Study on Prismatic and Non Prismatic Concrete Filled Steel Tube Columns encased with Engineered Cementitious Composite

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Abstract - *Concrete filled steel tube (CFST) columns are very popular these days. To increase durability and fire resistance of concrete filled steel tube (CFST) columns, engineered cementitious composites (ECC) encased CFST columns are adopted. This study examines the structural performance of CFST columns, encased with ECC, under various loading conditions. In the first column model, the outer core of the model is kept prismatic and the inner core is kept non prismatic. In the second model, the outer core is kept non prismatic and the inner core is kept prismatic. In the third column model, a prismatic column is adopted. Non-prismatic columns are important structural members in many engineering applications. Reasons for their increasing use are material savings, aesthetics and functional requirements. Non linear finite element models were developed using ANSYS to assess structural performance of these columns. Weight of columns was kept the same and configurations alone were changed. Columns were analyzed under axial, eccentric and lateral loading conditions. Failure pattern, buckling capacity and strength of specimens were investigated to identify the best model.*

Key Words: Prismatic, Non Prismatic, ECC, CFST, Finite element analysis, Axial loading, Eccentric loading, Lateral loading.

1. INTRODUCTION

Column is a vertical structural member which transfers load through compression. Columns are constructed using materials such as stone, masonry, concrete, timber or steel, which have good compressive strength. Concrete filled steel tube (CFST) columns have gained increasing attention over the last decades. Large number of studies have already been carried out on the performance of CFST columns under static and dynamic loading. It has been found that CFST columns have better structural performance than reinforced concrete (RC) columns in terms of ductility and load carrying capacity. Despite its structural advantages, the outer steel tube of CFST is susceptible to corrosion, especially under a chloride environment. It has been found that corrosion caused significant deterioration in compressive and flexural strength of CFST columns. Moreover, fire resistance of CFST columns is also a concern, as the outer steel tube nearly loses its strength at 600 °C. It was also found that post-fire load carrying capacities of CFST columns can be 50% lower than those at ambient temperature without fire exposure.

In order to improve durability and fire resistance of CFST composite columns, engineered cementitious composite (ECC) encased CFST columns are adopted. ECC is a fiber reinforced cementitious material which features high tensile strain and superior crack control capacity. Tensile strain capacity for ECC is in the range of 2–7%, which is several hundred times than that of conventional concrete. After reaching such strain level, crack width can still be controlled below 60μm. ECC has similar compressive strength as that of normal concrete, but has higher ductility as well as larger strain at reaching its compressive strength. ECC's crack control and self-healing ability leads to superior durability under various mechanical and environmental loading conditions such as freeze-thaw and chloride exposure. It has also been observed that mechanical performance of fire-deteriorated ECC material is better than that of conventional concrete and no explosive spalling occurred in ECC specimens, since PVA fiber could introduce additional channels to escape vaporized moisture in ECC without creating high internal pressure in the material. Due to these unique features, ECC material has been successfully applied to structural members such as beams, columns, slabs and beam-column connections.

Tapered members are generally not considered by designers as structural analysis is rather cumbersome, design criteria are practically nonexistent, and construction is tedious and expensive. There are many areas where tapered members could be used. Non prismatic sections minimize volume of column material. Non-prismatic columns are important structural members in many engineering applications. Some of the reasons for their increasing use are; material savings, aesthetics and functional requirements.

In this study, structural performance of prismatic and non prismatic columns is done. Finite element models of columns were developed in ANSYS 16.1 and were analyzed under axial, eccentric and lateral loading conditions.

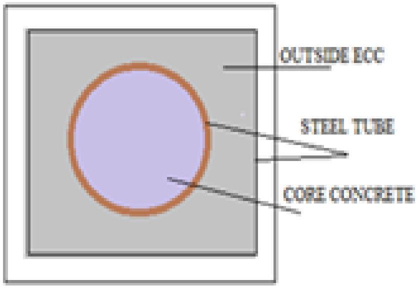


Fig 1 :Typical section of ECC encased CFST Prismatic column

2. FINITE ELEMENT MODELLING

2.1 General

To investigate structural behaviour of prismatic and non prismatic columns, finite element models were developed using ANSYS 16.1. Solid186 elements were used to model square and circular steel tubes. SOLID186 is a higher order 3D 20-node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having six degrees of freedom per node; translations and rotations in x, y and z-directions.

