STUDY ON BEHAVIOUR OF DEEP BEAM STRENGTHENED WITH GFRP SHEETS

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Abstract: This article discusses the behavior of a reinforced concrete deep beam that has been strengthened with GFRP sheets. The GFRP shows many essential and necessary properties such as low weight to strength ratio, non-corrosive, high fatigue strength, high tensile strength, etc. In this paper, four deep beams were cast, in which one beam is a control beam, and another one is with special confinement reinforcement. The rest of the two beams are strengthened with the GFRP sheets in standard control beam and special confinement reinforcement beam under static or monotonic loading under three points, and the corresponding behavior is determined. The behavior of the RC Deep beams, such as load-carrying capacity, first crack load, load-deflection behavior, crack patterns, and stress vs. strains, are determined. The analysis of the reinforced concrete deep beams was done using the finite element software called ANSYS. Additionally, this article provides preliminary support for proposing a novel shear strengthening technique during the member's design. In the finite element simulations, the proposed deep beams have been modeled and analyzed using the finite element software, ANSYS, and the results are compared with experimental work.

Keywords: RC Deep Beams, GFRP Sheets, special confinement reinforcement, shear behavior, ANSYS software.

I. INTRODUCTION

The Reinforced Concrete (RC) deep beam is a beam with a depth comparable to the span length or Beams with a significant depth to span length, or thickness quantitative relation is mainly referred to as deep beams. Different design codes propose different values for the span to depth quantitative relationship (Le/d) and the shear span to depth quantitative relationship (a/d) when defining deep beams. In step with the Indian Standard Code (IS 456:2000), the deep beam with depth/thickness or depth/span length is less than 2.5 for concentrated load and depth/thickness, or depth/span length is less than 5.0 Uniformly Distributed Load. [1].

Enhanced Concrete deep beams are used in various structural applications, including offshore structures, transfer girders, wall footings, foundation pile caps, tall buildings, floor diaphragms, and shear walls. Reinforced Concrete deep beams are usually used as load-distributing structural elements wherever the space between two columns or supports is ample to resist or withstand the bending moment that occurs due to heavy load.

The reinforced concrete deep beams have an excellent flexural strength when put next to the shear strength because of its shear span to depth quantitative relation. A more considerable depth resists the beam from the cause of the bending. The shear failure essentially happens in
RC deep beams instead of traditional RC beams because of the dimensional configuration. The deflection could additionally happen at the diagonal portion and thus creates the diagonal shear cracks. If the depth of the profound beams increases, the shear strength decreases. Hence, the Shear carrying capability should be augmented within the RC deep beams while not increasing the depth of the deep beams [2].

1.1 STRENGTHENING TECHNIQUES

Structural strengthening is that the method of upgrading structures to boost their structural performance below existing loads or to enhance the strength of the structural members to resist the extra loads. The strengthening of the reinforced concrete structures is essential to increase the load carrying capability of the structural component, extend the flexural and the shear strength of the structures, decrease the propagation of the crack, and the development of the crack width and its dimensions [3]. There are several techniques in strengthening the reinforced concrete structures victimization Steel jacketing, Reinforced concrete jacketing, FRP confining or jacketing, the other replacement of various reusable materials or fibers with the partial quantity of cement or aggregates, etc.

1.2 FIBER REINFORCED POLYMERS

Throughout the past years, strengthening or retrofitting structural members using Fiber Reinforced Polymers (FRP) is wide inflated for its various properties. Those fibers are generally made up of Natural fibers and Synthetic fibers. Some synthetic fibers are glass, carbon, polyolefin fibers, basalt fibers (volcanic rock fibers), or aramid, though different fibers like paper or amphibole are typically used. Some of the Natural fibers are jute, wood, coir, etc. The polymer is usually made out of epoxy, vinyl, or polyester plastic and resins of methanol are still in use. The regional, aerospace, car, marine, and construction industries typically use FRPs [5]. Fiber Reinforced Polymers (FRP) has become wide to extend or increase the high strength of the structural member to carry the heavy loads and increase the load-carrying capacity of the particular member. All FRPs have entirely different properties and have different strength parameters in keeping with the raw state of the fiber from wherever it is obtained. The price additionally varies in keeping with the supply and also the strength it gains. The FRPs are accessible in the various states as reinforcing bar, sheets, dry state, laminates, cloth, etc., each has its specific output when incorporated with the structural elements [6].

