Experimental Study on the Flexural Behaviour of Cold Formed Steel Concrete Composite Beam

K. Girija
U.G. Student
Valliammai Engineering College, Tamil Nadu,India

A. Gitanjali
U.G. Student
Valliammai Engineering College, Tamil Nadu,India

M. Pradeepkumar
U.G. Student
Valliammai Engineering College, Tamil Nadu,India

G. R. Iyappan
Assistant Professor
Valliammai Engineering College, Tamil Nadu,India

Abstract

The main motive behind the composite construction is to make two different materials of different properties to combine together to resist the externally applied load. An experimental investigation was carried out with 6 simply supported beam specimens to understand the flexural behaviours. Out of the 6 beams two beams were composite beams and the rest of the four beams were composite beams with 2 different type of shear connectors. The cross section of the beams were kept such that, span to depth ratio is 8. The grade of concrete used was M30 and the grade of steel used is Fe415. The connection between the steel and the concrete section was provided using C-shear connectors, Stud-shear connectors. The beam specimens were tested by subjecting them to two point loading and the cracking load, load-deflection behaviour, ultimate load and failure pattern of the beam specimens were studied. The experimental results indicate that, the load carrying capacity of the composite beams was increased by 20%. The mid-span deflections at ultimate load for the composite beams were reduced by 50% when compared to control beams. It was observed that, the steel-concrete composite beams failed due to shear-compression failure in the shear span.
Keywords: Composite Beams, Shear Connector, Cracking Load, Load-Deflection, Ultimate Load etc.

I. INTRODUCTION

A structural member composed of two or more dissimilar materials joined together to act as a unit. The first known use of composites is credited to the Mesopotamians; these ancient people glued wood strips at different angles to create plywood in 3400 B.C.

Composite steel-concrete structures are used widely in modern bridge and high rise building construction. It is a powerful construction concept in which compressive strength of concrete and the tensile strength of steel are almost effectively used Steel and concrete have almost the same thermal expansion apart from an ideal combination of strength, hence these essential different materials are completely compactable and complementary to each other.

If the steel beams are connected to the concrete slab in such a way that the two act as one unit, the beam is called as composite beam. Composite beams are similar to concrete T-beams where the flange of the T-beam is made of concrete slab and the web of the T-beam is made of the steel section.

An example in civil structures is the steel-concrete composite beam in which a steel wide-flange shape is attached to a concrete floor slab. The many other kinds of composite beam include steel-wood, wood-concrete and plastic-concrete or advanced composite materials-concrete etc. Composite beams as defined here are different from beams made from fibre-reinforced polymeric material. Steel-concrete composite beams have long been recognized a one the most economical structural systems for both multi-story steel buildings and steel bridges.

As a material, concrete works well in compression, but it has less resistance in tension. Steel, however, is very strong in tension, even when used only in relatively small amounts. Steel-concrete composite elements use concrete's compressive strength alongside steel's resistance to tension, and when tied together this results in a highly efficient & lightweight unit.

The connection between the steel and concrete section is very important and it influences the structural behaviour of the composite section. The connection is necessary to make steel and concrete sections act as a single composite unit. The mechanical devices called shear connectors are used to establish the connection between steel and concrete.

A. Scope of the Project

The scope of this project work is to study and compare the flexural behaviour of the steel-concrete composite beams cast as reinforced rectangular concrete sections into steel channels with control beams having same span and dimensions. These types of composite beam have been recognized as one of the most economical structural system for both multi-storey steel building and bridges. Generally building and bridges require a floor slab to provide a surface for occupants and vehicles, respectively. These types of beams are the best choice for the slab because its mass and stiffness can be used to reduce deflections and vibrations of the floor system and to provide the required fire protection. This type of composite beam are generally shallower (for any given span and loading) than non-composite beams and they can be used commonly in long span applications.

B. Objectives

- The main objective of this project is to develop a Cold Formed Steel-Concrete Composite beam.
- To evaluate the bending resistance of cold formed steel section subjected to flexure.
- To study the various Modes of Failure.

