

# Flexural and Shear Behavior of Beams Reinforced with GFRP Rebars

Axetha Menam, K. Sunil Kumar, P. Rupa



**Abstract:** A new inexperienced constructing material is glass fibre reinforced polymer (GFRP) rebar. GFRP rebars are non-corrosive, non-conductive, light-weight substances and have an excessive longitudinal tensile capacity that is beneficial for use in civil infrastructure applications. In this analysis, the overall performance of GFRP rebar-reinforced concrete beams was assessed. Full scale exams had been conducted underneath four-point bending on eight one hundred fifty x 250 x 1500 mm beams to inspect the influence of GFRP specimens reinforced through both GFRP or metal rebars with flexural reinforcement ratios ( $\rho_f$ ) ranging from 0.53 to 1.45 times the balanced ratio ( $\rho_{fb}$ ). In phrases of crack pattern, load deflection behaviour, load strain conduct and peak capacity, the check facts used to be analysed to decide the flexure and shear conduct of GFRP RC beams. The find out about confirmed that the ultimate load capacity of beams is immediately proportional to the flexural reinforcement ratio, and for steel bolstered specimens, cracking moments had been greater, relative to GFRP. For GFRP RC beams, the peak carrying ability is extra than steel beams. GFRP beams confirmed greater deflections than bolstered beams of steel. The findings additionally confirmed that the building of GFRP bolstered beams in concrete with GFRP stirrups can be influenced by means of shear failures. The reinforcement ratio and shear design of GFRP bolstered concrete beams is affected by way of their behaviour.

**Keywords:** GFRP Rebar; Steel Rebar; Flexure; Shear; Deflection; GFRP stirrups.

## I. INTRODUCTION

One of the most extreme troubles due to corrosion in the metal which is hooked up into the concrete is the degradation of concrete. The reinforcement in concrete responds to quite number varieties of salts such as sulphates, chlorides, etc. present in sea environments results in corrosion of steel. Decades of investigations. And practical applications have proven that convention steel can be replaced by fibre reinforced polymer (FRP) bars, keeping off issues of corrosion due to their benefits over traditional materials, which includes excessive tensile strength, light weight material, and ease of handling and high durability even in excessive environments. There are different types of FRP bars classified according to American code, namely: CRFPs, GRFs and ARFPs.

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All FRP bars have their own benefits and disadvantages regarding its cost, physical and durability characteristics. Among of these, GFRP bar is popular due to the fact its low value in contrast to CFRP and AFRP bars, and are most frequent picks in discipline applications.

Extensive investigations has been carried out on bending and shear capacity for GFRP bars as longitudinal bars and steel as stirrups, but there is a minimum research on beams reinforced with GFRP in longitudinal directions as well as vertical stirrups. This is because of inflexibility of GFRP bars which cannot bend unlike steel bars. Special equipment is needed to make GFRP stirrups which are to be done by heating, but results in loss of strength in stirrups.

For constructions placed in marine and salt environments, the usage of FRP bars in structural factors is favourable as FRP is a non-destructive material. It is cited for traditional steel structures, which are accountable for steel-corrosion and subsequently lead toward loss of operability and strength, that concrete-alkalinity decrease due to severe conditions, along with humidity and temperature. By using the FRP rebar as internal reinforcement load carrying capacity of beam increases [1]. The load carrying capability of beam will increase by increasing the FRP tensile reinforcement ratio[2]. Crack widths and deformations are greater for GFRP-built beams than conventional RC-built beams with an equal reinforcement ratio [3]. This is because of low modulus of elasticity of GFRP bars, which was given by ACI guidelines for design of structural components with FRP bars [4]. As FRP bars are inflexible in nature, until failure they show linearly elastic response without showing any yielding which is different from response of steel bars [5]. Thus, GFRP RC beams show bi-linear response of load deflection beneath static load [6]. GFRP bar reinforced beams displayed low ductility compared to RC steel beams [7]. The resistance to shear of reinforced concrete with FRP is extra complicated than steel-RC beam specimens because of the large range of mechanical traits in FRP bars. Therefore, FRP RC members shear response unlike steel RC beams. Several experimental researches have been carried out to evaluate the essential impact on the shear capacity of steel-RC beams without vertical reinforcement [8]. The shear capacity of member has improved through increasing the reinforcement ratio of FRP, and was not affected by the vertical reinforcement [9]. Bond traits and elastic modulus are responsible shear deformation of the stirrup material [10]. Thus, the literature overview located that several experimental investigations have been carried out to apprehend GFRP concrete beams flexural response while few research have been performed to recognize GFRP RC beams flexure and shear behaviours with GFP stirrups. Current research was carried out to find flexure and shear response GFRP RC beams in terms of flexural behaviour, pattern of cracks, load deflection behaviour, load-strain behaviour, ultimate strength, and mode of failure.



