Experimental Study on the Performance of RC Beams Strengthened with CFRP

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Abstract:
The Reinforced concrete structures constructed earlier to 1990’s are found to be distress due to several causes. The structure requires immediate attention and evaluation to know the cause of distress and require suitable precautions or remedial measures to bring the structures back to their functional use. The performance enhancement of such deficient structural elements is referred to as strengthening of structural members. The Strengthening of Reinforced concrete member with externally applied carbon fiber reinforced polymers is an accepted option for repair and rehabilitation of structures which will improve the load carrying capacity as well as the stiffness of the member. In future buildings should be modern and stable, in such cases to increase stiffness and stability of structures strengthening of structural elements is essential. The study was carried out on the conventional reinforced concrete beam designated as control beam and reinforced concrete beams strengthened with Carbon Fiber Reinforced Polymers (CFRP). The study contains an experimental investigation on the structural behavior of strengthened reinforced concrete beams. The results of reinforced concrete beams strengthened with Carbon Fiber Reinforced Polymers showed that there is a significant improvement in load carrying capacity and stiffness of the beams. Hence enhancing the structural performance of the Reinforced concrete member with Carbon Fiber Reinforced Polymers is an acceptable option.

Keywords: Carbon Fiber Reinforced Polymers (CFRP), Control beam, Strengthening, Ultimate load, Stiffness, Failure pattern.

1. INTRODUCTION

In the field of structural engineering, new contemporary researches were carried out using advanced materials in order to build structures with better strength aspect. Due to new innovations the plain cement concrete was introduced with steel members and it gives quite satisfactory results but the problem is that the steel member introduced in the plain cement concrete may get corroded if it’s affected by aggressive environment. To overcome this, new ideas emerged and one of such kind is strengthening or retrofitting and it is applied on old structures, and structures in seismic zone to resist their structural collapse. The Strengthening can be achieved by using composite materials. By effectively doing strengthening process, we can improve the strength of existing structures against seismic activity. The maintenance and upgrading of structural members are one of the most important problems in civil engineering. Moreover, a large number of structures constructed previously in the past using the older design codes in different regions of the world are structurally unsafe according to the present guidelines of IS design codes for seismic and wind forces as many regions upgraded and updated to higher seismicity. Since replacement of such deficient elements of structures is a problem and require much public money and time, hence strengthening has become the acceptable way of improving their stability, load carrying capacity and extending their service lives. In infrastructure decay and degradation caused by deterioration of buildings and structures has led to the investigation of several methods for repairing or strengthening purposes. One of the challenges in strengthening of concrete structures is selection of a strengthening method that will enhance the strength and serviceability of the structure while addressing limitations such as constructability, building operations, and budget.

Investigation of the behavior of CFRP strengthened reinforced concrete structures and members have become a very important research field. In terms of experimental application several studies has been done to study the behavior of strengthened beams and how various parameters influence its behavior. The FRP composites are different from traditional construction materials such as steel or Aluminum. The FRP composites are anisotropic whereas steel or aluminum is isotropic. Composite materials are made from two or more constituent materials with significantly different physical and chemical properties that when combined produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. Technologically the most important composite are those in which the dispersed phase is in the form of fiber. The fibers are either long or short. Long and continuous fibers are easy to orient and process, whereas short fibers cannot be controlled fully for proper orientation. The principal fibers in commercial use are various types of glass, carbon, graphite and Kevlar. All these fibers are incorporated in matrix form either in continuous length or in discontinuous length. The polymer is most often epoxy, but other polymers, such as polyester, vinyl ester or nylon, are sometimes used. The properties of FRP depend on the layout of the fiber, the proportion of the fibers relative to the polymer and the processing method. A survey of existing residential building reveals that many buildings are not adequately designed to resist earthquake. In the recent revision of the Indian earthquake code, (IS1893-2002) many regions of the country were placed in higher seismic zones. As a result many buildings designed prior to the revision of the code may fail to perform adequately as per the provisions of the new code. It is, therefore, recommended that the existing deficient buildings be retrofitted to improve their performance in the event of an
earthquake and to avoid large scale damage to life and property. Experimental study involves the determination of ultimate load by the beams under four point loading condition and corresponding load deflection curve was plotted.

