EXPERIMENTAL STUDY ON FAILURE MODES OF RC BEAMS EXTERNALLY STRENGTHENED WITH MULTIPLE LAYERS OF FRP SHEETS

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Abstract. The FRP material plays a major role as strengthening material in RC structural elements. It is popularly used to improve the load carrying capacity and the stiffness in RC structural elements by wrapping with FRP sheets (combination of GFRP & CFRP). The usefulness of FRP laminates in external strengthening at both the sides full and as vertical strips at interval of 100mm on RC beams is studied. In this experimental study nine reinforced concrete beams were cast and in that three beams are control beams and six RC beams are strengthened with one layer of GFRP and another layer of CFRP laminates. The prime aim of the test is to study the effect of FRP laminates in enhancing the strength of the strengthened/wrapped RC beams compared to control beams. The ultimate strength and maximum deflection of reinforced concrete beams by externally bonded with multiple layers of FRP sheets are examined.

Keywords: RC beams, load carrying capacity, both sides full and sides vertical strips 100mm, FRP laminates, controlled beams and wrapped beams.

1. Introduction

In general every structure is designed according to the nature, purpose, and the importance and in turn the design period is decided accordingly. For a residential building, the design period can be twenty-five years, whereas for a public building, it has to be fifty years. Damage or Deterioration in concrete structures is a major challenge to the construction experts in the world. The weakness can be principally because of natural impacts, which incorporates consumption of steel, continuous loss of solidarity with maturing, rehashed focused energy stacking, variety in temperature, contact with synthetics and saline water and openness to bright radiations. As complete substitution or remaking of the construction won't be practical and possible, reinforcing or retrofitting is a viable method for accomplishing the necessary assistance life of the design. Though there are external and internal strengthening techniques in practice widely used techniques for strengthening of RC beams externally is by using epoxy-bonded with various materials like steel and FRP laminates. This technique proves to be an effective method to improve their strength in both flexural and shear deficiencies. Flexural strength of a structural member can be improved by using this technique. Steel bonding technique is simple, cost-effective and efficient, but deterioration of bond at the steel and concrete inter-phase takes place due to corrosion of steel. Generally in framed structures, frames made up of members like columns and beams which are subjected to axial load combined with/without bending and, torsion, bending & shear respectively.
Hence, throughout the world more research works are going on. The technique of retrofitting of concrete beams and columns with externally bonded FRP composites and other elements such as slabs also the application of this technique being extended to increase service life of the structures.

1.1 Strengthening of RC beams
Various methods are utilized to fortify RC radiates with FRP materials. These strategies include the utilization of Externally bonded (EB) overlays, Near surface mounted (NSM) bars/strips, mechanical dock frameworks, or scoring techniques with or without glues. EB FRP reinforcing can be performed with the ideal number of fortifying layers on the pillar in any design, like side holding, U-wrapping, or full wrapping. Fortifying designs by means of outer holding of cutting edge fiber-built up polymer composite has become extremely well known around the world. Therefore, an incredible amount of examination, both trial and hypothetical, has been directed on the conduct of FRP-fortified built up substantial constructions.

1.2 Scope
The beams are strengthened with externally bonded FRP sheets in two layers on both the sides of the beams in full and as vertical strips at 100 mm interval.

1.3 Objective
The main objective is to investigate the failure modes of the control beams and strengthened beams. The ultimate load and the maximum deflection of control beams and strengthened beams to be studied. Further a Comparative study to be carried out to check the experimental results of control beams and strengthened beams.

2. Review Relevance
The reviews of work done by different authors on external strengthening of the RC beams wrapped with various fibre reinforced polymer (FRP) sheets were carried out. The gaps in the literature were identified through this review and thus the objectives for this project were framed. Through the study on research papers the ultimate load carrying capacity of the beams and the cracked beams were strengthened with various FRP (carbon, glass, basalt) laminates with wrapping methods of different shapes were tested until complete failure.

