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Cyclic Load Behaviour of RC T - Beams internally Reinforced with GFRP Reinforcements

[I]J.Karthick, [II]Dr. K.Natarajan, [III]R.Murugan
[I]Dept. of Civil Engineering Sree Sowdambika College of Engineering, Aruppukottai, Tamil Nadu, India
[II,III]Dept. of Civil and Structural Engineering, Annamalai University, Tamil Nadu, India
[I]jkdheena@gmail.com, [II]nataraj_dgl@yahoo.com, [III]ermurugan.cdm@gmail.com

Abstract

Fiber reinforced polymers are very much used in the Rehabilitation and retrofitting of existing structures because of their high strength to weight ratio and stiffness to weight ratios ,light weight and durability. They are especially used in the reinforced concrete structures like buildings, bridges, chimney etc. Now a day FRP composites are available in the form of rebars as conventional steel reinforcements. In structures corrosion protection is a primary concern. FRP material is corrosion resistant and several properties that make them suitable as structural reinforcement. The present study aim is to cyclic behaviour of flanged beams reinforced with GFRP reinforcements. Eighteen beams were casted, among these six reinforced with conventional steel reinforcements and remaining six reinforced with GFRP grooved bars and remaining six reinforced with GFRP sand coated bars with a consideration of different reinforcement and mix ratios. These test specimens were tested for cyclic loading with two point loads. The load deflection characteristics, crack width, ultimate load and deflection moment curvature relationship were found for all the beams and compared with the theoretical moment Vs curvature curve was compared with actual values. The present study is also having the comparison of experimental values with theoretical results.

Keywords

Reinforced concrete, Flanged beam, Fiber reinforced polymer, GFRP, Cyclic behaviour, Crack pattern, Crack width

I. Introduction

Concrete structures reinforced with conventional steel reinforcements cause a concern in aggressive environmental condition due to the accelerating problem of corrosion. The downfall results in costly maintenance and replacement of the existing structures. FRP Bars are intended for use as concrete reinforcing in areas where steel reinforcing has a limited life span due to the effects of corrosion. They are also used in situations where electrical or magnetic transparency is needed. Glass Fibre Reinforced Polymer (GFRP) are non metallic reinforcement utilizing high performance hybrid, encapsulated in resin matrix. These rods are manufactured by Pultrusion process. The surfaces of the rods are treated with undulations to provide mechanical interlock with concrete. Their application is seen primarily as means to avoid corrosion problems encountered in concrete structures when using conventional steel reinforcements. In addition to reinforcing for new concrete construction, FRP bars are used to structurally strengthen existing masonry, concrete or wood members. Keeping this in mind, the present study has been planned to study the behaviour of GFRP reinforcements for flanged concrete beam. So far, studies are largely Confined to cyclic test on FRP reinforcements alone. Considerable research has also been carried out mainly on FRP reinforced concrete specimens under monotonically increasing load (Navy 1977, Benmorkrane 1995, ACI - 440, Michaluk 1998, Theriault 1998,Ombres 2000,Sobhy Masoud 2001, Ganesh Thaigarajan 2003). Only a limited research has been carried out on FRP reinforced Concrete specimens under pulsating or repeated loading conditions (Ragaby 2007, Sivagamsundari 2007). Therefore the present sudy deals mainly with the behaviour of Reinforced Concrete (RC) T- Beam reinforced internally with Glass Fibre Reinforced Polymer (GFRP) reinforcements under repeated loading conditions. Based on rigorous modeling and experimental analysis, improved recommendations are proposed for Indian Standard (IS) codes.

II. Behaviour of concrete under fatigue loading

Fatigue is a permanent internal structural (micro cracking) change in a material subjected to fluctuating stresses or strains, if the loading exceeds a certain limit. Fatigue failure of materials normally occurs at a stress level much lower than the static stress because of repeated stress or deformation, and in most cases it appears in an abrupt brittle fracture pattern. Pavements, bridges and other structures supporting oscillating machinery are included in this category. Fatigue fracture of Concrete is characterized by Considerably large micro cracking and strains when compared to fracture of concrete under static loading. The degree of fatigue damage can be measured by the magnitude of elastic and residual (plastic) deflection, crack widths and strains at various levels along the thickness of the specimen.

