Retrofitting of RC Beams using Glass Fiber Reinforced Polymer Sheets: an Experimental Study

Rohit Vasudeva* and Mandeep Kaur

School of Civil Engineering, Lovely professional university, G.T. Road, Phagwara, Jalandhar-Delhi, Punjab –144411, India; rohitvasudeva.ce@gmail.com, mandeep.kaur@lpu.co.in

Abstract

Objective: An experimental investigation to check flexure and shear behavior of Reinforced concrete (RC) beams retrofitted with glass fiber reinforced polymer composites. Methods/Analysis: Two point symmetric loading. In this study two set of beams were cast out of those first set was weak in flexure (A) and second was weak in shear (B). In all beams same grade of concrete was used but with different structural detailing. In set A three beams (weak in flexure) were cast out of which one was control beam and other two were retrofitted using Glass Fiber Reinforced Polymer Sheets (GFRP) sheets in soffit of beam and till neutral axis including soffit. In set B three beams (weak in shear) were cast out of which one was control beam and other two were retrofitted by using GFRP sheets on sides and U-jacking at corners respectively. Hand wet lay-up method was used for application of GFRP sheets on beam. The retrofitting of beams was done with different amount and configuration of GFRP sheets. Retrofitted RC beams with epoxy-bonded glass fiber reinforced sheets were tested till failure using a symmetric two point loading system. Load, deflection, failure modes and crack pattern of each beam was recorded for a particular GFRP orientation. Experimental investigation concluded that there was increase in load at initial crack and also at ultimate failure for retrofitted beams as compare to control beams. Failure in case of set A retrofitted beams was flexural shear failure. It was also recommended that flexural retrofitting should be performed along with shear retrofitting. In case of set B beams failure was shifted to flexural failure which was initially shear failure. So retrofitting in shear zones was observed most effective. Finding: Retrofitting in shear zones was observed most effective in case of ultimate, flexural failure and shear failure.

Keywords: Epoxy Resin, Glass Fiber Reinforced Polymer Sheets, Retrofitting, Weak in Flexure, Weak in Shear

1. Introduction

Retrofitting is modification of existing structures to make it more resistant to external forces like seismic forces, wind force and vibrational forces. In case of increase in live load, accidental loads and in excessive severe environmental conditions; we need to redesign building as per new load combinations. Generally we have to take decision that whether to demolish the building or retrofit it. It will depend upon the stressing level of the structure. Also it is to be checked that retrofitting system is capable of taking increased loads or not, if not, structure should be demolished. Many times it is seen that with some restoring measures, building can be retrofitted and the age could be increased for some more years. Depending upon the conditions, various methods of retrofitting can be used, but these can be chosen as per experience. Some methods of retrofitting are by using steel plates and jacketing of steel to structural elements, using steel bars bonded to structural elements external pre-stressing for the bridge...
girders, chemical methods (filling up the cracks by chemicals or adhesives) and using Fibre-Reinforced Polymer (FRP) composites bonded to surface of concrete. One of the techniques out of these for strengthening is externally bonded glass fiber reinforced sheets applied externally by wet layup method. Inclined GFRP sheet were used for retrofitting of beams weak in shear. Detail study was done on orientation, width and spacing of GFRP strips and their effect on re-strengthening of flexural members. It was concluded that shear strength was improved by external application of GFRP. As tensile strength of glass fiber reinforced polymer sheet is quite good so it can be used as strengthening material in tension face of flexural members. Also a similar study was performed for shear strengthening of RC beams using hybrid composite plates fabricated by using kenaf fibers and carbon fibers. It was observed that on addition of 10% of kenaf fibers the tensile strength of hybrid composite plate was increased up to 130% from standard carbon fiber plate. FRP jackets made up of glass fiber were used as strengthening material on 4.55m long beams. They used 40 mm thick jacket for strengthening and for retrofitting. They concluded that proposed technique is effective in ultimate and serviceability limits. These fibers are available in market in form of sheets and they can be bonded with epoxy resin to get hardened material which possesses a good tensile strength. FRP has been used in buildings damaged because of seismic loads or due to creep also. It may be also beneficial in non-seismic zones too and also can be used for increasing the axial load carrying capacity of columns which are under higher vertical loads. Beams and slabs may be strengthened in flexure by use of FRP composites bonded to their tension zone using epoxy as a common adhesive for strengthening purpose. Recently an experimental was conducted on study of structurally damaged RC beams retrofitted with help of Carbon Fibre-Reinforced Polymer (CFRP) bonded externally. They concluded that there was 23% increase in for retrofitting in shear and 7% to 33% in case of retrofitting in flexure. The main failure mode in testing was de-bonding which reduced the effectiveness of retrofitting. It was also recommended that numerical analysis should be done before to predict the behavior of retrofitted beams so that suitable orientation should be selected. As casting of slab and beams are done monolithically so it also important to study the behavior of T beams with externally bonded laminates. Behavior of RC beams (T type) was studied, which were strengthened as well as to improve shear strength of beam by using CFRP sheets. It was concluded that in strength was increased considerably. Hence, FRP composites are effective and economical. As majority of study was done on Carbon fibers and glass fiber of type unidirectional and bidirectional, but there is lack of research for un-directional glass fiber reinforced polymers. So in this study un-directional glass fiber sheets were used which were locally available. This experimental investigation was performed to investigate the flexural and shear behavior of the Re-in forced Cement Concrete (RCC) beam with the different orientation of GFRP sheets. In more detail effect of GFRP sheets bonded to RCC beams is to be investigated on the strength and ductility of beams. In this study two set of beams (a) weak in Flexure (b) weak in shear were cast and tested up to failure. Set beams were cast, in which one was control beam and other two were retrofitted by using GFRP sheets in bottom middle of beam. Set B beams were casted, in which one was control beam and other two were retrofitted by using GFRP sheets at edges. The retrofitting of beams is done with different amount and configuration of GRFP sheets. Experimental data of load, deflection, failure modes and crack pattern of each beam was obtained. Hand wet lay-up method of application of epoxy was included. The effect of different GFRP orientation on ultimate load carrying, deflection and failure mode of the beam were investigated.

