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Study on Flexural Strength of Truss Reinforced Concrete Beams

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Abstract - *The role of steel reinforcement in reinforced concrete beams is to handle the bending and shear stresses that develop within a beam. The horizontal longitudinal bars are designed to carry the bending stresses and vertical stirrups to carry the shear force. Alterations in the reinforcement pattern within the beam affects the flexural as well as shear carrying capacity of the beams considerably. A steel truss reinforced concrete beam is constituted by a prefabricated steel truss installed within the concrete core. The truss, usually is composed by a system of steel rebars welded to form the diagonals of the truss and the main bars used to form the upper and bottom chords of the truss. This paper aims at the results of experimental study to find out the flexural behavior of reinforced concrete beams, with two types of truss arrangements*

***Key Words*: Truss Reinforcement, Flexural Strength, Ultimate Failure Load, Deflection, Yield Load**

1. INTRODUCTION

Under loaded conditions, flexural and shear stresses are developed in a beam. Depending upon the magnitude of bending and shear stresses developed at various locations, different types of cracks are formed within a reinforced concrete beam. In beams, flexural cracks may develop at the regions of peak moments, under high flexural stresses and low shear stresses. Longitudinal tensile bars are provided in beams to take up flexural stresses and to control the bending failure of the beam. Since bending moment is very much reduced near the supports, some of the main bars can be bent up near the supports. Such bent up bars resist the diagonal tension (bent usually at 45°). If the bent up bars are not sufficient to resist the shear, additional vertical stirrups are also provided with the inclined bars.

The stirrups, bent up bars, main tensile bars and the anchor bars together can be called as reinforcement system within a concrete beam. Usually, shear reinforcement in the form of vertical stirrups are provided, when the externally applied shear force is more than the design shear strength of the beam, without shear reinforcement. However nominal shear reinforcement is provided in all beams.

In order to increase the flexural strength of the reinforced concrete beams, various methods are developed in the past few decades. All these methods are focused on the enhancement of flexural strength by changing the geometry or by introducing additional aids in the flexural zone of the beams. All these methods results in increased cost, as well as additional efforts. If the reinforcement system within the concrete beam itself can provide better flexural strength to the beams, without altering the geometry or by using additional aids, it would be economic as well as convenient. By changing the arrangement of the stirrups within the beams, the shear strength and flexural strength can be increased.

The conventional way of providing vertical stirrups in beams is time consuming and leads to increase in cost. To overcome these problems, the use of inclined and horizontal bars in the high shear region are recommended by many researchers. Aziz & Yaseen conducted experimental studies to explore the effect of orientation and position of the different shear reinforcements in deep beams. In their study, beams with inclined stirrups show more ultimate strength but less deflection than vertical and horizontal bar systems [1].

Asha et al. studied another type of shear reinforcement called swimmer bars in which increased ultimate strength with less deflection in reinforced concrete beams was observed [2]. The research work conducted by Muneeb et al. also agreed with the above results [3].

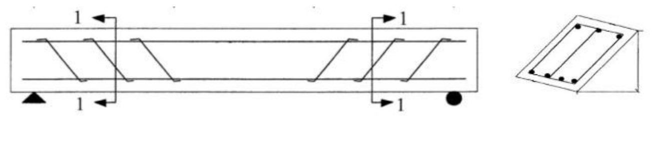


Fig - 1: Reinforced concrete beam with swimmer bars [2]

Atteshamuddin et al., in their experimental investigations on lateral, inclined and vertical stirrup designs with two different shear span to depth ratios, concluded that, inclined stirrups were effective in increasing the flexural response of the beams [4].

Recently in construction industry, a special steel-concrete composite beam called Hybrid Steel Trussed Concrete Beams (HSTCBs) was introduced, in which prefabricated truss reinforcement is embedded within the concrete. The truss structure is usually made with or without steel plate or a precast concrete slab, which represents the bottom chord. A typical HSTCB is shown in Fig - 2 . The load carrying capacity of HSTCB is found to be more than that of conventional RC beams [5], [6].

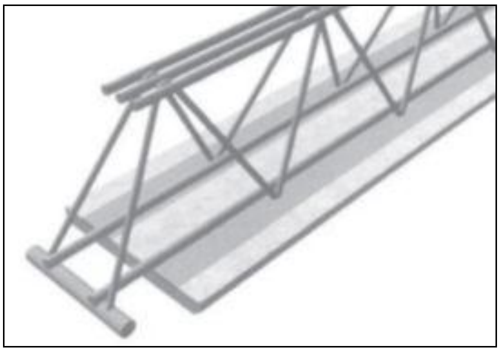


Fig - 2: Hybrid Steel Trussed Concrete Beam Topology [5]

Djamaluddin et al. conducted experiments on the truss embedded concrete beams without concrete in tension zone, and observed more flexural strength compared to the normal beams with vertical stirrup system [7].

