Strengthening of RC Column using GFRP and CFRP

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SUMMARY
Seismic retrofitting of constructions vulnerable to earthquakes is a current problem of great political and social relevance. Most of the Indian building stock is vulnerable to seismic action even if located in areas that have long been considered of high seismic hazard. During the past thirty years moderate to severe earthquakes have occurred in India. Such events have clearly shown the vulnerability of the building stock in particular and of the built environment in general. Hence it is very much essential to retrofit the vulnerable building to cope up for the next damaging earthquake. The present study focuses on the behaviour of reinforced concrete beam-columns strengthened using Glass Fibre Reinforced Polymer (GFRP) and Carbon Fibre Reinforced Polymer (CFRP) subjected to reverse cyclic loading. Reinforced concrete columns designed as per IS 456-2000 possess less necessary ductility to dissipate seismic energy during earthquake. Such beam-columns are seismically deficient and require additional confinement to improve their seismic parameters. Fiber reinforced polymer (FRP) composites are increasingly used for this purpose. Hence, experiments were conducted on Reinforced concrete beam-columns with and without FRP wrapping. One Specimen each was tested without GFRP and CFRP wrapping, three specimens were tested with 2 layers, 4 layers and 6 layers of GFRP wrapping and other two specimens were tested with CFRP wrapping. The specimens were tested under a constant axial load and reversed cyclic lateral loading. Experimental results indicate a significant increase of ductility and increase in energy absorption capacity of RC beam-column when strengthened by both GFRP and CFRP Jacket.

Keywords: Reinforced concrete columns, Fibre Reinforced Polymer, Reversed cyclic loading, Ductility.

1. INTRODUCTION

In recent years, the construction industry has seen an increasing demand to reinstate, rejuvenate, strengthen and upgrade existing concrete structures. This may be attributed to various causes such as environment degradation, design inadequacies, poor construction practices, lack of regular maintenance, revision of codes of practice, increase in loads and seismic conditions etc. In India most of the structures are designed for gravity loading as per IS 456:2000. These structures are susceptible for damage during earthquake. 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.

Houssam[1] et al. studied the behavior of large-scale rectangular columns. It was found that the higher aspect ratio resulted in a reduction in the confinement pressure and the compressive strength of a confined column increased as the corner radius increased. The behaviour of FRP wrapped concrete cylinders with different wrapping materials and bonding dimensions has been studied by Lau and Zhou[2] using the finite element method (FEM) and other analytical methods. It was found that the load-carrying capacity of the wrapped concrete structure is governed by mechanical properties such as tensile elasticity modulus and Poisson's ratio of the wrapping sheet. Manuel and Carios[3] have conducted tests on models of circular cylindrical columns of concrete with GFRP jackets subjected to axial loading for different heights of cylinders and it was found that the increase in number of layers led to an increase in the maximum load. Riad et al.[4] conducted tests on square prismatic concrete column, strengthened with external glass fibre composite. It was found that the stiffness of the applied FRP jacket was the key parameter in the design of external jacket retrofits. Shamim et al [5] have investigated the seismic behavior of concrete columns confined with steel and FRP. It was concluded that the use of FRP significantly enhances strength, ductility, and energy absorption capacity of columns. Richard D. lacobucci et al[6] (2003) investigated the retrofit of square concrete columns with Carbon Fibre Reinforced Polymer (CFRP) for seismic resistance. It was found that added confinement with CFRP at critical locations enhanced ductility, energy dissipation capacity and strength of all substandard members. Zhao and Feng[7] (2003), investigated experimentally the seismic strengthening of RC columns with wrapped CFRP sheets. The ductility enhancement with the confinement of CFRP sheets was studied by the strain development and distribution in the CFRP sheets. Based on the experimental results, a confinement factor of CFRP and an equivalent transversal reinforcement index were suggested. In spite of the extensive work on reinforced concrete columns, very few researchers have worked on reinforced concrete columns strengthened using FRP subjected to reversed cyclic loading.

