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# Comparing the repair techniques of retrofitting for R.C.C. members using different GFRP wraps

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## ABSTRACT

***Concrete structures deteriorate with time, a process that becomes much faster in aggressive environmental conditions. Broadly, methods to repair them can be classified under structural repair and nonstructural repair. Structural repair is carried out by repair, renovation and retrofitting of the entire system as a whole for structural strengthening to carry additional loads or for retrofitting. In the present work, attempt is made to study and compare the effects of Glass fiber reinforced polymer (GFRP) wraps on the behavior of reinforced concrete (RC) beams through experimental investigations. The experimental study consists of casting of four sets of reinforced concrete (RC) beams having cross-sectional dimensions of 150mm x 200mm and 1000mm length and of grade M30. , Total 48 no. of RC beam are cast and curing for 28 days. First set of (3 no.) RC beams designated as control RC beams (SET I). Second set of (9 no.) RC beams (SET II); all are strengthened using single GFRP mat wrap, (for three beam both side wrap, three beam bottom wrap and three beam (U) shape wrap), Third set of (9 no.) RC beams (SET III); all are strengthened using Double GFRP mat wrap, (for three beam both side wrap, three beam bottom wrap and three beam (U) shape wrap). Fourth set of (9 no.) RC beams (SET IV) are strengthened using Woven Roving GFRP mat wrap, (for three beam both side wrap, three beam bottom wrap and three beam (U) shape wrap).***

**Keywords***: GFRP, resins, repair, retrofitting*

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## 1. INTRODUCTION

There are considerable numbers of existing concrete structures in India that do not meet current design standards because of inadequate design and construction or need structural up gradation to meet new seismic design requirements because of new design standards, deterioration due to corrosion in the steel caused by exposure to an aggressive environment and accident events such as earthquakes [1,2,3]. Inadequate performance of this type of structures is a major concern from public safety standpoint. That is why reinforced concrete structures often have to face modification and improvement of their performance during their service life. In such circumstances there are two possible solutions: replacement or retrofitting [4,5]. Full structural replacement might have determinate disadvantages such as high costs for material and labour, a stronger environmental impact and inconvenience due to interruption of the function of the structure. When possible, it is often better to repair or upgrade the structure by retrofitting [6,7].

Retrofitting have become the increasingly dominant use of the material in civil engineering, and applications include increasing the load capacity of old structures that were designed to tolerate for lower service loads than they are experiencing today, seismic retrofitting, and repair of damaged structures [6,8]. Concrete structures deteriorate with time, a process that becomes much faster in aggressive environmental conditions [7]. Broadly, methods to repair them can be classified under structural repair and non-structural repair. Structural repair is carried out by repair, renovation and retrofitting of the entire system as a whole for structural strengthening to carry additional loads or for retrofitting [8,9].

Glass Fibers are produced from wild range of glass types, E, S, R glass, which differ only in the proportioning of their contents. Such glass fibers are weak in alkali resistance. To overcome this problem, surface coating of glass fiber is used to reduce alkali effect and increase wearing resistance of fibers. Such glass fibers are known as alkali-resistance glass fiber. Alkali resistant glass fibers give good results when reinforced with alkaline environment of concrete. Nowadays Alkali-resistance glass fibers are used in FRC [9,10]. The recent developments in the application of the advanced composites in the construction industry for concrete rehabilitation and strengthening are increasing on the basis of specific requirements, national needs and industry participation. The need for efficient rehabilitation and strengthening techniques of existing concrete structures has resulted in research and development of composite strengthening systems [11].

## 2. MATERIALS

### 2.1 Fiber reinforced polymer

Fiber reinforced polymer (FRP) is a composite material made by combining two or more materials to give a new combination of properties. However, FRP is different from other composites in that its constituent materials are different at the molecular level and are mechanically separable. The mechanical and physical properties of FRP are controlled by its constituent properties and by structural configurations at micro level. Therefore, the material properties which are dependent on the manufacturing process and the properties of constituent materials. FRP composite is a two phased material, hence its anisotropic properties. It is composed of fiber and matrix, which are bonded at interface. Each of these different phases has to perform its required function based on mechanical properties, so that the composite system performs satisfactorily as a whole. In this case, the reinforcing fiber provides FRP composite with strength and stiffness, while the matrix gives rigidity and environmental protection.

