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Comparative Study on Seismic Performance of Steel Building & Composite Building with CFT & CFST Column

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Abstract

In this paper a comparative study is done on Steel building & Composite building with CFT, CFT with stiffeners, CFDST Hollow & CFDST column. Seismic Analysis of (B+G+9) building is done in both Equivalent Static method & Response Spectrum method using ETABS software & Optimum Composite column is obtained from Parameter 1 (Steel Ratio, Buckling Load, Plastic Resistance, H/T Ratio), Parameter 2 (Displacement, Story Drift, Base Shear, Overturning Moment, Story Stiffness), Parameter3 (Moment of Inertia, C/S Area, Total Weight, Total Tonnage).

Keywords: CFT; CFT with Stiffeners; CFDST Hollow; CFDST Column; Response Spectrum Method; H/T Ratio; Displacement; Total Tonnage

Abbreviations: CFT: Concrete Filled Tubes; CFDST: Concrete Filled Double Skin Tubes.

Introduction

- In-present, composite structures are becoming more popular in INDIA due to the benefits in structural performance and construction sequence.
- Due to the adoption & advancement of composite structures, the buildings are becoming more slender, having longer span, has increase in stiffness and Buckling Load, has Reduction in total Tonnage and C/S Area of the composite column than R.C.C and Steel column and the performance is good in case of earthquake conditions.
- CFT (Concrete Filled Tubes) column is a type of composite column, where local buckling is delayed by concrete core & buckling load of concrete is increased by the confinement effect of steel tube.
- CFT with stiffeners is same as CFT column but this column has additional steel plates in longitudinal or transversal direction of the column, this addition of steel plate is to increase the stiffness of composite column by increasing the steel ratio of the column.
- CFDST Hollow (Concrete Filled Double Skin Tubes) is a creative innovation which is formed by two layers of steel tube which is embedded by a concrete layer between these steel tubes. The second layer of steel tube is left hollow to reduce the C/A area & weight of the column. It has additional advantages like high strength, high stiffness, good seismic and fire performance.
- CFDST column is same as the above column, but the second layer of steel tube is filled with high strength

concrete or same grade of concrete as of the embedded concrete.

- This type of column is normally used when the building has very high axial load which is commonly used in High-Rised building.
- The design of composite slab & composite column is done as per Eurocode 4.

Objective

- To Study the characteristics and structural performance of building with inclusion of CFT (Concrete Filled Tubes), CFT with Stiffeners, CFDST Hollow & CFDST (Concrete Filled double Skin Tubes) columns.
- To analyse the building in Response Spectrum method.
- To obtain the effective performance of different composite column using Parameter 1 (Buckling Load, Plastic Resistance, H/T Ratio, Steel Ratio) & Parameter 2 (Displacement, Story Drift, Base Shear, Overturning moment, Stiffness) in ETABS.
- To find the Optimum Tonnage for different types of columns.

Scope

- Analytical study on the Seismic performance of Composite building with CFT (Concrete Filled Tubes), CFT with Stiffeners, CFDST Hollow & CFDST (Concrete Filled Double Skin Tubes) composite columns & comparing with Steel building by Response Spectrum method.

Methodology

- Literature survey.
- Using different types of Composite column by changing its inner tube dimension (75,100,150,200,250,300mm) & thickness of tubes (i.e., column with same inner & outer tube dimension (ST), column with thick inner & thin outer tube dimension (IT), column with thin inner & thick outer tube dimension (OT)) [1].
- Seismic Analysis of the model by both Equivalent Static Method & Response Spectrum Method is performed in ETABS [2].
- The considered parameters are, Parameter 1(Buckling Load, Plastic Resistance, H/T Ratio, Steel Ratio), Parameter 2(Displacement, Storey Drift, Base Shear, overturning moment, Stiffness), Parameter 3(C/S Area, Total Tonnage) [3].
- Obtaining the Optimum column with respect to different parameters [4].