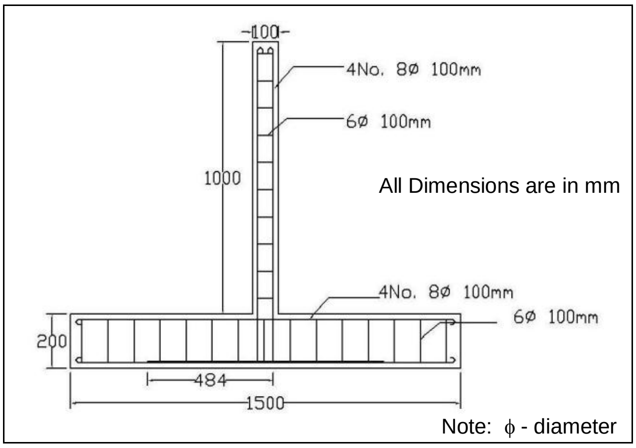
In this paper, the effect of GFRP and CFRP on the strength, ductility and energy absorption capacity of the reinforced concrete beam-columns strengthened with GFRP and CFRP are experimentally investigated. A six storey RC building was analysed to simulate the vertical load and lateral load that would act on the interior column of the ground storey. The height of the column used in the analysis was 3000 mm with a cross section of 300 x 300 mm and length of the beam was 4500 mm with 300 x 600 mm cross section. The test specimens were cast as one-third scale models. Four Reinforced concrete columns with and without GFRP jacketing were tested. One specimen was tested without GFRP jacketing and other three specimens were tested with 2 layers, 4 layers and 6 layers of GFRP wrapping respectively. Three Reinforced concrete columns with and without CFRP jacketing were tested. One specimen was tested without CFRP jacketing and other two specimens were tested with CFRP wrapping the specimens were tested under a constant axial load and reversed cyclic lateral loading. Lateral load versus lateral displacement curve, Energy absorbed versus lateral displacement curve, Strength capacity and ductility curves are presented.

2. EXPERIMENTAL INVESTIGATION

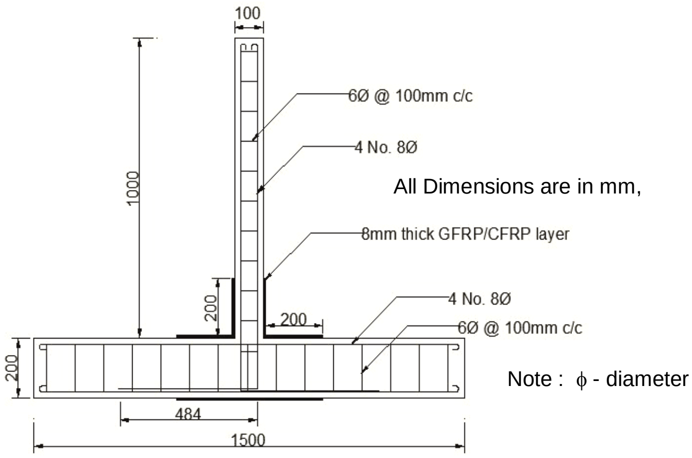
2.1. Test Specimen Details

Experiments were conducted on six, one-third scaled columns. The height of the column is 1000mm and of 100 mm x100 mm size. Reinforcement details for the column are shown in Figure1 and the details of the specimens tested are given in Table 1. Column is made with M20 grade concrete and Fe-415 grade steel is used for longitudinal reinforcements and Fe-250 grade steel is used for stirrups and lateral ties. The size of the column and the beam are 100 x 100 mm and 100 x 200mm, respectively. The columns are longitudinally reinforced with 4 Nos. of 8mm diameter bars and laterally tied with 6mm diameter bars placed at 100 mm c/c. The same reinforcement was provided for beams also.

