COMPARATIVE STUDY ON GFRP JACKETED RC COLUMNS AND CFRP JACKETED RC COLUMNS OF DIFFERENT SHAPES

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Abstract— Column jacketing with FRP sheets plays an important role in enhancing the performance of RC column. FRP is an Advanced Composite Material (ACM) that is relatively new material to civil engineering. It holds a better choice than reinforcing steel in certain applications. In order to attain large deformation before failure occurs and to enhance an adequate load resistance capacity, RC columns has to be laterally jacketed. Jacketing RC column with FRP improves column performance not only by carrying some fraction of axial load applied to it but also by providing lateral confining pressure to the column externally. In this work a comparative study on GFRP jacketed RC columns and CFRP jacketed RC columns of different shapes having same cross-sectional area were analysed. Buckling analysis on RC columns of circular, rectangular and square cross-sectional shapes has been done in ANSYS 15. FRP Jacketing increases the load carrying capacity of all RC columns. CFRP Jacketed RC columns shows a better load carrying capacity than GFRP Jacketed RC Columns when both axial and eccentric loadings were applied in circular, rectangular and square cross-sectional shapes.

Keywords— Column Jacketing, Rectangular, Square, Circular, Crossesctional Shapes, Repair and Rehabilitaion, Buckling Analysis, Ultimate Load Carrying Capacity etc.

1.INTRODUCTION

Concrete deterioration is one of the issue affecting most structures. Problems associated with the deterioration of RC structures are usually due to corrosion of the reinforcing steel and spalling of the concrete. Most of the structures are designed for gravity loading as per IS 456:2000. During a severe earthquake, the structure is likely to undergo inelastic deformation and has to depend on ductility and energy absorption capacity to avoid collapse. Such buildings designed for gravity loading need to be strengthened to increase strength, stiffness and ductility. Thus, retrofitting measures must be taken to maintain the integrity of the structure.

In recent years, For strengthening and rehabilitation of existing structures Fiber Reinforced Polymer (FRP) composites have their advantage over traditional materials. The advantages such as corrosion resistance, light weight, high-strength to weight ratio, and high efficiency in construction encourage civil engineers to use this material. Effective lateral confinement is provided by FRP jackets to the concrete columns that can improve their compressive strength and ultimate axial strain. Retrofitting with FRP materials provides successful solutions for strengthening, repairing, adding ductility, rapid execution, long-term durability, and consequently lower life-cycle costs. R.Kumutha reported that GFRP jacketing in RC column resulted in enhancing the compressive strength and ductility [1].

The Glass Fiber Reinforced Polymer (GFRP) jacketed RC column performed much better than steel reinforced column. GFRP has significantly increased the strength and ductility of concrete by creating a perfect adhesive bond in between concrete and the jacketing material [8].

Fig.1.1.Jacketing of GFRP sheets around column

Carbon Fiber Reinforced Polymer (CFRP) is a very light, strong composite material used in the past two decades for structural engineering purposes. The most popular use of CFRP is retrofitting, where the load capacity of structures, is increased through CFRP wraps[3]. External confinement of concrete columns by means of jacketing high-strength fiber composites around the perimeter of the column enhances their strength and ductility.

Fig.1.2.Jacketing of CFRP sheets around column

2.SCOPE

The scope of work includes comparison of the effectiveness of external Glass Fiber Reinforced Polymer (GFRP) and Carbon Fiber Reinforced Polymer (CFRP) strengthening on behaviour of circular, rectangular and square. RC columns to upgrade existing concrete structures. From past studies, most of the works were carried out for circular column jacketing. Only few studies were conducted for rectangular and square column jacketing. However, the majority of columns in buildings are rectangular columns. Hence their strength and retrofitting must be given more attention to maintain the integrity of building structures. The use of externally jacketed FRP composite for strengthening and rehabilitation can be an economical alternative for restoring or upgrading the overall performance of existing concrete columns.

3.OBJECTIVES

1. To determine the effect of cross-sectional shape in RC columns.
2. To investigate the number of FRP layers: Models with zero, one, and two layers of FRP.
3. To study the performance of column under axial and eccentric compression loadings.
4. To find out the parameter i.e. ultimate failure load of the columns using Finite Element software.
5. Comparison of results will be done from GFRP jacketed RC Columns and CFRP jacketed RC Columns.

4. METHODOLOGY

- Preparation of Literature Review.
- Validation of Finite Element software.
- Finite element modelling will be done in ANSYS 15.
- Analysis of the structure using FE Software.
- Interpretation of results.

5. VALIDATION

A finite element model of RC control column and FRP confined RC column of circular, square and rectangular cross-sectional shapes was developed and validated by existing experimental results in journal [1] and [2].

Table.5.1.Validation Model Details

Column c/s Shape	Breadth (mm)	Depth (mm)	Height (mm)	Main Bars	Lateral Ties
Circular	Diameter 150 mm		600	6# 12 mmØ	8 mmØ @ 190 mm c/c
Square	125	125	750	4# 10 mmØ	6 mmØ @ 125 mm c/c
Rectangular	112	140	750	4# 10 mmØ	6 mmØ @ 125 mm c/c

The validation results are shown in **Table.5.2**.

Table.5.2.Validation of Results

Column Designation	Ultimate Failure load	Deformation (Experiment)	Deformation (ANSYS 15)	Error (%)
0 Square	766.3 kN	1.18 mm	1.25 mm	5.9
1 Square	786 kN	1.2 mm	1.27 mm	5.8
0 Rectangular	750 kN	1.21 mm	1.22 mm	0.82
1 Rectangular	772 kN	1.34 mm	1.24 mm	7.4
0 Circular	509 kN	4.5 mm	4.26 mm	5.33
1 Circular	876 kN	7.9 mm	7.3 mm	7.5

6. PRESENT STUDY

6.1 RC COLUMNS

Circular, square, and rectangular columns having approximately same cross-sectional area and 3m height were modelled. Design details of RC column are presented in **Table.6.1**. Reinforcement detailing are shown in **Fig.6.1**.