### 2.2 Reinforcement materials

A great majority of materials are stronger ad stiffer in fibrous form than as bulk materials. A high fiber aspect ratio (length: diameter ratio) permits very effective transfer of load via matrix materials to the fibers, thus taking advantage of their excellent properties. Therefore, fibers are very effective and attractive reinforcement materials.

### 2.3 Fiber

A fiber is a material made into a long filament. The aspect ratio of length and diameter can be ranging from thousand to infinity continuous fibers. The main functions of the fibers are to carry the load and provide stiffness, strength, thermal stability, and other structural properties in the FRP.

### 2.4 Glass fibers

Glass fibers are used in a multitude of FRP products for structural engineering, from FRP reinforcing bars for concrete, to FRP strengthening fabrics, to FRP structural profile shapes. Glass is an amorphous inorganic compound of primarily metallic oxides that is produced in fibrous form in a number of standard formulations or types. Silica dioxide (SiO) is the largest single compound in all glass formulations, constituting from 50 to 70% by weight of the glass. Different grades of glass fiber are identified by letter nomenclature.

**Table 1 Typical composition of fiberglass (% in weight)**

| Composition of fiberglass | E-glass | S-glass |
|---|---|---|
| Silicon oxide | 54.3 | 64.20 |
| Aluminum oxide | 15.2 | 24.80 |
| Iron oxide | - | 0.21 |
| Calcium oxide | 17.2 | 0.01 |
| Magnesium oxide | 4.7 | 10.27 |
| Sodium oxide | 0.6 | 0.27 |
| Boron oxide | 8.0 | 0.01 |
| Barium oxide | - | 0.20 |

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**Table 2 Properties of common grades of glass fibers**

| Grades of Glass Fiber | Density [ g/cm$^3$] | Tensile Modulus [GPa] | Tensile Strength [MPa ] | Max Elongation (%) |
|---|---|---|---|---|
| E | 2.57 | 72.5 | 3400 | 2.5 |
| A | 2.46 | 73 | 2760 | 2.5 |
| C | 2.46 | 74 | 2350 | 2.5 |
| S | 2.47 | 88 | 4600 | 3.0 |

### 2.5 Polymer resins

The term polymer is used to describe an array of extremely large molecules, called macromolecules that consist of repeating units or chains, in which the atoms are held together by covalent bonds. The term polymer generally is used to describe an organic material of this type; however, it can also be used to describe an inorganic material. The term polymer resin, or simply resin, is used in the composites industry to refer to the primary polymer ingredient in the non fibrous part of the FRP material that binds the fibers together. This non fibrous part is also known as the matrix or binder. When used in commercial and industrial products a polymer-based material is often known as a plastic and the acronym FRP is also often used to denote a fiber-reinforced plastic. The acronym RP is often used to connect a reinforced plastic, although this is mostly used to describe short-fiber reinforced plastic products of lower strength and stiffness. The different types of resins mentioned below were used, they are unsaturated polyester resin, epoxy resins, vinyl ester resins, phenolic resins and polyurethane resins.

## 3. METHODOLOGY

### 3.1 Experimental Work

The experimental work consists of casting of four sets of reinforced concrete (RC) beams having grade M30, cross-sectional dimensions of 150mm x 200mm and 1000mm length. 2-12mm Ø bottom reinforcement and 2-8mm Ø top with 6mm Ø vertical stirrups @ 160mm c/c were provided. The strengthening of the beams using GFRP sheet is done with three different configurations namely both side wrap, bottom wrap & U wrap. The experimental study consists of casting of four sets of reinforced concrete (RC) beams of grade M30, Total 30 no. of RC beam are cast and curing for 28 days. First set of (3 no.) RC beams designated as control RC beams (SET I). Second set of (9 no.) RC beams (SET II); all are strengthened using single GFRP mat wrap, (for three beam both side wrap, three beam bottom wrap and three beam (U) shape wrap), Third set of (9 no.) RC beams (SET III); all are strengthened using Double GFRP mat wrap, (for three beam both side wrap, three beam bottom wrap and three beam (U) shape wrap). Fourth set of (9 no.) RC beams (SET IV) are strengthened using Woven Roving GFRP mat wrap, (for three beam both side wrap, three beam bottom wrap and three beam (U) shape wrap). Four sets of beams as mentioned are identical. Reinforcement detail of beam and section is shown in fig. no. 1

