

# Investigation of Flexural Behaviour of RCC Beams using GFRP Bars

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**Abstract**— Glass Fibre Reinforced Polymer is an advanced composite material that has been identified as a potential new construction material. These materials have strength higher than steel but exhibit linear stress –strain response up to failure. Furthermore the modulus of elasticity of GFRP is significantly lower than that of steel. Experiment will be undertaken until failure to fully understand the influence of parameters on the flexural behaviour of concrete beams reinforced with GFRP bars and the experimental observation includes failure mode, crack pattern, load carrying capacity, load deflection behaviour and ductility.

**Keywords**— GFRP Bars, Ultimate Moment, Deflection, Cracking Pattern, Flexural Behaviour

## 1 INTRODUCTION

Glass Fibre Reinforced Polymer bars possess mechanical properties different from steel bars, including high tensile strength combined with low elastic modulus and elastic brittle stress- strain relationship. Due to the linear elastic brittle behaviour of GFRP bars, the flexural behaviour of GFRP reinforced concrete beam exhibit no ductility. GFRP reinforced concrete beams must be over reinforced so that they fail by concrete crushing rather than by rebar rupture. The flexural capacity of the beam was computed by sectional analysis in which the rebar is assumed to maintain perfect bond with the surrounding concrete. In all these work the longitudinal reinforcement is assumed to be perfectly bonded to the surrounding concrete at failure. The low modulus of elasticity of GFRP rebar resulting in relatively large deformations and smooth surface characteristics of the GFRP leading to debonding type of failures are important in determining the serviceability performance of GFRP reinforced beam sections. Hence the serviceability constraints generally will control the design of the GFRP reinforced beam sections. The unique advantages of GFRP materials such as excellent resistance to corrosion, high strength to weight ratio, electromagnetic neutrality and ease of handling make these materials potentially suitable for the use in reinforced concrete under conditions where conventional steel reinforced concrete has resulted in unacceptable serviceable problem.

## 2 EXPERIMENTAL WORK

The current research program was carried out to investigate the flexural behaviour, crack pattern. In this study, flexural behaviour of rectangular concrete beams reinforced with glass fiber reinforced polymer will be examined with manufacturing 4 specimen. Considering the

constant length and diameter of bars are used with various bar in tension and compression zone.

### 2.1 Test Program

In one beam made with control specimen of 12mm dia Fe415 bar in tension zone and 10mm diameter bar in compression zone. Second beam made with 12mm diameter GFRP bar in tension zone and 10mm diameter Fe415 in compression zone. Third beam made with 12mm diameter Fe415 in tension zone and 10mm diameter GFRP bar in compression zone. Fourth beam made with 12mm diameter GFRP bar in tension zone and 10mm diameter GFRP bar in compression zone. Table 1 shows the experimental program.

Table 1  
The experimental program for the tested beams

Description	Type of rod	Diameter	Position
C2	Fe415	12mm	Bottom
	Fe415	10mm	Top
GT2	GFRP	12mm	Bottom
	Fe415	10mm	Top
GC2	Fe415	12mm	Bottom
	GFRP	10mm	Top
GF2	GFRP	12mm	Bottom
	GFRP	10mm	Top

### 2.2 Properties of material

#### 2.2.1 Concrete

The concrete mix for the normal strength grade was produced from ordinary Portland cement, natural sand and aggregate of 20mm size used.

#### 2.2.2 GFRP Bars

Steel bars were used for the stirrups and they were of 8mm diameter. The main longitudinal GFRP bars were of 10mm diameter of top reinforcement and 12mm diameter for bottom reinforcement. Table 2 shows the

mechanical properties of the GFRP bars which were locally manufactured. The bars were sand coated to improve their bond with concrete. Steel and GFRP tension behaviour is shown in figure 1

Length	1.2m
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Table 2  
 Mechanical Properties of GFRP bars

Description	Units	Values	Diameter
Ultimate tensile strength $f_{tu}$	Mpa	407.4	10 mm
	MPa	347.5	12 mm
Modulus of Elasticity $E_f$	GPa	33.81	10 mm
	GPa	32.67	12 mm
Rupture Strain $\epsilon_{fu}$		0.029	10 mm
		0.05	12 mm