Table.6.1.Design details of RC columns.

Column c/s Shape	b (mm)	d (mm)	h (mm)	Main Bars	Lateral Ties
Square	150	150	3000	4# 8 mmØ	6 mmØ @ 100 mm c/c
Rctngulr	110	210	3000	4# 8 mmØ	6 mmØ @ 100 mm c/c
Circular	Diameter 170mm		3000	4# 8 mmØ	6 mmØ @ 100 mm c/c

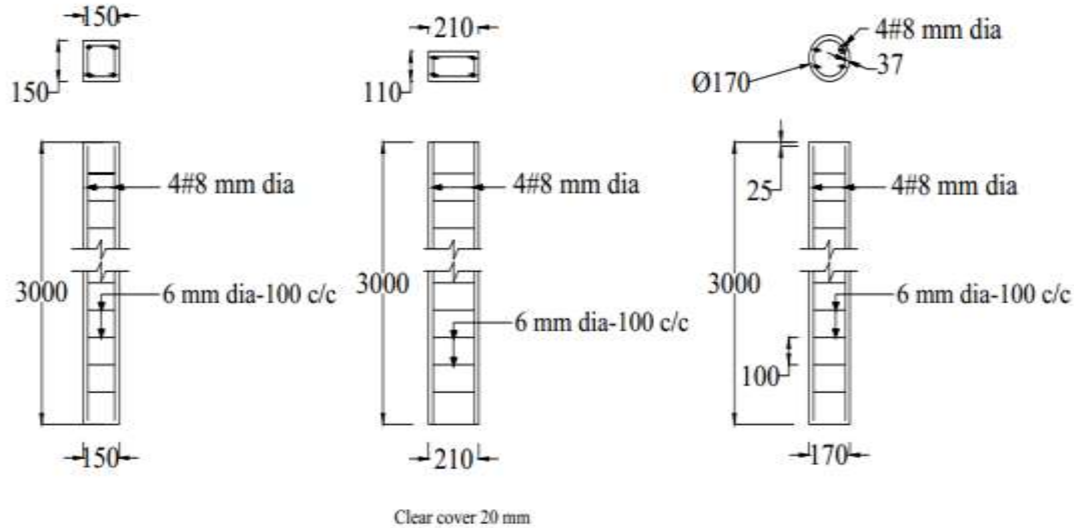


Fig.6.1.Reinforcement details of square, rectangular and circular columns.

6.2 FINITE ELEMENT MATERIAL MODELS

6.2.1 Concrete

M25 mix concrete having modulus of elasticity (E) = 25000 N/mm^2 is used to model the RC columns. The Poisson's ratio (ν) = 0.15 was taken.

6.2.2 Reinforcement

Fe415 steel was used in reinforcement steel bars having modulus of elasticity (E) = 200000 N/mm^2 is used to model the RC columns. The poisson's ratio (ν) = 0.2 was taken.

6.2.3 FRP Sheet

The properties of GFRP sheet and CFRP sheet are presented in **Table.6.2**.

Table.6.2.Properties of GFRP sheet [1] and CFRP sheet [14]

FRP Sheets	Modulus of Elasticity (E)	Poison's ratio (ν)	Thickness of Sheet	Ultimate Tensile Strength	Shear Modulus (G)
GFRP	10500 MPa	0.26	1.1 mm	3400 MPa	1520 MPa
CFRP	230000 MPa	0.22	1.1 mm	3500 MPa	3270 MPa

6.3 FE MODEL

Finite Element modelling has been done in ANSYS 15. All control RC columns and FRP jacketed RC columns were modelled. Following figures shows the geometry and meshed model of all columns.

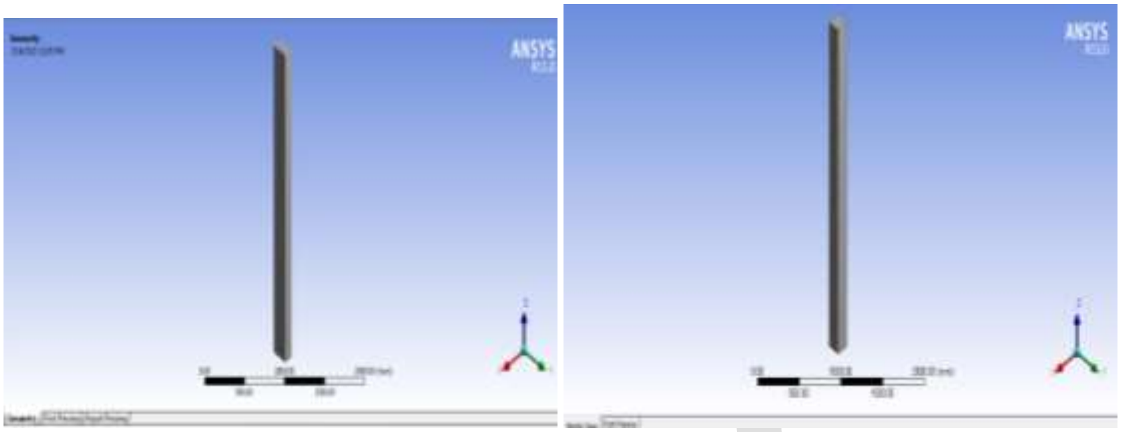


Fig.6.2.Geometry of Rectangular control and FRP jacketed RC column.