The present study concentrated on Steel Trussed Concrete Beam with different type of reinforcements to explore the flexural resistance behavior.

2. EXPERIMENTAL PROGRAM

2.1 MATERIALS

Cement used for the experimental study is Ordinary Portland cement of 53 grade. M Sand is used as fine aggregate and coarse aggregate of 20mm size broken stone is used. Various tests were conducted as per the IS specifications and results are tabulated in Table-1.

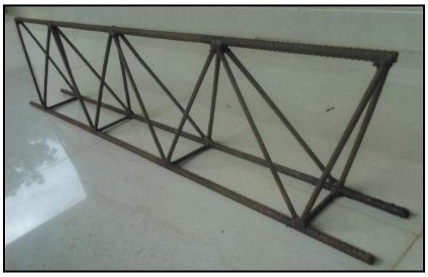
Table - 1: Material properties

Material	Specific gravity	% fineness
Cement	3.15	2
Fine aggregate	2.73	-
Coarse aggregate	2.81	-

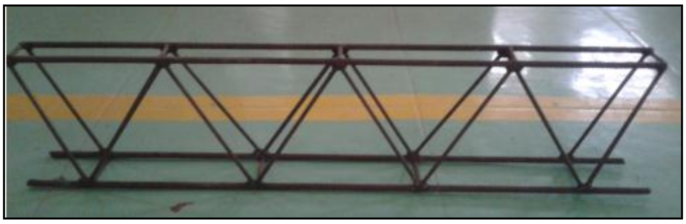
A mix of M30 grade was designed as per IS 10262:2009 and arrived the mix proportion as 1:2.23:2.01 with water cement ratio 0.42 for beam specimens.

2.2 Specifications of the test specimens

Required number of beam specimens of length 1000 mm and cross section 150 mm x 260 mm were casted. In order to avoid the shear failure, adequate shear reinforcement is provided for the beams. The same percentage of reinforcement is provided in the two types of experimental systems. In the first system longitudinal bars with vertical stirrups are used (Fig-3. (c)) whereas in the second system a truss shaped reinforcement system is used (Fig-3.(a,b)).



(a) Reinforcement cage for specimen B00

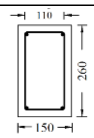
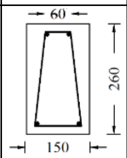
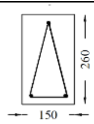


(b) Reinforcement cage for specimen B06

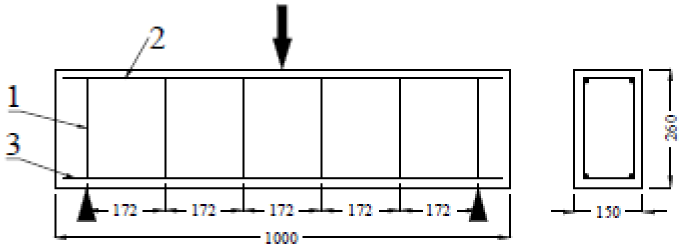
(a) Reinforcement cage for specimen B11

Fig - 3: Reinforcement details of beam specimens

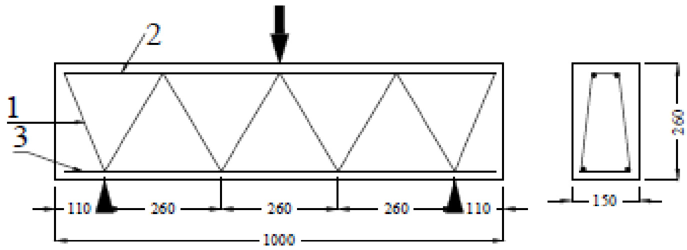
Table - 2: Details of beam specimen

Designation	Distance between the upper chord members of reinforcement (mm)	Cross section	Diameter of stirrups (mm)	Diameter of main bars (mm)
B11	110		6	10
B06	60		6	10
B00	0		6	10

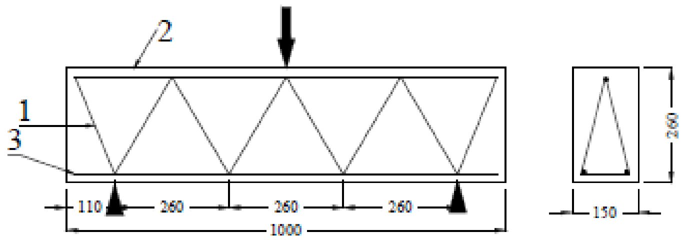
The beams B11 with vertical stirrup reinforcement and are treated as control specimens. For the beams designated as B06, two numbers of 10 mm diameter bars are provided in tension zone and two numbers of 10 mm diameter anchor bars in the compression zone. Diagonal bars of 6 mm diameter are welded to the top and bottom chords of B06 so as to have a truss arrangement. For beams B00, only one anchor bar is provided in the compression zone. All the specimens were water cured and tested after 28 days. The details of beam specimen are shown in table 2 and Fig-4.