2.2 Scope

The work is limited to modelling and analysis of Prismatic and Non Prismatic columns by using ANSYS.. The investigations are carried out to study the axial, shear and moment capacity using Non linear finite element approach. Investigation of various Prismatic and Non Prismatic condition is performed. The study includes the behaviour of five models in which the outer core is made as prismatic and inner core is made as Non Prismatic and outer core is made as Non prismatic and inner core is made as prismatic. The inner CFST core and the outer core is made as non prismatic by changing the shape configuration (L shape and V shape).These models are analysed by fixing the weight of the column to be the same. The Axial Loading performance is carried out to evaluate buckling load, axial shortening, stiffness and eccentricity loading is carried out for different eccentric ratios and its failure capacity is also determined. Lateral loading performance is also carried out to investigate the seismic factors like target displacement, lateral stiffness, and lateral strength.

2.3 Geometry

Prismatic and non prismatic columns were considered for analysis. Prismatic column consisted of concrete filled steel tube of diameter 200mm encased with engineered cementitious composite and outer square steel tube of 400mm x 400mm. First two models of non prismatic column (outer core prismatic and inner core non prismatic) consisted of outer square steel tube of 400mm x 400mm embedded with engineered cementitious composite composed of concrete filled steel tube (CFST with V and L shape) of top diameter 177.6mm and bottom diameter 222mm. Second two models of non prismatic column (outer core non prismatic and inner core prismatic); consisted of top square steel tube of 356mm x 356mm and bottom square steel tube is 445mm x 445mm (steel tube V and L shape) embedded in engineered cementitious composite composed of concrete filled steel tube of diameter 178mm. Length of all the columns were 3000 mm and thickness of steel tube was 6mm. In all cases, weight was kept constant throughout the analysis. Taper ratio of non prismatic columns is taken as 1.25. Geometry of prismatic and non prismatic columns in finite element modelling is shown in Figure 2. Material properties of steel tube, ECC, and concrete are shown in Table 1. Multi linear isotropic hardening is used to reproduce plastic behavior of materials.

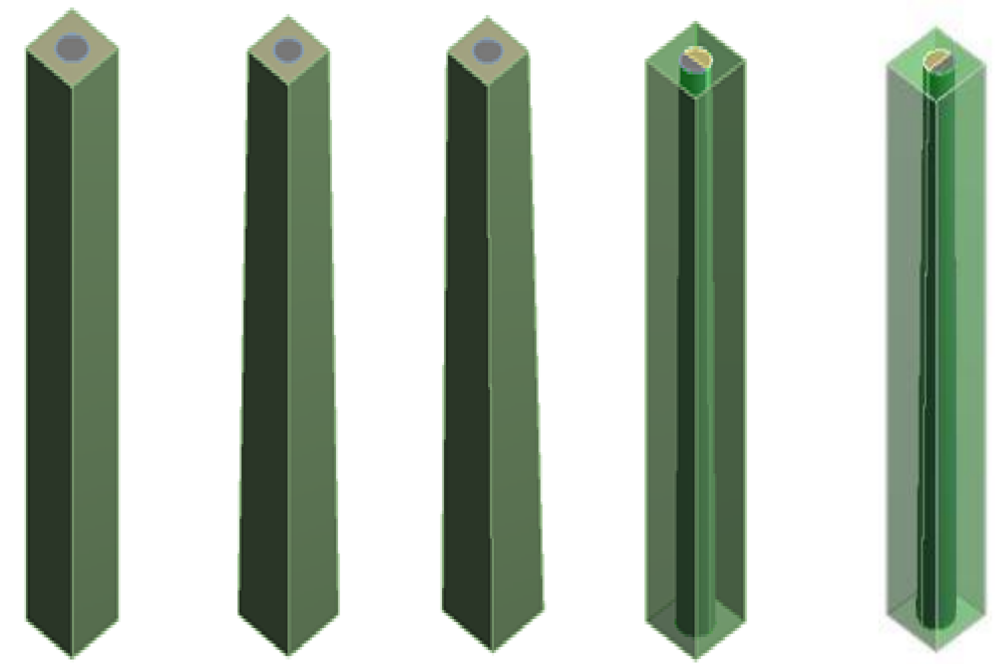


Fig -2: Geometry of Prismatic and Non Prismatic columns (Outer core V shape, Outer core L shape, Inner core V shape, Inner core L shape)

Table -1: Material Properties of Steel Tube, ECC and Concrete

Material Properties	**Steel Tube**	**ECC**	**Concrete**
Young's Modulus (MPa)	2.06e+05	27000	30360
Poisson's ratio	0.3	0.15	0.2
Compressive strength (MPa)	-	53	41.2
Yield Strength(MPa)	367	-	-

2.4 Meshing

Meshing divides the whole component into a finite number of small elements as per requirement. Size of the element must be as small as possible to achieve accuracy. In this analysis, fine mesh was adopted to achieve maximum accuracy in results. Solid models are converted into a finite element model after meshing.

