Retrofitting of Reinforced Concrete Beams using CFRP Sheets

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Abstract

This research work reports the experimental study of functionally damaged reinforced concrete beams retrofitted in flexure using CFRP sheets. CFRP sheet scheme is the key variable in this study, and a total of seven different strengthening schemes have been considered in the experimental program. In general, the study results stipulate that the flexural retrofitting of reinforced concrete beams using CFRP sheets are functionally efficient, besides, the strength and stiffness restored values are almost equivalent to or larger than that of the control beam. It has been observed that the effectiveness of flexural retrofitting mechanism is varying as per the layout of CFRP sheet. In the research work the major failure mode was steel rupture and crushing of concrete that causes the tearing of CFRP sheet in retrofitted beams.

Keywords: Concrete CFRP, Retrofitting, Reinforced, Stiffness, Rupture.

1 Introduction

Many present-day structures do not obey specified demands. These shortcomings may be due to corrosion of the reinforcement bar, expanded loading, enhancing of the design codes, errors in the construction, and sudden violent acting as earthquakes. For redressing the inadequate capacity, structures require replacement or retrofitting. The replacement might have a determinate disadvantage such as the high cost of material and labor. The
need to renovate some old infrastructures and historic buildings with environmentally friendly materials become increasingly important. Retrofit or rehabilitation of building parts, bridge decks, marine structure, etc. has been a major issue in past decades. Ageing, corrosion due to poor environmental condition, lack of maintenance, inappropriate initial design and construction, earthquake causes deterioration of structures. In the present era, the necessity for rehabilitation in the civil construction industry arises from deterioration/aging of structures, adaptation of old structures to new design standards, mistakes in design, accidental overloading, and a change in the functionality requirements of the structure. The objective of rehabilitation, repair and strengthening is to make durable structure at low cost.

Beams are considered to be the most important part in any Reinforced Cement Concrete (RCC) structure. CFRP sheet rehabilitation is considered as the popular technique. Epoxy impregnation is often chosen as adhesive for structural bonding. Due to CFRP sheet superior property like high durability, easy installation, light weight, it has been taken into account in these applications. Valdmanis V. et al. (2007) in this study it has been observed that retrofitting of RC beams using FRP is an effective method and has flatter imperceptibly attractive compared to other techniques of retrofitting. FRP composites strengthen the RC beam in both flexure and shear. Compare to other orientations of wrappings, U-wrapping of RC beam using CFRP laminate gives excellent performance in both shear and flexure after complete-wrapping technique. As complete-wrapping is practically not possible. Moreover, the flexural capacity of RC beams retrofitted with FRP laminates have contrary relation with longitudinal steel ratio of RC beams. Because using FRP laminates results in reduced deflection ductility of RC beams. However, CFRP strips which are a worthwhile technology concord with the steel grade of main reinforcement, whereas the higher strain in the CFRP strips achieved with the higher yield point of reinforcement. Strengthened RC beams fail before hybrid FRP sheets reach failure point. This restricts the retrofitting effect of hybrid FRP. Obaidat et al. (2011) performed an investigational revision about the behavior of functionally damaged RC beams rehabilitated with the using of CFRP laminates. The focal focus was on the length of CFRP laminate and the main reinforcement ratio and the layout of the CFRP laminates. Following conclusions were drawn from research. The beams were loaded till cracks arose after that the beams were strengthened. It showed that the using of CFRP laminates bonding led to exaggerate the ultimate load. The rise in the maximum load for strengthened beams amount to 23% for shear strengthening and 33% for strengthening in flexure. And the desired retrofitting positive impact is not achieved with insufficient retrofitting lengths. The stiffness of the CFRP coated beams was enhanced in comparison to control beams. It showed that
the using of CFRP laminates bonding led to exaggerate the ultimate load. The rise in the maximum load for strengthened beams amount to 23% for shear strengthening and 33% for strengthening in flexure. And the desired retrofitting positive impact is not achieved with insufficient retrofitting lengths. Moreover, the flexural capacity of RC beams retrofitted with FRP laminates have contrary relation with longitudinal steel ratio of RC beams. Because using FRP laminates results in reduced deflection ductility of RC beams. However, CFRP strips which are a worthwhile technology concord with the steel grade of main reinforcement, whereas the higher strain in the CFRP strips achieved with the higher yield point of reinforcement. Baggio et al. (2014) explored the retrofitting RC beams which were deficient in shear loading. And they were strengthened with several FRP schemes and the following conclusions were made: The decrease in the efficiency of CFRP retrofitting with the increase in the preloading level is not significant in the cases of U-Strips, Wings, and U-Wing schemes. This is due to the enough anchorage length (U-Strip) or the large area of CFRP sheets applied to the beam (Wings) or both (U-Wing). The application of large area of CFRP sheets can successfully arrest the cracks and the use of enough anchorage length can confine the tensile corroboration and so increase the influence of the dowel act. Consequently, the beam can restore higher shear strength even if it was precracked to any stage. The mode of failure strengthened reinforced concrete beams depends mainly on the layout of coated CFRP. A sudden explosive failure mode always takes place in the case of Strips or U-Strips scheme by debonding of the strips at their ends showing a debonding shear failure mode. Also, as the level of preloading increases the failure becomes less explosive. A more ductile failure mode takes place in beams retrofitted using CFRP fabrics in the scheme U-Wing. The mode of failure in this case is a pure flexural one. In most of the cases, failure of RC beams, having a shear span to depth ratio less than 2, and strengthened using CFRP sheets takes place by concrete crushing due to the diagonal compression component of shear forces. The existing models found in the literature for estimating the contribution of CFRP to the ultimate shear force capacity of reinforced concrete beams are reliable. Results from applying these models showed good agreement with the current test results. However, theoretical results are always found to be greater than the experimental ones. Moreover, it is recommended here in that more theoretical models be developed for the estimation of the contribution of CFRP to the total shear capacity of beams having low values of shear span to depth ratio.

