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Analytical Behaviuor of Concrete Filled Steel Tubular Columns under Axial Compression

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Abstract ***Steel-concrete composite columns are used extensively in high rise building and bridges, as a type of hybrid system. However this approach is a relatively new concept for construction industry. In concrete-filled steel tube (CFST) columns, the steel tube provides formwork for the concrete, the concrete prevents local buckling of the steel tube wall. The load carrying capacity and behavior in compression, bending and shear are all superior to reinforced concrete. An analytical investigation of behavior of Concrete Filled Steel Tubes column and a theoretical design procedure according to EN 1994-1-1 Euro Code-4 are presented. The investigation has been carried out for rectangular and circular CFST columns under axial compression. The analytical model is developed to predict the capacity of CFST accounting for interaction between steel and concrete. The results obtained by theoretical calculation is validated using ANSYS 11.0 Multi physics utility tool. The results are illustrated by load carrying capacity table and modes of failure.***

Keywords Concrete filled steel tube, ANSYS, Finite element analysis, Euro code 4, contact element, composite column etc.

1. Introduction

A composite column is a structural member that uses a combination of structural steel shapes, pipes or tubes with or without reinforcing steel bars and reinforced concrete to provide adequate load carrying capacity to sustain either axial compressive loads alone or a combination of axial loads and bending moments. The interactive and integral behavior of concrete and the structural steel elements makes the composite column a very cost effective and structural efficient member among the wide range of structural elements in building and bridge constructions.

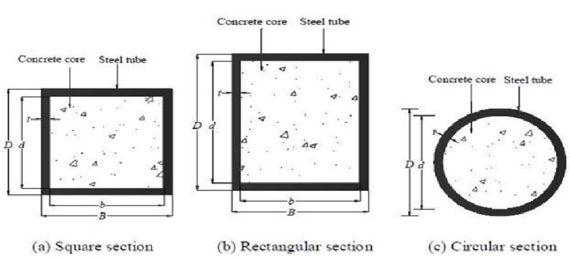

Figure 1. Cross-sections of concrete-filled steel tubular beam-columns.

A typical example of a composite column subjected to bending moments around two major perpendicular axes due to wind, earthquake, or unbalanced live loads and in combination with axial compressible loads could be found in bridge piers and at the corners of a three-dimensional building frame, as shown in Figure 1. We could also find those columns subjected to bending moments in combination with axial tensile loads, in which case it would be necessary to have a design method that includes the overall range of combinations of axial load and bending moments. CFST columns have several advantages over the conventional reinforced concrete and structural steel columns. Firstly, the concrete infill is confined by the steel tube. This confinement effect increases the strength and ductility of the concrete core in rectangular steel tubes. Secondly, the concrete infill delays local buckling of the steel tube. Thirdly, the combined capacity of the steel and concrete significantly increases the stiffness and ultimate strength of CFST columns which makes them very suitable for columns and other compressive members. Finally, the steel tube serves as longitudinal reinforcement and permanent formwork for the concrete core, which results in rapid construction and significant saving in materials. The steel tube can also support a considerable amount of construction and permanent loads prior to the pumping of wet concrete. The in-filled concrete effectively prevents the inward local buckling of the steel tube so that the steel tube walls can only buckle locally outward. The local buckling modes of hollow columns and CFST box columns are depicted in Figure 2.

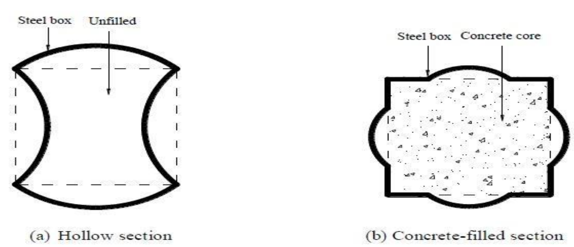

Figure 2 Local buckling modes of steel box columns.

2. Finite Element Modelling

2.1 Description of the model

Short Rectangular and circular plain Cement Concrete filled Steel tube has modeled. For the present study, the cross section of 70 mm x 30 mm for rectangular column and diameter of 60.3 mm for circular column is taken also length 300 mm has modeled with the thickness of steel tube as 2.90 mm and 3.20 mm. The grade of concrete has varied between 20 to 30 MPa and yield strength of steel is kept constant 310 MPa. The Poissonôs ratio for steel is taken as 0.3. The correct simulation of composite action between concrete and steel tube is the single most important factor guiding the behavior of the CFT column. To model this interaction, the normal contact between the two materials is provided using friction, with the inner

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surface of the stiffer steel tube serving as the rigid surface and the outer surface of the concrete core as the slave surface. The coefficient of friction between the two surfaces is chosen as 0.25. The boundary condition is that fixed at the bottom of the specimen and axially loaded at the top of the column specimen.