Three specimens were jacketed externally by 2, 4 and 6 layers of GFRP sheets. Before jacketing the specimens with GFRP sheets, a surface preparation was carried out, which included cleaning, forming one layer of epoxy-polyamine primer and one layer of epoxy putty, then epoxy adhesive was used for bonding GFRP sheets on the specimens. Additional layers of epoxy adhesive were applied between GFRP sheets. Two specimens were jacketed externally by single layer of CFRP sheet. Before jacketing the specimens with CFRP sheets, a surface preparation was carried out, which included cleaning, forming one layer of epoxy-polyamine primer and one layer of epoxy putty, then epoxy adhesive was used for bonding CFRP sheet on the specimens. One specimen was tested without any wrapping.



a) Column without wrapping



b) Column with GFRP/CFRP wrapping

Figure 1. Reinforcement details for the column (note - ϕ - diameter)

Table 1. Details of the wrapping of columns.

Sl. No.	Specimen Identification	No. of GFRP layers	No. of CFRP layers
1	GFC 0	0	0
2	GFC 1	2	-
3	GFC 2	4	-
4	GFC 3	6	-
5	CFC 1	-	1
6	CFC 2	-	1

2.2. Test Set-Up

The test set up consist of a reaction frame, a hydraulic actuator of capacity 200 kN with a stroke length of ± 100mm and a loading frame with hydraulic jack of 50 kN to apply loads to the test specimens. 50 kN hydraulic jacks were used to apply constant axial compressive load and 200 kN actuator was used to apply reversed cyclic load on the specimens. A steel reaction frame was used to support the 200 kN actuator providing lateral load to the specimen. Instrumentation included Linear Voltage Differential Transducers (LVDT) for lateral displacement measurement at the top of the column and one load cell attached to the actuator was used for the measurement of cyclic lateral loads. A loading frame was used to apply a vertical constant axial load through steel rollers placed with the support of steel plates in between the jack and column head. The vertical load was chosen to a design compression rate of 0.45 RC axial resistance found in the analysis. The experimental set- up for both GFRP and CFRP specimens were shown in Figure 2.

a) Specimen without wrapping

b) Specimen with GFRP wrapping c) Specimen with CFRP wrapping

Figure 2. Experimental set-up

3. TEST RESULTS

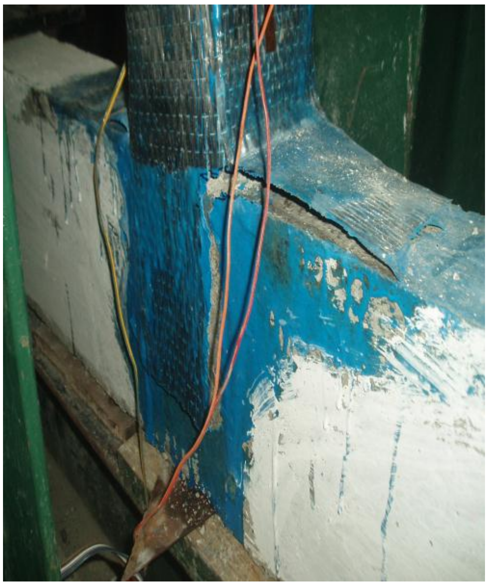
3.1. Observed Failure modes

Figure 3 shows the failure pattern of the test specimens. In the specimen without FRP wrapping (GFC 0), failure was due to concrete crushing at the beam-column junction and minor cracks were noticed along the height of the column as shown in Fig.3(a). For the other Glass fibre wrapped and Carbon fibre wrapped specimens, failure occurred due to the fracture of GFRP and CFRP composite at the beam-column junction due to the stress concentration in those regions. In all the cases, the columns failure was the result of the rupture of the FRP jacket, associated with concrete crushing at the beam-column junction and marked by wraps rupturing in the circumferential direction. Approaching failure load, the appearance of white patches was found, which indicated the yielding of fibre glass and resin.

