Hollow Core FRP- Concrete- Steel Column with Inner Square Steel Tube Subjected to Eccentric Loading

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***Abstract*— Hollow Core FRP- Concrete- Steel (HCFCS) columns are an advancement over hollow core columns, in which concrete is confined between an outer FRP tube and an inner steel tube. They consists of different types of materials and hence, combines and make advantage of all these materials. Steel tube in these columns itself act as a formwork and also as longitudinal and shear reinforcement. The concrete sandwiched between FRP tube at outside and steel tube inside is effectively confined. Outer FRP and inner steel tube offer continuous confinement to the concrete core, thus improving the strength and ductility of column. They are mainly used as bridge columns in seismic areas. This study is concerned with the behavior of Hollow Core FRP- Concrete- Steel columns with inner square steel tube subjected to eccentric loading. Finite Element study was done in Ansys Workbench. Various parameters were examined including the thickness of steel tube, type of fiber and the shape of column section. HCFCS column with inner square steel tube has shown a larger ultimate load compared to the column with inner circular steel tube.**

Keywords—Hollow core, FRP, Concrete, Steel

I. INTRODUCTION

Different types of column construction are followed and practiced from years. Composite columns were introduced years ago, that consists of two or more types of materials, usually concrete and steel. Concrete Filled Steel Tubular (CFST) columns consisted of steel hollow sections filled with plain or reinforced concrete. Then, Hollow Core columns were introduced with the idea of reducing the self-weight of the structure. Double skin tubular column was such a type, with the concrete confined within two concentric steel tubes. Despite the various advantages, one of the limitation with such a construction was the corrosive nature of steel tubes, which affect the performance of the column adversely. In this scenario, an advancement over such columns is presented by Hollow Core FRP- Concrete- Steel (HCFCS) Columns. HCFCS columns incorporates FRP tube and steel tube respectively at outside and inside, with concrete filled in between them. They are mainly used as tall piers in bridge construction. Being a hollow structural member, they have low self weight, which make constructions easy and reduce freight costs when used in precast constructions. They make use of advantages of various kinds of materials: concrete, steel and FRP. The outer FRP tube, being corrosion resistant, eliminate the disadvantage of double skin tubular members. The concrete is effectively confined by FRP and steel tube, which by itself function as a formwork for construction.

Several research works were conducted to evaluate the behaviour of HCFCS columns subjected to axial compression, flexural, seismic and impact loads. Under axial compression, failure of HCFCS column was due to rupture of FRP tube [1]. The concrete in HCFCS column was efficiently constricted by both steel and FRP tube and the behaviour of confined concrete was same as that of concrete in solid columns confined only by FRP. Failure of all tested specimens occurred because of the rupture of FRP tubes, generally at the position where deformation of steel tube was found [2]. Steel tube at the interior of the column failed by elephant foot buckling.

The concrete in an HCFCS column has shown highly ductile compressive behaviour due to effective confinement. The ultimate axial stress and strain of concrete was found to increase with larger diameter of inner steel tube [3].

The performance of HCFCS column with expansive consolidating concrete and self-consolidating concrete was studied. The number of FRP layers were found to influence the prestressing. It is also affected by the diameter of steel tube [5]. A reduction of prestress in concrete was observed with the increase in diameter of the steel tube.

Seismic performance of HCFCS column was studied by many researchers. Bending strength was found to increase with increasing axial load, concrete compressive strength and the number of FRP layers, while with the increase in concrete wall thickness and the diameter-to-thickness ratio of the steel tube, it reduced [7]. A non- linear flexural analysis of column was also done and the bending strength was calculated following analytical procedure. Comparison of the experimental and analytical results was done and found overestimated strength results in analytical procedure.

Very low lateral displacement was observed for columns with larger steel tube. When concrete is filled inside the hollow steel tube, HCFCS column has shown significant increase in the lateral deformation capacity. In addition to that, when larger steel tube is used, higher lateral deformation is observed than that seen in a column with smaller steel tube [10].

Improved flexural capacity was observed for HCFCS column [12]. The flexural strength of column was found to increase with the confinement, strength of concrete and the applied load. Outward local buckling of the steel tube was delayed because of the presence of concrete filled between FRP and steel tube [1, 12].

