The Study on Strength and Stiffness of RC Beams Retrofitted with GFRP Wrapping

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Abstract: **This work presents the experimental study on strengthening of RC beam with glass fibre reinforced polymer (GFRP). Total nine RC beam specimens were casted & tested in this work. The beam dimensions considered for this study are 150X200X1300 mm. Fe415 grade steel and M25 grade concrete has been used for the casting beams. In this experimental work, three parameters such as balanced, under reinforced and over reinforced RC beam sections were considered. The under reinforced and over reinforced beams were retrofitted with two layers of U-shaped GFRP wrapping on full length of the beam. The beam specimens were tested under two point loading and the load-deflection behavior was observed up to failure. Also the maximum load, the stress-strain behavior and the complete crack patterns were recorded and presented. Experimental investigation reveals that the balanced and over reinforced RC beams retrofitted with two layers of GFRP exhibit more strength and stiffness than the under reinforced RC beams retrofitted with GFRP.**

Keywords: strengthening, glass fibre reinforced polymer (GFRP), wrapping, reinforcement,

I. INTRODUCTION

In the earlier it was thought that concrete will be a maintenance free Structure. Later on, this myth has proved wrong. Due to majority of Civil Engineering structures being RCC and on account of its requirement of maintenance, quantum of such rehabilitation/strengthening work has also increased tremendously. Constant maintenance and repairing is needed to enhance the life cycle of those structures which are deteriorated. Retrofitting of reinforced concrete element is traditionally accomplished by externally bonding steel plates to concrete.

Although this technique has proved to be effective in increasing strength and stiffness of reinforced concrete elements, it has the disadvantages of being susceptible to corrosion and difficult to install. In the last decade, the development of strong epoxy glue has led to a technique which has great potential in the field of upgrading structures. Basically the technique involves gluing steel plates or fibre reinforced polymer (FRP) plates to the surface of the concrete. The plates then act compositely with the concrete and help to carry the loads. Also recent development in the field of composite materials, together with their inherent properties, which include high specific tensile strength good fatigue and corrosion resistance and ease of use, make them an attractive alternative to any other retrofitting technique in the field of repair and strengthening of concrete elements.

FRP can be convenient compared to steel for a number of reasons. These materials have higher ultimate strength and lower density than steel. The installation is easier and temporary support until the adhesive gains its strength is not required due to the low weight. They can be formed on site into complicated shapes and can also be easily cut to length on site. A Fiber Reinforced Polymer (FRP) composite is defined as a polymer (plastic) matrix, either thermoset or thermoplastic, that is reinforced (combined) with a fiber or other reinforcing material with a sufficient aspect ratio(length to thickness) to provide a discernable reinforcing function in one or more directions. FRP composites possess some outstanding properties such as: resistance to corrosion, good fatigue and damping resistance, high strength to weight ratio, and electromagnetic transparency. FRP has found an increasing number of applications in construction either as internal or as external reinforcement for concrete structures. It is well known that FRP possesses a major advantage over conventional steel in reinforced concrete structures. Civil structures made of steel reinforced concrete are normally susceptible to environmental attacks that lead to the initiation of an electrochemical process which leads to the corrosion of steel reinforcement.

Bridge deck deterioration due to direct exposure to environment, deicing chemicals and ever increasing traffic loads is one of the most common deficiencies in a bridge system. The use of FRP's for concrete bridge decks and also girders provides a potential for increased service life, economic, and environmental benefits. Beams are the critical structural members subjected to bending, torsion and shear in all type of structures. Similarly, columns are also used as various important elements subjected to axial load combined with/without bending and are used in all type of structures. Therefore, extensive research works are being carried out throughout world on retrofitting of concrete beams and columns with externally bonded FRP composites. Several investigators took up reinforced concrete beams and columns retrofitted with carbon fibre reinforced polymer (CFRP)/ glass fiber reinforced polymer (GFRP) composites in order to study the enhancement of strength and ductility, durability, effect of confinement, preparation of design guidelines and experimental investigations of these members. The object of retrofitting of a beam in earthquake resistant frame is that, it must not deform excessively. A beam is subjected to excessive flexural stresses and shear stresses when either member reaches it's over strength capacity associated with the hardened plastic hinges.

The objective of the FRP wrapping is to improve the flexural strength and stiffness of deficient beams due to various causes. Beams are the main structural elements need to be rehabilitated as and when fracture or fault is noticed. As the FRP wrapping is the one of the rehabilitations method, the faulty beams can be strengthened using FRP. Moataz Badavi and Khaled Soudki (2002) carried out the investigation on different issues with GFRP and CFRP confinement on the flexural behavior of reinforced and plain concrete beams and using GFRP and CFRP in the flexural member as confined materials can minimize the amount of cracks and eventually enhance the performance of the structure.

