Design of Short Columns Reinforced with GFRP Bars Subjected to Axial Loading

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Abstract. Due to the ongoing environmental changes, degradation of directly exposed material is seen very often. This results in issues related to aesthetics, function, and most importantly, the safety of the structures. Reinforced cement concrete (RCC) is the most commonly used material for construction where steel bars are used as reinforcement. Steel reinforcement in contact with the chemicals like chlorides and sulphates etc. which are very commonly present in urban and industrial areas and other aggressive environment, gets corroded, thus affecting the structural behaviour. Research studies propose replacing steel rebars with Glass Fibre Reinforced Polymer (GFRP) bars due to its non-corrosive properties. This paper presents the analysis and design of GFRP reinforced concrete columns. Present design methods mentioned in Indian Standard Code are not applicable to design GFRP reinforced RC columns directly. This study is an attempt to develop design provisions for GFRP reinforced concrete columns similar to those in practice for steel-reinforced columns. The spacing of ties influences the capacity of the column to carry load and failure type of compression member. So, this paper will also focus on the design of ties to provide proper confinement.

1. Introduction

Reinforced Concrete is a composite material that is widely used for construction. Various materials are being employed as reinforcing means for concrete which include bamboo, steel, wood, and some artificially produced composite materials [1]. Reinforcement in the form of steel reinforcing bar (rebar) is passively embedded in concrete before the concrete sets. However, rusting of steel rebar is identified as the foremost problem affecting structural stability [2]. In recent years, research has been carried out on Glass Fibre Reinforced Polymer (GFRP) bars as an alternative to steel reinforcement in concrete structures due to its non-corrosive nature [3]. The mechanical properties of the GFRP bar such as high tensile strength low density, lightweight, it is gaining prominence in the construction industry [3].

Castela et al. 2014 [4] investigated the effect of the corrosion rate of the steel bars wrapped with glass fibre-reinforced polymers (GFRP). They found that the corrosion rate and chloride ion penetration decrease due to the wrapping of GFRP. Experimental studies were conducted by Tu et al. [5], Mohamed et al. [6], Luca et al. [7], Hadi et al. [8] to find out the effect of compressive behaviour of GFRP bars in RC columns. From results, it is found that the columns having low longitudinal reinforcement ratio, fail in a brittle manner. The load-carrying capacity of GFRP reinforced concrete columns is 13-16% lower than the column reinforced with steel if provided longitudinal reinforcement ratio is the same[5]. Seismic analysis of GFRP reinforced concrete columns was conducted by Ali et al. Lateral cyclic quasi-static and constant axial loading applied during the testing. Experimental result shows that the drift capacity of GFRP-RC columns lies between 8.5 to 12.5% at failure. Due to well confined concrete core, columns shows insignificant strength degradation before failure[9]. Design equation of GFRP RC columns

\[ \text{Design equation of GFRP RC columns} \]
according to Indian standard is not available. Present study develops the design equation for GFRP reinforced concrete column considering provisions of Indian Standard code.

![Figure 1. GFRP Bars.](image)

2. **Minimum longitudinal reinforcement**

According to Indian standard (IS456: 2000) ratio of minimum reinforcement for compression member reinforced with steel is 0.8 percent of the gross cross-section area of the column\([10]\). Minimum reinforcement is necessary to cater to the bending moment in the column due to specified minimum eccentricity. Minimum reinforcement also prevents the passive yielding of the steel. From the literature survey, it is found that GFRP does not yield, so the same specification of the minimum reinforcement ratio can be applied to column reinforced with GFRP bars.

3. **Design equation: ultimate load-carrying capacity**

According to Indian standard (IS 456: 2000)\([10]\) the capacity to carry the axial load by short column reinforced with steel bars is given by Eq. (1) (Without partial factor of safety) and column are designed according to Eq. (2).

\[
P_u = 0.8 f_{ck} A_c + f_y A_{sc}
\]

\[
P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}
\]

where \(P_u\) is the ultimate load-carrying capacity of the column, \(A_c\) is the area of cross-section of concrete, longitudinal reinforcement area is denoted by \(A_{sc}\), \(f_y\) is yielding strength of the steel bar, \(f_{ck}\) is the characteristics strength in compression for the concrete.

![Figure 2. Cold work deformed bar: Stress vs Strain [11].](image)
GFRP bars show linear stress-strain behaviour. So, it is not easy to find out the yielding strength of these bars. Design equation of steel-reinforced concrete column given by IS456: 2000 is based on yielding strength of steel rebar because the yielding strength of these bars can be easily found out. Therefore, the design of the GFRP-RC column is not possible based on yield strength. It is assumed that elastic modulus in compression is comparable to the tension. The first part of the equation represents the load carried by concrete and the second part represents the load carried by GFRP bars. The experimental result shows that the ultimate stress compression for GFRP bars is 30 - 40 % of the ultimate stress in tension. Based on the experimental result, equation (3) is introduced to find out the load-carrying capacity of the GFRP reinforced concrete column. A new factor for strength reduction ($\beta$) is introduced. From literature (Mohamed et al. 2014 [6]), the value of the strength reduction factor is assumed 0.35.

