Comparison Of Seismic Behaviour Of A Typical Multi-Storey Structure With CFRP Wrapped CFST Columns And I Section Encased CFST Columns

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Abstract - *The use of Concrete Filled Steel Tubes (CFST) in building construction has increased significantly in the recent years mainly due to its simple construction sequence and superior structural performance. Therefore it is necessary to understand their behaviour as structural member. Extensive experimental studies about concrete filled steel tubes have been conducted in past. However experimental results are not sufficient to support the engineering of these components. Numerical investigation is to be done to know behaviour of Concrete-Filled Steel Tube columns strengthened with Carbon Fiber Reinforced Polymer (CFRP) sheet. The present study deals with seismic behaviour of G+12 to G+44 storey high rise buildings situated at Delhi assessed through response spectrum analysis using ETABS software package. The analysis were performed on Reinforced Cement Concrete (RCC) building with ordinary column, RCC building with CFST columns, CFRP wrapped CFST columns, and I section encased CFST columns. The analysis is done by just varying the column design and keeping all other structural members same for all the structures. Results were compared in terms of critical earthquake response parameters such as base shear, storey drifts, and storey displacements. Storey displacement is reduced up to 17% and drift is reduced up to 18% in composite columns compared to RC columns. The results of study indicate that the building with CFRP wrapped CFST columns, and I section encased CFST columns perform better against seismic forces.*

Key Words: **Concrete Filled Steel Tubes, Base shear, Storey displacement, Storey drift, Carbon Fiber Reinforced Polymer**

1. INTRODUCTION

Concrete-Filled Steel Tube (CFST) members have become most interesting composite members recommended by engineers for several modern structural projects. In the Concrete Filled Steel Tube (CFST) Structural System, concrete is used for filling steel tubes. These members are ideally suited for all applications because of their effective usage of construction material. In this type of composite members, the advantages of both Hollow Structural Steel (HSS) and concrete are utilized. Concrete Filled Steel Tube having excellent static and earthquake resistant properties and due to which, they are being used widely in real civil engineering projects. Concrete filled steel tubes possess properties such as high strength, high ductility and large energy absorption capacity. Local buckling is delayed due to interaction between concrete and steel tube. Concrete filled steel tubes are used in many structural applications including columns supported offshore platforms, roofs of storage tanks, bridge piers, piles and columns in seismic zones. However, the CFST members are similar to other structural members that may need strengthening for different reasons, such as degradation due to the environment, ageing, fire, fatigue, and upgrades to carry extra loads. The structural capacity of the column can be increased by rehabilitation and upgrading of existing infrastructure using section enlargement, external bonding of steel plates and fibers etc. Section enlargement and external bonding of steel plates are ineffective because of increase in cross section, extra project cost, it needs heavy tools, more time for repair work, installation difficulties and corrosion of steel plate causes de-bonding of members. These drawbacks are overcome by using external bonded Fiber Reinforced Polymer (FRP). Initially FRP is used in marine transportation, architectural cladding, aerospace transportation, automotive components, etc. Fiber-Reinforced Polymer (FRP) composite material has recently become an adequate solution for strengthening and upgrading structural members [10]. Carbon Fiber-Reinforced Polymer (CFRP) materials are used for strengthening steel members specifically, because it has a higher modulus of elasticity and tensile strength to weight ratio than steel, add to that it is very flexible to be applied to any shape of structural members.

When these types of composite members are used as structural columns, especially in high-rise buildings, CFST may be subjected to high lateral force. Therefore it is very important to study the behaviour of CFST Columns in axial compression and lateral loads. There is a need to study the residual strength and possible retrofit measures to enhance strength and/or ductility of the composite columns. Furthermore, strengthening may also be arisen if changes in the use of the structures imposing higher functional requirements than those anticipated in the original design are to take place. A limited number of studies have generally investigated the behaviour of CFST members strengthened by CFRP material. The main aim of this study is to analyze the performance of FRP strengthened CFST column in the structural aspects using ETAB2015 software. Results will be compared in terms of critical earthquake response parameters such as base shear, storey drifts, and storey displacements.

