Rehabilitation of Reinforced Concrete beams by using Micro-cement and Glass Fiber Reinforced Polymer (GFRP)

Sankalp. R[1], Dr. B. Shivakumara Swamy[2], Dr. S. Vijaya[3]

[1]M.Tech Student, Department of Civil Engineering, Dr. Ambedkar Institute of Technology, Bengaluru, Karnataka, India
[2]Professor and Head, Department of Civil Engineering, Dr. Ambedkar Institute of Technology, Bengaluru, Karnataka, India
[3]Professor, Department of Civil Engineering, Dr. Ambedkar Institute of Technology, Bengaluru, Karnataka, India

---

Abstract - *The rehabilitation, maintenance and upgrading of structural members, is one of the burning problems in the applications of Civil Engineering. In this current experimental work, an attempt has been made to rehabilitate the reinforced concrete beams using micro-cement and GFRP fabric. Five under-reinforced concrete beams were cast and were tested under two point loading, out of which one was control beam and the remaining beams were grouped into two i.e. Group A and Group B. Group A and B consists of two beams each which were damaged by pre-loading it for 80% of the ultimate load of control beam and were rehabilitated by injecting micro-cement and surface hair-line cracks were repaired by filling it with a paste made by micro-cement and epoxy resin. The group A beams was externally U-wrapped by single layer GFRP fabric and group B beams by two layers GFRP fabric respectively using epoxy-resin and hardener.*

The group A and group B beams were again tested under two point loading and the experimental results were found more effective in ultimate load bearing capacity/flexural capacity of strengthened beams and it is seen that further growth of repaired cracks are arrested by injecting micro-cement..

Key Words: Rehabilitation, GFRP, Micro-cement, epoxy-resin, Load bearing capacity.

1. INTRODUCTION

Civil engineering is a vast field and has different structures like residential, commercial and industrial buildings. Concrete is the most versatile construction material, which is used in all types of Civil Engineering structures. Because of the concrete's flexibility in giving desired shape, economy and other features, has made it one of the most suitable building material. Rehabilitation of the damaged structures which are already existing, have emerged as the most important construction activities globally. The replacement of deficient structural elements requires an enormous amount of money and time, so rehabilitation has become an important aspect in improving the load bearing capacity and increasing service life of structures. It is very essential to diagnose the nature and extent of damage and also the deterioration caused in structure because a wrong diagnosis will lead to improper choice of materials and repair technique leading to the failure again.

Fiber Reinforced Polymer is a composite material that is efficiently used for the purpose of rehabilitation and retrofitting of the structures. FRP is a composite material which is made of polymer reinforced matrix along with fibers such as carbon, basalt, glass, aramid etc. having very high strength and they act as single material when combined with two or more composite materials having their respective physical and chemical properties. Mechanical properties like high strength to weight ratio, impact resistance, stiffness and flexibility are superior in FRP composites.

Micro-cement is popularly known as ultrafine cement. It is a cementitious coating that is applied on the existing material to fix the flaws and fissures produced over a period of time and even by external aggressions. Micro-cement is modified with high strength and durable polymers which becomes a fine, smooth cement and very tough.

1.1 OBJECTIVES

The main objective of this current study is

1. To investigate the structural behaviour of RC beams under two point loading.
2. To evaluate the effectiveness in injecting of Micro-cement (Supermicrocem GP) into the cracks and GFRP wrapping in rehabilitation of damaged RC beams.
3. To study the ultimate load bearing capacity and failure pattern in the rehabilitated RC beam.
4. To evaluate flexural and shear strength of strengthened RC beams.

1.2 METHODOLOGY

The following methodology are adopted in this current study

1. For the study, a total of five RC beams were casted and cured for 28 days. Among the beams casted,

one is control beam and remaining four were grouped into two beams each (Group A and Group B).

2. Under two point loading, the control beam was tested for ultimate failure load and remaining four beams were loaded for 80% of the ultimate failure load.
3. The damaged beams were then rehabilitated by filling the cracks by injection of micro-cement and single layer wrapping of GFRP for Group A and two layers for Group B respectively.
4. The rehabilitated beams were tested for ultimate failure load and the results are compared with control beam and the effectiveness of the rehabilitation is determined.

2. MATERIALS and EXPERIMENTAL WORK

2.1 Materials

The overview of the materials and its properties that are used in the current experimental work is discussed.

