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Numerical Study of Hybrid Steel Trussed Concrete Beam

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Abstract - *A Hybrid Steel Trussed Concrete Beam (HSTCB) is constituted by a steel truss embedded in a concrete core. The truss, typically, is composed by a steel plate or a precast concrete plank working as bottom chord, a system of ribbed or smooth steel rebar welded to form the diagonals of the truss and coupled rebar used to form the upper chord. The beam is typically cast directly on site and its main practical advantages are that it is partially pre-fabricated, easily applicable to long spans and, in many cases, self-supported during the concrete cast. The scope of this study is to develop a new structural element that can be a substitution for the conventional way of providing stirrup reinforcement in beams, by utilizing the advantages of diagonal web bars in Hybrid Steel Trussed Concrete Beams. The objective is to conduct numerical analysis using FEM (ANSYS) by varying the truss configuration leading to the improvement of confinement in the shear and flexure region.*

Key Words: **rebar, FEM, ANSYS, HSTCB, shear, flexure**

1. INTRODUCTION

When concrete and steel are combined together they form a composite member. The composite construction has gained importance due to its ability to combine the advantage of steel and concrete. Concrete is best utilized in compression and steel in tension. As concrete is incapable of resisting tensile load and steel section that are slender are most likely to undergo buckling under critical load. But when combined together to form composite member their individual weakness are overcome both their strength are utilized fully to increase the strength, stiffness and durability of the structure. Reinforced concrete beams are used to transfer the imposed loads from slabs and walls to columns. A beam must have adequate safety margin against bending and shear stresses, so that it will perform effectively during its service life. Reinforced concrete structures being the most commonly used structures need proper design and utmost care in the joint construction. In reinforced concrete beams of usual proportions, subjected to relatively high flexural stresses, and low shear stresses, the maximum principal tensile stress is given by the flexural stress in the outer fibre at the peak moment locations, the resulting cracks are known as flexural cracks. On the other hand, in short span beams which are relatively deep are subjected to high shear stresses and low flexural stresses, it is likely that maximum principal stress is located at the neutral axis level at an inclination of 45^0 to the longitudinal axis of the beam. The resulting cracks occur near the supports termed shear cracks or diagonal tension cracks. At the quarter span of the beam, where the effect of bending and shear stresses are predominant, flexure-shear cracks are formed. These cracks are formed when a flexure crack occurs in combination with a diagonal tension crack.

Due to the problems of conventional shear reinforcement, the use of independent inclined and horizontal bars in the high shear region are recommended by many researchers in the past few decades and they conducted experimental studies to explore the effect of orientation and position of the different shear reinforcements in deep beams. He used various stirrup arrangements viz. horizontal, inclined and vertical stirrups were used in beams. Beams with inclined stirrups were found to show more ultimate strength and less deflection than vertical and horizontal bar systems.

A special steel-concrete composite beam called Hybrid Steel Trussed Concrete Beams (HSTCBs) was appeared recently in the construction industry, 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 system of ribbed or smooth steel bar is welded in order to form the diagonals of the truss. Some single or coupled rebars are provided, constituting the upper chord of the truss as shown in figure 1

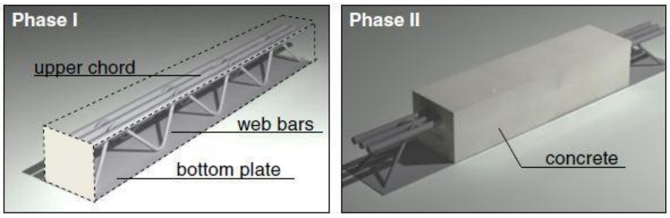


Fig-1: Hybrid steel Trussed concrete beam Topology [1]

HSTCBs represent a structural typology of composite beams typically employed as efficient structural solution for light industrialization and constituted by prefabricated steel truss embedded within a concrete matrix cast in situ. HSTCBs are typically constituted by a steel truss embedded in a concrete core. The truss is usually made up of a steel plate or a precast concrete slab, which represents the bottom chord, a system of ribbed or smooth steel bars welded to form the diagonals of the truss, with some single or coupled rebars constituting the upper chord. Among the large variety of beams currently produced, HSTCBs with a bottom steel plate, inclined tensile and compressed web bars, coupled upper rebars, and space cross-sections are considered. Such beams represent a structural solution for light industrialization; their main advantages are higher construction speed with minimum site labor, the possibility of covering wide spans with low depths, and economic benefits. Furthermore, they are frequently introduced in seismic-framed structures.