1.1 Objectives

- To compare RCC building with ordinary columns, RCC building with CFST columns and CFRP wrapped CFST columns, under Response Spectrum Analysis
- To compare RCC building with ordinary columns, RCC building with CFST columns and I section encased CFST columns under Response Spectrum Analysis
- To compare the influence of number of layers of CFRP wrapping on different cross sections of CFST columns by analysing base shear, storey drift, and storey displacement

2. MODELLING AND ANALYSIS

Investigation is carried out to assess the performance of the framed structure with different column schemes, RCC, CFST, CFRP wrapped CFST and I section encased CFST. The structural system of the building consists RCC slabs and beams, ordinary RCC columns and concrete filled steel tube columns. These buildings are analyzing in compliance to the Indian Code of Practice for Seismic Resistant Design of Buildings and ANSI/AISC 360-05 for analysis of CFST column. Institutional buildings with G+12, G+20, G+28, G+36, and G+ 44 storeys were considered at Delhi in seismic zone IV. Plan dimensions are chosen as 24mx20m.The buildings are assumed to be fixed at the base and floors acts as rigid diaphragms. Storey height for different building is taken as 4m. The preliminary sections of slabs have been fixed as 125mm on the basis of deflection criteria [i.e. span to depth ratio]. The program consists of analyzing each of the multi-storey buildings using ETABS 2015. The Storey drift, storey displacement, and base shear were observed for all models. The basic loading on all types of structures are kept same, other relevant data is tabulated in Table 6.1 to 6.3

Table-1: Material properties

Particulars	**RCC**	**CFST**
Grade of Concrete	M30	M30
Grade of Reinf. Steel	Fe415	-
Grade of structural steel	-	Fe250
Unit wt. of concrete	25kN/m^3	25 kN/m^3

Table-2: Building details

No. of stories	Beam sizes (mm x mm)	Size of rectangular columns (mm x mm)	Diameter of circular columns (mm)
G+12	450x450	550x600	550
G+20	600x600	650x700	700
G+28	650x650	750x830	830
G+36	700x700	800x950	950
G+44	750x750	950x1100	1100

Table-3: CFST Column Details

Modal	Column shape	Size
G+12	Rectangular	550mmx600mmx10mm
	Circular	550mmx10mm
G+20	Rectangular	650mmx700mmx12mm
	Circular	700mmx12mm
G+28	Rectangular	750mmx830mmx14mm
	Circular	830mmx14mm
G+36	Rectangular	800mmx950mmx16mm
	Circular	950mmx16mm
G+44	Rectangular	950mmx1100mmx18mm
	Circular	1100mmx18mm

The study investigated the effects of multiple layers of CFRP sheet (1, 2, and 3 layers) applied to CFST columns. Two types of tube cross-sections (rectangular and circle) were investigated in this study. The columns are fully wrapped with CFRP sheets. The CFRP sheets are assumed as linear orthotropic materials. Therefore, different material constants are to be given as input. The mechanical properties of the CFRP that were used in this study are shown in Table 6.4. The study also includes CFST columns encased with steel I section. ISW400 and ISW600 steel sections are used in the study.

Table-4: CFRP details

Elastic modulus	Tensile strength	Poisson's ratio	Ultimate strain (%)	Thickness
(GPa)	MPa			t_f (mm)
255	4212	0.42	1.67	5

2.1 Loading Considered

The dead load comprises of self-weight pertaining to all permanent construction, including walls, floor, roofs, partitions, stairways and equipment. The design dead loads are calculated in accordance with the unit weights of materials as per IS 456:2000, clause 19.2 and it is default in ETABS software. The live load includes the loads produced by personnel, movable equipment and other items placed on the structure, but not permanently attached to it. Live loads are in accordance with IS875 Part 2-1987, Table 1. For institutional buildings, live load is taken as 3 kN/m^2 Assumed floor finish= 1kN/m^2.Earthquake Load is taken as per IS 1893 (part-I):2002 clause 6.3.1.2

2.2 Load Combinations

The gravity loads and earthquake loads will be taken for analysis. The basic loads are Dead loads (DL), Imposed load (LL), Earthquake load (EQ) along X and Y in positive and negative direction. Load combinations for analysis are taken as per IS 875 part 5-1987, clause 8.1.