II. MATERIALS AND MIX PROPORTIONS

- Ordinary Portland cement of 53 grade conforming to IS: 1269-1987 was used.
- Locally available sand passing through 4.75mm sieve conforming to zone II of IS:383-1970 was used as Fine aggregate. The tests on fine aggregate was conducted to determine the specific gravity.
- Locally available aggregate passing through 20mm sieve and retaining on 4.75mm sieve was used as Coarse aggregate. The aggregate was conforming to IS: 383-1970.The tests on coarse aggregate were conducted to determine Specific gravity, Water absorption, Crushing strength, Impact value.
- The results are presented in Table-1. Potable water free from injurious salts was used for both mixing and curing.
- Fe415 grade steel was used for all the beams as conventional reinforcement and cold formed steel plates of 3mm thickness were used to form channel sections used for composite beams. Also, 3mm plates were used to fabricate shear connectors.

Table - 1
Properties of Cement

	TEST CONDUCTED	ATTAINED VALUE	ALLOWABLE VALUE
CEMENT (OPC 53 GRADE)	Specific gravity	3.17	3.1-3.2
	Initial setting time	24 minutes	30 minutes
	Consistency	29%	26% - 33%
	Fineness	4.3%	3% - 6%

Table – 2
Properties of Aggregate

	TEST PERFORMED	ATTAINED VALUE	ALLOWABLE VALUE
COARSE AGGREGATE	Specific gravity	2.9	2.6 - 3
	Water absorption	2.3	Upto 3
	Crushing strength	9.96	Not greater than 30
	Impact value	8.09%	Not greater than 30
FINE AGGREGATE	Specific gravity	2.6	2.3 – 2.7

Based on the properties of the materials obtained and the specifications as per IS: 10262-2009 the mix proportion for M30 grade of concrete was obtained as 1:1.46:2.47 with a W/C ratio of 0.42. The obtained mix proportion is shown in Table-

Table- 3
Mix Proportion For M30 Grade Concrete

Cement (Kg/m3)	Fine Aggregate (Kg/m3)	Coarse Aggregate (Kg/m3)	Water (Kg/m3)
456	666.91	1130 .35	199.5

III. EXPERIMENTAL WORK

The experimental work carried out in this research work involves, evaluation of material properties, fabrication of reinforcement cages as per the requirement, fabrication of shear connectors and welding them to the channel sections, casting of beam specimens and the companion cubes for compressive strength determination and testing of the beam specimens.

A. Nomenclature of Beams

The beam specimens were named separately for their identification as follows, CB/8/1/0, means, beam name/span to depth ratio/ beam number/Type of shear connector. The first letter 'CB' indicates conventional beam, second number '8' indicates span to depth ratio, third number '1' indicates beam number and the last number '0' indicates Type of shear connector. As the conventional beams does not have any shear connector, number '0' was used to identify the shear connector type, which indicates that, no shear connector was used.

B. Shear Connectors

Type 1 shear connector: In this type, the STUD-shear connector was provided in zig-zag manner with center to center spacing between adjacent connectors as 100mm. Totally 21 nos's of shear connectors were used. The dimension of the connectors was of diameter 16mm and height 75mm before welding and 65mm after welding. Arc welding was used to weld the stud connectors with the Cold-Formed Steel beam. The typical cross-section and the longitudinal section of Type 1 shear connector is shown in Fig-1.

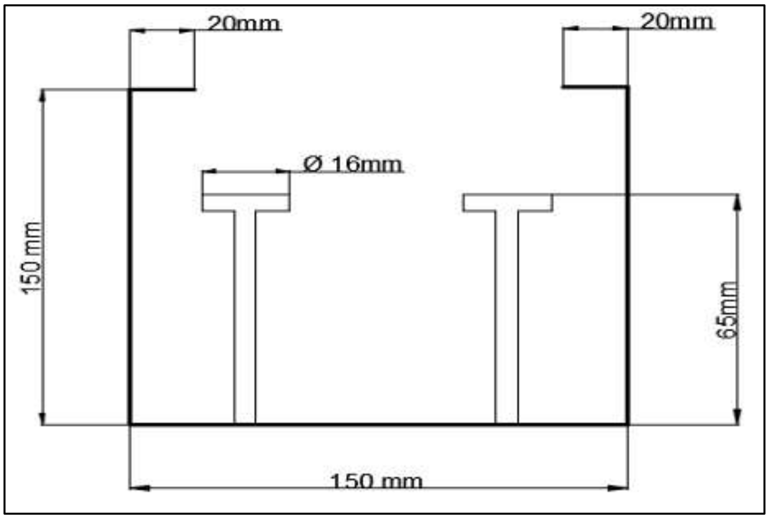

Fig. 1: Side view of CFS beam with stud connectors.