Cement of 53 grade Portland cement was used in this current experimental study. The specific gravity was 3.15, and normal consistency was 32%.

River sand confining under Zone II as per IS 383:1970 was used in this current experimental study. The specific gravity was 2.67 and bulk density 1525 Kg/m^3.

Coarse aggregate size of 20mm and downsize conforming to IS 383:1970 were used in this current experimental study. The specific gravity was 2.7, bulk density in loose state 1394 Kg/m^3 and was well graded and single size.

The water that is potable or fit for drinking is used for making concrete. Normal tap water was used in this current experimental work and even used for curing.

Supermicrocem GP (Talrak Construction Chemicals Pvt. Ltd.) **i**s the micro-cement used in this experimental work. It has very high mechanical stability, with no shrinkage and bleeding. It does not contain expansive metallic components. This product is recommended for PSC ducts, sealing of cracks in concrete structures, walls and also helps to strengthen the damaged structures internally. It has a maximum compressive strength of 65MPa and average flexural strength of 4.5MPa after 28 days of curing (as per the manufacturer).

GFRP is a high strength material and has Ultimate strength ranging 480-1600 MPa and elastic modulus of 35-51 GPa. At failure it has got lower strain ranging 2-4.5% (as per the manufacturer). Bi-directional GFRP of 360gsm was used in this current experimental work. Fig -1 shows the bi-directional GFRP fabric.

Fig -1: bi-directional GFRP fabric

Epoxy resin is a reactive polymer containing epoxide group. Hardeners are the reactants with which the epoxy resins are reacted. Lapox L-12 is the epoxy resin and hardener K-6 were the products used. Fig -2 shows the epoxy resin and hardener.

Fig -2: Epoxy resin and hardener

2.1.1 Reinforcement

As per IS 456:2000, under reinforced beams were designed. It has Tension reinforcement of 2-12T and 2-12T as compression reinforcement. Two legged 8mm dia. Stirrups at 125mm C/C as shear reinforcement. Fig -3 and Fig -4 shows the beam reinforcement detailing and reinforcement skeleton.

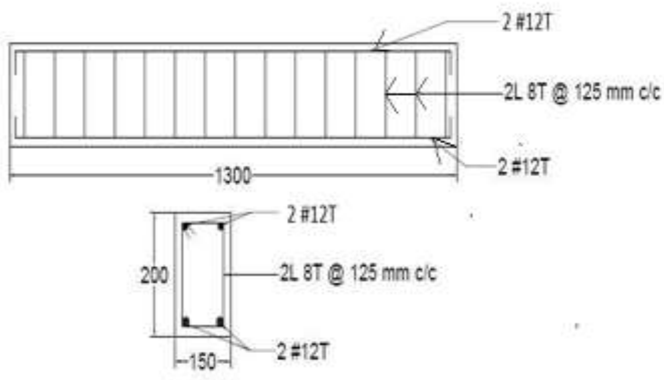

Fig -3: Beam reinforcement details

Fig -4: Reinforcement skeleton

2.1.2 Concrete

Mix design was done according to IS 10262:2009. M25 grade of concrete was designed and used in this current experimental study. The mix proportion is 1: 1.58: 2.58 (cement: fine aggregate: coarse aggregate) and water cement ratio is 0.45. The average compressive strength after 28 days is 28.88 MPa. Fig -5 shows the cube testing in compression testing machine.

Fig -5: Compression testing machine

2.2 Experimental Work

The experimental work which was carried out is discussed briefly and it includes casting of beams, experimental setup and testing procedure.

The formwork used was of bolted type. The formwork of size 150 x 200 x 1300 mm, which was available in the laboratory was used. After keeping the cover blocks of 25mm, the reinforcement skeleton was placed inside the formwork.

A uniform concrete mix was made by mixing all the ingredients in the concrete mixer. After a uniform concrete mix is made, it is poured out into a big tray. Then the concrete in plastic state was immediately poured into formwork. The concrete is poured into the formwork in layers. The compaction is done using a needle vibrator and then the surface was levelled and finishing was given by troweling. The concrete was allowed to set for twenty fours i.e. on the next day after casting, de-moulding was done. The beams were kept inside curing tank for 28 days curing.

2.2.1 Experimental Program

A total of five reinforced concrete beams were casted (All beams were under reinforced sections and of equal dimensions) and out of which one was control beam and remaining were grouped into two beams each i.e. Group A and Group B. The beams in these groups were damaged to 80% load of the control beams and then they were rehabilitated using the Micro-cement and GFRP.