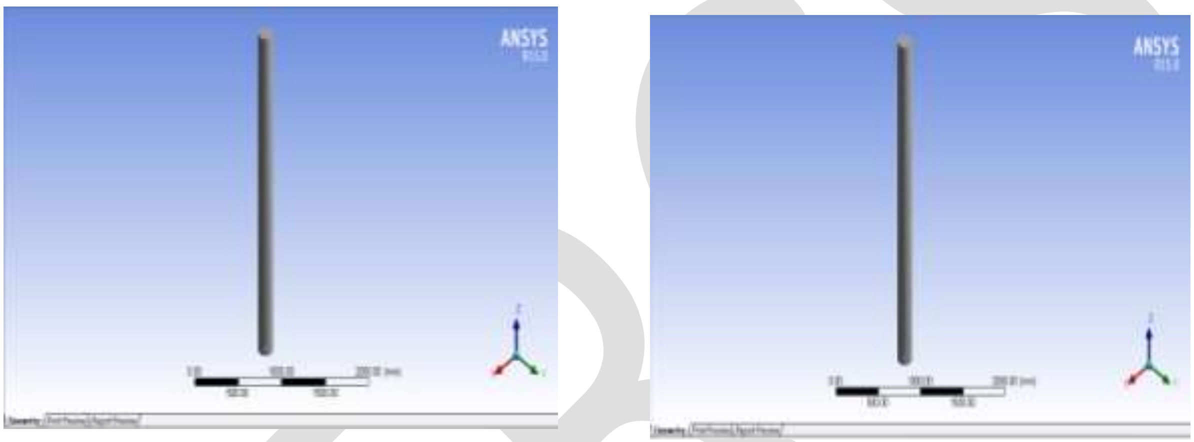


Fig.6.3.Geometry of Circular control and FRP jacketed RC column.

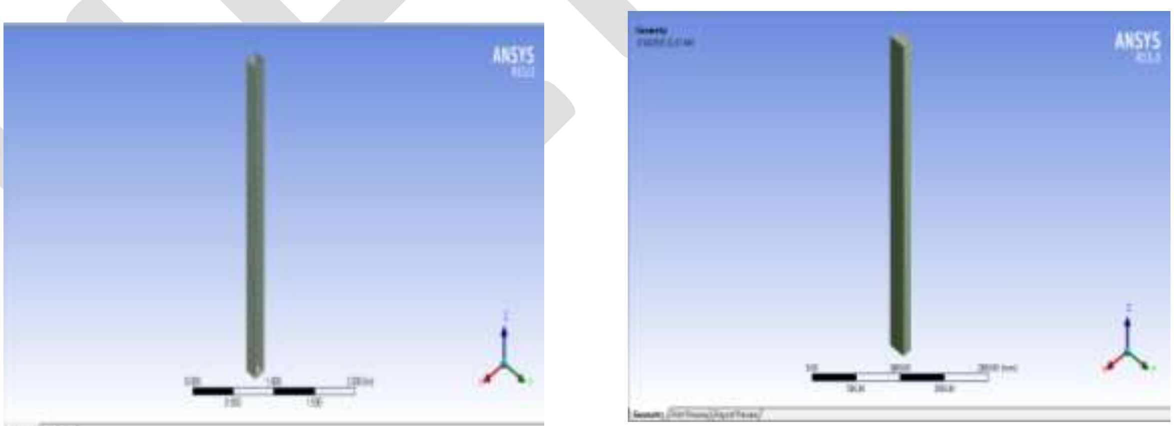


Fig.6.3.Geometry of Square control and FRP jacketed RC column.

6.4 BOUNDARY CONDITION

Fig.6.4. shows the boundary condition with loading for RC control and FRP jacketed columns. All columns were fixed at one end and free at other end.

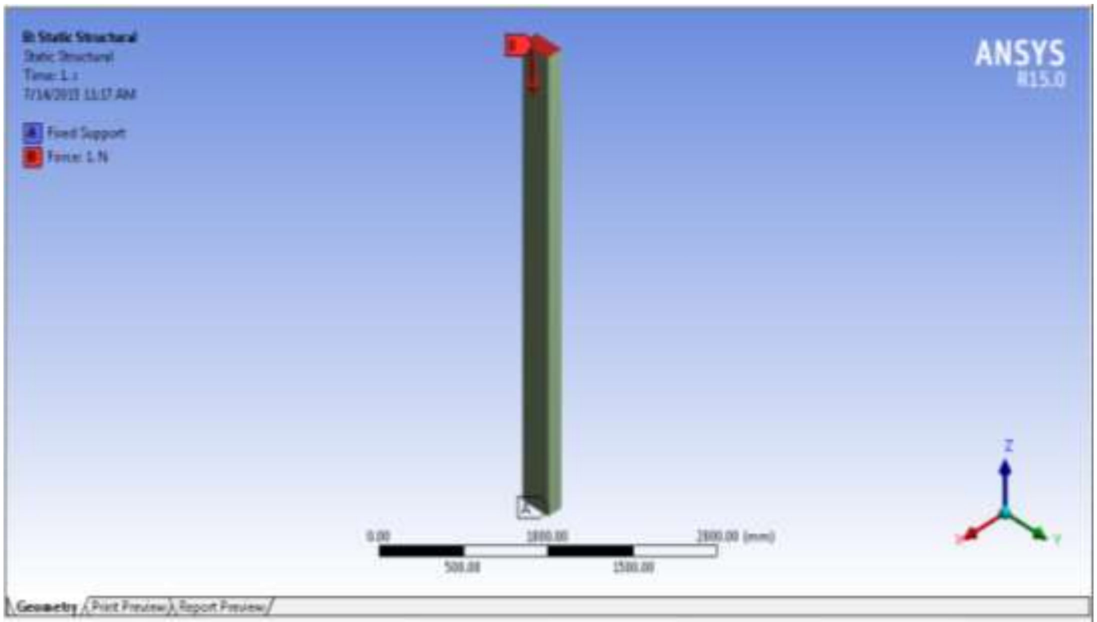


Fig.6.4.Boundary condition with loading for control and FRP jacketed RC columns.