2.5 Loading and Boundary conditions

To simulate real conditions, columns were modelled with pinned end condition. Rotation was allowed along the X and Z axis and load was applied only in one direction. Behaviour of columns under axial, eccentric and lateral loading was studied by ANSYS. Eccentricity was provided in X and Z directions with 25% and 50% eccentricity ratios. A 3D finite element model was formed for each column and comparison was made for prismatic and non prismatic columns. Boundary conditions of Prismatic and Non Prismatic columns are shown in Figure 3.

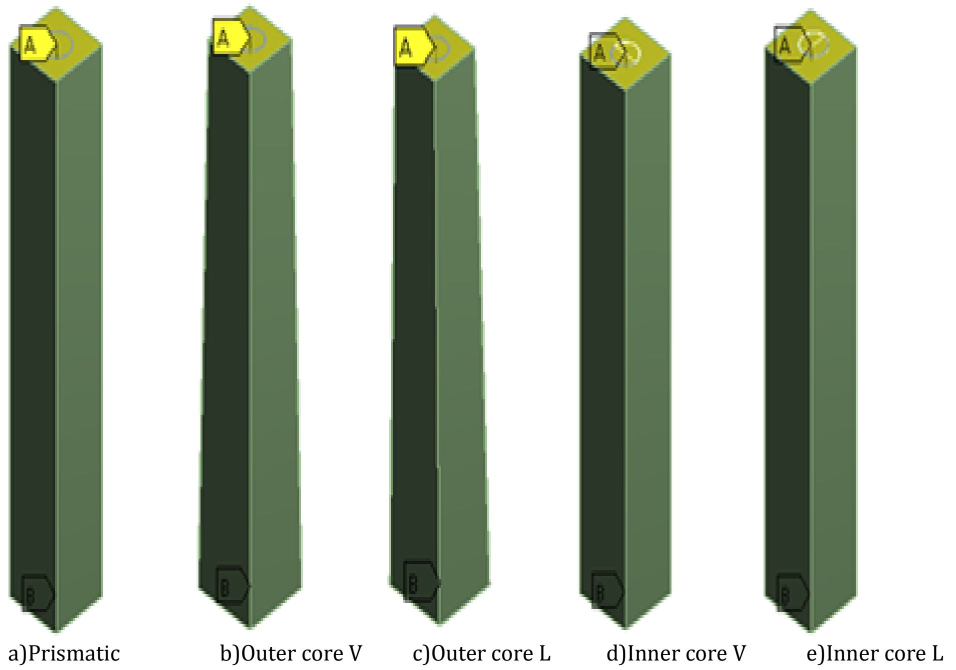


Fig -3: Boundary conditions of Prismatic and Non Prismatic columns

3. ANALYTICAL RESULTS AND DISCUSSIONS

3.1 Axial Loading

Columns are subjected to load at the centroid of column cross section. Figure 4 shows comparison of Load-Displacement curve of prismatic and non prismatic columns. Table 2 shows values of ultimate load and corresponding deformations of prismatic and four models of non prismatic columns. Figure 5 shows total deformation.

Table -2: Comparison of axial ultimate load and deformations of prismatic and non prismatic columns

Column Type	Lateral Deformation (mm)	Ultimate load (kN)
Prismatic	13.496	11326
Outer core V	17.754	9848.6
Outer core L	17.776	9842.9
Inner core V	13.001	10968
Inner core L	14.401	10772

From results, it is clear that the prismatic column performs more effectively than non prismatic columns. Displacement controlled force is given in finite element analysis. At the initial stage, all columns will be in an elastic state. When the ultimate load is reached, the column fails.