3. Materials and Methods
The properties of materials used for casting of RC beams and two different patterns of strengthening of beams using GFRP and CFRP are extensively discussed.

3.1 Properties of Cement
Preliminary test is defined as conducting experiments on the material and knowing the properties of the material. Cement opc53: The grade of cement is required to confirm the BIS specification IS: 12269-1987 with a designed strength for 28 days being a minimum of 53mpa (or) 530kg/sq.cm.

| SI.NO | Name of Test               | Result |
|-------|----------------------------|--------|
| 1     | Specific gravity           | 3.15   |
| 2     | Normal consistency (%)     | 31     |
| 3     | Initial Setting (min)      | 28     |
| 4     | Final setting (min)        | 570    |
3.2 Properties of Fine Aggregate

| Test particulars | Result obtained |
|------------------|-----------------|
| Specific gravity | 2.67            |
| Fineness modulus | 2.25            |
| Size             | 4.75mm sieve(Zone – 2) |

3.3 Properties of Coarse Aggregate

Tests were conducted to obtain the specific gravity and fineness modulus of the coarse aggregate used in this study as per IS: 2386-1983. The sieve analysis of coarse aggregate has been passing through size of 12.5 mm to the greatest size of 20 mm.

| Test particulars | Result obtained |
|------------------|-----------------|
| Specific gravity | 2.79            |
| Fineness modulus | 5.76            |
| Size             | Passing through 20mm sieve and retained in 12.5mm sieve (Zone – 2) |

3.4 Concrete Mix Proportioning

Concrete mix design for M30 grade concrete proportioned based on IS: 456-2000 after several trial mixes.

| SI NO | Material | Quantity |
|-------|----------|----------|
| 1     | Cement   | 414 kg/m³ |
| 2     | Water    | 186 lit/m³ |
| 3     | F.A      | 730 kg/m³ |
| 4     | C.A      | 1144 kg/m³ |

3.5 Beam Design

![Figure 3.1 RC Beam Details](image)

3.6 Experimental Investigation

3.6.1 Casting of Beams

For the experimental investigation 9 numbers of beam specimens of size 1500mm *200mm * 100mm are cast with M30 grade of concrete. Casting of the beam specimens involve the following processes in sequential order.

3.6.2 Placing of Reinforcement in the Moulds

Reinforcements used in the specimen consists of 2 no's of 10mm φ bars provided in tension zone (bottom) and 2
no's of 8mm φ bars which is provided in compression zone (top) and 6mm φ bars is used as stirrups at a spacing of 150mm centre to centre. Oiling of the mould is done before placing the reinforcements. 25mm cover block were used to keep the reinforcement in position as shown in figure.

![Figure 3.2 Reinforcement Placing in Mould](image)

**3.6.3 Mixing of Concrete**
According to the design mix proper batching of various ingredients has been done. Mixing of concrete has been done thoroughly to ensure that concrete of uniform mix is obtained. To ensure this here machine mixing is adopted.

**3.6.4 Compaction of Concrete**
Compaction is done with help of needle vibrator machine.

![Figure 3.3 Compaction of Concrete](image)

**3.6.5 Curing of Concrete**
After the de-moulding of specimen from the mould the curing has been carried out to prevent the loss of water due to hydration process which takes place once the concrete starts setting. Further the process of curing enhances the hardening of concrete elements due to removal of the entrapped air from the voids.

![Figure 3.4 Curing of Specimens](image)

**3.6.6 Application of Adhesive Material**
Epoxy: Resin and Hardener
Master brace ADH2200 is used as epoxy. Master brace ADH 2200 has two parts, part A & Part B, it is used in the ratio of 1:0.6. The epoxy is applied on the beam before wrapping of the FRP laminate.