III. Material Properties

A. Concrete

Normal strength concrete of grades 20Mpa and 30Mpa are used to cast the flanged beam. Ordinary Portland cement is used to prepare the concrete. The maximum size of aggregate used is 20mm and the size of fine aggregate ranges between 0 and 4.75mm. After casting, the specimens are allowed to cure in real environmental conditions for about 28 days so as to help the concrete to stabilize its own properties like compressive strength and modulus of elasticity. The strength of concrete under uniaxial compression is determined by loading standard test cubes (150mm) to failure in a compression testing. The materials used in the concrete were coarse aggregate, fine aggregate, cement etc., the properties of that material listed below,

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Table 1 : Characteristics Of Aggregates

Property	Coarse Aggregate	Fine Aggregate	Cement
Fineness Modulus	7.10	3.12	-
Specific Gravity	2.70	2.61	3.14

B. Mix Proportion

The Concrete mix is designed for relatively higher strength due to the high strength by fibre reinforcements. All the beam specimens are cast normal weight concrete of grade 20 Mpa and 30 Mpa. After casting the specimens, they are allowed curing in real environmental conditions for about 28 days. The properties of concrete mix are given in following table.

Table 2 : Amount of requirement of aggregate

Material	M 20 Grade	M 30 Grade
Cement	372	413
Fine Aggregate	654.066	641.80
Coarse Aggregate	1202.58	1180.17

C. Reinforcements

The use of FRP reinforcements in concrete structures is strongly influenced by their physical and mechanical properties. FRP bars can be designed and manufactured to meet specific requirements of a particular application. Available design variables include the choice of constituents, the volume fraction of fibre and matrix, fibre orientation and the manufacturing process. Other factors such as dimensional effects and quality control during fabrication play on important role in determining the characteristics of FRP bars. The properties of FRP materials are influenced by loading history, duration of loading temperature and humidity. A key element in evaluation of FRP properties is the characterization of the relative volume of various constituent materials. GFRP reinforcements used in this study are manufactured by Dextra industries Ltd. Three different types of GFRP reinforcements with different surface indentations shown in fig. (i) Threaded type GFRP reinforcements i.e. the surface of the reinforcements are given a continuous threads and are designated as G_1; (ii) Sand coated type GFRP reinforcements i.e. its surface is roughened with sand particles and are designated as G_2; (iii) grooved type GFRP reinforcements i.e. grooves are given on the surface of GFRP rods and are designated as G_3) are tried and conventional steel reinforcements (Fe 415) which are designated as S are used for comparison. The diameter of the longitudinal and transverse reinforcements is 10mm and 8mm respectively. The mechanical properties of all the types of GFRP reinforcements are obtained from appropriate test prescribed as per ASTM Standards.