a) Specimen without wrapping (GFC 0)

b) Specimen with GFRP (Specimen GFC 1)

c-i) Specimen with CFRP (Specimen CFC 1)

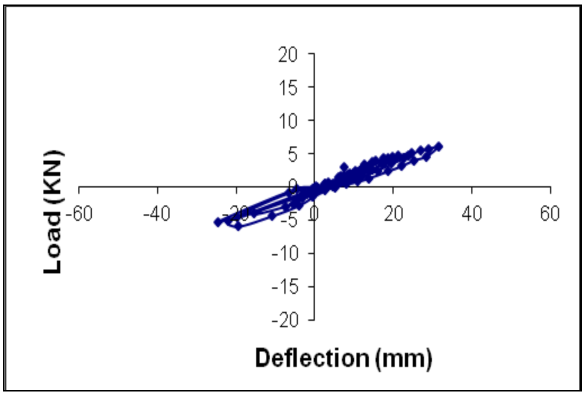


c-ii) Specimen with CFRP (Specimen CFC 2)

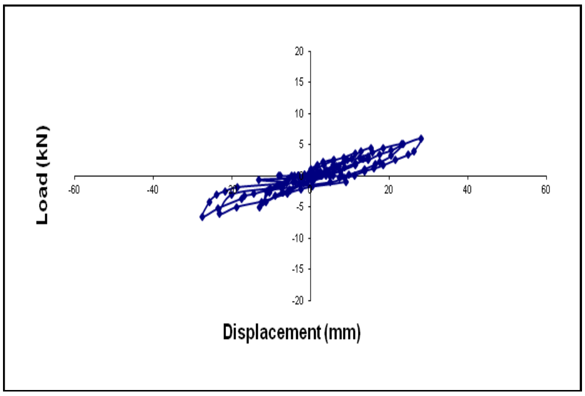
Figure 3. Failure patterns

3.2. Lateral Load versus Lateral Displacement Curve

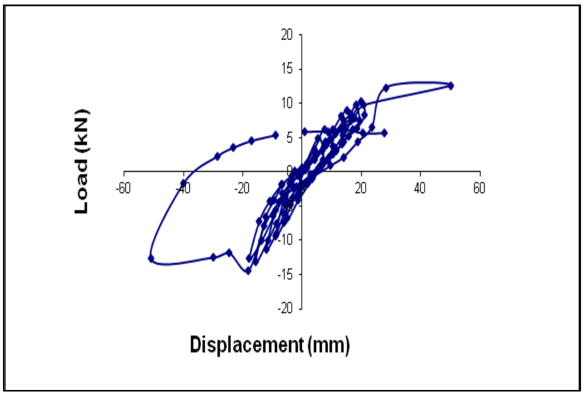
The variation of lateral displacement with that of the lateral load was plotted for all the specimens as shown in Figure 4. From the load-displacement curves it is observed that the unwrapped specimen GFC 0 failed at a load of 6.1kN with a lateral displacement of 31.5 mm. The GFRP wrapped specimens GFC 1, GFC 2 and GFC 3 failed at loads of 6.6 kN, 7.8 kN and 8.4 kN with the corresponding displacements of 33 mm, 38.5 mm and 46.12 mm. The CFRP wrapped specimens CFC 1 and CFC 2 failed at loads of 12.05 kN and 12.15 kN with the corresponding displacements of 51.08 mm and 51.67 mm.