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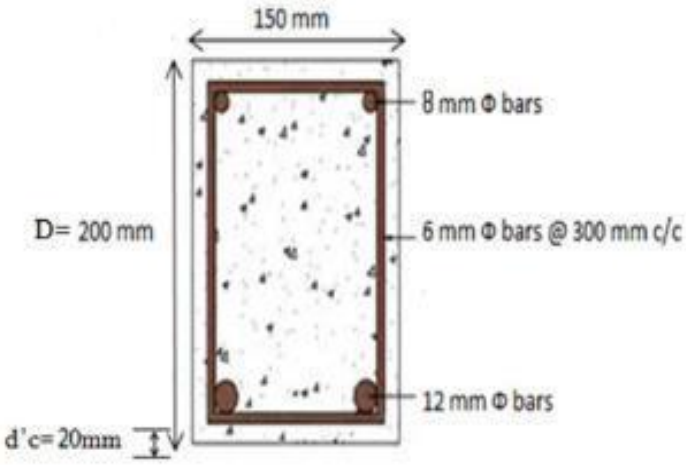


**Fig. 1 Reinforcement detail of beam**

### 3.2 Experimental Setup

All the specimens are tested in Universal testing machine (UTM) and the deflection will be check by using (LVDT) machine. The testing procedures for the all specimens are same. After the curing period of 28 days is over, control beams (SET I) are washed and its surface is cleaned for clear visibility of cracks. Where other sets of beams (SET II, SET III, SET IV) are strengthened by GFRP. The load arrangements for testing of all sets of beam is consist of two-point loading.

## 4. OBSERVATION

The two-point static loading is applied on the beams and at the each increment of the load (1KN/sec). Deflections at the middle in beams are noted down and load vs. deflection curve of all the sets of beams is plotted. The Load-deflection of each strengthened beam is compared with that of their respective control beams. Results obtained from experimental data are shown in table no. 3 (Average of 3 beams).