6.5 LOADING CONDITION

6.5.1 RC Column subjected to Axial Loading

If the load on a column is applied along the center of gravity of cross section, it is called an axial load or it can be force applied along the lengthwise centerline of column. Axial force can be compressive or tensile force on the member.

6.5.2 RC Column subjected to Eccentric Loading

Columns are basically vertical compression members that transfer axial loads to the foundations. Although the main function of the column is to transfer axial loads, most of the time, columns are subjected to moments as well. This may be due to accidental eccentricity arising from minor misalignment during construction, or due to reduction of the column size in multi-storey buildings. This may also occur due to lateral drift, even in cases when the columns are not part of the structural system resisting horizontal forces.

In this study RC control columns and FRP jacketed RC columns are analyzed for 25 mm eccentric loading The performance of the columns were evaluated by analyzing their load carrying capacity.

7. RESULTS AND DISCUSSION

7.1 RC COLUMNS SUBJECTED TO AXIAL LOADING

Buckling analysis has been carried out on all control columns to find out the ultimate load carrying capacity.

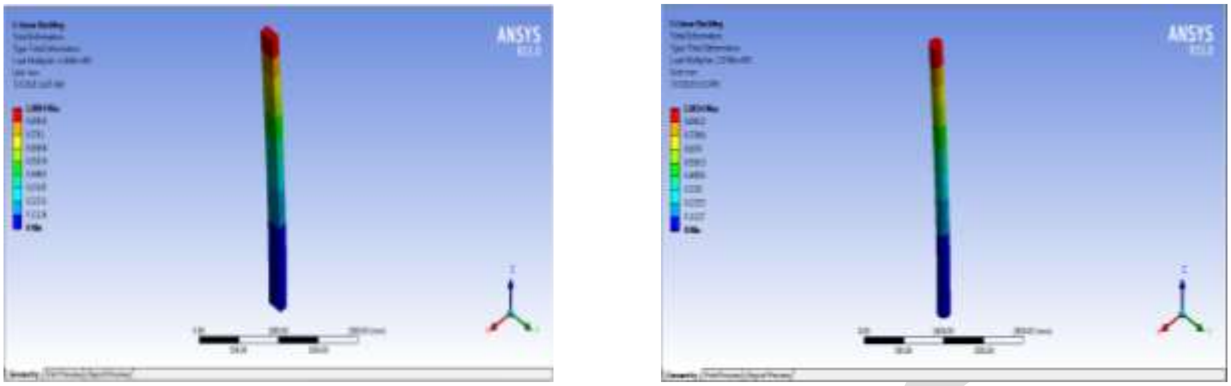


Fig.7.1.Rectangular and circular RC column subjected to Axial Loading.

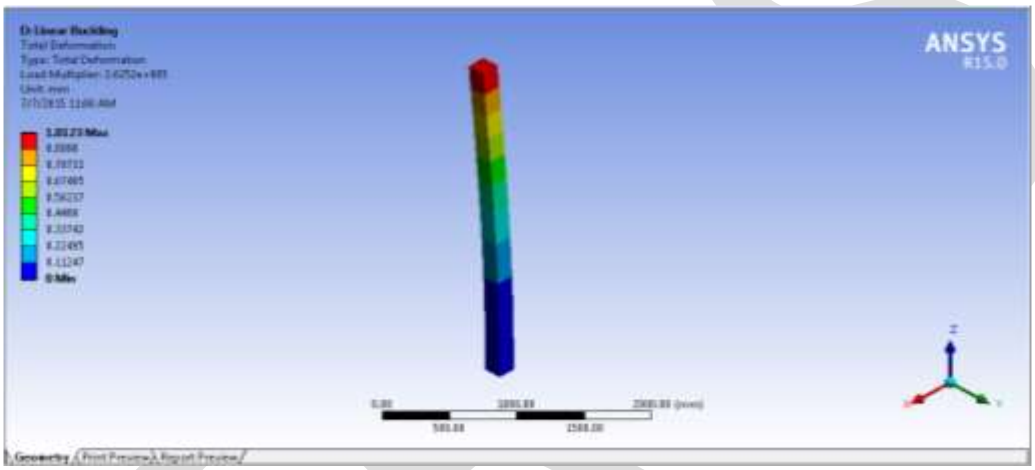


Fig.7.2.Square RC column subjected to Axial Loading.

Long columns can be analysed with Euler column formula

$$F = \frac{n\, \pi r^2\, E\, I}{L^2}$$

Where

F = allowable load

n = factor accounting for the end conditions

E = modulus of elasticity

L = length of column

I = Moment of inertia

Comparison of the critical value of controlled column from ANSYS with Eulers equation has been represented in the **Table.7.1** below.

Table.7.1.Comparison of Results with Eulers equation.

Column Types	Critical Load ANSYS 15 (kN)	Allowable Load (Eulers Equation) (kN)	% Variation
Rectangular	149.09	159.64	7.07
Circular	257.48	280.9	8.90
Square	262.52	285.14	8.61

Hence the load carrying capacity of controlled RC columns increases in the order of square, circular and rectangular.

7.1.1 GFRP Jacketed RC Column subjected to Axial Loading

GFRP jacketed RC columns of rectangular, square, and circular cross-section were axially loaded to find out the ultimate load carrying capacity.