![Figure 3.5 Master brace ADH 2200 epoxy resin](image)
3.6.7 Wrapping of RC Beams with FRP Sheets

Three beams are wrapped with multiple layers of FRP sheets of GFRP & CFRP on both sides of the beams to a length of 1200mm, leaving 150mm on each side and to the entire depth of 200 mm. Sufficient time is given for the first layer, GFRP to get dried and then the second layer CFRP is wrapped on the beams.

![Figure 3.6 Sides full wrapped beams](image)

Three other beams are wrapped on the sides with vertical strips of 100mm wide and 200 mm deep at an interval of 100 mm. Initially GFRP strips pasted using the epoxy and then CFRP strips are pasted over the first layer after 24 hrs.

![Figure 3.7 Side wrapped vertical strips 100mm](image)

3.6.8 Testing of Specimens

Once the cubes, cylinders and beams has been dried after curing, the compression strength test, split-tensile strength and flexural strength test of RC beams to be carried out. Tests on cube samples and cylinders have been carried out using UTM. Both the control beams and as well as strengthened beams are tested using the reaction frame. Two LVDT fixed to the beam to study the deflection due to the gradual load applied since the principle behind is the reaction frame ie. The hydraulic jack is working with load control that too application of load by manual operation. The deflection is noted down for every 5Kn in the 20 channel data logger. Application of load continued till the specimen fail and the load at initial crack and the ultimate load also noted. All the deflections and corresponding loads are tabulated and a plot between load and deflection is drawn for the control beam and the strengthened beams.

![Testing setup](image)
4. Experimental Results

**Flexural Test on RC Beams of Control and FRP Wrapped Beams**

Three control beams and three other beams wrapped on the sides with full sheets and three more beams with 100 mm wide vertical strips on both the sides at an interval of 100mm are tested in the reaction frame. The readings of deflections and so also the corresponding loads are noted. From the readings and the graph drawn it is evident that the strengthened beam specimens show enhanced strength than the control beams.

**4.1 Control Beam (CB1, CB2, CB3)**

Three parent beams said to be control beams are used as a reference for the beams strengthened with FRP (GFRP & CFRP). From results, CB1, CB2 and CB3 can deduce that the average maximum load carrying capacity of the control beam is 75 KN. The deflection corresponding to this load is noted. Manual application of the load continued till the specimen failed and the corresponding readings entered in the form of tabular column.

Table 4.1 Flexural beam test on CB1

| Load in KN | LVDT1 in mm | LVDT2 in mm |
|------------|-------------|-------------|
| 0          | 0           | 0           |
| 5          | 0.224       | 0.104       |
| 15         | 0.151       | 0.16        |
| 20         | 0.074       | 0.223       |
| 25         | 0.212       | 0.286       |
| 30         | 0.342       | 0.345       |
| 35         | 0.466       | 0.463       |
| 40         | 0.575       | 0.577       |
| 45         | 0.727       | 0.683       |
| 50         | 0.847       | 0.783       |
| 55         | 0.946       | 0.933       |
| 60         | 1.063       | 1.038       |
| 65         | 1.088       | 1.129       |
| 70         | 1.229       | 1.243       |
| 75         | 1.351       | 1.362       |
Graph 4.1 Load deflection response of CB1

Table 4.2 Flexural beam test on CB2

| Load in KN | LVDT1 in mm | LVDT2 in mm |
|------------|-------------|-------------|
| 0          | 0           | 0           |
| 5          | 1.107       | 0.346       |
| 10         | 1.186       | 0.464       |
| 15         | 1.206       | 0.518       |
| 20         | 1.308       | 0.65        |
| 25         | 1.449       | 0.8         |
| 30         | 1.529       | 0.936       |
| 35         | 1.623       | 1.041       |
| 40         | 1.672       | 1.204       |
| 45         | 1.91        | 1.393       |
| 50         | 2.071       | 1.613       |
| 55         | 2.244       | 1.815       |
| 60         | 2.409       | 2.022       |
| 65         | 2.644       | 2.313       |
| 70         | 2.912       | 2.613       |
| 75         | 2.992       | 2.715       |