2. ANALYTICAL MODEL

In this study, a Hybrid Steel Trussed concrete beam is considered. This beam includes weld bond between truss elements to steel plate and steel plate to concrete, to be created. There is a lot of software in the line allowing the creation of models. ANSYS is chosen here for the modeling purpose as it is found to be more suitable to go along with the requirements and creation of my model. In the present study finite element analysis of the models created are carried out using the finite element modeling and analysis software ANSYS. As ANSYS offers more accuracy and multiple ranges of platforms and tools to work with easiness, it is chosen for the study.

Model can be created in ANSYS itself or it can be imported from an Autocad software. Sketching, extruding, modeling, analysis can be completed in ANSYS software. Nonlinear analysis is carried down over here. By this analysis the behavior of element under certain range of loading can be observed. The extreme deformations, stresses, strains, moments can be noted

2.1 Model

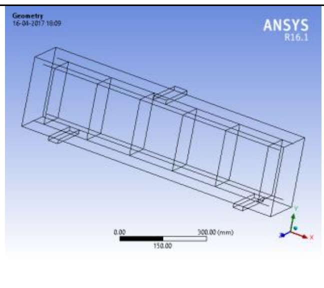
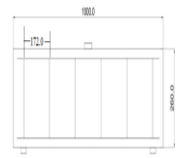
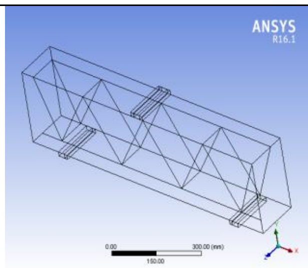
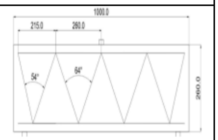
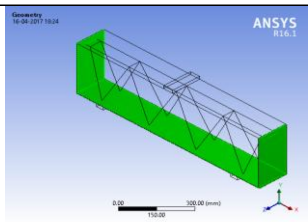
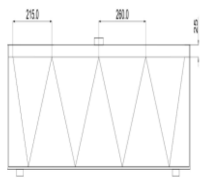
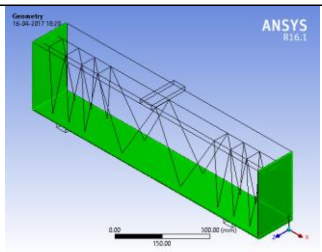
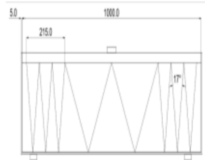
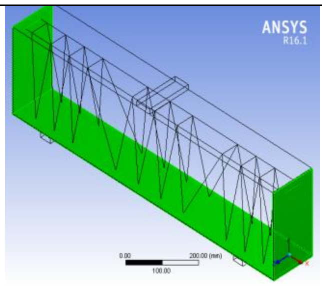
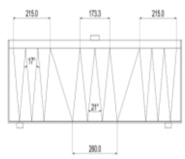
In this paper shear reinforcement/arrangement of shear reinforcement/type of shear reinforcement is varied for each model. Basic details like cross sectional dimensions, diameter of bars used are kept constant for all models in totals of five models are modeled and analysed in ANSYS software. One of which is modeled as conventional beam and other four with different types of shear reinforcements.

The beam is modeled with a cross section of 150×260mm with 1m span and using main reinforcement with 10mm bar diameter and shear reinforcement with 6mm diameter. Shear reinforcement used in the conventional beam is the typical vertical stirrups.