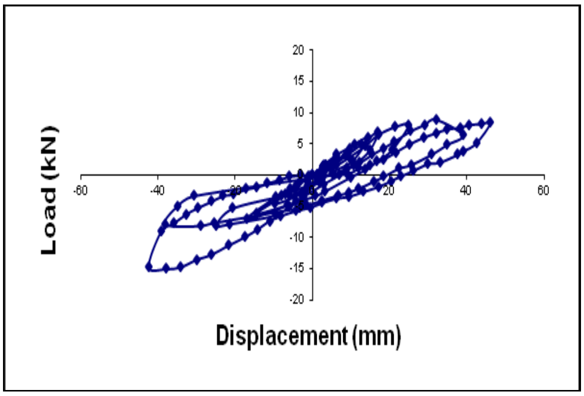
(a) Specimen GFC 0 (Unwrapped)



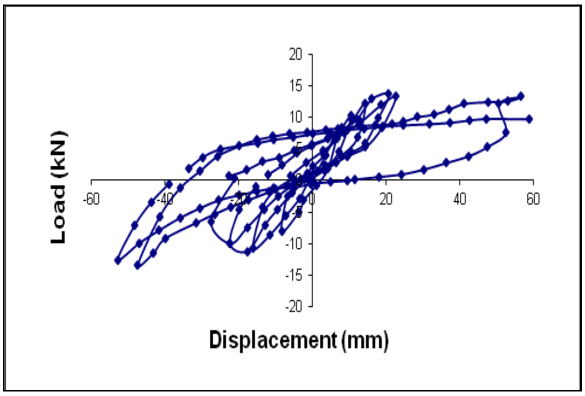
(b-i) Specimen GFC 1
(Wrapped with 2 layers of GFRP)



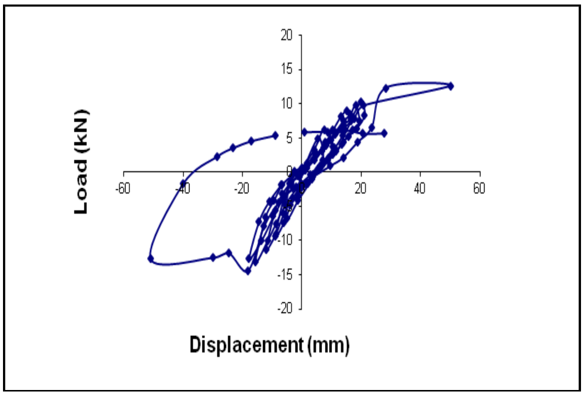
(b - ii) Specimen GFC 2
(Wrapped with 4 layers of GFRP)



(b-iii) Specimen GFC 3
(Wrapped with 6 layers of GFRP)



(c-i) Specimen CFC 1
(Wrapped with 1 layer CFRP)



(c-ii) Specimen CFC 2
(Wrapped with 1 layer CFRP)

Figure 4. Load-displacement curves for the 6 specimens

3.3. Load carrying capacity of the specimens

Figure 5 shows the trajectory of load-displacement of all the specimens such as unwrapped and wrapped. The GFRP specimens failed at a load of 6.1 kN, 6.6 kN, 7.8 kN and 8.4 kN respectively. Thus there is 8%, 28% and 38% increase in the strength capacity of specimens GFC 1, GFC 2 and GFC 3 respectively compared to the specimen GFC 0. There is an average of 98.3% increase in the strength capacity of specimens CFC 1 and CFC 2 compared to the specimen GFC 0.

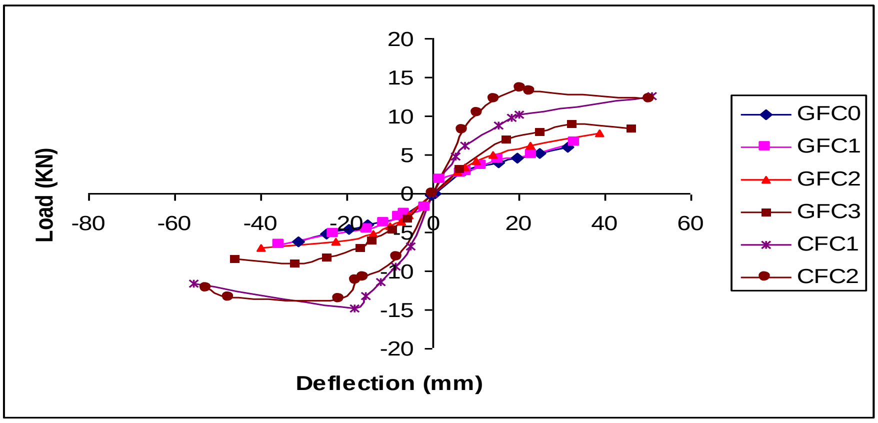


Figure 5. Comparison between Peak lateral loads – lateral Displacement of the specimens

