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Numerical Analysis on Strength Behaviour of Concrete Filled FRP tube Columns

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Abstract - *Fibre Reinforced Polymer (FRP) composites have emerged as a viable alternative of steel reinforcement due to higher ultimate tensile strength to weight ratio and corrosion resistance of FRP composites. The earlier studies demonstrated that CFFT columns sustained large inelastic deformations, which makes FRP tube an attractive alternative of steel reinforcement for the construction of new concrete columns with high strength and ductility. CFFTs have been used in different bridge components, including girders and piers. In this study a three-dimensional finite-element model was developed to determine the strength behaviour of CFFT columns and the deformation is compared with RC column. Parametric study is conducted to determine critical structural parameters.*

***Key Words*: FRP tube, FRP bars, CFFT, GFRP, axial load, deformation, confinement,**

1 INTRODUCTION

The construction industry, now a days uses varying technology in construction materials, construction method etc. In case of column construction, reinforced concrete columns are commonly used for the construction of any buildings. Even the technologies has changed, RC columns are still the first preference in construction projects. It is due to the easily available materials, initial cost of construction etc. In case of construction in coastal areas, bridge piers etc., the concrete gets abraded due to continuous contact of sea water and also lead to corrosion in reinforcement. Some of the new types of columns such as Concrete Filled Steel Tubular Columns (CFST), Concrete Filled FRP Tubular Columns (CFFT) etc. are used in such cases. When large magnitude loads acting on buildings, if RC columns are used, the size of columns should be designed as very large to withstand high loads. This leads to decrease in room size. The next method to increase the load carrying capacity of RC columns is to use large diameter reinforcement with in many numbers. This leads to the congested reinforcement and thus the concrete cannot be filled correctly without voids and cannot be compacted properly. So to avoid these problems, it is better to use new innovations like CFSTs and CFFTs.

1.1 Concrete Filled FRP Tube Column (CFFT)

A CFFT consists of an outer FRP tube filled with plain or steel-reinforced concrete. The FRP tube is typically manufactured through a filament-winding process. When a concrete-filled FRP tube is under compression, the axially compressed concrete is also subjected to lateral confinement from the FRP tube, which is in tension in the circumferential (or hoop) direction. As a result, a highly ductile compression member can be formed from the two brittle materials, namely, FRP and concrete, even when steel reinforcement is completely absent. This system provides an excellent alternative to conventional reinforced concrete or steel components in corrosive environments, especially tidal zones for marine piles and splash zones for highway accoutrements.

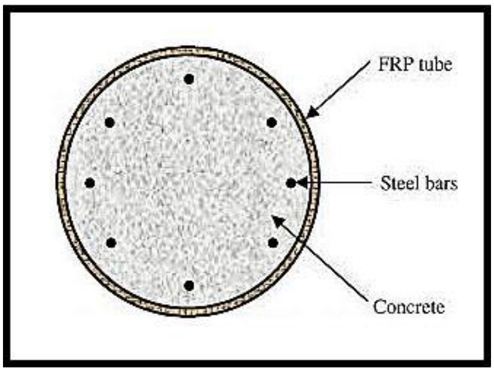


Fig -1: Cross Section of CFFT

1.2 Advantages of CFFT columns

The advantages of CFFT columns are: FRP composites have higher ultimate tensile strength to weight ratio which results in increased strength of CFFT columns. Lateral confinement from the FRP tube can significantly increase both the strength and the ductility of the concrete. The FRP tube provides lightweight and permanent formwork while acting as a noncorrosive reinforcement. Confining jacket for the concrete core delays local buckling of the tube. FRP tube serves as barrier to corrosion accelerating agents. FRP tube also increases the shear strength of concrete and increases the strength and ductility of columns. FRP tube restrains the lateral dilation of confined concrete.

1.3 Applications of CFFT columns

CFFT columns are used in the construction of large columns where load magnitude is very large. They are used in the construction of bridge piers . They are used in constructing overhead sign structures, constructing marine piles etc. They are suitable for construction in earthquake prone areas.

2. MODELLING

A total of 15 specimens were modelled of diameter 300mm, 400mm and 500mm respectively each of length 3000mm. There are 1.5 mm, 2 mm, 2.5 mm and 3 mm GFRP tubes for each column and RC columns of same diameters for comparison. The columns were modelled in ANSYS-15 Mechanical APDL as per specification in manual design. The modeling of CFFT columns is done by modelling the GFRP tube shell and RC column and providing a flexible contact between them.