Under lateral impact loading also, the HCFCS column behave in a ductile manner [13, 14]. With increase in the

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number of FRP layers, the lateral deformation of column decreased.

II. VALIDATION

A. Description of experimental model

The results of experiment conducted by researchers [5] on hollow core FCS columns under axial loading condition was validated. 20 Hollow core FCS column with both inner and outer circular cross section were cast and applied with axial compressive load. The outer diameter and inner diameter of the column were 150.334 mm and 52 mm respectively. The height of the column was 300 mm. FRP tube of 0.334 mm thickness and steel tube of 4 mm thickness were used. The cross sectional details of the specimen (Qui Cao et.al, 2018) is shown in Fig. 3.

B. Finite element model

The validation of hollow core column is done using ANSYS Workbench 16.1. The cross sectional dimensions as obtained from the study of Cao et.al is used in the model. The column specimen was modelled with the help of design modeller in ANSYS Workbench. Young's modulus and Poisson's ratio of steel tube were 200 GPa and 0.3 and that of concrete were 28284.27 MPa and 0.15 respectively. Yield and ultimate strength is 394 MPa and 565.2 MPa for steel. Concrete ultimate strength is given as 26 MPa. Carbon FRP tube is used in the study having an elastic modulus of 224 GPa and Poisson's ratio of 0.33. The yield strength and ultimate tensile strength of the same were 372 MPa and 3400 MPa respectively. A resin was used having Youngs modulus of 2620 MPa and ultimate tensile strength equal to 20 MPa.

The concrete wall and steel tube were modelled using SOLID 186 element. It is a higher order 3D twenty-node solid element that exhibit quadratic displacement behaviour, with three degree of freedom per each node: translations in the x, y and z directions. Since the thickness is less, FRP tube and epoxy are modelled by SHELL 181 element. It is well suited for analyzing thin elements. Shell 181 is a four-node element with six degree of freedom at each node: translations in x, y and z directions and rotations about the x, y and z- axes. The interface between concrete shell and FRP tube, and between concrete and steel tube were provided as Bonded. To simulate the experimental support condition of cantilever column, displacement and rotation in all directions were prevented at the bottom face of the column. Load is applied as displacement at the top face of the model. The ultimate load value as obtained from the numerical study was compared with the experimental results of researchers [5]. Comparison of the results is given in Table 1.

TABLE I. COMPARISON OF RESULTS

	Ultimate load (kN)
Experimental	1177
FE Analysis	1148.2
% Error	2.45

The ultimate load of the column in experiment and that obtained by numerical analysis differ by a small value of 2.45%. Thus, the model created in the study is validated using the experimental study of Cao et.al, 2018 [5].

III. PARAMETRIC STUDY

A. HCFCS column with inner square steel tube

To study the behaviour of column with square steel tube, a new HCFCS column with inner square steel tube is modelled. The steel tube dimension is selected so that the area of cross section is same as that in circular section. So, in that case, the calculated value of steel tube dimension is 53.2 mm and thickness of 3.5 mm. Under axial loading, the column has shown an increase of 5.09% in the ultimate load compared to column with circular steel tube.

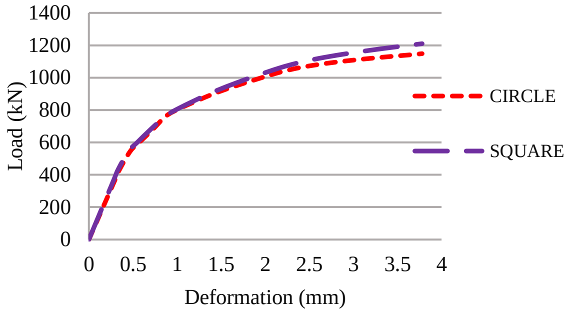

Fig. 1. Load- Deformation curve

Thus, HCFCS columns with inner square steel tube shows a better performance over that with circular steel tube in terms of its ultimate load. Moreover, inner square steel tube is helpful in connecting column to the corresponding superstructures like girder and footing. Thus, square steel tube is a better option.