$$P_u = 0.8 f_{ck} A_c + \beta f_u A_{gf}$$

where $f_u$ is the ultimate tensile strength of the GFRP bar. Based on equation (3) design equation of the column is given as

$$P_u = 0.4 f_{ck} A_c + \beta f_u A_{gf}$$

4. Analytical results vs Experimental results

Experimental studies are carried out on square columns of size 150 ×150 × 850mm. GFRP bars are used as reinforcement for longitudinal bars and 6mm steel bars are used for stirrups. The grade of concrete used in studies is M30. The longitudinal reinforcement ratio is 1.39%. Four bars of 10mm are provided as longitudinal reinforcement. Table 1 shows the comparative analysis of theoretical and experimental results.

| Specimen no. | Specimen ID | Axial Compressive Strength (MPa) | Experimental load (kN) | Analytical load (kN) | % Difference in Experimental load and Eq.3 |
|---------------|-------------|----------------------------------|------------------------|----------------------|------------------------------------------|
| 1             | C-G75       | 42.35                            | 1000.62                | 873.70               | +12.6                                    |
| 2             | C-G50       | 43.8                             | 1177.2                 | 899.44               | +23.5                                    |

*aC stands for control mix, G stands for GFRP bars and 75, 50 represents the spacing of stirrups.*
5. Validation of analytical equation

i. To validate the analytical equation for square columns experimental results are considered from literature (Tu et al. 2019)\[5\]. Eight GFRP reinforced concrete columns (200 × 200 ×600mm) were tested. The longitudinal reinforcement ratio is provided as 0.8, 1.1, and 1.5%. Four numbers of bars are provided as longitudinal reinforcement. All the columns are cast from the same concrete of having an axial compressive strength of 32.1 MPa. GFRP bars of 8 mm is used for stirrups. Table 2 shows the comparative analysis of theoretical and experimental results.

Table 2. Square columns reinforced with GFPR bars: Analytical vs Experimental results \[5\].

| Specimen No. | Specimen ID\[b\] | Longitudinal reinforcement ratio % | Experimental load (kN) | Analytical Load (kN) Eq.3 | % Difference Experimental load and Eq.3 |
|-------------|------------------|-----------------------------------|------------------------|----------------------------|---------------------------------------|
| 1           | G12-S30          | 1.1                               | 970.0                  | 1120.08                    | -15.37                                |
| 2           | G12-S50          | 1.1                               | 951.6                  | 1120.08                    | -17.70                                |
| 3           | G12-S80          | 1.1                               | 937.7                  | 1120.08                    | -19.45                                |
| 4           | G10-S50          | 0.8                               | 936.8                  | 1099.99                    | -17.42                                |
| 5           | G14-S50          | 1.5                               | 981.7                  | 1135.09                    | -15.62                                |
| 6           | G12-H30          | 1.1                               | 954.0                  | 1120.08                    | -17.41                                |
| 7           | G12-H50          | 1.1                               | 943.2                  | 1120.08                    | -18.75                                |
| 8           | G12-H80          | 1.1                               | 927.7                  | 1120.08                    | -20.74                                |

\[b\] G represents GFRP bars, S stands for Spirals, and H represents hoop 10,12, 14 are the diameter of the longitudinal bars 30, 50, 80 are the spacing of the ties.

Figure 4. Experimental Analytical result comparison for square columns.

Figure 5. Experimental vs Analytical result comparison for square columns.
i. For circular columns, the experimental result of the load carried by the columns is taken from studies by Mohamed et al. 2014[6]. Concrete columns of diameter 300 mm. and height 1500 mm. reinforced with GFRP reinforced were tested. 8 numbers of GFRP bars of diameter 15.9 mm provided as longitudinal reinforcement. The longitudinal reinforcement ratio is provided at 2.2%. All the columns made from the same concrete of having an axial compressive strength of 42.9 MPa. GFRP bars are used for stirrups.

**Table 3. Circular columns reinforced with GFRP bars: Analytical vs Experimental results.**

| Specimen No | Specimen ID | Experimental load (kN) | Analytical Load (kN) Eq. 3 | % Difference in Experimental load and Eq.3 |
|-------------|-------------|------------------------|-----------------------------|------------------------------------------|
| 1           | G2S         | 2857                   | 2890.68                     | -1.17                                    |
| 2           | G3S         | 2920                   | 2890.68                     | +1.00                                    |
| 3           | G4S         | 3019                   | 2890.68                     | +4.25                                    |
| 4           | G3H200      | 2840                   | 2890.68                     | -1.70                                    |
| 5           | G3H400      | 2871                   | 2890.68                     | -0.68                                    |
| 6           | G3H600      | 2935                   | 2890.68                     | +1.50                                    |

* G represents GFRP, 2-3-4 represents number of horizontal bar, S stands for spiral, H represents hoops, 200, 400 and 600 stands for the lap splices length in mm for GFRP hoops.

