STUDY ON FLEXURAL BEHAVIOUR OF RC BEAM STRENGTHENED WITH FRP

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Abstract: This paper provides the analytical and experimental work of reinforced concrete beams strengthened with FRP. The main objective of this investigation is to study the flexural behaviour of reinforced concrete beams of different methods of strengthening methods using GFRP to find the flexural strength, failure modes, and ductility of the reinforced concrete beam. All beams were strengthened for flexure with external bonding to prevent flexural failure. The analytical and experimental results indicated that the externally bonded GFRP used for flexural strengthening of reinforced concrete beams increased the cracking load, increased the ultimate load-carrying capacity, and exhibited decreased ductility corresponding to the unstrengthen control specimen. The analytical work was carried out using ANSYS 17.0 Software and found the parameters of total deformation, stress strain curves, and Load deflection graph plotted.

Keywords: RC beam, Strengthening methods, Flexural Strength, ductility, Glass fiber reinforced Polymers, ANSYS.

1. Introduction
In reinforced concrete structures, the most common methods of strengthening are external bonding methods were used. In this paper, the GFRP were used on the external surface, which is wrapped on the different methods to increase the load carrying capacity of the existing concrete structures and bridges, which helps increase the life span of the structures and the service lives of the structures. In recent years, the primary material used for reinforcement has been fibres-reinforced polymer (FRP), which provides excellent tensile strength, corrosion resistance, high durability, and is readily available.Externally connected FRP reinforcement effectively strengthens several reinforced concrete structures, including beams, columns, plates, bridges, tunnels, chimneys, and silos, to increase reinforced concrete structures' flexiblity and ductility. In this study, four specimens of the reinforced concrete beam were casted and strengthened with GFRP by different methods and tested for flexure and analyzed used ANSYS Software for better results. The results show the significant variation of reinforced concrete beam for the flexural capacity [1]

2. Literature review
Sharif, Al-Sulaimani et al., (1994) investigated the effects of various repair schemes using FRP plates on initially loaded RC beams. The plate thickness was varied to assess the initiation of premature failure at the plate curtailment zone. Different repair and anchoring schemes were conducted to eliminate such undesirable failures and to ensure ductile behavior. The authors discussed the behavior of repaired beams in terms of load-deflection curves and different failure modes. They concluded that I-jacket FRP
plates provided the best anchorage system; repaired beams provided enough ductility indicating the effectiveness of FRP plates; the shear and everyday stresses at the plate ends increased with increasing plate thickness leading to plating separation and concrete rip-off \[8\].

Arduini and Nanni et al., (1997) conducted a parametric study of beams with externally bonded FRP reinforcement. The parameters considered in the analysis were stiffness, strength, and adhesive stiffness. The authors reported that the bonded length of FRP should be as high as possible, and the adhesive should have high ultimate elongation \[1\].

Ross et al., (1999) presented experimental and analytical studies on the external bonding of FRP laminates to RC beams for flexural reinforcement. The authors used a non-linear finite element analysis and an inelastic section analysis to predict the retrofitted beams' load-displacement response. They concluded that significant strength enhancements in flexure can be obtained in lightly reinforced beams and that the bond strength between the composite plate and the concrete had a significant effect on the beam response \[4\].

Grace, Sayed et al., (2002) investigated the flexural behavior of reinforced concrete beams reinforced with various types of FRP laminates. They investigated the effect of varying the number of FRP layers, the type of epoxy, and the reinforcement pattern on the beam behavior. They discussed how strengthening affects deflection, failure load, mode of failure, strain, and ductility. The authors concluded that by combining vertical and horizontal sheets with a suitable epoxy, they could significantly increase the ultimate load-carrying capacity of the beams and that all strengthened beams experienced brittle failure, necessitating a higher factor of safety in design \[3\].

Tarek Almusalam (2006) studied the load-deflection behavior of RC beams strengthened with GFRP sheets subject to various environmental conditions. For this study, 84 samples of beams have been prepared. They were monitored in the laboratory environment, outside, wet-dry alkaline water, and second class covered with ultraviolet paint protection. The unreinforced and strengthened beams in each category. The specimens of various wet-dry environments were exposed within the solution to a two-week time cycle and outside the solution for two weeks. The tests were carried out in different environmental conditions following 6, 12, and 24 months of exposure. The author concluded that neither of the above-mentioned environmental conditions significantly impacts the beams' flexicurity \[13\].