Fig.7.3.One and two layers GFRP jacketed rectangular RC column subjected to axial loading

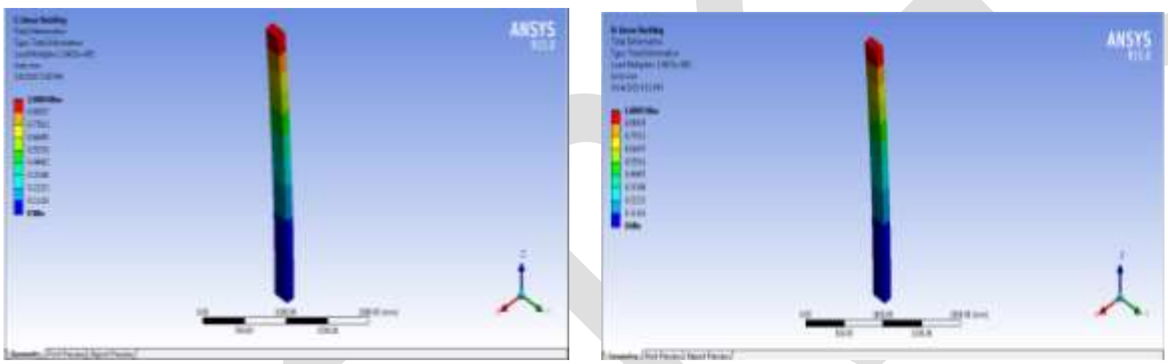
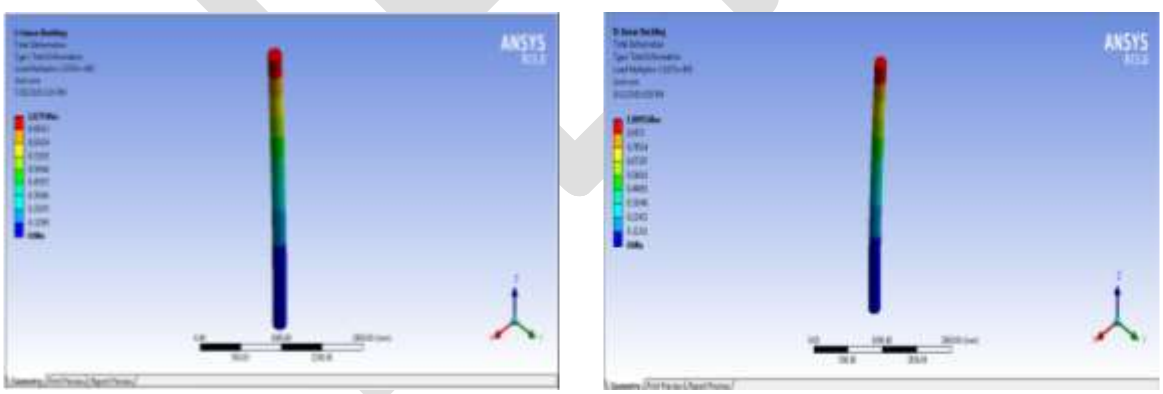


Fig.7.4.One layer and two layers GFRP jacketed circular RC column subjected to axial loading



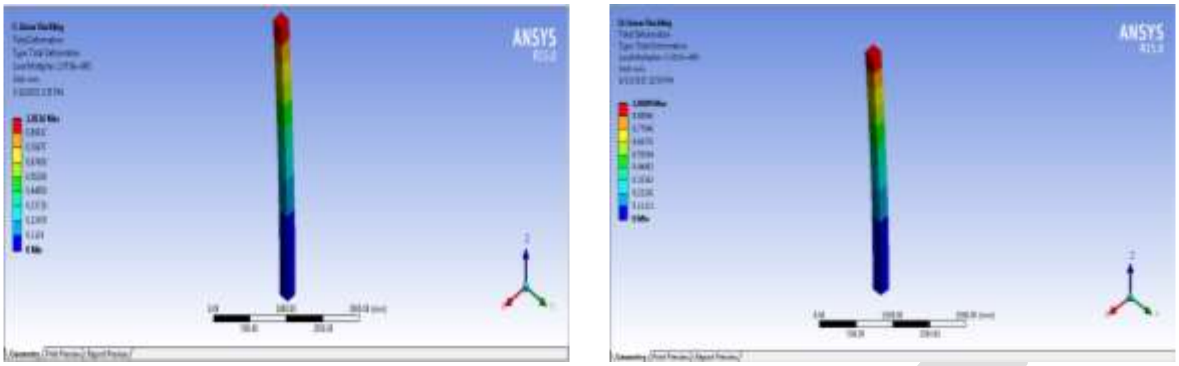


Fig.7.5.One layer and two layers GFRP jacketed square RC column subjected to axial loading.

From the above results we can conclude that GFRP jacketing increases the load carrying capacity of all columns of different cross-sectional shapes. Load carrying capacity increases when two layer GFRP jacketing is provided compared to one layer GFRP jacketing. Hence the load carrying capacity of one and two layer GFRP jacketed RC columns increases in the order of square, circular and rectangular. Load increment of one layer GFRP jacketing increases in the order of rectangular, square and circular.

7.1.3 CFRP Jacketed RC Column subjected to Axial Loading

CFRP jacketed RC columns of rectangular, square, and circular crossection was axially loaded to find out the ultimate load carrying capacity.