Table -1: Material Properties

Concrete	fck =25 N/mm^2 Frictional Coefficient = 0.2 Young's Modulus = 25000N/mm^2 Poisson's Ratio = 0.15(assumed) Open shear transfer coefficient = 0.23 Closed shear transfer coefficient = 1 Uniaxial Cracking Stress = 3 N/mm^2
GFRP tube	Young's Modulus of GFRP tube in circumferential direction = 180000 N/mm^2 longitudinal direction = 54000 N/mm^2 Poisson's Ratio of GFRP tube in circumferential direction: = 0.45 longitudinal direction: = 0.35
GFRP bar	Young's Modulus = 18000N/mm^2 Poisson's Ratio = 0.45

Table -2: Specimen Details

SPECIMEN NAME	DIAMETER	TUBE THICKNESS
RC-1	300mm	Nil
RC-2	400mm	Nil
RC-3	500mm	Nil
GTGR-1A	300mm	1.5mm
GTGR-1B	300mm	2mm
GTGR-1C	300mm	2.5mm
GTGR-1D	300 mm	3 mm
GTGR-2A	400mm	1.5mm
GTGR-2B	400mm	2mm
GTGR-2C	400mm	2.5mm
GTGR-2D	400 mm	3 mm
GTGR-3A	500mm	1.5mm
GTGR-3B	500mm	2mm
GTGR-3C	500mm	2.5mm
GTGR-3D	500 mm	3 mm

4. DESIGN DETAILS AND LOADING

The numerical analysis is done by conducting axial load capacity of all the columns. The 300mm diameter columns are loaded with magnitude of 1000kN; 400mm columns are loaded with 1500kN and 500mm diameter columns with 2000 kN.

Table -3: Manual Design Details

Diameter of Column	Reinforcement Details
300 mm	7 numbers of 16 mm diameter bars and 4 numbers of 20 mm diameter bars 8 mm diameter ties at 300mm spacing
400 mm	11 numbers of 20 mm diameter bars 8 mm diameter ties at 300mm spacing
500 mm	12 numbers of 20 mm diameter bars 8 mm diameter ties at 300mm spacing

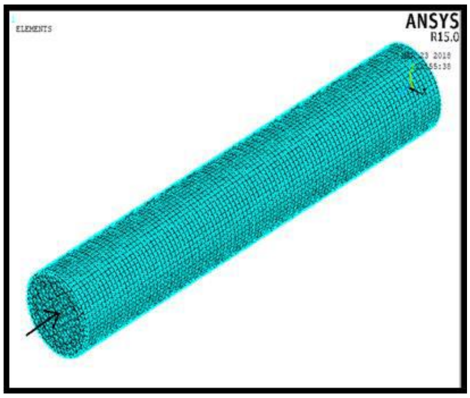
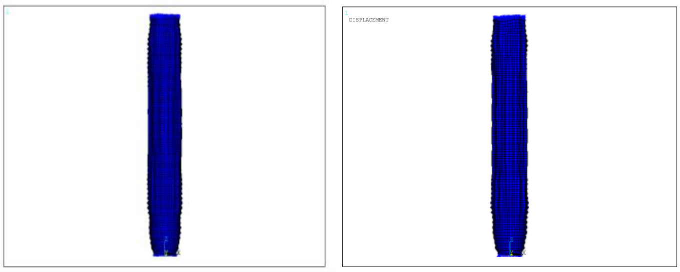


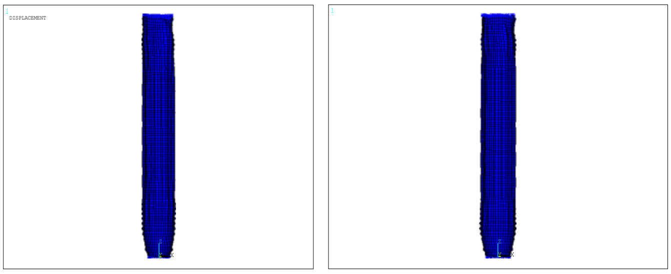
Fig -2: Load Applied on 500 mm Diameter Column

5. RESULTS AND DISCUSSIONS

The results of numerical analysis are shown in table below. CFFT columns and RC columns of same diameters are compared and the optimum diameter and tube thickness is determined. The figures below show the deformed shape of column specimen.

