. For the study of type of connectors having diameter of 9mm, length of 40mm and 10mm thick head, the tail portion of stud was welded with the cold rolled sheet on either side.

The prism section was then filled with concrete of mix ratio 1:1.5: 2.8 (Design mix m25 grade concrete) and the water - cement ratio of 0.45 were poured into it to form. The specimens were cured by placing the prism inside the curing tank for 28 days and air dried for one day before testing. Once the concrete has poured and cured, the steel and concrete act compositely with complete interaction until the bond is broken.

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February 2016

DETAILS OF SPECIMEN

TABLE-1

S.NO	TYPES OF SHEAR CONNECTORS		NO. OF SHEAR CONNECTORS	NO. OF SPECIMEN	DETAILS OF CONNECTION
1	stud				A 9mm dia bolts of overall height 50mm, head dia of 25.4mm and head thick 10mm. Welded at the tail portion
		S2C1	2 (one on each side)	1	
		S2C2			
		S2C3			
		S4C1	4 (two on each side)	1	
		S4C2			
		S4C3			
2	Plain	P1C1	-	1	A plain CR sheet of 450mm x 70mm x 1.2mm thick
		P1C2			
		P1C3			

Plain sheet with four stud connectors

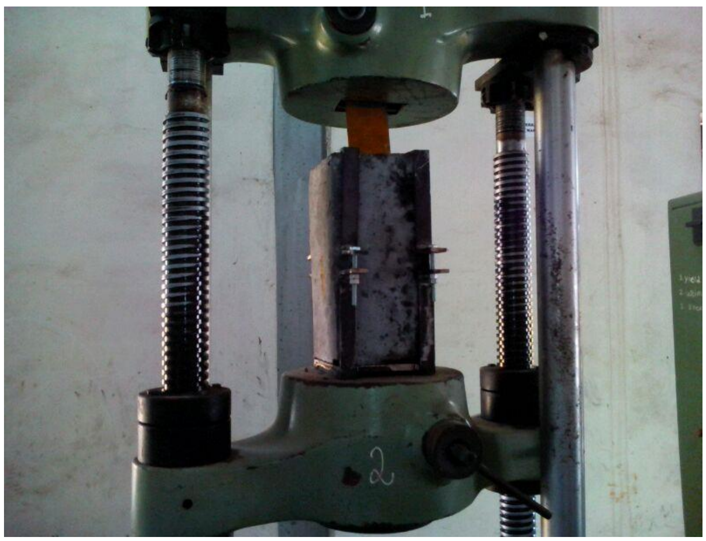
TESTING PROCEDURE

1 Pull out test
2 Tension Coupon test
3 Tension test on reinforcement steel
4 Compression test on cube
5 Flexure test on prism

Pull out test

The pull out test was carried out in the computerized UTM machine. The specimen is placed inside the mould, which was used to the mould. Then the moulded prism was placed in the UTM machine. The cold formed sheet, which projects out from the concrete is locked in the upper clamp and the mould is locked in the lower part of the UTM machine.

The UTM pulls out the cold sheet out from the concrete. The bond was established between the concrete. The bond was established between the concrete and the steel by the shear connector. When the sheet pulls out the shear connector comes into act. At this stage, we can able to find out the strength and behaviour of the shear connector.



Loading set up

Initial failure mode **Tension coupon test**

To find the yield stress, modulus of elasticity and ultimate strength of the cold formed steel sheet used for fabrication, coupons were prepared as per IS 1079-1986 in the form shown in the fig. the coupons were tested in computerized UTM, the result are below with graph.