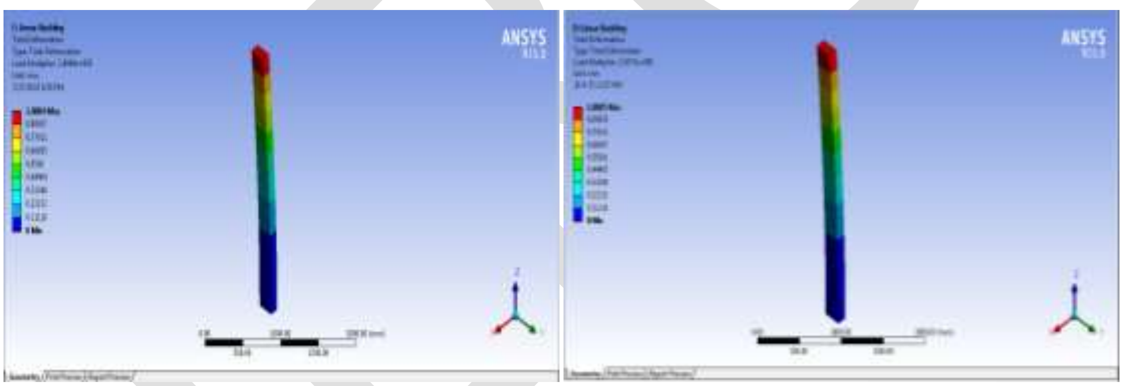


Fig.7.6.One and two layers CFRP jacketed rectangular RC column subjected to axial loading.

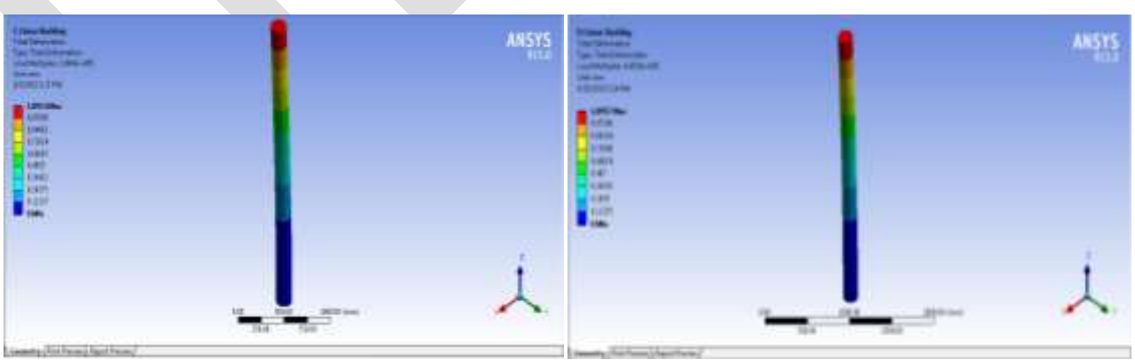


Fig.7.7.One and two layers CFRP jacketed circular RC column subjected to axial loading.

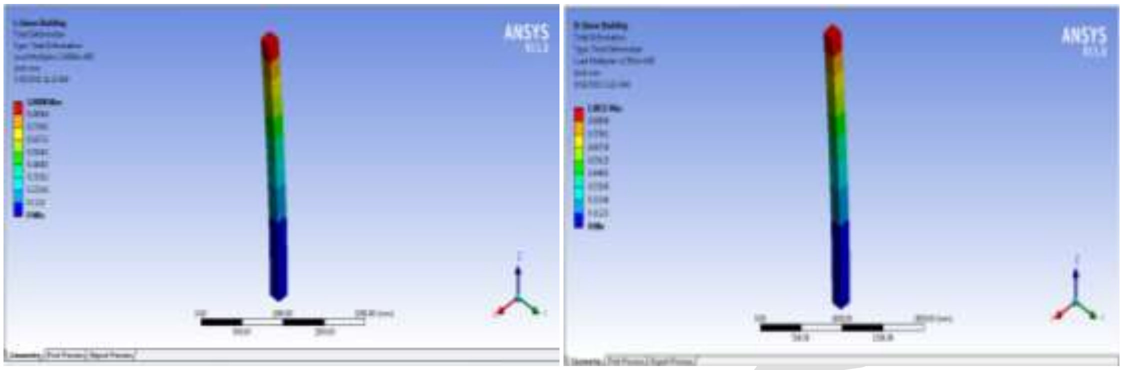


Fig.7.8.One and two layers CFRP jacketed square RC column subjected to axial loading.

From the above results we can conclude that CFRP jacketing also increases the load carrying capacity of all columns of different cross-sectional shapes. Load carrying capacity increases when two layer CFRP jacketing is provided compared to one layer CFRP jacketing. Hence the load carrying capacity of one and two layer CFRP jacketed RC columns increases in the order of square, circular and rectangular. Load increment of one layer CFRP jacketing increases in the order of rectangular, square and circular.

FRP jacketing increases the load carrying capacity of all RC columns subjected to axial loading. The percentage increase in load carrying capacity is shown in **Table 7.2**.

Table.7.2. Percentage increase in load carrying capacity of columns under axial loading.