Graph 4.2 Load deflection response of CB2
Table 4.3 Flexural beam test on CB3

| Load in KN | LVDT1 in mm | LVDT2 in mm |
|------------|-------------|-------------|
| 0          | 0           | 0           |
| 5          | 1.475       | 0.563       |
| 10         | 1.522       | 0.6549      |
| 15         | 1.663       | 0.792       |
| 20         | 1.782       | 0.918       |
| 25         | 1.828       | 1.003       |
| 30         | 1.963       | 1.098       |
| 35         | 2.109       | 1.234       |
| 40         | 2.261       | 1.372       |
| 45         | 2.461       | 1.558       |
| 50         | 2.571       | 1.67        |
| 55         | 2.732       | 1.822       |
| 60         | 2.956       | 2.029       |
| 65         | 3.203       | 2.15        |
| 70         | 3.355       | 2.328       |
| 75         | 3.487       | 2.498       |

Graph 4.3 Load deflection response of CB3

4.2 Sides Full Wrapped Beam (SFB1, SFB2, SFB3)

This beam are similar to the control beam but having FRP composites of glass fiber reinforced polymer (GFRP) and carbon fiber reinforced polymer (CFRP) fabric applied to both sides full to a length of 1200mm. The beam failed at 100 KN with a maximum deflection of (linear variable displacement transducers) LVDT1 12.44 mm, LVDT2 10.667 mm of SFB1, for SFB2 maximum capacity of the load failed at 95 KN at LVDT1 13.896 mm, LVDT2 10.953 mm response of maximum load deflection and the maximum load failed for SFB3 at 105 KN of maximum deflection LVDT1 13.852 mm, LVDT2 12.250 mm.

Table 4.4 Flexural beam test on SFB1

| Load in KN | LVDT1 in mm | LVDT2 in mm |
|------------|-------------|-------------|
| 20         | 2            | 2           |
| 40         | 4            | 4           |
| 60         | 6            | 6           |
| 80         | 8            | 8           |

CONTROL BEAM – CB3

Graph 4.3 Load deflection response of CB3
Graph 4.4 Load deflection response of SFB1

Table 4.5 Flexural beam test on SFB2

| Load in KN | LVDT1 in mm | LVDT2 in mm |
|------------|-------------|-------------|
| 0          | 0           | 0           |
| 5          | 1.872       | 0.482       |
| 10         | 2.619       | 1.329       |
Graph 4.5 Load deflection response of SFB2

Table 4.6 Flexural beam test on SFB3

| Load in KN | LVDT1 in mm | LVDT2 in mm |
|-----------|-------------|-------------|
| 0         | 0           | 0           |
| 5         | 2.486       | 1.621       |
| 10        | 2.897       | 2.031       |
| 15        | 3.296       | 2.419       |
| 20        | 3.676       | 2.812       |
| 25        | 4.104       | 3.272       |
| 30        | 4.542       | 3.754       |
| 35        | 4.926       | 4.121       |
| 40        | 5.347       | 4.492       |
| 45        | 5.789       | 4.907       |
4.3 Wrapped beam on Sides with Vertical Strips 100mm (SVS100-1, SVS100-2 and SVS100-3)

Three beam specimens wrapped with FRP composites of glass fiber reinforced polymer (GFRP) and carbon fiber reinforced polymer (CFRP) on the sides with vertical strips 100mm wide and 200mm deep at an interval of 100mm. The strengthened beams failed at 85 KN with a maximum deflection of LVDT\(_1\) 9.232 mm, LVDT\(_2\) 9.128 mm of SVS100-1, SVS100-2 has failed at maximum capacity load of 80 KN at maximum load deflection of LVDT\(_1\) 9.335 mm, LVDT\(_2\) 8.982 mm and the beam failure at maximum load for SVS100-3 at 85 KN of maximum deflection LVDT\(_1\) 11.120 mm, LVDT\(_2\) 10.234 mm.