Lt = 200mm, a = 10mm, b = 20mm, Lo = 60mm, Le = 80mm

Tension test on reinforcement steel

Steel specimen of 460mm length of steel was cut from the whole length and test in computerized UTM machine to determine the properties of the steel used. Three specimens were tested for tension. The results are,

Table 2

TENSION TEST ON STEEL REINFORCEMENT

S.NO	Diameter of Rod (mm)	Yield Load (KN)	Yield Stress (N/mm²)
1	6	11.8	417
2	6	11.9	421
3	6	11.6	410

The average yield stress of reinforcement steel is 416 N/mm²

Compression test on cube

The cube- crushing test was done in compression testing machine. The load was applied as per IS: 516-1964. The ultimate load was noted, the results are shown,

TABLE 3

COMPRESSION TEST ON CUBE

Cube designation	Weight (kg)	Load (KN)	Compression strength (N/mm²)
1	8.1	560	24.8
2	8.32	670	29.7
3	8.41	970	42.6

The average compression strength is 32.36 N/mm²

Loading set up

Failure of specimen

TESTING RESULTS

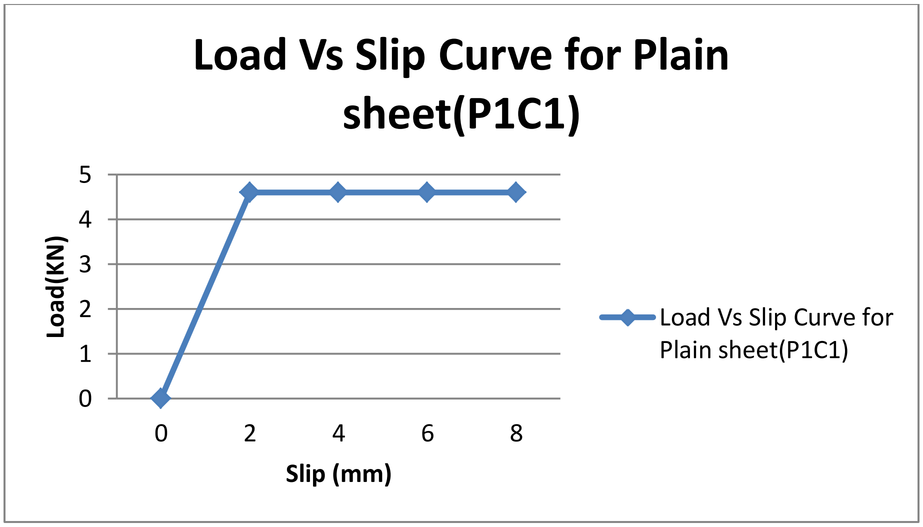
The results of companion specimen are

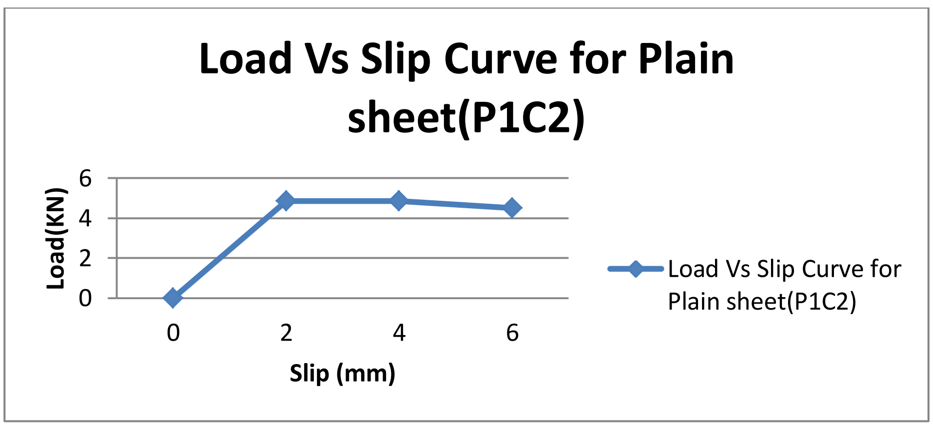
1. Cube compressive strength = 32.36 N/mm²
2. Young's modulus of concrete = 22.57 x 10^3 N/mm²
3. Yield stress of cold formed steel = 270 N/mm²
4. Yield stress of reinforced steel = 416 N/mm²