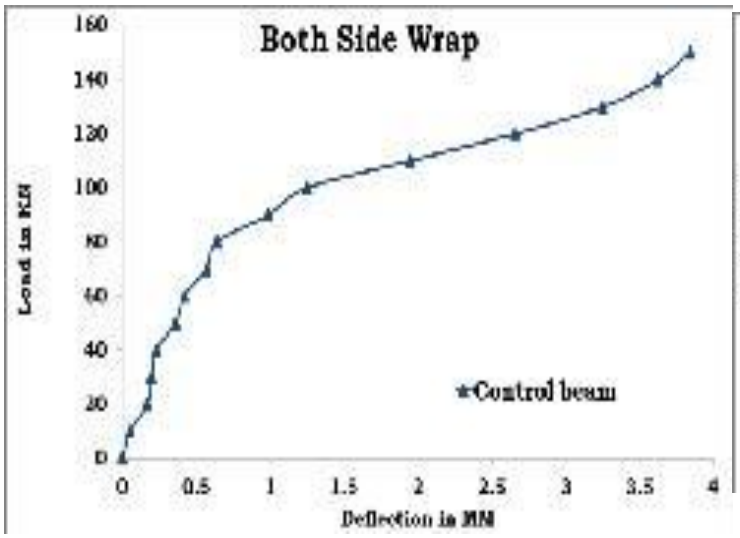


**Fig.2 Load vs deflection for control beam**

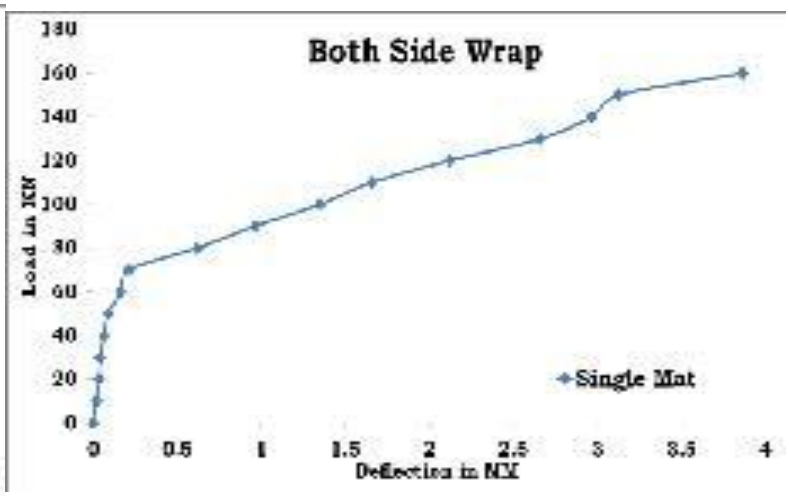


**Fig. 3 Set of Both side single mat wrap beam**

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**Table 3 Experimental results of static loading**

| Load (KN) | Control Beam | Both Side | | |
|---|---|---|---|---|
| | | Single Mat | Double Mat | Woven Roving |
| 0 | 0 | 0 | 0 | 0 |
| 10 | 0.053 | 0.0186 | 0.015 | 0.012 |
| 20 | 0.167 | 0.035 | 0.0215 | 0.0268 |
| 30 | 0.197 | 0.042 | 0.0385 | 0.0357 |
| 40 | 0.23 | 0.065 | 0.065 | 0.0521 |
| 50 | 0.36 | 0.0925 | 0.09 | 0.0725 |
| 60 | 0.42 | 0.165 | 0.124 | 0.125 |
| 70 | 0.57 | 0.215 | 0.218 | 0.195 |
| 80 | 0.64 | 0.618 | 0.295 | 0.235 |
| 90 | 0.987 | 0.965 | 0.524 | 0.438 |
| 100 | 1.25 | 1.35 | 1.025 | 0.625 |
| 110 | 1.948 | 1.658 | 1.648 | 1.025 |
| 120 | 2.657 | 2.125 | 1.962 | 1.352 |
| 130 | 3.254 | 2.658 | 2.215 | 1.762 |
| 140 | 3.625 | 2.965 | 2.655 | 2.015 |
| 150 | 3.842 | 3.125 | 3.015 | 2.425 |
| 160 | | 3.865 | 3.265 | 2.855 |
| 170 | | | 3.665 | 3.124 |
| 180 | | | | 3.315 |

