Investigation on Rehabilitation of Circular RCC Columns with FRP Composites

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Abstract. A detailed experimental investigation was done on the effect of rehabilitation using (i) carbon fibre reinforced polymer (CFRP) and (ii) glass fibre reinforced polymer (GFRP) on reinforced cement concrete (RCC) circular columns in order to compare the rehabilitation potential of these selected composites. The CFRP and GFRP laminates respectively consist of unidirectionally woven carbon fibre mat (230g/sqm) and bidirectionally woven glass fibre mat (220g/sqm), both impregnated in the same epoxy resin matrix. Even though there are many studies reported in the literature, comparative studies among these composites are limited. In order to have a level playing field, tension tests have been conducted on test coupons of these composites, and it was found that one layer CFRP was equivalent to 3 layers GFRP. In this study, pre-distressed RCC circular columns of 150mm diameter and 850mm length were rehabilitated with these equivalent laminates and tested under uniaxial compression. For rehabilitation purposes, the levels of pre-distress induced were at 70%, 80% and 90% of the ultimate capacity of the specimen. The compression behaviour of the rehabilitated columns was compared in terms of strength and serviceability. It was noted that both the composites improve the strength significantly, and CFRP performed much better than GFRP in terms of strength and serviceability.

1. Introduction

Concrete deterioration in RCC structural members due to aging, unexpected overloading, unfavourable environmental conditions, corrosion of steel reinforcement etc. are very common and these may lead to a reduction in load-carrying capacity and the structural integrity of the RCC members. However, the replacement of such deteriorated elements requires a considerable amount of time and money. Structural rehabilitation will be one of the solutions, and it involves determining the origin and amount of distress, removing damaged materials and causes of distress, as well as selecting and applying appropriate repair materials that extend the life of the structure. In recent years, the technology of strengthening the distressed structural elements with fibre reinforced polymers (FRPs) gained more momentum over the technologies using traditional materials. The primary reason is its advantages like more strength to weight ratio, easy and rapid application, minimal change in structural geometry, etc.

Several studies were conducted on FRP rehabilitation [1-5] and confirm its effectiveness in enhancing the ductility and load-carrying capacity of RCC columns. Even though the studies comparing the confinement effectiveness of different FRPs on RCC columns, based on strength and serviceability are limited. This study deals with an experimental investigation on the enhancement of compression behaviour of preloaded RCC columns using (i) Carbon Fibre Reinforced Polymers (CFRP) and (ii) Glass Fibre Reinforced Polymers (GFRP). The parameters considered in this study are (i) the composite materials used for strengthening, and (ii) the amount of pre-distress induced to the columns.
2. Experimental Programme

The experimental work was conducted on eight circular columns having 150mm diameter and 850mm length. These columns were grouped into two with four columns each viz. Group-1 and Group-2. One column in each group was tested up to failure under uniaxial compression in a universal testing machine (UTM) of 300T capacity to find the ultimate capacity and kept as control specimens. The other columns in each group were preloaded to 70%, 80% and 90% of the ultimate capacity. The Group-1 and Group-2 preloaded columns were then rehabilitated with CFRP and GFRP respectively, by complete wrapping with these composites by wet lay-up procedure. The rehabilitated specimens were cured for two weeks at ambient temperature. These columns were then tested to failure and the behaviour was compared. In order to do the comparison study in a level playing field, initially, tension tests were conducted on CFRP and GFRP coupons to equalise their strengths.

2.1. Tension tests on FRP coupons

2.1.1. FRP composites used. CFRP consisted of unidirectional carbon fibre woven mat of weight 230g/sqm impregnated in epoxy resin. Similarly, GFRP consisted of bi-directionally woven glass fibre mat of weight 220g/sqm impregnated in the same resin material. The average thicknesses of the dry mat were 0.26mm and 0.18mm for carbon and glass respectively. The epoxy resin used for making both kinds of FRP was a two-part system of base and hardener (viz. CERA EPS) which was mixed in a proportion of 5:3 by weight. For preparing the FRP composites, the fibre and the resin were taken in a ratio of 1:1 by weight. The selected fibre mats and resin are shown in figure 1.

![Figure 1. Constituents of composites selected for rehabilitation.](image1)

(a) Carbon fibre mat  
(b) Glass fibre mat  
(c) Epoxy resin

2.1.2. Test coupons. The tensile tests were conducted as per ASTM D3039/D3039M [6]. Test coupons were fabricated by following the wet lay-up procedure given in ASTM D7565/D7565M [7]. Coupons of width 25mm and length 280mm were cut from 300mm×300mm laminate sheets which were prepared as per the given procedure. Two flat rectangular aluminium tabs of thickness 1.5mm, width 30mm, and length 80mm were glued on the opposite faces of the test coupons at each end to prevent the gripping damage. This may ensure that the failure occurs within the gauge region. Typical test coupons are shown in figure 2.