2. Material for Casting of Concrete

**Cement:** Ordinary Portland Cement (OPC) 43-grade was used for casting of beams. Cement used was confirming as per IS 8112:1989. The specific gravity was 3.15. The initial and final setting time was 30 min and 600 min respectively.

**Coarse aggregate:** Locally available crushed stones, basalt stone were used for casting of concrete. Both 10mm
and 20 mm aggregates were used. The material satisfied IS 383-1970. The specific gravity of 10mm and 20mm was 2.67 and 2.7 respectively. Water absorption was 0.75%.

**Fine aggregates:** Locally available river bed sand was used as per IS: 383-1970 provision it was in range of zone II. Specific gravity of CA was 2.6 and water absorption was 1.5%.

**Water:** Tap water was used for the casting of concrete and curing of concrete. Water should fulfill all requirements as per IS 456-2000.

**Fiber Sheet:** Fiber sheet used in current investigation was E-glass Figure 1. Its nature was un-directional woven glass fiber mat. This wasn’t reactive to atmospheric agents. Glass fiber mat was also non corrosive in nature.

**Mix proportion**

Design mix of M 25 concrete is done by IS 10262 2009.

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>320.00 Kg</td>
<td>= 1</td>
</tr>
<tr>
<td>Water</td>
<td>144.00 Kg</td>
<td>= 0.45</td>
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<tr>
<td>FA</td>
<td>765.84 Kg</td>
<td>= 2.39</td>
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<tr>
<td>CA</td>
<td>1237.8 Kg</td>
<td>= 3.86</td>
</tr>
<tr>
<td>10mm</td>
<td>618.94 Kg</td>
<td></td>
</tr>
<tr>
<td>20mm</td>
<td>618.94 Kg</td>
<td></td>
</tr>
<tr>
<td>Admixture</td>
<td>3.2 Kg</td>
<td></td>
</tr>
</tbody>
</table>

**Ratio of concrete mix** = 0.45: 1: 2.39: 3.86

**Epoxy Resin:** Epoxy resins are relatively low molecular weight pre-polymers. In civil engineering industry, for coating and bonding purpose epoxy resins are used. The epoxy resin is two part system, resin as adhesive and hardener as catalyst.

The resin and hardener used in this our study are Araldite LY. 556. and Hardener HY. 951.

**2.1 Specimen Layout**

Two set of beams were cast in this experimental investigation Figure 2, Figure 3. In set A, 3 number of beams (F1, F2, and F3), which were weak in flexure were cast using M25 concrete grade and Fe 415 grade of steel. In set B 3 number of beams (S1, S2, S3), which were weak in shear were casted using M25 grade of concrete and Fe
415 grade of steel. The dimensions of all the beams were same. Beam is 1350 mm long and having area of cross-section 150mm* 200 mm. In set a beams 2 numbers 10 mm diameter High Yield Strength Deformed (HYSD) bars were used all through as main reinforcement and 2 legged, 8 mm diameter bars @ 225 mm C/C were used as stirrups. In set B beams 3 number 10 mm diameter HYSD bars were used all through as main reinforcement without any stirrup but U- rings of 8 mm diameter @ 350 mm C/C were used to tie hanging bars in compression zone. In both set of beams hanging bars of 8 mm diameter all trough were used.