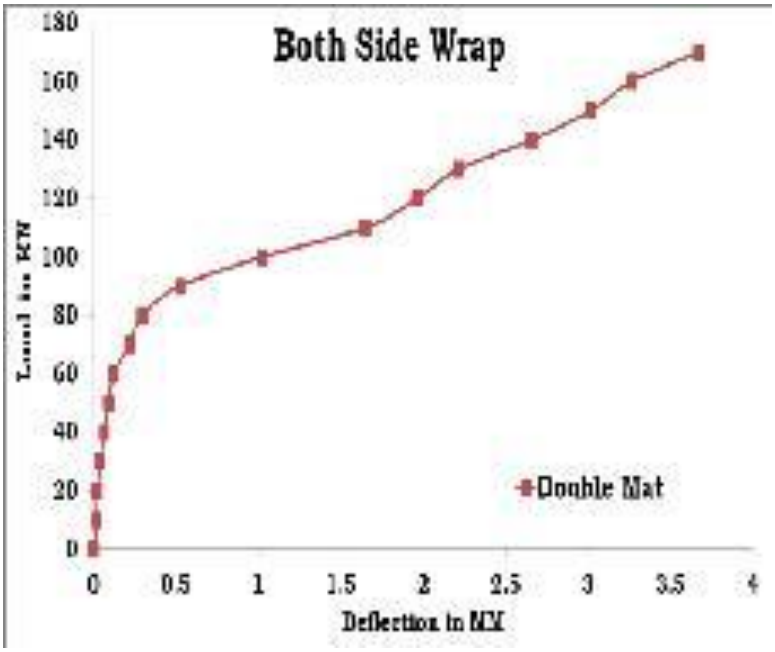


**Fig. 4 Set of Both side double mat wrap beam.**

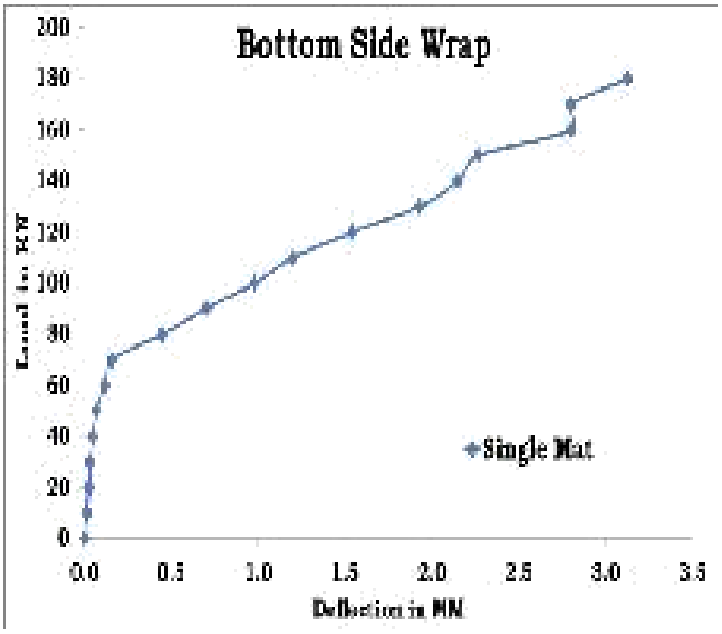


**Fig. 5 Set of Bottom side Single mat wrap beam**

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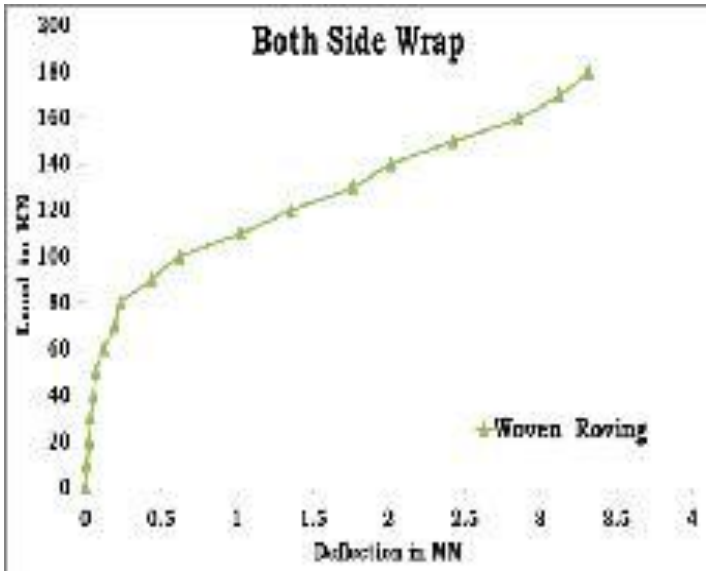