1.3 GLASS REINFORCED POLYMER SHEETS

The required strength for the structural components can be achieved by using some technologies with Glass Fiber Reinforced Polymers (FRP). The Glass Fiber Reinforced Polymers (GFRP) Sheets are used to enhance the shear carrying capacity of the deep beams. The GFRP sheets are most economical and readily available when compared to the other types of polymeric fibers such as Carbon Fiber Reinforced Polymers (CFRP), Basalt Fiber Reinforced Polymers (BFRP), Aramid Fiber Reinforced Polymers (AFRP), etc [7]. The characteristics properties of glass fibers are high strength, less weight, economy, low maintenance, good design flexibility, durability, chemical resistance, good tensile strength, etc., A key reason for using GFRP is their corrosion resistance, and one of the main reason is the fact that it does not conduct electricity. The glass fibers are available in many types, such as reinforcement rods, sheets, fabrics, the dry state in case of replacement, etc. The externally bonded glass fiber sheets with layers give additional stability and ductile property to the beam and decrease the reach of shear failure. The glass fiber sheets are also wrapped externally and bonded with the epoxy resin with its respective hardener to the RC deep beams. The GFRP sheets are available in different sizes and thicknesses, and the individual sizes show different efficiency [8].
1.4 SPECIAL CONFINEMENT REINFORCEMENT

The deep beams with special confining reinforcement with variation in the stirrups reinforcement give better ductility. Usually, to resist the shear failure, web reinforcements are provided to the RC beams. The capacity of the RC beam is generally the amount of Shear and moment that it can withstand. The spacing of the shear reinforcement at the center should be maximum, and at the support, it should be minimum. According to IS 13920: 1993, Cl: 6.3.5, Beam shall not exceed d/4 and eight times the diameter of the smallest longitudinal reinforcement bar on the shear side or zone. On either side, the beam shall not exceed d/2 of the longitudinal reinforcement on the flexure zone [9].

There is only limited literature in strengthening RC deep beams with Glass Fiber Reinforced Polymers (GFRP) and unique confining reinforcement methods. I have studied the various literature or review papers and described the research they have done in this paper [10].

As examined and described here, Extensive research work, Amr H. Zaher and et al (2019) investigated behaviour of RC beam by adopting glass fiber and carbon to enhance the shear strength. The beams have been divided in to five sections so that CFRP sheets shows better peformance by enhancing strength of 2,3, and 4th sections whereas GFRP provides better resistance 5th sections [1]. M. R. Islam and et al. (2004), This study explores a reinforcing technique using externally bonded FRP systems for structurally deficient deep beams. Three different availability of carbon fibers are used. They are fiber wrap called MBrace 130, in the form of strips called Sika and girds called NEFMAC. The FRP grids placed in the normal orientation are concluded to be the most effective. An improvement of about 40% is achieved in this paper [8]. Rizwan Azam and et al. (2018), This literature explains the effectiveness, by contrast to epoxy-based carbon fiber-reinforced polymers, of cement-based composites for strengthening RC-deep beams. This paper conveys the concept because of the bi-directional fabric used in cement-based enhancement compared to the unidirectional sheets in the high-bonding epoxy-based enforcing system and its enhanced connection to the concrete substratum. The total thickness of the FRP used in this strengthening is about 6-8mm for Carbon Fiber Reinforced Cement Mortar and 8-12mm for CFRP grid in mortar. The epoxy-based system (CFRP) sheets are applied on the beams as per the manufacturer's requirements and specifications. The appearance and development of the cracks were readily visible and indicated a failure in the case of the cement-based mortar; on the other hand, the beams strengthened with CFRP sheets do not indicate failure and visible cracks [14].

