A Theoretical Study of GFRP RC Beams Deflection

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Abstract
The use of GFRP reinforcing bars as an innovative material for substituting steel bars in reinforced concrete is now increasingly popular for structures which are located in corrosive areas. The GFRP bars have low modulus of elasticity (35-51 GPa), such that the stiffness of GFRP reinforced concrete will be lower than those of the corresponding steel reinforced concrete. Lower in stiffness means larger deflection will occur. This paper aims to introduce the use of GFRP bars in reinforced concrete beams particularly in terms of theoretical deflection calculation of GFRP reinforced concrete beams with ratios of 0.5%; 0.8%; 1.1%, and 1.7%; and based on the equations proposed by several researchers and the design guidelines from several countries such as ACI 440.1R-15; CSA S806-12; CNR-DT 203/2006; ECP 208-2005; Fib bulletin 40 (2007).

1. Introduction

The biggest problem in reinforced concrete is the deterioration of reinforced concrete cause by the corrosion of reinforcing steel bars. As an innovative material for substituting the steel bars in reinforced concrete structures, glass fiber reinforced polymer (GFRP) have an advantages like non-corrosive, and light weight but have lower modulus of elasticity than steel reinforcing bars. As a non-corrosive material, GFRP bars can extend the life cycle of reinforced concrete structures, decreases the cost of maintenance and repair the structures. Lower modulus of elasticity will decreases the stiffness of reinforced concrete structures. Lower in stiffness means larger deflection will occur.

Research the flexural behavior of GFRP RC beams such a deflection nowadays being an interesting study, because of it large deflection, design should be limitation by the deflection. In several countries, the design guidelines of structural concrete reinforced with FRP have been establish, such as ACI 440.1R-15 [1] (American standard); CSA S806-12 [2] (Canadian standard); CNR-DT 203/2006 [3] (Italian standard); ECP 208-2005 [4] (Egyptian standard); Fib bulletin 40 [5] (European standard).

2. Study Programme

Four beams specimens designed with 200 mm width, 300 mm height, and 3000 mm length. Four beams will designed with an adequate GFRP longitudinal and shear reinforcement, with reinforcement ratios of 0.5% (2#13); 0.8% (2#16); 1.1% (4#13); and 1.7% (4#16); GFRP stirrups install with #6-100 mm, the detail of the beams are given in figure 1, and cross section in table 1.

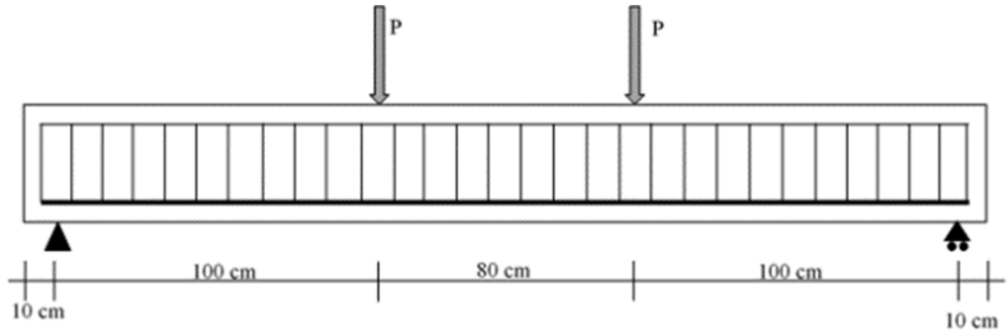
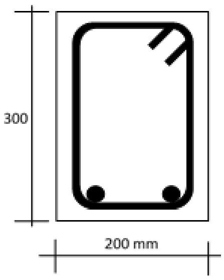
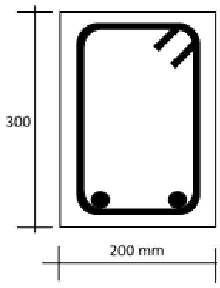
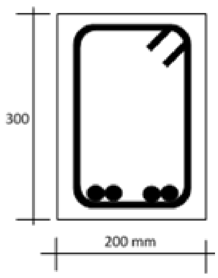
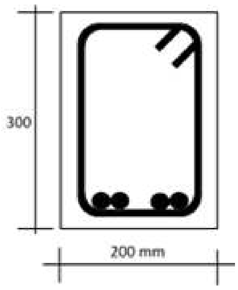


Figure 1. Details and test setup of the beams

Table 1. Cross section of the beams

Notation	L13-2	L16-2	L13-4	L16-4
Cross section				
Dimension	200x300x3000	200x300x3000	200x300x3000	200x300x3000
Reinforcement	2#13	2#16	4#13	4#16
Ratio	0.5%	0.8%	1.1%	1.7%
Stirrups	#6@100	#6@100	#6@100	#6@100

3. Results and discussion

A flexural concrete member with FRP reinforced bars generally experiences extensive cracking and large deflections prior to failure, which is, typically, sudden and catastrophic [6]. In the case of tension failure of reinforced concrete member with FRP-reinforced bars, the FRP reinforcement ruptures followed by sudden failure of the member. Large crack-widths and deflections occur prior to the rupture of FRP bars [7]. In a steel-reinforced concrete beams, the balanced condition state is defined as when the reinforcing bars yields, not when it fails, which means that the section can continue to receive loads since the steel will not failure, there will be some stress redistribution from steel bars to the concrete, and a gradual pseudo-ductile failure or an excessive deflection will occur. In the case of an FRP-reinforced concrete beams, when the FRP bars fails there can be no redistribution of stresses from FRP bars to the concrete in the section and a catastrophic collapse will occur [8]. The ratio of the reinforcement had a considerable effect on the beam deflection and stiffness after the first crack initiation, this is confirmed by some researchers [9, 10].