2.3 Analysis of Building

The explained 3D building models were analysed using Response spectrum method. Different parameters such as storey drift, base shear and storey displacement are to be studied for the models.

Table-5: Seismic data

Building situated	Delhi
Seismic zone (Z)	IV
Response Reduction Factor (RF)	5
Importance Factor (I)	1
Damping Ratio (DM)	.05
Response Spectrum Function	IS 1893 – 2002 Spectrum
Soil Type	Medium soil

3. RESULTS AND DISCUSSIONS

Here results obtained for G+12 storey buildings are explained and discussed.

3.1 G+12 Storey Building with Circular Columns Comparison

This section deals with the comparison of G+12 building having ordinary circular columns, composite circular columns, CFRP wrapped circular composite columns and circular composite column encased with I section. The parameters used for the comparison are displacement, storey drift and base shear and the values obtained in x and y directions are shown in graphs.

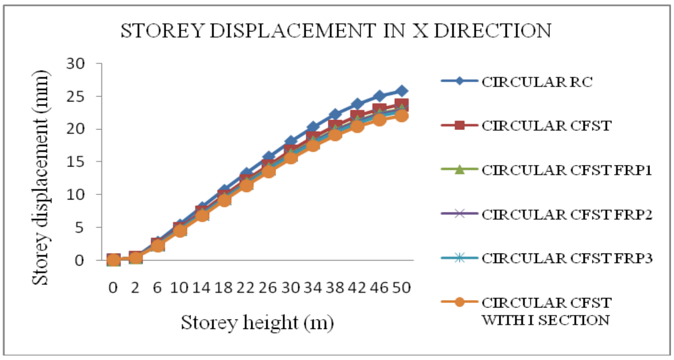

Chart-1: Comparison of storey displacement of G+12 building with circular columns along X direction

According to IS 456 clause 20.5, the maximum limit for lateral displacement is H/500, where H is building height. Here the maximum limit is 96mm and all the values obtained are within the permissible limit. CFST columns shows 8.69% decrease in storey displacement and I section encased CFST columns shows 17.22% decrease in displacement compared to ordinary RC columns in X direction. As per analysis, buildings with 1, 2, and 3 layers wrapped circular CFST columns shows 12.28%, 12.97%and 13.66% decrease in storey displacement in X direction as compared to building with ordinary RCC columns. Encasement of steel I section in CFST columns reduces storey displacement by 7.85% and 3 layers of wrapping using CFRP reduces 4.58% storey displacement compared to CFST columns in X direction.

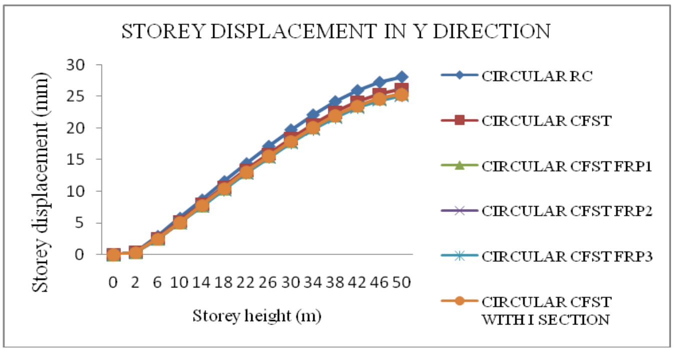

Chart-2: Comparison of storey displacement of G+12 building with circular columns along Y direction

Storey displacement in Y direction is more for all structures compared to X direction. CFST columns shows 7.26% decrease in storey displacement and I section encased CFST columns shows 10.63% decrease in displacement compared to ordinary columns in Y direction. As per analysis, buildings with 1, 2, and 3 layers wrapped circular CFST columns shows 10.31%, 10.91%and 11.49% decrease in storey displacement in X direction as compared to building with ordinary RCC columns. Encasement of steel I section in CFST columns reduces storey displacement by 3.14% and 3layers of wrapping using CFRP reduces 3.95% storey displacement compared to CFST columns in Y direction. Building with RCC columns shows highest displacement. Wrapping of CFST columns using CFRP sheets reduces the storey displacement. But number of layers has less influence on storey displacement. Steel I section increases the stiffness of structure.