The Micro-cement was injected to the beams by hand pumped pressure grouting machine and the GFRP fabric was U-wrapped throughout the length of the beam. To paste the GFRP fabric, epoxy resin was used as an adhesive.

Experimental results like ultimate load, deflection, strain and failure modes were observed and presented in Table -1 which gives the specifications and designations of the beams.

Table -1: Specification and designation of beams

Sl. No.	Group	Particular	Designation	Pattern	No. of Layers
1	---	Control Beam	CB	---	---
2	Group A	2 Damaged beams (80% loaded)	BSL1 BSL2	Micro-cement injected & Full length U-pattern wrapped	Single layer
3	Group B	2 Damaged beams(80% loaded)	BTL1 BTL2		Two layers

2.2.2 Rehabilitation of damaged RC Beams

Rehabilitation of the damaged beams was done by two stages. In the first stage, the cracks formed in the core and surface of beams were filled by micro-cement and rehabilitated. The damaged beams were drilled with two bore holes on top of the beam. Then the surface was cleaned by air blower and small pipes were inserted into the bore holes and packed. It was allowed to set for 30mins. In the meantime the micro-cement slurry was prepared by mixing the micro-cement with a water-cement ratio of 0.47(as per micro-cement product guidelines). The hand pumping Pressure grouting machine having inlet and outlet was used to pressure grout the slurry. Then by pressure grouting, the micro-cement slurry was injected into the beams and allowed to spread across the core to fill the hair-line cracks which helps to strengthen the beam from internally.

The hair-line cracks formed on the surface of damaged beams were widened and cleaned by air blower. A micro-cement paste was prepared using micro-cement, epoxy resin and hardener to perfect consistency and applied to fill the cracks. They were allowed to cure for 2 days which intern gains strength.

In the second stage, the rehabilitation of beams was done by wrapping the full length of beams by GFRP fabric in U shape, which intern gives strength to the damaged beams. It was taken care to clean the surface before pasting the GFRP fabric. By mixing the epoxy resin and hardener in the proportion 100:10 to 12 (as per the manufacturer) to get a high viscosity uniform paste. Firstly, the epoxy resin was brushed on the beam and the pre-cut GFRP fabric was pasted by pressing gently so the epoxy oozes out from bottom to the top. Then the pasted fabric was allowed to set for 24 hours. Fig -6 shows GFRP sheet wrapped on the beam.

Fig -6: GFRP sheet wrapped on the beam

2.2.3 Experimental Setup and Test Procedure

A loading frame of capacity 50 tonnes was used to test the beams. After 28 days of curing, the beams were tested. The beams were tested under two point loading. Using a hydraulic jack, the load was applied on a spreader beam, which in turn transfers the load to the beam on two points. Using three linear variable deformation transducer (LVDT) at the centre and at the point of loading, the deflections were determined. Fig-7 shows experimental setup.

Fig -7: Experimental setup

The beams were placed on the loading frame and the LVDTs and strain gauges were fixed. The hydraulic jack was lowered till a point such that there is contact between jack and spreader beam. At increments of 10KN, the load was applied and the corresponding deflections and strain gauge readings were noted. The control beam was tested for ultimate load and the remaining beams were damaged by 80% of the ultimate load. Then the damaged beams were rehabilitated by injecting micro-cement and GFRP fabric and tested up to failure. The load vs deflection and stress vs strain curves were plotted and then the results were compared to identify the effectiveness of rehabilitation.

3. RESULTS and DISCUSSION

The test results shows that the control beam fails at 150KN load with numerous cracks in the flexure and shear region. The rehabilitated Group A beams i.e. BSL1 and BSL2 fails by complete delamination of GFRP fabric at 170 KN and 166KN respectively. The rehabilitated Group B beams I.e. BTL1 and BTL2, fails at 200KN and 192KN with delamination of GFRP fabric. Fig -8 shows the crack pattern of control beam after failure.

Fig -8 Crack pattern of control beam

3.1 Load v/s Deflection

The load v/s Deflection readings were tabulated and the curves were plotted for all the beams. Fig -9 shows the load v/s mid span deflections of all the specimen beams.

