Enhancement in the Load-Carrying Capacity of RC Rectangular Columns Adopting CFRP and GFRP

Md Ibrahim and Y. K. Guruprasad

Abstract There exist various techniques for retrofitting of reinforced concrete structural elements that have undergone damage. The use of FRP wrapping is one of the retrofitting techniques to enhance the load-carrying capacity of reinforced concrete (RC) columns (up to 20% increase). In this work, enhancement of axial load-carrying capacity of distressed RC columns adopting CFRP and GFRP was carried out. An RC column having a cross-sectional dimension of 400 mm × 600 mm and a height of 4 m is considered for this study. The RC column considered for the study was initially designed using concrete having a compressive strength of 30 N/mm^2. Eventually, due to erroneous mixing and placing of concrete in the site, it resulted in the concrete in the column to have developed a lower compressive strength of 25 N/mm^2. This distressed RC column eventually tends to have a lower load-carrying capacity due to a reduction in the compressive strength of concrete. This RC column is retrofitted using fibre-reinforced polymer (FRP) composites by wrapping the column to restore its original load-carrying capacity through the confinement provided by the FRP wrapping. The FRP composites considered in this study are carbon fibre-reinforced polymer (CFRP) and glass fibre-reinforced polymer (GFRP) fabrics wrapped around the distressed RC column with the application of epoxy. The design and estimation of quantity of the retrofit using CFRP and GFRP are adopted based on ACI codal provisions (ACI 440.2R-08). It was learnt by carrying out the design of the retrofit for the distressed RC column, the number of CFRP and GFRP layers obtained for wrapping are five numbers and ten numbers, respectively. From this study, it is learnt that CFRP is better when compared to GFRP in terms of enhancement in strength and load-carrying capacity of the distressed RC column with a lesser number of layers of wrap.

M. Ibrahim (✉)
Final Year M.Tech Student Structural Engineering, Ramaiah Institute of Technology, Bangalore 560054, India
e-mail: md.ibrahim.r70@gmail.com

Y. K. Guruprasad
Associate Professor, Department of Civil Engineering, Ramaiah Institute of Technology, Bangalore 560054, India
e-mail: guruprasad.civil.iisc@gmail.com

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1 Introduction

Retrofitting/Strengthening is the modification of existing structures to make them more resistant to seismic activity, soil failure, or ground motion due to earthquakes. Most of the buildings failed or collapsed under seismic activity mainly due to column failure. Therefore, confinement of columns becomes an important parameter while increasing stiffness, ductility of structure. The idea of column confinement was originally developed back in the 1920s [1]. In India, most of existing structures are designed based on IS 456:2000 codal provisions.

There exist various techniques for retrofitting of reinforced concrete structural elements that have undergone damage [2].

- Confinement with fibre-reinforced polymers (FRP) such as aramid fibres, carbon fibres and glass fiber-reinforced composite.
- Confinement with external steel caging techniques.
- Confinement with RC jacketing [7].
- Confinement with composite material.

In the above, all techniques retrofitting with FRPs have less weight–strength ratio, no extra changes in cross section, easy to handle, and less labour cost.

Yazdani et al. [2] carried out a computational analysis on various circular column specimens. They used the CFRP for strengthening and finite element analysis for the interpretation of results with given by ACI and NCHRP. The conclusion drawn is that CFRP wrapping increased peak load capacities and ductility of confined columns. Wang et al [3] performed experimental analysis on large-scale rectangular column retrofitted with CFRP under lateral loading in different directions and reported 60° is the weakest axis or critical axis other than 90° for both unretrofitted and CFRP-retrofitted columns. Jaya and Mathei [4] has done an experimental and analytical study on beam–column wrapped with GFRP and CFRP. The column is wrapped with an increasing number of plies. The result has been recorded as an increase in axial load-carrying capacity and ductility. Parghi et al. [5] have carried out an experimental analysis on strengthening and repair of reinforced concrete structures using composite material. GFRP is used as a composite material for strengthening. It has found that a sufficient amount of increase in load-carrying capacity of column and beam compared to control specimen.

1.1 Significance of Present Work

By examining the research database, it is found that the comparative strength and cost estimation for distress RC columns repaired using CFRP and GFRP based on ultimate strain and confining pressure. That leads to the calculation of number of layers of FRP material that has been identified as an important, design-perspective point of view. In this work, reinforced concrete (RC) column having a cross-sectional dimension of 400 mm × 600 mm and a height of 4 m has been considered for the present study. The same column that is undergone distress due to the reduced compressive strength of concrete due to erroneous mixing and placing of concrete in the site is strengthened by externally wrapping it using CFRP and GFRP separately.

2 Methodology

- The column considered for the study was initially designed using concrete having a compressive strength of 30 N/mm^2.
- Eventually, due to erroneous mixing and placing of concrete in the site, it resulted in the concrete in the column to have developed a lower compressive strength of 25 N/mm^2.
- The design and estimation of quantity of the retrofit using CFRP and GFRP is adopted based on ACI codal provisions (ACI 440.2R-08)

2.1 Design of retrofit using CFRP and GFRP (for Axial Load)

Following cross-sectional details and properties of the materials used are as shown below.