II. EXPERIMENTAL PROGRAMME

A. Material Properties:

The main material used in casting of beams is concrete and it mainly consists of cement, fine aggregate (sand), coarse aggregate and water. These materials are mixed proportionally with designed water cement ratio gives required strength of concrete. OPC-53 grade (ordinary Portland cement) was used for the investigation. It was tested for its physical properties in accordance with Indian Standard specifications. The fine aggregate used in this investigation was clean river sand, passing through 4.75 mm sieve with specific gravity of 2.60. The grading zone of fine aggregate confirms to zone II as per Indian Standard specifications. Machine crushed granite broken stone angular in shape was used as coarse aggregate. The maximum size of coarse aggregate was 20 mm with specific gravity of 2.64. Ordinary clean portable water free from suspended particles and chemical substances was used for both mixing and curing of concrete. Concrete mix design is carried out to achieve the strength of 25 N/mm2 the proportion is 1 : 2.26 : 3.91. The water cement ratio 0.45 is used. Fe415 grade steel was used for all reinforcements.

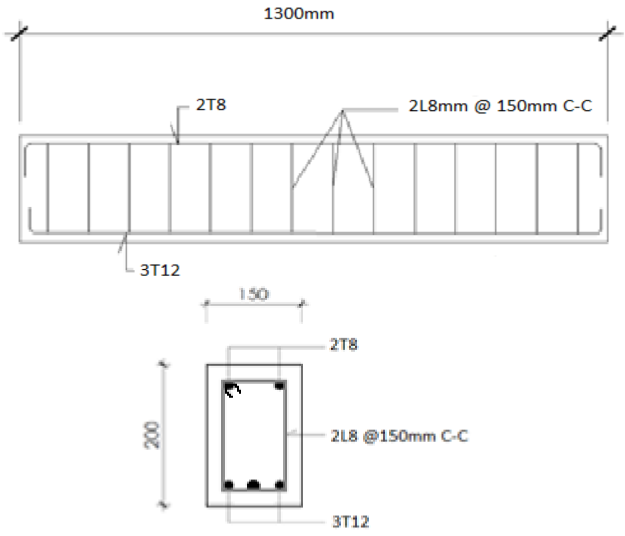

Fig 1(a) reinforcement details for controlled beams

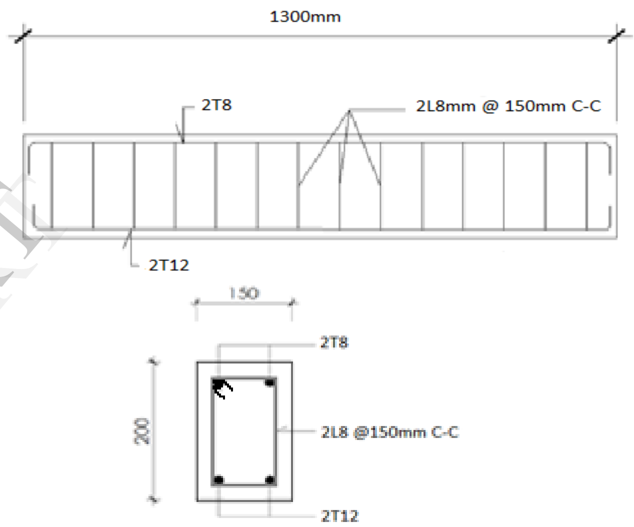

Fig 1(b) reinforcement details for under reinforced beam

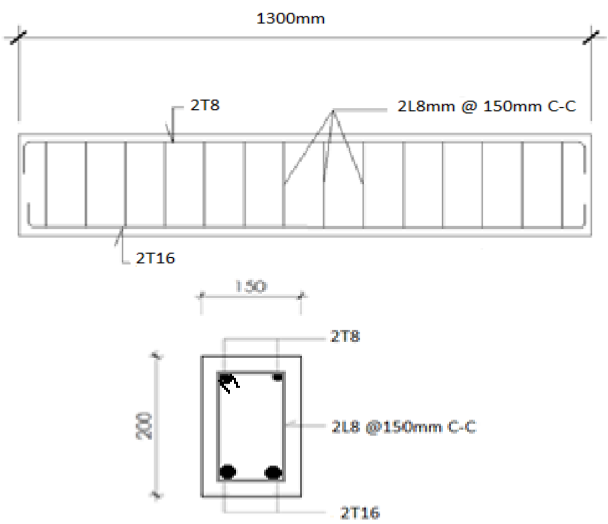

Fig 1(c) reinforcement details for over reinforced beams

Glass Fiber Reinforced Polymer (GFRP): Glass fibers are considerably cheaper than carbon and aramid fibers. Therefore glass fiber composites shown in Fig 2 have become popular in many applications. The moduli of fibers are 70-85 GPa with ultimate elongation 2-5% depending on quality. Glass fibers are sensitive to stresses corrosion at high stress levels and may have problems with relaxation. Glass fibers are sensitive to moisture, but with the correct choice of matrix, the fibers are protected.