2.2 Mixing of Concrete

Raw materials of concrete should be mixed in such a manner so that uniform quality of concrete should be obtained. In our work hand mixing was done. Raw materials were weighed according to the design mix and poured into the tray. 10% extra cement was used because of hand mixing. Firstly materials were mixed without water for some time till uniform texture was obtained. After that water was added in slowly. Mix was mixed three times to obtain proper consistency. Cement and sand mortar was used for finishing the top surface of beam. A square pointed D-handled shovel was used to give final finishing.

2.3 Retrofitting of Beams

First step before application of FRP sheets on surface of beam Figure 4, the area on which GFRP sheet was to be bonded was made rough using sand paper. After making surface ready for application of GFRP sheet, epoxy resin was mixed as per the manufacturer’s instructions. Mixing was done in jug with Araldite LY. 556 – 100 parts by weight and Hardener HY 951 - 7.5 parts by weight. It was mixed till uniformed texture. On other side fiber sheets were cut as per the requirement. Ready epoxy resin was applied on the surface of beam with help of paint brush Figure 5. The glass fiber sheets were placed on the sur-

![Figure 2. Structural detailing of set A beams.](image2)

![Figure 3. Structural detailing of set B beams.](image3)
face of the beam and epoxy resin was applied gently with help of brush. With help of roller air bubbles entrapped in the sheet were removed. Then 2nd layer of epoxy resin was applied over the first sheet and second layer of glass fiber was placed on top of epoxy resin coating. Same procedure was followed again. This whole work was performed at room temperature.

2.3 Retrofitting of Beams

The experimental data was obtained for loads, deflections and failure modes. The change in ultimate load carrying capacity, load at initial crack, deflections at points (L/3, L/2), cracking patterns and modes of failure were inves-

![Figure 4. Application of epoxy resin on glass fiber sheet.](image1)

![Figure 5. Application of epoxy resin on second layer of glass fiber sheet.](image2)
tigated as per configuration and amount of GFRP sheets applied.

2.3.1 Experimental Set Up

Beams were cured for 28 days and then they were cleaned with water so that cracks should be visible. Two point loading arrangement was used for testing of beams. The beam was placed over the two steel rollers bearings leaving 75 mm from the both sides of beam. Rest of the part was equally divided in to three equal parts. Load was applied by loading cell of 1000 kN. Two dial gauges were used for recording deflection. One dial gauge was placed at center and other was placed under the one of the point load.

2.3.2 Testing of GFRP Sheets

Double layer GFRP sheets having uniform cross-section and thickness, were fabricated for testing in Universal Testing Machine (UTM). From test it was calculated that ultimate load bearing capacity is 171.9 MPa.

3. Results and Discussion

The parameters which were studied were:

- Failure mode;
- Deflections at mid and one by third of span
- Load at first crack;
- Ultimate load when failure took place;
- Cracking patterns;

3.1 Failure Modes

The GFRP Retrofitted beams were tested to get ultimate load carrying capacity. In this process we got the various modes of failures Table 1.

- Control beams F1 and S1 failed in flexure and shear as they were designed weak in flexure and weak in shear respectively.
- In set A beam F2 failed due to fracture of GFRP sheets into two parts and then flexure shear failure took place.
- Beam F3 failed because of de-bonding of GFRP sheets after fracture in GFRP sheets then flexure shear failure took place.
- In set A beams F1 and F2 main cause of failure was GFRP rupture and flexure shear failure.
- In set B beam S2 failed due to flexural failure, rupture of GFRP sheet and crushing of concrete on top of beam.

<table>
<thead>
<tr>
<th>S.no</th>
<th>Type of beam</th>
<th>Beam designation</th>
<th>Load at initial crack(kN)</th>
<th>Ultimate load(kN)</th>
<th>Nature of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Set A beams weak in flexure</td>
<td>F1</td>
<td>42.61</td>
<td>110.78</td>
<td>Flexure failure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F2</td>
<td>48.28</td>
<td>147.28</td>
<td>GFRP rupture and flexure shear failure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F3</td>
<td>69.39</td>
<td>158.98</td>
<td>GFRP rupture and flexure shear failure</td>
</tr>
<tr>
<td>2</td>
<td>Set B beams weak in shear</td>
<td>S1</td>
<td>49.70</td>
<td>116.32</td>
<td>Shear failure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S2</td>
<td>55.38</td>
<td>152.86</td>
<td>Flexure failure and crushing of concrete</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S3</td>
<td>56.80</td>
<td>173.25</td>
<td>Flexure failure and crushing of concrete</td>
</tr>
</tbody>
</table>
• In set B beam S3 failed due to flexural failure, debonding of GFRP sheet and crushing of concrete on top of beam.
• In set B beams flexural failure was main dominating failure.