Structural System

Steel Structure: The structural system consists of Steel Beams, Deck Slabs, Steel Columns, Footing and RC core. Transfer Girders will be supporting the floors which is cantilever [5].

Composite Structure: The structural system consists of Steel Beams, Deck Slabs, CFT, CFT with Stiffeners, CFDST Hollow & CFDST Composite Columns with different steel ratio, Footing and RC Core. Transfer Girders will be supporting the floors which is cantilever (Table 1).

Grade of Steel	Steel Grade for Steel Building	Steel Grade for Composite Building
Columns	Fe350	S355
Beam	Fe350	Fe350
Deck Slab	Fe350	Fe350
Inclined Member	Fe350	Fe350

Table 1: Grade of Steel.

Design Methodology

All Steel structures are designed according to the Limit State Method as specified in IS 800:2007 and the Deck Slab is designed as per ASCI 360-16. Composite column is manually designed as per Euro code 4. Appropriate loads and its combination for the building are considered as per relevant IS codes [6].

Earthquake Load

The loading due to earthquake is assumed based on the provisions of IS1893:2016 considering seismic zone – III [7].

Design factors:

- Zone factor, Z = 0.16
- Importance Factor, I = 1.5 (Hospital Building)
- Response reduction factor, R = 4.0 (Steel Building)
- Response reduction factor, R = 4.0 (Composite Building)
- Damping Ratio= 5%

Beam and Column Orientation

The beams and columns are orientated based on the shear force and bending moment diagrams. The orientation for typical floor & 3D View is as follows (Tables 2-6):

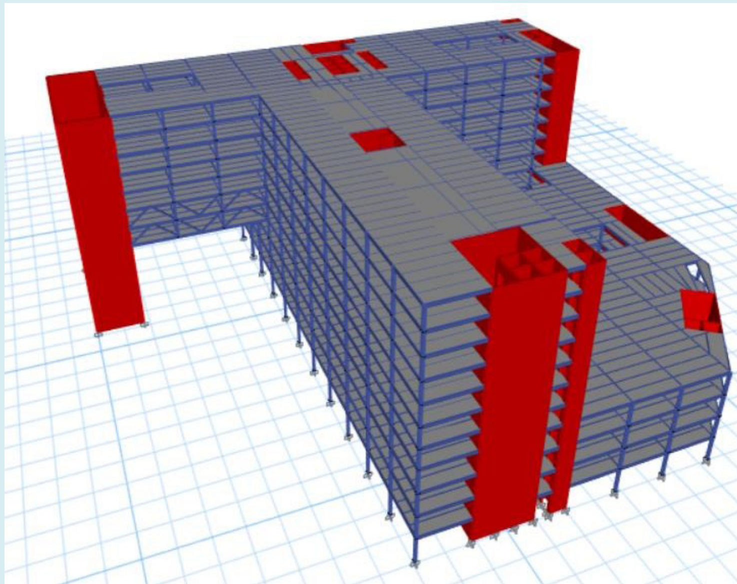


Figure 1: 3D View.

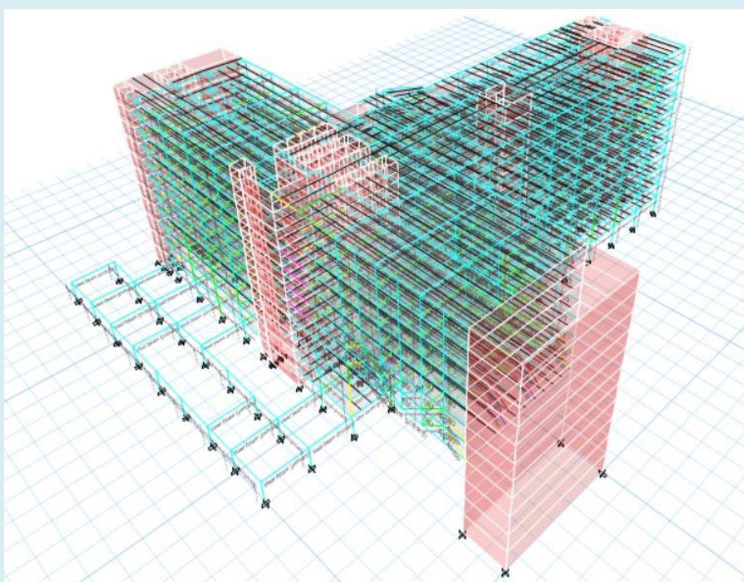


Figure 2: Design of Beam & Column in Building.