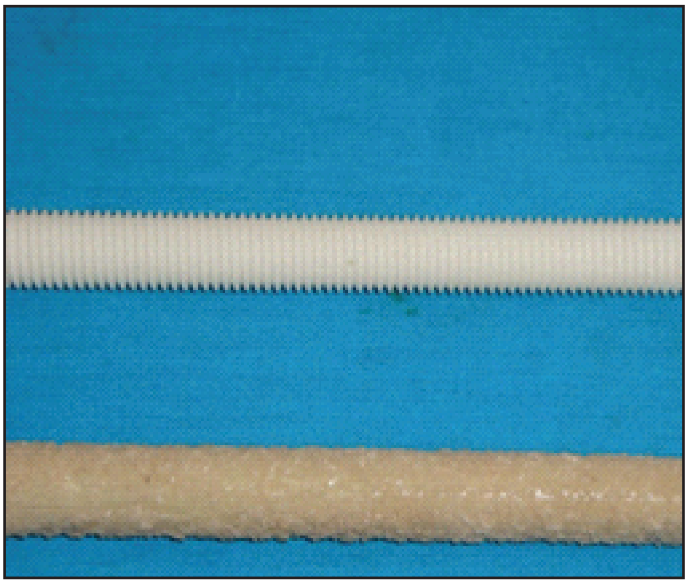


Fig. 1: Typical GFRP reinforcements test setup

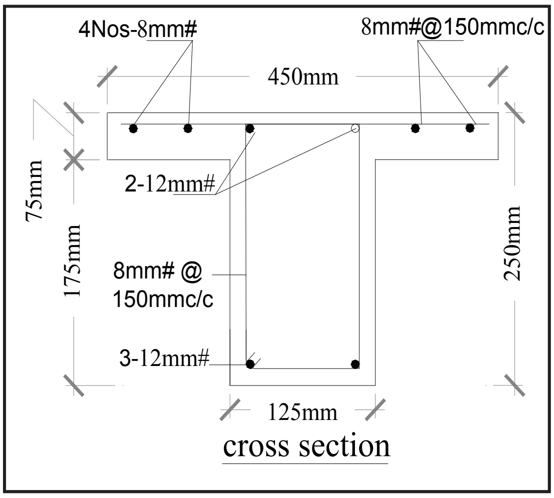
Table 3: Characteristics of reinforcements

Properties	Steel Fe 415	Threaded GFRP (FT)	Sand Coated GFRP (Fs)
Tensile strength (Mpa)	490	610	670
Longitudinal Strength (Gpa)	200	63.75	-
Strain	0.002	0.012	0.153
Poisson's Ratio	0.25 - 0.3	0.22	-

IV. Methodology

Totally eighteen beams were casted with the consideration of different reinforcement ratio and different mixes. Out of which six beams are reinforced with conventional steel reinforcements and six beams are reinforced with grooved glass fiber reinforced polymer reinforcements and six beams are reinforced with sand coated glass fiber reinforced polymer Reinforcements. FRP composites are defined as a polymer matrix, which is reinforced by Fibres and are currently used as reinforcement for concrete structures. Hence it is necessary to carry out tension test for GFRP reinforcements and for conventional steel. Therefore for casting beam-column joint HYSD bars of 12mm dia. And 8mm dia. Stirrups are used. Similarly 12mm dia. GFRP reinforcements and 8mm GFRP stirrups are used. The specimens are reinforced in such under, balanced, over reinforced flanged concrete beam. The specimen consists of flange of size 450*75mm and web of 125*175mm reinforced with conventional steel and the length of the beam is 3200mm.

Main reinforcements of flanged beam were made up of high yield strength deformed steel bars of 12mm diameter for control specimens and GFRP bars of same diameters used for GFRP specimens. The control specimen is reinforced with 2nos. of 12mm dia. At bottom in reinforced, 3nos. 12mm dia. In Balanced reinforced concrete 5nos. of 12mm dia rod is provided at bottom. In Over reinforced beam 2 no. of 10mm dia rod is provided at bottom and at top and 8mm dia. Stirrups same as the GFRP bars. For better bonding the GFRP bars are made with threaded made with surface.