![Figure 2. Tension test coupons.](image2)

(a) CFRP  
(b) GFRP

2.1.3. Test results. Coupons were prepared with different numbers of layers. CFRP coupons were prepared with one and two layers. GFRP coupons were prepared with two to five layers. Five samples were prepared with each layer group and tested to failure in a UTM of 200kN capacity. The rate of loading was set as constant with a standard head displacement of 2 mm/min, such that the failure occurs within 1 to 10 minutes as specified in ASTM D3039 [6]. The failure mode was noted and was found that
all the specimens failed in the recommended modes, which were either long splitting or lateral breaking of FRP laminate within the gauge region. The maximum tensile force per unit width for the specimens was calculated as per ASTM D7565 [7]. CFRP with 1 and 2 layers showed the tensile strength of 246.71N/mm and 541.24N/mm respectively. Similarly, GFRP coupons attained the tensile strengths of 118.43N/mm, 242.1N/mm, 312.46N/mm, 389.96N/mm respectively for 2 to 5 layers. It may be noted from these results that one layer of CFRP exhibits a tensile strength which is almost equal to the tensile strength given by three layers of GFRP. Hence CFRP with one layer and GFRP with 3 layers were selected as equivalent laminates for rehabilitating RCC columns for conducting the comparative study.

2.2. Preparation of column specimens
Eight circular columns of size 150mm diameter × 850mm length were cast using a design concrete mix of grade M35. The materials used for preparing the concrete mix were Portland Pozzolana cement, manufactured sand as fine aggregate, 12mm crushed stone as coarse aggregate and potable water. The mix obtained was 1:1.55:2.78 with a water-cement ratio of 0.5. Columns were axially reinforced with six numbers of 6mm diameter high yield strength deformed (HYSD) bars. Transverse reinforcement was of 6mm diameter HYSD bars at a centre to centre spacing of 85mm. The spacing of lateral ties was reduced to 50mm at both the ends of the column over a length of 100mm to avoid crushing at the ends due to stress concentration while loading. In order to ensure the occurrence of failure of columns within the mid-height region, internal confinement to the core concrete was provided using a 10mm square welded wire mesh, and external confinement to the cast column was provided using two layers of CFRP for a length of 50mm at both the ends. Reinforcement details of the column, an actual reinforcement cage with wire meshes at the ends, and an actual cast column with external CFRP confinement at the ends are shown in figure 3.

2.3. Preloading of columns
The Group-1 columns were meant for rehabilitation with CFRP and those in Group-2 with GFRP. The control specimens in both groups were tested to failure to find the ultimate load-carrying capacity. The remaining three columns in each group were tested up to 70%, 80% and 90% of the ultimate load for inducing pre-distress. The columns were designated with a letter and a number in which the letter indicates the composite (viz. C for CFRP and G for GFRP) and the number indicates the amount of pre-distress (viz. 100, 90, 80 and 70 respectively for the pre-distress levels of 100% (control specimen),
90%, 80%, and 70%). For example, the column specimen having a pre-distress of 80% of the ultimate load that rehabilitated with CFRP was designated as C80.

The specimens were preloaded under axial compression in a UTM with a capacity of 300T. The rate of loading was kept constant at 20kN/min. Two linear variable differential transformers (LVDT) with a least count of 0.01mm were placed longitudinally at mid-height to measure the axial deformation. The gauge length was kept as 100mm. Another two LVDTs were kept laterally at mid-height such that the tips touched two diametrically opposite points on the column surface, to measure the lateral deformation of the column. Two lateral extensometers were placed at a distance of 1/4th height of the column from both the ends, to note the lateral deformations. The test set-up is shown in figure 4.