Different Types of Composite Column

CFT- Concrete Filled Tube
CFT(S)- Concrete Filled Tube with Stiffeners
CFDST Hollow- Concrete Filled Double Skin Tube with inner Hollow
(ST1)- CFDST Hollow of same thickness
(IT1)- CFDST Hollow of Inner thick Tube
(OT1)- CFDST Hollow of Outer thick Tube
CFDST- Concrete Filled Double Skin Tube
(ST2)- CFDST of same thickness
(IT2)- CFDST of Inner thick Tube
(OT2)- CFDST of Outer thick Tube

Different Composite Columns used in Building

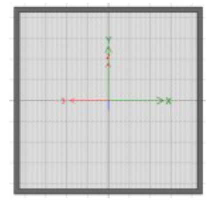
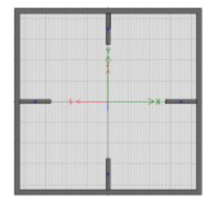
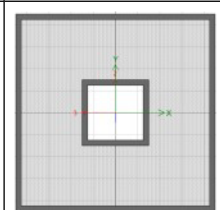
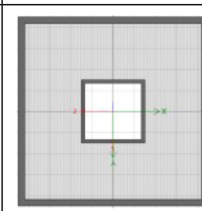
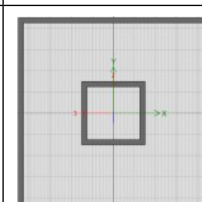
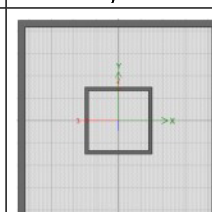
Composite Column Section	OUTER TUBE Dimension			Inner Tube Dimension			Figure
	B	L	T	B	L	T	
	mm	mm	mm	mm	mm	mm	
CFT	450	450	12	-	-	-	
CFT(S)	450	450	12	4 nos. Plate Section (75x8mm)			
ST1	450	450	12	75-300	75-300	12	
IT1	450	450	8	75-300	75-300	16	N/A
OT1	450	450	16	75-300	75-300	8	
ST2	450	450	12	75-300	75-300	12	
IT2	450	450	8	75-300	75-300	16	N/A
OT2	450	450	16	75-300	75-300	8	
TOTAL							

Table 2: Different Composite Columns used in Building.

Model Output

Parameter 1

(Steel Ratio, Buckling Load, Plastic Resistance, H/T Ratio)

	CFT	CFT (S)	(ST1)	(IT1)	(OT1)	(ST1)	(IT1)	(OT1)	(ST1)	(IT1)	(OT1)	(ST1)	(IT1)	(OT1)	(ST1)	(IT1)	(OT1)	(ST1)	(IT1)	(OT1)	THICK NESS LIMIT
Inner steel tube	-	-	75	75	75	100	100	100	150	150	150	200	200	200	250	250	250	300	300	300	-
Steel Ratio	0.35	0.37	0.38	0.32	0.42	0.39	0.34	0.42	0.41	0.38	0.44	0.44	0.42	0.47	0.48	0.46	0.5	0.52	0.5	0.53	-
Buckling Load	8704	9040	11646	9965	13238	11841	10251	13337	12158	10759	13455	12386	11194	13468	12521	11561	13372	12556	11852	13156	-
Plastic Resistance	12592	13290	13388	11631	15067	13635	12007	15185	14010	12640	15302	14225	13112	15258	14279	13425	15054	14174	13578	14691	-
H/T Ratio (outer Tube)	37.5	37.5	37.5	56.25	28.13	37.5	56.25	28.13	37.5	56.25	28.13	37.5	56.25	28.13	37.5	56.25	28.13	37.5	56.25	28.13	42.31
H/T Ratio (InnerTube)	-	-	6.25	4.69	9.38	8.33	6.25	12.5	12.5	9.38	18.75	16.67	12.5	25	20.83	15.63	31.25	25	18.75	37.5	42.31