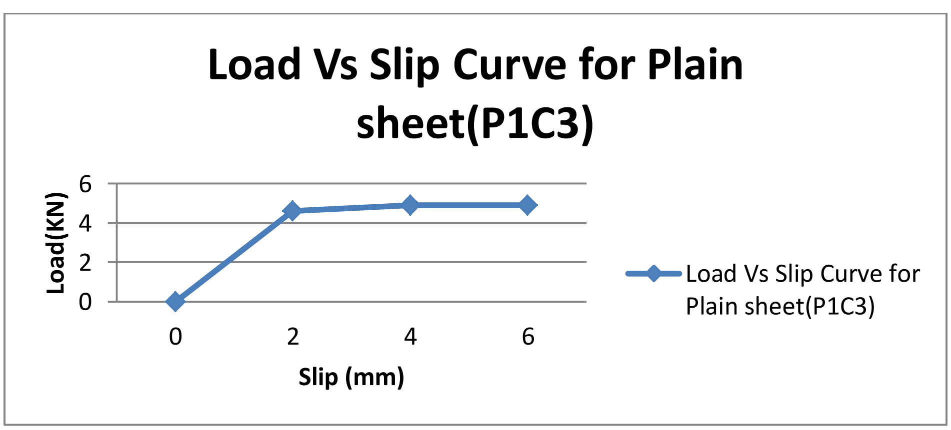
TABLE 4

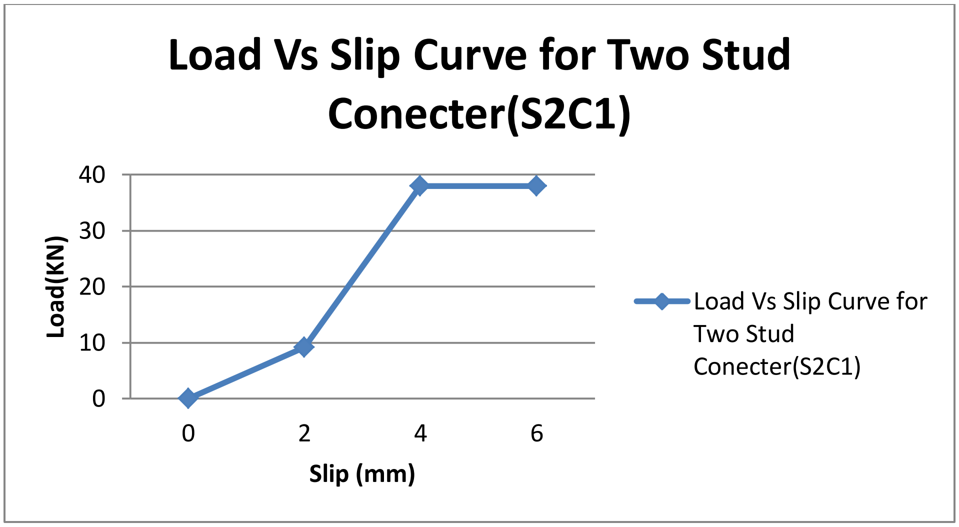
SUMMARY OF LOADS SLIPS

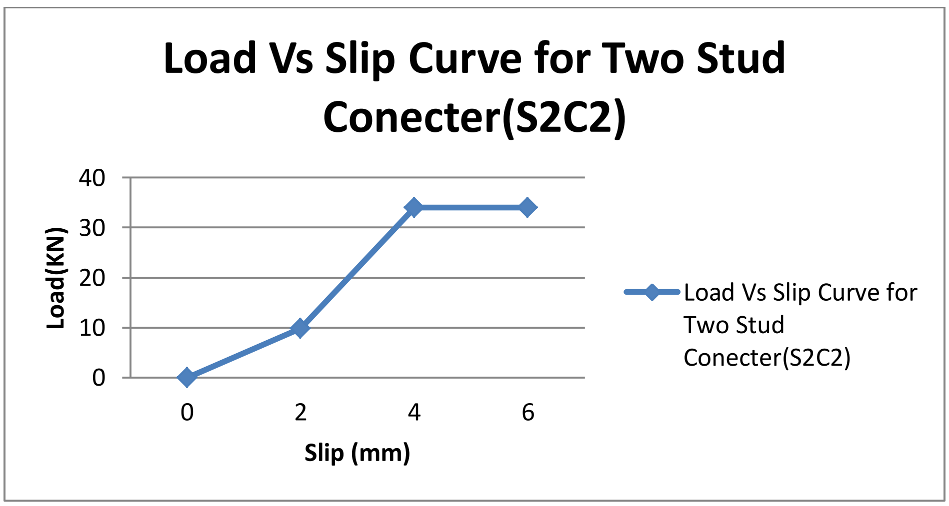
S.NO	TYPES		PEAK LOAD (KN)	MAX. SLIP (mm)	LOAD @ 4mm SLIP (KN)
1	STUDS	S2C1	9.13	38	5.5
		S2C2	9.78	34	5.5
		S2C3	10.5	40	5.5