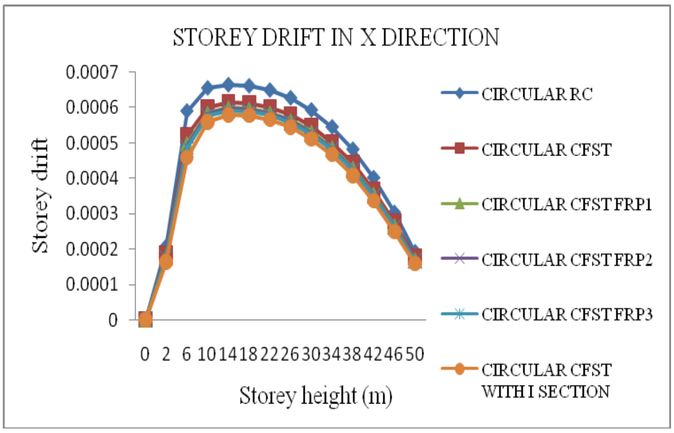

Chart-3: Comparison of storey drift of G+12 building with circular columns along X direction

According to IS 1893 part 1:2002 clause 7.11.1, the maximum horizontal relative displacement due to earthquake forces between two successive floors shall not exceed 0.004 times the difference in levels between these floors. Here the storey drift limit is 0.016 and all the values are within the permissible limit. The greater the drift value, the greater the likelihood of damage. CFST columns shows 7.80% decrease in storey drift and I section encased CFST columns shows 14.11% decrease in storey drift compared to ordinary RC columns in X direction. As per analysis, buildings with 1, 2, and 3layers wrapped circular CFST columns shows 10.68%, 11.24%and 11.99% decrease in storey drift in X direction as compared to building with ordinary RCC columns. Encasement of steel I section in CFST columns reduces storey drift by 5.85% and 3 layers of wrapping using CFRP reduces 3.88% storey drift compared to CFST columns in X direction.

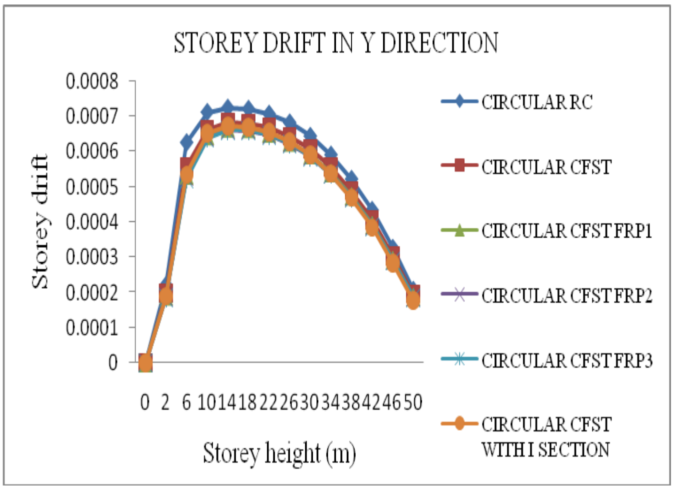

Chart-4: Comparison of storey drift of G+12 building with circular columns along Y direction

CFST columns shows 6.30% decrease in storey drift and I section encased CFST columns shows 7.89% decrease in storey drift compared to ordinary RC columns in Y direction. As per analysis, buildings with 1, 2, and 3 layers wrapped circular CFST columns show 8.69%, 9.19%and 9.68% decrease in storey drift in Y direction as compared to building with ordinary RCC columns. Encasement of steel I section in CFST columns reduces storey drift by 1.49% and 3layers of wrapping using CFRP reduces 3.18% storey drift compared to CFST columns in Y direction.