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## II. TEST PROCEDURE

### 2.1. Beam specimens

This investigation carries a whole of 8 reinforced concrete beams. The beam samples were 1500mm x 150 mm x 250 mm. The concrete was used for casting the beam samples possessing a compressive strength of 58.25 MPa. The various parameters of beam samples are presented in Table I. The specimens were divided into 2 phases: Phase-1 beams are reinforced with conventional steel bars whereas GFRP bars are used as reinforcement in phase-2 beams. In two phases beams are designed for two flexural reinforcement ratios (0.81% and 1.61%) i.e under reinforced and over reinforced with and without of vertical (shear) reinforcement. The beam samples were designated in such a way that their key attributes were represented. The initial letter in name of the beam represents steel (S) or GFRP rebar (G). The subsequent is a quantity that displays the reinforcement ratio (0.81% and 1.6%), and last letter represents either presence of shear reinforcement (Y) or no shear reinforcement (N). Example S81Y is steel reinforced concrete beam specimen which is designed for reinforcement ratio of 0.81 and shear reinforcement is present(Y).

In each phase, 4 beam samples had been built and tested. The flexural/ hybrid reinforcement ratios ranged from 0.53

to 1.45 times of balanced reinforcement ratio for two phases. Two specimens were taken out at each phase to assess the specific concrete contribution ( $V_c$ ) to the overall shear resistance ( $V_r$ ) of the stirrups. Beam specimens which are designed to fail in shear are provided with 5 stirrups over the span to confine the rebar cage together.

By making use of the equilibrium and compatibility prerequisites and the usage of the equal rectangular stress block balanced reinforcement ratio,  $\rho_b$  used to be obtained, as

$$\rho_b = \frac{0.85\beta_1 f'_c}{f_u} \left( \frac{0.003E_f}{0.003E_f + f_u} \right)$$

<sup>1</sup>

The balanced ratio of concrete components for GFRP and steel reinforced concrete beams was 1.1% and 1.51%, respectively. Because of its excessive tensile strength and low young's modulus of the GFRP bars in contrast with conventional steel, conventional beams has high balanced ratio compared to GFRP RC beams. [4]. It is evident to say that the flexural failure, either GFRP RC beams built for over-reinforced or under-reinforced, will be a brittle failure. This is because, as in the case of steel reinforcement, the GFRP reinforcement does not yield

**Table I Test Matrix**

Phase	Specimen ID	$\rho(\%)$	$\rho_b(\%)$	$\rho/\rho_b$	Longitudinal bar	Stirrups	$f_c$ (mpa)	$E_f$ (Gpa)
I	S81Y	0.81	1.51	0.53	12 mm steel	Bent steel	50	200
	S81N							
	S16Y	1.61	1.51	1.06	12 mm steel	Bent steel	50	200
	S16N							
II	G81Y	0.81	1.10	0.72	12mm GFRP	Straight GFRP	50	42
	G81N							
	G16Y	1.6	1.10	1.45	12 mm GFRP	Straight GFRP	50	42
	G16N							