**Fig. 6 Set of Both side woven roving wrap beam.**

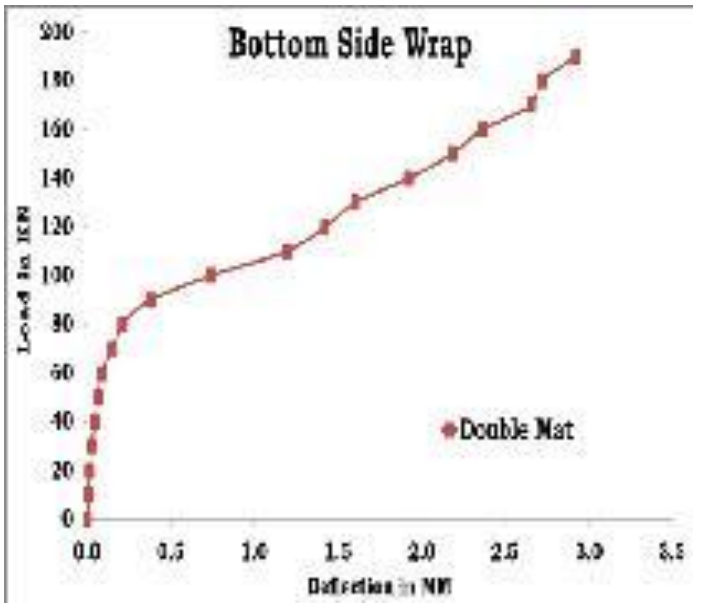


**Fig. 7 Set of Bottom side double mat wrap beam**

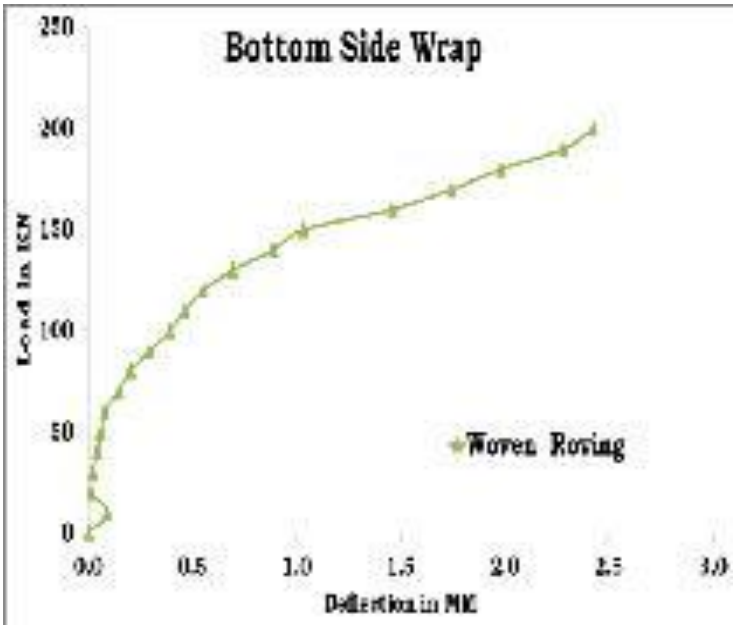


**Fig. 8 Set of Bottom side woven roving mat wrap beam**

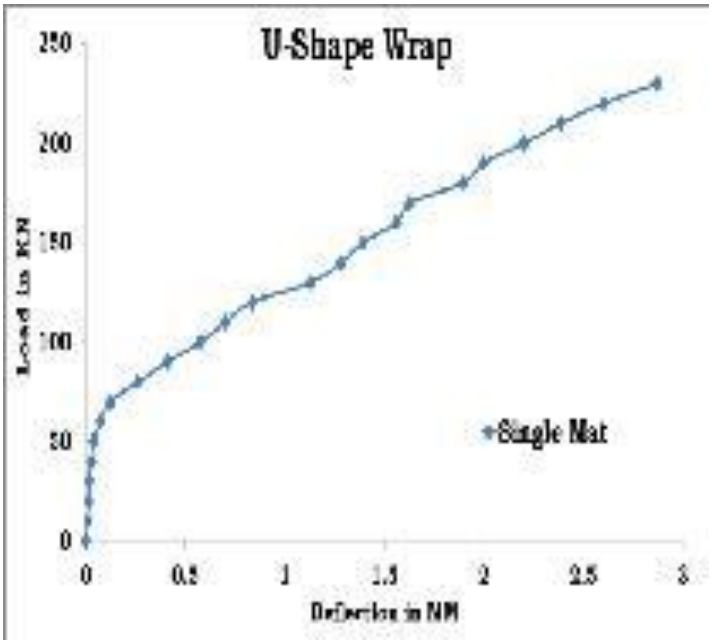


**Fig. 9 Set of U-Shape Single mat wrap beam**

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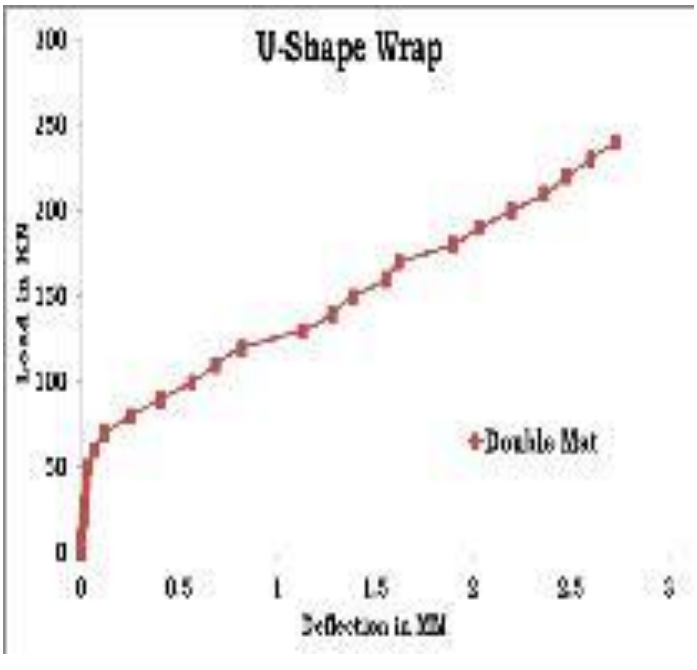