Fig -9: the load v/s mid span deflections of the beams

In rehabilitated beams, by injecting micro-cement and GFRP has helped to reduce the deflections at higher ultimate loads i.e. decrease in deflection by 20.5% to 21.5% for group A beams and 22.3% to 24.2% for group B beams respectively when compared to control beam.

3.2 Ultimate Load

To find the ultimate flexural load the beam specimens were tested until failure. Fig -10 shows the ultimate loads of all the tested beam specimens.

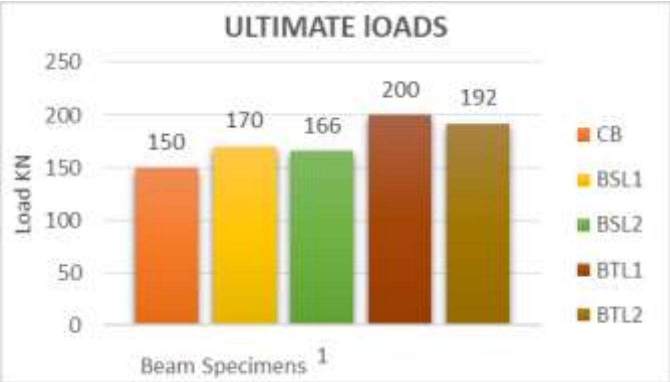

Fig -10: Ultimate loads of all the tested beam specimens

The ultimate load of Control beam is 150N. Table -2 gives the percentage increase in ultimate strength due to rehabilitation of beams with reference to control beam.

Table -2: percentage increase in ultimate strength

Beams	Ultimate load (KN)	% increase in strength compared to CB	No. of layers of U-wrapping
CB	150	-----	-----
BSL1	170	13.33%	1
BSL2	166	10.6%	1
BTL1	200	33.33%	2
BTL3	192	28%	2

From the above table it is seen that there is increase in ultimate strength of the beams when compared to control beam. It is observed that there was significant increase in strength by injection of micro-cement and number of layers of GFRP fabric wrapped. The percentage increase in ultimate strength for beams BSL1 and BSL2 varies from 10.6% to 13.33% when compared of ultimate strength of control beam. And also it was seen that there is 28% to 33.33% increase in ultimate strength for beams BTL1 and BTL2 when compared to control beams.

There is increase in stiffness for Group A beams i.e. BSL1 and BSL2 by 37.5% when compared to control beam and there is increase in stiffness for Group B beams i.e. BTL1 and BTL2 by 83% when compared to control beam. There is 33% increase in stiffness for beams BTL1 and BTL2 when compared to beams BSL1 and BSL2 respectively.

By increasing the number of layers of GFRP fabric, there was significant increase in ultimate strength. From the table we can see that there is 20% increase in ultimate strength of beams when compared to single layer U-wrapped GFRP fabric and two layers U-wrapped GFRP fabric.

And it is seen that by injecting micro-cement has given considerable strength by filling the internal cracks of damaged beams and filling up the hair-line cracks on the surface of damaged beams by micro-cement and epoxy resin, there is reduction in growth of crack width at higher ultimate loads.

3.3 Stress-Strain of Beams

Using Demec-gauge the strain was measured at top and bottom of the neutral axis. For all beam specimens, at top and bottom of neutral axis, stress-strain graphs was plotted. Table -3 Stress-Strain at top and bottom of neutral axis at the 1st crack load/ initial delamination load and failure load respectively. Fig -11, 12, and 13 shows the stress-strain curve for control beam, BSL1 and BTL1.

Table -3: Stress-Strain at top and bottom of neutral axis

Beam	load (KN)	STRAIN	
		Top	Bottom
CB	60	-0.00009	0.00125
	150	-0.0036	0.01201
BSL1	110	-0.0023	0.0036
	170	-0.00493	0.0128
BSL2	110	-0.00204	0.00303
	166	-0.00515	0.013
BTL1	150	-0.00373	0.00465
	200	-0.00544	0.0158
BTL2	150	-0.00375	0.0044
	192	-0.00551	0.016