2.1.1 Column Cross-Sectional Details and Properties

Required compressive strength of column, ϕPn req	3860 KN
Width of column, b	400 mm
Depth of column, d	600 mm
Length of column, L	4000 mm
Compressive stress in concrete, f_c	30 N/mm^2
Specified yield strength of non-prestressed steel reinforcement, f_y	415 N/mm^2

Total area of longitudinal reinforcement, A_{st}	3350 mm^2 [6]
Specified compressive strength of concrete, f'_c	25 N/mm^2
Radius of edges of prismatic cross section confined with FRP_{rc}	25 mm
Gross area of concrete, A_g	240,000 mm^2
Strength reduction factor, ϕ	0.65
FRP strength reduction factor, Ψ	0.95
$\rho_g = A_{st}/bh$	1.40%.

The column is located in an interior environment.

2.1.2 CFRP Properties

Thickness of ply t_f	0.33 mm
Ultimate tensile strength $f * f_u$	3792 MPa
Rupture strain $\varepsilon * f_u$	0.0167 mm/mm
Modulus of elasticity E_f	227527 N/mm^2

2.1.3 GFRP Properties

Thickness of ply t_f	1.3 mm
Ultimate tensile strength $f * f_u$	552 MPa
Rupture strain $\varepsilon * f_u$	0.020 mm/mm
Modulus of elasticity E_f	27600 N/mm^2.

2.2 Strengthening of a Distress Rectangular RC Column for Confinement and Axial Load Increment

2.2.1 Design Steps as per ACI 440.2R-08 [8] for CFRP and GFRP Distress RC Column

Step-1: Design FRP material properties

$$f_{fu} = C_E \times f_{fu}^* \tag{1}$$

$$\varepsilon_{fu} = C_E \times \varepsilon_{fu}^* \tag{2}$$

Step-2: Required maximum compressive strength of confined concrete f'_{cc}

$$f'_{cc} = \frac{1}{0.85(A_g - A_{st})}\left[\frac{P_n \,\text{req}}{0.80\varphi} - f_y A_{\text{st}}\right] \tag{3}$$

Step-3: Max confining pressure due to the FRP jacket

$$f_1 = \frac{f'_{cc} - f'_c}{3.3\kappa_a} \tag{4}$$

where

$$\kappa_a = \frac{A_e}{A_c}\left(\frac{b}{h}\right)^2 \tag{5}$$

$$\frac{A_e}{A_c} = \frac{1 - \frac{\left[\left(\frac{b}{h}\right)(h-2r_c)^2 + \left(\frac{h}{b}\right)(b-2r_c)^2\right]}{3A_g} - \rho_g}{1 - \rho_g} \tag{6}$$

Step-4: Number of plies/layers

$$n = \frac{f_1\sqrt{b^2 + h^2}}{\psi_f 2E_f t_f \varepsilon_{fe}} \tag{7}$$

$$\varepsilon_{fe} = \kappa_\varepsilon \varepsilon_{fu} \tag{8}$$

Step-5: Checking for the minimum coefficient ratio

$$\frac{f_1}{f'_c} \geq 0.08 \tag{9}$$

Step-6: Verifying that the ultimate axial strain of the confined concrete $\varepsilon_{\text{ccu}} \leq 0.01$

$$\varepsilon_{\text{ccu}} = \varepsilon'_c\left(1.5 + 12\kappa_b \frac{f_1}{f'_c}\left(\frac{\varepsilon_{fc}}{\varepsilon'_c}\right)^{0.45}\right) \tag{10}$$

where

$$\kappa_b = \frac{A_e}{A_c}\left(\frac{h}{b}\right)^{0.5} \tag{11}$$

Table 1 Design details of CFRP and GFRP as a retrofit

Parameter	For CFRP	For GFRP
f_{fu}	3603 N/mm^2	552 N/mm^2
$\varepsilon_{\mathrm{fu}}$	0.0159 mm/mm	0.015 mm/mm
f'_{cc}	30 N/mm^2	30 N/mm^2
f_{l}	7.456 N/mm^2	7.456 N/mm^2
n	5 no's	10 no's
$\frac{fl}{f'c} \geq 0.080$	0.2982	0.2982
$\varepsilon_{\mathrm{ccu}} \leq 0.01$	0.01	0.01

3 Results and Discussion

The design is carried out for both the cases of wrapping with CFRP and GFRP. The numbers of plies/layers for CFRP and GFRP retrofit RC column thus obtained in the design are shown in Table 1.

- The analysis was carried out for both cases; it is observed from the result that the layers with CFRP retrofit are five in numbers and GFRP retrofit are about ten in numbers for increasing the compressive strength of concrete in distress column through confinement pressure by 17.5% of column strength.
- The reason for more number of layers for GFRP retrofit is due to its lower modulus of elasticity when compared to CFRP that has the larger modulus elasticity.

4 Conclusion

- Retrofitting using FRP materials such as GFRP and CFRP is more convenient due to its ease of application and high strength-to-weight ratio.
- Both CFRP and GFRP have improved load carrying capacity of distress RC column.
- Due to higher modulus of elasticity, CFRP retrofit results in lesser number of layers to restore the distress RC column.
- In the case of GFRP, more number of plies are required to restore the distress RC column due to the lower value of modulus of elasticity of GFRP.
- Comparatively, when the economy is to be considered, GFRP is comparatively economical than CFRP to restore distress RC column. But when the numbers of layers are to be restricted to maintain aesthetic of the member, CFRP would better option for retrofit.

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