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Research paper

Flexural Behaviour of RC beams using GFRP Composites

S.Sivasankar*[1], T.Bharathy[2], R.Vinodh Kumar[3]

[1]Associate professor, [2]PG Student, [3]Assistant Professor
[1]Department of Civil Engineering, St.Joseph's College of Engineering, Chennai-119,
[2]Department of Civil Engineering, MNM Jain Engineering College,Chennai-97,
[3]Department of Civil Engineeering, Mohamed Sathak A J College of Engineering, Chennai-103 .
**Corresponding Author Email: :avinbhar23@gmail.com[1]*

Abstract

Reinforced Concrete (RC) structures damaged by sudden accidental loads due to earthquake and severe environmental exposure. Traditional strengthening methods are not meeting the service life of the structure for long time. Recently, FRP strengthening is used successfully in all kind of exposure with minimum cost and less duration. In this paper RC beams were strengthened by GFRP sheets in two different orientations. Two specimens are control beams, two specimens are wrapped with U wrapping and the remaining beams are bottom wrapping. The size of the beam is 1700mm long, 150mm wide and 250mm depth. The test specimens consit of 2 nos of 10mm dia rods as longitudinal reinforcement in compression zone and 2 nos of 10mm dia steel rods in tension zone. 2-legged stirrups of 8mm diameter were used with a centre-to-centre spcaing of 150mm. All beams were tested under four-point loading. Experiments will be undertaken until beams fails so that the influence of GFRP characteristics on the Flexural behaviour of beams which includes Flexural behaviour, Ultimate load carrying capacity, Deformation and Stress-strain behaviour. Evaluation of the results will lead to optimum GFRP jacketing /wrapping arrangements for the concrete beams are considered here.

Key words: *Reinforced Concrete, GFRP sheets, strengthening, wrapping, Flexural behaviour, Ultimate load carrying capacity.*

1. Introduction

Strengthening of existing reinforced concrete structural elements has become one of the most esteemed activities in civil engineering. The upgrading of existing structures is an integral part of structural engineering practice and requires a dedicated solution at hand. In recent years, an increased application of new repair and strengthening techniques of reinforced concrete structures have been noted. Structural repair and rehabilitation of reinforced concrete structure is becoming an increasing important option for all deteriorated or damaged structures to restore, which enhance the load carrying capacity and increases the life span of the structure. The problem of strengthening the reinforced concrete structure appeared for the first time when their proper function was modified or they were used in a different manner than previously planned. The designers of the existing reinforced load carrying structures constructed many years ago could not predict their use in practice and determine all deterioration effects produced by the external factors during their services.

Strengthening is the modification of a structure. However, each time the structure need not to be damaged one. Many a time the sole purpose of strengthening could be to increase the load carrying capacity or stability with respect to its previous conditions. Nevertheless, most commonly, the strengthening is carried out to restore the structure which through evaluation process is found to be deficient. Structures may need strengthening in case of any of the following cases: (a) deficiencies caused by erroneous design and detailing, deterioration caused due to ageing , lack of adequate maintenance, environmental effects like corrosion, exposure to marine environments, deicing salts, aggressive industrial pollutants (b) structures requiring to be upgraded to a different load category superior to that for which it had been originally designed (c) to adapt to the code changes in lieu of seismic upgrade of the region where the structure is to be located.

To overcome the problems, researchers needed an elaborate study about the composite materials for strengthening. FRP composites have been used for strengthening of Reinforced concrete (RC) since the early 1980's. Fibre reinforced polymers exhibit several improved properties, such as high strength-weight ratio, high stiffness-weight ratio, non-corrosiveness, flexibility in design, high fatigue strength, and ease of applications. Studies conducted by Mander et al [1], Nanni& Bradford [2], Mirmiran & Shahawy [3] and Saadatmanesh et al [4], have shown that the strength and ductility of concrete columns are substantially improved by wrapping FRP sheets around the columns.

Gillespie et al [5] conducted a series of flexural tests to examine the strength and stiffness behaviour of steel I-girders reinforced with five different reinforcing techniques of FRP composites. From test results, they observed that an increment in stiffness of the composite beam. Corrosion and fatigue problems in many steel bridges were successfully upgraded with CFRP fabrics were reported by many researchers Tavakkolizadeh & Saadatmanesh [6], Tavakkolizadeh & Saadatmanesh [7] and Miller et al [8]. Jiao & Zhao [9] investigated the performance of butt-welded very high strength circular tubes (VHS) strengthened with CFRP.

