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ANALYSIS OF CFT, RCC AND STEEL BUILDING SUBJECTED TO LATERAL LOADING

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Abstract

Steel–concrete composite columns are used extensively in modern buildings. Extensive research on composite columns in which structural steel section are encased in concrete have been carried out. In-filled composite columns, however have received limited attention compared to encased columns. In this paper a comparative study of 10, 20 and 30 storey Concrete Filled Steel Tube (CFT), R.C.C. and Steel building is done. Comparison of parameters like time period, displacement, base shear and load carrying capacity is done with steel and R.C.C structures. Result shows CFT building is good in load carrying capacity with small cross section of column.

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Keywords: Concrete-filled steel tubular column, Confinement effect, Circular cross section, lateral load.

Nomenclature

f_{ck}	Compressive strength of concrete at 28 days
f_{sk}	yield strength of reinforcing steel
f_y	yield strength of structural steel
A_a	Cross-sectional area of the structural steel section
A_c	Cross-sectional area of concrete
A_s	Cross-sectional area of reinforcement
d	Overall diameter of circular hollow steel section parametric
t	Thickness of steel tube.

1. Introduction

In today's modern era of innovation, two materials widely and inevitably used as construction material are steel and concrete for structures ranging from buildings to bridges. Though these materials may have different properties and

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characteristics, they both seem to complement each other in many ways. Steel has excellent resistance to tensile loading but lesser weight ratio so thin sections are used which may be prone to buckling phenomenon. On the other hand concrete is good in resistance to compressive force. Steel may be used to induce ductility an important criteria for tall building, while corrosion protection and thermal insulation can be done by concrete. Similarly buckling of steel can also be restrained by concrete. In order, to derive the optimum benefits from both materials composite construction is widely preferred. In construction of composite structures generally two types of columns are used i.e. encased column and concrete filled steel tube column. This paper concentrates only concrete filled steel tube column due to enhanced compressive strength by its confinement. Steel tube is expected to carry stresses in longitudinal direction caused by axial loading and moments, shear stresses in transverse direction and internal passive pressure due to concrete dilation. A typical sketch of beam column junction of composite column is shown in Fig 1.

1.1 Confinement in CFT columns

The confinement effect produced by steel tube on the concrete core plays a pivotal role in governing the structural behavior of concrete filled tube columns. Though, confinement effect in first stages of loading can be neglected, since coefficient of Poisson of concrete is smaller than steel and steel tube expansion is faster than concrete core in radial direction and steel also does not restrain concrete core. At this point, the steel tube is subjected to compressive stresses, with no separation between the tube and the concrete core. However, with increase in load up to the level of uniaxial strength of concrete, there is increased micro cracking in concrete. Thus, when lateral expansion of concrete is maximum, the steel tube gets mobilized and is efficient in providing restraint to concrete core. In this way, the ultimate capacity of the CFT columns is higher than the sum of the resistance of their components, which are the steel tube ($A_a * f_y$) and the concrete core ($A_c * f_{ck}$) [1].

When load carrying capacity of square or rectangular cross sections CFT type columns is compared with steel or concrete column, they do not show any significant increase as compared to circular cross section columns. This may be due to plane portions of steel tube of square sections are not rigid enough to resist internal pressures due to expansion of concrete core, therefore only the concrete in the centre and in the corners of the cross section are effectively confined. Confinement provided by the steel tube depends on such parameters, like diameter-to-thickness ratio (d/t), length-to-diameter ratio (L/d), eccentricity of the load (e), strength and deformability of the materials, cross section shape.