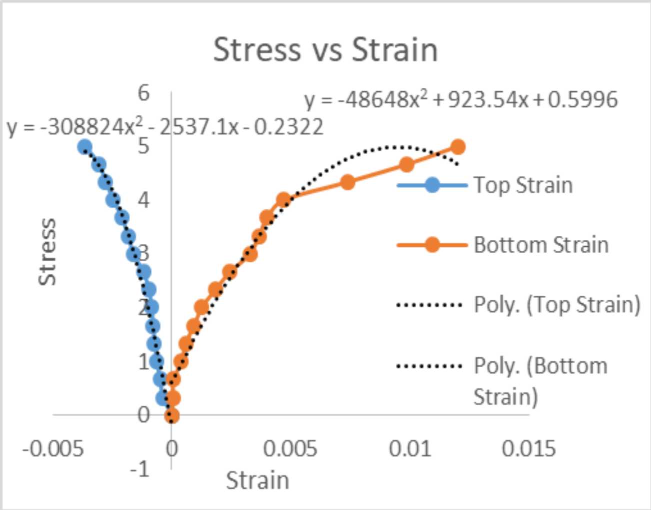

Fig -11: Stress v/s strain curve for control beam

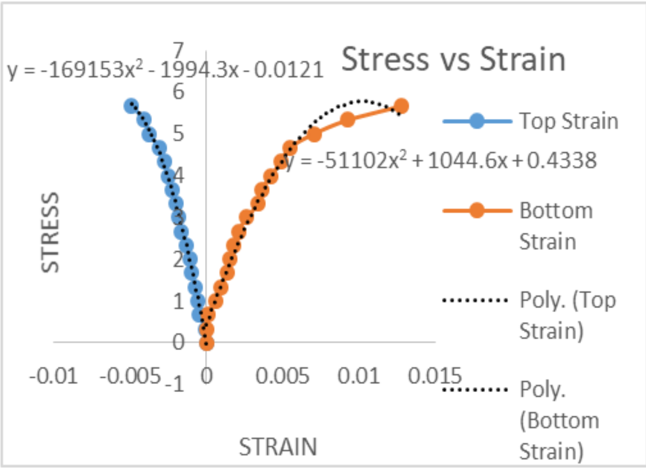

Fig -12: Stress v/s strain curve for BSL1

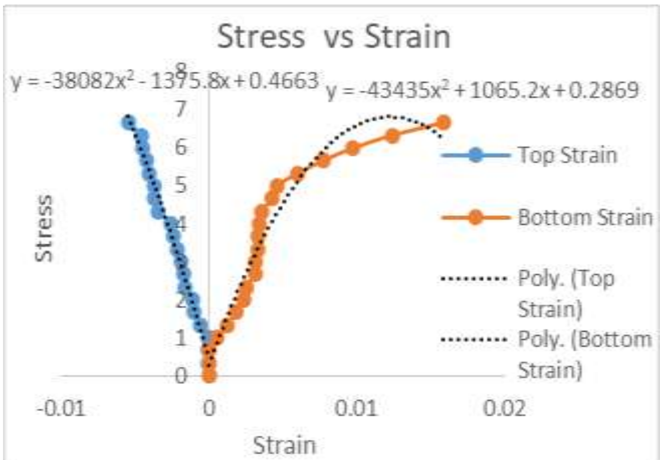

Fig -13: Stress v/s strain curve for BTL1

4. CONCLUSIONS

In this present experimental study, an attempt was made to rehabilitate the reinforced concrete beams by injecting micro-cement and wrapping it with GFRP fabric. The following are the conclusions drawn from the experimental study,

1. It is economical to rehabilitate the reinforced concrete structural members instead of demolition and reconstruction.
2. There is significant increase in ultimate load of rehabilitated beams by injecting micro-cement and GFRP sheets when compared to control beams.
3. Injecting the micro-cement has helped to rehabilitate the beams by strengthening internally and by filling of hair-line cracks of damaged beams by micro-cement and epoxy resin has helped to reduce the growth of crack width at ultimate loads.
4. In rehabilitated beams, by injecting micro-cement and GFRP has helped to reduce the deflections at higher ultimate loads i.e. decrease in deflection by 20.5% to 21.5% for group A beams and 22.3% to 24.2% for group B beams respectively when compared to control beam.
5. There is increase in stiffness for Group A beams by 37.5% when compared to control beam and there is increase in stiffness for Group B beams by 83% when compared to control beam. There is 33% increase in stiffness for Group B beams when compared to Group A beams respectively.
6. An increment of 20% in ultimate load is seen by increasing the number of layers of GFRP fabric.
7. Beams rehabilitated using micro-cement injection and single layer U-wrapped GFRP fabric, there is increase in ultimate load by 10.6% to 13.33% when compared to control beam.
8. There is increase in ultimate load by 28% to 33.33% for beams rehabilitated by injection of micro-cement and two layer U-wrapped GFRP fabric, when compared to control beam.