Numerous researches has done regarding retrofitting of reinforced concrete beam. But still the following research gaps exist: There was no research done in reinforced concrete beams incorporated with CFRP fabrics installed at different positions. In addition, it was found that study was not carried out in finding young’s modulus of elasticity and toughness in reinforced concrete beams retrofitted with CFRP fabrics.
2 Research Methodology

The step by step procedure is discussed in this portion to get the defined objective. The material which are going to be used, test performed on material as per standards, test for rheological properties of concrete and specimen require are discussed in this part.

The following chart shows the overall process of conducting research:

![Flow Chart for Methodology of Proposed Work](image)

3 Results and Discussion

3.1 Compressive Strength Test Results

In most of the structural applications, concrete is primarily used to resist compressive stresses. When concrete compression is occurring its failure occurred in the vertical plane. The test results of compressive capacity of M30 grade concrete at 7 and 28 days has been mentioned in table 1.

<table>
<thead>
<tr>
<th>Name of Sample</th>
<th>Compression strength</th>
<th>At 7 Days</th>
<th>at 28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>A</td>
<td>28.27</td>
<td>38.58</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>28.52</td>
<td>73.52</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>27.25</td>
<td>38.12</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td><strong>28.01</strong></td>
<td><strong>38.07</strong></td>
</tr>
</tbody>
</table>
### 3.2 Pull off Test Results

This test method measures the tensile bond strength of repair material and systems applied to standard reference concrete specimens. The test results of pull off test tabulated in Table 2.