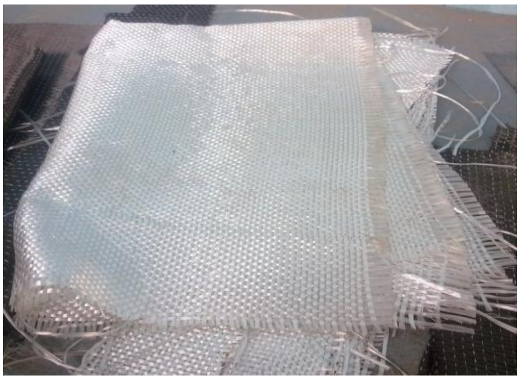

Fig 2 GFRP

The glass fibre supplied by the manufacturer (Harthy Chemicals (India) Pvt. Ltd.) and their properties are summarized in the table1 below.

Table 1: Properties of GFRP as per the manufacturer

Properties of GFRP	Value
Density of fibre	2.6 g/cc
Weight of fibre	920 g/mm^2
Fibre thickness	4 mm
Fibre orientation	±90^0
Nominal thickness per layer	1.5 mm
Tensile strength	3400 N/mm^2
Tensile modulus	73000 N/mm^2

Unsaturated Isopthalic Polyester Resin: Polyester resins are unsaturated resins formed by the reaction of dibasic organic acids and polyhydric alcohols. Polyester resins are used in sheet moulding compound, bulk moulding compound and the toner of laser printers. Wall panels fabricated from polyester resins reinforced with fiberglass so-called fiberglass reinforced plastic (FRP) are typically used in restaurants, kitchens, restrooms and other areas that require washable low-maintenance walls. Polyester resins are thermosetting and as with other resins, cure exothermically. The use of excessive catalyst can, therefore, cause charring or even ignition during the curing process. Excessive catalyst may also cause the product to fracture or form a rubbery material.

Table 2 Typical properties of cast Thermosetting Polyesters

Density, g/cc	12-13
Tensile modulus, MPa	55-130
Thermal expansion, $10^6/^0C$	45-65
Water absorption, % in 24hr	.08-0.15

Accelerator: The function of the accelerator is to accelerate the reaction (polymerization). In the present investigation accelerator used is cobalt octate 2%. The excessive use of Cobalt octoate causes brittleness and early failure of insulation. Cobalt octoate accelerates the catalytic action of Methyl ethyl ketone Peroxide (MEKP) to polymerize unsaturated polyester resin.

Table 3 Properties of cobalt octoate

Physical state	Liquid
Metal content	2%
Tolerance	±0.20%
Colour	Violet
Specific gravity at 30^0	0.815
Solid content	10%

Catalyst: In this investigation catalyst used is MEKP (Methyl Ethyl Ketone Peroxide). This catalyst is added to polyester resins and vinyl ester resins. As the catalyst mixes with the resin a chemical reaction occurs creating heat which cures (hardens) the resin. It is recommended that the use of MEKP Catalyst should be accurately measured and poured. For 1Kg of resin 1% or 10ml MEKP catalyst is added.

Table 4 Properties of MEKP catalyst

Appearance	Liquid
Odour	Pungent
Colour	Colourless
pH	4.7
Vapour pressure	20hPa
Density	1060 kg/m^3
Solubility	<10g/l partly
Solvents	Hexane and chloroform

The form work used for casting of all the specimens consists of mould prepared by wood. Form work was thoroughly cleaned and all the bolts were tighten properly. Shuttering oil was then applied to the inner face of the form work. The reinforcement cage was then placed in position inside the form work carefully keeping in view a clear cover of 25 mm for the top and bottom bars.

B. specimen details:

Experimental investigation was carried out on:

1. Reinforced concrete beams with balanced section (controlled beams).

2. Under reinforced, over reinforced concrete beams and balanced RC beams retrofitted with Glass fibre reinforced polymer composite sheets.

The main objective of the investigation was to study the flexural behavior of control RC beams and retrofitted RC beams. Retrofitting is done with DOUBLE LAYER U-WRAPPING of glass fibre reinforced polymer composite bonded onto the whole length of the beam. Initially three control beams (balanced) and then a total of nine retrofitted RC beams were tested, which consists of three under reinforced and three over reinforced concrete beams and three beams with balanced sections were tested. All the beams of size 150mmx200mmx1300mm were casted and tested under two point load with an effective length 1200mm. The mix proportion of M25 grade concrete is cement: fine aggregate: coarse aggregate, 1: 2.26 : 3.91 with minimum cement content (320Kg/m3) and the concrete was hand mixed. Beams were cured for 28 days then taken out for testing. The surface of the cured beam is full of dirt and grease, to enhance the perfect bonding of composite on the beams the surface of beams must be washed and degreased before proceeding to the application of the resin. Also the edges of the concrete members are grinded off so as to give a mild arc like finish to prevent stress concentration and hence damaging of fibres. This also helps the fibres to give a perfect finish where fibres are wrapped like a continuous cloth as they come in the form of sheets. After the surface preparation resin was applied to the beams, the composite fabric was then placed on top of resin coating and the resin was squeezed through the roving of the fabric with the roller. Air bubbles entrapped at the resin/concrete or resin/fabric interface were to be eliminated. Then the second layer of the resin was applied as shown in fig 3, and GFRP sheet was then placed on top of resin coating and the resin was squeezed through the roving of the fabric and the above process was repeated. Initially three number of controlled beams were tested up to first crack and strengthened with GFRP double layer U wrapping then again tested up to failure. Retrofitted under reinforced and over reinforced beams are tested later on.