3.2 Load Vs. Deflection Study
The mid span deflection and deflection at one third spans was recorded for all the beams. These deflections were compared with all other beams. Also load vs. deflection behavior between two schemes was also compared Figure 6 and Figure 7.

3.3 Loads at Initial Crack
When set A and set B beams were tested under two point loading, load, deflection and crack propagation were noted, with gradual increment of load. When first crack

![Figure 6. Load vs. deflection curve for beam F1, F2 and F3.](image)

![Figure 7. Load vs. deflection curve for beam S1, S2 and S3.](image)
in beam was observed load was recorded and show in Figure 8 and Figure 9.

Discuss all the results and corresponding discussions in this section. Make sure a proper that proper coherency is maintained and appropriate discussions are included.
3.4 Ultimate Load Carrying Capacity

Ultimate load carrying capacity of set A beams and set B beams are shown in Figure 10 and Figure 11. All beams were loaded up to their failure load and from this investigation it was found out control beam failed at lower loads as compare to retrofitted beams. It was noticed that GFRP sheet possess high tensile strength and enhance ductility of beam. As if nature of failure is shear it will result sudden failure but after using GFRP sheets failure is more ductile. It gives enough warning before failure. GFRP also delayed initial cracks and their further propagation.

![Figure 10. Ultimate load vs. initial crack (KN) of set A beams.](image)

![Figure 11. Ultimate load vs. initial crack (KN) of set B beams.](image)
Crack Pattern

Set A beams

i. In set A, in beam F1 wide cracks with larger spacing were observed, but in beams F2 and F3 cracks were small and closely spaced which indicates that GFRP had improved confinement of concrete.

ii. Because of proper bonding of GFRP with concrete, instead of steel failure, peeling of GFRP occurred. It means failure was shifted from flexural failure to flexural shear failure.

iii. Initially cracks were propagating in vertical direction but with increase in load they started propagating incline, which means failure was flexural shear failure.

Set B beams

i. In set B, cracks started from center of the shear span and started widening up, moving towards point of loading.

ii. Cracks were propagating at an angle of 45 degrees with horizontal.

iii. In beams S2 and S3 were vertical and were more closely spaced.

4. Conclusion

In the current experimental investigation flexural and shear behavior of RC beams retrofitted with GFRP sheets in examined. Six numbers of beams were casted in two sets i.e. set A and set B. The various conclusions drawn from this experimental investigation are:

Set A (F1, F2 and F3)

i. In case of beam F3 initial cracks appeared on higher loads as compared to beam F1 and F2. Load at initial crack for beam F2 was 13.32% more than beam F1. For F3 Ultimate load was 43.5% more than beam F1. Also Ultimate load for beam F3 was 7.93% as compared to beam F2.

ii. Beams which were not retrofitted failed in flexure but others failed in flexural shear failure. As flexural shear failure is more dangerous than flexural failure as it gives less warning before failure. So it is recommended that when we need to retrofit beam in flexure, shear retrofitting is also required.

iii. As in case F3 U-jacketing was used for retrofitting ultimate load carrying capacity increase but initial cracks appear at higher loads. So it will not give any early warning to failure compared to beam F2.

iv. U-type wrapping does not increase significantly in ultimate load but material required for U-jacketing is nearly three time more as compared to retrofitting at soffit.

Set B (S1, S2 and S3)

i. Beam S1 failed in shear which was weak in shear.

ii. In case of beam S2 and S3 initial cracks appeared on higher loads as compared to beam S1. Load at initial crack for beam S2 was 11.4% more than beam S1. For S3 load at initial crack was 14.27% more than beam S1. Also load at initial crack for S3 was 2.55% as compared to beam S2.

iii. In case of beam S2 and S3 failure was observed at higher loads as compared to beam S1. Ultimate load for beam S2 was 31.41% more than S1. For beam S3 Ultimate load was 48.9% more than beam S1. Also Ultimate load for beam S3 was 13.33% as compared to S2.

iv. When beam is retrofitted in shear zone it fails in flexure which gives sufficient warning before failure.

v. As bonding between GFRP and concrete is quite strong it means that GFRP and concrete behaves as composite.

vi. As cracks in shear zone were very less so application of GFRP in improving shear strength is very effective technique.
5. References