The flexural strengthening of the beams is done by wrapping with FRP fabrics on the tension side or on the side faces of the beam with the fibres parallel to the direction of maximum tensile stress. FRP wrapping provides additional tensile reinforcement and

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confinement which increases the strength of the beam members in bending. FRPs are expensive, but the higher costs of FRP materials are often offset by savings in reduced labour costs.
The main objective of this research is (1) To evaluate the effectiveness of the external GFRP wrapping techniques (2) to study the ultimate load carrying capacity for the flexural strength of the specimens strengthened by GFRP wrapping techniques. (3) To evaluate effect of wrapping patterns of GFRP on the ultimate strength of the confined concrete. (4) To evaluate the efficiency of the GFRP fabrics in terms of utilization of the strength and deformation capacity of theGFRP materials. The scope of this research is that strengthening of RC concrete beam by using GFRP by 2types of wrapping i.ePartial wrapping and U-wrapping technique, so that a comparative study can be made from the results obtained with different types of wrapping techniques.

2. Materials Used

2.1 Glass Fibres:

The unidirectional carbon fibre called MBrace 240, fabricated by BASF India Inc was used in this study. It is a low modulus CFRP fibre having modulus of elasticity of 45GPa and the tensile strength was 1500MPa.

2.2 Epoxy Resin:

Epoxy or polyepoxide is a thermosetting polymer formed from reaction of anepoxide “resin” with polyamine “hardner”. Epoxy has a wide range of applications, including fiber-reinforced plastic materials and general purpose adhesives.

2.3 Concrete Beams:

The beams were designed by limit state method considering the section to be as under-reinforced according to IS:456-2000 code. A prototype beam 1700 x 250x150 mm size was designed. Reinforcement details- 2 nos of 10mm dia rods as longitudinal reinforcement in compression zone and 2 nos of 10mm dia steel rods in tension zone. 2-legged stirrups of 8mm diameter were used with a centre-to-centre spcaing of 150mm.

3. Experimentation

3.1 Specimen Details:

Among six specimens, two were kept as control beams and other six were wrapped with GFRP strips .to identify the specimens it were named as UB-1,UB-2, BW-1, BW-2. Foe example, the GFRP strengthened beams UB-2 denotes that the beam is wrapped as U-wrap with 2layers of GFRP strips.The control beams were named as CB1 and CB2. The control beams are those beams which are unstrengthen.

3.2 Specimen Fabrication:

Surface preparation of the concrete is very important to achieve a good bond between concrete and the GFRP fabrics. Initially the surface of the concrete shall be free from droppings, foreign materials, and or cement laitance shall be removed from the concrete surfaces followed by mechanical grinding.



Fig. 1: Primer application



Fig. 2: epoxy Resin application

3.3 Experimental Set Up:

A loading frame was used for the testing purpose. To observe the flexural cracks the beams were white-washed and the necessary markings were made on the beams in order to place on the supports (simply supported). UDL was applied using metal plates and wooden planks over which jack was placed. Sand particles were applied on the beam to establish a uniform contact with the metal plates. All beams were tested under four-point loading.

4. Result and Interpretation

4.1 Failure Modes of the Specimens:

The beams were symmentrically loaded util the failure so that the influence of GFRP on the flexural behaviour of beams were analyzed. Furthermore beams were still loaded after the failure to understand the failure pattern. All unstrengthened control specimens exhibited a flexural failure which is proved to be the common failure mode in all reinforced concrete beams. The pure bending takes place in the central third portion of the beam. The beams have been loaded until failure took place. As the beams are reinforced beams, bending cracks were started at 57.15 KN. As the load reaches to 70KN more number of cracks was observed. Almost all cracks are vertical. Final deflection at centre was 298mm from bottom at an ultimate load of 105.6KN which can be seen in fig 3 and fig 4.