Fig 3 Applying Resin and GFRP

C. Test Procedure

All beams were tested under two point load. Each beam was placed on the loading frame in such way that, the centre of the beam and the centre of the loading frame were adjusted and aligned as a line. The effective span of the beam was 1200mm; the load was distributed uniformly by means of mild steel roller placed on the beam along the effective span of the beam, above the roller mild steel I-section was placed for the distribution of load equally on the rollers. A single hydraulic jack was used to apply load. The load was distributed to the beam through the I-section which resulted in two point loads being applied to the specimen. Two dial gauges were used to measure deflection. Deflection under the load and at the mid-span and were noted and strains were measured using demec gauge.

Dial gauge readings were taken for every 250 kg and demec gauge reading were taken for every 500 kg increment of the load. The cracks patterns were observed and marked by using marker; the initial crack load and maximum load (ultimate failure) were noted down. After failure the load was released slowly and the beam comes to normal position for some extent. The photographs of each specimen were taken and presented in the fig 5(a) and fig 5(b). Also the complete crack patterns and the failure load were recorded in each test. Stress strain curves are also presented in this experiment.

Figure 4 Test set up (Loading Frame)

Fig 5(a) Crack pattern for control beam

Fig 5(b) Crack pattern for retrofitted beam

III. RESULTS AND DISCUSSIONS

The test results of experiments conducted on nine RC beam specimens with and without GFRP wrapping has been presented. In that three beams were balanced RC beam specimens, three were under reinforced concrete beams, and three were over reinforced concrete beams. Under reinforced concrete beams and over reinforced concrete beams were retrofitted using double layer U-shape full wrapping of GFRP composites. And balanced control beams were also retrofitted after the testing till first crack. Mid span deflection and deflection under the load are taken into consideration in this work and the same has been presented. Stress strain curves are also presented in this experiment. The load-deflection curve of the structures is generally drawn up to the cracking load. The final failure gives an indication of the overall strength of structures.

A. Summary Of The Experimental Results

Table 5 Increase in strength at First Crack for all beams

Beam Type	Load at First Crack	Average Load at First Crack (KN)	% increase in strength
CB1	29.53	31.2	-
CB2	31.98		
CB3	31.98		
WCB1	46.71	40.56	30 %
WCB2	36.89		
WCB3	38.11		
WUB1	51.6	46.70	49.67 %
WUB2	34.43		
WUB3	52.83		
WOB1	55.28	60.18	92.88 %
WOB2	65.1		
WOB3	57.53		

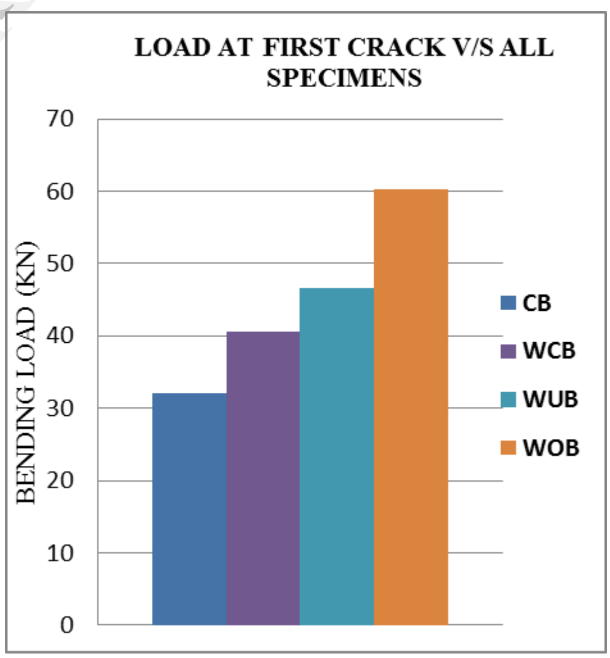

Fig 6 Comparison of Load at First Crack for All Beams

Load carrying capacity of controlled beams at first crack is 31.2 KN, after retrofitted with GFRP, it shows great improvement in strength. The improvement in strength of retrofitted balanced beam is about 30%, in retrofitted under reinforced beam is about 49.67%, in over reinforced beam is about 92% compared to control beam at the first crack as shown in Table 5. The increase in strength of retrofitted under reinforced and over reinforced beam is about 12.5% and 35.42% respectively compared to controlled beam at failure as shown in Table 6.