SCOPE FOR FUTURE STUDY

- The experimental investigation can be done for different grade of concrete and reinforcement steel.
- Experiments can be made by varying the beam sizes.
- Study by using different types of FRPs and increasing number of layers of FRP
- Experimenting by replacement of micro-cement by Nano-materials in varying percentages.
- Rehabilitation of beams with web openings can be made.

ACKNOWLEDGEMENT

The experimental study conducted on "Rehabilitation of Reinforced Concrete Beams by using Micro-cement and Glass Fiber Reinforced Polymer (GFRP)" is a VTU FUNDED PROJECT under "Health Monitoring Repair and Rehabilitation of RC Structures".

I am very thankful to VTU, Belgaum for helping me financially to carry-out this project and I am also thankful to The Principal, Dr. AIT, Bangalore, for providing the opportunity and means to carry out this project work.

I am thankful to my project guide Dr. B. Shivakumara Swamy HOD, Dept. of Civil Engineering, Dr.AIT, and co-guide Dr. S. Vijaya Prof. Dept. of Civil Engineering, Dr.AIT, for helping me to the get the financial support from VTU Project Funds and also for guiding and correcting me at various stages to carry-out the project successfully.

REFERENCES

[1] S. S. Mohite, Dr. M. M. Awati and R. A. Patil, "Flexural Behaviour of R.C. Beams with Side Bonded G.F.R.P. Laminates", *International Journal of Emerging Technology and Advanced Engineering*, Volume 4, Issue 8, August 2014, pp 271-281.

[2] Rohit Vasudeva and Mandeep Kaur, "Retrofitting of RC Beams using Glass Fiber Reinforced Polymer Sheets: An Experimental Study" *Indian Journal of Science and Technology*, November 2016, Vol 9(44), ISSN: 0974-5645.

[3] K.Mohandas and G.Elangovan, "Retrofitting Of Reinforced Concrete Beam Using Different Resins Bonded GFRP Laminates", *International Journal of Advanced Engineering Technology*, Volume 8, Issue 2, April-June 2016, ISSN 0976-3945, pp 1149-1155.

[4] Ahmed Ghazy, Mohamed T. Bassuoni, Eugene Maguire and Mark O'Loan, "Properties of Fiber-Reinforced Mortars Incorporating Nano-Silica", *Fibers,* 2016, Volume 4, Issue 6.

[5] Wail Nourildean Al-Rifaie, Nezar N. Ismaeel, Hamza Riyad, "Rehabilitation of Damaged Reinforced Concrete Beams", *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, Volume 14, Issue 3 Ver. VI. (May - June 2017), ISSN: 2278-1684, pp 58-70.

[6] T. P. Meikandaan and Dr. A. Ramachandra Murthy, "Retrofittng Of Reinforced Concrete Beams Using Gfrp Overlays", *International Journal of Civil Engineering and Technology (IJCIET)*, Volume 8, Issue 2, February 2017, pp. 423–439.

[7] Arockia Priyadharshini.A, Nirmala Vincy.S, Priya Shiny.C, Jemimah Carmichael .M, and Prince Arulraj. G, " Strengthening of Nano Concrete Beam with GFRP Wrapping" *International Journal of ChemTech Research,* 2017, Volume 10, No.8, ISSN(Online):2455-9555, pp 695-700.

[8] G.I. Gunarani and P. Saravanakumar, "Experimental Studies on RC Beams Strengthened with Epoxy and Polymer Grouting", *Asian Jounal of Applied Sciences 7(2)*, 2014, ISSN: 1996-3343, pp 88-95.

[9] Namasivayam Aravind, Amiya K. Samanta, D. K. Singha Roy and Joseph V. Thanikal, "Retrofitting Of Reinforced Concrete Beams Using Fibre Reinforced Polymer (FRP) Composites – A Review", *Journal of Urban and Environmental Engineering,* June 2013, Volume 7, ISSN: 1982-3932, pp 164-175.

[10] Kaushal Parikh and C.D.Modhera, "Application of GFRP on preloaded retrofitted beam for enhancement in flexural strength", *International Journal Of Civil And Structural Engineering,* Volume 2, No. 4, 2012, ISSN: 0976-4399, pp 1071-1080.