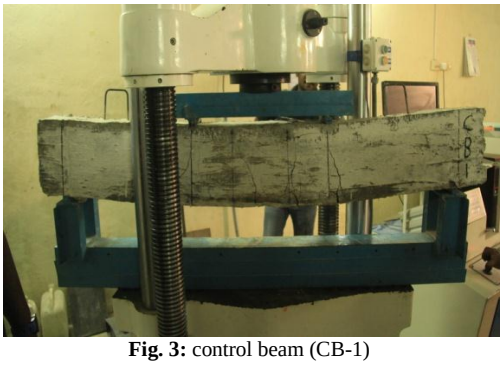

Fig. 3: control beam (CB-1)

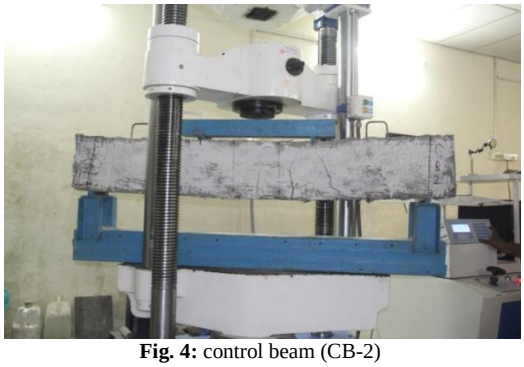

Fig. 4: control beam (CB-2)

The U-Wrapping beam with one layer of GFRP sheet is named as UW-(1). The U- wrapped beam with one layer of GFRP is loaded with a two-point loading system. The beams have been loaded until failure. As the beams are reinforced beams, bending cracks were started at 60 KN. As the load reaches to 93 KN more number of cracks was observed. Since only single layer of GFRP layer were wrapped, the fibre ruptured with small sounds of tearing. Almost all cracks are vertical. Final deflection at centre was 310 mm from bottom at an ultimate load of 114.35KN which can be seen in fig 5. The U- Wrapping beam with two layers of GFRP sheets was tested and named as UW-(2). The U- wrapped beam with two layers of GFRP is loaded with a two-point loading system. The beams have been loaded until failure. As the beams are reinforced beams, bending cracks were started at 79 KN. As the load reaches to 90 KN more number of cracks was observed. Almost all cracks are vertical. Final deflection at centre was 310 mm from bottom at an ultimate load of 123.20KN. As the load increases, the fibre which is wrapped as double layered gets delaminated with a huge tearing sound which can be seen in fig 6.

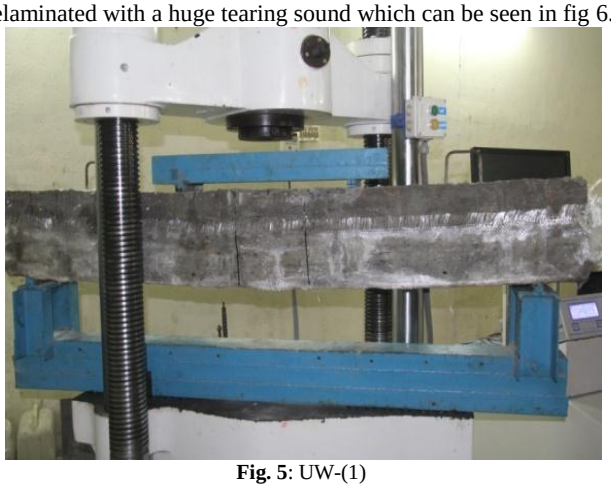

Fig. 5: UW-(1)

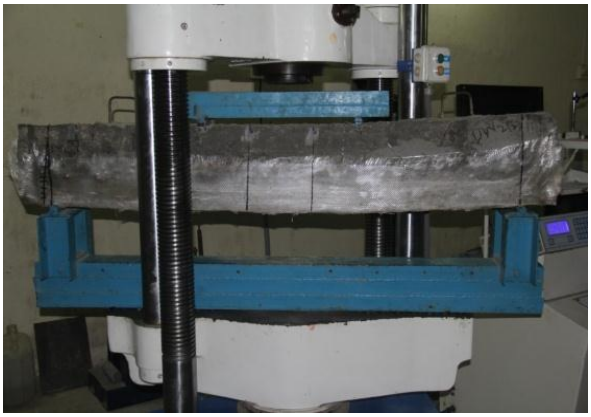

Fig. 6: UW-(2)

The Bottom wrap (i.e.) Partial wrapping with one layer of GFRP (BW -1) is tested. The Partially wrapped beam with one layer of GFRP is loaded with a two-point loading system. The beams have been loaded until failure. As the beams are reinforced beams, bending cracks were started at 50.40 KN. As the load reaches to 70.30 KN more number of cracks was observed. Since it is partially wrapped i.e only at the bottom of the beam. Only few tearing sounds can be heard. Almost all cracks are vertical. Final deflection at centre was 310 mm from bottom at an ultimate load of 109.80 KN which can be seen in fig 7. The Bottom wrap (i.e.) Partial wrapping with two layers of GFRP (BW -2) were tested. The Partially wrapped beam with two layers of GFRP is loaded with a two-point loading system. The beams have been loaded until failure. As the beams are reinforced beams, bending cracks were started at 50 KN. As the load reaches to 76.72 KN more number of cracks was observed. The fibre is ruptured and it gets delaminated continuously with a huge tearing sound. Almost all cracks are vertical. Final deflection at centre was 315 mm from bottom at an ultimate load of 100.6KN which can be seen fig 8.