II. MATERIALS AND EXPERIMENTAL PROCEDURE

Materials – Ordinary Portland cement of 53 grade satisfying the requirements of IS 12269-1987 was used for the investigation. The initial setting time was 75 minutes with a specific gravity of 3.15. The sand passing through 4.75 mm sieve is used as fine aggregate its fineness modulus is 2.8. The maximum size of coarse aggregate was 20mm. The potable water free from suspended particle and chemical substances was used for mixing and curing of concrete. Design concrete mix of 1:1.79:2.76 by weight is used. The water cement ratio of 0.5 is used and carbon fiber reinforced polymer sheets were used. Fiber reinforced polymer/plastic is a recently developed material for strengthening of RC and masonry structure. It has been found to be an effective replacement of steel plates for strengthening of columns by exterior wrapping. The main advantage of FRP is its high strength to weight ratio and high corrosion resistance. FRP plates are two to ten times stronger than steel plates, while their weight is just 20% of that of steel. However, at present their cost is high. FRP composites are corrosion resistant. FRP plates are two to ten times stronger than steel, while their weight is just 20% of that of steel.

Preparation of Composite - The Materials used for the preparation of composite were CFRP, Epoxy resin and hardener. Fiber made by mechanical interlocking of fiber themselves or with a secondary material to bind these fibers together and hold them in place, giving the assembly sufficient integrity to be handled. Fabric types are categorized by the orientation of the fibers: Unidirectional, 0/90°, Multi-axial, and random. The orientation and weave style of the fiber fabric is chosen to optimize the strength and stiffness properties of the resulting material.

Casting - The design mix ratio was adopted for casting the beams having the ratio of 1:1.79:2.76. There are 10 beams were casted. 5 beam as under reinforced beam specimen and other 5 beams as balanced reinforced beams for the strengthening. For the under reinforced beams 2 bars of 10 mm diameter provided as top and bottom reinforcement whereas transverse stirrups provided as 8 mm at a distances 125mm and for balance reinforced beams top reinforcement provided was 2 bars of 10 mm diameter, bottom reinforcement provided was 2 bars of 12 mm diameter whereas transverse stirrups provided as 8 mm at a distances 125mm C/C. The under reinforced and balance reinforced beam each had one control beam; another two beams were wrapped at the bottom with single and double layer of CFRP whereas other two beams were wrapped in U shaped with single and double layer of CFRP. The dimensions of all the beams are identical. The length of the beams was 1300 mm and cross sectional dimensions were 150x200mm. The typical reinforcement arrangement is shown in figure 2.

Strengthening of Beams - Hand layup method was used for strengthening of beams. The surface of the beam after curing was made rough and then cleaned with water to remove all dirt for the proper bonding with the CFRP. Then the beam was allowed to dry for 24 hours. Initially the required CFRP is cut for require size from the sheet to apply on RC beam. Then CFRP was placed on the top of epoxy resin and another coating of resin was applied on the top of the CFRP. This operation carried out at room temperature and is allowed to dry and achieve enough bonding with the beam member under sunlight for 6 hours as shown in fig 3 and fig 4.

Experimental study - All the specimens were tested in the loading frame of capacity 50 tones. The test procedure of all under reinforced and balance reinforced beam is same. After the curing period of 28 days all beams were washed and its surface is made clean for clear visibility of cracks. Load is
applied gradually on the member and the initial crack was observed on the member then loading is continued up to ultimate load carrying capacity of beam and corresponding deflection in beam is noted with the help of LVDT. The load deflection curve was plotted. The loading arrangements for testing of all sets of beams are as shown in figure 5 and 6, whereas crack pattern of beam is shown in figure 7.

