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RECOMMENDATIONS TO BIS FOR UNREINFORCED CFST COLUMNS UNDER AXIAL LOADING

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***Abstract*—This paper presents the analytical and finite element behaviour of short and long concrete-filled steel tube i.e. CFST columns. The objective is to compare the behaviour of CFST columns of circular and square cross sections under concentric axial loading. The load deformation characteristics were studied for different grades of concrete. The axial load carrying capacity for limit state of strength for both short and long CFST columns were tested in yielding and buckling respectively. The 8 noded 3D solid elements were used for finite element meshing in ANSYS-Workbench software. The research finding indicates that the circular cross section of CFST column is effective in resisting axial deflection as well as strength compared to square cross section having equal steel material.**

Keywords— **Concrete-filled steel tube, axial loading, Finite Element, Yielding, Buckling.**

I. INTRODUCTION

The CFST column is formed by filling the concrete in the thin steel tube with or without reinforcement. The concrete-filled steel tube (CFST) columns utilize the advantage of both steel and concrete. CFST columns are currently being increasingly used in the construction of buildings, due to their excellent static and earthquake resistant properties, such as high strength, large energy absorption capacity, bending stiffness, high ductility, fire performance along with favourable construction ability, etc. In current international practice, concrete-filled steel tube (CFST) columns are used in the primary lateral resistance systems of both braced and unbraced building structures. There exist applications in Japan and Europe where CFSTs are also used as bridge piers. The CFST structural member has a number of distinct advantages over equivalent steel, reinforced concrete, or steel-reinforced concrete member. The orientation of the steel and concrete in the cross section optimizes the strength and rigidity of the section. Steel is in the outer perimeter, where it performs more effectively in tension and in resisting a moment of bending. Steel, which has a much greater modulus of elasticity than concrete gives more contributions to the moment of inertia, is situated farthest from the centroid hence the stiffness of CFST column is greatly enhanced. Concrete forms an ideal core to withstand the compression load in typical applications, and delays and often prevents local steel buckling. The more fragile nature of high strength concrete is partially mitigated by the confinement of the steel pipe, and the local buckling of the thin steel pipe is delayed due to the support offered by the concrete when high strength concrete and thin-walled steel tubes are used together. Axially loaded columns, CFST beam-columns connections, have been studied worldwide and to some extent, many of the aforementioned issues have been reconciled for these types of members. This paper shows the comparison of a circular and square CFST column with varying grades of concrete (30, 50, 70 N/mm2) and for axial load, for their ultimate load carrying capacity and deformation.

II. METHODOLOGY

A. Finite Element Analysis –

Recently, the software uses the Finite element method for the analysis and design of the structure. In ANSYS Workbench, analyses are created as systems, which can be combined in a project. The project is driven by a schematic workflow that manages connections between systems. The study involves the use of ANSYS workbench (16.0) software for analysis.

B. Material Specification -

Multi-linear property of concrete and bilinear properties for steel tube is used. The modulus of elasticity of concrete is taken as $5000\sqrt{fck}$ according to IS 456:2000, where *fck* is characteristic strength of concrete

- Structural steel property

  Density – 7850 kg/m^3
  Young's modulus – $2x10^5$ N/mm^2

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Yield strength – 250 N/mm^2
Poisson's ratio – 0.3

- Concrete property

Density – 2400 kg/m^3
Young's modulus - 5000$\sqrt{fck}$
Compressive cube strength – 30, 50, 70 N/mm^2
Poisson's ratio – 0.18

C. Geometric Specifications –

Table - 1 Geometric Specifications of the model

Parameters	Circular	Square
Outer dimension (mm)	**200**	**177**
Inner dimension(mm)	**186**	**164.6**
Thickness of steel tube(mm)	**7**	**6.2**
Length of column(mm)	**2000, 3000, 4000**	**2000, 3000, 4000**