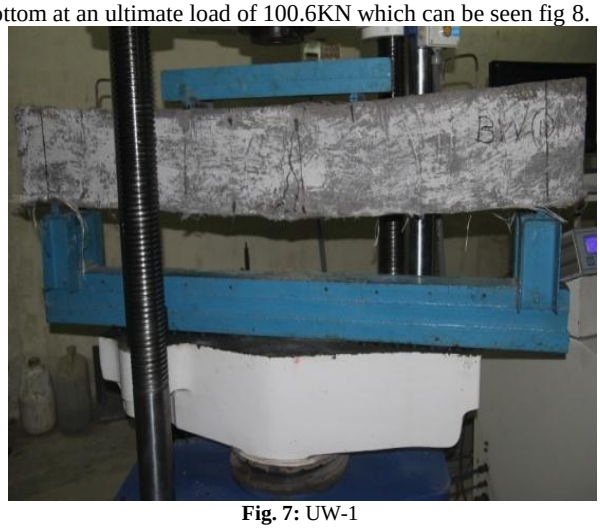

Fig. 7: UW-1



Fig. 8: UW-2

4.2 Load Carrying Capacity:

The load carrying capacity and axial deformation of different beams specimens are given in the following table 1. Here there is an increase in load carrying capacity from 105.3 KN to 114.06KN in case of beam wrapped with single layer of GFRP by U-wrapping technique, an increase to 123.06 KN for the beams wrapped with two layers of GFRP fabrics by U-wrapping and a load of 114.65 KN for the beams wrapped with single layer of GFRP fabrics by partial wrapping, which is then compared with the control beams.

Table 1: specimen details and test results

S.NO	Designation of specimens	Load carrying capacity (KN)	% increase in load carrying capacity	Axial deformation in mm
1	CB 1	105.3	-----	8.43
2	CB 2	105.6	------	8.54
3	UW-1	114.35	8.42	7.88
4	UW-2	123.05	16.67	7.54
5	BW-1	109.65	7.34	7.17
6	BW-2	114.65	15.76	7.19

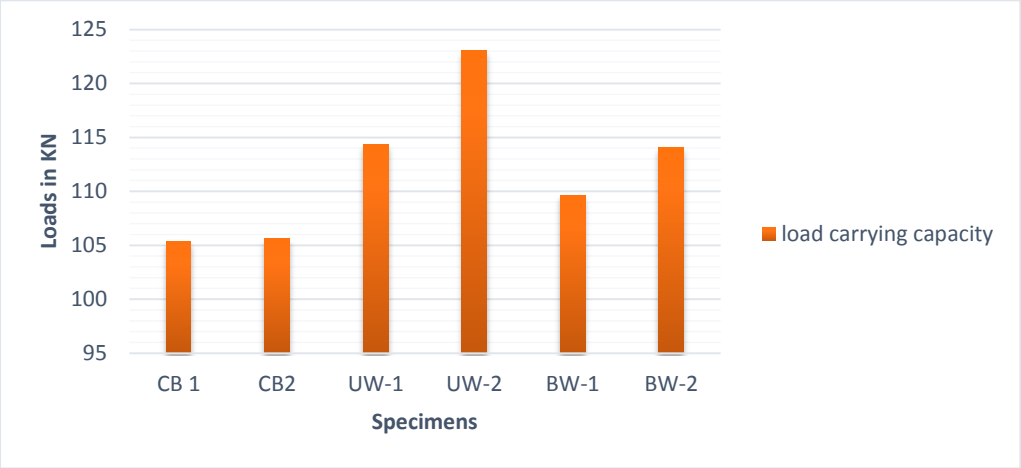

Fig. 9: Ultimate load carrying capacity

Fig 9 shows an ultimate load carrying capacity comparison of strengthened and un-strengthened beam specimens. From the graph it is evident that 4 specimens were wrapped with GFRP shows a considerable increase in the ultimate load carrying capacity over the unstrengthen beam specimen. This increase in load carrying capacity of the specimens increases with an increase in number of layers of the fabrics and the method of wrapping. The confinement provided by specimens wrapped with 2 layers of GFRP by the method of U-wrapping were more than that of with single layer of partial wrapping.