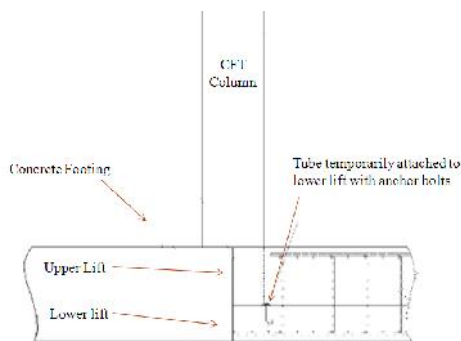


Fig. 1: Typical Beam column junction of Composite column

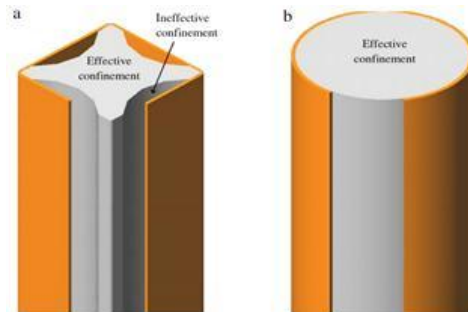


Fig. 2: Confinement effect in square and Circular column

1.2 Methodology for Design

Eurocode-4 provides two methods for calculation of the resistance of composite columns [2]. The first is a General Method which takes explicit account of both second-order effects and imperfections. The second is a Simplified Method which makes use of the European buckling curves for steel columns, which implicitly take account of imperfections. This method is limited in application to composite columns of bi-symmetric cross-section which does not vary with height. This method is used in this work.

Assumptions used in these two methods are:

- There is full interaction between the steel and concrete sections until failure occurs.
- Geometric imperfections and residual stresses are taken into account in the calculation, although this is usually done by using an equivalent initial out-of-straightness or member imperfection.
- Plane sections remain plane while the column deforms.

Eurocode -4 Procedure was used to develop a typical M- N interaction curve with reference to bending moment pattern and axial load in a circular concrete filled cross-section. Using two equations of equilibrium and Bernoulli assumption, critical points are evaluated using equations given in Eurocode -4 and M-N interaction curve is plotted. For example, a column of length 4 m, fixed at lower end and simply supported at top end and carrying axial load (N) of 850 kN and subjected to bending moment (M) 140 kN.m at top and -70 kN.m at bottom, an M-N interaction curve is derived as shown in Fig 3.

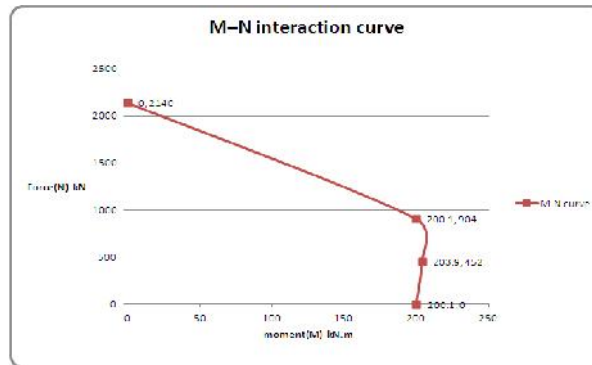


Fig 3 M-N interaction curve.

2. Analysis of CFT, RCC and Steel Building Configuration

Plan of building for study of three systems viz. Concrete filled tube, R.C.C and Steel building was 38.4m X 32m as shown in Fig 4. Columns were placed 6.4 m center to center both ways. Typical storey height was taken as 3 m while beam size and column size are taken as given in Table.1 and Table.2 respectively. Concrete of grade $f_{ck} = 30 \text{ N/mm}^2$, Reinforce steel of $f_{sk} = 415 \text{ N/mm}^2$ and structural steel of $f_y = 340 \text{ N/mm}^2$ is used. For loading purpose slab thickness taken 150mm and Live load = 2 kN/m^2 , Floor finish = 1 kN/m^2 , also Earthquake force (for zone III) $Z = 0.16$, Importance factor = 1, Response reduction factor = 5, Soil strata medium consider. For Wind load purpose basic wind speed $V_b = 39 \text{ m/s}$, probability factor $K1 = 1$, topography factor $K3 = 1$ is taken. Using above mention data analysis for 10, 20 and 30 storey building was done in STRAP software

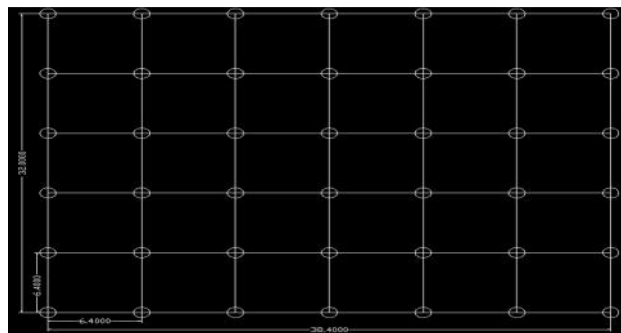


Fig. 4: Typical Plan view

Table 1 Beam Size

Type of Building	10 Storey(mm)	20 Storey(mm)	30 Storey(mm)
RCC Building	230x450	250x550	250x550
CFT Building	ISMB550	ISWB600	GF to 15 th Floor ISWB600 16 th to 30 th Floor ISWB550
Steel Building	ISMB550	ISWB550	ISWB550