(a) Specimen B11



(b) Specimen B06



(c) Specimen B00

Fig - 4: Details of test specimen

Where,
1 = shear reinforcement (6 mm diameter)
2 = anchor bars (6 mm diameter)
3 = longitudinal reinforcement (10 mm diameter)

2.3 Test setup for beams

All the specimens were tested for flexural strength under three point loading. Steel Trussed concrete beams and control beams were tested in universal testing machine of capacity 1000 kN. The specimens were arranged with simply supported end conditions over an effective span of 780 mm. The experimental test setup of the beams are shown in Fig - 5.

The maximum deflection at the midspan of the beam was measured by using a dial gauge. The load was applied at midpoint of the beam specimen, increased at a uniform rate till the ultimate failure. For each load increment, the deflection and crack pattern were observed and tabulated. The ultimate failure load and yield load are obtained during the experiment.

Fig - 5 : Test setup for beams

3. Results and discussion

3.1 Ultimate failure load of the beams

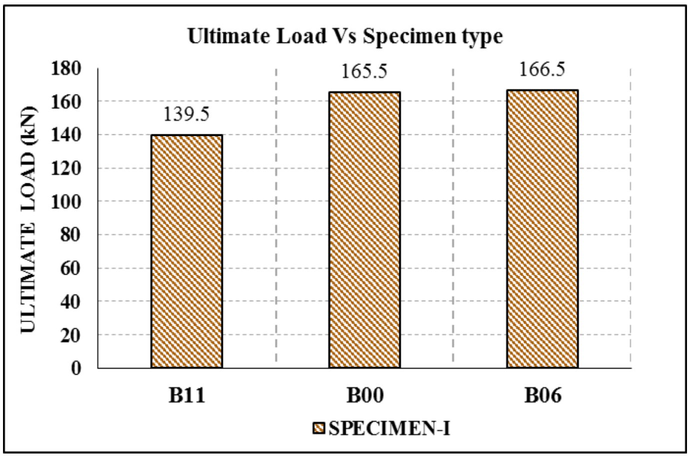


Fig - 6 : Ultimate load of specimens

The beams with truss reinforcement (specimen B00 and B06) has shown a considerable increase in ultimate load carrying capacity of about 20%, compared to the beam specimen B11 with vertical reinforcement. Whereas no considerable difference in ultimate load carrying capacity between the specimen B00 and B06. The graphical representation of the ultimate failure load obtained from the experiment are shown in Fig - 6.

The strut effect of the diagonal bars contributed to increased flexural strength of the specimen. Thus we can conclude that, better flexural strength is obtained on replacement of the conventional vertical reinforcement in reinforced concrete beams with truss arrangement of reinforcement system.

3.2 Load-deflection plots of the beams

Load-deflection curves were plotted for each beam and the results were compared. It is observed that the crack pattern of all the beams are same. Load-deflection of all beams shows almost linear pattern upto yield value and after that it shows a nonlinear pattern with gentle slope.

Due to the development of sudden and numerous cracks after the steel reinforcement has reached its maximum yield stress, the dial gauge readings were taken only upto some point before the ultimate failure load of the specimen. Hence the midspan deflection corresponding to the ultimate failure load was not taken using the dial gauge. The load-deflection diagram of specimen B11 and B00 are shown in Chart - 1. and load-deflection diagram of specimen B11 and B06 are shown in Chart - 2.

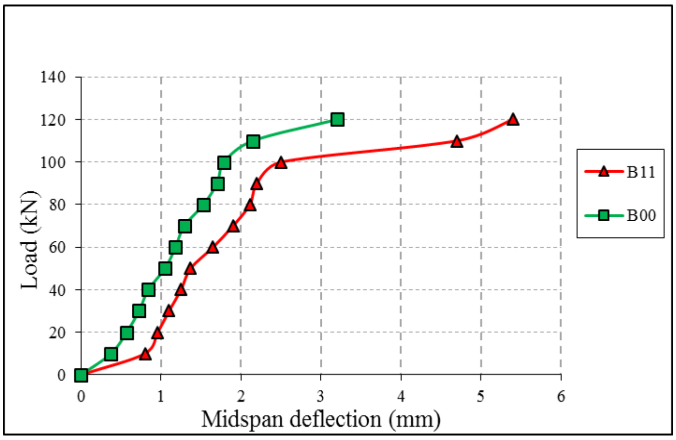


Chart - 1: Load-deflection plots for the beams B11 and B00 based on experiments

The deflection corresponding to the yield load is less for B00 when compared to B11 (control specimen), where yield load of B11 is less than B00. Thus the beam B00 demonstrated higher strength and stiffness than B11.