| Load in KN | LVDT1 in mm | LVDT2 in mm |
|------------|-------------|-------------|
| 0          | 0           | 0           |
| 5          | 0.569       | 0.609       |
| 10         | 0.967       | 1.07        |
| 15         | 1.369       | 1.489       |
| 20         | 1.864       | 2.047       |
| 25         | 2.346       | 2.602       |
| 30         | 2.857       | 3.171       |
| 35         | 3.427       | 3.783       |
| 40         | 3.907       | 4.252       |
Graph 4.7 Load deflection response of SVS100-1

Table 4.8 Flexural beam test on SVS100-2

| Load in KN | LVDT1 in mm | LVDT2 in mm |
|-----------|-------------|-------------|
| 0         | 0           | 0           |
| 5         | 2.302       | 1.312       |
| 10        | 2.882       | 1.836       |
| 15        | 3.272       | 2.199       |
| 20        | 3.743       | 2.651       |
| 25        | 4.232       | 3.085       |
| 30        | 4.699       | 3.497       |
| 35        | 5.104       | 3.914       |
| 40        | 5.612       | 4.275       |
| 45        | 6.067       | 4.585       |
| 50        | 6.431       | 4.896       |
| 55        | 6.876       | 5.296       |
| 60        | 7.579       | 5.936       |
| 65        | 7.969       | 6.259       |
| 70        | 8.806       | 6.891       |
| 75        | 9.015       | 7.350       |
| 80        | 9.335       | 8.982       |
Graph 4.8 Load deflection response of SVS100-2

Table 4.9 Flexural beam test on SVS100-3

| Load in KN | LVDT1 in mm | LVDT2 in mm |
|------------|-------------|-------------|
| 0          | 0           | 0           |
| 5          | 1.691       | 1.079       |
| 10         | 2.015       | 1.386       |
| 15         | 2.313       | 1.638       |
| 20         | 2.819       | 2.051       |
| 25         | 3.274       | 2.417       |
| 30         | 3.814       | 2.827       |
| 35         | 4.265       | 3.258       |
| 40         | 5.348       | 3.897       |
| 45         | 5.809       | 4.352       |
| 50         | 6.376       | 4.898       |
| 55         | 8.398       | 5.925       |
| 60         | 9.059       | 6.478       |
| 65         | 9.639       | 7.025       |
| 70         | 9.945       | 8.283       |
| 75         | 10.248      | 9.125       |
| 80         | 10.785      | 9.898       |
| 85         | 11.120      | 10.234      |
5. Conclusion
When compared to the control beams the load carrying capacity is more in the strengthened beams.

- It is concluded that the ultimate load for the strengthened beams on sides full is 100Kn and sides vertical strips at interval 100mm is 90kN.
- The increase in the load carrying capacity of the beams strengthened on both the sides full is 33.33% than the control beams.
- Additional capacity is noted on the strengthened beams on the sides with vertical strips 100mm wide and 200 deep at an interval of 100mm to 20% more than control beams.
- The properties of fiber reinforced polymer materials are; FRP have a low weight but are incredibly strong. It has good fatigue, impact and compression properties.
- The deflection of RC beams increase with increase in the number of layers. Hence from the performance of the study on flexural strengthening of RC beams the hybrid layers help in increased strength of RC beams in flexural increased after wrapping the GFRP and CFRP composites.

It tends to be closed from the trial results the strengthening of RC beams with the FRP materials brings about an increment in load conveying limit just as an expansion in firmness. Likewise this method is generally incredible for fortifying of cement primary supported individuals. These outcomes show that the utilization of FRP materials at whatever point required by thinking about of the FRP sheets with numerous layers does really expands the strength of the bars and gives extra burden conveying limit.
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