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Behavior of CFRP Confined Concrete under Axial Compression

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Abstract - **The strengthening techniques of RC column using carbon fiber reinforced polymer fully wrap are used to strengthen the columns. This technique is simple to use and has many advantages over other available methods. The CFRP wrap enhances the axial load carrying capacity and the ductility of RC column. This paper deals with Experimental and analytical studies of different parameters on RC columns wrapped with carbon fiber reinforced polymer (CFRP) are taken and investigated. A total of three columns were prepared and wrapped with CFRP cloth of thickness 0.35 mm. In which two are control specimens and rest are wrapped specimens. In this topic we study the combined effect of internal steel ties and external CFRP band ties. The columns were tested under axial compression, the results demonstrated significant enhancement in the compressive strength, stiffness and ductility of the CFRP wrapped RC column as compared to unconfined RC column were identified and discussed. The ultimate stress and strain, load vs deflection of confined and conventional concrete were compared with experimental results.**

***Key words: axial stress-strain behavior, CFRP band* wrap, CFRP fully wrap, ultimate stress-strain.**

Fiber reinforced polymer (FRP) composites consist of reinforcing embedded in a polymer matrix. The matrix may be polyester, vinyl ester (or) epoxy. The reinforcing are generally carbon, glass or aramid. The can be used in a variety of forms such as random chopped strands, woven roving and continuous roving. A variety of hybrids can also be prepared and used to suit different environs. Most applications of FRP composites were confined either to aerospace and automotive industries or to marine enterprises. Construction uses were generally non- structural, Renewal of Civil Engineering infrastructure has received considerable attention over the past few years throughout the world. The civil engineers have been encouraged to explore ways and means of strengthening and upgrading existing civil engineering infrastructure etc cater for changes in use and general deterioration. The search and research over years for an innovative solution triggered the development of FRP composites for the purposes.

The beneficial attributes of FRP composites include high strength–to–weight ratio, immunity to corrosion, greater case in site handling, reduction in labour costs, elimination of the need for scaffolding, large deformation capacity, minimum changes in geometrical dimensions, minimum interruption to existing services and availability of FRP in different sizes, geometry and dimensions.

2. CONSTITUENTS OF FRP

The selection of materials for different strengthening systems is a significant process. The and resins are designed to work together. This implies that a resin system for one strengthening system may not work properly for another strengthening system. Further, a resin system for may not provide good bond to concrete. Hence it is necessary that only those systems whose applicability has been qualitatively ascertained shall be used for strengthening purposes. The primary materials for an FRP strengthening material system include adhesives resin matrices and reinforcement .

The purpose of adhesive is to produce a continuous bond between the concrete surface and the composite material to ensure that full composite action is developed by the transfer of shear stress across the thickness of the adhesive layer. The best option is to use two-part cold curing epoxy adhesive as it possesses several advantages over other polymers as adhesive agents in Civil Engineering a comparison of typical properties for epoxy adhesive, concrete and steel is given in Table 1.

Table 1 Typical properties of epoxy adhesives, concrete and steel

Property	Epoxy adhesive	Concrete	Mild steel
Density (Kg/m^3)	1100-1700	2350	7800
Elasticity modulus (Gpa)	0.5-20	20-50	205
Shear modulus (Gpa)	0.2-8	8.21	80
Poisson’s ratio	0.3-0.4	0.2	0.3
Tensile strength (MPa)	9-30	1-4	200-600
Compressive strength (MPa)	55-110	25-150	200-600

Shear strength (MPa)	10-30	2-5	200-600
Tensile strain at Break (%)	0.5-5	0.015	25
Approximate fracture energys (J/m^2)	200-1000	100	10^5-10^6
Water absorption 7 days -25°C (%)	0.1-3	5	0
Co-efficient of thermal expansion(10^{-6}-°C)	45-80	-	-