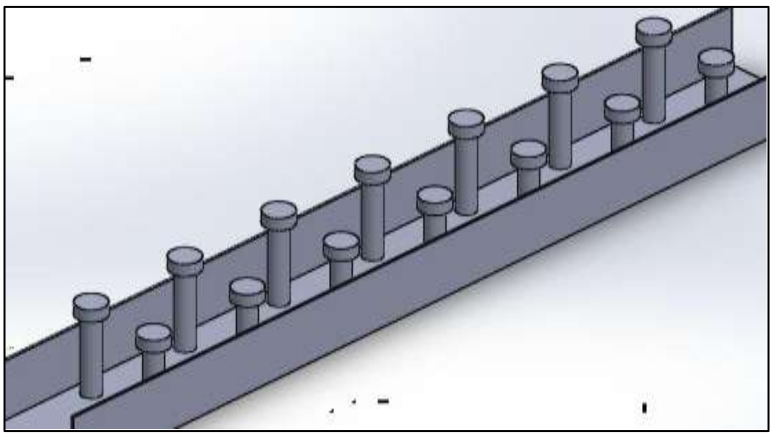

Fig. 2: View of CFS beam with stud connectors.

Type 2 shear connector: In this type, C-shear connector was provided in straight manner in the center of the CFS beam along its length. Totally 8 nos's of shear connectors were used. The dimension of the connectors is 100mm x 50mm x 150mm. Stitch welding was used to weld the C-connectors with the Cold-Formed Steel beam. The typical cross-section and the longitudinal section of Type 2 shear connector is shown in Fig-3 & 4.

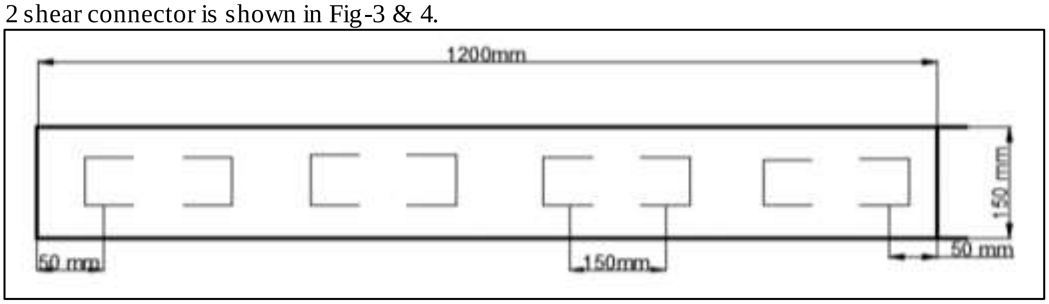

Fig. 3: Cross-section of CFS beam with channel-connectors.

Fig. 4:

C. Casting of Specimens

The beam specimens were cast by using the channel sections of cross-section 1200mm x 150mm x150mm. The channel sections were cleaned and oiled before concreting for easy demoulding. Then the reinforcement cages for conventional RC beams were placed into the beam moulds and were given a cover of 20mm as per IS:456-2000 guide lines and channel sections welded with C-shear connectors & STUD-shear connectors for composite beams.

Fig. 5 (a):

Fig. 5(b):

Fig. 5(c):

Fig. 5(d):

Fig. 5(a,b,c,d): Casting of CFS beam with C & STUD type shear connectors.

Then the fresh, workable concrete was placed in layers and was compacted. 9 cubes and 9 cylinders were also cast to determine the characteristic compressive strength and split tensile strength of concrete. The beam specimens and cubes were then remoulded after 24 hours. Then the cubes were cured for 7, 14 and 28 days before they were tested & the beam specimens were cured for 28 days before they were tested.

