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Analytical Performance of CFST 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.***

I. 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. control devices. Base isolation technique is shown to be quite effective and it requires insertion of isolation device at the foundation level, which may require constant maintenance.

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.

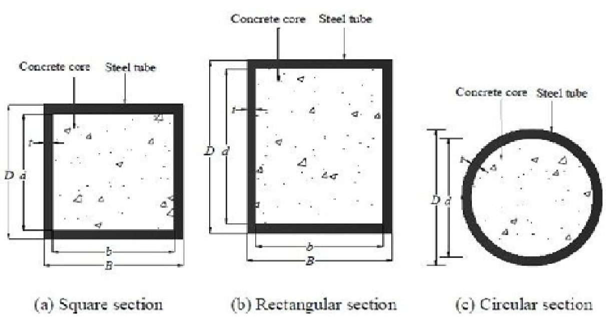

Fig1. Cross-sections of concrete-filled steel tubular beam-columns.

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 Fig.2.

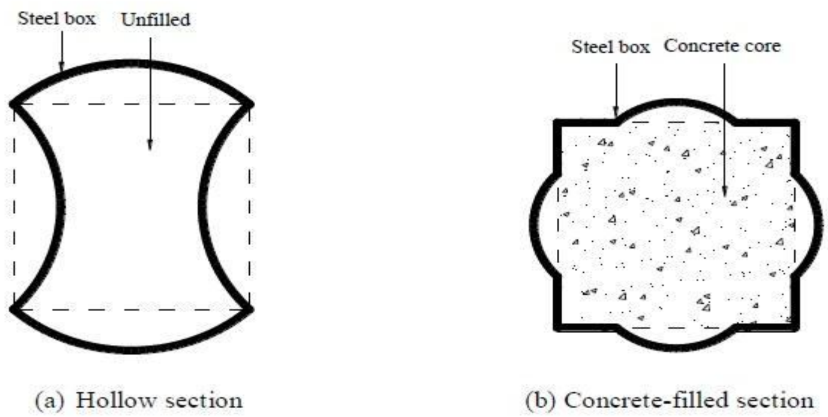

Fig. 2 Local buckling modes of steel box columns.

II. LITERATURE REVIEW

The literature review on CFST beam-columns under uniaxial loads, biaxial loads and cyclic loading. Existing experimental works and nonlinear analysis of CFST beam-columns have been highlighted. Researches on nonlinear analysis techniques for high strength CFST slender beam-columns have been very limited. In addition, the effect of the progressive local buckling of steel tubes and high strength materials on the strength and ductility of thin-walled CFST slender beam-columns were not taken into account in most of the nonlinear inelastic methods.

Bridge and O'Shea 1998 [1] studied experimentally the behavior of axially loaded thin walled steel box sections with or without concrete infill. The width-to-thickness ratios of these sections ranged from 37 to 131 while the length-to-width ratios of the columns ranged from 0.8 to 3. The performance of thin-walled CFST short columns was compared with that of hollow steel tubular columns. The buckling modes for a wide range of width-to-thickness ratios were examined. It was observed that the concrete core prevented the inward buckling of the steel tube. [2] This buckling mode significantly increased the strength of the steel tubes. They suggested that the effective width formula for clamped steel plates could be used to calculate the strength of thin-walled steel tubes with concrete infill. Local buckling of the steel tubes was found to reduce the ultimate strength of thin-walled CFST short beam-columns under axial compression.

[3] Han 2002 investigated experimentally the influences of constraining factors and the depth-to-width ratios on the ultimate strength and ductility of axially loaded rectangular CFST columns. [4] A total of 24 CFST columns were tested. The main variables examined in the test program were the constraining factor and depth-to-width ratio. The width of the steel tubes varied from 70 mm to 160 mm while the depth of the steel tubes ranged from 90 mm to 160 mm. The short columns were constructed by steel tubes filled with high strength concrete of 60 MPa. The steel yield strength varied from 194 MPa to 228 MPa. He reported that the axial strength and ductility of CFST columns decreased with an increase in the depth-to-width ratio but increased with an increase in the constraining factor. [5] A confinement factor was proposed for determining the section performance of composite columns but it did not take into account the effects of b t ratios on the behavior of composite sections [6].