The function of resin matrix is to protect the against abrasion or environmental corrosion, to bind the together and to distribute the load. The matrix has a strong influence on several mechanical properties of the composite. Physical and chemical characteristics of the matrix influence the choice of the fabrication process. Hence a proper selection of the matrix has to be made for the composite system. Epoxy resins, polyester and vinyl ester are the most common polymeric matrix materials used with high performance reinforcing .

are effective reinforcement materials. They are available in continuous as well as in discontinuous form. The continuous can be unidirectional (or) bi-directional. The shall be significantly stiffer than the matrix and shall also be of higher strength. The used for strengthening exhibit a linear elastic behavior up to failure and do not have a pronounced yield plateau as well. The commonly used reinforcement include glass, aramid and carbon. The glass can be of E- glass, AR-glass, C- glass or S-glass. The carbon can be of high strength carbon, ultra high strength carbon, high-modulus carbon or ultra high modulus carbon the aramid can be of low modulus aramid or high modulus aramid. A major distinction of aramid fibers is that they are highly tenacious in the non-composite form and do not behave in a brittle manner as bogh glass and carbon do. Typical mechanical properties of some fiber composites are presented in Table 2.

Table 2. Typical properties of FRP Composites

Material Glass	**Fibre content (%)**	**Density (kN/m^3)**	**Elastic modulus (GPa)**	**Tensile strength (GPa)**
Glass / polyesters GFRP Laminate	50-80	16-20	20-55	0.4-1.8
Aramid/Epoxy AFRP laminate	60-70	10.5-12.5	40-125	1.0-1.8
Carbon/Epoxy CFRP Laminate	65-75	16-19	120-250	1.2-2.3

3. STATE OF RESEARCH ON FRP WRAPPED CONCRETE COLUMNS

Concrete columns are commonly used in au engineering structures, whether building, bridges, marine construction (or) monumental structures. Rehabilitation of failed columns, repair of partially damaged columns and strengthening of in service column for enhanced performance are the typical areas where concentration of the construction industry is growing. An all in one mechanism for repair, rehabilitation and strengthening of concrete columns was formulated in the form of confinement of concrete columns against lateral expansion, which resulted in higher axial stiffness, higher ductility, higher capacity to resist lateral loads induced by earth quake on wind action and increased deformability in both the axial mud lateral directions before failure.

Traditionally, confinement for columns in the lateral direction was provided using steel tubes spaced uniformly along the higher of the columns. Steel tubes were also used for confining concrete columns. Research on the application of fiber reinforced polymer (FRP) was pioneerd by the proposal of a noval stay in – place FRP form work by mirmiran, a and sharawy, MC (1995). FRP confined concrete columns are relatively immune to the effect of environmental agencies encountered under normal service conditions. Durability studies on the FRP confined concrete columns found that alternate wet-dry cycles did not have any impact on compressive strength, but alternate freeze-thaw cycles led to significant degradation of compressive strength (Tautanji, Hand Balaguru, p. 1998). In addition, application of installation of FRP confinement is a relatively easy process due to the low weight, use of simple adhesives for bonding on the concrete surface.

Zhu, Z. et al (2004) proposed a stay-in place FRP form work for precast modular bridge pier system. The connections between modules were made using post tensioned joints.

Ye, L.P. et al., (2003) investigated the seismic behavior by studying the effect of cyclically applied combined transverse and axial loading on cantilever columns. The columns were applied wraps in the form of discrete bands and full wrap. All the FRP strengthened columns showed higher ultimate load, higher axial deflection at failure and higher ductility.

FRP confinement provides reasonable safeguard against the effects slenderness of columns. Experimental investigations were carried out by Mirmiran, A. et al (2001) on concrete columns having slenderness ration from 4 to 3.6. columns with higher slenderness showed reduction in load carrying capacity, reduction in ductility and reduction in lateral expansion at ultimate load.