2.4. Rehabilitation process
The Group-1 pre-loaded columns were rehabilitated with one layer of CFRP; and those in Group-2 with three layers of GFRP. The rehabilitation method adopted was full height wrapping of the column by using the equivalent laminate in order to ensure the complete confinement of the pre-distressed columns. Unidirectional CFRP was wrapped such that the fibre direction was along the circumference of the column. The surfaces of the pre-loaded columns were first applied with an epoxy primer (Cera EP18) to have a good bonding with the FRP laminate. The primer also was a two-part system of base and hardener that was mixed in a proportion of 2:1 by weight. The full height of the columns was applied with one coat of primer and cured at ambient temperature for 24 hours to get a smooth surface to bond with the composite. The application for FRP composite was made by wet lay-up procedure. The matrix which is the epoxy resin (EPS) was prepared by thoroughly mixing the base and hardener in the proportion 5:3 by weight. The FRP sheets were cut at the required sizes to cover the full height of the columns such that the CFRP was wrapped with one layer and three layers in the case of GFRP. The wrapping was done in such a way that there was no entrapped air and excess resin. The rehabilitated specimens were cured at ambient temperature for a period of 2 weeks to ensure the complete hardening of the laminate before final testing. The rehabilitated specimens are shown in figure 5.

![Figure 4. Test set-up.](image)

(a) Group-1 (CFRP)  (b) Group-2 (GFRP)

![Figure 5. Rehabilitated columns.](image)

3. Test results and discussion
The rehabilitated specimens were tested under axial compression as explained in section 2.3. LVDT and extensometer readings were noted at 20kN intervals. The columns were tested until complete failure occurred, and the failure modes were noted. The post-peak behaviour was recorded until the load reduced below 50% of the ultimate load.

3.1. Ultimate load carrying capacity
The ultimate load of the rehabilitated columns is shown in table 1 along with the control columns (CC). It can be observed that the rehabilitation by both the FRPs increases the load-carrying capacity of the
pre-distressed columns in which CFRP showed a better performance. Also, it may be observed that the load-carrying capacity increases with a decrease in the pre-distress level.

**Table 1.** The ultimate load of rehabilitated columns and control columns.

| Specimen group no. | Beam designation | % Distress level | Ultimate load (kN) | % Increase in load carrying capacity |
|--------------------|------------------|------------------|--------------------|-------------------------------------|
| 1 (CFRP rehabilitated) | C100 (CC) | 100 | 602 | - | 1.00 |
|                    | C90 | 90 | 960 | 59.47 | 1.59 |
|                    | C80 | 80 | 1137 | 88.87 | 1.89 |
|                    | C70 | 70 | 1185 | 96.84 | 1.97 |
| 2 (GFRP rehabilitated) | G100 (CC) | 100 | 600 | - | 1.00 |
|                    | G90 | 90 | 890 | 48.33 | 1.48 |
|                    | G80 | 80 | 905 | 50.83 | 1.51 |
|                    | G70 | 70 | 959 | 59.83 | 1.60 |

3.2. Failure modes
All the specimens failed due to FRP rupture and are shown in figure 6. The major rupture occurred around 1/3rd height from either the top or bottom ends. None of the specimens showed any cracks near the ends, which confirms the effectiveness of extra confinements provided at the ends both internally and externally. All the rehabilitated columns showed good ductility before the complete rupture of FRP laminates.

![Failure modes of rehabilitated columns](image)

**Figure 6.** Failure modes of rehabilitated columns with various pre-distress level.

3.3. Load-axial deformation behaviour
Compressive load versus axial deformation curves were plotted for both the groups of columns and are depicted in figure 7. It may be noted from the plots that the axial stiffness and the ductility are increased significantly due to rehabilitation. CFRP performed much better than GFRP in all levels of pre-distress. It is also noted that the increase in load-carrying capacity is more for lesser distressed columns, however these showed less ductility.
3.4. Compressive stress versus axial strain behaviour

The compressive stress-axial strain behaviour was compared between CFRP and GFRP rehabilitated columns at different levels of the pre-distress. The relationships are depicted in figure 8. It may be noted that there is a higher reduction in the stiffness of CFRP specimens as the pre-distress increases than for the GFRP rehabilitated specimens. CFRP showed more ductility than GFRP at all levels of pre-distress.

4. Conclusions

The following conclusions are arrived at based on the comparative study between CFRP and GFRP on their rehabilitation potential on RCC circular columns, pre-distressed to various levels of ultimate load.

- Both the FRP rehabilitation enhanced the load-carrying capacity significantly. The strength gain in CFRP rehabilitation was 59% to 97% over and above the control specimens, and that in GFRP, it was 48% to 60% with a decrease in pre-distress level from 90% to 70%.
- Axial deformation behaviour improved with a reduction in pre-distress level in both the FRPs, and CFRP showed a better behaviour than GFRP concerning stiffness and ductility.
- All the rehabilitated specimens showed a ductile failure, and at ultimate stage FRP rupture occurred away from the support region.
- CFRP outperformed GFRP in both the aspect of strength and serviceability in rehabilitating circular columns at all levels of pre-distress.

5. References

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