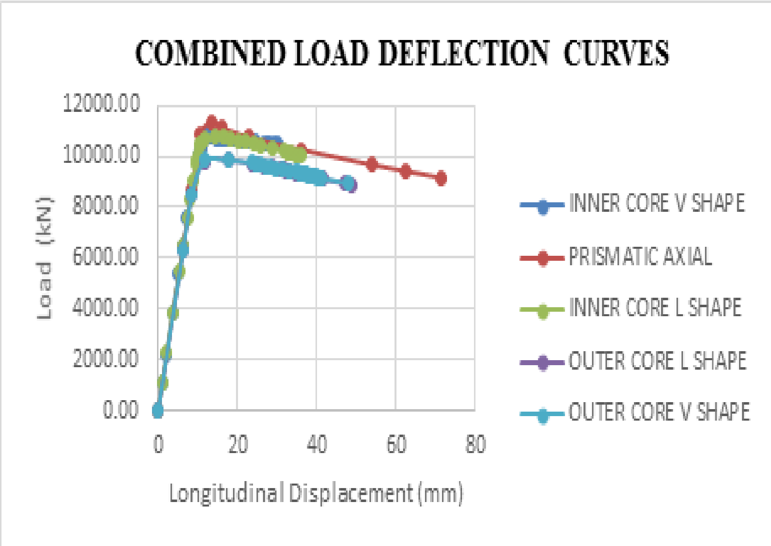
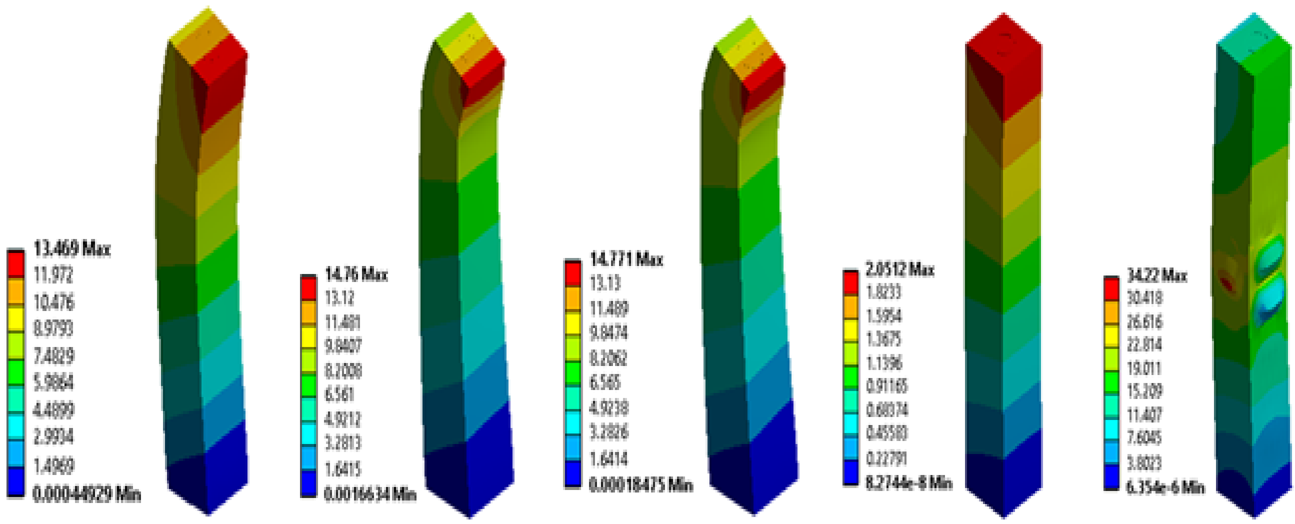


Chart -1: Comparison of Load – Displacement curves



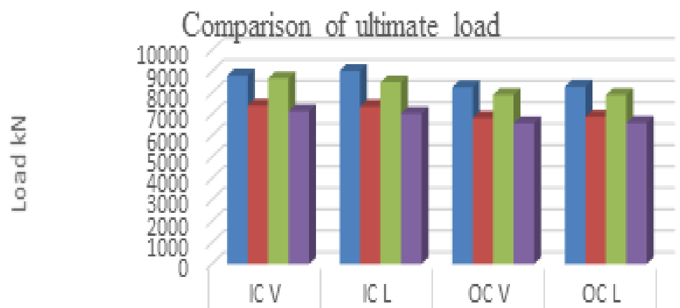
a)Prismatic b)Outer core V c)Outer core L d) Inner core V e) Inner core L

Fig -4: Total deformation of Prismatic and Non Prismatic column

From this it is clear that the mode of bending is resulting from top of column and inner core gets failed first.

3.2 Eccentric Loading

Eccentric load is applied on all specimens. Columns were analyzed for 25% and 50% eccentricity in X and Z directions. Figure 6 shows comparison of loads for eccentricity 25% and 50% in X and Z directions for non prismatic columns. Figure 7 shows the load displacement curves for eccentricity 25% and 50% in X and Z directions for the Prismatic column.



	IC V	IC L	OC V	OC L
Z DIRECTION 25%	8814.1	9033.8	8271.2	8302
Z DIRECTION 50%	7404.6	7367.6	6832.2	6877.6
X DIRECTION 25%	8685.1	8496.7	7914	7905.4
X DIRECTION 50%	7146	7036.1	6581	6603.3

Chart -2: Comparison of ultimate loads for eccentricity 25% and 50% in X and Z directions for Non Prismatic column

It was seen that ultimate load decreases with increased load eccentricity, which owes to additional bending moment induced due to higher eccentricity. From the result it was concluded that specimens performed better at 25% eccentricity in Z direction.