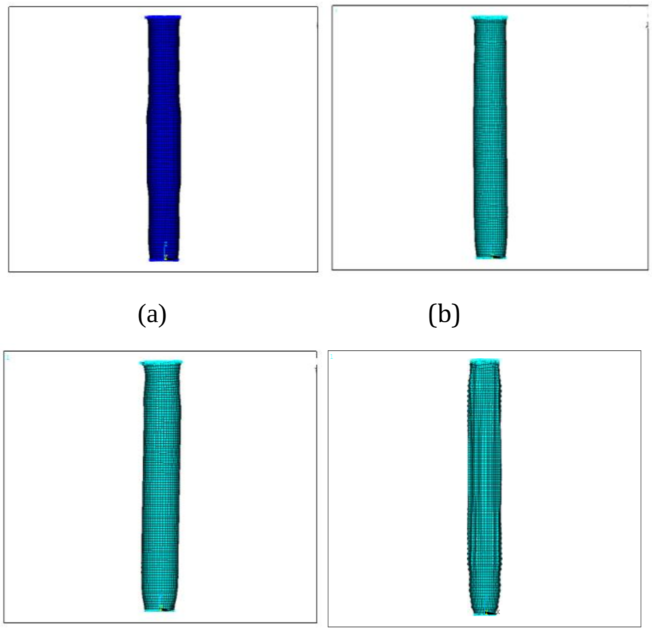


(a) (b)



(c) (d)

Fig -3: Deformed Model of 300 mm diameter CFFT column



(a) (b)

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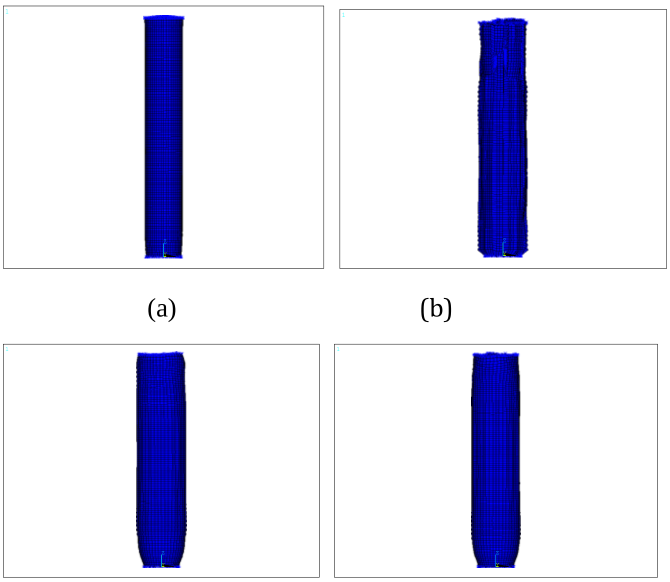
Fig -4: Deformed Model of 400 mm diameter CFFT column



(a) (b)

© (d)

Fig -5: Deformed Model of 500 mm diameter CFFT column

Table -4: Analysis Results

COLUMN DIAMETER-300mm; APPLIED LOAD- 1000kN		
COLUMN SPECIMEN	ULTIMATE LOAD (kN)	DEFORMATION (mm)
RC-1	1000	0.705
GTGR-1A	1000	3.803
GTGR-1B	1000	4.484
GTGR-1C	1000	4.907
GTGR-1D	1000	5.627
COLUMN DIAMETER-400mm; APPLIED LOAD- 1500kN		
COLUMN SPECIMEN	ULTIMATE LOAD (kN)	DEFORMATION (mm)
RC-2	1500	0.629
GTGR-2A	1500	5.234
GTGR-2B	1500	5.482
GTGR-2C	1500	4.1316
GTGR-2D	1500	4.743
COLUMN DIAMETER-500mm; APPLIED LOAD- 2000 kN		
COLUMN SPECIMEN	ULTIMATE LOAD (kN)	DEFORMATION (mm)
RC-3	2000	0.101 x10-6
GTGR-3A	2000	6.146
GTGR-3B	2000	6.78
GTGR-3C	2000	4.86
GTGR-3D	2000	5.386

From the above results we can conclude that the RC column fails at smaller deformation whereas CFFT columns take more deformation for same load. This is due to the brittle nature of RC column. RC column is less ductile than CFFT columns.

For 300mm diameter column, as the thickness of tube increases, the deformation increases. Minimum deformation is obtained at 1.5mm- 2mm thickness. So for 300 mm diameter column, the suitable GFRP tube thickness is 1.5 mm- 2 mm.

Similarly, for 400mm and 500mm diameter column, the suitable GFRP tube thickness is 2.5 mm- 3 mm.

6. PARAMETRIC STUDY

The parametric study is based on the parameters like diameter of column, Thickness of GFRP tube and diameter to thickness ratio.