It was observed that the ultimate load for the un-strengthened beams or control beams was 105.6KN and the ultimate load of the beams wrapped with single & double layer by U-wrapping technique were 114.35 KN and 123.65KN. The percentage increase in the load carrying capacity of the beams strengthened beams with double layer of GFRP by U-wrapping is 16.67 % when it is compared to control beams. For the beams wrapped with double layer of GFRP fabrics by partial wrapping i.e bottom wrapping, the percentage increase is about 15.76 % when compared to control beams.

4.3 Stress-Strain Behaviour:

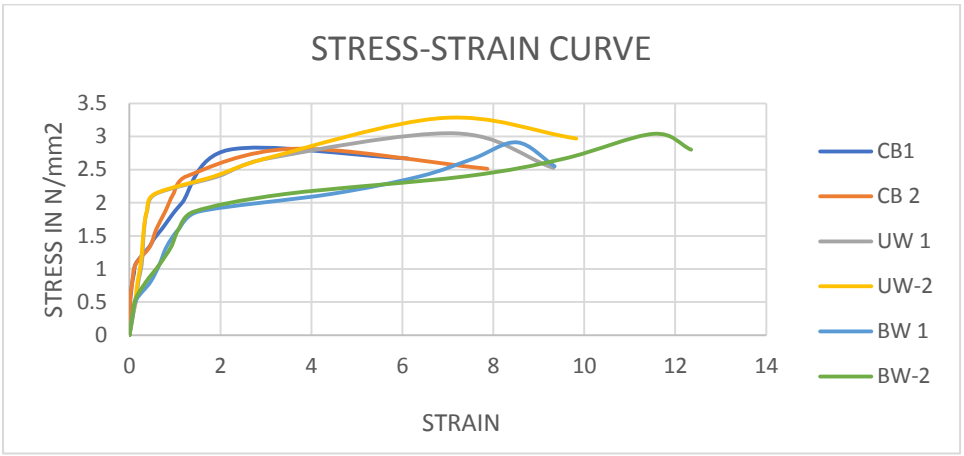

Fig. 10: stress-strain curve- comparison

The fig 10 shows the stress-strain curve for both strengthened and un-strengthened beams. From the figure, it was observed that the beams were confined with GFRP which shows better axial stress-strain behaviour than that of control beams. It also shows that beam confined with double layer of GFRP by U-wrapping technique shows better axial stress-strain behaviour than that of beams confined with single layer of GFRP. The axial deformation of the beams with single and double layer GFRP 7.83 and 7.19mm, this shows that there is a good axial deformation for the beams confined with 2 layers when it is compared to the control beams as well as beams confined with single and double layers.

4.4 Flexural Behaviour:

Flexural strength, also known as modulus of rupture, or bend strength, or transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexure test. The flexural strength represents the highest stress experienced within the material at its moment of yield. It is measured in terms of stress, here given the symbol σ.

Table 2: Flexural strength

Specimen name	Flexural Strength (N/mm^2)
CB 1	16.848
CB 2	16.896
UW 1	18.296
UW2	19.712
BW 1	17.568
BW 2	18.25

On comparison, it can be said that the flexural strength of the beam with double layer of GFRP by U-wrapping is highest than the beams with single layer of GFRP. The flexural strength of the beam which were not unstrengthen with GFRP layers were 16.848 N/mm^2 and 16.896 N/mm^2. As the layers of the GFRP strips were increased, the flexural strength of the beam gets increased. Hence it can be concluded that the flexural strength of the beam with double layer of GFRP strips with u-wrapping has the highest flexural strength of 19.712 N/mm^2.