From the research as mentioned above papers, it is concluded that using Fiber Reinforced Concrete (FRP) may be of any types will increase the structural behavior of the RC members, such as ultimate load-carrying capacity, ductility, shear strength, flexural behavior, and decrease in the failure modes, propagation of crack width, etc., The use of CFRP gives better results than any other types of frps. However, it is higher in cost when compared to other types of firms. The GFRP also gives additional strength in the case of flexure and Shear and the ultimate load carrying. Hence, while increasing the shear reinforcement in the shear zone than in the flexural zone, it can attain additional strength. When it is strengthened more with the GFRP sheets, it increases the load-carrying behavior, shear strength, etc. Three-point loading is given rather than two-point loading to determine the shear behavior of the beam. Analysis of the Control beam and GFRP strengthened with and without confinement reinforcement using (FEA) ANSYS software.

2. EXPERIMENTAL PROGRAM

To study the behavior of the deep beam strengthened with GFRP sheets, a full four beams were cast. Out of these four beams, two beams are the standard control beam, and the other two with special confinement reinforcement. Moreover, the one standard control beam and one special confined reinforced beam are wrapped with the GFRP sheets. The casted beams were tested under three-point loading conditions, and the respective load-deflection behavior, enhancement of shear capacity, failure modes are noticed. Details of the preliminary test
carried out, specimen casting, GFRP sheets or fabric wrapping, experimental setup, testing and observation, results, and discussions are presented below [11].

2.1 PRELIMINARY TEST FOR MATERIALS

Cement could be a binding agent used to build it, hardening it and adhering to other materials to bind it. The cement used is OPC 53 grade cement. Various tests were conducted for preliminary tests for cement. The fineness value is 2, which is less than 10 as per is code (IS 4031 - Part 1 - 1996), Specific gravity is 3.15, which is within the range 3.1 – 3.16 (IS 2720 - Part 3 - 1980), Consistency ratio is 32%, which is within the range 25 – 35% (IS 4031 - Part 4 - 1988), Initial setting time is 32mins and Final setting time is 360 mins, which is within the range >30 mins and <600 mins as per code (IS 4031 - Part 5 - 1988) [12].

Fine aggregate usually comprises natural sand or crushed stone. The fine aggregate aims to fill the pores between the coarse aggregates in concrete, therefore reducing the porosity of the concrete paste and increasing the strength. M sand is employed during this project. The specific gravity value is 2.58, which is within the range of 2.6 – 2.8 as per code (IS 2386 Part – 3 – 1963), Fineness modulus corresponds to grading zone II (90 – 100% passed through 4.75 mm sieve), and the value is 2.8, within in the range (2.2 – 3.2) (IS 383 – 2016).

Coarse aggregates are defined as materials with a sieve size greater than 4.75 mm. Coarse aggregates are a type of rock quarried from underground deposits. Usage of coarse aggregates will reduce the shrinkage that occurs. Specific gravity obtained is 2.66, within the range between 2.6 – 2.85 (IS 2386 – Part – 3 – 1963). Fineness modulus passed 90% through 20 mm sieve, and the value obtained is 7.5, which is between the range 6 – 8.5 (IS 383 – 2016), Water Absorption is 0.5%, which is within the range of 0.5 % to 2 % (IS 2386 – Part – 3 – 1963) [13].

2.2 CASTING OF SPECIMENS

Concrete grade of M30 and Steel grade of Fe415 is adopted. Mix design was done as per IS:10262-2009, in which the proportion of cement, fine aggregate, coarse aggregate with a water-cement ratio of 0.45 is 1:1.5:2.7 per cubic meter. Four rectangular concrete deep beams with 1000 × 420 × 120 mm specifications are adopted and cast for the experimental program. Before the specimen casting, six cube specimens were cast with 150 × 150 mm dimensions and cured for 7 and 28 days. The average compressive strength of the cube for the 7th-day test obtained is 23.45 N/mm2 and the average compressive strength of the cube for the 28th day obtained is 35.76 N/mm2. The slump value obtained for the fresh concrete after three trials are 75 mm, a true slump [14]. The reinforcement detailing of the deep beam is shown in figs a and b. fig 1 and 2 displays plan of normal cocontrol beam and Special Confinement Reinforcement (BSCR).