D. FE Modelling and Meshing –

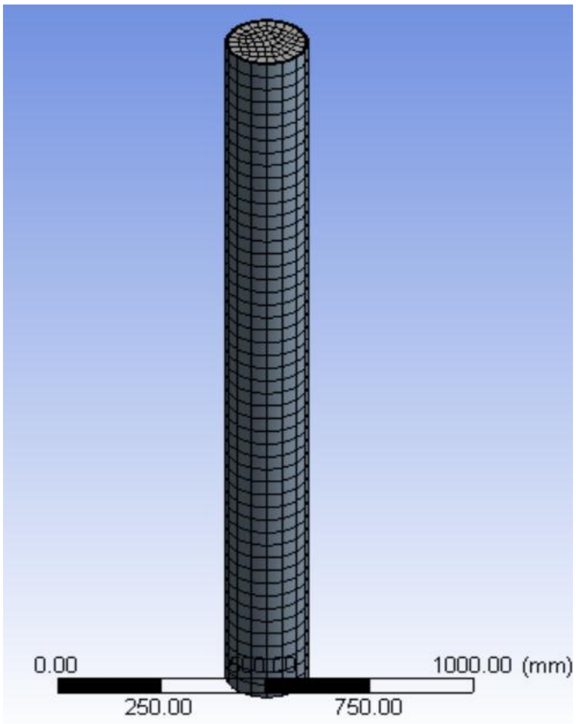

Fig.1. Meshing of circular CFST column

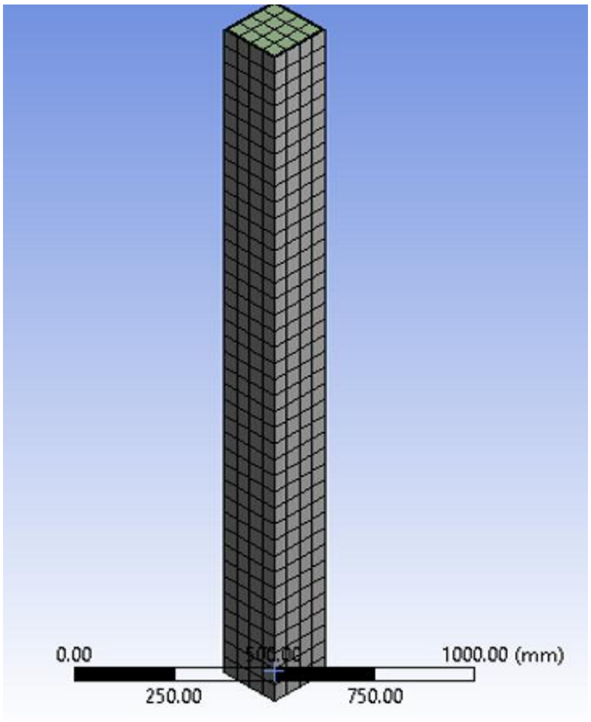

Fig.2. Meshing of square CFST column

E. Boundary Conditions –

For each of the two extremes, two different types of boundary conditions were used. At the fixed lower end, the degrees of freedom of movement in the directions X, Y, Z (U1, U2, U3), as well as the degrees of freedom of rotation in the X, Y, Z directions were restricted to zero. At the top end is the roller support. The translation of U2 (Y) is free whereas remaining U1, U3 are restricted and the degrees of freedom of rotation are free.

F. Contact between Steel Tube and Concrete –

The contact between the concrete filling and the steel pipe is given such that it always has bonded contact and the space between the steel pipe and the concrete filling is always closed and not allowed to penetrate each other.