Three bearing plates one on the upper face and two on the bottom face are provided. Plate on the upper face is the loading plate and plates on the bottom plates are supporting plates. After applying all properties, beam is analysed for maximum load carrying capacity and maximum deformation. A Load v/s Deformation curve is plotted so that to compare it with that for curves of other models. ANSYS model for the specimen is as shown in table 1.

Rest of the model consists of shear reinforcement similar to vertical stirrup but with an inclination. The inclined stirrups are arranged in such a way that it forms a truss pattern.

Table -1: ANSYS Model

Sl No.	MODEL NAME	ANSYS MODEL	BEAM SKELTON
1	Beam with conventional vertical stirrups		
2	Beam with inclined stirrups		
3	HSTCB without confinement		
4	HSTCB with shear confinement		
5	HSTCB with shear and flexural confinement		

3. RESULTS AND DISCUSSIONS

The Hybrid Steel Trussed Concrete Beam specimens were analysed using finite element analysis in ANSYS workbench. The results of the finite element analysis are included in this chapter. The deformations values, stress-strain relations and the ultimate load carrying capacity of each specimen are included in the results. Their corresponding graphs and figures are given below. The comparison of the ultimate load carrying capacity of various arrangements is discussed below.

3.1 Deformations of Specimens

After analyzing the specimens with a load range of 100-300 kN acting at the centre of the beam under three point loading, the deformations occurred to the beam arrangements were analyzed. The deformations at each and every load were obtained from ANSYS. Non-linear analysis was carried out for all the specimens.

Specimen with Conventional Vertical Stirrup

This was the first specimen analyzed using ANSYS Workbench. The load bearing plate is placed at the centre, on the top of the specimen and load is applied over it. A load range of 100-300 kN is applied at the centre of the beam element. The deformation values after the analysis and the deformed shape of the specimen is shown in the fig 2. The graph plotted between load and deformations were shown in chart 1. From the graph, the ultimate load carrying capacity of the specimen was found out to be 124kN.

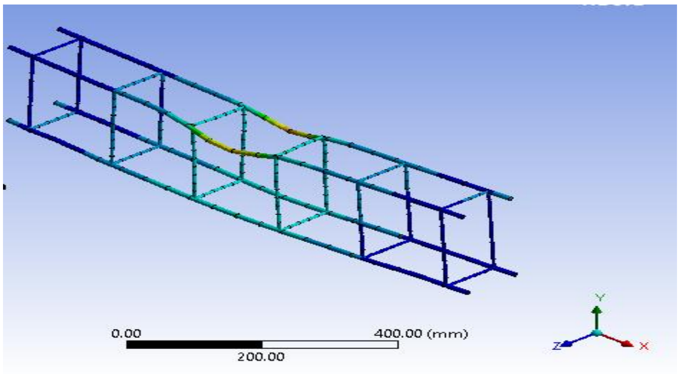


Fig -2: Deformation of specimen with Conventional Vertical Stirrup

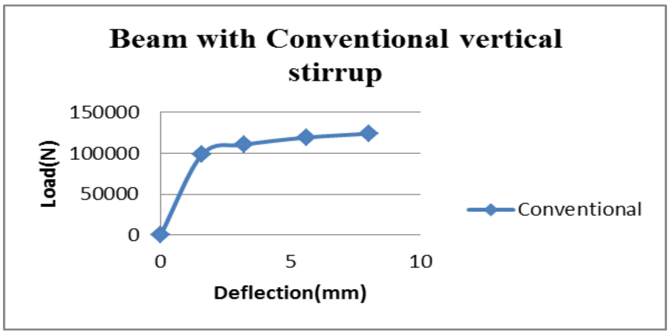


Chart-1: Load – Deformation curve for specimen with Conventional Vertical Stirrup

Specimen with Inclined Stirrup

This was the second specimen analyzed using ANSYS Workbench. The load bearing plate is placed at the centre, on the top of the specimen and load is applied over it. A load range of 100-300kN is applied at the centre of the beam element. The deformation values after the analysis and the deformed shape of the specimen is shown in the fig 3.