Zhang et al. 2003 [7] presented test results of 8 high strength CFST beam-columns subjected to axial load and uniaxial bending. A 150 × 150 mm cross-section was used in the tests. Test parameters included column slenderness ratios, steel ratios and loading eccentricity. Test specimens were made of high strength concrete with the compressive strength of 94 MPa and steel tubes with yield strengths of 316 MPa or 319 MPa.[8] Their test results indicated that increasing the column slenderness ratio and loading eccentricity reduced the ultimate axial strengths of CFST beam-columns. The ultimate axial strengths of CFST beam-columns were shown to decrease with increasing the steel ratio.

Han and Yang 2003[9] carried out several tests to study the behavior of rectangular CFST short columns under long-term sustained loading. They investigated the effects of steel ratios, long-term sustained load level, slenderness ratio, strength of the materials and depth-to-thickness ratio on the ultimate strengths of CFST columns.[10] A theoretical model given in ACI codes (ACI 1992) was used to compare the predicted behavior of CFST columns under long-term loading. It was found that the axial strain due to long term sustained loading affected the results and tended to stabilize after about 100 days of loading. The strength index decreased as the slenderness ratio and the concrete strength increased, when the slenderness ratio was less than 10. The maximum strength reduction due to long-term loading effects was approximately 20% of the strength under short-term loading.[11] A set of formulas was developed by Han and Yang (2003) for predicting the ultimate strengths of rectangular CFST short columns with long-term sustained loading effects.

Fujimoto et al. 2004 [12] examined experimentally the effects of high strength materials on the behavior of circular and square CFST short columns under eccentric loading. They tested CFST short columns with a wide range of parameters including the tubes' diameter-to-thickness ratio, normal and high strength concrete, and normal and high strength steels. Circular steel tubes used to construct these CFST columns were cold formed from a flat plate by press welding and seam welding. [13] The length-to-diameter ratio of the specimens was 3.0. The depth-to-thickness ratios of these specimens ranged from 27 to 101. The yield strengths of the steel tubes were 283, 579 and 834 MPa and the concrete cylinder compressive strengths were 25, 41 and 78 MPa. The applied axial load ranged from 13% to 59% of the ultimate axial load of corresponding column obtained by the theoretical model. They reported that the use of high strength concrete reduced the ductility of circular CFST beam-columns.[14] Also, the use of high strength steel tubes or steel tubes with a smaller diameter-to-thickness ratio increased the ductility of circular CFST columns. It was concluded that the confinement effect did not increase the moment capacity of square CFST beam-columns and local buckling must be taken into account in evaluating the strengths of square CFST beam-columns with large width-to-thickness ratios[15].

Sakino et al. 2004[16] have investigated experimentally the ultimate loads and behavior of circular CFST short columns under axial load. They tested 114 CFST columns to study the effects of the tube shape, steel yield strengths, diameter-to-thickness ratio and concrete strengths on the behavior of axially loaded CFST columns. The circular steel tubes used in these CFST columns were cold formed from a flat plate by press bending and seam welding. The depth-to-thickness ratios of these columns ranged from 17 to 102. The yield strengths of steel tubes ranged from 279 MPa to 853 MPa. The concrete cylinder compressive strengths ranged from 25 MPa to 85 MPa. The test data was used to develop design methods for CFST columns. A new design formula based on the test results was also proposed for circular and square CFST columns.

Liu 2006 undertook[17] experimental studies on the structural behavior of high strength rectangular CFST beam-columns subjected to axial load and uniaxial bending. He tested four slender and sixteen stub rectangular high strength steel tubes with yield strength of 495 MPa filled with high strength concrete of 60 MPa. The ultimate axial strengths of CFST columns measured from the tests were compared with the design ultimate loads calculated using Euro code 4. It was shown that EC4 accurately predicted the ultimate axial strengths of axially loaded CFST columns, but was quite conservative for predicting the ultimate axial strengths of eccentrically loaded CFST columns. The conservatism of the EC4 predictions increased as the eccentricity increased. Moreover, the ultimate capacities of CFST slender beam-columns were significantly reduced by increasing the load eccentricity ratio.