**Figure 6.** Experimental vs Analytical result comparison for circular columns.

6. **Maximum spacing of transverse reinforcement**

According to IS456:2000[10] for the steel-reinforced concrete column, spacing is limited to a minimum of

- Least lateral dimension of the column
- 16 times the longitudinal bar diameter
- 300 mm

The spacing between ties related to the longitudinal bar diameter based on the assumption that the bars are simply supported between the two-support provided only by the ties. For such member to avoid the buckling this condition must be satisfied [2].

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\[
\frac{\pi^2EI}{S^2} \leq AE\epsilon 
\]

(5)

\[ S_{\text{max}}^2 = \frac{\pi^2I}{AE} \]

(6)

For a circular bar of diameter \( d_b \), this expression can be written as

\[ S_{\text{max}} = \frac{\pi d_b}{4\sqrt{\epsilon}} \]

(7)

Where \( S \) is spacing of the ties, \( I \) is Moment of inertia of the bar, \( A \) is the cross-sectional area of the bar.

For steel bars to prevent buckling: \( \epsilon = \epsilon_y = 0.002 \). Substituting this value in Eq. (7)

\[ S_{\text{max}} = 17.5 \, d_b \]

which satisfies the code provision of IS456: 2000 \((S_{\text{max}} = 16 \, d_b)\).

For GFRP bars to prevent buckling before concrete crushing: \( \epsilon = \epsilon_{cu} = 0.0035 \), therefore

\[ S_{\text{max}} = 13.27 \, d_b \]

so considering all these points the spacing of the transverse reinforcement \( S_{\text{max}} \) is minimum of (1) least lateral dimension of column (2) 12 longitudinal bar diameter (3) 300 mm

7. The failure mode of GFRP columns

Failure of GFRP columns mainly depends on the spacing of stirrups. GFRP columns having large spacings failed in an explosive and brittle manner, and columns with small stirrups spacings are failed in a ductile manner. So, it is very important to provide proper confinement so that columns should be failed in a ductile manner.

Figure 7. The failure mode of GFRP columns.

8. Conclusions

- Using Equation 3, the variation in experimental and theoretical results are observed in the range of 12.6 % to 23.5 % for square columns and circular columns, respectively. Difference between experimental and theoretical results are observed in the range of 0.68% to 4.25%.
- It is observed that the columns with large stirrups spacing failed in a brittle manner compared to small stirrups spacing. Experimental results indicate that change in stirrups spacing causes variation in the load-carrying capacity of the column.
- By changing the spacing of the ties, difference between experimental and analytical results also varies and it is seen that reduction in spacing results in a decrease in the variation.
- Due to the limited availability of the data for GFRP bars, the design provision given in this paper does not apply to the structures in the seismic zone.
9. References

[1] Lin H and Liao C 2004 Compressive strength of reinforced concrete column confined by composite material Composite Structures 65 239–50

[2] Zadeh H J and Nanni A 2013 Design of RC columns using glass FRP reinforcement Journal of Composites for Construction 17(3) 294–304

[3] Nanni A, De Luca A and Zadeh H J 2014 Reinforced Concrete with FRP Bars: Mechanics and Design (CRC Press)

[4] Da Fonseca B S, Castela A S, Silva M A, Duarte R G, Ferreira M G and Montemor M F 2015 Influence of GFRP confinement of reinforced concrete columns on the corrosion of reinforcing steel in a salt water environment Journal of Materials in Civil Engineering 27(1) 04014107

[5] Tu J, Gao K, He L and Li X 2019 Experimental study on the axial compression performance of GFRP-reinforced concrete square columns Advances in Structural Engineering 22(7) 1554–65

[6] Mohamed H M, Afifi M Z and Benmokrane B 2014 Performance evaluation of concrete columns reinforced longitudinally with FRP bars and confined with FRP hoops and spirals under axial load Journal of Bridge Engineering 19(7) 04014020

[7] De Luca A, Nardone F, Matta F, Nanni A, Lignola G P and Prota A 2011 Structural evaluation of full-scale FRP-confined reinforced concrete columns Journal of Composites for Construction 15(1) 112–23

[8] Hadi M N S 2009 Behaviour of eccentric loading of FRP confined fibre steel reinforced concrete columns Constr. Build. Mater. 23(2) 1102–8

[9] Ali MA and El-Salakawy E 2016 Seismic performance of GFRP-reinforced concrete rectangular columns Journal of Composites for Construction 20(3) 04015074

[10] IS 456 2000 Plain And Reinforced Concrete - Code of Practice (Bureau of Indian Standards: New Delhi)

[11] Easy Engineering 2017 Reinforced Concrete Structures (https://easyengineering.net/)

[12] Hadi M N, Karim H and Sheikh M N 2016 Experimental investigations on circular concrete columns reinforced with GFRP bars and helices under different loading conditions Journal of Composites for Construction 20(4) 04016009