4. DISPLACEMENT DUCTILITY OF COLUMNS WITH FRP JACKETING

Ductility is the property which allows the structure to undergo large deformation without loosing its strength. Ductility is quantified by the ductility factor. It is the ratio of displacement at failure to the displacement at yield point. Figure 5 shows the lateral load versus lateral displacement curves and the comparison of ductility is given in Table 2.

Table.2 Comparison of Ductility of columns with FRP Jacketing

Specimen	**Displacement (mm)**				**Displacement Ductility**		**Average Ductility**	**% increase of Ductility**
	Yield		Ultimate					
	Downward direction	Upward direction	Downward direction	Upward direction	Downward direction	Upward direction		
GFC 0	6.93	6.53	33.33	31.5	4.8	4.82	4.81	-
GFC 1	6.37	5.15	35.67	33	5.6	6.4	6.0	25%
GFC 2	5.6	5.02	39.8	38.5	7.1	7.72	7.41	54%
GFC 3	5.69	5.67	47.32	46.12	8.31	8.13	8.21	70%
CFC 1	10.88	10.27	52.8	50.54	4.85	4.92	4.89	1.66
CFC 2	11.23	10.15	55.6	51.08	4.95	5.03	4.99	3.74

It is observed from Table 2 that GFRP wrapped specimens have much higher ductility than the CFRP wrapped specimens. The specimen GFC 3 with 6 layers of wrapping has the highest ductility. There is no benefit in wrapping specimen with CFRP considering the ductility aspect of column.

5. ENERGY ABSORPTION CAPACITY OF COLUMNS WITH FRP JACKETING

The ability of a structure to absorb the ground motion energy is an accurate measure for its expected seismic performance. In this study, the energy absorbed by the four tested specimens during reversed cyclic load testing was calculated as the area enclosed by each hysteresis loop (Figure 4) for each cycle. Figure 6 shows the plot of the energy absorbed during a load cycle versus the lateral displacement.

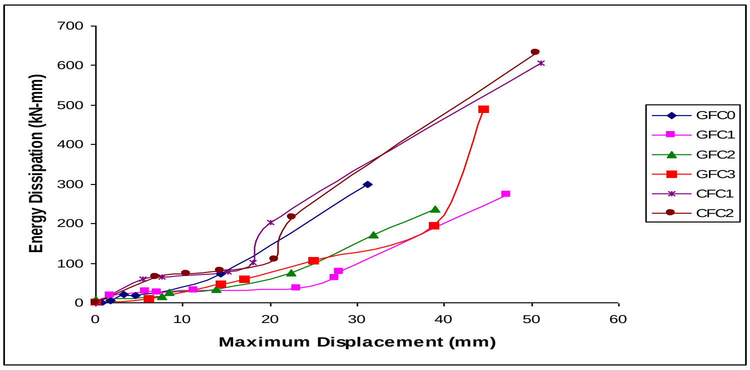


Figure 6. Energy Absorption versus Lateral Displacement curves for the specimens

It is observed that at low displacement levels, the energy absorbed by the specimens GFC 1, GFC 2, GFC 3, CFC1 and CFC2 were less than that by the specimen GFC 0. This was mainly due to the initial high stiffness due to FRP wrapping. At higher levels of displacement, it is clear that the energy absorbed by the both FRP wrapped specimens were much higher than the specimen GFC 0. It is clear from Figure 6 that the energy absorbed by CFRP specimens was much higher than the GFRP specimens. This proves that the seismic performance of the FRP wrapped specimens are expected superior to that of the specimen without any wrapping.