2.2 Elements Used to Model CFST in ANSYS

Solid65

This is used for the three-dimensional modeling of solids with or without reinforcing bars (rebarŝs). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. It is used model plain concrete infill.

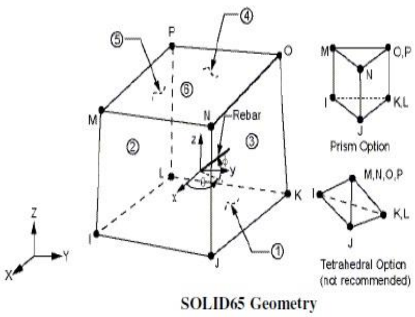

Figure 3. Geometry of Solid65

SHELL181

SHELL181 is suitable for analyzing thin to moderately-thick shell structures. It is a four-node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes. The element SHELL181 has used to model the steel tube. All specimens have modeled as 3D structural elements.

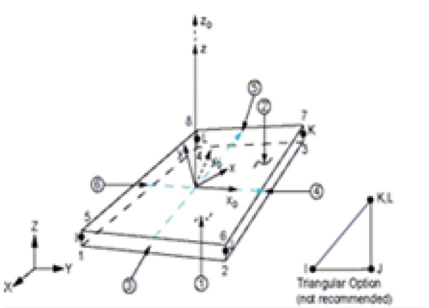

Figure 4. Geometry of Shell181.

2.3 Modeling of the Specimen

All modeling has conducted using ANSYS 11 finite element software. The modelling of columns have done in stages i.e. hollow specimens have modeled as 3D shell181 and concrete specimens have modeled as solid65 element with identical geometry. Contact elements are used for modeling interface between Concrete and Steel. When two separate surfaces touch each other such that they become mutually tangent, they are said to be in contact. The contact

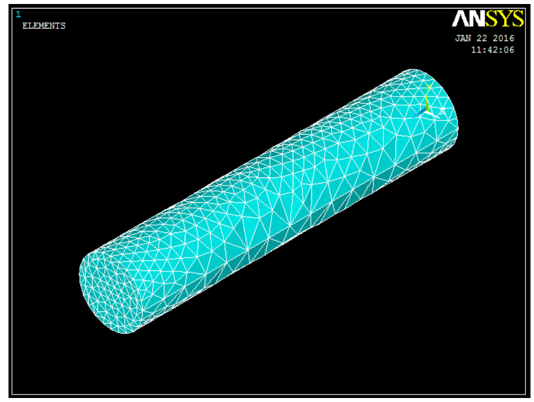

Figure 5. Model after Meshing of Circular CFST column

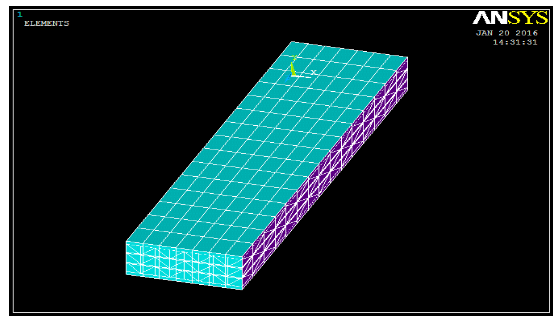

Figure 6. Model after Meshing of Rectangular CFST column

elements used are CONTA 173 and TARGE 170 elements.

The model is completed only after meshing them properly. Both steel tube and concrete infill are meshed of equal sizes to provide contact between them very easily.