**Table 1. Pull off Test Results**

<table>
<thead>
<tr>
<th>Name of Sample</th>
<th>No. of sheets Attached</th>
<th>Dia. Of Dolly (mm)</th>
<th>Area of Dolly ($mm^2$)</th>
<th>Load Rate (Mpa/Sec)</th>
<th>Pull off strength</th>
<th>Type of Failure</th>
<th>ASTM D7522</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-1</td>
<td>1</td>
<td>50</td>
<td>1962.5</td>
<td>0.015</td>
<td>3.78</td>
<td>Concrete Failure</td>
<td>G</td>
</tr>
<tr>
<td>P-2</td>
<td>1</td>
<td>50</td>
<td>1962.5</td>
<td>0.015</td>
<td>3.74</td>
<td>Concrete Failure</td>
<td>G</td>
</tr>
<tr>
<td>P-3</td>
<td>1</td>
<td>50</td>
<td>1962.5</td>
<td>0.015</td>
<td>3.80</td>
<td>Concrete Failure</td>
<td>G</td>
</tr>
<tr>
<td>P-4</td>
<td>1</td>
<td>50</td>
<td>1962.5</td>
<td>0.015</td>
<td>3.48</td>
<td>Concrete Failure</td>
<td>G</td>
</tr>
<tr>
<td>P-5</td>
<td>2</td>
<td>50</td>
<td>1962.5</td>
<td>0.015</td>
<td>3.99</td>
<td>Concrete Failure</td>
<td>G</td>
</tr>
<tr>
<td>P-6</td>
<td>2</td>
<td>50</td>
<td>1962.5</td>
<td>0.015</td>
<td>4.12</td>
<td>Concrete Failure</td>
<td>G</td>
</tr>
<tr>
<td>P-7</td>
<td>2</td>
<td>50</td>
<td>1962.5</td>
<td>0.015</td>
<td>3.73</td>
<td>Concrete Failure</td>
<td>G</td>
</tr>
<tr>
<td>P-8</td>
<td>2</td>
<td>50</td>
<td>1962.5</td>
<td>0.015</td>
<td>3.57</td>
<td>Concrete Failure</td>
<td>G</td>
</tr>
</tbody>
</table>

**Figure 2. Graphic Representation of Pull off Testing Results**
3.3 Load-Deflection Analysis

Beams’ load deflection outcomes are summed up in Table 3. Within the table, $P_c$ and $D_c$ are load and deflection, respectively, at which one more crack appeared along with pre-crack after retrofitting of strengthened beams. $P_u$ and $D_u$ are ultimate load and ultimate deflection, respectively, after retrofitting of strengthened beams.

Current data obtained by using dial gauge which is positioned at the mid-span of the test beam and load apply by hydraulic system. The mid-span deflection data was recorded for 20 mm deflection. The main reason behind this, because all the specimens were failed before reaching to that value.

All retrofitted beams were retested after 5 days of applying the CFRP sheets under Universal Testing Machine till failure occurred. The research was conducted utilizing the exact setup as defined in testing of control beam section.

3.3.1 Controlled Beam C1

Control beam act as a ductile nature and provide considerable deflection until final failure. Flexural cracks were appeared with less than 1 mm cracks width in positive moment region at load 156 KN. The deflection curve for load mid-span indicates the linearity of concrete cracking. With increasing of load, the cracks were expanded and were prolonged to the compressive part of the beam. The ultimate load, as shown in the figure 2, was 224 KN. Forward to the maximum load, for the remaining test no cracks were developed but bending cracks widened in the positive moment region. Beam’s failure was by normal steel yielding before concrete crushing and concrete crushing occurred just close to the point load.

<table>
<thead>
<tr>
<th>Beam designation</th>
<th>$P_c$ (KN)</th>
<th>$P_u$ (KN)</th>
<th>$D_c$ (mm)</th>
<th>$D_u$ (mm)</th>
<th>Mode of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>156</td>
<td>224</td>
<td>5.4</td>
<td>11.4</td>
<td>Flexural failure</td>
</tr>
<tr>
<td>S1</td>
<td>178</td>
<td>347</td>
<td>3.2</td>
<td>7.5</td>
<td>Steel rupture</td>
</tr>
<tr>
<td>S2</td>
<td>149</td>
<td>292</td>
<td>3</td>
<td>6.3</td>
<td>Steel rupture</td>
</tr>
<tr>
<td>S3</td>
<td>139</td>
<td>324</td>
<td>3.2</td>
<td>9.7</td>
<td>CFRP rupture</td>
</tr>
<tr>
<td>S4</td>
<td>112</td>
<td>328</td>
<td>3.4</td>
<td>8.5</td>
<td>CFRP rupture</td>
</tr>
<tr>
<td>S5</td>
<td>166</td>
<td>260</td>
<td>4.5</td>
<td>8.7</td>
<td>Steel rupture</td>
</tr>
<tr>
<td>S6</td>
<td>158</td>
<td>273</td>
<td>3.6</td>
<td>7</td>
<td>CFRP rupture</td>
</tr>
<tr>
<td>S7</td>
<td>140</td>
<td>227</td>
<td>5</td>
<td>9.2</td>
<td>Debonding of CFRP</td>
</tr>
</tbody>
</table>
3.3.2 Retrofitted Beams