The graph plotted between load and deformations were shown in chart 2. From the graph, the ultimate load carrying capacity of the specimen was found out to be 159kN.

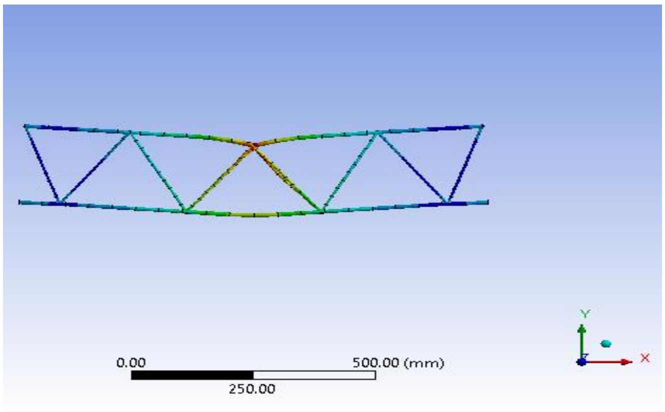


Fig- 3: Deformation of specimen with Inclined Stirrup

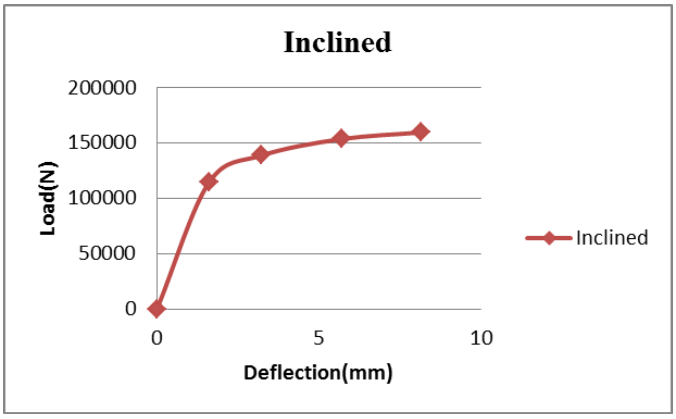


Chart-2: Load – Deformation curve for specimen with Inclined Stirrup

Specimen with HSTCB without Confinement

This was the third specimen analyzed using ANSYS Workbench. The load bearing plate is placed at the centre, on the top of the specimen and load is applied over it. A load range of 100-300 kN is applied at the centre of the beam element. The deformation values after the analysis and the deformed shape of the specimen is shown in the fig 4.

The graph plotted between load and deformations were shown in chart 3. From the graph, the ultimate load carrying capacity of the specimen was found out to be 216 kN