G. Comparison of different International codes –

1. Yielding load calculation for short columns (AISC/LFRD)

The axial strength of a composite element is computed similar to that of a structural steel column, except the material yield strength and stiffness are modified to account for the steel and concrete components in the composite column. The

AISC/LRFD defines the square of the column slenderness parameter as:

$$\lambda^2{}_c = F_{my}/F_E = (KL/r_m\pi)^2 (F_{my}/E_m)$$

Where, F_E - Euler's buckling stress for a column; r_m - Radius of gyration of the steel tube only; and KL - Effective simply supported column length. E_m is the Modified elastic modulus and F_{my} is the Modified yield strength of the CFST column which is defined by the equations:

$$E_m = E_s + 0.40\ E_c(A_c/A_s)$$

$$F_{my} = F_y + 0.85\, f'_{ck}(A_c/A_s)$$

E_s, A_s and Fy - Elastic modulus, Cross-sectional area, and the Yield strength of the steel tube, respectively; E_c, A_c, and f'_{ck} - Elastic modulus, Area, and Strength of the concrete core, respectively. Once the column slenderness parameter is known the critical stress F_{cr} is computed from:

$$F_{cr} = (0.658^{\lambda^2{}_c})F_{my} \quad \text{for} \quad \lambda_c \leq 1.5$$

$$F_{cr} = (0.877/\lambda^2{}_c)F_{my} \quad \text{for} \quad \lambda_c > 1.5$$

The ultimate strength of the CFST is determined by multiplying the critical stress by the cross-sectional area of the steel tube:

$$P_{cr} = A_s F_{cr}$$

2. Buckling load calculation for long columns (AISC/LRFD)

The ultimate axial crushing load is:

$$P_0 = 0.95 f_{ck} A_c + f_y A_s$$

Effective Stiffness,

$$EI_{eff} = E_s I_s + C' E_c I_c$$

Where, C' is effective stiffness factor given as:

$$C' = 0.15 + P/P_0 + A_s/(A_s+A_c)$$

Columns are analysed by Euler Formula:

Critical Load,

$$P_{cr} = \frac{\pi^2 EI_{eff}}{L^2{}_{eff}}$$

Where,

f_{ck} – Compressive cube strength of concrete

A_s, A_c – cross sectional area of steel tube and concrete respectively

P – Applied axial load

L_{eff} – Effective buckling length of column

Models were verified with the theoretical Euler's critical buckling load formula.

3. Buckling load calculation (EUROCODE 4)

The axial force Nsdand the maximum end moment Msd are determined from a first order structural analysis. For each of the bending axes of the column it has to be verified that:

$$N_{sd} \leq \chi k N_o$$

Where,χk is a reduction factor due to buckling.

The buckling curves can also be described in the form of an equation:

$$\chi_k = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}}$$

$$\text{Where, } \phi = 0.5[1+\alpha(\bar{\lambda} - 0.2) + \bar{\lambda}^2]$$

Where α depends on the buckling effects, a value of 0.21 was adopted for CFST column. The relative slenderness of λ is given by:

$$\bar{\lambda} = \sqrt{\frac{N_o}{N_{cr}}}$$

In which Ncr is the critical buckling stress resultant given by:

$$N_{cr} = \frac{\pi^2 (EI)_e}{L^2{}_e}$$

Where Le is the effective length and $(EI)_e$ is the actual elastic stiffness

$$(EI)_e = E_s I_s + 0.8(E_c/1.35)\ I_c$$

4. Yielding load calculation (EUROCODE 4)

$$P_n = A_s.\ F_{cr}$$

$$\left.\begin{array}{ll} (0.658^{\lambda^2{}_c})F_{my} & \text{for} \quad \lambda_c \leq 1.5 \\ (0.877/\lambda^2{}_c)F_{my} & \text{for} \quad \lambda_c > 1.5 \end{array}\right\} F_{cr}$$

$$\lambda_c = \frac{KL}{r_m \pi}\sqrt{\frac{F_{my}}{E_m}}$$

$$F_{my} = f_y + 0.85\ fc^1\ (A_c/A_z)$$

$$E_m = E_z + 0.4\ (A_c/A_z)\ E_c$$

$$E_c = W^{1.5\sqrt{fc1}}$$

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III. RESULTS AND DISCUSSION

The deformation behaviour of short CFST columns (L=2000mm) under different loadings is shown in the table below:

Table - 2 Deformation behaviour of short CFST columns

Load (kN)	Deformation (mm)	
	Circular	Square
1000	1.377	1.381
2000	2.754	2.762
3000	4.132	4.143

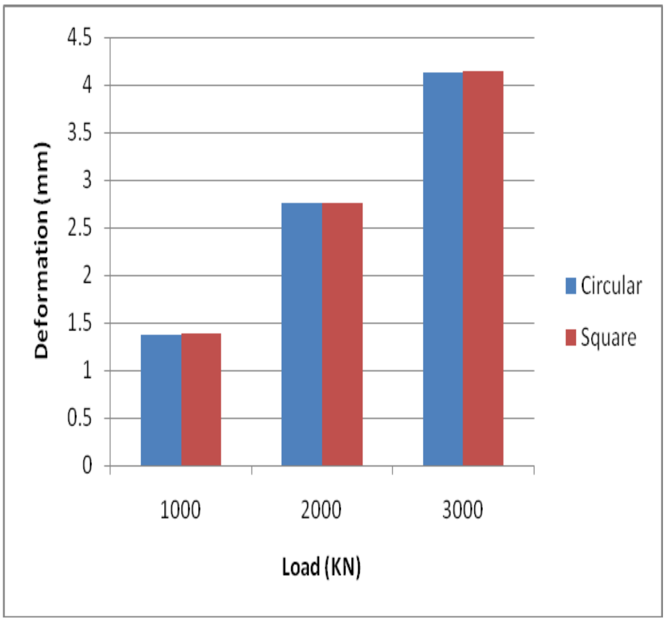

Chart 1. Deformation behaviour of short CFST column

Table - 3 Deformation behaviour for different concrete grades

Concrete Strength (*fck*)	Deformation (mm)	
	Circular c/s	Square c/s
M30	1.377	1.381
M50	1.152	1.155
M70	1.035	1.037