Table 2 Column Size

Type of Building	10 Storey(mm)	20 Storey(mm)	30 Storey(mm)
RCC Building	Diameter D=550	GF to 10 th Floor D=900 11 th to 20 th Floor D=700	GF to 10 th Floor D=1100 11 th to 20 th Floor D=900 21 th to 30 th Floor D=700
CFT Building	D=550 & t=6mm	D=800 & t=9mm	D=1000 & t=11mm
Steel Building	2ISWB450 With Flange Distance 20mm	2ISWB600 With Flange Distance 40mm	D=1000 & t=20mm

2.1 Comparison of Ten Storey CFT, RCC and Steel building

Table 3 : Design Parameter Comparison

Structure	CFT	RCC	STEEL
Load intensity (kN/m ²)	7.78	8.15	7.29
Time period(sec) for 1st mode	1.33	2.38	1.61
Base shear X-dir (kN)	1317	789	1434
Base shear Y-dir (kN)	1325	759	1390
Design capacity (kN)	5809	4924	5414

Load intensity in all three types of buildings is kept nearly same for comparison of various parameters and behavior of CFT, RCC and Steel building. When graph of mode shape v/s Time period for a ten storey CFT structure was plotted, first three mode shapes were found in Y direction, X- direction and XY direction. The time period for 1st mode in Y direction was 1.332 second while for X direction was 1.316 second. First mode in Y direction had maximum displacement and was governing. As shown in Table.3, percentage reduction in time period of CFT building is 44.1% and 17.4% with compared to RCC and Steel building respectively. Also base shear due to earth quake load and load carrying capacity of CFT building is found to be higher than RCC by 15.2%, while for steel by 6.8%

Table 4: Displacement Comparison

Storey	CFT	RCC	STEEL
10	16.8	48.1	27.6
9	16.4	47.7	26.9
8	15.5	45.7	25.5
7	14.3	42.8	23.7
6	12.9	38.8	21.5
5	11.1	33.6	18.6
4	8.9	27.3	15.3
3	6.6	19.9	11.6
2	4.1	11.9	7.5
1	1.7	4.4	3.3
0	0.0	0.0	0.0

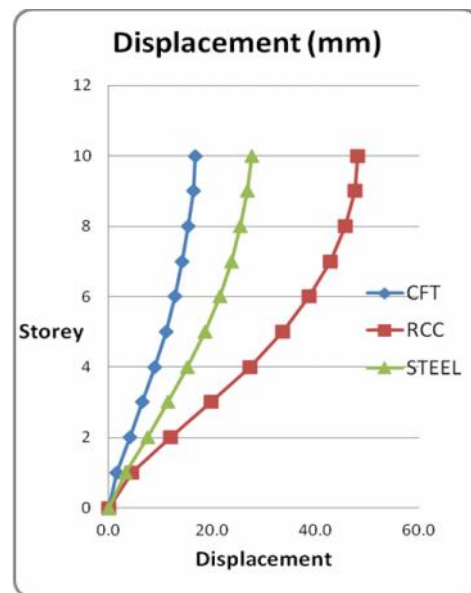


Fig 5 10 Storey Displacement

Percentage reduction in top storey displacement of CFT building is 65.1% and 39.1% with compared to RCC and Steel building respectively shown in Table.4 and compared in Fig 5

2.2 Comparison of Twenty storey CFT, R.C.C and Steel building

Table 5 : Design Parameter Comparison

Structure	CFT	RCC	STEEL
Load intensity (kN/m ²)	8.61	9.47	7.46
Time period(sec) for 1st mode	2.089	2.805	2.540
Base shear X-dir (kN)	1949	1695	1918
Base shear Y-dir (kN)	1881	1529	1969
Design capacity (kN)	14094	11402	10250