According to ACI 440.1R-15:

$$\Delta = \frac{Pa}{48E_cI_e}(3L^2 - 4a^2) \tag{1}$$

$$I_e = \frac{I_{cr}}{1-\gamma\left(\frac{M_{cr}}{M_a}\right)^2\left[1-\frac{I_{cr}}{I_g}\right]} \leq I_g \tag{2}$$

According to Fazza and GangaRao [11]:

$$\Delta_{max} = \frac{23\,PL^3}{648\,E_c\,I_m} \tag{3}$$

$$I_m = \frac{23I_{cr}I_e}{8I_{cr}+15I_e} \tag{4}$$

According to Masmoudi et al [12, 13, 14]:

$$\Delta = \frac{P\,a}{E_c}\left(\frac{4a\left(\frac{L}{2}-a\right)+\left(\frac{L}{2}-a\right)^2}{8I_{cr}}+\frac{a^2}{3I_e}\right) \tag{5}$$

$$I_e = \beta\left(\frac{M_{cr}}{M_a}\right)^3 I_g + \left[1{,}0-\left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr} \le I_g \tag{6}$$

According to Toutanji and Saafi [15]:

$$I_e = \left(\frac{M_{cr}}{M_a}\right)^m I_g + \left[1{,}0-\left(\frac{M_{cr}}{M_a}\right)^m\right] I_{cr} \le I_g \tag{7}$$

According to Razaqpur et al [16], and similar with CSA S806-12:

$$\Delta = \frac{P\,L^3}{48\,E_c\,I_{cr}}\left[3\left(\frac{a}{L}\right)-4\left(\frac{a}{L}\right)^3-8\eta\left(\frac{L_g}{L}\right)^3\right] \tag{8}$$

According to Habeeb and Ashour [17]:

$$I_e = \left(\frac{M_{cr}}{M_a}\right)^3 \beta_d I_g + \left[1{,}0-\left(\frac{M_{cr}}{M_a}\right)^3\right] \gamma_d I_{cr} \le I_g \tag{9}$$

According to Bischoff [18, 19, 20, 21]:

$$I'_e = \frac{I_{cr}}{1-\gamma\eta\left(\frac{M_{cr}}{M_a}\right)^2} < I_g \tag{10}$$

According to CNR-DT 203/2006 appendix E and similar with fib bulletin 40:

$$f = f_1\left(\frac{M_{cr}}{M_{max}}\right)^2 + f_2\left[1-\left(\frac{M_{cr}}{M_{max}}\right)^2\right] \tag{11}$$

According to ECP 208-2005:

$$\Delta = \frac{P\,L^3}{48\,E_c\,I_e} \tag{12}$$

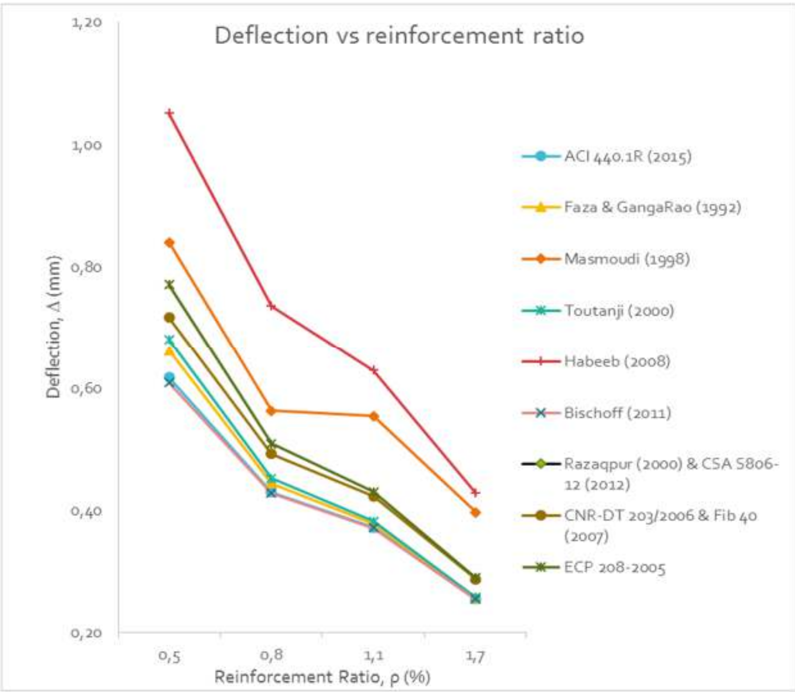


Figure 2. Comparison of deflection vs reinforcement ratio

4. Conclusions

The use of glass fiber reinforced polymer bars as an innovative material for substituting a steel bars in reinforced concrete structures has a lot advantages such as non-corrosive, lightweight, and high tensile strength, but has low stiffness and brittle failure mode. The flexural behavior of GFRP bars in reinforced concrete beams such a deflection can predicted using equations developed by some researchers and adopted by several countries as a guidelines for the design and construction of concrete structures reinforced with FRP bars.

From fig. 2 increment of reinforcement ratio will decrease the deflection, reinforcement ratio from 0.5; 0.8; 1.1; 1.6 the deflection decreases 30%; 40%; and 46%. Equation proposed by Habeeb was the moderate approach, ACI 440.1R-15, CSA S806-12, Razaqpur, and Bischoff has very similar deflection, equation proposed by Faza & GangaRao and Toutanji has similar deflection, CNR-DT 203/2006 and Fib 40, and ECP 208-2005 has similar deflection.

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