Column c/s Shape	Jacketing Provided	No. of Layers of FRP Jacketing	Ultimate Load Carrying Capacity (kN)	% Increase in Load Carrying Capacity
Rectangular	Control	-	140.94	-
	GFRP	1	164.23	16.52
		2	199.27	41.38
	CFRP	1	249.49	54.49
		2	293.73	77.01
Circular	Control	-	257.48	-
	GFRP	1	287.87	11.80
		2	318.57	23.72
	CFRP	1	399.98	55.34
		2	445.38	72.97
Square	Control	-	262.52	-
	GFRP	1	297.36	13.27
		2	333.17	26.91
	CFRP	1	369.08	40.59
		2	479.52	82.66

7.2. RC COLUMN SUBJECTED TO ECCENTRIC LOADING

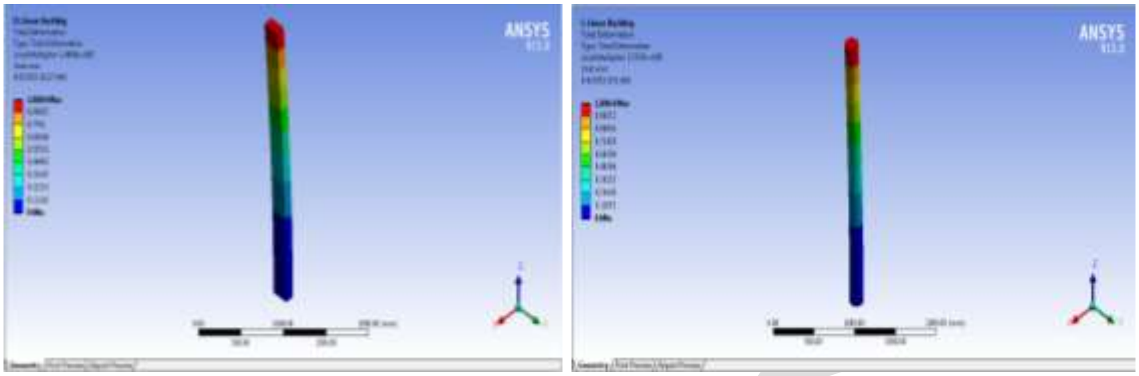


Fig.7.9.Rectangular and circular RC column subjected to eccentric loading.

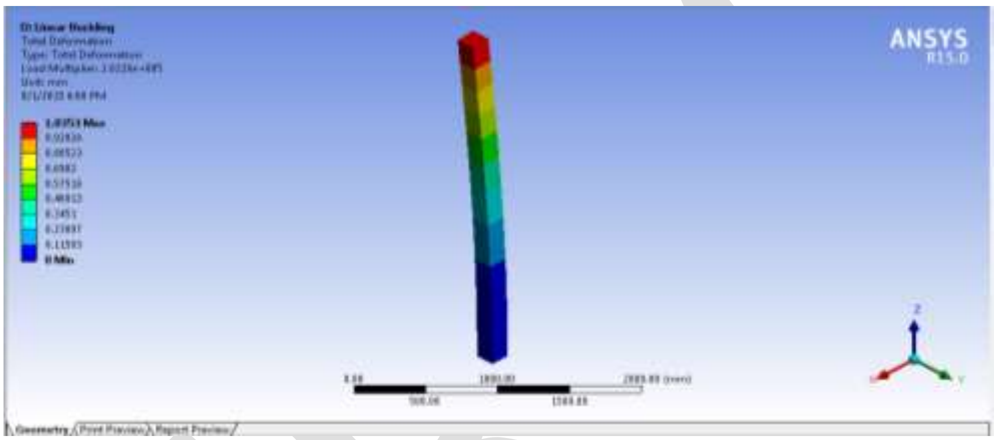


Fig.7.10.Square RC column subjected to eccentric loading.

Eccentric loading decreases the load carrying capacity compared to axial loading in all RC columns of different cross-sectional shapes and the load carrying capacity of RC columns in eccentric loading increases in the order of square, circular and rectangular.

7.2.1 GFRP Jacketed RC Column subjected to Eccentric Loading

GFRP jacketed RC columns of rectangular, square, and circular cross-section was eccentrically loaded to find out the ultimate load carrying capacity

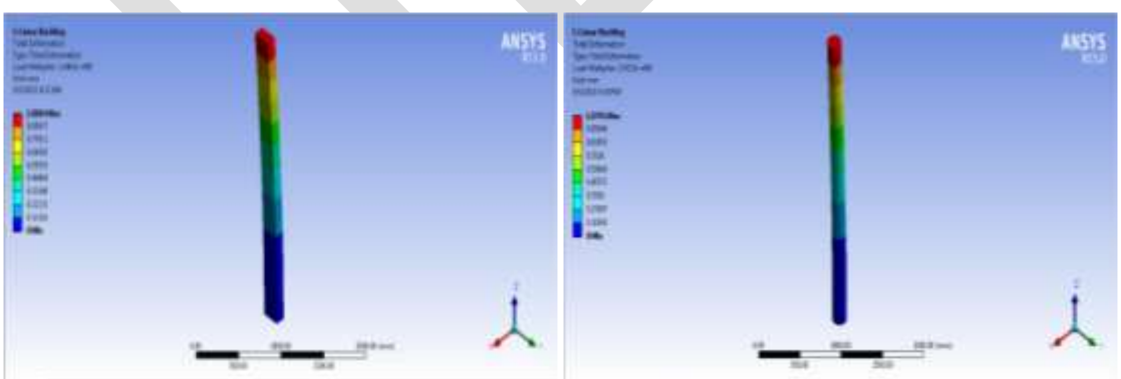


Fig.7.11.GFRP jacketed rectangular and circular RC column subjected to eccentric loading.

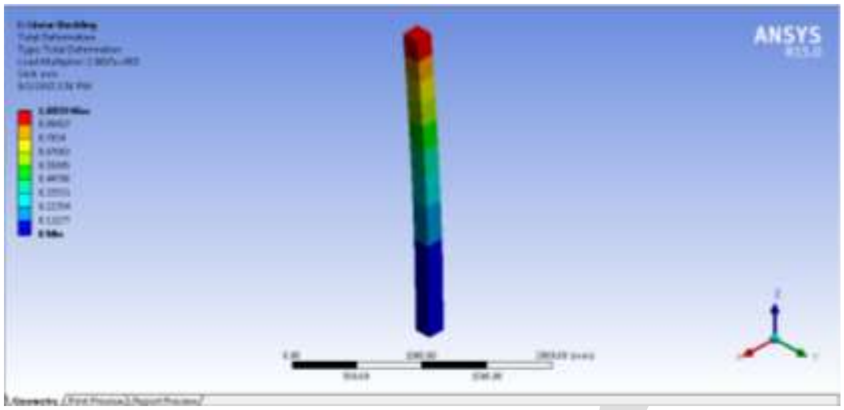


Fig.7.12.GFRP jacketed square RC column subjected to eccentric loading.