Barbato (2008) conducted a study on efficient modeling with reinforced concrete beams with fiber-reinforced polymers. To forecast the capacity of the load carrier and the application of a three- and the four-point bending response of the RC beams, FRP-Force-based formulas (FB) were used. Due to the many literature tests available and published by different authors, numerical simulations and experimental results were compared. The numerically simulated reactions agree with the relevant experimental results remarkably well \[2\].

### 2.1. Summary of the Literature review

FRP platform-specific RC beams provide a wide range of information about the study's load deflection behaviour and parameters, including resilience, deflective, and ductility of RC beams. Many of the researchers suggested models for RC beams using FRP laminates. Some researchers have presented maths for predicting study parameters in which FRP enhances RC structural members. Few researchers have carried out reliability analyses for reinforced concrete beams from FRP. A vast number of studies have been carried out on FRP-stärker beams, and further research has thus been required to understand the interaction of GFRP-stärker reinforced concrete beams' load-bearing capacity, deflectors, and ductility. FRP wrapping is the most common method to strengthen the bending behavior and rigidity of the beam. With the GFRP enhancement methods, the load beam capacity is also increased. In strengthening degraded concrete structures, the efficiency of externally binding CFRP has been assessed. Decreasing crack widths was the main impact of the service loading. Further research has to be done for the easy understanding of FRP materials and their behavior \[2\].

### 3. Experimental Investigation

#### 3.1. Preliminary Tests

To find the material property, the preliminary tests were taken for the cement, fine aggregates, coarse aggregate, and to increase the strength and workability, superplasticizer contrast SP 430 were used for
the concrete grade of M40 of concrete compressive strength were achieved, and results were given below. Table 1, 2, 3 and 4 represents test results of the cement, coarse aggregate and fine aggregate along with specimen testing respectively [3]

Table 1: Test results on Cement

| TEST ON CEMENT | RESULT OBTAINED | As Per IS Standard |
|----------------|-----------------|--------------------|
| CONSISTENCY    | 30%             | 25-35%             |
| INITIAL SETTING TIME | 32min          | Not less than 30min |
| SPECIFIC GRAVITY | 3.1            | 3.1 – 3.25         |

Table 2: Test results on coarse aggregate

| TEST ON COARSE AGGREGATE | RESULT OBTAINED | As Per IS Standard |
|--------------------------|-----------------|--------------------|
| Fineness Modulus         | 7.3             | 6.5- 8             |
| Specific gravity         | 2.70            | 2.6-2.9            |

Table 3: Test results on fine aggregate

| TEST ON FINE AGGREGATE | RESULT OBTAINED | As Per IS Standard |
|------------------------|-----------------|--------------------|
| Fineness Modulus       | 2.80            | 2.2-3.2            |
| Specific gravity       | 2.60            | 2.6-2.8            |

3.2. Testing of cube and Cylinder
Totally six cubes and six cylinders were cast and tested on the 7th and 28th day to determine the characteristic compressive strength of concrete accordingly. The results obtained were shown below. The average compressive strength of 150mm³ cubes after 28 days shows the better strength, and also the average split tensile strength of the cylinder also achieved the required strength. Test results were given below in the table. Fig 1 shows cube testing of cubes and cylinder [4].

Fig. 1. Testing of cube and Cylinder

Table 4. Test results on Cube and Cylinder

| S.NO | Compressive strength (N/mm²) | Split tensile Strength (N/mm²) |
|------|------------------------------|-------------------------------|
|      | 7th Day                      | 28th Day                      |
|      | 28th Day                     | 7th Day                       | 28th Day |
| 1    | 24.8                         | 46.9                          | 2.29     | 4.06 |
| 2    | 26.4                         | 49.9                          | 2.10     | 3.73 |
| 3    | 26.3                         | 47.2                          | 1.98     | 3.83 |