4. CFRP CONFINEMENT CONFIGURATIONS

CFRP may be applied for confining concrete columns in the form of complete wrapping over the entire height of the column, discrete bands of wrapping over the entire height of the column, discrete bands of wrapping at uniform spacing or in the form of continuous spiral wrapping applied over the height of the column in figure1. Full wrapping of concrete columns consumer higher amount of FRP but provides the most comprehensive protection against lateral expansion. The banded wraps are to be judiciously applied, since their effectiveness depends upon the spacing of bands, spacing of internal steel ties and the location of the FRP bands with reference to the internal ties, spiral wrapping of concrete columns with FRP strips requires care in executing the wrapping work. Spiral configuration of wrapping at particular pitch is more effective in providing confinement to a column compared to discrete bands installed at the same spacing.

The columns with discrete bands and spiral strips of FRP wrap might fail by the crushing of concrete where it is exposed without confinement. Sometimes, the failure might be explosive, where the internal coarse aggregate and fine aggregates escape with high velocity at the time of failure of the column. This phenomenon is not common in the case of full wrapping. Hence, the use of discrete bands and spiral strips should be decided based on sound reasoning and adoptability to a particular, rather than based on the ultimate compressive strength achieved by the column.

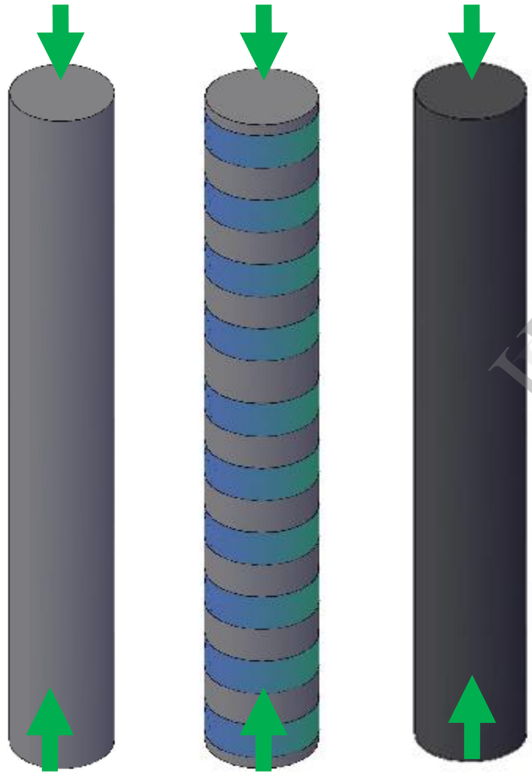

Fig1. Conventional Concrete column with band, full wrap CFRP

5. EXPERIMENTAL INVESTIGATION

Experimental investigation were carried out of three reinforced concrete column having 150mm diameter, 1200mm height, the concrete used for casting had a characteristic compressive strength of 47.954 MPa and modulus of elasticity of 200,000 Mpa longitudinal reinforcement was provided using 6 numbers of 12mm diameter steel rods of Fe500 grade. Lateral steel ties were provided using 8mm diameter mild steel having yield strength of 500 Mpa. The spacing of steel ties was maintained at 125mm c/c.

The column were wrapped with 0.35mm thick CFRP having uni directional cloth (UDC) . The wrapping was carried out using UDC mat held in ISO – Phthalic resin. The properties of CFRP used for the experimental work are presented in Table 2. The specimen details are presented in table 3. Figures 2 to 6 show the preparation and testing of specimen.