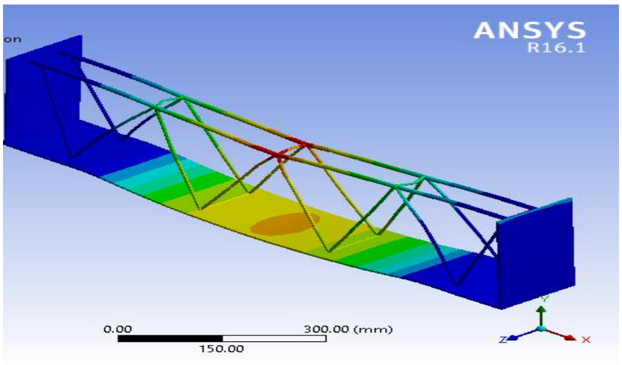


Fig-4: Deformation of Specimen with HSTCB without Confinement

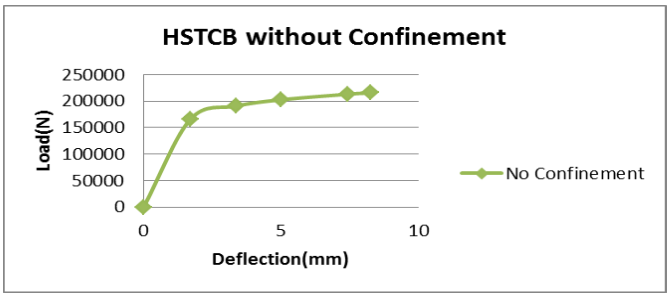


Chart-3: Load – Deformation curve for Specimen with HSTCB without Confinement

Specimen with HSTCB with Shear Confinement

This was the fourth specimen analyzed using ANSYS Workbench. The load bearing plate is placed at the centre, on the top of the specimen and load is applied over it. A load range of 100-300 kN is applied at the centre of the beam element. The deformation values after the analysis and the deformed shape of the specimen is shown in the fig 5. The graph plotted between load and deformations were shown in chart 4. From the graph, the ultimate load carrying capacity of the specimen was found out to be 227 kN

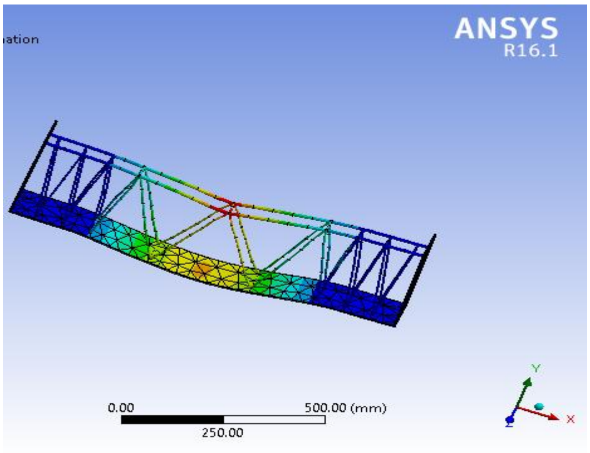


Fig-5: Deformation of Specimen with HSTCB with Shear Confinement

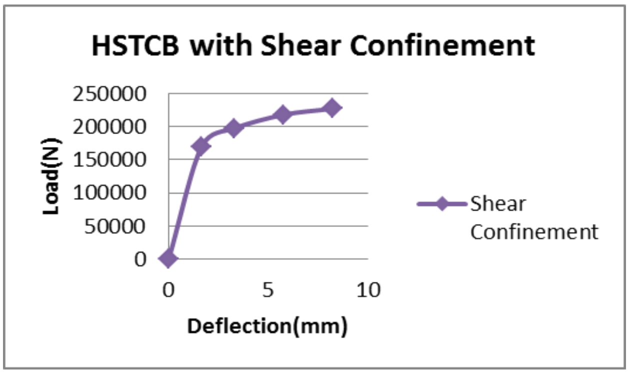


Chart-4: Load – Deformation curve for Specimen with HSTCB with Shear Confinement

Specimen with HSTCB with Shear and Flexural Confinement

This was the fifth specimen analyzed using ANSYS Workbench. The load bearing plate is placed at the centre, on the top of the specimen and load is applied over it. A load range of 100-300 kN is applied at the centre of the beam element. The deformation values after the analysis and the deformed shape of the specimen is shown in the fig 6.

The graph plotted between load and deformations were shown in chart 5. From the graph, the ultimate load carrying capacity of the specimen was found out to be 226 kN

