Flexural Strengthening of Reinforced Concrete Beams using Various Configurations of Steel Plates

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Abstract— This project presents the outcome of an experimental program aimed to investigate the flexural behaviour of externally plated reinforced concrete beams. A total of four beams were tested in this program. The beams were designed to fail in flexure. Then, they were strengthened using various configurations of steel strips and angles which have been connected by the weld and bonded to the beams by epoxy adhesive. Test results revealed an enhancement in the bending resistance of the strengthened beams, particularly in the post-yield range of loading due to partial composite effect. The pattern of steel strips played a significant role in the behavior of the strengthened beams. The failure of beam due to peeling of steel plates has been avoided. The load carrying capacity of the strengthened beams has been increased as compared to the control beam.

Key words: Flexural Strengthening, Steel Strips, Epoxy Adhesive, Peeling of Steel Plates

I. INTRODUCTION

Existing reinforced concrete structural elements may be damaged by chemical processes due to aggressive environment, excessive loading and poor initial design. The existing reinforced concrete beams may require stiffening or strengthening in order to increase their flexural resistance, to control deflections and cracking. It is becoming both environmentally and economically preferable to repair or strengthen rather than rebuild them. The choice between repair, strength and rebuild is based on specific factors of each individual case, but certain issues are considered in every case. The strengthening of these beams would be desirable if rapid, economic, effective and simple strengthening techniques are available.

Different methods are available for strengthening of existing RC elements. These are bonding with steel plates, glass fiber reinforced plastic (GFRP) sheets, external pre-stressing, external post tensioning and additional concreting. The plate bonding technique is becoming preferable for strengthening due to several advantages such as easy construction work, and minimum change in the overall size of the structure after plate bonding. The plate bonding technique has proved to be an effective and low-cost worldwide technique in many engineering applications. The plate bonding technique is becoming preferable for strengthening due to several advantages such as easy construction work, and minimum change in the overall size of the structure after plate bonding. The structural characteristics of the R/C member like strength, stiffness and ductility are significantly upgraded by application of steel jackets.

External plate bonding techniques aims at both increasing or restoring the load carrying capacity of a beam and decreasing its service-load deflections. Many studies in the literature focused on the mechanism of the premature plate peeling failure mode and parameters affecting this mode. G. Arslan (2006) conducted a study on flexural strengthening of reinforced concrete beams using epoxy-bonded continuous horizontal steel plates with different configurations as defined by variations in plate curtailment length. Sabahattin A (2013) conducted test on strengthened RC beam for the following parameters, the various anchorage and thickness of the plate, the ultimate loads carried by the beams, the stiffness and ductility of the beams. M. S. Mohamed Ali (2001) investigated the shear peeling of steel plates bonded to tension faces of RC beams. Bilal Hamad (2010) conducted experimental study on behavior of T-shaped reinforced concrete beams partially confined by structural steel. Deric J. O. (1990) conducted an investigation on premature failure of externally plated reinforced concrete beams in the tension face. B. Hwan Oh (2003) conducted test on static and fatigue behavior of reinforced concrete beams strengthened with steel plates for flexure.

The objective of this paper is to find the effective configuration of steel plates to increase the flexural strength of reinforced concrete beam.

II. EXPERIMENTAL INVESTIGATION

A. Details of Test Beams:

A total of 4 beams were tested. All the beams had the same dimensions and reinforcement details as shown in Fig. 1. The beam size used was 150 mm(b) x 180mm(h) x 1200mm(l).  The beams were reinforced with two 8mm diameter bars in compression zone and two 10mm diameter bars in tension zone.  The control beam was expected to fail in flexure while strengthened beams to fail in shear and not in flexure.  Internal stirrups were provided 8mm diameter bars at 100mm c/c distance.

The average compressive strength of concrete used was in the range of 25 – 28 MPa at the time of testing. The average yield strength and elastic modulus of longitudinal reinforcement were 413 MPa and 200GPa respectively. The properties of strengthening plates were shown in Table 1 and properties of epoxy adhesive used for bonding the steel plates were shown in Table 2.

Fig. 1: Reinforcement Details of Beams (All Dimensions Are In Mm)
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Table 1: Mechanical Properties of Mild Steel Plate Used For Strengthening

<table>
<thead>
<tr>
<th>Plates</th>
<th>Size</th>
<th>Yield strength (MPa)</th>
<th>Elastic modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel strips</td>
<td>20mm width x 3mm thick</td>
<td>253</td>
<td>200</td>
</tr>
<tr>
<td>Steel angles</td>
<td>20mm x 20mm x 3mm thick</td>
<td>255</td>
<td>200</td>
</tr>
</tbody>
</table>

Table 2: Properties of Epoxy Adhesive Used For Steel Plate Bonding

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pot life (mm)</td>
<td>50</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>48</td>
</tr>
<tr>
<td>Compressive strength (MPa)</td>
<td>73</td>
</tr>
<tr>
<td>Tensile shear strength (MPa)</td>
<td>16.8</td>
</tr>
<tr>
<td>Elastic modulus (GPa)</td>
<td>2.14</td>
</tr>
</tbody>
</table>

B. Strengthening of Beams:

Beam CB was kept as control beam. Other beams were strengthened using different configurations of external steel plate systems as shown in Fig. 2. Beam-DP bonded with double plate at bottom face of the beam for full length. Beam-SP was bonded with Single Plate at bottom face of the beam for the full length. Beam-FP was bonded with Full Solid Plate at bottom face of the beam for the full length. For all the beams steel angles were provide at corners and steel plate were provide as shown in figure which were bonded on beam using adhesive and connected to the strips by means of weld.