Table 3 Details of test specimens

S. No	Specimen designation	Tie spacing (mm)	CFRP wrap thickness (mm)
1	CC	125	0
2	BWC	125	0.35
3	FWC	125	0.35

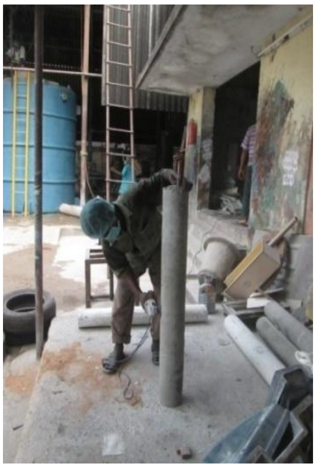

Fig. 2 Removal of loose material

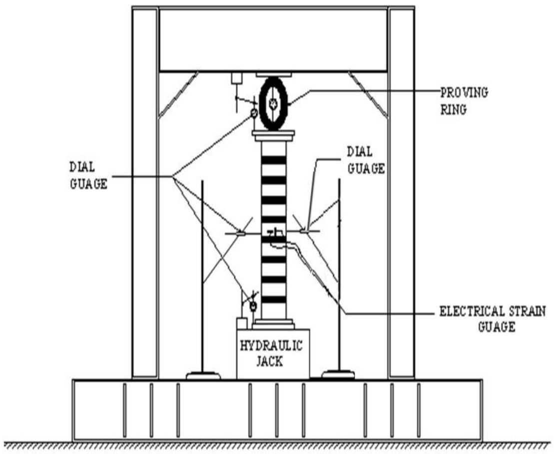

Fig 3.Test setup on RC Column under axial compression

Fig. 4. CFRP Bonding

Fig 5. The Test setup of conventional column

Fig.6. The Ultimate crack on the conventional column

6. BEHAVIOR OF CFRP CONFINED COLUMNNS

Columns with lateral confinement behave differently from the unconfined columns. The application of an axial compressive force produces an axial deformation, which in turn triggers a lateral expansion. The idea behind FRP wrapping is to check the lateral expansion. For the same amount of load, a confined concrete column exhibits less lateral expansion compared to the unconfined concrete column. This reduction in lateral expansion is accompanied by reduction in axial deformation as well. Hence, confining concrete column leads to higher stiffness in both the axial direction and the lateral direction.

The behavior of FRP confined concrete column resembles that of the unconfined concrete column up to the point where concrete fails in compression. Once the concrete crushes in compression, there is a marked increase in the transfer of stresses from concrete to FRP. After this point, FRP becomes highly active in confining the concrete. Hence, the role of FRP becomes pronounced in the case of confined concrete column where the unconfined concrete column normally fails due to crushing of concrete. This means that the second limp of the load deflection curve for confined concrete, Columns is much longer than that of the unconfined concrete column, resulting in more load carrying capacity, more ductility, more capacity to undergo axial deflection and more capacity to take lateral expansion.

The stress – strain behavior of a typical pain of unconfined & FRP confined concrete column is shows in Fig. 7.

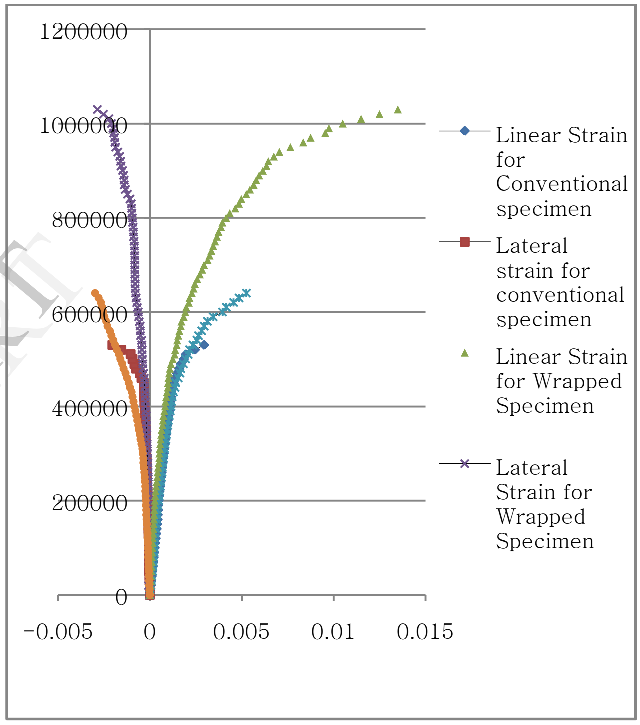

Fig.7. Typical stress strain Behavior of conventional and CFRP confined columns

7. Experimental Results and Discussion

The specimens were monotonically loaded up to failure. The yield load, yield deflection, ultimate load, ultimate deflection, deflection ductility and energy ductility values specimens are presented in Table 6 and Fig. 8- 13. The load deflection curves for the unwrapped RC columns are shows in Fig 14 and those of CFRP wrapped columns are show in Fig.15.The of CFRP wrapping on the performance of RC columns at yield condition, ultimate condition, ductility and load-deflection behavior were studied.