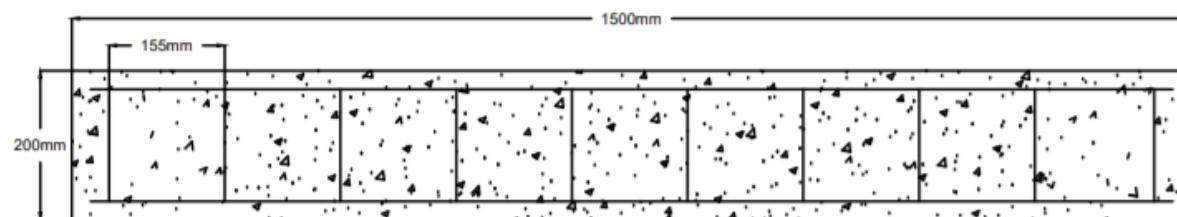
(a) Steel rebar cage



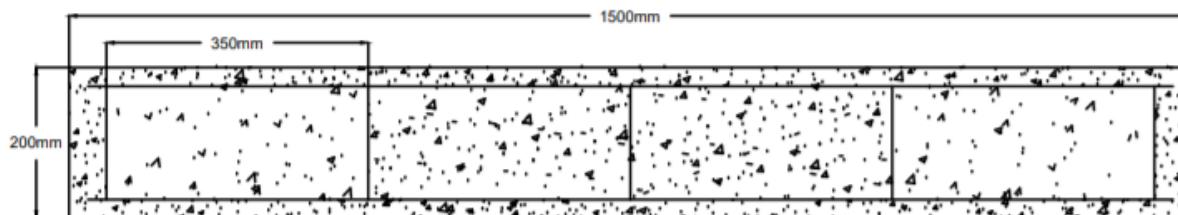
(b) GFRP rebar cage

**Fig 1 Rebar cages**

GFRP bars were cut as single straight legs and were offset in the longitudinal direction to make a rectangle shape as can be seen in Fig. 1.b. GFRP rebars are made of resin thermosetting and thus, except a warmth therapy a straight GFRP rebar can't be bent. The bars had been heated, ensuing in the loss of force, to create a bent stirrup. So in present research straight legs had been used as stirrups in the present day research. The cross-section of all beams was clearly shown in fig 3. Fig. 2 shows the elevation of the beam specimens constructed with and without stirrup



a. With vertical reinforcement

b. Without vertical reinforcement  
Fig 2 Beam elevations

(All dimensions are in millimeters)

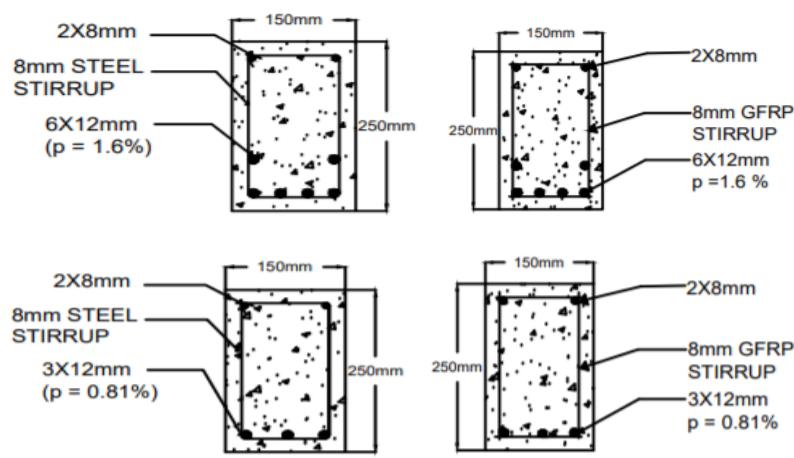


Fig 3 Cross sections

## 2.2 Material properties

### 2.2.1 Concrete

Concrete was made from ordinary Portland grade 53 cement confined to IS:269[13], river sand and squashed granite with a maximum size of 12.5 mm and chemical additives for the high strength concrete of grade (M50). Mix design has been done according to IS:10262[12]. Compressive strength of concrete was carried out according to IS:516[14]. After 24 hours of casting, the beams were dismoulded, covered with wet gunny bags and stored for 28 days under laboratory conditions before progressing to the test phase.

### 2.2.2 Steel and GFRP bars

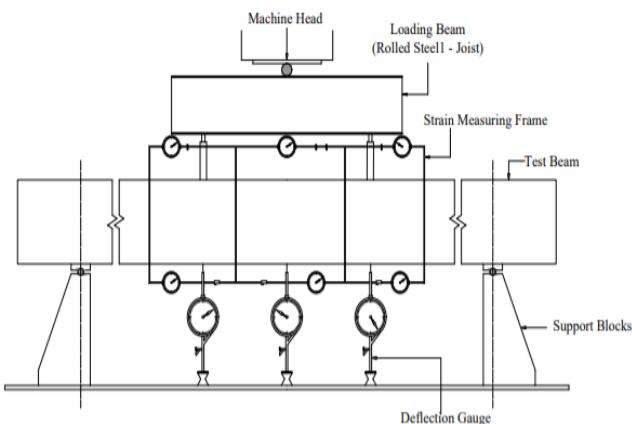
For both G- and S- series beams 12 mm diameter is used as the longitudinal bottom reinforcement and 8 mm diameter bars are used as hanging bars i.e., longitudinal top reinforcement. Both GFRP and steel of 8mm diameter is used for vertical reinforcement in corresponding beams respectively. The mechanical properties of the steel and GFRP bars that are produced locally are presented in Table II. All the beams are simply supported over the span of 1200 mm and tested with UTM of 1000 KN capability. The point load was uniformly spread over a beam length of 400 mm with the steel I element. Under four-point bending, specimens were tested. Three dial gauges are placed on the