B. Eccentric loading

For the parametric study, a new HCFCS column with inner square steel tube is modelled with steel tube of size 60 mm. First, the column is loaded axially and analysed. Then, eccentric loading is applied in x- direction. Load is applied as displacement on top of the column at different eccentricities in x-direction. Minimum possible theoretical eccentricity is calculated as 20 mm. The model is analysed for eccentricity of 20 mm, 25 mm and 30 mm. When load is applied at some eccentricity with respect to an axis, it is found that the column fails at a smaller load as compared to the load value at axial loading condition. When loaded at an eccentricity, the column is subjected to a uniaxial moment in addition to the axial load. This may lead to a reduced load bearing capacity for columns. Also, the ultimate load capacity goes on decreasing with increase in eccentricity value.

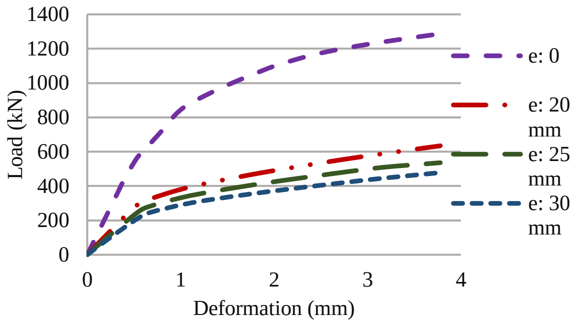

Fig. 2. Load- Deformation curve for different eccentricity

C. Effect of steel tube B/t_s ratio

Thickness (t_s) of steel tube is varied while keeping the width (B) same. Here, width- to- thickness ratio is taken as the parameter for study. So, the model is analysed under different B/t_s ratio of 10, 12, 15 and 20 corresponding to thickness of 6

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mm, 5 mm, 4mm and 3 mm at an eccentricity of 20 mm. Width of steel tube was 60 mm. There is an increase in ultimate load

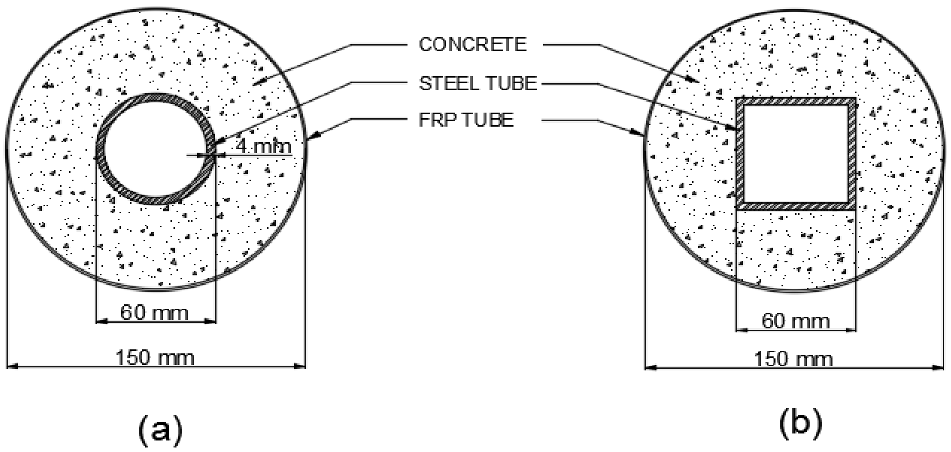

Fig. 3. Cross section details of HCFCS column

with the increment in thickness of steel tube. As the width to thickness ratio (B/t_s) of steel tube is changed from 10 to 20, the ultimate load decreased by 16.41% from 698.2 to 583.6 kN. With the increase in thickness, more area of steel tube is available to take the load and hence, more load carrying capacity. The loaded side of the steel tube is stressed maximum with the top and bottom portion of steel tube showing smaller value of stress.