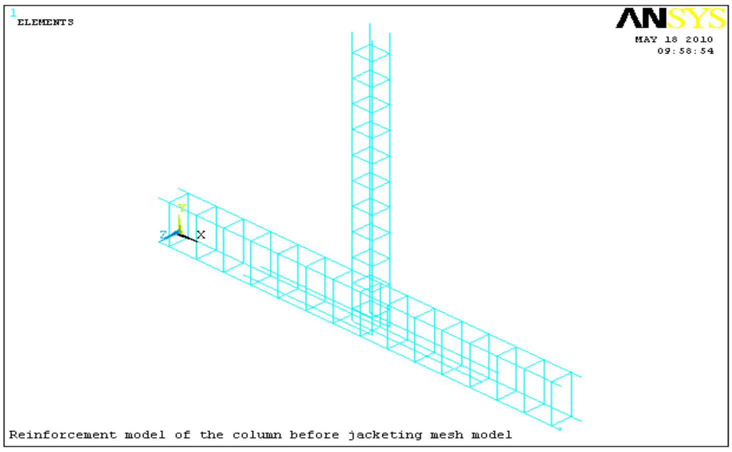
6. VALIDATION OF THE RESULTS

An analytical study was conducted by using the finite element package ANSYS. An eight-node solid element, SOLID65, was used to model the concrete. The solid element has eight nodes with three degrees of freedom at each node – translations in the nodal x, y, and z directions. The element is capable to undergo plastic deformation, cracking in three orthogonal directions, and crushing. A LINK8 element was used to model the steel reinforcement. Two nodes are required for this element. Each node has three degrees of freedom, – translations in the nodal x, y, and z directions. The element is also capable of plastic deformation. A layered solid element, SOLID46, was used to model the FRP composites. The element allows for up to 100 different material layers with different orientations and orthotropic material properties in each layer. The element has three degrees of freedom at each node and translations in the nodal x, y, and z directions. A typical finite element model of a column used in the present study is shown in Figure 7.
The ultimate displacements for the original and jacketed columns obtained from the experimental and analytical findings and their relative differences are shown in Table 3.

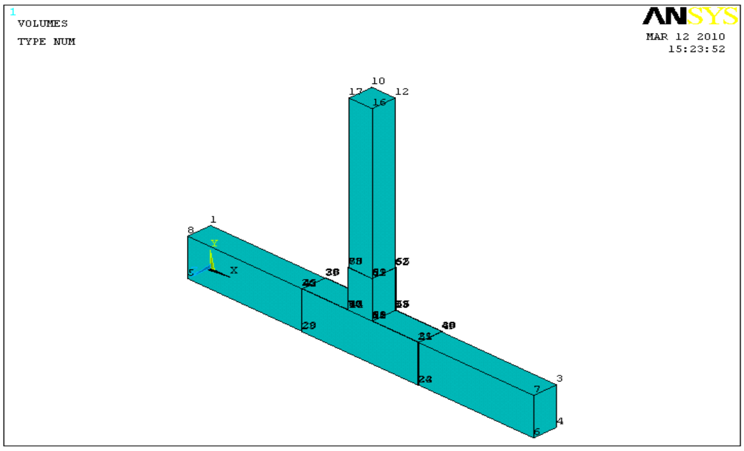
Table.3 Ultimate displacements of the specimens (Experimental vs Analytical values)

Specimen	Experimental ultimate displacement (mm)	Analytical ultimate displacement (mm)	Percentage variation
GFC 0	31.5	29.5	6.35
GFC 1	33	31.08	5.82
GFC 2	38.5	35.38	8.1
GFC 3	46.12	44.09	4.4
CFC 1	50.54	48.23	4.57
CFC 2	51.08	48.56	4.93