		S4C1	27.6	70	5.8
		S4C2	28.1	68	5.2
		S4C3	28.1	68	5.5
2	PLAIN	P1C1	4.62	4.6	4.76
		P1C2	4.6	4.87	4.87
		P1C3	4.6	4.89	4.85

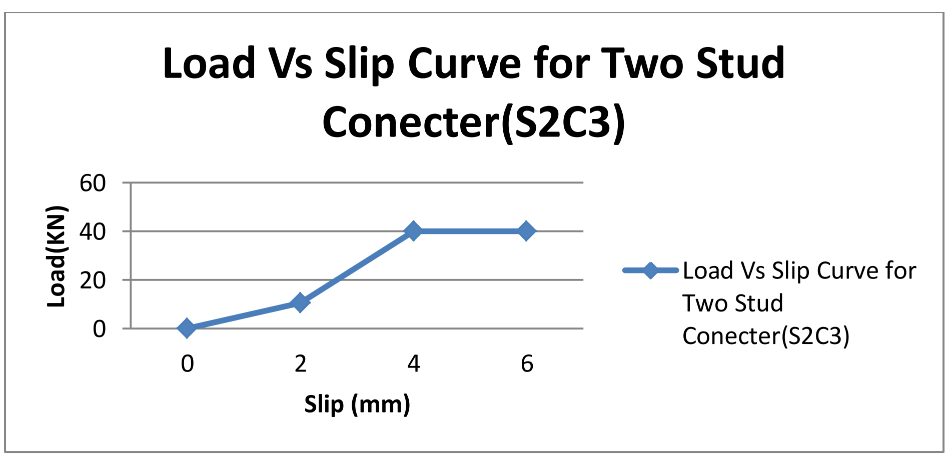

Load Vs Slip Curve for Plain sheet(P1C1)
Load(KN)
5
4
3
2
1
0
0
2
4
6
8
Slip (mm)
Load Vs Slip Curve for Plain sheet(P1C1)