tension side of the beam having least count 0.01 mm to measure the deflection along the length, three strain gauges are placed on compression zone and three strain gauges are placed on tension zone to measure the strains in corresponding zones respectively. Fig 4 presents the testing arrangement of the beam samples.

Table II Mechanical Properties of GFRP Bars

Specifications	GFRP 12 mm	Steel 12 mm
Cross section (A)	113.04 mm <sup>2</sup>	113.09 mm <sup>2</sup>
Tensile strength( $f_{tu}$ )	750 Mpa	550 Mpa
Poisson's ratio( $\mu$ )	0.26	0.3
Flexural modulus(E)	42 Gpa	200 Gpa

The beam was subjected to monotonic load by the hydraulic jack. The load on beam was gradually increased at an increment of 1 kN initially up to 5 kN and 5 kN subsequently distributed over two points. The beams were loaded until failure. The load values were recorded at the initial crack and at the final failure state.



**Fig 4: Test setup for beams**

### III. EXPERIMENTAL RESULTS AND DISCUSSION

In terms of following parameters, this section discusses the results: Crack pattern, response to load-strain, response to load-deflection, ultimate capacity and failure modes. In terms of these parameters, the influence of GFRP on flexure and shear at two reinforcement ratios is defined and discussed.

#### 3.1. Modes of failures

Generally, the mechanical characteristics of materials used, i.e. the reinforcement type and tensile strength of the concrete mix are responsible for the initiation and propagation of beam cracks. Different failure modes noticed for the examined beam specimens as follows. The first was

**Table III Experimental results of examined beams**

Phase	Specimen ID	P <sub>c</sub> (KN)	P <sub>ult</sub> (KN)	Δ <sub>c</sub> (mm)	Δ <sub>ult</sub> (mm)	Failure modes
I	S81Y	45	135	0.86	5.19	Flexural tension failure
	S81N	65	200	1.5	9.8	Shear compression failure
	S16Y	135	265	2.85	6.6	Compression failure
	S16Y	100	240	2.1	5.8	Shear failure
II	G81Y	25	240	0.48	17.14	Flexural failure
	G81N	35	250	2	11.16	Shear compression failure
	G16Y	70	300	2.4	10.9	Compression failure
	G16N	65	280	2.75	11.1	Shear failure

#### 3.2 Crack pattern

The crack patterns of the phase I and phase II beams are presented in Fig. 5. Initial vertical flexural crack originated in the unchanging moment zone for steel RC beams at a load varying between 45 and 135 kN without being substantially affected by the  $\rho_f/\rho_{fb}$  ratio. After the initial crack within the constant moment zone, more flexural cracks were formed. Further increment of load, cracks due to shear begin to appear in shear span on both sides and diagonally propagated up to the top supports from bottom face of the beam. The phase I beams continued to sustain load in the shear span region until they reached the peak load, upon which the beams failed. It was noticed that the minor cracks were formed and the beams having higher  $\rho_f/\rho_{fb}$  ratios