The Load Deflection Curve of Under Reinforced beams strengthened with CFRP shown in fig 8 states that the control beam has the lowest load carrying capacity of 120KN with a deflection of 15 mm, the single layer bottom wrapped has the next better load carrying capacity of 135KN with a deflection of 10.6 mm, the single layer U Shape wrapped has the next better load carrying capacity of 140KN with a deflection of 10.1 mm, the double layer bottom wrapped has the next better load carrying capacity of 160KN with a deflection of 11.2 mm, the Double layer U shape wrapped has the highest load carrying capacity of 165KN with a deflection of 10.2 mm. This shows Double layer U shape wrapped beam has the highest load carrying capacity with less deflection. Hence it has the maximum stiffness.

The Load Deflection Curve of Balance Reinforced beam strengthened with CFRP shown in fig 9 states that the control beam has the lowest load carrying capacity of 130KN with a deflection of 12.4 mm, the single layer bottom wrapped has the next better load carrying capacity of 145KN with a deflection of 11.4 mm, the single layer U Shape wrapped has the next better load carrying capacity of 150 KN with a deflection of 10.7 mm, the double layer bottom wrapped has the next better load carrying capacity of 170KN with a deflection of 11 mm, the double layer U shape wrapped has the highest load carrying capacity of 175KN with a deflection of 11.4 mm. This shows double layer U shape wrapped beam has the highest load carrying capacity with less deflection. Hence it has the maximum stiffness.

III. RESULTS AND DISCUSSION

The average compressive strength of M20 grade concrete cube of size 150X150X150mm obtained is 29N/mm².
The percentage increase in load carrying Under Reinforced Beam strengthened with Single layer of CFRP at the bottom (USB) is 12.5% whereas the percentage increase in load carrying capacity of under reinforced beam strengthened with U shaped single layer of CFRP (USU) is 16.67% with respect to control beam. The percentage increase in load carrying Under Reinforced Beam strengthened with double layer of CFRP at the bottom (UDB) is 33.33% with respect to control beam whereas the percentage increase in load carrying capacity of under reinforced beam strengthened with U shaped double layer of CFRP (UDU) is 37.5% with respect to control beam. The under reinforced beam strengthened with U shaped double layer of CFRP is the most effective beam member. The Ultimate load carrying capacity of Balance reinforced beam is shown in fig 10.

![Ultimate load carrying capacity of Balance reinforced beams](image)

**Figure 11. Ultimate load carrying capacity of Balance reinforced beams**

The percentage increase in load carrying of Balance Reinforced Beam strengthened with Single layer of CFRP at the bottom (BSB) is 11.54% with respect to control beam whereas the percentage increase in load carrying capacity of balance reinforced beam strengthened with U shaped single layer of CFRP (BSU) is 15.38% with respect to control beam. The percentage increase in load carrying Balance Reinforced Beam strengthened with double layer of CFRP at the bottom (BBD) is 30.77% with respect to control beam whereas the percentage increase in load carrying capacity of balance reinforced beam strengthened with U shaped double layer of CFRP (BDU) is 34.62% with respect to control beam. The balance reinforced beam strengthened with U shaped double layer of CFRP is the most effective beam member. The Ultimate load carrying capacity of all beams is shown in fig 11.

**Table 1. Result data of tested beams**

<table>
<thead>
<tr>
<th>S/NO</th>
<th>Designation</th>
<th>Load (KN)</th>
<th>Strenthened Beam % Increase</th>
<th>Control beam</th>
<th>Average %</th>
<th>Ductility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UC</td>
<td>120</td>
<td>1</td>
<td>0</td>
<td>1.25</td>
<td>2.24</td>
</tr>
<tr>
<td>2</td>
<td>USB</td>
<td>135</td>
<td>1.13</td>
<td>12.5</td>
<td>1.66</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>UDB</td>
<td>160</td>
<td>1.33</td>
<td>33.33</td>
<td>25</td>
<td>1.62</td>
</tr>
<tr>
<td>4</td>
<td>USU</td>
<td>140</td>
<td>1.17</td>
<td>16.67</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>UDU</td>
<td>165</td>
<td>1.38</td>
<td>37.5</td>
<td>1.55</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>BC</td>
<td>130</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>BSB</td>
<td>145</td>
<td>1.12</td>
<td>11.54</td>
<td>1.63</td>
<td>1.68</td>
</tr>
<tr>
<td>8</td>
<td>BDB</td>
<td>170</td>
<td>1.31</td>
<td>30.77</td>
<td>23.08</td>
<td>1.59</td>
</tr>
<tr>
<td>9</td>
<td>BSU</td>
<td>150</td>
<td>1.35</td>
<td>15.38</td>
<td>1.57</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>BDU</td>
<td>175</td>
<td>1.35</td>
<td>34.62</td>
<td>1.52</td>
<td></td>
</tr>
</tbody>
</table>