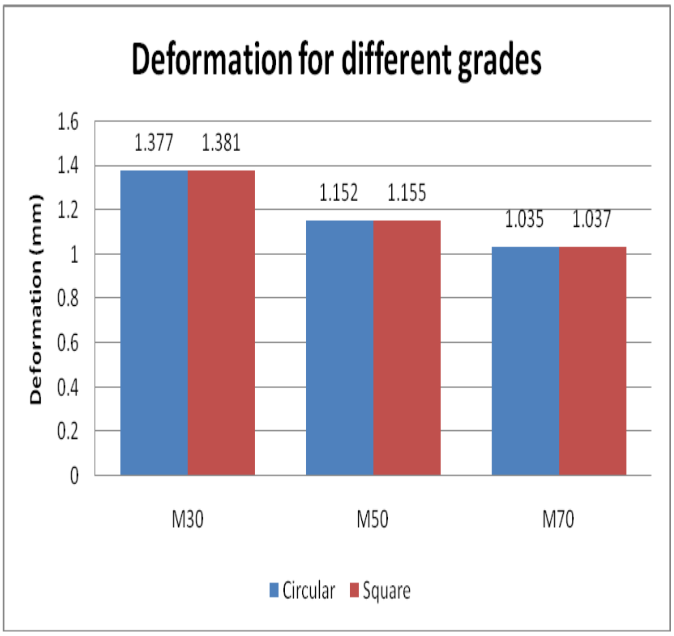

Chart 2. Deformation behaviour for different concrete grades

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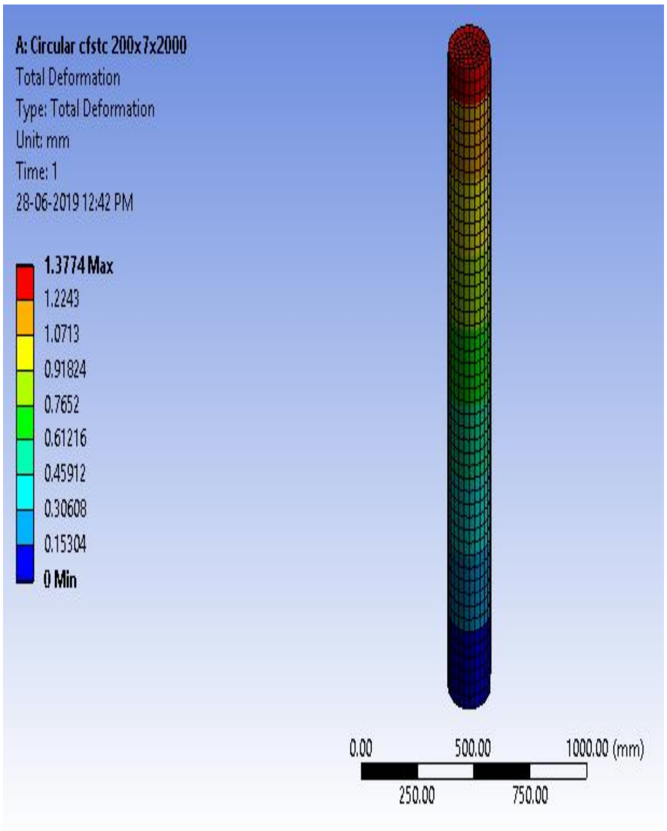

Fig. 3. Deformation behaviour of short CFST column

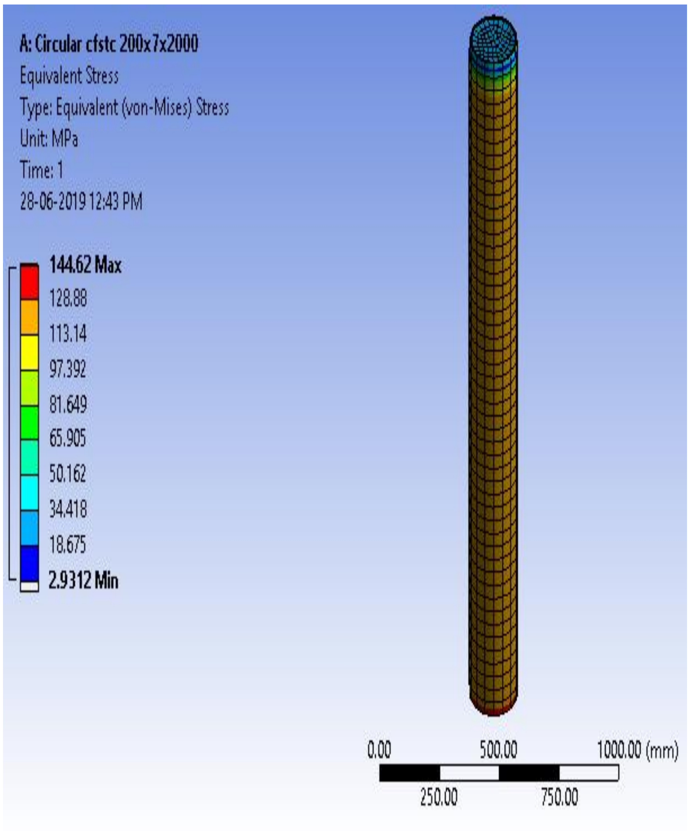

Fig. 4. Stress behaviour of short CFST column

Table - 4 Stress and strain behaviour of CFST short columns for different loads (M30)

Load (kN)	Stress (MPa)				Strain			
	Circular c/s		Square c/s		Circular c/s		Square c/s	
	Concrete	Steel	Concrete	Steel	Concrete	Steel	Concrete	Steel
1000	35.12	144.62	37.16	158.45	0.00141	0.00072	0.00149	0.00080
2000	70.239	289.24	74.32	316.89	0.00282	0.00144	0.00289	0.00161
3000	105.36	433.87	111.49	475.34	0.00423	0.00217	0.00448	0.00242