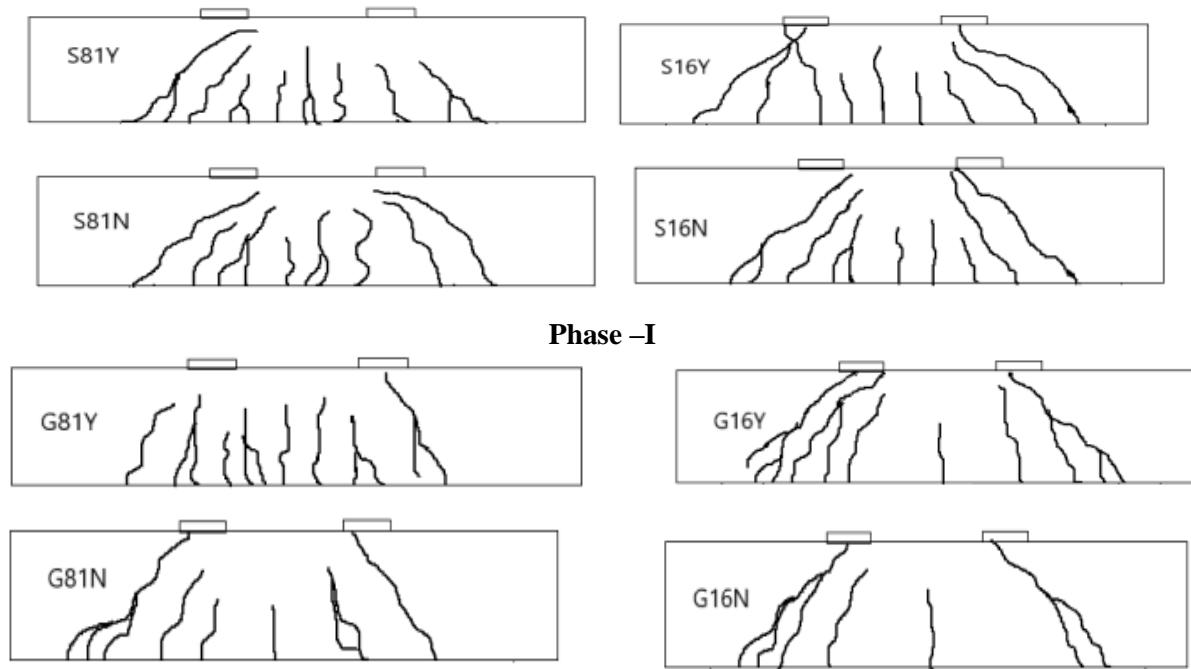
flexural tension failure noticed in beams S81Y & G81Y. The second was the combination of compression failure with one major shear crack which initiated at the bottom of beams and extended to the compression zone observed in S16Y & G16Y. The third was shear tension failure seen in beams S16N & G16N and fourth was Shear compression failure observed in S81N & G81N. Table III presents the cracking loads, peak load carrying capacity and maximum deflections. For beams S81Y and G81Y, the first cracks were appeared at 45 KN and 25 KN respectively. These recorded load values at initial cracks were about 33% and 9.6 % of ultimate loads, of the beams S81Y and G81Y respectively. For beams S16Y and G16Y, the initial cracks were appeared at 135 KN and 70 KN, respectively. These recorded load values at initial cracks were about 53% and 23% of ultimate loads, of the beams S16Y and G16Y, respectively. For the beams S81N and G81N which do not have shear reinforcement, the initial cracks were noticed at the loads 65 and 70 KN, respectively and these recorded loads were 32.5% and 26.9% of ultimate loads, of the beams S81N and G81N respectively. For the beams S81N and G81N which do not have shear reinforced and having reinforcement ratio 1.6 %, the initial cracks were observed at the loads 100 and 65 KN, respectively and these recorded loads were 41% and 22.2% of ultimate loads, of the beams S16N and G16N respectively. Table 3 presents that the cracking loads were lower for beams which are reinforced with GFRP rebars compared to beams which are reinforced with conventional bars due to the lower young's modulus of GFRP rebars

experienced a little more cracks before failure. The development of new cracks has decreased dramatically at higher loading levels. In addition, the current cracks, especially the first cracks created, develop wider and break into small cracks adjacent to the main bars. In the phase-II beams, the crack pattern differed from the phase-I beams. In unchanging moment region, first flexural crack originated at a load varying between 25 and 65 KN in the middle of the beam. As predicted, due to the low young's modulus of GFRP rebars, the initial crack began at a lower load for GFRP reinforced beams.



By increasing the load, shear cracks were originated with steeper crack angles than phase I beams in the shear span. It was evident from Fig 5 that the beams reinforced with steel rebars had a more number of flexural tensile cracks than the GFRP reinforced beams. No major influence on crack

patterns was shown by the reinforcement ratio. However, in the lower third of the beam, G-series beams did not show substantial branching, possibly because of increased reinforcement ratio