The average percentage increase in load carrying capacity of under reinforced beam is 25% whereas the average percentage increase in load carrying capacity of under reinforced beam is 23.08%. This shows that the under reinforced beams have 1.92% more percentage increase in load carrying capacity because it is more ductility than balance reinforced beams and can undergo long deformation. The percentage increase in load carrying Under Reinforced Beam strengthened with single layer of CFRP at the bottom (USB) is 12.5% with respect to control beam and having a ductility of 1.66 whereas the percentage increase in load carrying of Balance Reinforced Beam strengthened with Single layer of CFRP at the bottom (BSB) is 11.54% with respect to control beam and having a ductility of 1.63. This shows that the under reinforced beam has 0.96% percentage increase in load carrying capacity more than balance Reinforced Beam because it is more ductility than balance reinforced beams and can undergo long deformation. The percentage increase in load carrying capacity of under reinforced beam strengthened with U shaped single layer of CFRP (USU) is 16.67% with respect to control beam and having a ductility of 1.6 whereas the percentage increase in load carrying capacity of balance reinforced beam strengthened with U shaped single layer of CFRP (BSU) is 15.38% with respect to control beam and having a ductility of 1.57. This shows that the under reinforced beam has 1.28% percentage increase in load carrying capacity more than balance Reinforced Beam because it is more ductility than balance reinforced beams and can undergo long deformation. The percentage increase in load carrying Under Reinforced Beam strengthened with double layer of CFRP at the bottom (UDU) is 33.33% with respect to control beam and having a ductility of 1.62 whereas the percentage increase in load carrying capacity of balance reinforced beam strengthened with U shaped double layer of CFRP (BDU) is 34.62% with respect to control beam and having a ductility of 1.52. This shows that the under reinforced beam has 2.88% percentage increase in load carrying capacity more than balance Reinforced Beam because it is more ductility than balance reinforced beams and can undergo long deformation.

**IV. CONCLUSIONS**

Based on the experimental results the following conclusions can be made:

- The beams strengthened with CFRP shows less deflection than control beam which confirms that the strengthened beams have more stiffness than control beam.
- The percentage increase in load carrying capacity of Under Reinforced Beam strengthened with single layer and double layer of CFRP at the Bottom is 12.5% and 33.33% respectively with respect to control beam.
- The percentage increase in load carrying capacity of under reinforced beam strengthened with U shaped single
layer and double layer of CFRP is 16.67% and 37.50% respectively with respect to control beam.

- The percentage increase in load carrying of Balance Reinforced Beam strengthened with single layer and double layer of CFRP at the Bottom is 11.54% and 30.77% respectively with respect to control beam.
- The percentage increase in load carrying capacity of balance reinforced beam strengthened with U shaped single layer and double layer of CFRP is 15.38 % and 34.62% respectively with respect to control beam.
- The average percentage increase in load carrying capacity of under reinforced beam is 25% with respect to control beam specimen.
- The average percentage increase in load carrying capacity of balance reinforced beam is 23.08 % with respect to control beam specimen.
- The under reinforced beams has more percentage increase in load carrying capacity because it is more ductility than balance reinforced beams and can undergo long deformation.
- The ultimate load carrying capacity of all the strengthened beams is higher when compared with controlled beam.

**V. ACKNOWLEDGEMENT**

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