Lue et al. 2007 [18] tested twenty-four rectangular CFST slender beam-columns with a depth-to- thickness ratio of 33 and concrete compressive strengths varying from 29 to 84 MPa. These beam-columns with a cross-section of 100 × 150 mm were constructed by cold-formed steel tubes. Specimens were fabricated from 4.5 mm thick steel tube so that their depth-to-thickness ratio was 33. The length of the column was 1855 mm. The yield strength of the steel tube was 379 MPa. It was observed that CFST columns with normal strength concrete failed by the global buckling while local buckling failure mode was found in the specimens with high strength concrete. Test results were compared with various composite design codes to examine the validity of the design codes. It was concluded that the AISC-LRFD 2005generally gave a good estimate of the ultimate loads of high strength CFST columns while the AISC-LRFD 1999 overestimated the ultimate loads of high strength CFST columns.

Caihua C. et.al. [19] Referred in his paper to the rapid development of high-rise buildings in China, the steel-concrete composite structure is widely used because of its excellent seismic performance. So far, all of the high-rise buildings that rise more than 300 m in China are of a steel- concrete composite structure, which are designed based on Chinese codes. During the construction process, two main problems are encountered, as follows:(1) Minimum stirrup ratio, and (2) embedded depth ratio for steel-concrete composite columns, which are strictly limited by Chinese codes.[20] To solve those problems, 26 steel-concrete composite columns were tested under low cyclic reversed loading to simulate an earthquake load. By analyzing the failure patterns, hysteresis loops, skeleton curves, energy-dissipation capacity, and ductility of such specimens, the influence of the axial compression ratio, stirrup ratio, steel section shape, and steel embedded depth ratio on the seismic behavior of steel-concrete composite members are discussed. In accordance with the test results, the minimum stirrup ratio and embedded depth ratio for steel concrete composite columns can be reduced relative to the limiting value given by Chinese codes.

III. FINITE ELEMENT MODELLING

A. Discription 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 Poisson's 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 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.

B. Elements Used to Model CFST in ANSYS

1) *Solid65:s* This is used for the three-dimensional modeling of solids with or without reinforcing bars (rebar's). 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.

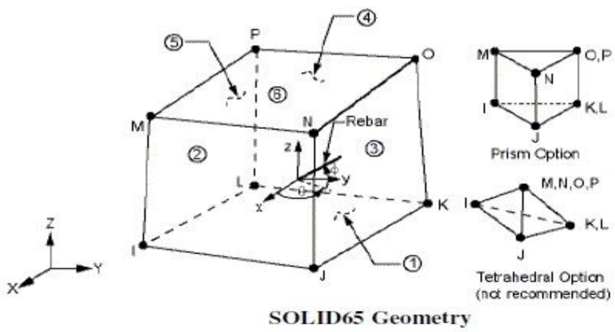

Fig 3. Geometry of Solid65

2) *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.

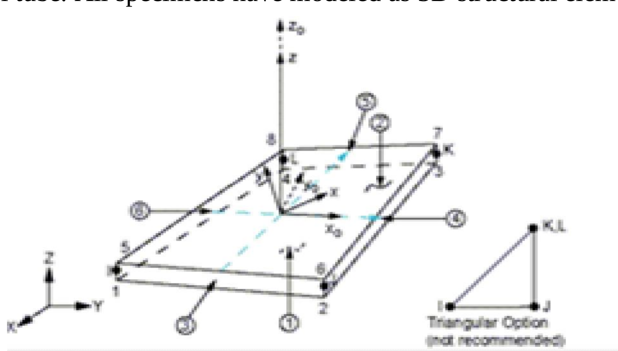

Fig. 4. Geometry of Shell181

C. 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 elements used are CONTA 173 and TARGE 170 elements.

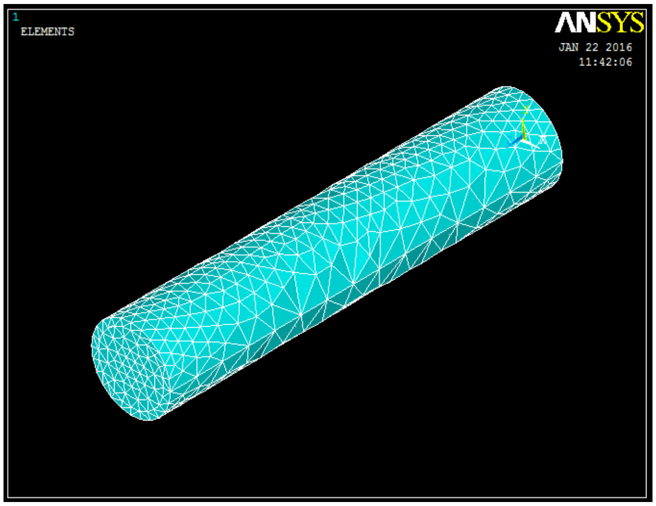

Fig. 5. Model after Meshing of Circular CFST Column

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.