The average Compressive Strength of Cube (N/mm²) = 47.8 N/mm²  
The average Split tensile strength Of Cylinder (N/mm²) = 3.89 N/mm²
3.3. Test Specimen and Strengthening methods
In the experimental investigation, six specimens of armored cement beams have been tested under a two-point load. The fig 2 shows dimensions and refurbishment details. The beam was 1000mm in length. The beams were 150mm and 200mm in width and depth, respectively. For all specimens, the cross-sectional geometries and the length reinforcements were identical. The length reinforcement tension consists of three high tensile bars with a diameter of 12mm. Two bears of high tensile steel deformed in diameter of 10 mm. The vertical stirred were spaced at 150mm center reinforcement with a diameter of 8mm, round, mild steel bars. GFRP reinforced all beams at different thicknesses. The beams are shown in the fig 2 for the refinement details. The Glass Fibre Reinforced Polymer type is Unidirectional Cloth fiber were used. The epoxy resin and the adhesive were applied and cured for 48hours at room temperature before loading. Fig 3 depicts casting and curing of specimens [4]

3.4. Specimen Details

![Reinforcement Details](image)

**Fig. 2 Reinforcement details**

The following specimen details were given below in the table.

| SPECIMEN ID | STRENGTHENING METHODS | THICKNESS |
|-------------|------------------------|-----------|
| BCN         | Control specimen       | -         |
| BB01        | Bottom wrap            | 1mm thickness |
| BB02        | Bottom wrap            | 2mm thickness |
| BL01        | Loading surface        | 1mm thickness |
| BL02        | Loading surface        | 1mm thickness |
| BF01        | Full wrap              | 1mm thickness |

3.5. Casting and Curing of specimen
The specimen is cast and cured for 28 days in the curing tank, and after curing, the strengthening process has to be done on various methods.

![Casting and Curing of Specimen](image)

**Fig. 3. Casting and Curing of Specimen**
3.6. Strengthening Process
For the strengthening process, the Glass Fibre Reinforced Polymer type is Unidirectional Cloth fiber were used. Both the epoxy resin and the adhesive have been used and cured 48 hours before loading at room temperature given in fig.4

![Strengthening of specimen](image1)

4. Test Setup and Instrumentation
All beams with a capacity of four hundred kN have been tested in a two-point load. To get better results and read the measuring devices, every test started with several cycles of small loading (i.e., about 5-10kN). The load was applied until the failure happened afterward. The beams were fitted with the load control cell, the LVDT was fitted with midspan to measure deflection, and three electrical resistor gauges were attached on which the single pressure gauge is located. The fig 5 shows an experimental view of the test set-up. During the tests and the crack pattern, the visual inspection also observed the crack initiation, beam deflection, strains, and load values [5].

![Experimental view of test setup](image2)

5. Experimental results
The tests of all beams and the load causing the initial cracks, the load causing the yield of the voltage steel reinforcement are presented in the table 6. A baseline value for comparison with the strengthened beams is also calculated and presented on a table for the obtained deflection and the failure load for control specimens [6].
**5.1. Enhancement of Load-carrying Capacities**

The graph represents the load-deflection curves of the tested specimen, respectively. The result shows that the glass fiber reinforced polymer with full wrap gives high load carrying capacity, and the beam with the bottom wrap also gives a slight increase in the ultimate failure. Compared to the unstrengthen beam (i.e.) Control specimen, the full wrap is achieved with a 28% higher load-carrying capacity. Table 6 depicts initial cracks and failure load comparison.

![Load deflection Curve](image)

**Fig.6** Load deflection Curve

| SPECIMEN ID | INITIAL CRACK LOAD (kN) | ULTIMATE FAILURE LOAD (kN) |
|-------------|--------------------------|-----------------------------|
| BCN         | 90                       | 205                         |
| BB01        | 70                       | 230                         |
| BB02        | 80                       | 240                         |
| BL01        | 105                      | 225                         |
| BL02        | 60                       | 215                         |
| BF01        | 110                      | 250                         |

**5.2. Service Load Calculation**

The maximum expected charge intensity during the structure's lifetime is called the service charge. The service load is calculated and given in the below table.

| SPECIMEN ID | SERVICE LOAD (kN) |
|-------------|-------------------|
| BCN         | 136.67            |
| BB01        | 153.33            |
| BB02        | 160               |
| BL01        | 166.67            |
| BL02        | 156.67            |
| BF01        | 167.33            |

**5.3. Failure modes**

The failure modes (i.e.) Crack Patterns for the control specimen, and strengthened beams are shown in fig 7. The given fig 7 show the failure modes of different specimens observed during the testing of beams and are described. The failure modes are briefly given below in the table as follows.
Fig. 7 Failure modes of the specimen