A. Critical load calculations for short CFST columns

Type of c/s	Critical load in yielding(FEM) kN	Critical load in yielding(AISC) kN	% Difference with FEM	Critical load in yielding(Eurocode 4) kN	% Difference with FEM
Circular	1725	1740	-0.8%	1700	1.14%
Square	1680	1700	-1.19%	1650	1.78%

Table - 5 Critical load in yielding for short column (L=2000mm)

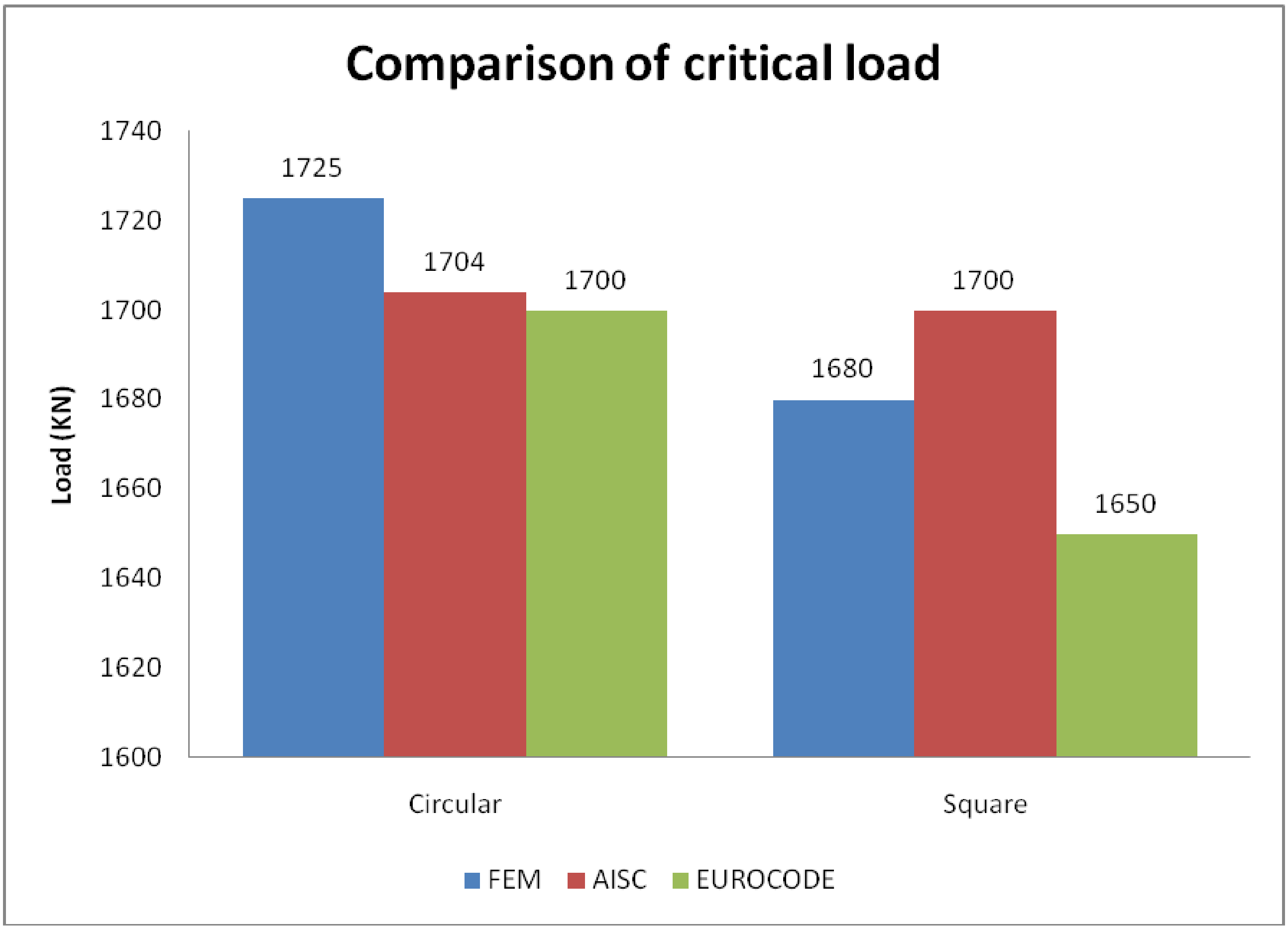

Chart 3. Critical load comparisons of short CFST columns

B. Critical load calculations for slender CFST columns

Table - 6 Critical load in buckling for slender column (L=3000mm)