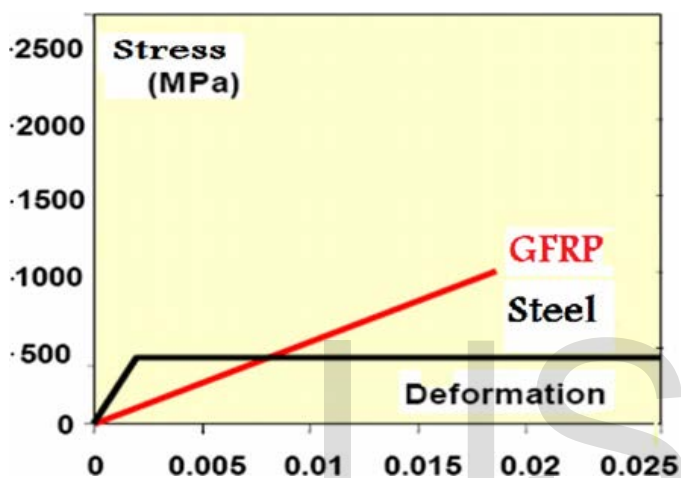


Figure 1 Steel and GFRP tension behaviour

**2.3 Test setup**

The beams were tested with simply supported over two rigid support. To point loads were applied to all the beams. The loads were applied vertically at the centre of beam which transmitted the load equally on two bearings resting on the beam's top, spaced 450mm and aligned symmetrically around the beam's centreline. The deflection were measured at the mid span using  $\pm 200$ mm linearly variable differential transducer.

Table 3  
 The experimental program of the tested beam

Beam 1	Size	150x 250
	Length	3 m
Beam 2	Size	200x300

**3. ANALYTICAL STUDY**

Analytical study is done using the ANSYS software. The models are made in this software and deflections are predicted. The models of the beams are shown in the figures 2, 3, 4 and 5