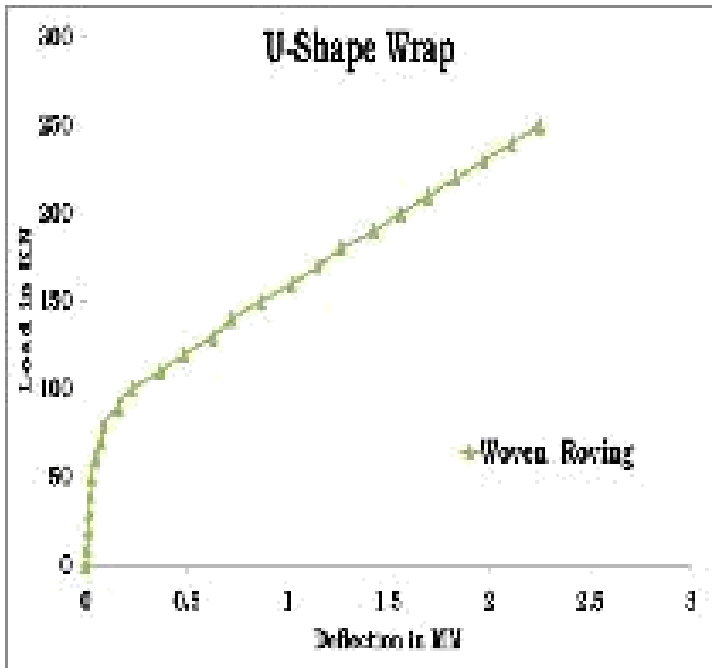


**Fig. 10 Set of U-Shape double mat wrap beam**

**Fig. 11 Set of U-Shape woven roving mat wrap beam**

### 4.1 Failure Mode

Failure modes have been observed in the experiments of RC beams strengthened by GFRP. The GFRP strengthened beams and the control beams are tested to find out their ultimate load carrying capacity. It is found that the control beams (SET I) failed in shear. In control beams (SET I) the shear cracks started at the supports. As the load increased, the crack started to widen and propagated towards the location of loading. The cracking patterns show that the angle of inclined crack with the horizontal axis is about 45°. And strengthened beam are also found that shear cracks appeared when loaded up to ultimate load.

## 5. CONCLUSION & DISCUSSION

- The maintenance, rehabilitation and upgrading of RC structural members, is perhaps one of the most crucial problems in civil engineering applications. Moreover, a large number of structures constructed in the past using the older design codes in different parts of the world are structurally deficient according to the new design codes.
- Since replacement of such deficient elements of structures incurs a huge amount of money and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives.
- The experimental work was carried by Hand layup method, for that GFRP sheet was used, like E Class Glass continuous filament mat and woven roving mat. The unsaturated polyester resin with cobalt accelerator and Hardener was used for wrap.
- GFRP is provided to increase the strength and stiffness of existing concrete beams when bonded to both side, bottom side and U-Shape by using single mat, double mat and woven roving wrap as compare to control beam, however the mode of failure associates with application of GFRP was more ductile and preceded by warning signs such as snapping sounds or peeling of the GFRP.
- The results of this study show that GFRP can be used to increase the strength and stiffness of beams without causing catastrophic brittle failure associated with this strengthening technique.

- Cost of woven roving wrap was more as compare to single mat and double mat wrap but load carrying capacity also increases as compared to single mat and double mat wrap.
- It was indicated that woven roving U shape wrap is more beneficial and preferable for retrofitting.
- Retrofitting is always affordable to strengthen the structure than replacement. It avoids excess time required for replacement and reduces cost of material and labour.

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