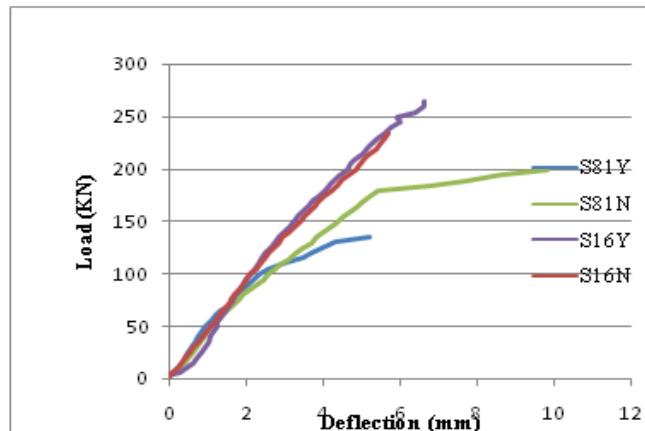
**Fig 5: Pattern of cracks at failure of all tested beams**

### 3.3 Response to Load deflection

In Fig 6 and Fig7, respectively, the load deflection behaviour of beams in phase I and phase II is shown. The action of load deflection is divided into three phases: pre-cracking, shift from pre-cracking to post-cracking, and post-cracking.

#### 3.3.1 Phase I beams

At a deflection of less than 3 mm and at a load varying from 45 to 135 KN, the initial crack due to flexure formed in phase I beams. The major influence was shown by  $\rho_f/\rho_{fb}$  ratio on transition zone and the post-cracking stiffness of the specimens. Beams with low ratios of  $\rho_f/\rho_{fb}$  (Fig.8) encountered few variations in the behaviour of load deflection, suggesting the successive development of cracks after the first crack. With a smoother transition, less fluctuation was observed as the  $\rho_f/\rho_{fb}$  ratio increased [Fig.8] the load increased approximately linearly in the post cracking zone before failure. The stiffness of the beams has increased with the growth of  $\rho_f/\rho_{fb}$  ratio.

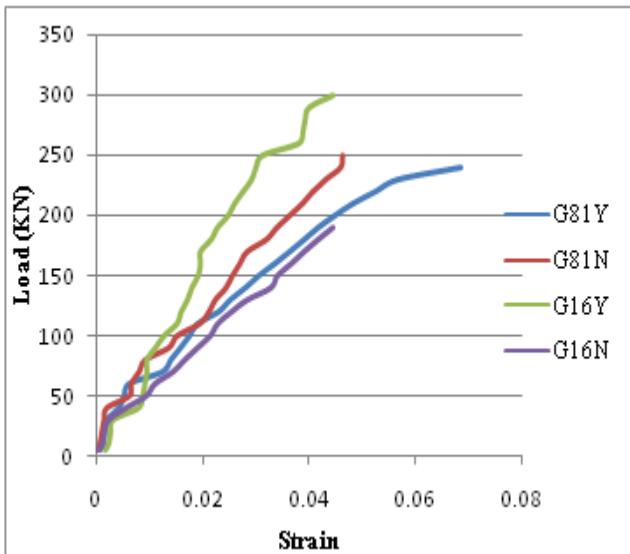


**Fig 6 Load deflection behaviour of S-series beams**

#### 3.3.2 Phase II beams

The initial flexural crack formed at a deflection of less than 3 mm and at a load varying from 25 to 70 KN in a similar fashion to phase I beam. After the formation first crack due to flexural, beams with greater reinforcement ratios encountered fewer variations in the transition region. As shown in Fig7, stiffness of beam and ultimate load increased compared to the remaining GFRP RC beams, excluding the beam G16N that failed at a lower ultimate load. Furthermore, beams without stirrups did not display a major difference in the behaviour of load-deflection.

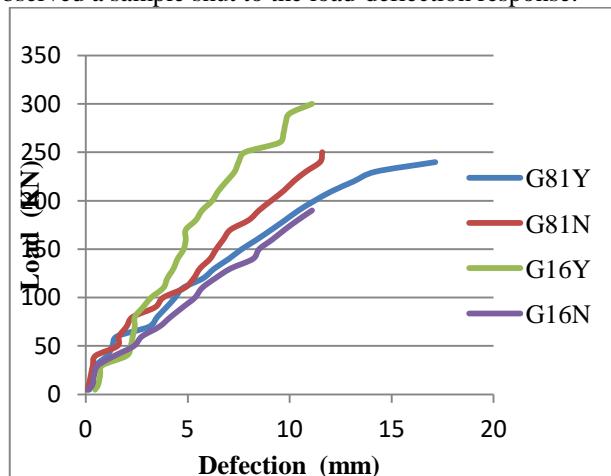
## Flexural and Shear Behavior of Beams Reinforced with GFRP Rebars



**Fig 7 Load deflection behavior of G- Series beams**

### 3.4 Load strain response

The load vs stress is introduced in the figures in concrete and GFRP. 8 and 9 respectively for phase-I and phase-II beams. Phase I and II beams load pressure response observed a sample shut to the load-deflection response.

