Experimental Investigation on the Static Performance of GFRP Strengthened Prestressed Concrete Beams

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Abstract: The strengthening or retrofitting of existing concrete structures has been traditionally accomplished by using conventional techniques and materials. In this context, the advanced composites have the potential to be a promising solution for strengthening the deteriorated structures. This paper mainly focuses on the behaviour of fibre reinforced polymer (FRP) strengthened unbonded post-tensioned prestressed concrete beams. A total of four unbonded post-tensioned beams were cast and tested under four point bending system. The PSC beams were strengthened with Uni-Directional Cloth Glass Fibre Reinforced Polymer plates for different grades of concrete. The parameters such as load and deflection at various stages were investigated. The experimental test results showed that the GFRP strengthened post-tensioned prestressed concrete beam showed a higher load carrying capacity of 54.4% when compared to that of the control beam. A flexural type of failure was observed in all the tested beams. The strengthened beam was failed by debonding of FRP from concrete surface.

Key words: FRP • GFRP • Post-tensioned • Prestressed beam • Strengthening

INTRODUCTION

Concrete structures are prone to various natural, aberrant and other calamitous conditions. These conditions may have adverse affects on the structural strength of the structures. Beams are one the most important structural member for any structures; it may be bridge, Industrial building, roadways etc. Beams must be designed in such a way that it can withstand any type of loads without producing any deformation or cracking to the structures. But at times the beams may experience sudden static loads for which they are not designed. Due to these sudden loads the beams tends to crack. This is mainly due to the tension or compression in the beam. In the bridges, industrial buildings etc the most common type of beams used are prestressed beams. The prestressed beams are designed to withstand heavy loads. These beams have lesser beam depths, posses improved resistance to shearing. These beams are mostly used where the span is more. In order to protect the beam from the cracking produced due to the sudden application of the fatigue load additional strengthened should be done. By strengthening the beams it is observed that the crack produced in the beams are greatly reduced. The size and the width of the crack are considerably reduced.

Population is growing at faster rates when compared to previous decade and their needs also growing day by day. The needs for structural rehabilitation of concrete structures were increased and a many research activities has implemented in this field. The strengthening or retrofitting of existing concrete structures has been traditionally accomplished by using conventional techniques and materials. Fibre Reinforced Polymer (FRP) composites have some unique characteristics such as high strength, light weight, ease of installation, lower cost, aesthetics and corrosion resistance which make them an effective solution.

For the rehabilitation and retrofitting of structures, many researchers investigated on the behaviour of FRP strengthened on various structural components include slabs [1, 2], beams [3, 4], column [5, 6], beam-column joint [7, 8]. Revathy et al. [9] carried out an experimental investigation on the static behavior of prestressed concrete beam strengthened with fibre reinforced polymer laminates. The study showed that the UDCGFRP plates were found to be very effective in ultimate load carrying
capacity, deflection and ductility when compared to other beams. Hussien et al. [10] conducted a study on behaviour of bonded and unbonded prestressed normal and high strength concrete beams. The beams were tested under cyclic loading up to failure to examine its flexural behaviour. Meski et al. [11] conducted a study on unbonded posttensioned concrete members strengthened using external FRP composites. It was found that the use of FRP laminates increases the load capacity and post-cracking stiffness of unbonded members. The increase in load capacity was accompanied by a reduction in the deformation capacity. Failure of the specimens occurred either by concrete crushing or by FRP debonding or FRP fracture. Limited research was available on the behavior of FRP strengthened prestressed concrete beams. The present study investigated on the effectiveness of procured glass fibre reinforced polymer plated on the post-tensioned prestressed concrete beams. The parameters such as load and deflection at various stages and their failure mode, crack pattern have to be evaluated.

**Experimental Programme**

**Materials and its Properties**

**Concrete:** The common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. Concrete was prepared using ordinary Portland cement of 53 grade having a specific gravity of 3.15. River sand was used as fine aggregate, passing through 4.75 mm sieve with a specific gravity of 2.74. The coarse aggregate was crushed granite of 20 mm size and specific gravity of 2.54 was used in the study. Potable water was used for concreting and curing the specimens. Two types of grade of concrete include normal strength concrete (NSC) and high strength concrete (HSC) was used in this investigation. For NSC and HSC, M35 and M60 grade of concrete was adopted. The trial mix was done and the design mix ratio for M35 grade concrete was 1: 1.3: 2.35: 0.42. The design mix ratio for M60 grade concrete was 1: 1.35: 2.19: 0.29. The average characteristic compressive strength of concrete obtained from the laboratory test for M35 and M60 were 42 N/mm$^2$ and 69 N/mm$^2$ respectively.