Table 8. Crack Pattern observed on the specimen

| SPECIMEN ID | CRACK PATTERN OBSERVED ON THE SPECIMEN                                                                 |
|-------------|------------------------------------------------------------------------------------------------------|
| BCN         | The unstrengthened control specimen is failed by steel yielding followed by concrete crushing b/w loading points. |
| BB01        | Initially, the flexural crack attains, and the crack propagated toward the one end of the support.    |
| BB02        | The beam strengthened at the bottom surface attains flexural cracks, and crack is initiated at the midspan and extended towards one support. |
| BL01        | At a certain load level, the concrete started to break down, and a failure spread to the end.          |
| BL02        | In this, the crack occurred at two supports and extended up to the midspan.                           |
| BF01        | The strengthened beam of complete wrapping is failed in the form of a horizontal crack propagated towards the midspan. |

5.4. Beam deflection

The fig. 6 compares the load-deflection curves for a strengthened beam with the unstrengthen beam, a control specimen. The figure 6 indicates that the curves of beam B2 exhibit more load carrying capacity and attain high ductility compared to the unstrengthen beam. The table value shows that bottom wrap also has high tensile strength and load-carrying capacity. Comparing the beam B3 and B4 shows a slight increase in ultimate strength and shows a gradual increase in good ductile behaviour. Hence the maximum deflection curve could also be observed in these beams. The beam B2 strengthened with a full wrap of 1mm thickness achieved more strength, and the load -deflections observed that the beam is 39% higher and 28% higher load carrying capacity when compared to the unstrengthen beams. Table 9 shows deflection of beams [8].
5.5. Beam Ductility (7)
The ductility of a ratio called the Ductility Index has usually been measured. The index of deflection ductility is used to measure the ductility of the beams, as shown in table 10.

\[ \mu \Delta = \Delta u / \Delta y \]
where
\[ \Delta u = \text{Midspan deflection at ultimate load} \]
\[ \Delta y = \text{Midspan deflection at yielding of tension steel reinforcement} \]

| SPECIMEN ID | DUCTILITY INDEX \( \mu \Delta \) | DUCTILITY RATIO |
|-------------|-------------------------------|-----------------|
| BCN         | 1.98                          | 1               |
| BB01        | 4.33                          | 2.10            |
| BB02        | 2.27                          | 1.15            |
| BL01        | 3.08                          | 1.56            |
| BL02        | 3.20                          | 1.61            |
| BF01        | 5.17                          | 2.60            |

5.6. Initial Stiffness
Initial rigidity is the degree to which an object in response to applied force resists deformation. The initial stiffness is calculated and showed in table 11.

| SPECIMEN ID | INITIAL STIFFNESS (kN/mm) |
|-------------|----------------------------|
| BCN         | 33.21                      |
| BB01        | 36.08                      |
| BB02        | 32.12                      |
| BL01        | 39.77                      |
| BL02        | 28.03                      |
| BF01        | 75.86                      |

5.7. Energy Absorption
It is defined as the maximum energy absorbed by a member within the elastic region. The energy absorption is found and given below table 12.

| SPECIMEN ID | ENERGY ABSORPTION (kN.mm) |
|-------------|---------------------------|
|             | ABSOLUTE       | RELATIVE   |
| BCN         | 4445           | 1          |
| BB01        | 9710           | 2.18       |
| BB02        | 11725          | 2.63       |
| BL01        | 10275          | 2.31       |
| BL02        | 662.5          | 0.14       |
| BF01        | 144424         | 3.24       |

6. Software Analysis
An instant finite element analysis tool used in conjunction with CAD and Design Modeler is an intuitive, upfront workbench environmental system. ANSYS 17.0 is available. ANSYS 17.0 is a software
environment for structural, thermal, and electromagnetic analyses. The course focuses on geometry development and optimization, attachment of the existing geometry, finite element modeling, resolution, and evaluation results. The class describes how you can use code and fundamental concepts for simulation and interpretation of finite element results. ANSYS 17.0 is software for the general-purpose, used to simulate the interaction among engineering engineers in all disciplines of physics, structural, vibration, fluid dynamics. CAD data can be imported, and geometry can also be built with its 'pre-processing' abilities. ANSYS 17.0. The finite element model (a.k.a. mesh) needed for the computer is generated similarly in the same preprocessor [9]. After loading definition and analysis, the results can be considered numerical and graphical. The material properties of the fibre GFRP UDC are given in table 13.