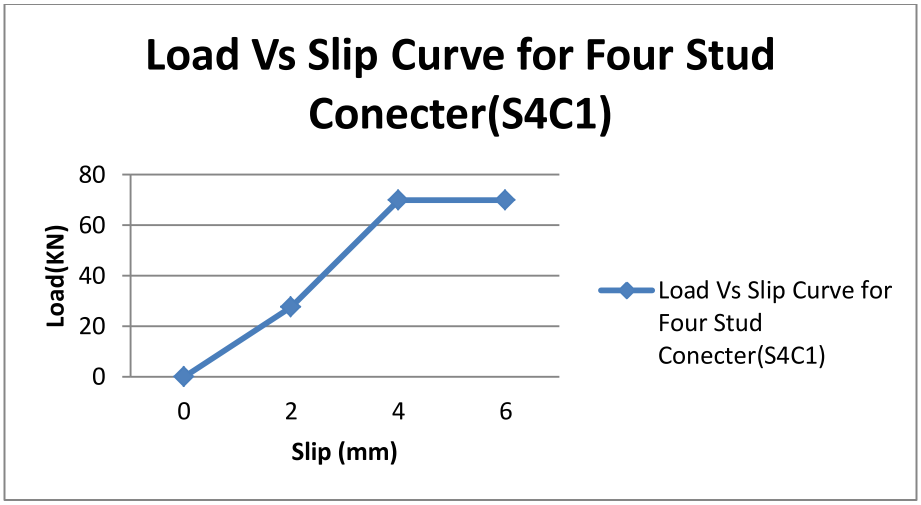

Load Vs Slip Curve for Plain sheet(P1C2)
Load(KN)
6
4
2
0
0
2
4
6
Slip (mm)
Load Vs Slip Curve for Plain sheet(P1C2)

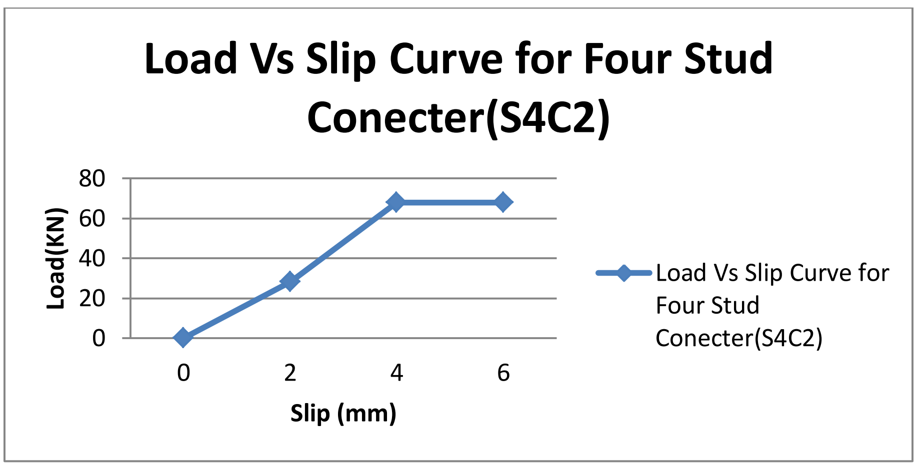

Load Vs Slip Curve for Plain sheet(P1C3)
Load(KN)
6
4
2
0
0
2
4
6
Slip (mm)
Load Vs Slip Curve for Plain sheet(P1C3)


Load Vs Slip Curve for Two Stud Conecter(S2C1)
Load(KN)
40
30
20
10
0
0
2
4
6
Slip (mm)
Load Vs Slip Curve for Two Stud Conecter(S2C1)


Load Vs Slip Curve for Two Stud Conecter(S2C2)
Load(KN)
40
30
20
10
0
0
2
4
6
Slip (mm)
Load Vs Slip Curve for Two Stud Conecter(S2C2)


Load Vs Slip Curve for Two Stud Conecter(S2C3)
Load(KN)
60
40
20
0
0
2
4
6
Slip (mm)
Load Vs Slip Curve for Two Stud Conecter(S2C3)


Load Vs Slip Curve for Four Stud Conecter(S4C1)
80
60
40
20
0
Load(KN)
0
2
4
6
Slip (mm)
Load Vs Slip Curve for Four Stud Conecter(S4C1)


Load Vs Slip Curve for Four Stud Conecter(S4C2)
80
60
40
20
0
Load(KN)
0
2
4
6
Slip (mm)
Load Vs Slip Curve for Four Stud Conecter(S4C2)