**Steel:** The tensile and compression longitudinal reinforcement used was high-yield strength deformed bars of 12 mm and 10 mm diameter. The vertical stirrups were made up of 2 legged 8 mm. The yield strength of steel reinforcement was 430 N/mm$^2$. A high tensile steel (HTS) wire of 7 mm diameter was used with an ultimate strength of 1532 N/mm$^2$.

**Glass Fibre Reinforced Polymer:** An uni-directional cloth glass fibre reinforced polymer with thickness of 3 mm was used for strengthening the post-tensioned concrete beams. The properties include tensile strength and modulus of elasticity for uni-directional cloth glass fibre reinforced polymer was 446.90MPa and 13965.63MPa respectively.

**Description of PSC Beam:** A total of four unbonded post-tensioned concrete beams were constructed for the study. All the PSC beams had a cross-section of 150mm x 250mm over a span length of 3000mm. Two beams were cast for each grade of concrete. Two beams were served as control specimen (P1 & P2). The other two beams were strengthened with GFRP plates (P1U & P2U). P1 and P2 referred to NSC and HSC beam specimens. The high tensile steel was fastened at one end and at the other end, stressing of HTS wire was done with a prestressing force of 3 tonne. The elongation of HTS wire was measured. The PSC beams were strengthened with precured uni-directional cloth glass fibre reinforced polymer plates. The bottom surface of the PSC beam was cleaned well with a wire brush to remove the dirt and loose materials. After surface preparation, epoxy adhesive was used to bond the procured GFRP plates. The strengthened beams were cured for a period of 10 days.

**Testing of PSC Beam:** All the beams were tested in a loading frame at B.S.Abdur Rahman University, Chennai. The PSC beams were tested under two point bending system as shown in Fig.1. A static load was applied gradually. A hydraulic jack of 50 tonnes capacity was used to apply the load, the load was transferred to the beam through a load cell of 50 tonnes capacity. Linear variable displacement transducers were used to measure the deflection. Load and deflection were collected through a data acquisition system. At each load stage the crack pattern were also observed.

![Fig. 1: Test setup](image-url)
RESULTS AND DISCUSSIONS

The results were observed at various stages of loading and their corresponding deflections are shown in Table 1.

Table 1: Test Results of Load & Deflection

<table>
<thead>
<tr>
<th>Beam ID</th>
<th>Load (kN)</th>
<th>Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial stage</td>
<td>Yield stage</td>
</tr>
<tr>
<td>P1</td>
<td>16.21</td>
<td>18.76</td>
</tr>
<tr>
<td>P1U</td>
<td>45.1</td>
<td>52.22</td>
</tr>
<tr>
<td>P2</td>
<td>36.2</td>
<td>40.23</td>
</tr>
<tr>
<td>P2U</td>
<td>66.7</td>
<td>75.8</td>
</tr>
</tbody>
</table>

Fig. 2: Load-Deflection of Beams

From the above test results it was found that the P1U showed an increase in ultimate load carrying capacity by 48.3% than that of the control beam P1. Similarly, P2U showed an increase in ultimate load by 54.4% than P2 specimen. It was also found that HSC grade of concrete showed a higher load carrying capacity in all stages. It was found that GFRP strengthened beam showed maximum increase in deflection by 72%.

A load- deflection behaviour of all the beams are shown in Fig 2. The failure of beams was due to the debonding between the GFRP plate and concrete. When compared to control beams, GFRP strengthened beams have adequate deformation capacity and higher load carrying capacity. The GFRP strengthened specimens developed a considerably stiffer load-deflection response than the control specimens in the post cracking stage.

Failure Modes & Crack Pattern: The typical failure mode and crack patterns of the PSC beam specimen are shown in Fig. 3. All PSC beam specimens developed their first flexural cracks within the constant moment region during initial loading. As the applied load increased, the cracks increased in number in the mid-span region of the beam. The control specimens P1 and P2 were failed due to crushing of concrete at the compression face. The GFRP strengthened PSC beam failed due to FRP deboning is shown in Fig.4. This was due to the propagation of interface crack in the concrete. The crack widths were very less in GFRP strengthened PSC beams when compared to the control beams.

CONCLUSIONS

From the experimental results the following conclusions were drawn,

- The prestressed concrete beams strengthened with Glass fibre reinforced polymer plates were found to be very effective in load carrying capacity and deflection when compared to control beam.
- GFRP strengthened PSC beam showed a significant and maximum increase in load carrying capacity by 54.4% over the control beam.
- GFRP strengthened beam showed an maximum increase in ultimate deflection when compared to the control beam.
- The flexural failure mode was noticed in all the tested PSC beams.
- GFRP strengthened beams were failed due to debonding. The width of cracks was very less in GFRP strengthened PSC beams when compared to the control beams.

REFERENCES