Table 3: Comparison of Different CFDT Hollow Column.

	(OT1)	(OT1)	(OT1)	(OT1)	(OT1)	(OT1)	(RS1)	(RS1)	(RS1)	(RS1)	(RS1)	Thickness Limit
Outer Steel Tube Dimension	450	450	450	450	450	450	375	375	375	375	375	-
Inner Steel Tube Dimension	75	100	150	200	250	300	75	100	150	200	250	-
Steel Ratio	0.42	0.42	0.44	0.47	0.5	0.53	0.45	0.46	0.48	0.51	0.55	-
Buckling Load	13238	13337	13455	13468	13372	13156	9625	9718	9841	9877	9821	-
Plastic Resistance	15067	15185	15302	15258	15054	14691	11692	11810	11926	11883	11679	-
H/T Ratio (Outer Tube)	28.13	28.13	28.13	28.13	28.13	28.13	23.44	23.44	23.44	23.44	23.44	42.31
H/T Ratio (Inner Tube)	9.38	12.5	18.75	25	31.25	37.5	9.38	12.5	18.75	25	31.25	42.31

Table 4: Comparison of OT1 & RS1 Column.

	CFT	CFT (S)	CFDST (ST2) 75	CFDST (IT2) 75	CFDST (OT2) 75	CFDST (ST2) 100	CFDST (IT2) 100	CFDST (OT2) 100	CFDST (ST2) 150	CFDST (IT2) 150	CFDST (OT2) 150	CFDST (ST2) 200	CFDST (IT2) 200	CFDST (OT2) 200	CFDST (ST2) 250	CFDST (IT2) 250	CFDST (OT2) 250	CFDST (ST2) 300	CFDST (IT2) 300	CFDST (OT2) 300	THICK NESS LIMIT
Inner Steel Tube Dimension	-	-	75	75	75	100	100	100	150	150	150	200	200	200	250	250	250	300	300	300	-
Steel Ratio	0.35	0.37	0.48	0.43	0.51	0.48	0.44	0.51	0.5	0.47	0.52	0.51	0.49	0.52	0.52	0.5	0.5	0.53	0.52	0.53	-
Buckling Load	8704	9040	9500	7741	11178	9789	8120	11372	10372	8884	11765	10972	9674	12166	11595	10505	12577	12245	11388	12997	-
Plastic Resistance	12592	13290	10616	8737	12417	10984	9227	12663	11720	10209	13153	12457	11190	13644	13193	12172	14135	13929	13153	14626	-
H/T Ratio (outer tube)	37.5	37.5	37.5	56.25	28.13	37.5	56.25	28.13	37.5	56.25	28.13	37.5	56.25	28.13	37.5	56.25	28.13	37.5	56.25	28.13	42.31
H/T Ratio (Inner tube)	-	-	6.25	4.69	9.38	8.33	6.25	12.5	12.5	9.38	18.75	16.67	12.5	25	20.83	15.63	31.25	25	18.75	37.5	42.31

Table 5: Comparison of Different CFDT Column.