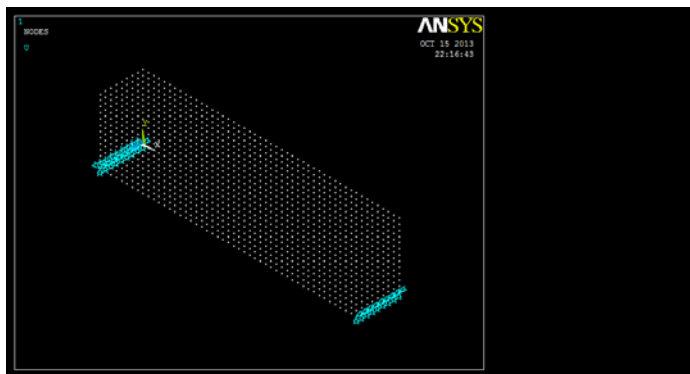


Figure 2 Nodes of the beam

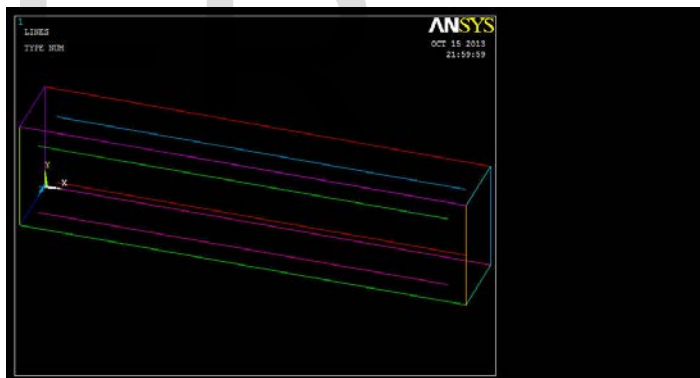


Figure 3 Model of the beam

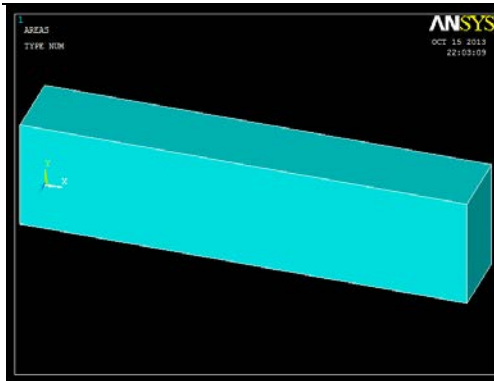


Figure 4 Full view of the beam

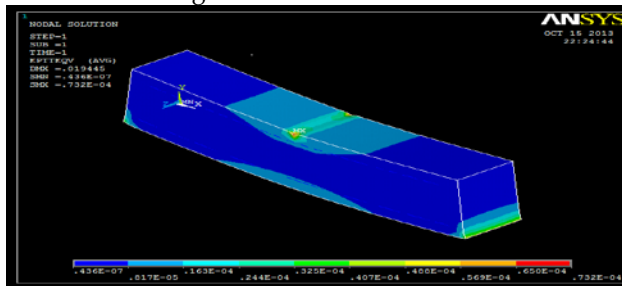


Figure 5 Deflection of the beam

### 3.1 Ductility

The ductility of a beam can be defined as its ability to sustain inelastic deformation without loss of its load carrying capacity prior to failure. Following this definition, ductility can be expressed in terms of deformation or energy absorption. In the case of steel reinforced beams, where there is clear plastic deformation of steel at yield, ductility can be calculated as the ratio of ultimate deformation to deformation at yield. With FRP reinforced beams there is no yield point; consequently, this simple definition cannot be applied. Vijay and Ganga Rao reported that the ductility of the FRP reinforced beams can be evaluated by means of the deformability factor (DF), defined as the ratio of the energy absorption at ultimate (area under load-deflection curve up to ultimate load) to the energy absorption at service load (at the serviceability deflection limit of span/180)

### 3.2 Deflection Calculations

The design of GFRP reinforced concrete beams is typically governed by serviceability limit State requirements. This is because the modulus of elasticity of GFRP bars is much smaller than that of steel. Thus, a method is needed that can accurately calculate the expected deflection of GFRP reinforced members. In the following paragraphs the calculations of deflections will be explained

with emphasis on the different method used to calculate the effective moment of inertia.

The tested beams are simply supported of span L and are loaded by concentrated load of W at the centre. After calculating an effective moment of inertia (I<sub>e</sub>) throughout the beam length, the deflection at the beam centre can be calculated as

$$\Delta = WL^3 / 48E_c I_e$$

Where E<sub>c</sub> is the modulus of elasticity of concrete and is equal to 4700 √f<sub>c</sub> MPa

In a comprehensive experimental program, Ghobarah and Al. (19) defined the effective moment of inertia for members reinforced with FRP as

$$I_e = (3I_g / 7 + 0.84[1 - (M_{cr} / M_a)^3] I_{cr}) \leq I_g$$

where M<sub>cr</sub> is the cracking moment, M<sub>a</sub> is the applied moment, I<sub>g</sub> is the moment of inertia of the gross section, and I<sub>cr</sub> is the moment of inertia of the cracked section transformed to concrete.

Brown and Bartholomew proposed that a fifth order equation can be used rather than a cubic. The form of equation is

$$I_e = (M_{cr} / M_a)^5 I_g / 7 + 0.84 [1 - (M_{cr} / M_a)^5] I_{cr} \leq I_g \text{-----(2)}$$

Toutanji and Saafi found that the order of the I<sub>e</sub> equation depends on the modulus of elasticity of the FRP as well as the reinforcement ratio. They recommended the following equation

$$I_e = (M_{cr} / M_a)^m I_g / 7 + 0.84 [1 - (M_{cr} / M_a)^m] I_{cr} \leq I_g \text{-----(3)}$$

Where m = 6-10 E<sub>FRP</sub> / E<sub>s</sub> ℓ<sub>FRP</sub> if E<sub>FRP</sub> / E<sub>s</sub> ℓ<sub>FRP</sub> > 0.3

Otherwise m = 3

Actual Moment of Inertia (I)

$$I = bd^3 / 12 \text{-----(4)}$$

Where E<sub>FRP</sub> is the modulus of elasticity of the FRP bars, E<sub>s</sub> is the modulus of elasticity of the steel bars, and ℓ<sub>FRP</sub> is the FRP reinforcement ratio.