Table 6 Increase in strength at Failure for all retrofitted beams

Beam Type	Ultimate Load at Failure (KN)	Average Ultimate Load at Failure (KN)	% increase in strength	Mode of failure
WCB1	51			
WCB2	46	48		
WCB3	47			
WUB1	55			
WUB2	44	54	12.5%	All beams were failed in flexure
WUB3	60			
WOB1	59			
WOB2	71	65	35.42%	
WOB3	65			

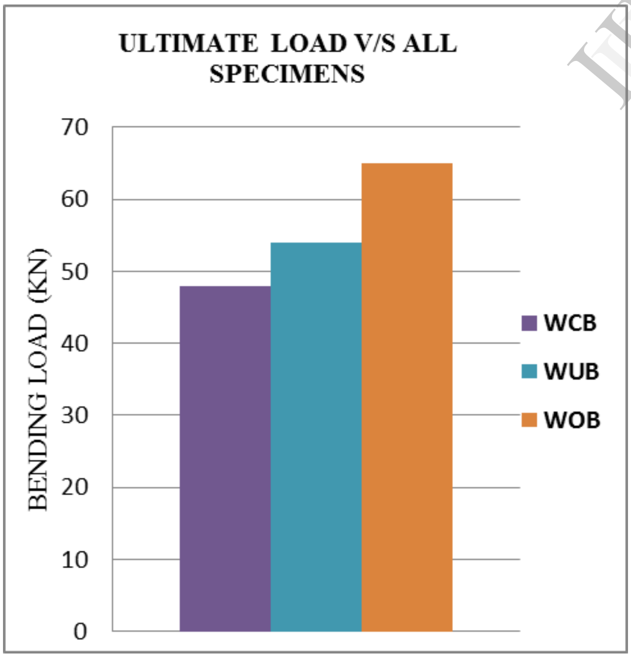

Fig 7 Comparison of Ultimate Load for All Retrofitted Beams

Nomenclature

CB- controlled beam

WCB- wrapped control beams (balanced)

WUB- wrapped under reinforced beam

WOB- wrapped over reinforced beam

Based on test results obtained ultimate strength, deflection, stress and strain of the all the beams has been calculated and is compared. From the experimental results, the loads v/s deflection curves are plotted including the bar charts shown in fig 6 and fig 7.

B. LOAD v/s DEFLECTION

Load v/s deflection curve means a curve in which the increasing flexural loads are plotted on the ordinate axis and the deflections caused by those loads are plotted on the abscissa axis. Up to the service load, the deformation plays an important role while studying the behavior of structures. The load-deflection of the structures is generally drawn up to the cracking load. The final failure gives an indication of the overall strength of structures.

Mid span deflection and deflection under the load are taken into consideration in this work and the same has been presented. Central deflection of all the beams was more than deflection under load. First crack for CB was observed at 31.2KN and corresponding deflections were 7.6mm (centre) and 6.1mm (under load).

The load – deflection behavior was plotted for all the beams and presented in fig8, fig9, fig10 and fig11.

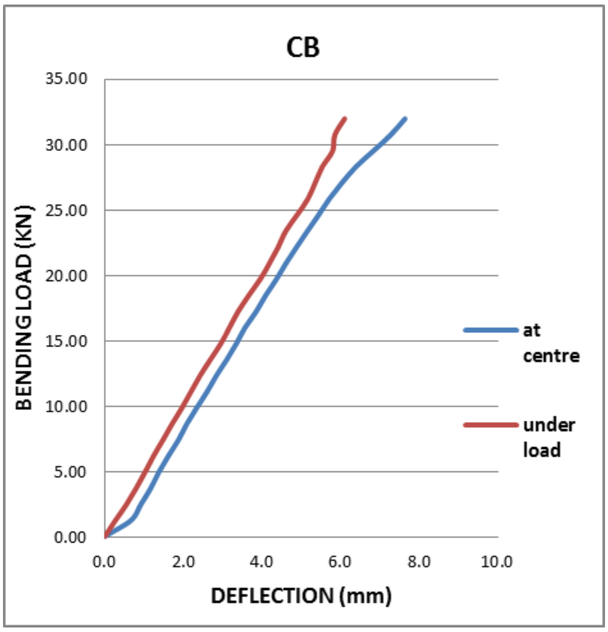

Fig 8 Load v/s deflection curves for CB

Ultimate load carrying capacity of WCB was 48 KN and maximum deflections were 8.72mm (centre) and 8.25mm (under load).

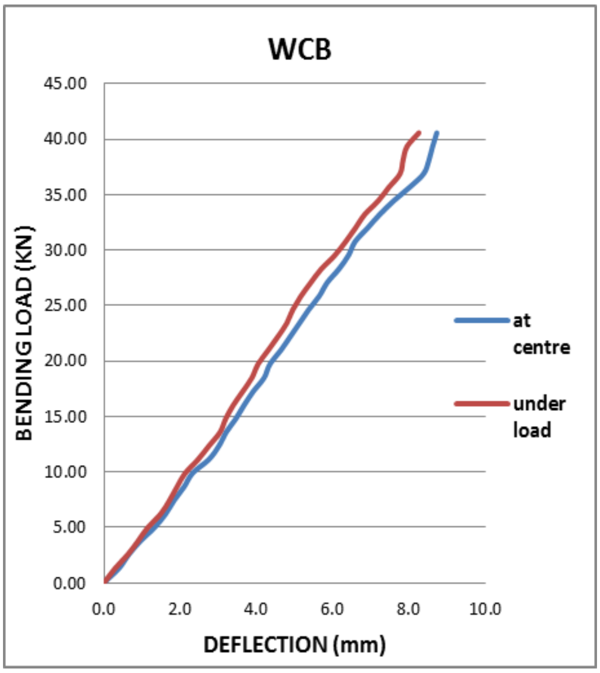

Fig 9 Load v/s deflection curves for average WCB

Ultimate load carrying capacity of average WUB was 54KN. and maximum deflections were 12.44mm (centre) and 11.1mm (under load).

