Design of Flexural Members Reinforced with GFRP Bars

Abinash Kumar Sethi\textsuperscript{1*}, Trupti A Kinjawadekar\textsuperscript{2}, Praveen Nagarajan\textsuperscript{1} and A P Shashikala\textsuperscript{1}

\textsuperscript{1}Department of Civil Engineering NIT, Calicut, India
\textsuperscript{2}Manipal School of Architecture and Planning, MAHE, India

\textsuperscript{*}abhinas.sethi@gmail.com

Abstract. Reinforced concrete has emerged as a primary construction material since the nineteenth century. A passive combination of concrete and steel reinforcing bar (rebar), this composite material is widely used in various types of structures. However, corrosion of steel reinforcement has been identified as a significant problem affecting the structural integrity of such concrete structures. In this context, the use of GFRP bars is gaining prominence due to their non-corrosive nature. This paper presents behaviour of flexural members reinforced with GFRP bars. The strength reduction factors and guidelines available with different codes for flexural members are studied. The design of flexural members reinforced with GFRP bars has been done using Indian Standard code parameters. The flexural capacity of the beams is estimated from the strain compatibility and equilibrium of forces. The theoretical and experimental results are compared. It is seen that designing the beams as an over-reinforced section will increase the stiffness of the beams.

1. Introduction

In reinforced cement (RC) concrete design of structures quality and strength of structures are central points under thought. The interior steel gets corroded over time resulting in reduced durability of structures. Ports, coastal structures and various industry offices are structures, which are subjected to the aggressive environment causing corrosion problem in the steel reinforcement [1]. Research has been done to recommend a substitute in the form of a glass fiber reinforced polymer (GFRP) bar for regular steel rebar. It is a composite bar made up of glass fiber and epoxy resin [1]

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{gfrp_bars.png}
\caption{GFRP bars [2].}
\end{figure}

1.1. Advantages and disadvantages of GFRP bar

Favourable aspects of utilising GFRP bar is that it has less weight compare to steel rebar, it has more strength and is non-corrosive in nature. It can be viewed as the best alternative to use GFRP bars in construction particularly in the marine environment [2]. GFRP is a ribbed composite bar in which glass strands are impregnated and bound by amazingly strong polymeric epoxy resin. GFRP rebars have
different specific properties, for instance, high quality to weight proportion, magnificent behaviour under fatigue, non-conductivity, and high rigidity, additionally the thermal expansion value of the GFRP is close to that of cement. When it is used as rebar in RCC bending elements, the modulus of elasticity, bond stress and behaviour under tension is the main mechanical properties to be considered in studying the structural behaviour of components [1]. The behaviour of GFRP bars under tension is given by a linear stress-strain relationship to failure. The sections reinforced with GFRP bars are generally over-reinforced sections, and they exhibit brittle failure without notification.

Figure 2. Stress- Strain behaviour: GFRP bars [2].

2. Literature survey
Harris et al. (1998) [3] experimented and studied concrete structures using hybrid ductile reinforced bars, and discovered that the unique technique of reinforcement yields bilinear stress-strain characteristics so as to implement in the distressed and new concrete structures. In addition hybrid reinforced bars possess comparatively superior properties like lower weight, corrosion resistance and excellent strength against the traditional reinforcement. Also, the tensile experimentation yields linear stress-strain characteristics. After experimentation, it is observed that the beam exhibits the capacity to withstand larger deformation. The ductility index is assessed considering the energy, curvatures, and deflections, considering the FRP reinforced beam (three in numbers) is establish to behave similar to that of a steel rebar [3]. Joseph R. Yost et al. (2001) presented studies over shear strength [4]in the beam reinforced using GFRP bars and also observed that the longitudinal reinforcement has not much effect over shear capacity in the beams reinforced using GFRP bars with numerous ratios ranging from 2.10 - 4.32 $\rho_b$. So, those standard pragmatic equations can be used for the approximation of shear strength. The behavior under shear failure in the beams reinforced with the GFRP is found comparable to that of concrete beams reinforced using the steel. However, shear strength is found to be of lower value in beams reinforced using GFRP when compared to beams reinforced using steel. The shear strength equation is developed considering the data obtained from experimentation over steel-reinforced member which is found to be unconservative in the beams reinforced using GFRP [5]. H.Y. Leung et al. (2003) experimented on seven rectangular RC flexural members strengthened with steel and GFRP rebars (hybrid reinforcement). The length of the member was 2.5m, depth 200 mm width 150 mm. Different types of rebars were used wherein they were utilised in two separate layers along the tension side of the specimen. Reinforcing bars with a high yield strength and a diameter of 10 mm which displayed the value of elastic modulus and yield strength as 200 GPa and 460MPa, respectively were used. Also, the two designed concrete mixes provided strengths of 30MPa and 50MPa each. Four point bending experimentation was conducted over beams as depicted in figure 1 [6].