Table 4

Deflections at service load

Beam	Exp. Deflection	Equations	
C	4.15	Equation (1)	1.79 mm
GT	9.23	Equation (2)	0.486 mm
GC	9.25	Equation (3)	0.456 mm
GF	10.8	Equation (4)	0.409 mm

**3.3 Calculation in prejudicial cracking**

The dimensioning of sections with respect to the deflection in the event of prejudicial cracking or very prejudicial is carried out by applying the following assumption

- The cross section remain plane after deformation
- There is no relative slip between steel and the concrete
- Tensile strength neglected in the concrete; only the steel which takes again the traction effort
- The creep problem was not taken into account, the concrete and steel are considered as elastic linear materials, which makes possible to apply the force deformation relations.

In calculations of the GFRP reinforced concrete, the general method for the strength of the material was applied. The beam is supposed to be in the elastic phase. The reinforced concrete is not homogeneous; to use the strength of the materials, the diagram of the strength must be linear. The section of the reinforced concrete beam will be homogenized:

- the GFRP section should be taken 17 times
- $\epsilon_{GFRP} = \epsilon_c$  (not for relative slip)
- $f_{GFRP} = E_{GFRP} \times \epsilon_{GFRP}$

The section works to the maximum when  $f_c = 0.6 f_{c28}$  and  $f_{GFRP}$  is function of cracking type

$$M = (f_c / 2 \times Y_{sls} \times b) \times (d - Y_{sls} / 3)$$

Where d is the effective depth of cross section and  $Y_{sls}$  is the position of the neutral axis.

**3.4 Prediction of ultimate moment**

In this section, the prediction of ultimate moment is mainly addressed on GFRP reinforced concrete. Some reported results show that the currently available ACI structural design code can be used to predict the ultimate strength and the deflection of FRP reinforced beams with the same accuracy as for the concrete beams reinforced with steel. The following equation generally used to predict the ultimate moments for concrete beams with GFRP bars as reinforcement:

$$Mu = 0.85 f_c a b (d - a/2)$$

Where a is the depth of the stress block, computed as  $A_p f_p / 0.85 f_c b$ ; b the width of the beam at the compressive side; d the effective depth of the beam measured from the extreme compression section to the centroid of GFRP reinforcement area;  $A_p$  the area of the GFRP rebar ; in case of steel bars the area is  $A_s$ ;  $f_c$  the compressive strength of the concrete; and  $f_p$  the usable stress in GFRP rebar, i.e. 2/3 of its UTS ( $f_{pu}$ ) to cater for the absence of yield point; for steel bar,  $f_y$  is the yield strength.

Table 5  
 Moment for the beam size 200x300

Description	Values
Cracking Moment	32.75 kNm
Ultimate Moment	36 kNm
Ultimate Moment Using GFRP	40.05 kNm

**3.5 Cracking Pattern**

**3.5.1 Flexural Failure**

Most of the steel reinforced concrete beams without FRP bars failed in flexure. Flexural failure occurred close to the centreline of the beam by widening of the vertical cracks. As the external load increased, additional crack developed in the neutral axis and beyond, with a marked increase in the deflection of the beam. It is worth to note that crack in concrete were less wide and finer. This is probably due to the comparatively low elastic modulus of concrete and their high degree of compressibility. The flexural failure crack is shown in figure 6

**3.5.2 Shear and Compression Failure**

All GFRP reinforced concrete beams failed consistently in a combination of shear and compression failure of concrete as well as the development of a full tensile capacity of the GFRP. In this type of failure mode, a few fine cracks first developed at mid-span and stopped propagation as destruction of the bond occurred between the longitudinal bars and the surrounding concrete near the support region. There after a steep inclined crack suddenly developed and propagated towards the neutral axis. The rate of its progress was reduced with the crushing of concrete in the top compression fibres, and the stresses within the top region were redistributed. Sudden failure took place as the principal inclined crack reached the crushed concrete zone. Shear and compression failure is shown in figure 7.