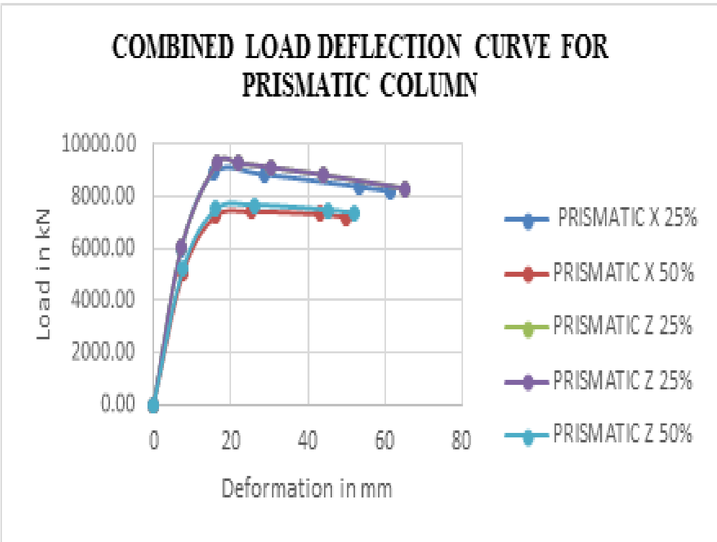


Chart -3: Load Deflection curve of Prismatic columns under different eccentric ratios

3.3 Lateral Loading

Lateral load was applied at the top of columns, in a deformation controlled mode, incremented from zero up to column failure. Lateral loading is very important at zones of seismic risk. Table 3 shows comparison of ultimate values of load deflection curves and Figure 8 shows Load Deflection curves..

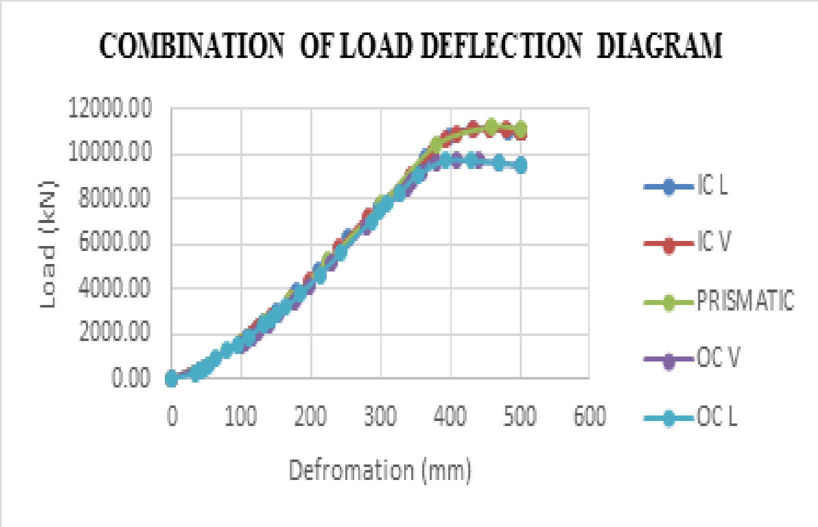


Chart -4: Comparison of Load Deflection curves for the specimens

Table -3: Comparison of ultimate lateral load and deflection values

Column Type	*Lateral Deformation (mm)*	*Ultimate load (kN)*
Prismatic	458.93	11212
Outer core V	409.43	9747.8
Outer core L	391.95	9710.9
Inner core V	432.79	11133
Inner core L	431.42	11147

4. CONCLUSIONS

In this study, a comparison of prismatic and non prismatic ECC encased CFST columns were done and following conclusions were arrived at:

1. All the ECC encased prismatic and non prismatic CFST columns failed in ductile mode.
2. Axial loading capacity of prismatic columns is higher than that of non prismatic columns.
3. Ultimate load for axial loading of non prismatic column Outer core V is 13.04%, Outer core L is 15.06%, Inner core V is 3.26% and Inner core L is 4.89% lesser than that of prismatic columns.
4. Ultimate load on columns decreased with increased eccentricity ratio due to additional bending moment induced.
5. Prismatic column showed better performance in lateral loading. Among the non prismatic columns, the Inner core L shape showed better resistance to lateral loading.
6. Ultimate load for lateral loading of non prismatic columns Outer core V is 15.0%, Outer core L is 15.45%, Inner core V is 0.7% and Inner core L is 0.58% less than that of prismatic columns.

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