Type of c/s	Critical load in buckling (FEM) kN	Critical load in buckling (AISC) kN	% Difference with FEM	Critical load in buckling (Eurocode 4) kN	% Difference with FEM
Circular	**11009**	**11353**	**-3.12%**	**10589**	**3.81%**
Square	**11473**	**12000**	**-4.59%**	**11197**	**2.40%**

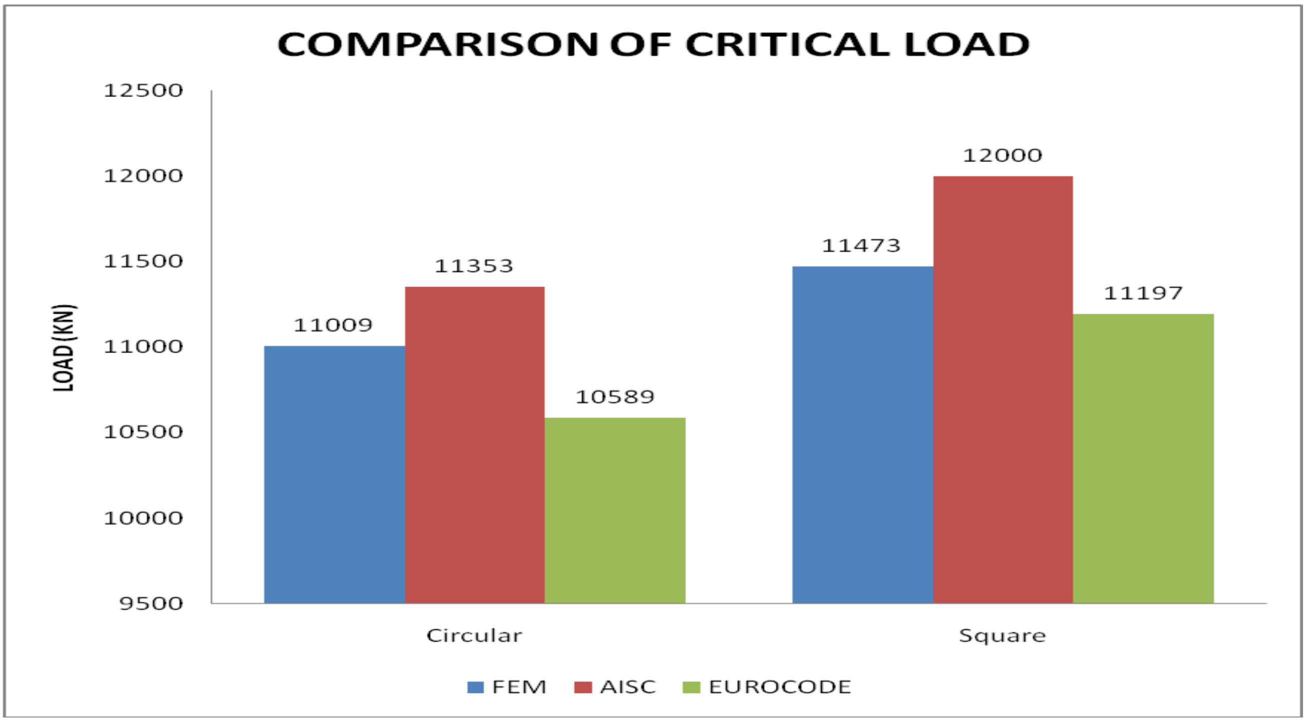

Chart 4. Critical load comparisons of slender CFST columns (L=3000mm)