**3.5.3 Shear Failure**

In beams reinforced with lower-stiffness GFRP bars (only 1/4 that of steel), flexural cracks would therefore

penetrate deeper into the section, and wider cracks would form compared to those beams reinforced with an equal area of higher stiffness bars. Deeper flexural cracks decrease the depth of the compression zone, thereby reducing the contribution of the uncracked concrete to the shear strength. Wider cracks on the other hand, may result in a reduction in shear strength contribution from stirrups and aggregate interlock. Finally, the lower modulus of elasticity of GFRP bars coupled with the increased crack width result in a shear failure mode. Since the structural failure due to FRP reinforcing bar rupture is rather catastrophic, over reinforced beam design should be made in the field application to ensure that the compressive failure of concrete occurs prior to the tensile failure of GFRP. The shear failure is shown in figure 8

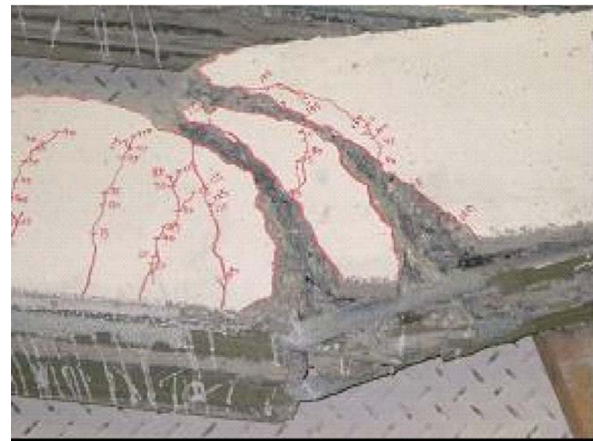


Figure 7 Shear and Compression Failure

## 4 RESULT AND DISCUSSION

Flexural performance of the tested beams including modes of failure, crack pattern, ultimate moment capacity discussions are made in the following section.

### 4.1 Modes of failure

In the initial stage of loading, for all the beams, cracks first appeared in the constant moment zone. As the load increased, additional crack developed in the mid span and new vertical cracks formed in the shear span. With further increase in load in steel reinforced beams one of the flexural crack in the constant moment zone extended deep into the compression zone, reducing the area of concrete in compression leading to crushing of concrete. Hence crushing of concrete was observed in beams reinforced with steel bar at the ultimate



Figure 8 Shear Failure



Figure 6 Flexural Failure

stage of loading. In the case of GFRP reinforced concrete beams, one of the vertical cracks in the shear span became critical and extended towards the loading point at the ultimate stage. These beams failed at the load lower than the design load and failure was observed to be mainly due to the slip of the rebar in GFRP reinforced beams was indicated by splitting of concrete at the level of reinforcements.

All the beams reinforced with the steel rebar failed in flexure approximately at an ultimate load close to the design load.

The cracking strength of the beams was observed to be varying with the compressive strength of the concrete. As the mechanism of failure in GFRP reinforced concrete beams was due to the slip of rebar, ultimate strength was not much affected by the variation of concrete strength. In addition debonding of the secondary surface deformations from the GFRP rebar surface was observed at ultimate stages of the loading.

### 4.2 Cracking Pattern

Figure 6, 7 and 8 shows the crack width in the test beams at various loading stages. As seen in these figures, crack widths are higher in beams with GFRP rebars as compared to similar beams with steel bar. This may be attributed to the significantly reduced stiffness of the GFRP reinforcement.

### 4.3 Ultimate moment capacity

The ultimate moment capacity of the tested beam is shown in table 6.

Table 6  
 Experimental moment of the tested beam

Beam	Load (kN)	Length(mm)	Exp.Moment (kNm)
C	41.25	3000	30.94
GT	52.5	3000	39.38
GC	51.5	3000	38.63
GF	51	3000	38.25

## 5 CONCLUSION

1. In most cases of RC beams without GFRP bars, flexure failure, shear failure and the combination of failure modes were observed. On the other hand, beams strengthened with FRP bars failed in shear.
2. Failure of the GFRP reinforced concrete beams was mainly due to its reduced post cracking stiffness and the slip between rebar and the concrete matrix.
3. GFRP bars have a weaker elasticity modulus, which generate more deflection for equal loads and span
4. After the first crack, beams reinforced with low stiffness GFRP bars in general deflected more rapidly and non-linearly with moment up to the ultimate moment.
5. The load deflection response of the various GFRP reinforced beams have been predicted and seems to closely predict the corresponding experimentally observed response.

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