M.W. Goldston et al. (2017) experimented and studied Flexural behaviour in the concrete beam with GFRP reinforced ultra-high and high strength concrete [7]. Observations showed that using Ultra High Strength Concrete with 117 MPa is more advisable for enhancing the load carrying capacity in over-
reinforced beams (GFRP-RC) comparing with the High Strength Concrete with 95 MPa [7]. Also as the strength of concrete is enhanced to 117MPa UHSC from 95 MPa, load carrying capacity is elevated by 13% and 27% for the reinforcement ratio $\rho = 1.0\%$ and 2.0\%, respectively [7]. The mid-span deviation is observed to elevate with strength of the concrete 117 MPa from 95 MPa [7].

![Figure 3. Test setup for flexural member [6]](image)

3. **Design of flexural member**

3.1. **Design modulus of elasticity**

The modulus of elasticity of FRP ($E_f$) is the slope of the stress-strain curve within the elastic range.

3.2. **Ultimate rupture strain**

The ultimate rupture strain is taken as 0.012 to 0.015 for GFRP bars.

3.3. **Ultimate tensile strength**

The tensile strength of FRP ($F_{fu}$) is the maximum tensile load that can be applied while stretching.

3.4. **Positioning of neutral axis**

From strain compatibility diagram,

$$X_{u,lim} = \left(\frac{0.0035}{0.0035 + 0.0128}\right)d = 0.214d$$

where,

- $X_{u,lim}$ = Maximum depth of Neutral Axis,
- $d$ = effective depth of beam

Total compressive and tensile force can be written as,

$$C = 0.542f_{ck}x_ub$$

$$T = Af_f\varepsilon_f$$

where,

- $x_u$ = Actual depth of Neutral Axis
- $b$ = width of beam
- $E_f$ = Modulus of elasticity of GFRP bars
- $A_f$ = Area of GFRP reinforcement
- $f_{ck}$ = Characteristic Compressive strength of concrete

Equating both the forces we get,

$$X_u = \frac{Af_f\varepsilon_f}{0.542f_{ck}b}$$

4. **Theoretical analysis vs experimental studies**

For verification of the above equation, experimental results obtained by VG Kalpana and K Subramanian [9], Maher A et al. [10] have been taken into consideration.
Table 1. Comparison of ultimate load carrying capacity.

| Beam ID | Grade of Concrete ($f_{ck}$) (MPa) | Theoretical Ultimate Load (kN) | Experimental Ultimate Load (kN) | Variation % | Average Variation % |
|---------|-----------------------------------|--------------------------------|-------------------------------|-------------|---------------------|
| M20 D16 | 20                                | 62.41                          | 81.5                          | +23.42      | 24.8                |
| M20 D20 | 20                                | 79.76                          | 105                           | +24.03      |                     |
| M20 D24 | 20                                | 83.98                          | 115                           | +26.97      |                     |
| M40 D16 | 40                                | 86                             | 115                           | +25.21      |                     |
| M40 D20 | 40                                | 102.71                         | 135                           | +23.91      | 19.45               |
| M40 D24 | 40                                | 131.56                         | 145                           | +9.26       |                     |
| M60 D16 | 60                                | 95                             | 125                           | +24         |                     |
| M60 D20 | 60                                | 110.36                         | 150                           | +26.42      | 21.23               |
| M60 D24 | 60                                | 147.41                         | 170                           | +13.28      |                     |

It is observed that, maximum capacity to carry the load is increased considerably using high strength concrete. Table 1 shows ultimate load capacity based on change in reinforcement ratio and variation in concrete grade. The percentage increase of 0.50 in reinforcement ratio in high strength and regular concrete results in load carrying capacity about 20% to 30%, respectively.