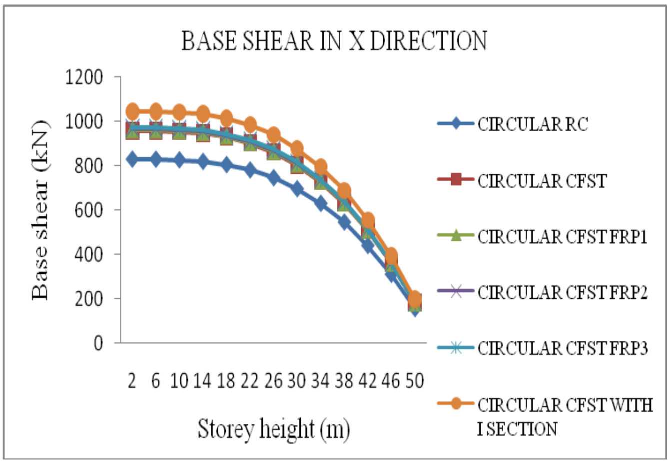

Chart-5: Comparison of base shear of G+12 building with circular columns along X direction

Base shear in the CFST columns with encased I section used building 20.84% more compared to RCC structures. This is because weight of the structure is more in this type of structures. CFRP wrapping also increases the base shear by13.93%, 14.37% and 14.81% for 1, 2 and 3 layers of wrapping in CFST columns compared to ordinary RCC columns in X direction.

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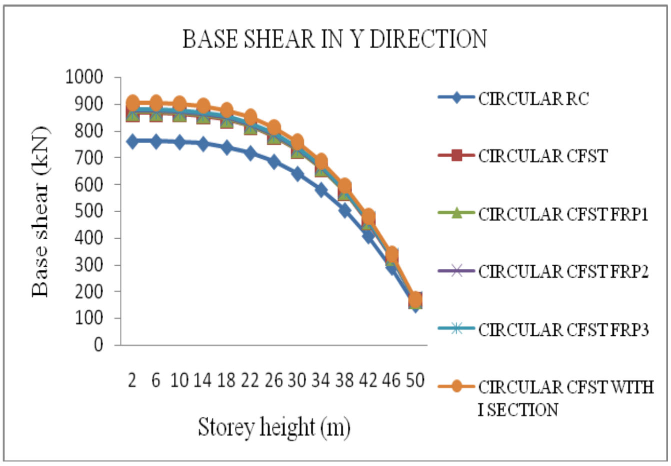


Chart-6: Comparison of base shear of G+12 building with circular columns along Y direction

Base shear in the CFST columns with encased I section used building 8.60% more compared to RCC structures. This is because weight of the structure is more in this type of structures. CFRP wrapping also increases the base shear by12.4%, 12.8% and 13.2% for 1, 2 and 3 layers of wrapping in CFST columns compared to ordinary RCC columns in Y direction.

3.2 G+12 Storey Building with Rectangular Columns Comparison

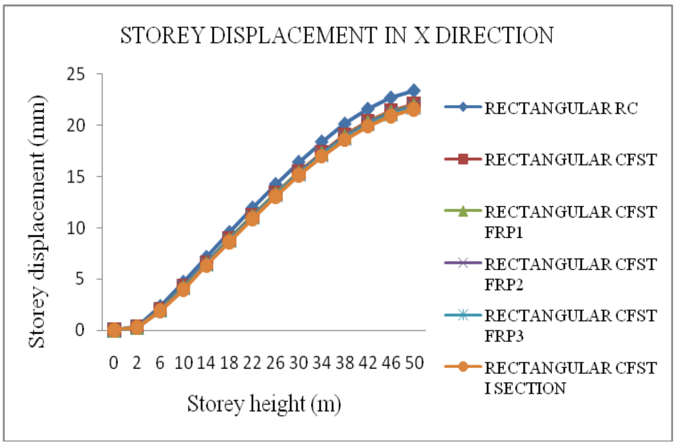


Chart-7: Comparison of storey displacement of G+12 building with rectangular columns along X direction