Table 4 Experimental Result

S.No	Specimen designation	Tie spacing	Wrapp thickens	Yield load (kN)	Yield deflection (mm)	Ultimate load (kN)	Ultimate deflection (mm)	Deflection ductility	Energy ductility
1	CC	125	0	420	3.01	530	4.26	1.42	1.14
2	BWC	125	0.35	530	3.04	640	4.97	1.63	1.74
3	FWC	125	0.35	880	6.09	1030	12.88	2.11	2.63

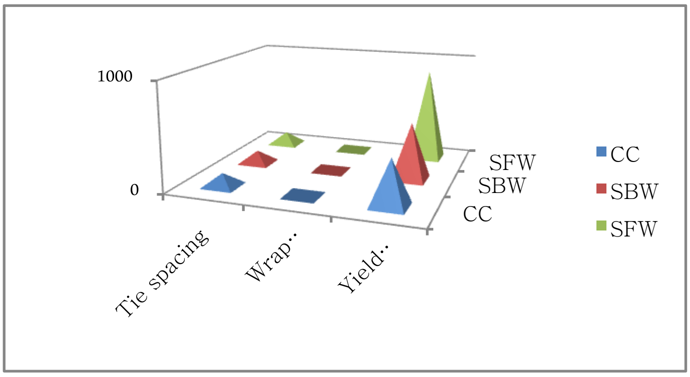

Fig.8 Yield load for Conventional, Single Band, Fully Wrapped RC Column

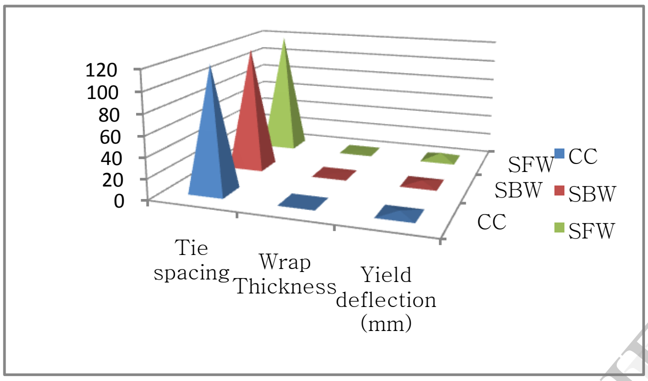

Fig.9 Yield deflection for Conventional, Single Band, Fully Wrapped RC Column

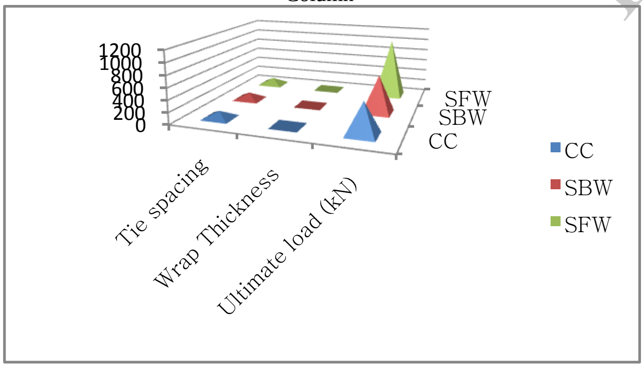

Fig.10 Ultimate load for Conventional, Single Band, Fully Wrapped RC Column

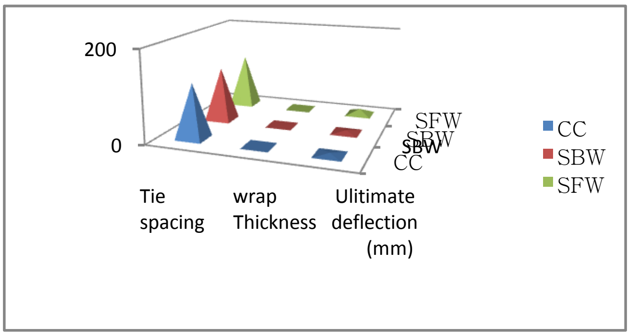

Fig. 11 Ultimate deflection for Conventional, Single Band, Fully Wrapped RC Column

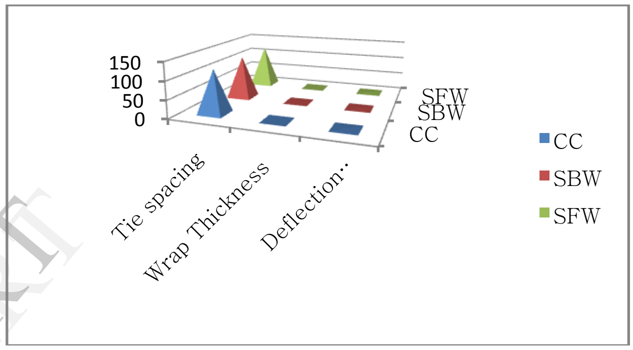

Fig. 12. Deflection ductility for Conventional, Single Band, Fully Wrapped RC Column