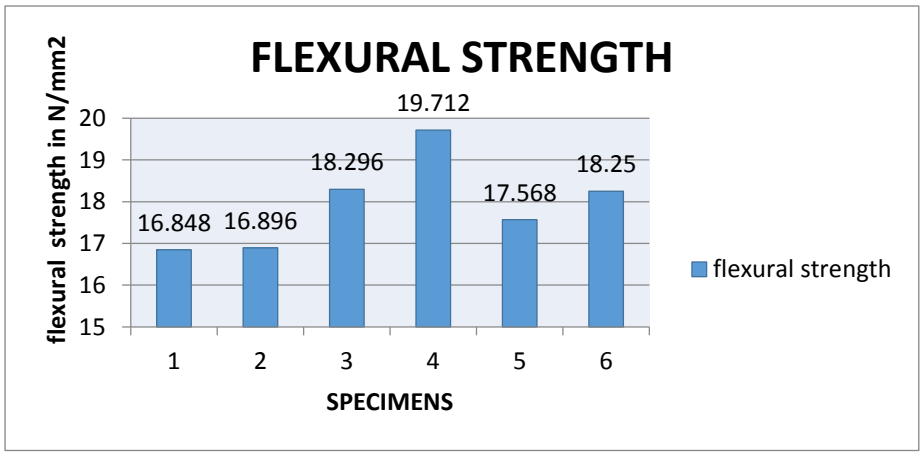

Fig. 11: Comparison of Flexural strength of beams

5. Conclusion

Strengthening of RC beams for the flexural behaviour using externally bonded GFRP sheets have been studied through several investigations. In present work, the flexural behaviour with respect to the strength of RC beam strengthened for flexure by GFRP sheets has been studied. From the detailed study of the experimental results and the data obtained from that of the FRP strengthened RC beams, the major conclusions are summarized below:

- The result of this study shows that the uses of GFRP sheets are feasible and effective for strengthening of concrete structures.
- It can be concluded from the study that load carrying capacity and deflection are increased simultaneously.
- In control beam 1 [i.e CB-1] the first crack appeared at 57.5kN and more number of cracks were observed at 70 kN. Final deflection was 298mm from the bottom of the beam. The base height of this beam was 340mm initially.
- Similarly, for control beam -2 [CB-2] , the first crack load appeared at 48 kN and more number of cracks appeared at 80 kN. Initial base height of the beam was 338mm; finally the height of the beam was reduced to 310mm.
- The strengthened beams restore the original strength percentage additional load capacity.
- For double layer of GFRP wrapping, it was increased by from initial stage than from single wrap which is good sign of strength improvement.
- The failure mode associated with application of GFRP sheet was due to stretching of fibre wrap and was more ductile and it was preceded by warning signs such as snapping or blast like sounds or peeling of GFRP sheets.
- Interfacial fracture which propagates between GFRP and beam, upgrading strength of the beam is due to GFRP wrapping.
- Due to the cracks in strengthened beam, the contact between the GFRP sheet and beam was considerable super-eminent.
- The load- deflection relationships for all the six beams shows a comparison of UW-1, UW-2, BW-1 and BW-2 schemes strengthening with control beams. When GFRP wrapped beams compared with un-sheeted control beams, the sheeted beams achieved consequential gain in the strength.
- For U-wrapping with one layer of GFRP sheet [UW-1] failed at an ultimate load of 114.35 kN with a deflection of 310mm from the base of the beam. The base height of the beam was 338mm initially.
- Similarly , U-wrapping with two layers of GFRP sheets [UW-2] failed at an ultimate load of 123.20 kN with a deflection of 320mm. The base height of the beam is 340mm.
- For Partial wrapping of beam with a single layer of GFRP sheet at the bottom, [BW-1] the ultimate load at which the beam failed is 109.80 kN and the deflection was about 310mm; where the base height was 345mm from bottom.
- For Partial wrapping of beam with two layers of GFRP sheets at the bottom, [BW-2] the ultimate load at which the beam failed is 100.6 kN and the de3flection of the beam is about 315mm from the base and the actual height of the beam was about 342mm.
- It is noted that flexural strength of the beam is increased by wrapping the beam with the GFRP sheets.
- The flexural strength of control beams i.e. CB 1 and CB 2 are 16.848 N/mm^2 and 16.896 N/mm^2 respectively.
- The flexural strength of U-Wrapped beams with single layer of GFRP sheets and double layer of sheets are 18.296 N/mm^2 and 19.712 N/mm^2 respectively.

- Similarly, flexural strength of partially wrapped beam with single and double layer of GFRP sheets are 17.568 N/mm^2 and 18.25 N/mm^2 respectively.
- It can be seen that the beam wrapped with two layers of GFRP sheets shows higher percentage of flexural strength. The percentage of flexure increased is double times the control beam.
- The strength gained is the main feature of flexural strengthening RC beams with GFRP sheets.
- By strengthening the structural elements using GFRP sheets, the life of the building i.e. serviceability of the structure can be increased, as GFRP sheets are corrosion resistant in nature.

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