Rectangular CFST columns shows 6.12% decrease in storey displacement and I section encased CFST columns shows 8.2% decrease in displacement compared to ordinary RC columns in X direction. As per analysis, buildings with 1, 2, and 3 layers wrapped rectangular CFST columns shows 6.14%, 6.51%and 6.87% decrease in storey displacement in X direction as compared to building with ordinary RCC columns. Encasement of steel I section in CFST columns reduces storey displacement by 1.97% and 3 layers of wrapping using CFRP reduces 1.17% storey displacement compared to CFST columns in X direction.

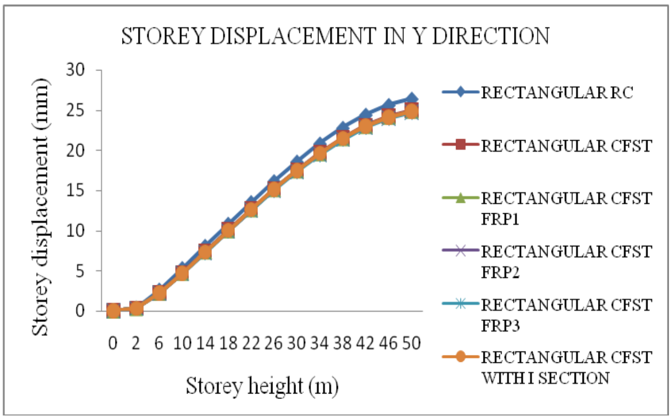


Chart-8: Comparison of storey displacement of G+12 building with rectangular columns along Y direction

Rectangular CFST columns shows 5.72% decrease in storey displacement and I section encased CFST columns shows 6.06% decrease in displacement compared to ordinary RC columns in Y direction. As per analysis, buildings with 1, 2, and 3 layers wrapped rectangular CFST columns shows 6.13%, 6.52%and 6.91% decrease in storey displacement in Y direction as compared to building with ordinary RCC columns. Encasement of steel I section in CFST columns reduces storey displacement by 1.12% and 3 layers of wrapping using CFRP reduces 0.31% storey displacement compared to CFST columns in Y direction.

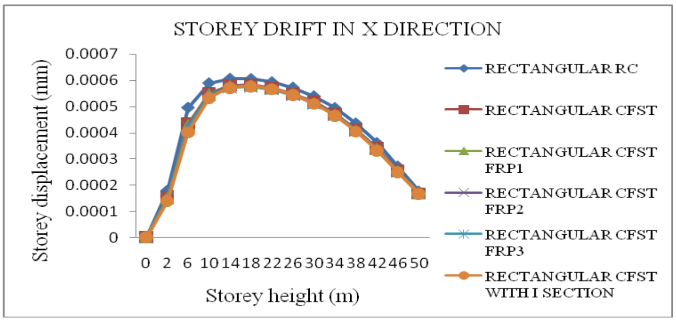


Chart-9: Comparison of storey drift of G+12 building with rectangular columns along X direction

CFST columns shows 4.65% decrease in storey drift and I section encased CFST columns shows 5.75% decrease in storey drift compared to ordinary RC columns in X direction. As per analysis, buildings with 1, 2, and 3layers wrapped circular CFST columns shows 4.76%, 5.26%and 5.59% decrease in storey drift in X direction as compared to building with ordinary RCC columns. Encasement of steel I section in CFST columns reduces storey drift by 1.38% and 3 layers of wrapping using CFRP reduces 1.20% storey drift compared to CFST columns in X direction.