	(OT2) 75	(OT2)100	(OT2)150	(OT2)200	(OT2)250	(OT2)300	(RS2)75	(RS2)100	(RS2)150	(RS2)200	(RS2)250	THICKNESS LIMIT
Outer Steel Tube Dimensions	450	450	450	450	450	450	375	375	375	375	375	-
Inner Steel Tube Dimensions	75	100	150	200	250	300	75	100	150	200	250	-
Steel Ratio	0.51	0.51	0.52	0.52	0.5	0.53	0.53	0.53	0.54	0.55	0.55	-
Buckling Load	11178	11372	11765	12166	12577	12997	8451	8592	8953	9330	9726	-
Plastic Resistance	12417	12663	13153	13644	14135	14626	10011	10200	10691	11182	11673	-
H/T Ratio (Outer Tube)	28	28	28	28	28	28	23	23	23	23	23	42.31
H/T Ratio (Inner Tube)	9.38	12.5	18.75	25	31.25	37.5	9.38	12.5	18.75	25	31.25	42.31

Table 6: Comparison of OT2 & RS2 Column.

Output 1

1. Load carrying capacity of CFT column is greater than Steel column [8].
2. CFT(S) has higher Buckling Load than CFT column due to increase in Steel Ratio [9].
3. CFDST Hollow column

- Considering dimension for CFT, CFDST HOLLOW, composite column are 450X450 mm, 650X650mm, 800X800mm & for RS1 the column dimension is 375X375mm, 575X575mm, 725X725mm.
- CFDST Hollow (IT1) composite column does not satisfy the H/T ratio limit as per Euro Code 4 (H/T<= Sqrt(235/Fy)). So, CFDST Hollow (IT1) composite column is only considered for comparison of Steel Ratio, Buckling Load, Plastic Resistance.
- Comparing CFT, ST1 & OT1, OT1 has higher Buckling Load & Steel Ratio.
- Higher the Steel Ratio higher the Buckling Load & Plastic Resistance for ST1, IT1, RS1. In case of OT1, when Steel Ratio increases, there is increase to some extent but decreases in Buckling Load & Plastic Resistance due to less amount of concrete participation. OT1 Buckling Load is always greater than ST1, IT1, RS1.

4. CFDST column

- Considering dimension for CFT, CFDST composite column are 450X450 mm, 650X650mm, 800X800mm & for RS2 the column dimension is 375X375mm, 575X575mm, 725X725mm.
- Higher the Steel Ratio higher the Buckling Load & Plastic Resistance for ST2, IT2, OT2, RS2. Inner tube dimension of 75, 100mm of IT2, RS2 CFDST column has lesser Buckling load than CFT column (due to use of lesser grade of concrete in CFDST column)

5. Comparing the Steel Ratio & Buckling Load of CFDST Hollow & CFDST composite column the CFDST Hollow (ST1, IT1, OT1, RS1) performs good with lesser Steel Ratio and higher Buckling Load than CFDST (ST2, IT2, OT2, RS2) column, due the lesser grade of concrete provided in CFDST column [9].
6. The steel Ratio of different composite column should be in between 0.2=> <=0.9, so all composite columns satisfies the condition as per Eurocode4 [10].

Parameter 2

(Displacement, Story Drift, Base Shear, Overturning Moment, Story Stiffness) Table 7.

CFDST Hollow column						
RSX	**STEEL**	**CFT**	**CFT(S)**	**(ST1)**	**(OT1)**	**(RS1)**
DISPLACEMENT	11.066	11.139	11.159	11.137	11.126	11.149
STORY DRIFT	0.000284	0.000286	0.000286	0.000286	0.000285	0.000286
BASE SHEAR	65286	65058.4	65007.8	64652	64687.2	64241.2

Table 7: Comparison of CFDST Hollow Column in X-Direction

Output 2

1. Displacement & Story Drift of CFT column has a percentage increase of 0.66% & 0.70% respectively and the Base Shear, Overturning Moment, Stiffness of CFT column has percentage decrease of 0.35%, 0.25%, 3.59% when compared to Steel column. So, CFT column performs good when compared to Steel column [11].
2. Displacement, Stiffness of CFT(S) column has a percentage increase of 0.18%, 0.13% respectively and the Base Shear, Overturning Moment of CFT(S) column has a percentage decrease of 0.08%, 0.11%, when compared to CFT column. So, CFT(S) column performs well when compared to CFT column [12].
3. CFDST Hollow column:

- Displacement, Base Shear, Overturning Moment of ST1 column has a percentage decrease of 0.02%, 0.62%, 0.66% respectively and the Stiffness of ST1 column has a percentage increase of 11.03% when compared to CFT column. So, ST1 column performs good when compared to CFT column [13].
- Displacement, Story Drift, Base Shear, Overturning Moment of OT1 column has a percentage decrease of 0.12%, 0.35%, 0.57%, 0.61% respectively and the Stiffness of OT1 column has a percentage increase of 16.91% when compared to CFT column. So, OT1 column performs good when compared to CFT column [14].
- Displacement, Story Drift of OT1 column has a percentage decrease of 0.10%, 0.35% respectively and the Base Shear, Overturning Moment, Stiffness of OT1 column has a percentage increase of 0.05%, 0.06%, 6.61% when compared to ST1 column. So, OT1 column performs good when compared to ST1 column [15].
- Displacement, Story Drift, Base Shear, Overturning Moment, Stiffness of RS1 column has a percentage decrease of 0.21%, 0.35%, 0.69%, 0.71%, 36.78% respectively when compared to OT1 column. So, RS1 column performs good when compared to OT1 column

[16].
- In ST1, OT1, RS1 columns considering different inner tube dimensions such as 75,100,150,200,250,300mm, larger dimension tube performs good in considered parameters [17].

4. CFDST column:
- Displacement, Story Drift of ST2 column has a percentage increase of 0.70%, 0.69% respectively and the Base Shear, Overturning Moment, Stiffness of ST2 column has a percentage decrease of 0.10%, 0.12%, 1.10% when compared to CFT column. ST2 column performs good when compared to CFT column [18].
- Displacement, Story Drift, Base Shear, Overturning Moment, Stiffness of OT2 column has a percentage increase of 0.81%, 0.69%, 0.07%, 0.03%, 4.45% respectively when compared to CFT column. CFT column performs good when compared to OT2 column because the grade provided in CFT column is M60 & grade provided in OT2 column is M30 (Outer & Inner) [19].

Parameter 3

(Moment of Inertia, C/S Area, Total Weight, Total Tonnage) Tables 8-10.

Weight (Kg/m2)			Total Weight (Kg/m2)	Total Tonnage	Percentage Reduction
	steel	concrete			
STEEL	4354	-	4354	335.23	-
CFT	188	1022	1211	123.03	63.3
CFT(S)	314	1022	1336	133.38	60.21

Table 8: Comparison of Steel & Composite Column.

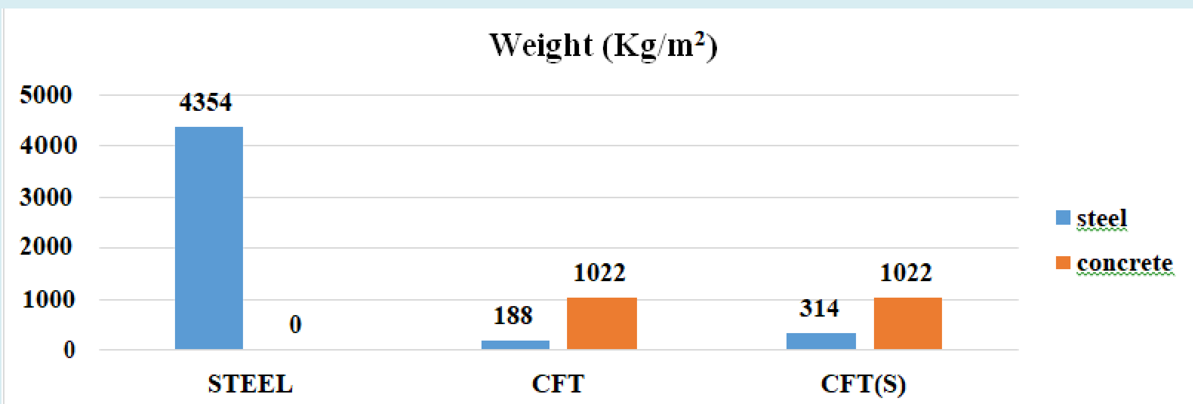


Figure 2: Weight of Steel, CFT, CFT(S) column.