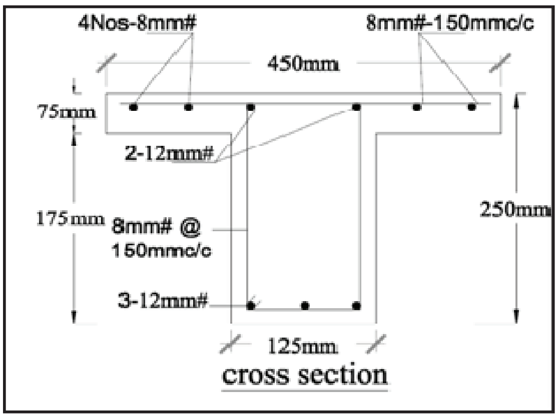


Fig. 2: Placing of GFRP rods in Beams

V. Result and Discussion

A. Experimental Set up For Constant Amplitude of Fatigue Loading Condition

To simulate the traffic loading, two types of repeated loading have been tried in this study. First set of beams (twelve in numbers) are subjected to constant amplitude of fatigue loading scheme. Beams are kept on the loading frame. A 20 mm thick neoprene sheet is used between the steel plate and concrete and concrete surface to avoid local effect. A clear span of 2200mm is adopted between the supports. A 50KN capacity with 250 mm stroke actuator monitored by computer is programmed to apply fatigue loads on the beams. A data acquisition system is used to monitor and acquire all strain readings with the help of strain gauges and LVDTs for both the static and repeated loadings. Demec gauges are also used to observe the displacements on a predefined positions i.e on the brass pellets. The minimum load level is at 2 KN to prevent any impact due to repeated loading and also to represent the effect of superimposed loads on a bridge like pavement and insulation (Kumaran 2002, Kumaran 2003, Vijayaprakash 2004, Rashid 2005). The fatigue loading range is chosen to be approximately symmetrical around the service load so that the upper limit simulates some kind of over loading on the specimen; and enables the failure of the beam within a reasonable time. The results of Beams under constant amplitude of fatigue loading scheme are presented in the following table.

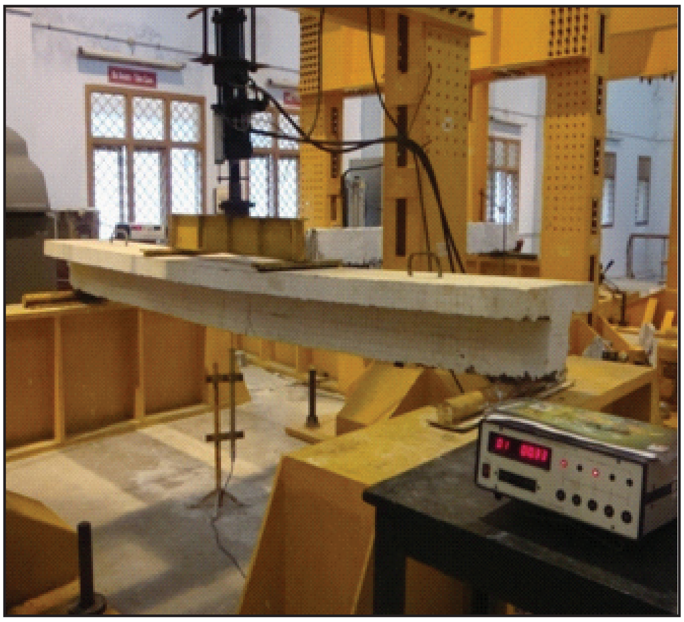


Fig. 3: Photograph of Test Setup for repeated loading

Table IV : Cyclic loading results (constant amplitude)

S.No	Designation of flanged beam	Number of load cycles at first crack	Crack width in mm	Residual deflection in mm
1	Bm1ρ1S`	61,800	0.14	2.56
2	Bm1ρ1FT	78,500	0.12	1.81
3	Bm1ρ1Fs	88,800	0.10	1.70

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Table V : Cyclic loading results (constant amplitude)

S.No	Designation of flanged beam	Crack widths at various load level (mm)			Crack width at service loads (mm)
		0.3P	0.6P	0.9P	
1	Bm1ρ1S`	0.14	0.16	0.18	0.18
2	Bm1ρ1FT	0.12	0.14	0.16	0.16
3	Bm1ρ1Fs	0.10	0.12	0.14	0.14