![Figure. 1 Normal control beam (CB)](image-url)
Figure 2 Special Confinement Reinforcement (BSCR)

The tension reinforcement is four no. of 12 mm ɸ bars, compression reinforcement is two no. of 10 mm ɸ bars, skin reinforcement adopted is four no. of 8 mm ɸ bars, while the shear reinforcement is given as 8 mm ɸ 2-legged stirrups @ 200 mm c/c spacing for the standard control beam (CB) shown in table 1. The tension, compression, and skin reinforcement for the special confinement reinforcement (BSCR) are adopted as same as given for standard control beam while the shear reinforcement is given as 8 mm ɸ 2-legged stirrups @ 64 mm c/c spacing in shear zone and @ 110 mm c/c spacing in flexure zone [15]. Fig 3,4 and 5 depicts reinforcement details and casting of beams.

Table 1 Designation for the beam specimens

| SL.NO | BEAM DESIGNATION | GFRP LAYERS |
|-------|-----------------|-------------|
| 1     | CB              | -           |
| 2     | BSCR            | -           |
| 3     | SCB             | 3           |
| 4     | SBSCR           | 3           |

2.3 WRAPPING OF GFRP SHEETS ON TEST SPECIMENS

The GFRP sheets used for this project study are a Uni-directional cloth fiber with 0.3 mm thick and is usually made with cross glass fiber. These Uni-directional cloth fibers are wrapped all over the beam with the Epoxy resin with its hardener in a 1:9 ratio. First, the resin and hardener were mixed with proper proportion and then applied over the deep beam with the help of the roller after the beam surfaces are adequately cleaned. The GFRP sheet wrapped beams are cured for 3-4 days, and the tests are processed [16].
2.4 LOADING SETUP

The deep beams were tested under a three-point loading condition where the loadings point is given with the distance of l/4 on roller supports. The effective length is 800 mm. 100mm is taken for the support region. The loading frame used in this project has a capacity of about 1000 kN. The load from the hydraulic jack is transferred to the spreader beam, and it is split into three, where the load enters into the beam shown in fig 8. Here the load is applied through a pressure gauge. The deflection values are observed with the help of two dial gauges kept under the beam, each one at both of the supports. Loads were applied continuously with the constant rate, and the corresponding load and deflection value is noted [17]. Fig 6 and 7 represents GFRP and glass cloth fiber in specimen.

3. RESULTS AND DISCUSSIONS

During testing, the deflection for the corresponding applied load is detected using a dial gauge. The two dial gauges are kept at a point below the loading points, each at either support of the span. The load-deflection behavior is noticed. The deflection increases with the load's increment and increases after the reduction in the load after it reaches the ultimate load.
3.1 LOAD VS DEFLECTION

The load-deflection curve for the four specimens at the right side of the span and the left side of the span is shown in fig. 9 and 10, respectively.

![Fig. 9 Load vs. Deflection curve at the right side of the span](image)

![Fig. 10 Load vs. Deflection curve at the left side of the span](image)

From the above graphs, fig.9 shows the maximum deflection of CB is 1.83 mm at 300 kN, whereas the maximum deflection for BSCR is 1.4 mm at 345 kN. The maximum deflection of SCB is 2.11 mm at 335 kN, whereas the maximum deflection for SBSCR is 4.32 mm at 385 kN. Fig.10, the maximum deflection of the CB was 1.85mm at 300 kN, whereas the maximum deflection of BSCR was 1.36 mm at 345 KN. The GFRP strengthened beam SCB shows a maximum ultimate deflection of 2.13 mm at 335 kN, whereas the maximum deflection of SBSCR is 4.38 mm at 385 kN. Compared with the CB, the load-carrying capacity of the special confined reinforcement (BSCR) was increased. The deflection increases as the applied load increases, showing more significant load carrying capacity until the ultimate load. The load-deflection behavior shows slight variations in their curve, and finally, the right side shear region fails due to shear failure.