Load intensity in all three types of buildings was kept nearly same for comparison purpose. First three mode shapes in case of CFT building were in Y direction, X- direction and XY direction with time period in first and second mode in Y direction being 2.089 second and X direction being 2.056 second. The maximum displacement was due to wind in Y direction, thus becoming a governing case. As observed from Table.5 percentage reduction in time period of CFT building is 25.5% and 17.8% with compared to RCC and Steel building respectively. Base shear due to earth quake load and load carrying capacity of CFT building is found to be higher than RCC by 19.1%, while for steel by 27.3% as given in Table.5. Top storey displacement reduction in CFT building is 39.5% and 33.5% with compared to RCC and Steel building respectively as shown in Table 6 and Fig 6

Table 6 : 20 Storey Displacement Comparisons

Storey	CFT	RCC	STEEL
20	37.7	62.3	56.7
19	37.4	61.8	56.3
18	36.8	61.1	55.4
17	36.2	60.2	54.6
16	35.3	59.0	53.6
15	34.4	57.3	52.2
14	33.2	55.4	50.6
13	32.0	52.8	48.5
12	30.5	50.0	46.2
11	28.7	46.7	43.5
10	26.7	42.9	40.5
9	24.5	39.2	37.1
8	22.1	35.0	33.5
7	19.5	30.6	29.6
6	16.7	26.0	25.4
5	13.7	21.0	21.0
4	10.5	15.9	16.4
3	7.4	10.8	11.4
2	4.2	5.9	6.6
1	1.4	2.0	2.4
0	0.0	0.0	0

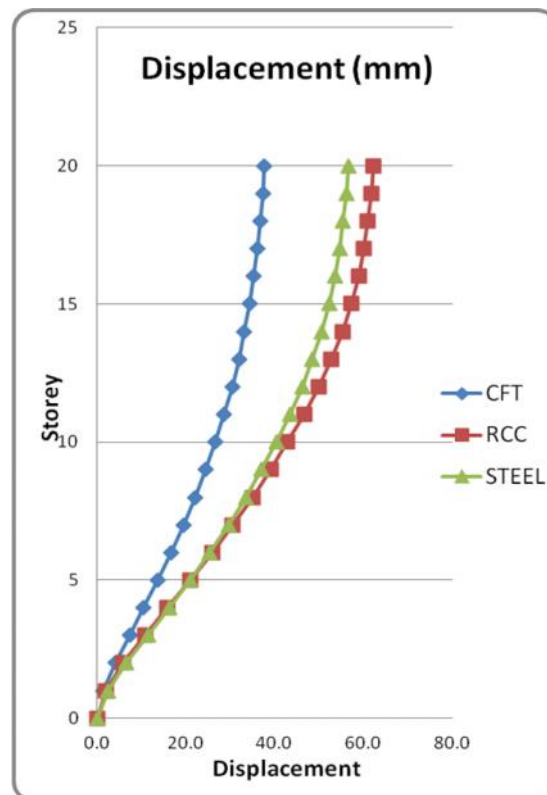


Fig. 6: Displacement of 20 storey CFT, RCC and Steel Building

2.3 Comparison of Thirty storey CFT, RCC and Steel Building

Table 7 : Design Parameter Comparison

Structure	CFT	RCC	STEEL
Load intensity (kN/m ²)	9.33	9.59	7.66
Time period(sec) for 1st mode	3.30	4.47	3.42
Base shear X-dir (kN)	2175	1946	2256
Base shear Y-dir (kN)	1927	1633	1880
Design capacity (kN)	21588	16675	19032

For comparison of various parameters and behavior of CFT, RCC and Steel building, load intensity in all three types of buildings was kept nearly same. Time period for first and second mode in Y direction and X direction was 3.297 and 3.238 second.