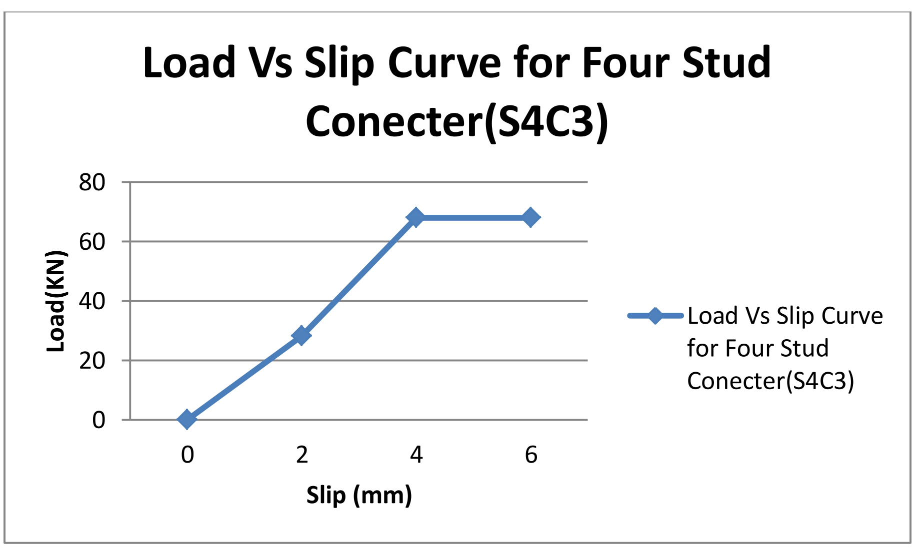

Load Vs Slip Curve for Four Stud Conecter(S4C3)
80
60
40
20
0
Load(KN)
0
2
4
6
Slip (mm)
Load Vs Slip Curve for Four Stud Conecter(S4C3)

TABLE 5

Load at 4mm slip of the plain sheet

S.NO	Type of shear connector	Load @ 4mm slip of the plain sheet
1	Plain (without studs)	4.6
2	Two stud connectors	5.5
3	Four stud connectors	5.2