The contact pairs are provided using contact pair option. The inner side of the steel tube is selected as target surface and contact surface is contact infill. The contact between concrete infill and steel tube should be such that it will always have bonded contact. Once the meshing done, contact between the concrete and steel tube needs to be established in order to ensure composite action. Surface to surface contact is made. This is done with the help of contact manager. It is shown below

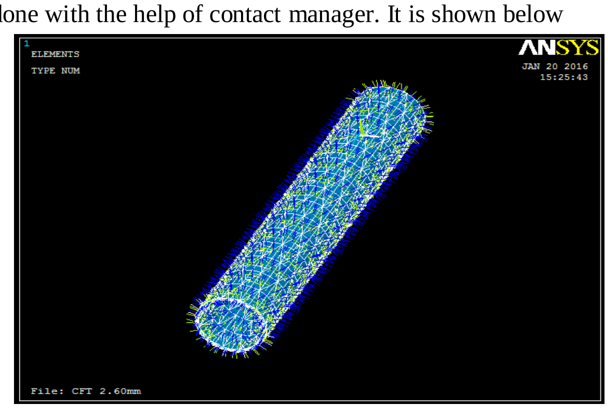

Figure 7. Model after applying contact elements

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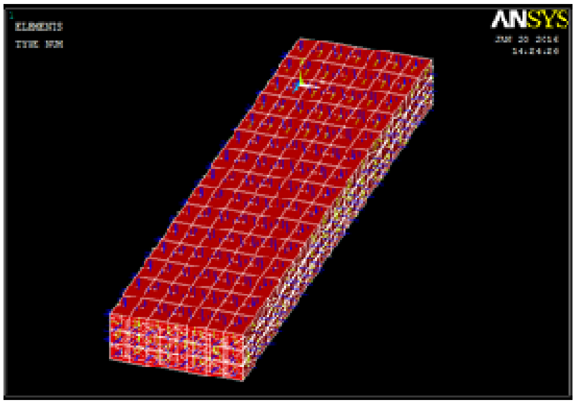

Figure 8. Model after applying contact elements

2.4 STEEL (CIRCULAR HOLLOW STEEL TUBES-CHS)

The steel columns used were hot-rolled CHS sections of diameters (60.3mm and 70 x 30 mm). The allowable D/t ratios of the steel hollow sections are less than the limits specified in EC-1994 and thus the premature buckling failure of CFT specimens is avoided.

Table 1. Material Property of Steel

Density	7850 kg/m^3
Poissonôs ratio	0.3
Elastic Modulus	2.01 x 10^5 N/mm^2
Yield strength	310 N/mm^2

2.5 CONCRETE

The concrete infill used for CFST are of M20, M25 and M30 grades. The proportions obtained by mix design of concrete by using IS 10262:1982.

Table 2. Material Property of Concrete

Density	2500 kg/m^3
Poissonôs ratio	0.18
Elastic Modulus	25000 N/mm^2
Compressive cube strength	20 N/mm^2

3. ANALYSIS

3.1 Finite Element Method

For many engineering problems analytical solutions are not suitable because of the complexity of the material properties, the boundary conditions and the structure itself. The basis of the finite element method is the representation of a body or a structure by an assemblage of subdivisions called finite elements.

3.2 ANSYS

ANSYS is a commercial FEM package having the capabilities ranging from a simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis. It is available in modules. Each module is applicable to specific problem. For example, Ansys/Civil is applicable to civil structural analysis. Similarly Ansys/Flotran is CFD software applicable to Fluid Flow. The advantage of Ansys compared to other competitive softwareôs is, its availability as bundled software of pre, post and a Processor.

3.3 Static analysis

Buckling is a critical phenomenon in structural failure. It is the failure of structures under compression load. Also buckling strength of structures depends on many parameters like supports, linear materials, composite or nonlinear material etc. Also buckling behavior is influenced by thermal loads and imperfections. Buckling proceeds either in stable or unstable or equilibrium state. Buckling and bending are similar in that they both involve bending moments. In bending these moments are substantially independent of the resulting deflections, whereas in buckling the moments and deflections are mutually inter-dependent - so moments, deflections and stresses are not proportional to loads.

3.4 Eigen Value Buckling Analysis

Eigen value buckling analysis predicts the theoretical buckling strength (the bifurcation point) of an ideal linear elastic structure. This method corresponds to the textbook approach to elastic buckling analysis: for instance, an Eigen value buckling analysis of a column will match the classical Euler solution. However, imperfections and nonlinearities prevent most real-world structures from achieving their theoretical elastic buckling strength. Thus, Eigen value buckling analysis often yields unconservative results, and should generally not be used in actual day-to-day engineering analyses.