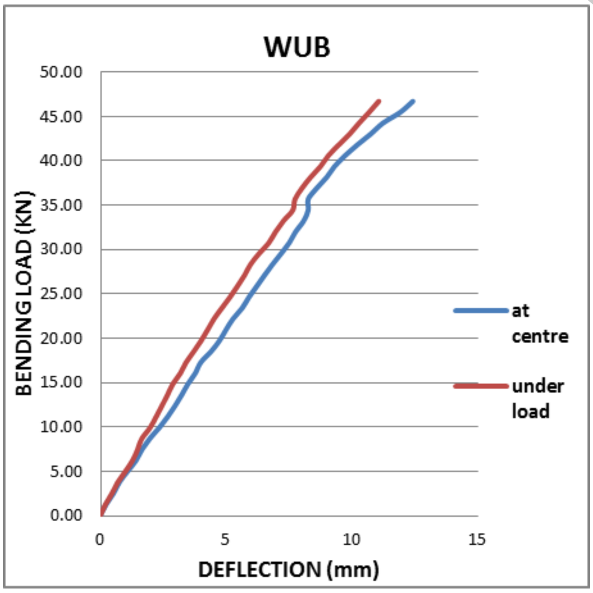

Fig 10 Load v/s deflection curves for average WUB

Ultimate load carrying capacity of average WOB was 65KN. And maximum deflections were 10.87mm (centre) and 10.29mm (under load).

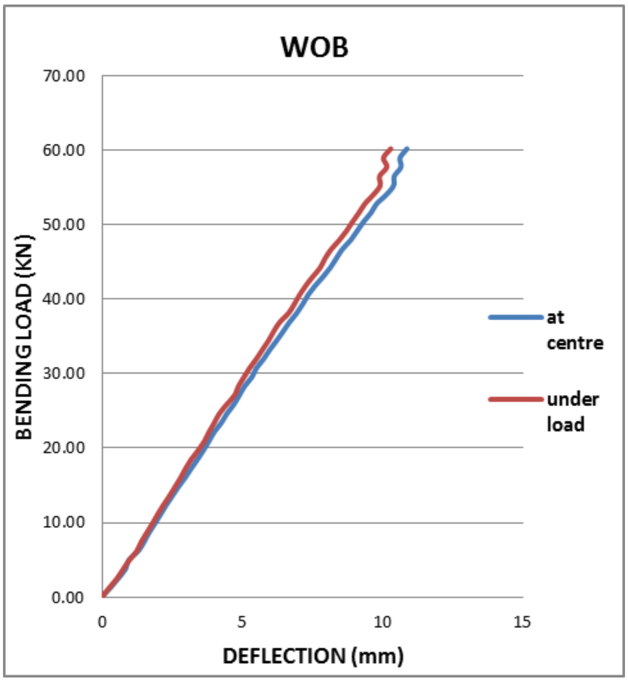

Fig 11 Load v/s deflection curves for average WOB

Fig 12 A typical failure pattern of retrofitted RC beam

For all the beams load v/s deflection behavior was linear and deflection at the centre was more than deflection under load. There is a small variation in load deflection curve for WCB shown in fig.9 from 35KN to 40KN and same happened in WOB shown in fig.12 there is a small variation from load 55KN to 60KN.

- Deflection at the centre is more than deflection under the load for all beams.
- The maximum deflection was observed in retrofitted under reinforced beam (WUB) 12.44 mm at centre and 11.1 mm under load for the load of 46.70KN.

Combine plot shows the comparison in load v/s deflection behavior of all the beams.