TABLE 6

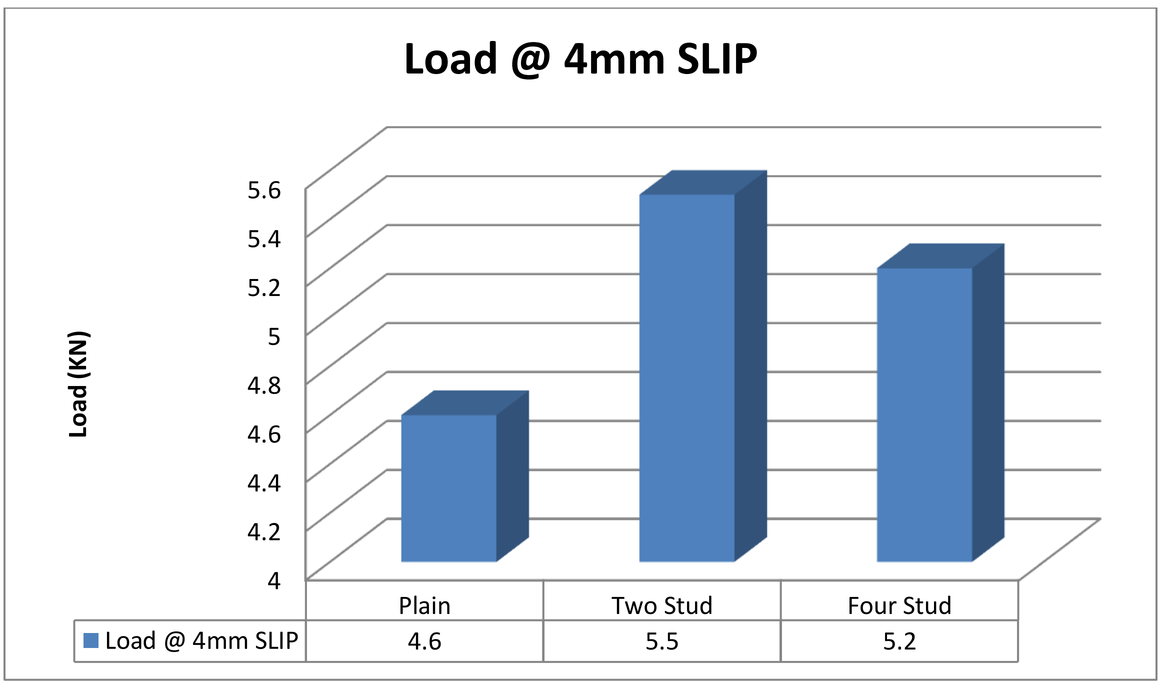
Slip at peak load

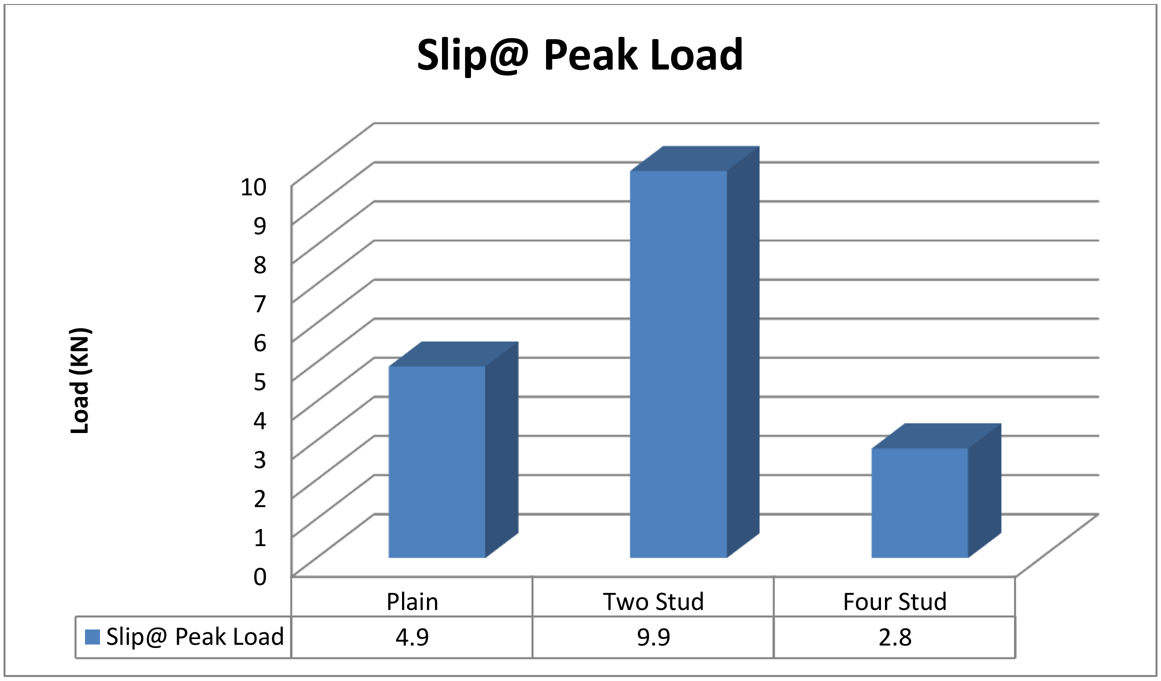
S.NO	Type of shear connector	Slip @ peak load
1	Plain (without studs)	4.9
2	Two stud connectors	9.9
3	Four stud connectors	2.8