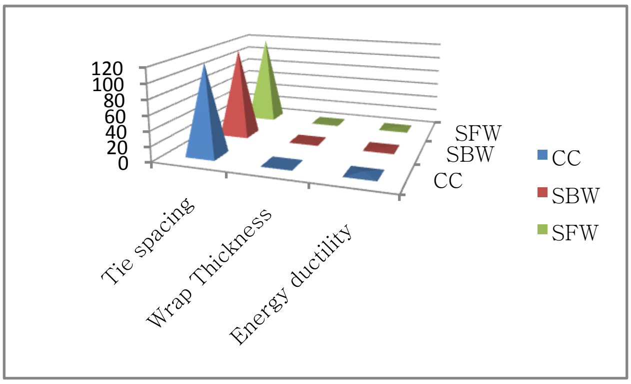

Fig 13. Energy ductility for Conventional, Single Band, Fully Wrapped RC Column

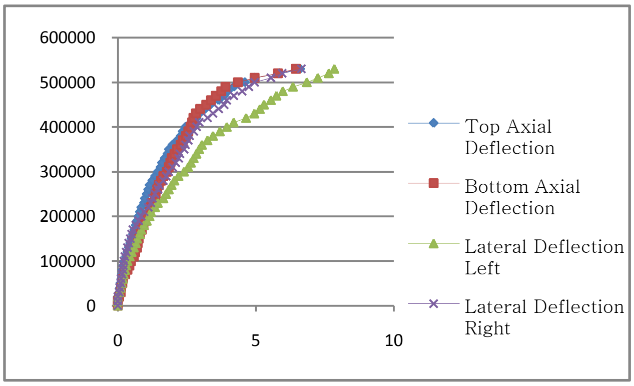

Fig. 14. Behavior of conventional column

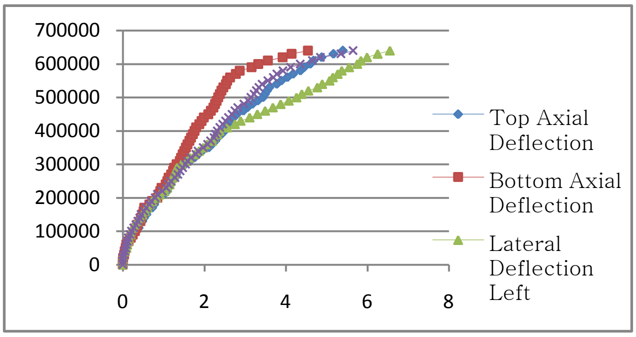

Fig. 15 Behavior of Band wrap CFRP column

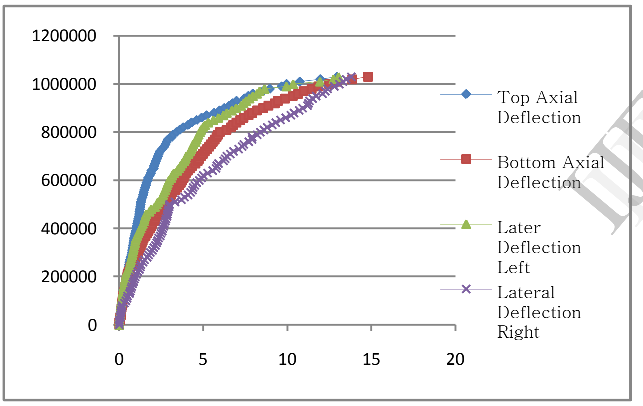

Fig.16. Behavior of full wrap CFRP column

Columns wrapped with CFRP showed higher yields loads compared to the unwrapped columns. The extent of improvement in yield load ranged from 15.38% to 64.62% the yield deflection of CFRP confined columns also showed similar trends. The extant of increase in yield deflection values ranged from 25.54% to 112.32% column with higher thickness of wrapping showed more increase in both yield load and deflection.

Tie spacing of reinforced concrete columns plays an important role in deciding the extent of improvement achieved in yield load and yield deflection, columns with higher tie spacing showed lower increase in yield loads yield deflection compared to those having lower tie spacing. The role of steel ties as confinement to core concrete is confirmed by the yield loads deflection values of the CFRP wrapped reinforced concrete columns. Ultimate load and deflection values for CFRP wrapped reinforced concrete columns increased for higher thickness of wrapping. The increases in ultimate load ranged from 36.99% to 116.44% the extent of increase being higher for columns with closer steel sties and higher thickness of CFRP. The increase in ultimate deflection values ranged from241.62% to 57.08%. This increase did not mean reduction in stiffness of CFRP wrapped reinforced concrete columns, since the load deflection trend clearly slows lower deflection for columns with higher thickness of CFRP wrapping for the same load levels.