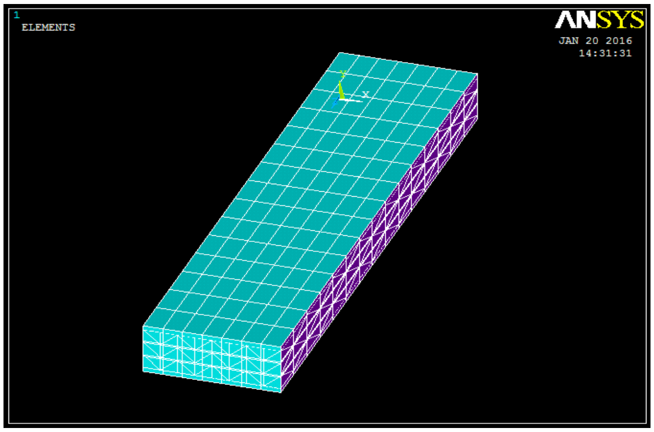

Fig. 6. Model after Meshing of Rectangular CFST column

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

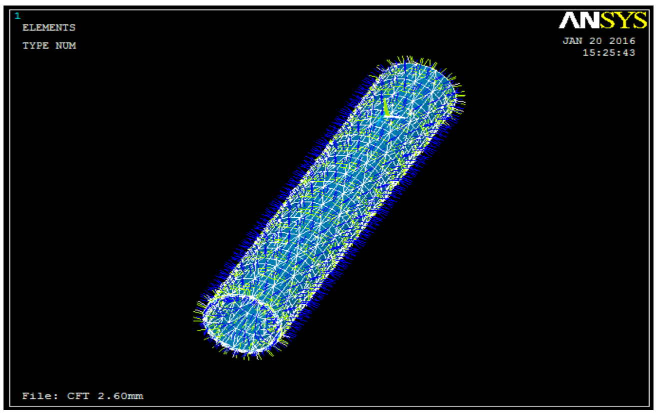

Fig. 7. Model after applying contact elements

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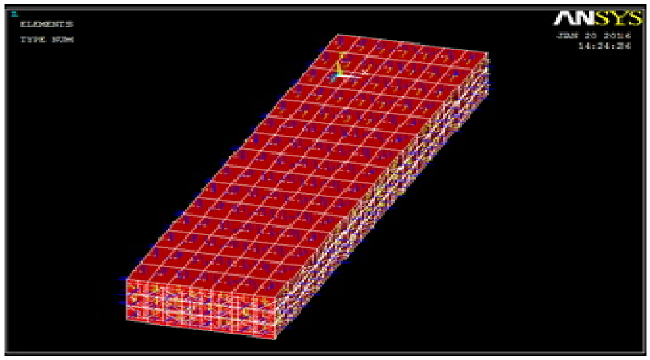

Fig. 8. Model after applying contact elements

D. 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 I. Material Property of Steel

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

E. 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 II. Material Property of Concrete

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

IV. ANALYSIS

A. 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.

B. 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 software's is, its availability as bundled software of pre, post and a Processor.

C. 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.

D. 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.

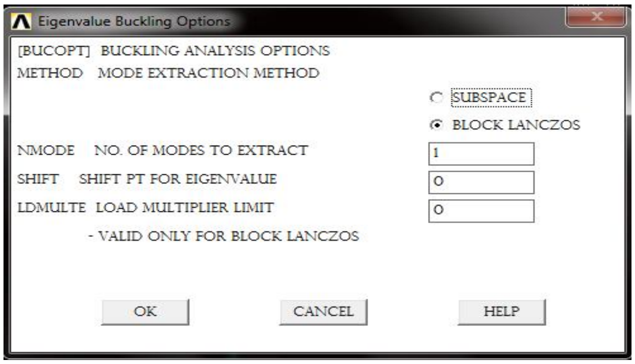

Fig 9. Eigen Value Buckling Table

V. RESULTS AND DISCUSSION

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

(EI) ey =EaIax + 0.8 EcmIcx + EsIsx

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

& equivalent static analysis has been used to find the design lateral forces.