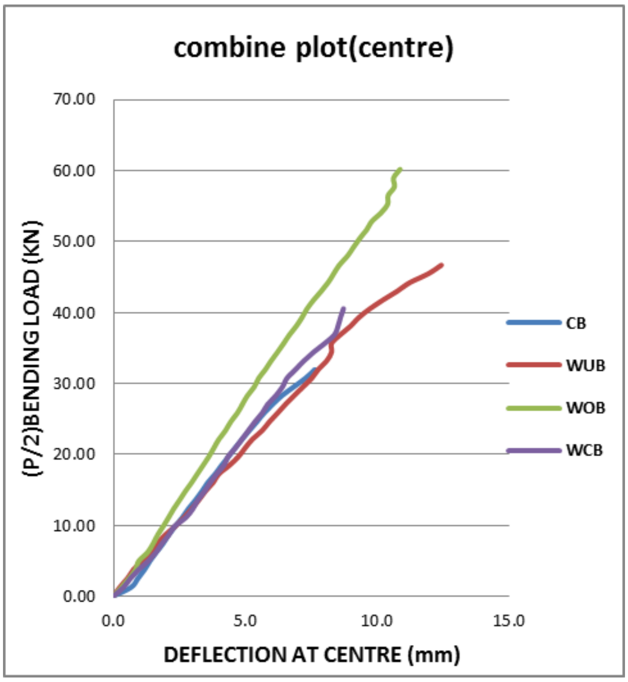

Fig 13 comparison of load v/s deflection at centre for all beams

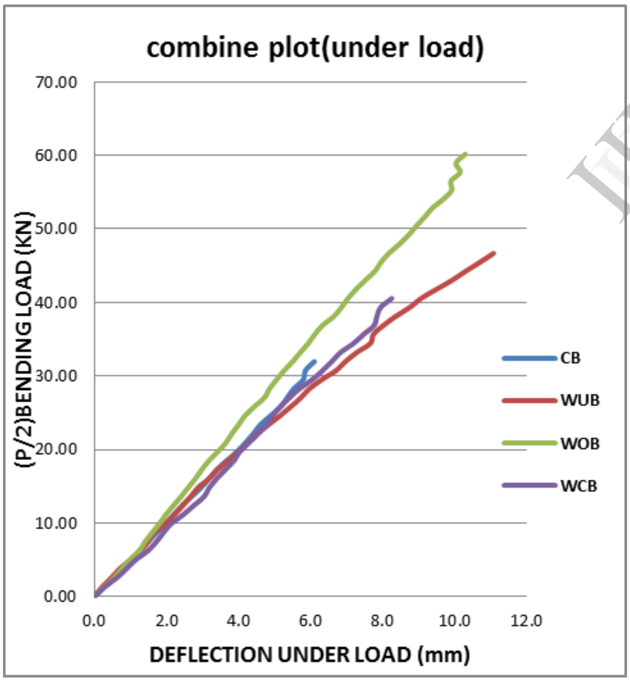

Fig 14 comparison of load v/s deflection under load for all beams

C. STRESS AND STRAIN BEHAVIOR

Strain is measured for all the beams in such a way that two points above the neutral axis (compression side) and two points below the neutral axis (tension side).