Both deflection ductility and energy ductility undergo marked improvement as a result of wrapping with CFRP. The deflection ductility values increased in the range of 82.10% to 180.25% and energy ductility increase in the range of 196.71% to 350.91%

The failure of unwrapped columns was sudden and brittle. The failure of CFRP wrapped columns was preceded by a zone of progressively higher deflection for the same increase in load. But the ultimate failure was accompanied by a mildly explosive, failure accompanied by tearing of the wrap.

8. CONCLUSIONS

Wrapping of reinforced concrete columns with CSFRP leads to improvement in yield load, yield deflection, ultimate load, ultimate deflection, deflection ductility and energy ductility values. The major observations on the effect of CFRP wrapping on RC columns may be summarized as follows.

The following Conclusion were made after conducting the axial compression test on the CFRP wrapped RC column:

i) The ultimate load causing capacity of the control specimen is 540 KN and the maximum axial deflection is 12.36 mm.
ii) The ultimate load casing capacity of CFRP Band wrapped column is 630 KN and the ultimate deflection is 6.25mm which is 74% higher than that of control specimen and the ultimate causing capacity is 37.04% higher than that of the control specimen.
iii) The ultimate load causing capacity of CFRP fully wrapped column is 1020 KN and ultimate deflection is 15.05 which is 74% higher than that of control specimen and the ultimate load causing capacity is 88.88% higher than that of control specimen.
iv) The ultimate load causing capacity comparison of CFRP Band wrap and fully wrap is 59.37% .

In general, CFRP wrapping is an ideal material for improving the performance of reinforced concrete columns.

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