From the above results we can conclude that GFRP jacketing increases the load carrying capacity of all columns subjected to eccentric loading of different cross-sectional shapes. Hence the load carrying capacity of GFRP jacketed RC columns increases in the order of square, circular and rectangular.

7.2.3 CFRP Jacketed RC Column subjected to Eccentric Loading

CFRP jacketed RC columns of rectangular, square, and circular cross-section was eccentrically loaded to find out the ultimate load carrying capacity.

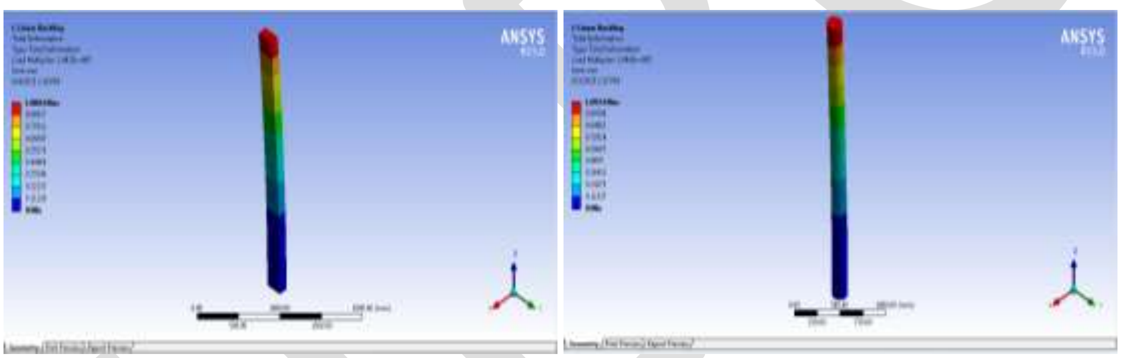


Fig.7.13.CFRP jacketed rectangular and circular RC column subjected to eccentric loading.

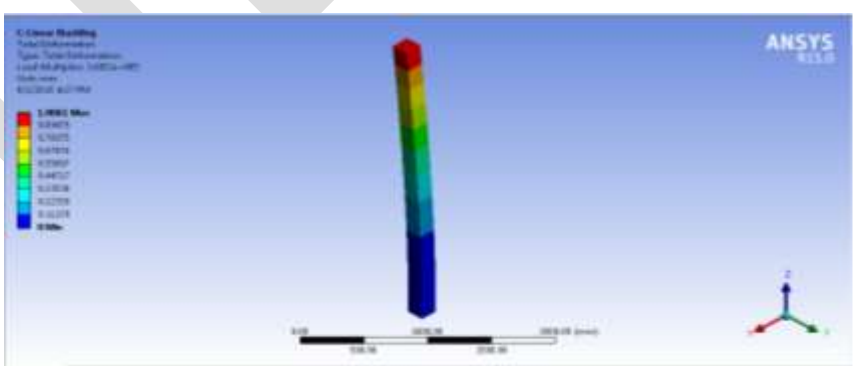


Fig.7.14.CFRP jacketed square RC column subjected to eccentric loading.

From the above results we can conclude that CFRP jacketing also increases the load carrying capacity of all columns subjected to eccentric loading of different cross-sectional shapes. Hence the load carrying capacity of CFRP jacketed RC columns increases in the order of square, circular and rectangular.

FRP jacketing increases the load carrying capacity of all RC columns subjected to eccentric loading. The load carrying capacity of RC column subjected to eccentric loading is less than column subjected to axial loading. The percentage increase in load carrying capacity is shown in **Table 7.3**.

Table.7.3. Percentage increase in load carrying capacity of columns under eccentric loading.

Column c/s Shape	Jacketing Provided	Ultimate Load Carrying Capacity (kN)	% Increase in Load Carrying Capacity
Rectangular	Control	140.88	-
	GFRP	164.63	16.85
	CFRP	249.25	76.92
Circular	Control	257.65	-
	GFRP	287.23	11.48
	CFRP	399.43	54.91
Square	Control	262.26	-
	GFRP	296.97	13.23
	CFRP	368.52	40.51

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8. CONCLUSION

- Load carrying capacity of control RC columns increases in the order of square, circular, rectangular.
- GFRP and CFRP jacketing enhances the axial load carrying capacity by providing additional confinement without increasing the column size.
- Effective confinement with GFRP and CFRP jacketing resulted in improving the compressive strength. GFRP and CFRP jacketing for square columns produced progressive increase in axial load carrying capacity followed by circular and rectangular columns.
- From this study it can be concluded that the eccentricity in loading reduces the load carrying capacity and performance of RC columns.
- RC column jacketing with FRP sheets also increases the load carrying capacity when subjected to eccentric loading.
- CFRP jacketing is found to be more effective than GFRP in case of both axial and eccentric loading.
- CFRP jacketed rectangular RC column provides higher increment in load carrying capacity followed by circular and square RC column compared to GFRP jacketing in axial and eccentric loading.
- Thus, it can be recommended from the study that FRP jacketing is a very good alternative for strengthening of existing square, circular and rectangular RC column and it helps in economical construction by concrete reduction in designing new RC columns.

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