6.1 Diameter of Column

Table -5: Parametric Results of 1.5 mm thick tube column

SPECIMEN	DIAMETER	APPLIED LOAD	AXIAL DEFORMATION
GTGR-1A	300 mm	1000 kN	3.803 mm
GTGR-2A	400 mm	1500 kN	5.234 mm
GTGR-3A	500 mm	2000 kN	6.146 mm

Table -6: Parametric Results of 2 mm thick tube column

SPECIMEN	DIAMETER	APPLIED LOAD	AXIAL DEFORMATION
GTGR-1B	300 mm	1000 kN	4.484 mm
GTGR-2B	400 mm	1500 kN	5.482 mm
GTGR-3B	500 mm	2000 kN	6.78 mm

Table -7: Parametric Results of 2.5 mm thick tube column

SPECIMEN	DIAMETER	APPLIED LOAD	AXIAL DEFORMATION
GTGR-1C	300 mm	1000 kN	4.907 mm
GTGR-2C	400 mm	1500 kN	4.1316 mm
GTGR-3C	500 mm	2000 kN	4.86 mm

Table -8: Parametric Results of 3 mm thick tube column

SPECIMEN	DIAMETER	APPLIED LOAD	AXIAL DEFORMATION
GTGR-1D	300 mm	1000 kN	4.827 mm
GTGR-2D	400 mm	1500 kN	4.743 mm
GTGR-3D	500 mm	2000 kN	5.386 mm

6.2 Thickness of GFRP Tube

Table -9: Parametric Results of 300 mm diameter column

SPECIMEN	TUBE THICKNESS	AXIAL DEFORMATION
GTGR-1A	1.5 mm	3.803 mm
GTGR-1B	2 mm	4.484 mm
GTGR-1C	2.5 mm	4.907 mm
GTGR-1D	3mm	4.827 mm

Table -10: Parametric Results of 400 mm diameter column

SPECIMEN	TUBE THICKNESS	AXIAL DEFORMATION
GTGR-2A	1.5 mm	5.234 mm
GTGR-2B	2 mm	5.482 mm
GTGR-2C	2.5 mm	4.1316 mm
GTGR-2D	3mm	4.743 mm

Table -11: Parametric Results of 500 mm diameter column

SPECIMEN	TUBE THICKNESS	AXIAL DEFORMATION
GTGR-3A	1.5 mm	6.146 mm
GTGR-3B	2 mm	6.78 mm
GTGR-3C	2.5 mm	4.86 mm
GTGR-3D	3mm	5.386 mm

For 300 mm diameter columns, deformation is increased with respect to the thickness of GFRP tube. The minimum deformation is obtained at 1.5 mm thickness.

For 400 mm diameter columns, deformation is increased up to 2.5 mm thickness and then decreased when 2.5 mm thick tube is provided. The minimum deformation is obtained at 2.5 mm thickness.

For 500 mm diameter column, deformation is increased up to 2.5 mm thickness and decreased when 2.5 mm tube is provided. The minimum deformation is obtained at 2.5mm thickness.

6.3 Diameter to Thickness Ratio

Table -12: Parametric Result of Specimens on D/T Ratio

SPECIMEN NAME	D/t RATIO	AXIAL DEFORMATION
GTGR-1A	200	3.803 mm
GTGR-1B	150	4.484 mm
GTGR-1C	120	4.907mm
GTGR-1D	100	4.827 mm
GTGR-2A	267	5.234 mm
GTGR-2B	200	5.482 mm
GTGR-2C	160	4.1316 mm
GTGR-2D	133	4.743 mm
GTGR-3A	333	6.146 mm
GTGR-3B	250	6.78 mm
GTGR-3C	200	4.86 mm
GTGR-3D	167	5.386 mm

From the analysis results we have found out the suitable thickness for each column diameter. Based on the tube thickness range and minimum deformation obtained, we can conclude that the D/T ratio should be within the range of 150-200 for an economical CFFT specimen.

3. CONCLUSIONS

- GTGR-1A, GTGR-1B and GTGR-1C specimens shows an increase of 66.67 % in load carrying capacity than RC-1.

- GTGR-2A, GTGR-2B, GTGR-2C specimens shows an increase of 98.6% in load carrying capacity than RC-2.
- GTGR-3A, GTGR-3B, GTGR-3C specimens shows an increase in 14.7% in load carrying capacity than RC-3.
- As the diameter of column increases, the percentage reduction in deformation increases.
- As the thickness of GFRP tube increases, the deformation decreases up to a certain value and then increases.
- The optimum range of diameter to thickness ratio of CFFTs should be between 150-200

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