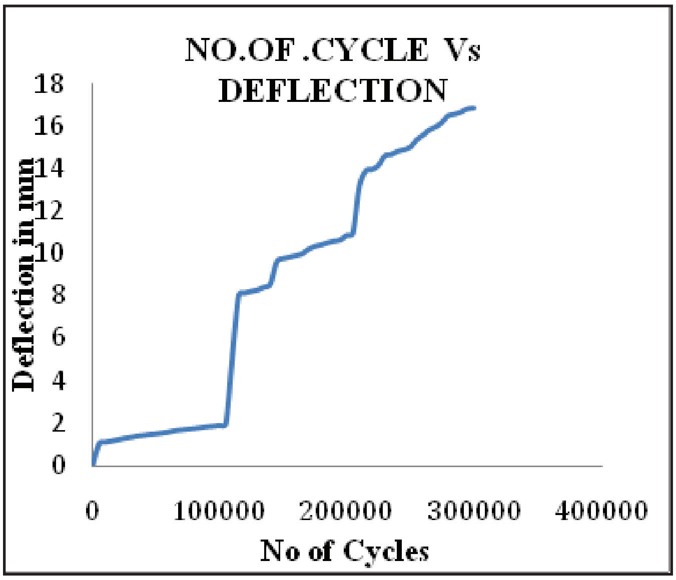

Fig.4. Deflection curve for Cyclic loading (Constant amplitude)

B. Experimental Set up For Variable Amplitude of Fatigue Loading Condition

The Second sets of beams are subjected to variable amplitude of fatigue loading scheme. The experimental set up for variable amplitude of fatigue loading condition is similar to constant amplitude of fatigue loading condition. The variable loading scheme is applied by selecting 2 KN as minimum load for all the beams and different percentages of their ultimate loads (i.e 30%, 60% and 90%) as maximum loads to assess the effect of cycling at lower peak load levels. Each and every fatigue loading steps is applied for 7, 00,000 cycles at frequency of 4 Hz till the failure of beams. The degree of fatigue damage can be evaluated by the magnitudes of strain in reinforcement, crack width, elastic deflection and residual (plastic) deflection. The magnitude of residual deflection is energy dissipation of the beam which is considered as a proper measure to estimate the degree of damage. The deflections, crack widths, crack propagation, crack patterns, modes of failure and number of cycles up to failure are measured at the end of each repeated loading step. The results of beams under variable amplitude of fatigue loading scheme are presented in the following table.

Table VI : Cyclic loading results (variable amplitude)

S.No	Designation of flanged beam	Number of load cycles at first crack	Crack width in mm	Residual deflection in mm
1	$Bm_1\rho_1S$`	4,75,500	0.19	18.6
2	$Bm_1\rho_1FT$	5,68,800	0.18	9.58
3	$Bm_1\rho_1Fs$	6,24,600	0.17	8.66

Table VII : Cyclic loading results (variable amplitude)

S.No	Designation of flanged beam	Crack widths at various load level (mm)			Crack width at service loads (mm)
		0.3P	0.6P	0.9P	
1	Bm1ρ1S`	0.16	0.18	0.20	0.20
2	Bm1ρ1FT	0.12	0.16	0.18	0.18
3	Bm1ρ1Fs	0.10	0.14	0.16	0.16

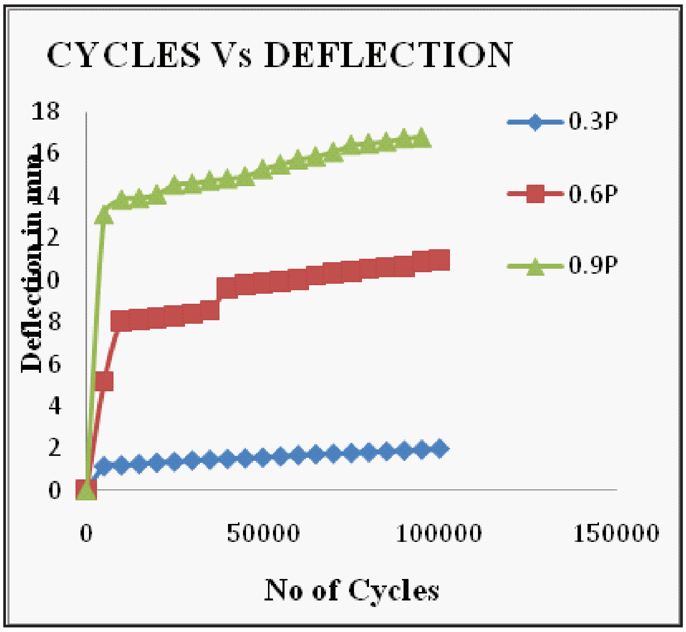

Fig. 5. Deflection Curve for cyclic loading condition (Variable Amplitude)