The initial stiffness of the CB was 197.53 kN/mm. The special confined reinforced beam (BSCR) shows a high stiffness value than CB, which shows that the resistance for deformation increases and exhibits high load-carrying capacity. The SCB also reaches a high stiffness value when they are strengthened with GFRP sheets, whereas SBSCR shows a low stiffness value due to the debonding of the GFRP sheets after the several increment of the applied load, the deflection value increases and also exhibits more significant load-carrying capacity. The energy absorption capacity of the CB, measured as the area under deflection, is the smallest as measured by the slope of the load-deflection curve, and thus the CB has a low ductility compared to the other specimens. The energy absorbed by the BSCR increases up to the ultimate deflection and shows high ductile behavior for the beam with additional shear reinforcements. The GFRP strengthened beams SCB and SBSCR also show high energy absorption capacity in which SBSCR exhibits more excellent absorption than SCB, and the ductile behavior also increases as per the slope of the load that it reaches [18].

3.2 CRACKING PATTERN

Testing is done, and the corresponding observations are recorded. The control beam (CB) reaches the ultimate load of 300 kN with the first initial diagonal crack in the proper side support of the beam, and the first crack load is at 160kN. After the increment of the load, the propagation of crack increases into the widened diagonal crack, and also the crack develops on the left side of the span, and finally, the beam leads to shear failure at the right side shear span region.
In BSCR, the initiation of the crack was delayed after several increments of the load, and the first minor crack was observed at 185kN, and the ultimate load reaches 345 kN. The crack that occurred is a minor crack that starts on the right side shear span at the bottom face of the span, and the beam fails due to the shear failure. The formation of the first yield load cracks is also delayed in BSCR and hence carried a higher load when compared with CB [19]. Fig 11 and 12 shows failure mode.

The GFRP strengthened beams indicate the debonding of the strengthened GFRP sheets with debonding sound at the bottom face of the surrounding the whole beam at the tension face, and the shear cracks may be obtained at the shear region of either of the beams. The SCB beam reaches the ultimate load up to 335 kN with a maximum deflection of 2.12 mm with debonding sound, whereas the SBSCR beam reaches the ultimate of about 385 kN with a maximum deflection of about 4.35 mm[20]. The GFRP strengthened beams SCB and SBSCR show higher load carrying capacity and show high ductile behavior compared with CB and BSCR. The deflection increases gradually more than the CB and BSCR due to the debonding of the GFRP sheets at the bottom face of the beam at the shear zone [21]. Fig 12 and 13 depicts debonding of SCB and SBSCR.

### Table 2 Experimental results of the tested specimens

| Test Specimens | First Crack Load (kN), $P_y$ | First Crack deflection (mm), $\delta_y$ | Ultimate Load (kN), $P_u$ | Avg. Max. Deflection (mm), $\delta_u$ |
|----------------|-------------------------------|----------------------------------------|--------------------------|----------------------------------|
| CB             | 160                           | 0.83                                   | 300                      | 1.84                             |
| BSCR           | 185                           | 0.59                                   | 345                      | 1.38                             |
| SCB            | 196                           | 0.93                                   | 335                      | 2.12                             |
| SBSCR          | 240                           | 1.81                                   | 385                      | 4.35                             |

### Table 3 Load deflection characteristics

| Test Specimens | Initial Stiffness (kN/mm) | Energy Absorption (kN.mm) | Ductility factor |
|----------------|---------------------------|---------------------------|------------------|
|                | Absolute                  | Relative                  | Absolute        | Relative |
| CB             | 197.53                    | 2755                      | 1                | 2.22     | 1       |
| BSCR           | 240.26                    | 3597                      | 1.31             | 2.34     | 1.05    |
| SCB            | 210.75                    | 5384                      | 1.95             | 2.28     | 1.03    |
| SBSCR          | 118.81                    | 11405                     | 4.14             | 2.40     | 1.09    |
4. ANALYTICAL WORK