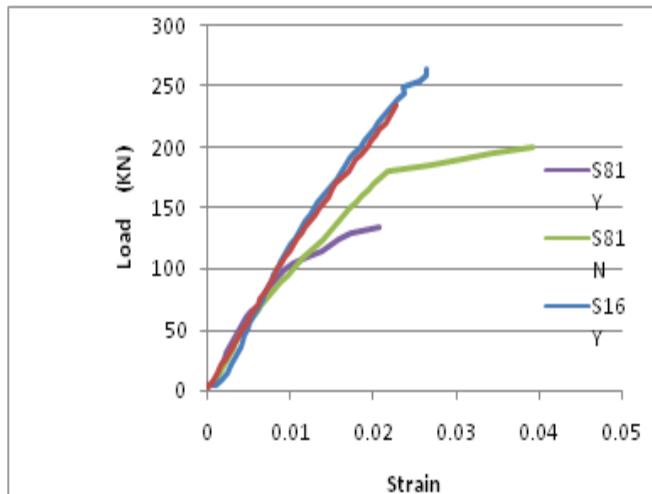


**Fig 8 Load strain behaviour of S-series beams**

**Table IV: Experimental and theoretical shear capacities**

Phase	Specimen ID	P <sub>ult</sub> (kN)	M <sub>cr</sub> (KN-M)	M <sub>ult</sub> (KN-M)	V <sub>r</sub> (KN)	V <sub>c</sub> (KN)
I	S81Y	135	18	54	67.2	121.2
	S81N	200	26	80	100	121.2
	S16Y	265	54	106	132	101.1
	S16N	240	40	96	120	101.1
II	G81Y	240	10	96	120	115.6
	G81N	250	28	100	125	115.6
	G16Y	300	32	120	150	132.3
	G16N	280	26	72	190	132.3

Table IV presents the experimental and theoretical shear and peak loads of the specimens, as well as an overview showing the contribution of concrete V<sub>c</sub> and stirrups to each specimen's overall shear resistance, V<sub>r</sub>. The theoretical ACI [4, 11] standard predictions of shear capacity are presented.



**Fig 9 Load strain behavior of G- series beams**

### 3.5 Shear analysis of GFRP RC beams

Generally, the shear reaction of reinforced concrete beams is complex than the flexural response. Under combined stresses arising from applied shear force and bending moment, failure in shear occurs. According to the ACI-318 Code [11], the shear strength of conventional beams without stirrups is given in SI units by

$$V_c = \frac{1}{6} \left( \sqrt{f'_c} + 100\rho \frac{V_u d}{M_u} \right) b_w d \quad 2$$

The shear performance of FRP reinforced concrete members is not expected by the steel reinforced concrete structures construction codes. In compliance with the ACI-440 design guidelines, the shear performance of FRP RC beams with not vertical reinforcement can be obtained by multiplying the shear capacity of steel reinforced concrete members by a factor (E<sub>f</sub>/E<sub>s</sub>) [4]. Hence the shear capacity of FRP reinforced concrete members can be estimated in SI units by

$$V_c = \frac{1}{6} \left( \frac{E_f}{E_s} \right) \left( \sqrt{f'_c} + 100\rho \frac{V_u d}{M_u} \right) b_w d$$

#### IV. CONCLUSIONS

The following conclusions are drawn based on the findings of the experimental programme. However, the conclusions may be limited to the individual examined specimens.

- a. Steel reinforced beams demonstrated a larger number of flexural and shear cracks at all reinforcement ratios than GFRP RC beams. Reinforced GFRP beams displayed slightly steeper cracks and less shear cracks than reinforced steel beams.
- b. GFRP reinforced beams displayed high deflections compared to S-series beams due to the low energy absorption and low modulus of elasticity of GFRP rebar.
- c. For S-series concrete beams, the cracking moments are higher than those of G-series beams.
- d. The ultimate beam capacity is directly proportional to the flexural reinforcement ratio, irrespective of the mode of failure, whether bending or shearing. On the other hand, the load deflection behaviour of the beams tested was not significantly impacted by the form of shear reinforcement.
- e. As the GFRP flexural reinforcement ratio increased, the ultimate shear capabilities increased.

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