C. Behaviour of steel/GFRP reinforcements

Steel reinforcements have an elasto- plastic behaviour and is defined by its yield strength, with a typical elastic modulus of 210 Gpa where as GFRP reinforcements are made from unidirectional polyester - glass materials having a modulus of elasticity 60, 68 and 47 Gpa and ultimate stress of 600, 690 and 525 Mpa for the grooved, sand coated and plain GFRP reinforcements respectively. In this study, all the GFRP reinforcements are modeled as layers of equivalent thickness. Each reinforcing layer exhibits a uniaxial response, having strength and stiffness characteristics in the longitudinal direction of the reinforcement only.

D. Compression behaviour of concrete

The Non- linear behaviour of concrete is inelastic. A perfect plastic and strain hardening plasticity approaches are used to model the compression behaviour of concrete. A dual criterion for yielding and crushing in terms of stresses and strains is considered (Ferreira 2001).

E. Tensile behaviour of concrete

The response of concrete under tensile stresses is assumed to be linear elastic until the fracture surface is reached. This type of fracture or cracking is governed by a maximum tensile stress criterion. Cracks are expected to form in planes perpendicular to the direction of maximum tensile stress, as soon as it reaches a specified concrete tensile strength. In this study, concrete is assumed to be an isotropic material before cracking and the concrete becomes orthotropic after cracking, with a material axis oriented along the direction of cracking.