The analytical results are in good agreement with the experimental findings and the percentage variation is within 10%. For the GFRP and the CFRP wrapped columns, the ultimate displacements obtained are smaller than those obtained experimentally.



a) Mesh model of Reinforcement configuration of the column before jacketing



b) Solid model of the column after FRP jacketing

Figure 7. Finite element model of the specimen

7. CONCLUSIONS

This paper presents an experimental and analytical investigation conducted to assess the behaviour of beam-column wrapped with GFRP and CFRP. One specimen without FRP wrapping, three specimens with 2, 4 and 6 layers of GFRP and two specimens with one layer of CFRP were tested. The following conclusions were drawn based on the results of cyclic tests.

- The column specimens wrapped with two layers, four layers and six layers of GFRP shows 8%, 28% and 32% increase in the load carrying capacity respectively compared to the specimen without wrapping.
- The specimen jacketed with 6 layers of GFRP has the highest load carrying capacity and there is 32% increase in the strength compared with the specimen without GFRP wrapping.
- The column specimens wrapped with two layers, four layers and six layers of GFRP shows 25%, 54% and 70% increase in ductility respectively compared to the specimen without wrapping.

- The specimen jacketed with 6 layers of GFRP has the highest ductility and there is 70 % increase in the ductility compared with the specimen without GFRP wrapping.
- The specimens jacketed with CFRP have an average of 98.3% increase in the strength capacity compared to the specimen without CFRP wrapping.
- There is an average 2.7% increase in ductility for the specimens wrapped with CFRP when compared to the specimen without CFRP wrapping.
- It is observed that at low displacement levels, the energy absorbed by both GFRP and CFRP wrapped specimens were less than that by the specimen without FRP wrapping
- At higher levels of lateral displacement, the energy absorbed by the beam-column wrapped with both GFRP and CFRP was much higher than the beam-column without FRP wrapping.
- The analytical results are in good agreement with the experimental findings and the percentage variation is within 10%.
- Even though, the load carrying capacity of CFRP wrapped specimen with one layer of jacketing is 98.3% and 70% for GFRP with 6 layers of wrapping, the ductility of CFRP wrapped specimen is increased only 2.7% compared to the increase in ductility of 70% for GFRP with 6 layers of wrapping. All these comparisons are made with respect to unwrapped control specimen.
- The increase in cost of construction for CFRP wrapping is 43% compared to specimen with 6 layers of GFRP wrapping.

Hence it is recommended that GFRP wrapping is much suited for the retrofitting of RC columns.

REFERENCES

Houssam A. Toutanji et al..(2007). Axial load behavior of rectangular concrete columns confined with frp composites. *FRPRCS-8 University Of Patras*, Patras, Greece, July, 16-18.

Lau, K. T.; Zhou, L. M. (2001). The mechanical behaviour of composite-wrapped concrete cylinders subjectedto uniaxial compression load, *Composite Structures* .**52:** 189–198.

Manuel A.G. Silva and Carios C Rodrigues (2006). Size and relative stiffness effcts on compressive failure of concrete columns wrapped with glass FRP. *Journal of Materials in Civil Engineering, ASCE*. 334-342

Riad Benzaid et al. (2008). Behaviour of square concrete column confinedwith GFRP composite wrap. *Journal of Civil Engineering and Management.* **14(2)**. 115–120.

Shamim, A. Sheikh and Grace Yau (2002). Seismic behaviour of concrete columns confined with steel and fibre reinforced polymers. *ACI Structural Journal*, **99 (1).** 72-80.

Richard D. Lacobucci et al.. (2003). Retrofit of square concrete columns with carbon fibre reinforced polymer for seismic resistance. *ACI Structural Journal*. **100 (6)**. 785-794.

K. Zhang et al. (2003). Experimental study on seismic strengthening of RC columns with wrapped CFRP sheets. *Construction and Building Materials*, **17 (6 - 7).** 499-506.