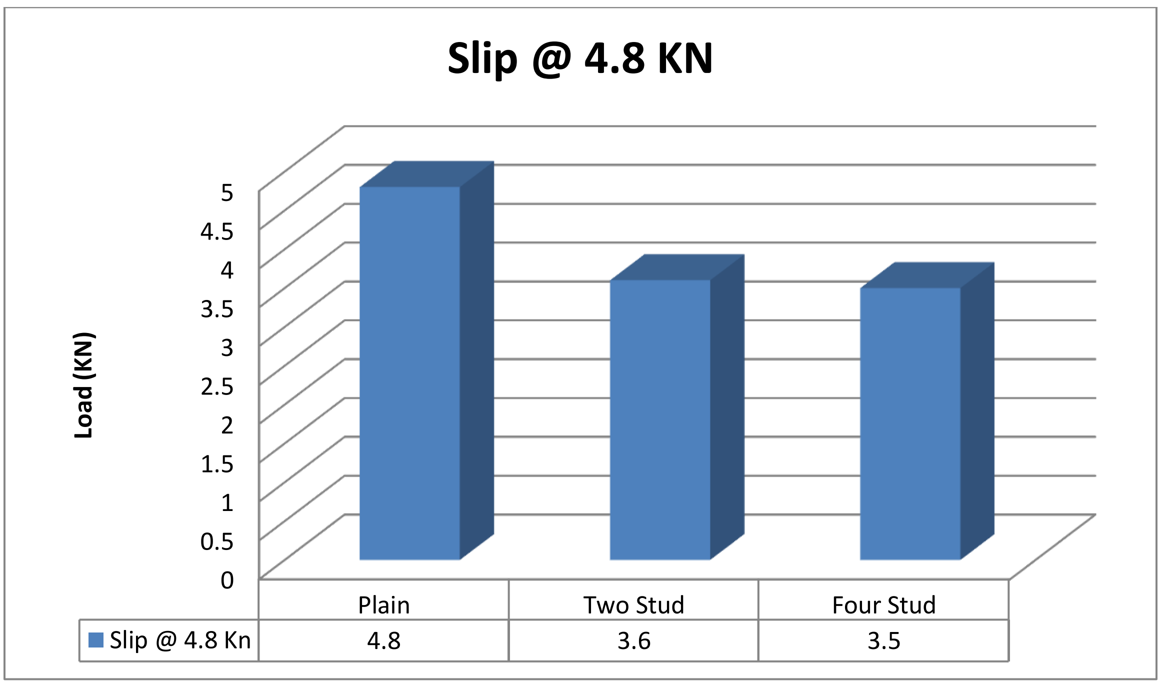
TABLE 6

Slip at4.8KN load

S.NO	Type of shear connector	Slip @ 4.8 KN load
1	Plain (without studs)	4.8
2	Two stud connectors	3.6
3	Four stud connectors	3.5







DISCUSSION ON RESULTS

GENERAL

Five various kinds of shear connectors were used and we cast prism embedded with the cold rolled sheet. Along with the shear connectors the pull out tests were carried out. These experiments were carried out to study the behavior of the shear connectors in the composite construction. The results of those tests are discussed below,

DISCUSSION

The graph shows the ductile behavior of various shear connectors in composite construction. The curve of plain sheet shows that there is infinite slip after it reaches the peak load, but in other connector, there is ductile region in between the peak load and infinite slip.

1. The two-stud shear connector has initial slip, it reaches the peak load of 9.5 KN at 16mm slip, and it has an infinite slip on reaching 32mm.

2. The four-stud type connector has initial slip, it reaches the peak load of 26 KN at 36mm slip, and it has an infinite slip on reaching 70mm.

SALIENT FEATURES

1. Composite prisms, which did not have any shear connector, lost the composite action immediately after the initial step (approximately 4mm)
2. Composite prisms with shear connectors could withstand more pullout load then the one without shear connectors.
3. Composite prisms, which employed shear connectors, showed a reduction in the pullout loads before the ultimate final slippage occurs.
4. Occurrence of final slippage indicates loss of composite action.
5. Prisms with increased number of shear connectors showed improved ductile behavior before final slip.

CONCLUSIONS

1. Ductile nature of steel increases the collapse time.
2. Increases in number of shear connector increase the slip time & ductility.
3. Re-entrant type of shear connectors can be well exploited because of high load carrying capacity at initial slippage.
4. Performance of such connectors can be improved by combining them with other types of connectors.
5. Increase in the number of stud connectors can be made increase the time of occurrence of final slippage.
6. The concept of stress transfer through the connectors can be exploited to form plastic hinges in the beam at the desired location. This can be done by neglecting shear connector at the desire regions.