Bonding of plates on beams was done using an epoxy adhesive after grinding the concrete surface and cleaning thoroughly with acetone. Bonding faces of steel plates were sandblasted and cleaned thoroughly with acetone before bonding. The thickness of epoxy layer was kept about 2mm using steel spacers.

C. Testing and Instrumentation:

Strain gauges were used to measure strains in steel plates bonded on tension face of the beam. Mid-span deflections of the beams were measured by the Linear Variable Differential Transducers (LVDTs). All the beams were tested under four-point loading. Loads were applied at a distance of 1/3 distance of effective span of the beam. Test set up is shown in Fig. 3. Load was applied monotonically to the test beams till failure. Crack initiation and propagation were monitored by visual inspection during testing.

III. TEST RESULTS AND DISCUSSION

A. Failure Mode and Ultimate Load:

Table 3 shows the deflections for the corresponding load at various stages. Also failure mode and increase in strength have been mentioned. Fig. 4 shows the failure mode and crack pattern of all the beams. The control beam failed in flexure. Failure of the beam occurred due to formation of flexural cracks. But in strengthened beams, flexural cracks were considerably reduced and failure of the beams were delayed due to the partial confinement effect provided by the external plates as well as the sufficient adhesive layer between the steel plate and concrete. Failure mode of the beams was changed from shear to flexure. Debonding of the plate due to critical diagonal cracks was observed in Beam-FP. The average increase in flexural strength of the strengthened beams was 2.2 times of control beam.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>1st Crack Load $P_1$ (kN)</th>
<th>Deflection $D_1$ (mm)</th>
<th>Yield Load $P_1$ (kN)</th>
<th>Deflection $D_y$ (mm)</th>
<th>Ultimate Load $P_u$ (kN)</th>
<th>Deflection $D_u$ (mm)</th>
<th>Failure mode</th>
<th>Relative strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB (Control Beam)</td>
<td>40</td>
<td>0.7</td>
<td>97.5</td>
<td>2</td>
<td>130</td>
<td>12.9</td>
<td>Flexure</td>
<td>1.00</td>
</tr>
<tr>
<td>FP (Full Plate)</td>
<td>47.5</td>
<td>3.3</td>
<td>142.5</td>
<td>3.1</td>
<td>210</td>
<td>18.3</td>
<td>Flexure</td>
<td>1.62</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Configuration</th>
<th>Load (kN)</th>
<th>Flexure (mm)</th>
<th>Shear (mm)</th>
<th>Flexure Strain (x10^-6)</th>
<th>Shear Strain (x10^-6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP (Single Plate)</td>
<td>48</td>
<td>2.9</td>
<td>160</td>
<td>224</td>
<td>16.1</td>
</tr>
<tr>
<td>DP (Double Plate)</td>
<td>52</td>
<td>2.4</td>
<td>204</td>
<td>296</td>
<td>11.9</td>
</tr>
</tbody>
</table>

Table 3: Experimental Results

C. Load-Strain Behavior:
Load – strain curve of Beam-DP shows the gradual increase in strain against the load increment and after failure of the concrete beam, loads were transferred through the steel plates.

Load-strain curve of Beam-SP shows similar behaviour of beam-DP but steel plates in this beam allow larger strain values than the Beam-DP for the corresponding loads. It indicates that the load carrying capacity for the beam-DP was more than the Beam-SP.

Load – strain curve of Beam-FP shows the linear change in the strain for the applied load till the separation/peeling of steel plates from the beam, after that the curve tends to reverse which shows that the strain values have been decrease because the yielding stress can’t developed by the steel plates.

Fig. 5: Load Versus Mid-Span Deflection Curve

B. Load-Deflection Behavior:
Fig. 5 shows the relationship between load and mid-span deflection of control and flexural strengthened beams. The strengthened beams showed greater stiffness throughout loading than the control beams. Beams with bonded steel plates also exhibited more ductile behaviour than the control beam, which results in smaller deflection at higher load. Particularly in the beam-DP, deflection was reduced more when compared to the other beams.

Fig. 4: Failure Mode and Cracking Pattern of the Beams

IV. CONCLUSION
Experiments have been performed to study the effectiveness of different configurations of steel plate for flexural enhancement of reinforced concrete beam. From the test results, the following conclusions can be drawn.

1) It has been confirmed that the externally bonded steel plates can improve the ultimate shear strength of reinforced concrete beams and change the failure mode from brittle flexural to shear one.

2) Test results revealed an enhancement in the flexural resistance of the strengthened beam, particularly in the post-yield range of loading due to partial composite effect.

3) The bonded steel plates increased the load carrying capacity of the three strengthened beams between 1.6 to 2.3 times that of the control beam.
4) The pattern of steel strips played a significant role in the behavior of the strengthened beam. Double strips (Beam-DP) were found to be very effective in flexural strengthening.

5) Plate debonding of the strengthened beam have been avoided because of formation of Critical Diagonal Crack has been reduced.

6) The external steel plates did not fracture in any of the tests conducted.

7) The externally bonded steel plate method is easy for construction and requires less anchorage work and can be used effectively to strengthen RC beams requiring shear upgrading.

REFERENCES