Fig. 6: Mixing of concrete for cube and cylinder casting

Fig. 7: Casting of Cylinder

D. Testing

After the curing period of 28 days, beam specimens were kept for 24 hours in a dry state and then they were cleaned to remove grit and dirt. The cubes and cylinders were also tested in compressive testing machine (CTM) to evaluate the compressive strength of concrete and the split tensile strength of concrete on 7, 14 and 28 days of curing of the specimens. The loading arrangement is shown in Fig-8 &10 and the failure specimen is shown in Fig-9 &11.

Fig. 8: Compressive loading on cube.

Fig. 9: Failure on cube.

Table – 4
Compression Test Results

DAYS	*TRIALS*	*COMPRESSIVE STRENGTH(N/mm^2)*
7 days	*Trial 1*	*18.5*
	Trial 2	*19*
	Trial 3	*18.3*
14 days	*Trial 1*	*26.5*
	Trial 2	*25.4*
	Trial 3	*26*
28 days	*Trial 1*	*29.3*
	Trial 2	*29.5*
	Trial 3	*29*

Fig. 10: Split tensile loading on cylinder.

Fig. 9: Failure on cylinder.

Table – 5
Split Tensile Test Result

DAYS	*TRIAL*	*OBTAINED TENSILE STRENGTH(N/mm²)*
7 days	*Trial 1*	*2.45*
	Trial 2	*2.40*
	Trial 3	*2.32*
14 days	*Trial 1*	*3.41*
	Trial 2	*3.38*
	Trial 3	*3.40*
28 days	*Trial 1*	*3.80*
	Trial 2	*3.82*
	Trial 3	*3.98*

The beam specimens were tested in a reaction frame of 500 ton capacity and hydraulic jack of 500 kN capacity subjected to two point loading. The beams were tested at the load increment of 5kN. The load increment was increased after the first crack load and the deflection of the beam specimens was noted down for every increase in the load till the failure of the beam specimens. The first crack load, deflection at first crack load, ultimate load and deflection at ultimate load were noted down and the crack pattern was marked on the beam. The loading arrangement is shown in Fig-12, 13,14.

Fig. 12: Testing of Conventional beam.

Fig. 13: Testing of Composite beam with stud-shear connectors.

Fig. 14: Testing of Composite beam with Channel-shear connectors.

E. Results

NAME	TYPE OF BEAM	TYPE OF SHEAR CONNECTORS	DIMENSION	Pcr (KN)	Δcr (mm)	Pu (KN)	Δu (mm)	MODES OF FAILURE
CB/8/1/0	CONVENTIONAL	NIL	1.2m x 0..15m x 0.15m	95	0.6	170	2.1	WEB FAILURE
CB/8/2/0	CONVENTIONAL	NIL	1.2m x 0..15m x 0.15m	115	0.7	185	2.3	WEB FAILURE
STB/8/1/1	STUD TYPE	STUD	1.2m x 0..15m x 0.15m	130 Crack @ top zone	1.6	215	2.5	FLEXURE FAILURE @ mid span
STB/8/2/1	STUD TYPE	STUD	1.2m x 0..15m x 0.15m	155 Crack @ top zone	1.75	250	2.9	FLEXURE FAILURE @ mid span
CTB8/1/2	C TYPE	CHANNEL	1.2m x 0..15m x 0.15m	115 Crack @ top zone	0.8	190	1.4	WEB FAILURE @ mid span
CTB8/2/2	C TYPE	CHANNEL	1.2m x 0..15m x 0.15m	125 Crack @ top zone	0.7	200	1.9	WEB FAILURE @ mid span

Where,
Pcr-1st cracking load in KN
Δcr-Deflection at 1st crack in mm
Pu-Ultimate load in KN
Δu-Deflection at ultimate load in mm.

F. Flexural behaviour (Load-deflection)

Load-deflection behaviour is the major factor which shows the flexural behaviour of the beams. Load-deflection curve serves as the basis for calculating many structural parameters like, energy absorption, deflection ductility etc.