Table 8 : 30 Storey Displacement Comparisons

Storey	CFT	RCC	STEEL
30	98.6	179.6	130.8
29	97.8	177.9	129.5
28	96.8	176.7	128.3
27	95.6	175.2	126.6
26	94.1	173.4	124.8
25	92.3	171.5	122.6
24	90.0	167.3	120.2
23	87.6	163.8	117.3
22	84.9	159.5	114.2
21	81.9	153.5	110.9
20	78.8	148.2	107.4
19	75.5	143.3	103.7
18	72.0	138.5	99.8
17	68.6	132.5	95.6
16	65.0	125.6	91.2
15	61.5	119.0	86.7
14	57.9	112.1	81.8
13	54.2	104.7	76.7
12	50.4	96.9	71.3
11	46.5	88.5	65.7
10	42.3	79.8	59.7
9	38.0	70.8	53.6
8	33.5	61.8	47.1
7	28.8	52.4	40.5
6	24.0	42.9	33.6
5	19.1	33.5	26.7
4	14.3	24.3	19.8
3	9.5	15.6	13.1
2	5.1	8.0	7.1
1	1.7	2.4	2.3
0	0.0	0.0	0.0

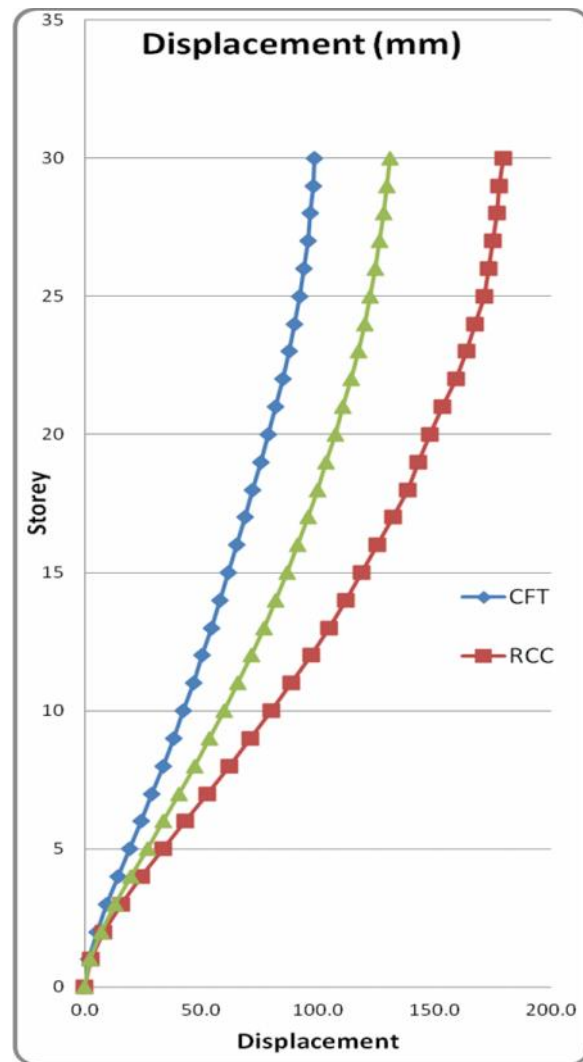


Fig. 5: Displacement of 30 storey CFT, RCC and Steel Building

Percentage reduction in time period of CFT building is 26.2% and 3.5% with compared to RCC and Steel building respectively. Also base shear due to earth quake load and load carrying capacity of CFT building is found to be higher than RCC by 22.8%, while for steel by 11.8% as shown in Table.7. From the graph of displacement v/s storey height, it is observed that concrete filled steel tube structure has less displacement compared to RCC and Steel building. Percentage reduction in top storey displacement of CFT building is 45.1% and 24.6% with compared to RCC and Steel building respectively.

3. Conclusions

1. For 30 storey building permissible displacement limit is 180mm as per deflection criteria and RCC building top story displacement was 179.6mm very near to permissible limit. Therefore it can be said that beyond 30 storey RCC will not be useful with this geometric frame structure.
2. Percentage reduction in time period was 26.2 % and 3.5 % for a 30 storey CFT building compared to RCC and steel building while for 20 storey it was 25.5 and 17.8% compared RCC and Steel structure.
3. Load carrying capacity for 20 storey CFT structure increased by 19.1 % and 27.3% compared to steel and RCC structure while for 30 storey CFT structure increase was by 22.8% and 11.8% compared to RCC and Steel building.
4. Present work shows the use of concrete filled steel tube columns has been consistently applied in the design of tall buildings as they provide considerable economy in comparison with conventional steel building. Also performance wise result good compared to RCC and Steel building.

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