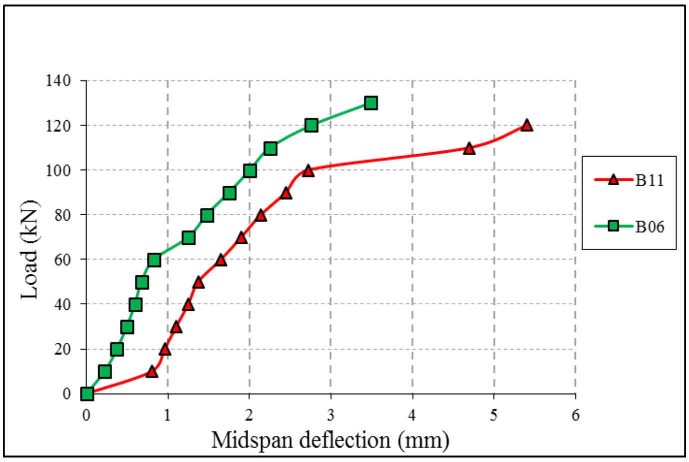


Chart - 2: Load-deflection plots for the beams B11 and B06 based on experiments

The load deflection plots of B11 and B06 shows similar trend as in the case of B11 and B00. The reinforcement of B11 yields earlier than B06. During the working load, the beam B06 is less deflected than B11. This means, the model B06 is stiffer than the control beam B11 with vertical stirrups.

Considering the load-deflection diagram of the beams, it is clear that, the specimens with truss reinforcement is better than control specimen where the deflection is less for truss reinforced beams. Thus it can be concluded that, change in the pattern of reinforcement from vertical to inclined, increases the stiffness and strength of the beam. That is, the inclined diagonals of the truss reinforcement contributed to increased flexural strength of the beams. Whereas, the difference in inclination of the diagonals in truss reinforcement do not have any effect in the failure mode or load carrying capacity of the beams as they shows similar load-deflection pattern.

3.3 Crack pattern of specimens

The first flexural cracks appeared at the midspan of the beam B11 earlier than B00 and B06. Increase in the applied loads induces additional flexural cracks near midspan.

All the specimens tested were failed in flexure and the crack pattern of the beams are shown in Fig-7,8 and 9.

Fig - 7: Cracking pattern of B11

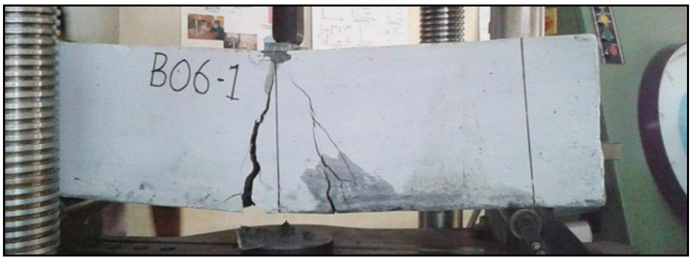


Fig - 8: Cracking pattern of B06

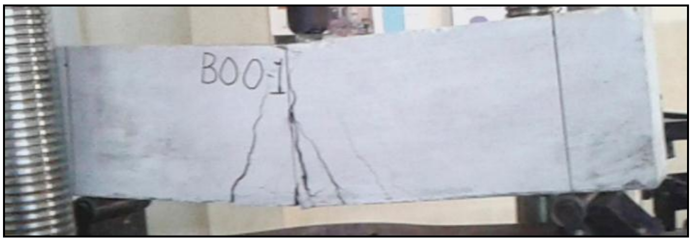


Fig - 9: Cracking pattern of B06

4. CONCLUSIONS

From the Experimental study on truss reinforced concrete beams, it can be concluded as follows,

- 20% increase in ultimate failure load was observed with Reinforced concrete beams with truss reinforcement compared to beam with vertical stirrups.
- The change in inclination of the truss reinforcements along the width of the beam do not have much effect on the ultimate failure load and failure mode of the beams. The crack pattern of both beams were similar.
- The beams with truss reinforcements are less deflected during the service stage (before yielding) and hence, they have more strength and stiffness than the beams with vertical reinforcement.
- The failure of the beams with vertical stirrups are sudden compared to beams with truss reinforcement.

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