Table 2. Comparison of ultimate load carrying capacity.

| Beam ID | Grade of Concrete ($f_{ck}$) (MPa) | Theoretical Ultimate Load (kN) | Experimental Ultimate Load (kN) | Variation % | Average Variation % |
|---------|-----------------------------------|--------------------------------|-------------------------------|-------------|---------------------|
| A25-1   | 25                                | 24.5                           | 35                            | +23.74      | 20.3                |
| A25-2   | 25                                | 24.5                           | 30.91                         | +24.05      |                     |
| A25-3   | 25                                | 24.5                           | 65.32                         | +13.13      |                     |
| A45-1   | 45                                | 48                             | 43                            | +22.93      |                     |
| A45-2   | 45                                | 48                             | 66                            | +19.41      | 22.65               |
| A45-3   | 45                                | 48                             | 81.66                         | +25.62      |                     |
| A70-1   | 70                                | 74.4                           | 70                            | +17.25      |                     |
| A70-2   | 70                                | 74.4                           | 100.22                        | +24.47      | 18.95               |
| A70-3   | 70                                | 74.4                           | 123.132                       | +15.13      |                     |

It is found that when the grade of concrete is increased, the ultimate load carrying capacity of the specimen also increased. The GFRP RC members are showing better performance with High strength concrete.

5. Experimental investigation

Figure 4. Cross-section and reinforcement details.
### Table 3. Behaviour of GFRP RC Flexural member.

| Beam ID   | $b \times D$ (in mm) | Grade of concrete($f_{ck}$) (MPa) | Theoretical Ultimate Load (kN) | Experimental Ultimate Load (kN) | Type of Failure                     | % Variation |
|-----------|-----------------------|----------------------------------|-------------------------------|-------------------------------|------------------------------------|-------------|
| C-T08 B10 | 100 $\times$ 150      | 30                               | 26.88                         | 35.216                        | Concrete crushing                  | + 23.67     |

The experimental results show that the specimen was found flexure critical and crushing of concrete at the top occurred due to over-reinforcing the bottom layer. As we increase the percentage of reinforcement, the load carrying capacity also increased. The experimental ultimate load is found to be 35.216 kN. The experimental load varies 23.67% with the theoretical ultimate load.

The specimen was tested under Two-point loading and for the measurement of strain, LVDTs were attached at the top and bottom of the specimen and to measure the displacement at the mid-span one dial gauge was attached below the specimen, to measure the total deflection.

The cracks in the vicinity of the tension zone within and near the constant moment region are found to be vertical. Those vertical cracks start propagating towards the compression zone as the load increases and small branches appear near lower tension surface up to approximately 60% of the maximum load.

### 6. Summary and conclusions

- From the Analytical analysis, it is concluded that increase in reinforcement ratio in the flexural member increases the load carrying capacity of the member and it is recommended to design the GFRP RC structure as over-reinforced.
The variation in theoretical and experimental results range between 18% to 25%.
The GFRP reinforced concrete structure gives better performance with the high strength and ultra-high strength concrete. If the grade of concrete is increased then the ultimate load carrying capacity is also increased.
From the literature study, it is observed that hybrid reinforcement plays a significant role to enhance the bending strength in the concrete beams. It improves flexural strength.

7. References
[1] Tavares D H, Giongo J S and Paultrê P 2008 Behavior of reinforced concrete beams reinforced with GFRP bars Rev. IBRACON Estruturas e Mater. 1(3) 285–95
[2] Nanni A, De Luca A and Zadeh H J 2014 Reinforced Concrete with FRP Bars: Mechanics and Design (CRC Press)
[3] Harris H G, Somboonsong W and Ko F K 1998 New ductile hybrid FRP reinforcing bar for concrete structures Journal of Composites for Construction 2(1) 28–37
[4] Yoo D Y, Banthia N and Yoon Y S 2016 Flexural behavior of ultra-high-performance fiber-reinforced concrete beams reinforced with GFRP and steel rebars Engineering Structures 111 246–62
[5] Yost J R, Gross S P and Dinehart D W 2001 Shear strength of normal strength concrete beams reinforced with deformed GFRP bars Journal of composites for construction 5(4) 268–75
[6] Leung H Y and Balendran R V 2003 Flexural behaviour of concrete beams internally reinforced with GFRP rods and steel rebars Structural Survey 21(4) 146–57
[7] Goldston M W, Remennikov A and Sheikh M N 2017 Flexural behaviour of GFRP reinforced high strength and ultra high strength concrete beams Construction and Building Materials 131 606–17
[8] Bank L C, Campbell T I and Dolan C W 2003 Guide for the design and construction of concrete reinforced with FRP bars reported by ACI Committee 440 Concrete 1–42
[9] Varghees K and Subramanian K 2011 Behavior of concrete beams reinforced with GFRP bars Journals of Reinforced Plastics and Composites 30(23) 1915–22
[10] Adam M A, Said M, Mahmoud A and Shanour A 2015 Analytical and experimental flexural behavior of concrete beams reinforced with glass fibre reinforced polymers bars Construction and Building material 84(13) 354–66