Fig 15 measuring strain with demec gauge

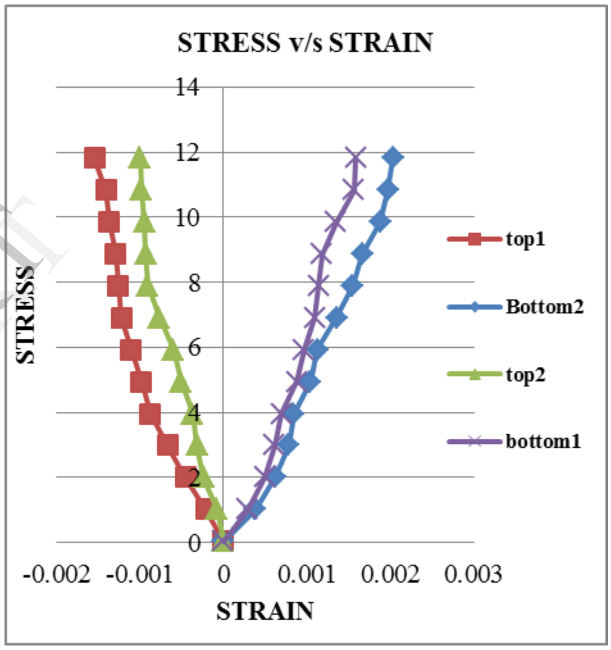

Fig 16 Stress v/s strain curve for CB

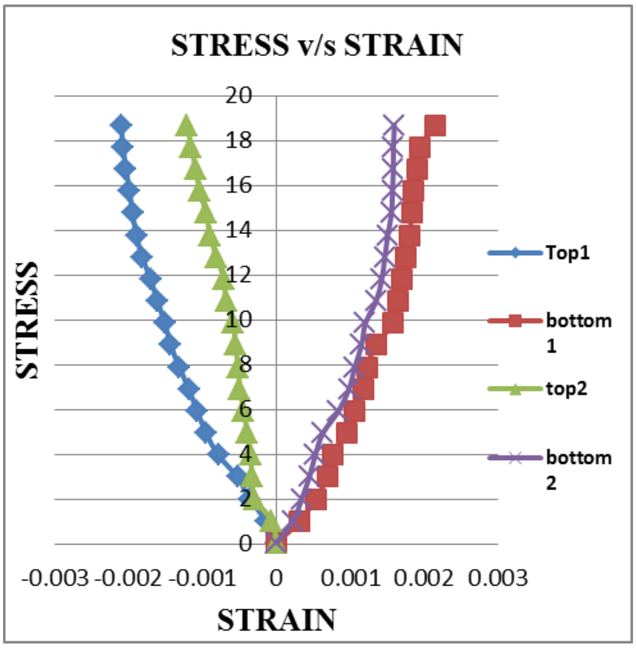

Fig 17 Stress v/s strain curve for WCB

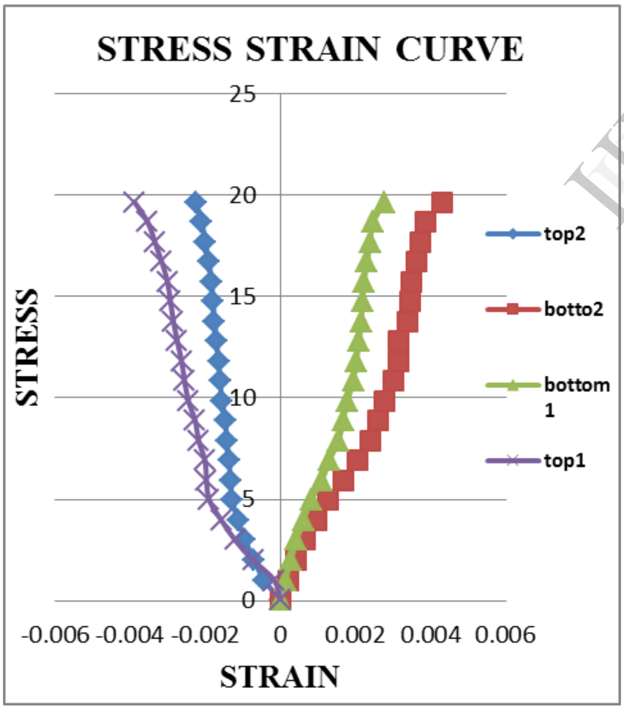

Fig 18 Stress v/s strain curve for WUB

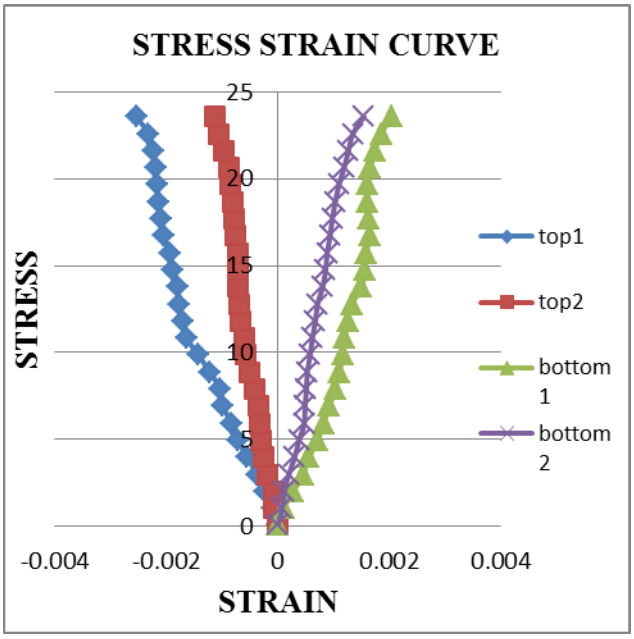

Fig 19Stress v/s strain curve for WOB

The graphs shown in fig16, fig17, fig18 and fig19 represent the stress strain variation of the specimens tested. The strain calculated by measuring the elongation over standard length on the surface at the centre of the beam. This measurement is taken by demec gauge. The beam will yield under service loads if the tensile stress in the concrete exceeds the bending strength of concrete. After formation of cracks, the steel carries the tensile force needed to support the applied load. The cracked beam can continue to support increasing loads until the ultimate capacity is attained due to compression failure of the concrete. The term stress is often defined in two terms force per unit area or the total internal force within a single member. The mechanical properties of concrete such as its stress-strain curve, depend on a number of factors like rate of loading (Creep),type of aggregate, strength of concrete, age of concrete, curing conditions etc.

Strengthening technique proved to be efficient in improving the load carrying and deformation resistant capabilities. Experimental investigations reveals that the balanced RC beams and over reinforced concrete beams retrofitted with GFRP exhibits more strength than the than under reinforced concrete beams retrofitted with GFRP.

IV. CONCLUSION

From the test results obtained from the experimental work, control RC beams and retrofitted RC beams are compared and the following summary and conclusions are obtained.

1. The load carrying capacity of controlled beam at first crack was 31.2 KN and after retrofitted with two layers of GFRP, the improvement of strength was 30 %.

2. The improvement in load carrying capacity of strengthened under reinforced beam at first crack was 49.67% compared to controlled beams.

3. The improvement in load carrying capacity of strengthened over reinforced beam at first crack was 92.88% compared to controlled beams.

4. The improvement in ultimate load carrying capacity of strengthened under reinforced beam was 12.5% compared to retrofitted balanced beam and almost equal to the ultimate load carrying capacity of controlled beams.

5. The improvement in ultimate load carrying capacity of strengthened over reinforced beam was 35.42% and 20.6% compared to retrofitted balanced beam and controlled beams respectively.

6. Instead of demolishing and reconstruction of the structures, it is economical to rehabilitate the structural element using GFRP.

7. The ultimate load carrying capacity of all the strengthened beams is higher when compared to the control beams.

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