The finite element method (FEM) for solving engineering and mathematical model issues is the most widely used. ANSYS WORKBENCH 19.2 version of finite element software is used for taking the analytical result for this study. The model of the beam is created as per the beam specifications, and the support conditions are applied. The meshing is done using excellent mesh in order to obtain an accurate result. The loadings are given in the experimental program, and the corresponding load-deflection behavior is obtained [22]. Fig 14,15,16,17,18,19 shows behaviour of beams thorugh ANSYS modelling.

![Fig. 15 Modelling of CB](image1)

![Fig. 16 Modelling of BSCR](image2)

Results obtained from the analytical study are the deformation behavior with the applied loads, which we observed from the experimental study. The beam specimens CB, BSCR, SCB, and SBSCR, are analyzed in ANSYS, and the corresponding deflection is shown in the below figures.

![Fig. 17 Deformation of CB](image3)

![Fig. 18 Deformation of BSCR](image4)
4.1 RESULTS AND DISCUSSIONS

In the analytical study, it is clearly shown that the deformation of the BSCR is reduced due to the implementation of the special confined reinforcement when compared with the control beam (CB). The GFRP sheets strengthened beams are also analyzed, and it shows the increase in the ultimate load-carrying capacity and the increase in the deflection as the GFRP gets debonding. Finally, the comparison between the experimental and the analytical results shows a good correlation in their percentage of variation. Nearly 96% of the experimental observations match the analytical results and are similar and are shown in table.4. The BSCR shows a 30% decrease in the deflection compared with the CB due to the special confining reinforcement [23].

Table. 4 Comparison of Analytical and Experimental results of the test specimens

| Test Specimens | Ultimate Load (kN) | Maximum Deflection (mm) |
|----------------|--------------------|-------------------------|
|                | Experimental       | Analytical               |
| CB             | 300                | 1.84                    | 1.78                     |
| BSCR           | 345                | 1.38                    | 1.37                     |
| SCB            | 335                | 2.12                    | 2.04                     |
| SBSCR          | 385                | 4.35                    | 4.43                     |

5. CONCLUSION

- The experimental and the analytical study was conducted to investigate the effectiveness of the special confined reinforced deep beam and GFRP strengthened deep beams with the control beam, and the following conclusions are drawn.
- The special confinement reinforcement (BSCR) effectively increased the shear capacity of the deep beam by increasing its load-carrying capacity, which also delays its initial first crack load. It shows a 15% increase in ultimate load when the comparison is made with the control beam (CB).
- The GFRP sheets, when it is wrapped with the control beam and special confined beam, it shows an 11.6% increase in their ultimate load when both the test specimens SCB and SBSCR compared with CB.
- The Energy Absorption increases in BSCR with the area under deflection in the load-deflection slope and hence exhibits the high ductile behavior. The BSCR shows a 5.4% increment in their ductile behavior when compared with CB. The Energy Absorption capacity of the GFRP strengthened beams is high compared to the beams unstrengthen with GFRP sheets. SCB and SBSCR show a 3% and 8.1% increase in their ductile behavior than the control beam (CB).
- The Initial Stiffness value for the BSCR increases about 22% compared with the
control beam, which shows that the beam's resistance for deformation is enhanced. The initial stiffness of the SCB shows a 6.7% increase in their resist for deformation, whereas the SBSCR decrease in their stiffness due to the debonding of the GFRP sheets highly due to the high load-carrying capacity is reached.

- The analytical results also correlate with the experimental results in which the BSCR shows a 30% decrease in their deflection range to the CB. Both the experimental and the analytical results show 96% similar matches in their values. The analytical results show the BSCR is highest and it considerably increases the shear capacity of the deep beam.

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