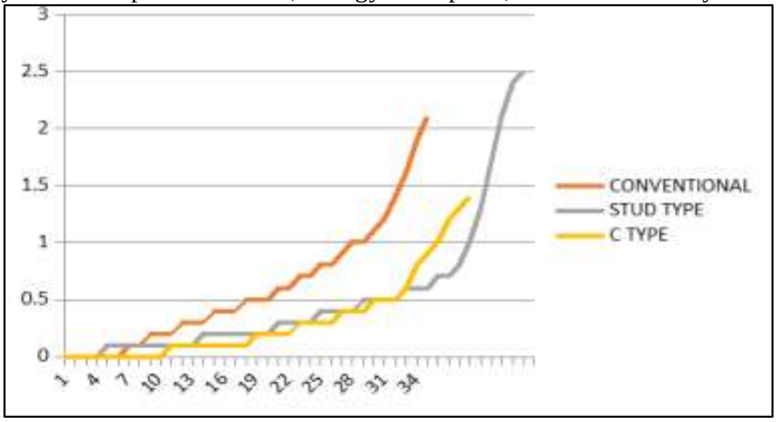

Fig. 15: Load vs Deflection curve for trial-1 beam specimens (3 types).

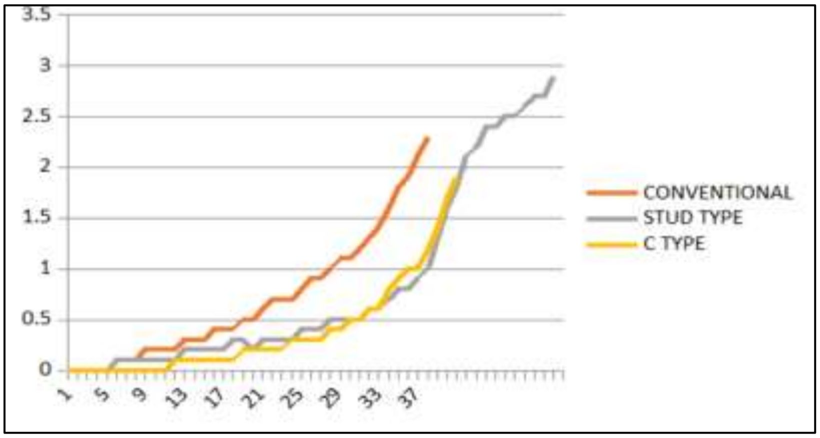

Fig. 16: Load vs Deflection curve for trial-2 beam specimens (3 types).

Fig-15 & 16 shows the Load-Deflection curves for beams. By comparing the experimentally obtained test results of all the beams it was absorbed that composite beam having stud type shear connector shows high resistance to flexural bending and shows less deflection when compared to conventional and composite beam having channel type shear connector. The load-deflection curves for all the beams indicate reduction in stiffness with increase in load. But, reduction in stiffness observed was more for conventional beam when compared to steel-concrete composite beam with shear connectors. Therefore the overall efficiency of the composite beam having stud type shear connectors is 20% more than the conventional beam.

IV. CONCLUSIONS

1) The properties of the material is having significant influence on arrival of the concrete mix design of M30 grade concrete. Also trial mix preparation should be done in a proper manner as it played an important role in arriving at the mix proportion.
2) It is observed that, cracking load for composite beams is 20% more than the cracking load for conventional beams.
3) It is evident from the Fig-15 and Fig-16, that, Type 1 shear connector is more efficient in increasing the cracking load.
4) The increase Ultimate load carrying capacity of composite beam with stud type shear connectors is observed to be varied between 45kN- 60kN in comparison with the respective conventional beam.
5) The increase Ultimate load carrying capacity of composite beam with stud type shear connectors is observed to be varied between 15kN- 20kN in comparison with the respective conventional beam.
6) The composite beams having the same span to depth ratio were recorded for different percentage increase in the load carrying capacity whose result indicates that the shear connector arrangement also has a great significant influence on the load carrying capacity of the composite beam specimens.
7) It was absorbed that composite beam having stud type shear connector shows high resistance to flexural bending and shows less deflection when compared to conventional and composite beam having channel type shear connector.
8) Therefore the overall efficiency of the composite beam having stud type shear connectors is 20% more than the conventional beam.

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