Table III. 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

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

Shape	Outside Diameter (mm)	Thick-ness (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

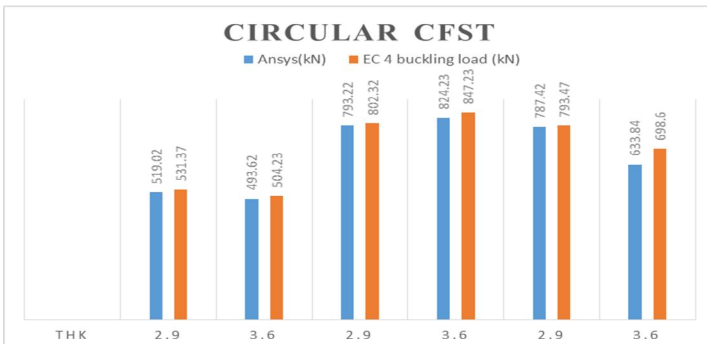

Fig.10. Comparison of Ansys and EC-4 Buckling loads

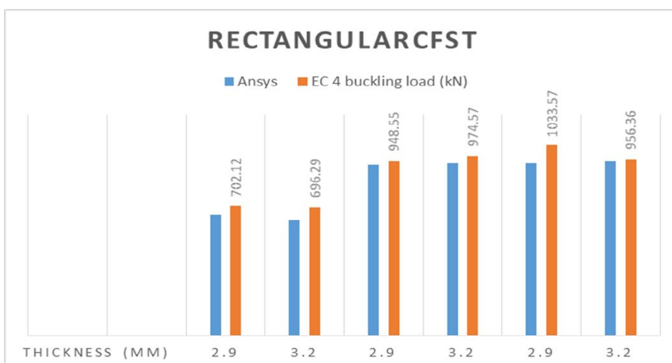

Fig. 11. Comparison of Ansys and EC-4 Buckling loads

It is observed from Table 3 and 4, the ultimate load carrying capacity of CFST tubes shows good agreement with the Euro code 4 data's 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.

VI. CONCLUSION

This paper has to find out behavior of rectangular and circular CFST columns under axial loads. To achieve goal of this paper, different shapes of CFST columns i.e. rectangular and circular are selected. Then the design of CFST columns has been carried out using EC-4 and all models of rectangular and circular CFST columns which is listed in table. All models analyzed for nonlinear behavior i.e. buckling analysis has been carried out. Analysis results obtain in terms load vs deflection and ultimate loads. The deflections are observed to be more in RCC columns than in CFST columns. To observe nonlinear behavior of CFST columns load vs deflection curves are plotted, it is observed that the deflections are more in RCC columns than in CFST columns. The comparison of ultimate loads of all CFST columns are then obtained. Also the comparisons are done to observe the maximum deflections between RCC and CFST columns.

1) Strength of Rectangular CFST columns increases as grade of concrete and thickness of steel tubes has been increased.
2) Similarly strength of Circular CFST columns increases as grade of concrete and thickness of steel tubes has been increased.
3) The axial load carrying capacity of circular columns are very much more than rectangular columns as thickness of steel tubes and grade of concrete increases.
4) Cross-sectional area of the steel tube has the most significant effect on both the ultimate axial load capacity and deformation of column.
5) The deflections in Rectangular columns are decreases as grade of concrete and thickness of steel tubes are varied.

The future scope for this paper is as follow

1) FE modeling needs more study and new interface elements should be developed to represent the complex behavior of the steel/concrete interface in composite column construction full-scale and embossment behavior. The ultimate objective with improved FE packages and faster computers with large memories will be to model the full-scale composite columns, which will enable all the parameters to be studied together.
2) The present study is based only for axial loading. The CFST columns are also need to study under different loading conditions like cyclic loading, blast loading, preloading effects etc.
3) This study deals with fixed support condition as the base of the column is assumed to be fixed, thus the study can be extended to the columns having different support conditions, and soil structure interaction can also be considered for further studies.

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