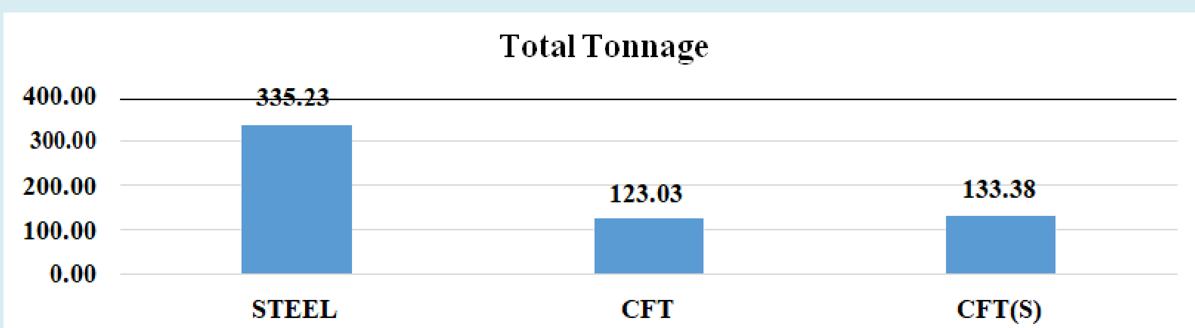


Figure 3: Tonnage of Steel, CFT, CFT(S) column.

	Weight (Kg/m²)		Total Weight (Kg/m2)	Total Tonnage	Percentage Increase
	steel	concrete			
STEEL	188	1022	1211	123.03	-
CFT(S)	314	1022	1336	133.38	7.76

Table 9: Comparison of CFT & CFT(S) column.

	Weight (Kg/m²)		Total Weight (Kg/m²)	Total Tonnage	Percentage Increase
	steel	concrete			
CFT	188	1022	1211	123.03	-
(ST1)	377	1022	1399	138.3	11.03
(OT1)	377	1003	1380	136.74	10.02

Table 10: Comparison of CFT & CFDST Hollow column.

Output 3

1. Comparing Steel, CFT & CFT(S) column, the C/S Area of CFT & CFT(S) is higher than that of Steel column. M.O.I of Steel column is high than that of CFT & CFT(S) and the Total Tonnage of CFT & CFT(S) column is less than that of Steel column where the Percentage of Reduction in Tonnage is 63.30% and 60.21% respectively [20].

2. Comparing CFT, CFT(S) composite column, C/S Area & M.O.I of both columns are same. The Total Tonnage of CFT(S) is higher than that of CFT, where the percentage increase is 7.76% with respect to CFT column [21].

3. CFDST Hollow column

- Comparing CFT, ST1, OT1 composite column, OT1 has less C/S Area than other columns (OT1<ST1<CFT). There is no significant change in M.O.I. The Total Tonnage of CFT is less than that of ST1, OT1 where the Percentage Increase is 11.03% & 10.02% for ST1 & OT1 respectively. (CFT<OT1<ST1) [22].
- Eliminating ST1 due to high Total Tonnage & less Buckling Load comparative to OT1 [23].
- So, while comparing the CFT & OT1 in Parameter 1, OT1 performs well and in Parameter 2 OT1 performs well and in Parameter 3 CFT performs well (where the Tonnage of CFT is less than that of OT1). So, the Reduced Size of OT1 comes in account and it is coined as Reduced Size RS1 [24].
- Comparing CFT, OT1, RS1 composite column, C/S Area of RS1 has less C/S Area (RS1<OT1<CFT). M.O.I of RS1 column is less than that of CFT & OT1. The Total Tonnage of RS1 is less than that of CFT, OT1 where the Percentage Decrease in Tonnage for RS1 is 0.71% when compared to CFT & Percentage Decrease for RS1 is 10.66% when compared to OT1 (RS1<CFT<OT1) [25].