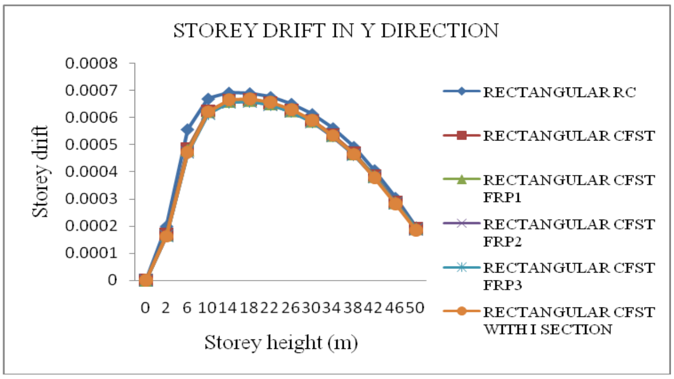


Chart-10: Comparison of storey drift of G+12 building with rectangular columns along Y direction

CFST columns shows 4.33% decrease in storey drift and I section encased CFST columns shows 5.35% decrease in storey drift compared to ordinary RC columns in Y direction. As per analysis, buildings with 1, 2, and 3layers wrapped circular CFST columns shows 4.77%, 5.06%and 5.35% decrease in storey drift in Y direction as compared to building with ordinary RCC columns. Encasement of steel I section in CFST columns reduces storey drift by 1.05% and 3 layers of wrapping using CFRP reduces 1.05% storey drift compared to CFST columns in Y direction. Storey drift is different in both X and Y direction because of the difference in moment of inertia in the column sections. Storey drift is more in transverse direction in all structures.

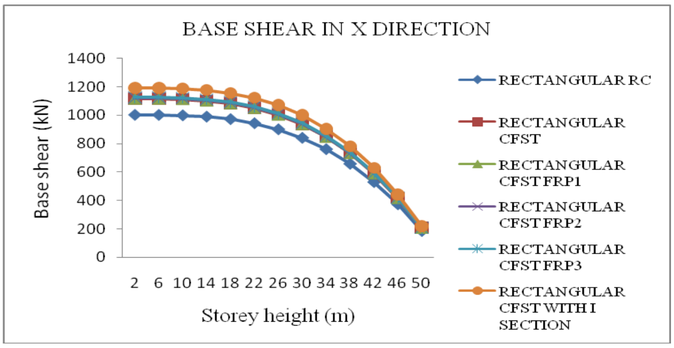


Chart-11: Comparison of base shear of G+12 building with rectangular columns along X direction

Base shear in the CFST columns with encased I section used building 16.01% more compared to RCC structures. This is because weight of the structure is more in this type of structures. CFRP wrapping also increases the base shear by10.46%, 12.07% and 12.48% for 1, 2 and 3 layers of wrapping in CFST columns compared to ordinary RCC columns in X direction. But CFST buildings distribute loads more evenly than RCC. Composite structures are being more ductile, resist lateral load better than RCC structures. Composite structure (CFST) gives more ductility to the structure as compared to the R.C.C. which is best suited under the effect of lateral forces.

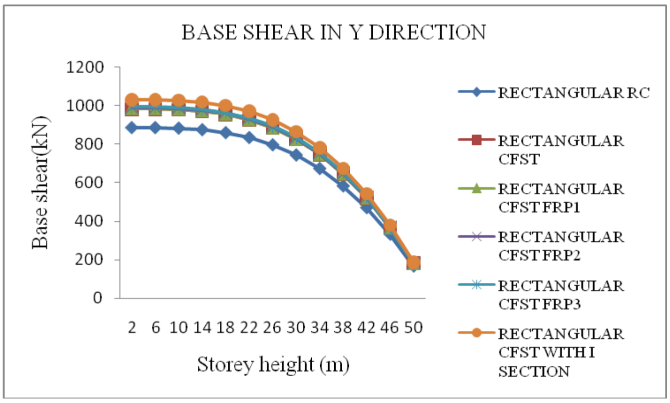
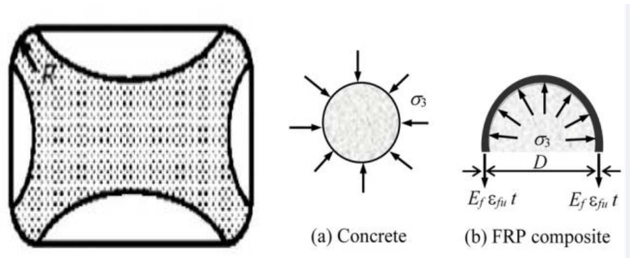