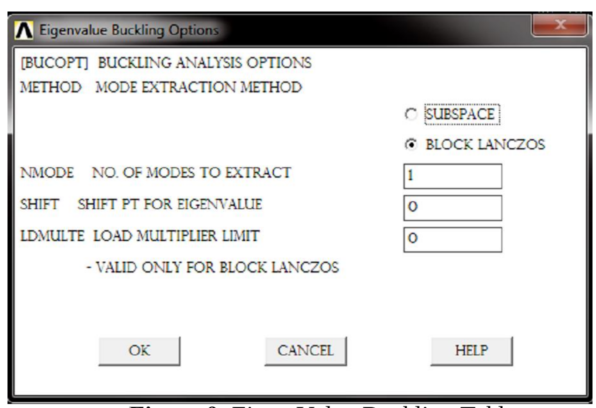

Figure 9. Eigen Value Buckling Table

4. Results and discussions

For obtaining appropriate relation between material and geometric properties buckling analysis performed. The buckling analysis gives more accurate results.

$$P_e = \frac{\pi^2 (EI_{eff})_y}{(L)^2}$$

$$(EI)_{ey} = E_a I_{ax} + 0.8\, E_{cm} I_{cx} + E_s I_{sx}$$

Where,
fy = Nominal yield strength
Ea = Modulus of elasticity
Ecm = Secant modulus of elasticity for short term loading,
Iax = second moments of area of the steel section
Icx = the concrete (assumed uncracked)
Isx = the reinforcement about the axis of bending

Table 3 Comparison of ANSYS and EC-4 buckling loads

Shape	Outside Diameter (mm)	Thickness (mm)	Grade of the conc.	Ansys Output kN	EC 4 buckling load (kN)
Circular CFST	60.3	2.9	M20	519.02	531.37
		3.6		493.62	504.23
Circular CFST	60.3	2.9	M25	793.22	802.32
		3.6		824.23	847.23
Circular CFST	60.3	2.9	M30	787.42	793.47
		3.6		633.84	698.6

Table 4. Comparison of Ansys and EC-4 buckling loads

Shape	Outside Diameter (mm)	Thickness (mm)	Grade of the conc.	Ansys Output kN	EC 4 buckling load (kN)
Rect. CFST	70 x 30	2.9	M20	655.21	702.12
		3.2		623.41	696.29
Rect. CFST	70 x 30	2.9	M25	926.12	948.55
		3.2		933.21	974.57
Rect. CFST	70 x 30	2.9	M30	935.63	1033.57
		3.2		945.81	956.36

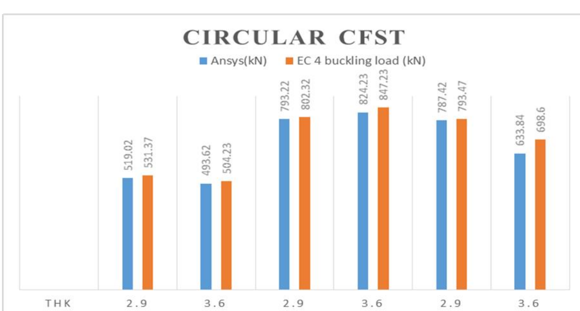

Figure 10. Comparison of Ansys and EC-4 Buckling loads

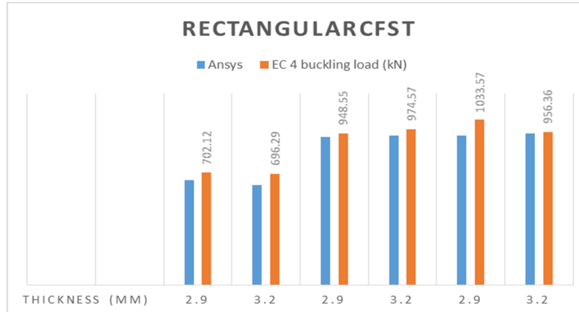

Figure 11. Comparison of Ansys and EC-4 Buckling loads

It is observed from Table 3 and 4, the ultimate load carrying capacity of CFST tubes shows good agreement with the Euro code 4 dataὂs obtained for the same. It is also observed from Fig. 9 and 10 that buckling load increases as the thickness of steel tube increases also as grade of concrete increases there is increase in load carrying capacity of CFST columns.

5. Conclusions

In this work behavior of CFST rectangular and circular columns has been elaborately done by theoretical calculations according to EC 4 and FE analysis of given specimens has been carried out, we can draw the following general conclusions,

Strength of Rectangular and circular CFST columns increases as grade of concrete has been increased.

Cross-sectional area of the steel tube has the most significant effect on both the ultimate axial load capacity and deformation of column.

From the above analysis geometric parameters like thickness of steel tube, grades of concrete and D/t ratio of tube it has been observed that strength of CFST column has been affected.

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