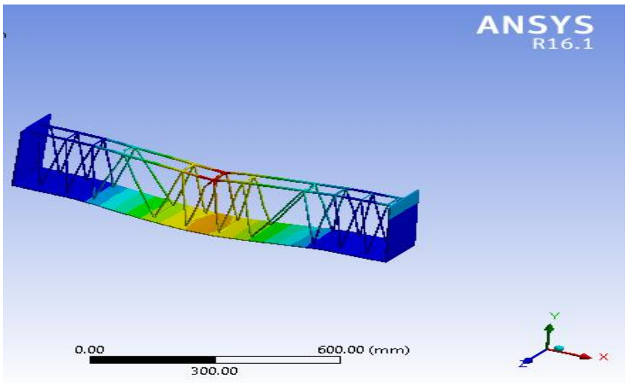


Fig-6: Deformation of Specimen with HSTCB with Shear and Flexural Confinement

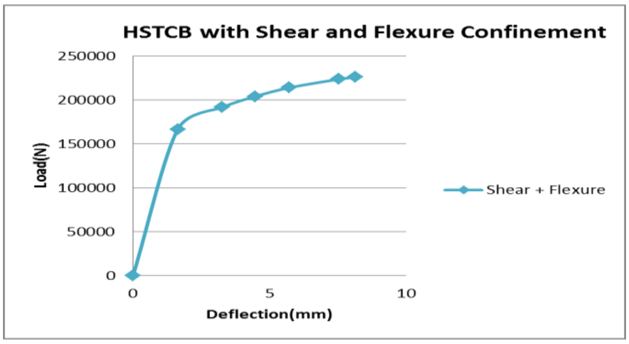


Chart-5: Load – Deformation curve for Specimen with HSTCB with Shear and Flexural Confinement

Table-2: Ultimate Load Carrying Capacity of Each Specimen

SPECIMEN NAME	ULTIMATE LOAD CARRYING CAPACITY(kN)
Conventional beam(with vertical stirrup)	124
Inclined(with inclined stirrup in a truss)	159
HSTCB without confinement(with same angle throughout the length)	216
HSTCB with shear confinement (congested or small angles at shear portions near support)	227
HSTCB with shear and flexural confinement (small angles at support and mid span)	226

After plotting the load v/s deformation graph for different models, all was compared with the conventional model and a comparison graph was plotted for all specimens as shown in chart 6.

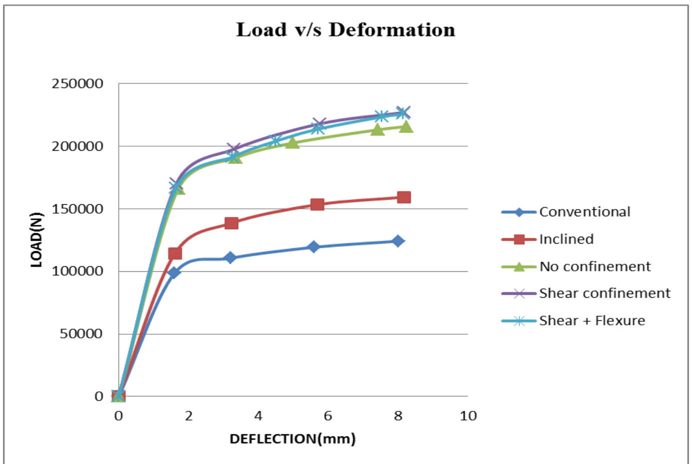


Chart-6: Comparison of Load – Deformation curve for all the Specimens

The finite element analysis results carried out in ANSYS Workbench of the hybrid steel trussed concrete beam specimens are discussed in this chapter. The ultimate load carrying capacity, equivalent stress, equivalent strain and deformation values are discussed here.

4. CONCLUSION

The finite element analysis of hybrid steel trussed concrete beam for five different specimen models were analyzed.

- The load carrying capacity of the model with inclined stirrups is 28% more compared with that of a conventional beam
- The load carrying capacity of HSTCB without confinement is 74% more compared with that of a conventional beam
- The load carrying capacity of HSTCB with shear confinement is 83% more compared with that of a conventional beam
- The load carrying capacity of HSTCB with shear confinement and flexural confinement is 82% more compared with that of a conventional beam

So it can be concluded that by replacing a conventional beam with a truss arrangement or by providing inclination to the vertical stirrup the ultimate load carrying capacity of the beam gets increased. Scopes for the future work related to this topic are the following:

- More complicated type of truss geometries can be tried. The through type of composite truss can be attempted with a few modifications in analysis and design procedure.
- Study based on varying the shape of truss in the concrete.
- Study based on altering the confinement.

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