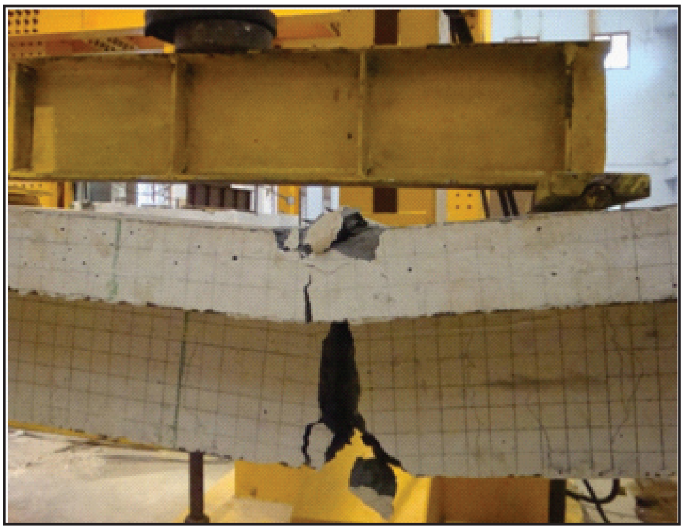

Fig. 6 : Failure of Flanged beam

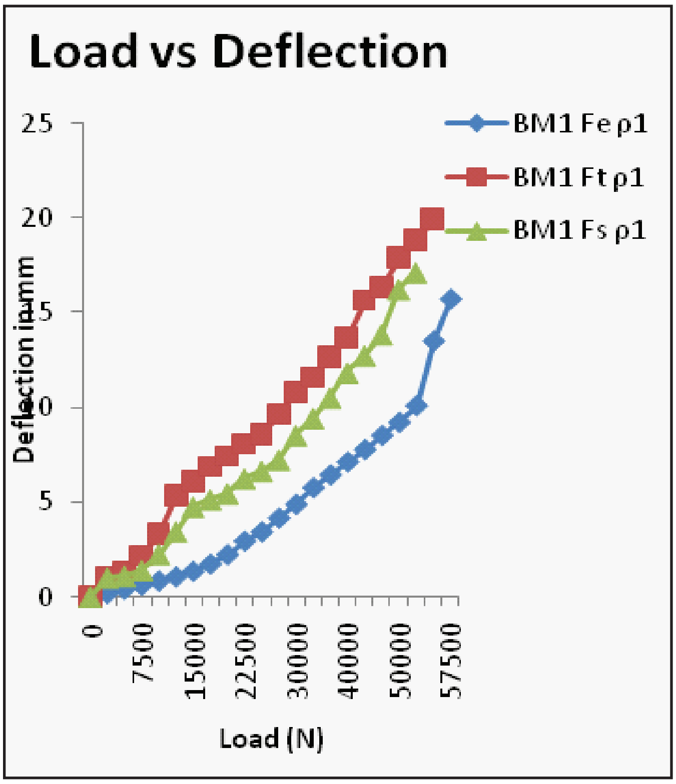

Fig.7 : Graph shows the relation between fatigue load and deflection

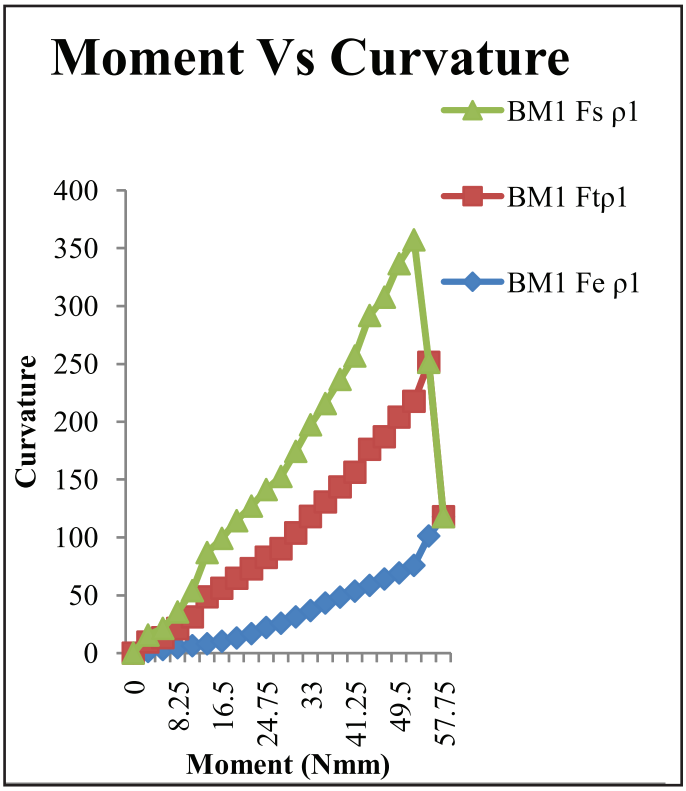

Fig.8 : Graph shows the relation between Moment and Curvature

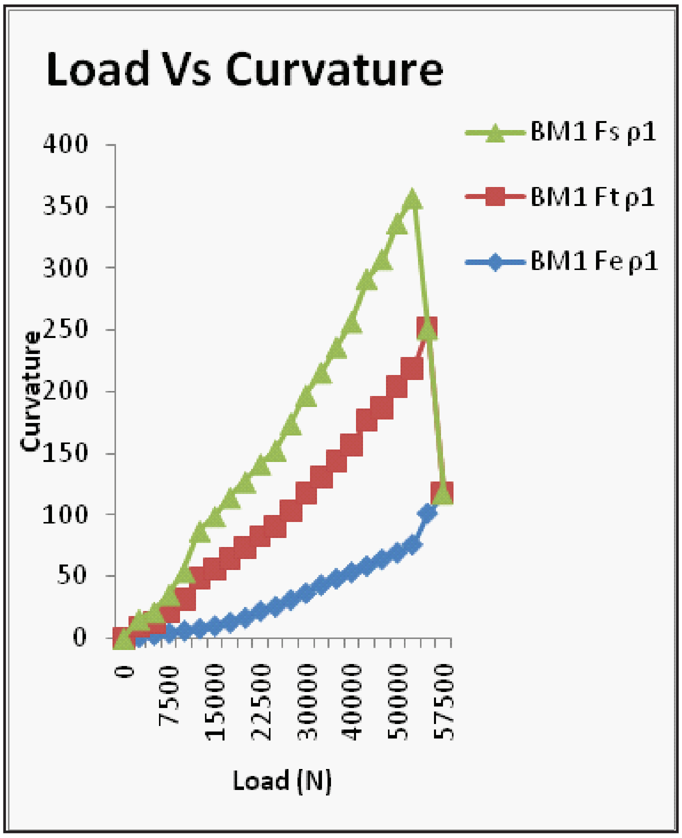

Fig. 9 : Graph shows the relation between the fatigue loads applied with Curvature

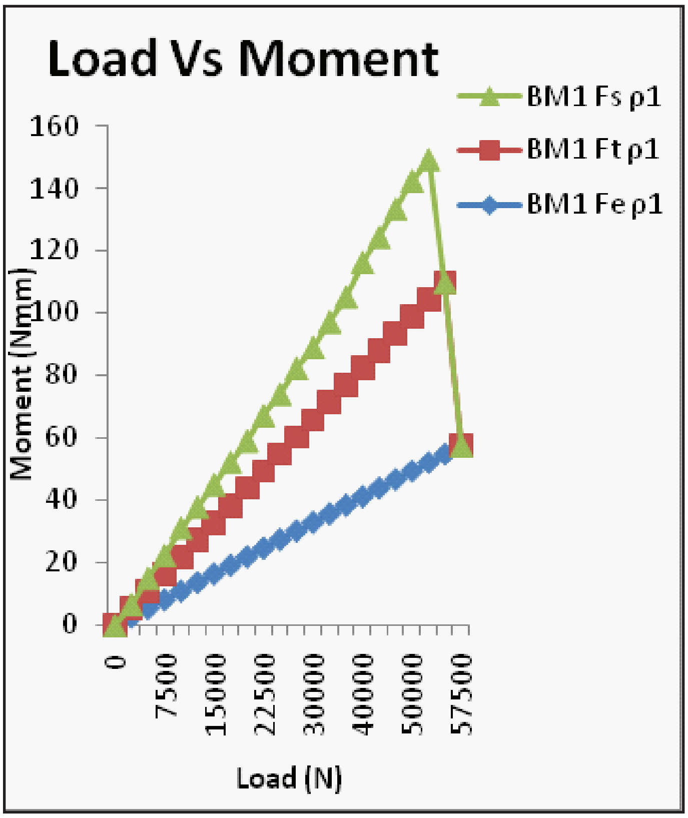

Fig.10 : Graph shows the relation between the fatigue loads applied with Moment

VI. Conclusion

A total number of eighteen T- beams (out of which six beams are reinforced with conventional steel reinforcements and six beams were reinforced with Grooved Glass Fibre Reinforced Polymer (GFRP) reinforcements and Six beams were reinforced with Sand coated GFRP reinforcements) are studied. A rigorous experimental studies on the behaviour of conventional and GFRP reinforced concrete T- beams under static and repeated loading are investigated by considering reinforcement ratios, grade of concrete, thickness of slabs and type of GFRP reinforcements. GFRP T-beams are investigated for repeated loading (with constant and variable amplitude loading). At ultimate load, GFRP reinforced T- beams experience concrete crushing followed by rupture of GFRP reinforcements. As the ultimate load carrying capacity of GFRP reinforced T- beams is increased, the corresponding deflections, strains and crack width are reduced by increasing the thickness, grade of concrete, reinforcement ratio of the beams. GFRP reinforced concrete beams experiences better performance under repeated loading than those beams reinforced with conventional steel. It is due to the fact that the onset of permanent deformations is delayed due to the higher strains in the GFRP specimens than the conventionally reinforced beams. This is mainly attributed due to the equal values of the modulus of elasticity for GFRP reinforcements and concrete in addition to the linear - elastic behaviour of GFRP reinforcements.

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