Table -7 Critical load in buckling for slender column (L=4000mm)

Type of c/s	Critical load in buckling (FEM) kN	Critical load in buckling (AISC) kN	% Difference with FEM	Critical load in buckling (EUROCODE 4) kN	% Difference with FEM
Circular	**6200**	**6386**	**-3.0%**	**5956**	**3.93%**
Square	**6458**	**6786**	**-5.07%**	**6298**	**2.47%**

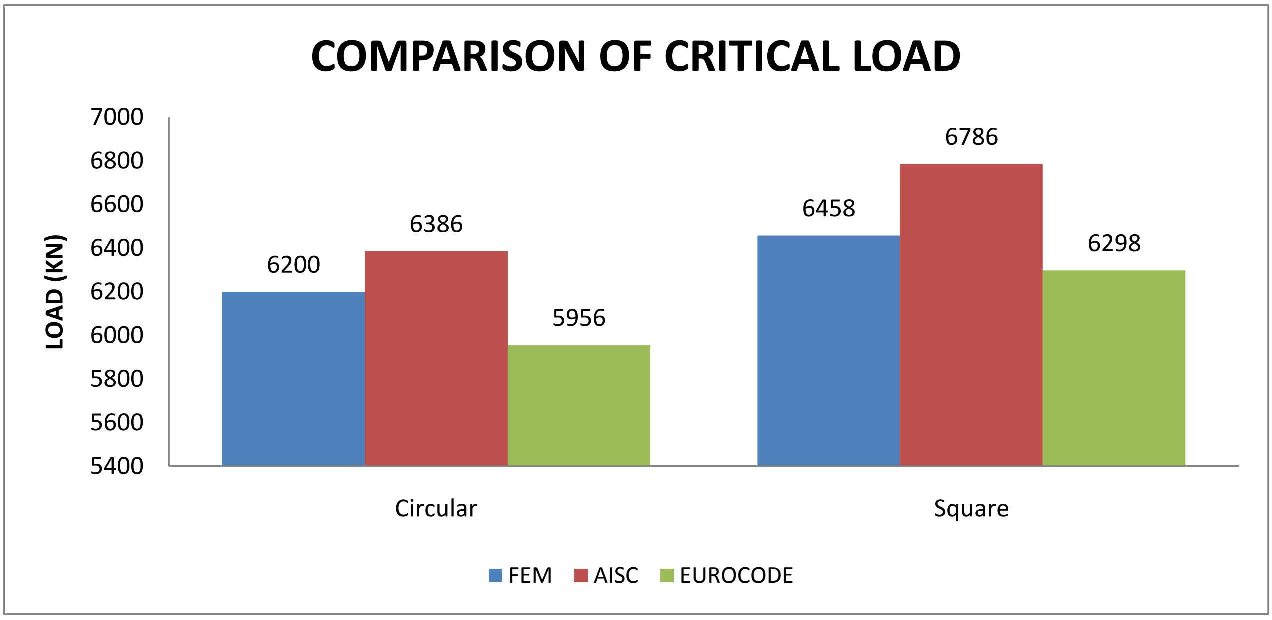

Chart 5. Critical load comparisons of slender CFST columns (L=4000mm)

IV. CONCLUSION

The use of CFST columns has increased due to ease and speed in construction. Codal provisions in Indian standards are under revision and draft code of IS 11384 is silent about CFT without any reinforcement.

The attempt has been made in this paper to perform the finite element analysis on CFST columns and to verify results with codal provisions given in AISC and Euro.

The research finding indicates that the circular cross section of CFST column is effective in resisting axial deflection as well as strength compared to square cross section having equal steel material.

On comparison of finite element analysis results it is observed that the AISC code differs by 3 to 5% on higher side. The results given by Euro code 4 are rather closer to FEM solution in the range of 2 to 4%.

Euro code 4 provisions can be safely adopted by BIS to estimate axial load capacities of short as well as long CFT columns containing no reinforcements.

V. Acknowlwdgement

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