Chart-12: Comparison of base shear of G+12 building with rectangular columns along X direction

Base shear in the CFST columns with encased I section used building 14.06% more compared to RCC structures. This is because weight of the structure is more in this type of structures. CFRP wrapping also increases the base shear by10.23%, 10.51% and 10.77% for 1, 2 and 3 layers of wrapping in CFST columns compared to ordinary RCC columns in Y direction.

Wrapping of circular CFST columns using CFRP shows better performance in terms of drift, displacement and base shear than rectangular CFST columns. This behaviour may be attributed to variation in lateral confining pressure distribution for rectangular columns from a maximum at the corners to a minimum in between, which is in contrast to even confining pressure observed for circular columns in order to achieve the full confinement effect. A more complex behavior characterizes and rectangular columns due to the presence of the corners, a part of the cross-section remains unconfined, so that rectangular cross-section columns were found to experience less increase in strength and ductility than their circular counterparts.



Full wrapping increases the confining area and number of layers improves the intensity of confinement pressure. Lateral deflection is reduced by wrapping of CFRP sheets by overcoming the insufficient stiffness of composite columns. Also CFRP sheets improve the performance of composite columns by delaying overall buckling.
The results of second and third layer wrapping of CFRP do not show any serious reduction in displacement and drift values in composite columns. This may be due to

delamination failure of CFRP sheets. Delamination is a mode of failure for composite materials and steel. In laminated materials, repeated cyclic stresses, impact, and so on can cause layers to separate, forming a mica-like structure of separate layers, with significant loss of mechanical toughness. Delamination is a critical failure mode in composite structures, not necessarily because it will cause the structure to break into two or more pieces, but because it can degrade the laminate to such a degree that it becomes useless in service. The delamination may lead to redistribution of stresses which would eventually promote gross failure. The FRP wrap can delay the outward local buckling deformation of the steel tube and suppress the lateral expansion of the concrete in the CFST column FE models with a full wrapping length demonstrate a continual decrease in the storey displacement and storey drift as the number of CFRP layers increases. But it is not as much significant, because of the CFRP delamination failure previously occurred due to the increasing layers of CFRP sheets. So second and third layer of CFRP wrappings are provided in G+12 storey buildings only.

4. CONCLUSIONS

1. In RCC and composite structures, storey displacement and storey drift values are within permissible limit.
2. Storey displacement is reduced up to 20% and 18% in CFST columns encased with I section in X and Y directions respectively. And CFRP wrapping on CFST columns reduced the displacement up to 18% and 17% in X and Y directions respectively.
3. It is clear that the maximum storey displacement and storey drift in a CFST columns with encased I section, by response spectrum analysis, compared to an R.C.C. structure in both longitudinal and transverse directions are less which is due to the higher stiffness of members in a composite structure compared to an RCC structure. So CFST columns encased with steel I section performs well under earthquake forces.
4. Base shear values are 28% and 27% more for CFST columns encased with steel I section compared to RCC columns in transverse and longitudinal directions respectively. This may be due to increase in weight of Composite columns.
5. CFRP Wrapping reduces storey displacement, and storey drift up to 8% and 5% respectively compared to unwrapped CFST columns. So CFRP wrapping improves overall performance of composite columns by providing additional confinement to the concrete without increasing the original column size. CFRP wrapping on CFST column is effective in multi-storied structure.
6. CFRP wrapping is more effective in circular composite columns compared to rectangular columns due to variation in lateral confining pressure distribution for rectangular columns. Also more numbers of CFRP layers are not performing well due to delamination failure of CFRP sheets.
7. Structural frames with CFST columns have good performance due to near field earthquakes, they bear higher base shear in comparison to equivalent ordinary RC frames which can be collapse due to earthquake, but because of their high shear capacity they remain safe during the earthquake.

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