The load deflection curves of series A beams and control beam, series B beams and control beam are given in figure 3 and 4, respectively. The stiffness for beams at minor load is nearly similar as shown in the figure 3 and 4. After a load about 130 KN (approximately cracking phase) control beams stiffness decreases significantly due to cracking. The reduction in stiffness for retrofitted beams is lower, as the CFRP sheet layer prevent cracks from forming and widening. In series A, bonding of whole tension face with partial wraping of the side faces of the beam or using U-shaped CFRP sheets along with tension face bonding make the beam stiffer. This is apparently because of using U-shaped CFRP sheet or beam’s side face wrapping along with whole tension face bonding have provide anchorage and thus are quiet effective in the cracking region. As per the amount usage of CFRP sheet, tension face CFRP sheet with partial wrapping of the side faces of the beam as in S3 and S4 is In series B, the beams are less stiff because, bonding has been done on the hogging moment region only. Fully U-wrapped maximum moment region provide much stiffness as compare to other two schemes in series B. It is worth remembering that if the control beam is loaded until it began cracking, unloads, then apply load on it again, the second time, the stiffness will decrease due to beam damage.

The load deflection curves depicts that the strengthening mechanism increased the ultimate strength considerably over control beam. In Series A, the ultimate load in scheme 1 was 347 KN, which is an increase 54% in comparison to the control beam. Ultimate strength for scheme 2 was 292 KN, 28% increase in comparison to the control beam. The ultimate load for scheme 3 was 324 KN, 44% more than the control beam. For scheme 4 the ultimate load was 328 KN which coincides to a raise in overall load of 45%. In Series B, the ultimate load in scheme 5 was 260 KN, which is an increase 16% in comparison to the control beam. The ultimate strength for scheme 6 was 273 KN, 21% increase from the control beam. In scheme 7, 227 KN ultimate load has been achieved which reinstates the strength loss because of preloading.
Figure 3. Load deflection curves for series A beams and control beam.

Figure 4. Load deflection curves for series B beams and control beam.
3.3.3 Ductility Factor

For estimating the ductile characteristics, ductility factors of beams have been measured. The ratio of RC beam deflection at cracking load to the deflection at maximum load is called ductility factor as depicted in the figure 5. Wrapping of the beams at hogging moment region have the greater ductility factors. Scheme 5 gives a greater ductility factor 0.52, which exhibit large deflection as compare to other schemes. S2 and S4 beams are less ductile which have 0.401 and 0.37 ductility factors, respectively.

![Ductility factors of control and retrofitted beams](image)

**Figure 0.** Ductility factors of control and retrofitted beams

4 Conclusion

The paper studied the effectiveness of various flexural strengthening CFRP sheet schemes for retrofitting of preloaded RC beams. The conclusions below are obtained from test results:

1. Using CFRP sheets to strengthen preloaded damaged RC beams is incapable to preserve the functional stability beside, enhancing the maximum load of damaged beams into a degree beyond the control beam’s maximum load.
2. As observed in the series A and series B beams that CFRP sheet strengthening layout was more essential than the overall amount used for enhancing the strengthening of damaged beams.
3. Wrapping of CFRP sheet around side faces of RC beam along with the tension face bonding resulted a sufficient stiffness and bear the ultimate load into a great extent, as observed in S3, S4 and S7.
beams. And wrapping of the hogging moment zone of the beam with mentioned schemes only restore the strength of the beams.

References


Biographies

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