Results

1. Comparing Steel & CFT Column, in Parameter 1,2,3, CFT column performs better than Steel column. Steel column can be replaced by CFT column.
2. Comparing CFT & CFT(S) Column, in Parameter 1,2, CFT(S) column performs better than CFT column and in Parameter 3 CFT column performs better than CFT(S) column.
3. CFT column can be replaced by CFT(S) column only in parameter 1&2, but CFT is optimum in parameter 3.
4. In parameter 1, comparing ST1, OT1& RS1 column with LITD (Larger Inner Tube Dimension), the buckling load of OT1, RS1 column performs slightly lesser than SITD (Smaller Inner Tube Dimension) for OT1 & RS1 column. This is due to less participation of concrete in CFDST Hollow column. But in case of ST1 column with LITD has higher buckling load than column with SITD.
5. In parameter 2, ST1, OT1, RS1 column with LITD performs well.
6. In parameter 3, comparing CFT, ST1 & OT1 column, CFT column has less tonnage than other columns (CFT<OT1<ST1).
7. In parameter 3, comparing CFT, OT1 & RS1 column, RS1 column has less tonnage than other columns (RS1<CFT<OT1).
8. CFT column can be replaced by ST1 column only in parameter 1&2, but CFT column is optimum in parameter 3.
9. CFT column can be replaced by OT1 column only in parameter 1&2, but CFT column is optimum in parameter 3.
10. Comparing ST1 & OT1 column, OT1 column performs good in all three parameters.
11. CFT column can be replaced by RS1 column in parameter 1,2,3. Done.
12. In parameter 1, when ST2, OT2 & RS2 column with SITD,

the buckling load performs lesser than column with LITD.

13. In parameter 2, ST2, OT2 & RS2 column with SITD performs well.
14. In parameter 3, comparing CFT, ST2 & OT2 column, CFT column has less tonnage than other columns (CFT<OT2=ST2).
15. In parameter 3, comparing CFT, OT2 & RS2 column, RS2 column has less tonnage than other columns (CFT<RS2<OT2).
16. CFT column can be replaced by ST2 column only in parameter 1&2, but CFT is optimum in parameter 3.
17. CFT column can be replaced by OT2 column only in parameter 1, but CFT is optimum in parameter 2&3.
18. In parameter 1, comparing ST1, IT1, OT1 column, where OT1 column performs good with Higher Steel Ratio and higher Buckling Load than ST2, IT2, OT2 column. This is due to M30 grade of concrete which is provided in inner & outer parts of CFDST column, where CFDST Hollow column is provided with M60 grade of concrete.
19. In parameter 2, comparing ST1, ST2, OT1, OT2 column, where OT1 column performs good than ST2, OT2 column. This is due OT1 column has highest Stiffness.

Conclusion

The Steel & Composite Building is compared with 3 different parameters, in which CFT column performs better than Steel Column. CFT(S) column performs good than CFT column. OT1 column performs better than CFT, ST1, ST2 & OT2 column. RS1 column performs better than CFT, OT1, OT2 and RS2 column. To conclude CFT column is a better replacement for Steel column. CFT(S) column is a better replacement (without increasing the column dimension) for CFT column when building has slightly higher buckling load. OT1 column is best replacement (without increasing the column dimension) for CFT column due to the Hollow inner tube which provides less C/S Area without compromising the buckling load. CFDST column is not optimum as CFDST Hollow column, where the inner tubes are filled with higher grade of concrete.

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