### Table 13. Material Properties

| Material    | Density    | Modulus of Elasticity | Poisson ratio |
|-------------|------------|-----------------------|---------------|
| Concrete    | 2400 kg/m³ | 32 Mpa                | 0.2           |
| Steel       | 7850 kg/m³ | 2x10⁵ Mpa             | 0.3           |
| GFRP (UDC)  | 1921 kg/m³ | 73 Gpa                | 0.26          |

6.1. Geometry creation and Mesh Generation

I have created the model with the primary reinforcement as 12mm, stirrups of 8mm, and a cross section of beam as 150x200x1000m, which is shown in the figure. After completing the geometry design, I have gone to the modeling phase and assign all the material properties. Then I have generated mesh that helps us solve the model in finite element method, and results can be obtained accurately, as shown below in fig.8 The Mesh generation is applied to convert larger size particles into several nodes. The process of generating the nodes is called Discretization [10]. This process helps to apply the loads in each node to be distributed throughout the structures shown in Figure.8

6.2. Loading pattern

The RC beam applied two-point loads to investigate the failure modes and improvement in strength, as shown in fig.8

6.3. Total Deformation

The total deformation of all the specimens, including the conventional beam and also the beam, which is strengthened with various methods are given in fig. and results are also furnished [11][12]. The deformation of BCN, BB01, BB02, BL01, BL02 and BF01 are given in fig.9.
Fig. 9 Total deformation

6.4. Analytical Results and Experimental results

The analytical results show the results of various computations, and the results obtained are compared with experimental work is given in table. 14. The total deformation and load-deflection graph have been plotted from the analytical work, and the results obtained are related to the experimental work [13]. The comparison of results is given in fig.10.

| SPECIMEN ID | ANALYTICAL RESULTS | EXPERIMENTAL RESULTS |
|-------------|---------------------|----------------------|
|             | ULTIMATE LOAD (kN)  | DEFLECTION (mm)      | ULTIMATE LOAD (kN) | DEFLECTION (mm) |
| BCN         | 195                 | 4.17                 | 205                | 5.38             |
| BB01        | 210                 | 6.85                 | 230                | 8.23             |
| BB02        | 200                 | 3.89                 | 240                | 5.67             |
| BL01        | 220                 | 7.26                 | 235                | 8.15             |
| BL02        | 210                 | 4.72                 | 215                | 6.05             |
| BF01        | 225                 | 6.89                 | 250                | 7.50             |

Fig.10 Comparison of results
7. Results and Discussion

- From the above experimental and analytical work, it is observed that GFRP strengthening exhibits higher load-carrying capacity. The control specimen has exhibited less load carrying capacity of 205kN while the beam strengthened with GFRP exhibits 250kN.
- The GFRP wrapped beam attains 28% of the ultimate failure load from the obtained results compared to the unstrengthen beam.
- There is no much difference in its ultimate failure load on the bottom wrap since the load increases slightly and is also considered the reasonable solution for strengthening the beams and the practical solution.
- The beam with full wrap indicated the additional flexural strength compared to the unstrengthen beam.
- On the bottom wrap of thickness 1mm and 2mm, the ultimate load-carrying capacity increases up to 20.5% than the control specimen.
- The ductility of the increased when GFRP fully wraps the beam gives gradually increases with 2.7% of unstrengthen beam.

8. Conclusion

- The above experimental work shows that the wrapped beam has high deductibles and a wide bending to failure.
- From the conventional beam, 28% of load carrying capacity is achieved in complete wrapping, and 39% of the ductility is obtained on the complete wrapping
- The external wrapping on the bottom surface shows that it enhanced the cracking load and shows the significant variation in flexural load carrying capacity.
- Strengthening the RC beam with GFRP on the external surface with a double layer indicates the significant variation in increasing the strength and the ultimate load carrying capacity compared to the unstrengthen control beam.
- The analytical work was also done using ANSYS software, and the results were obtained for total deformation, equivalent stress, equivalent strain and load deflection curve, and stress strain graph.
- The experimental work concludes that reinforced concrete beams with GFRP will give an effective solution for premature failure.
- Hence it shows that the RC beam strengthened with GFRP will reduce the cracks compared to the unstrengthen reinforced concrete beam.
- Good results were obtained from the analytical and experimental work in terms of load-deflection curve and ductility behaviour of the beam.

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