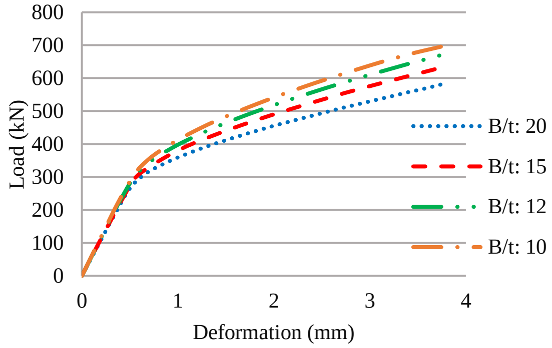

Fig. 4. Load- Deformation curve for different B/t values

D. *Effect of various type of fibers*

The performance of column with FRP tubes of various kinds of fibers were analysed. The validated model has an FRP thickness of 0.334 mm. Thus, columns were modelled with FRP tube of same thickness, made of two different types of fibers: Aramid and Glass fibers. Type of fiber significantly affect the load carrying power of HCFCS columns. Aramid FRP has a tensile strength of 2663 MPa and poisson ratio of 0.25. Modulus of elasticity is 125.7 GPa. For the glass fiber, modulus of elasticity is 46 GPa, poisson's ratio is 0.18 and the ultimate tensile strength is taken as 1200 MPa.

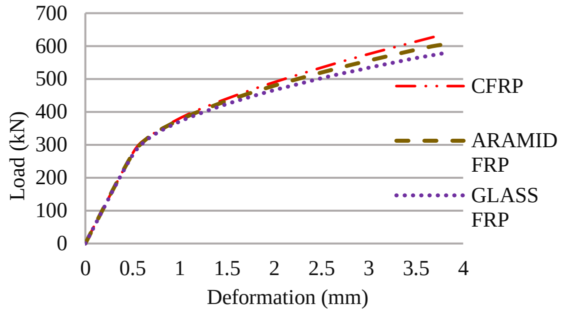

Fig. 5. Load- Deformation curve for different fibers

The analysis has shown a large load carrying capacity for column with aramid fiber compared to that with glass fiber, while both being lower than column with carbon fiber. Compared to column with Glass fiber tube, ultimate load of column with Aramid fiber has an increased value of 4.53%. This significant increase in load value is due to better material properties of aramid fiber compared to glass fiber. It is very much evident from the tensile strength and elastic modulus value of different fibers.

E. *Cross sectional shape*

To study how the outer shape of the column affect the behaviour of HCFCS column, two models were created having rectangular and elliptical cross sections. The dimensions in each models were selected so that the cross sectional area of each three materials remain the same as that of the validated model. Thus, for square column, outer dimension is 132.9 mm, with all other dimensions remaining the same. For the elliptical section, the major axis and minor axis were 90 m and 62.5 mm respectively. The square column has gained more load carrying capacity. i.e., 8.24% more than circular column. The ultimate load and the load- deformation curve were comparable for both circle and elliptical column section, with the former showing 1.33% higher value of ultimate load.

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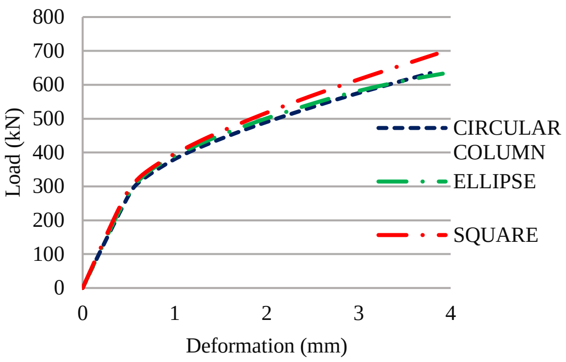

Fig. 6. Load- Deformation curve for different shapes of column

IV. CONCLUSION

This study presents FE model and parametric studies for HCFCS column under eccentric loading. A numerical model is validated against the experimental results of Cao et al, 2018 and the below conclusions can be made from the study:

- HCFCS column with inner square steel tube has much higher load carrying capacity as compared to that with inner circular steel tube.
- HCFCS column shows excellent performance in terms of load carrying capacity and deformation under eccentric loading.
- Different fibers have significant effect on the performance of column. The load carrying capacity and deformation ability of column increases with the thickness of steel tube.
- A square HCFCS column with inner square steel tube and made of Carbon FRP tube show better performance as a column.

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