Strengthening of reinforced concrete beams using glass fiber reinforced polymer composites

P.Nagi Reddy¹ and V. Raj Kumar²
¹PG student, Dept of Civil Newton’s institute of science & technology
²Asst Professor, Dept. of Civil, Newton’s institute of science & technology

Abstract—Worldwide, a great deal of research is currently being conducted concerning the use of fiber reinforced plastic wraps, laminates and sheets in the repair and strengthening of reinforced concrete members. Fiber-reinforced polymer (FRP) application is a very effective way to repair and strengthen structures that have become structurally weak over their life span. FRP repair systems provide an economically viable alternative to traditional repair systems and materials. Experimental investigations on the flexural and shear behavior of RC beams strengthened using continuous glass fiber reinforced polymer (GFRP) sheets are carried out. Externally reinforced concrete beams with epoxy-bonded GFRP sheets were tested to failure using a symmetrical two point concentrated static loading system. Two sets of beams were casted for this experimental test program. In SET I three beams weak in flexure were casted, out of which one is controlled beam and other two beams were strengthened using continuous glass fiber reinforced polymer (GFRP) sheets in flexure. In SET II three beams weak in shear were casted, out of which one is the controlled beam and other two beams were strengthened using continuous glass fiber reinforced polymer (GFRP) sheets in shear. The strengthening of the beams is done with different amount and configuration of GFRP sheets.

I. INTRODUCTION

The maintenance, rehabilitation and upgrading of structural members, is perhaps one of the most crucial problems in civil engineering applications. Moreover, a large number of structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the new design codes. Since replacement of such deficient elements of structures incurs a huge amount of public money and time, strengthening has become the acceptable way of improving their load-carrying capacity and extending their service lives. Infrastructure decay caused by premature deterioration of buildings and structures has lead to the investigation of several processes 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. Structural strengthening may be required due to many different situations.

- Additional strength may be needed to allow for higher loads to be placed on the structure. This is often required when the use of the structure changes and a higher load-carrying capacity is needed. This can also occur if additional mechanical equipment, fillin systems, planters, or other items are being added to a structure.

Strengthening may be needed to allow the structure to resist loads that were not anticipated in the original design. This may be encountered when structural strengthening is required for loads resulting from wind and seismic forces or to improve resistance to blast loading.

- Additional strength may be needed due to a deficiency in the structure's ability to carry the original design loads. Deficiencies may be the result of deterioration (e.g., corrosion of steel reinforcement and loss of concrete section), structural damage (e.g., vehicular impact, excessive wear, excessive loading, and fire), or errors in the original design or construction (e.g., misplaced or missing reinforcing steel and inadequate concrete strength).

II. STRENGTHENING USING FRP COMPOSITES

Only a few years ago, the construction market started to use FRP for structural reinforcement, generally in combination with other construction materials such as
wood, steel, and concrete. FRPs exhibit several improved properties, such as high strength-weight ratio, high stiffness-weight ratio, flexibility in design, non-corrosiveness, high fatigue strength, and ease of application. The use of FRP sheets or plates bonded to concrete beams has been studied by several researchers. Strengthening with adhesive bonded fiber reinforced polymers has been established as an effective method applicable to many types of concrete structures such as columns, beams, slabs, and walls. Because the FRP materials are non-corrosive, non-magnetic, and resistant to various types of chemicals, they are increasingly being used for external reinforcement of existing concrete structures. From the past studies conducted it has been shown that externally bonded glass fiber-reinforced polymers (GFRP) can be used to enhance the flexural, shear and torsional capacity of RC beams. Due to the flexible nature and ease of handling and application, combined with high tensile strength-weight ratio and stiffness, the flexible glass fiber sheets are found to be highly effective for strengthening of RC beams. The use of fiber reinforced polymers (FRPs) for the rehabilitation of existing concrete structures has grown very rapidly over the last few years. Research has shown that FRP can be used very efficiently in strengthening the concrete beams weak in flexure, shear and torsion. Unfortunately, the current Indian concrete design standards (IS Codes) do not include any provisions for the flexural, shear and torsional strengthening of structural members with FRP materials. This lack of design standards led to the formation of partnerships between the research community and industry to investigate and to promote the use of FRP in the flexural, shear and torsional rehabilitation of existing structures. FRP is a composite material generally consisting of high strength carbon, aramid, or glass fibers in a polymeric matrix (e.g., thermosetting resin) where the fibers are the main load carrying element.

Advantages:
1. Laps and joints are not required
2. The material can take up irregularities in the shape of the concrete surface
3. The material can follow a curved profile; steel plate would have to be pre-bent to the required radius
4. The material can be readily installed behind existing services
5. Overlapping, required when strengthening in two directions, is not a problem because the material is thin.

Disadvantages:
1. The main disadvantage of externally strengthening structures with fiber composite materials is the risk of fire, vandalism or accidental damage, unless the strengthening is protected.
2. A particular concern for bridges over roads is the risk of soffit reinforcement being hit by over-height vehicles.
3. However, strengthening using plates is generally provided to carry additional live load and the ability of the unstrengthened structure to carry its own self-weight is unimpaired.
4. Damage to the plate strengthening material only reduces the overall factor of safety and is unlikely to lead to collapse

III. MATERIALS AND METHODS

Materials
Concrete
Concrete is a construction material composed of portland cement and water combined with sand, gravel, crushed stone, or other inert material such as expanded slag or vermiculite. The cement and water form a paste which hardens by chemical reaction into a strong, stone-like mass. The inert materials are called aggregates, and for economy no more cement paste is used than is necessary to coat all the aggregate surfaces and fill all the voids. The concrete paste is plastic and easily molded into any form or troweled to produce a smooth surface. Hardening begins immediately, but precautions are taken, usually by covering, to avoid rapid loss of moisture since the presence of water is necessary to continue the chemical reaction and increase the strength. Too much water, however, produces a concrete that is more porous and weaker. The quality of the paste formed by the cement and water largely determines the character of the concrete. Proportioning of the ingredients of concrete is referred to as designing the mixture, and for most structural work the concrete is designed to give compressive strengths of 15 to 35 MPa. A rich mixture for columns may be in the proportion of 1 volume of cement to 1 of sand and 3 of stone, while a
Lean mixture for foundations may be in the proportion of 1:3:6.

Cement
Cement is a material, generally in powder form, that can be made into a paste usually by the addition of water and, when molded or poured, will set into a solid mass. Numerous organic compounds used for adhering, or fastening materials, are called cements, but these are classified as adhesives, and the term cement alone means a construction material. The most widely used of the construction cements is portland cement.

Fine Aggregate
Fine aggregate / sand is an accumulation of grains of mineral matter derived from the disintegration of rocks. It is distinguished from gravel only by the size of the grains or particles, but is distinct from clays which contain organic materials. Sands that have been sorted out and separated from the organic material by the action of currents of water or by winds across arid lands are generally quite uniform in size of grains.

Coarse Aggregate
Coarse aggregate are the crushed stone is used for making concrete. The commercial stone is quarried, crushed, and graded. Much of the crushed stone used is granite, limestone, and trap rock. The last is a term used to designate basalt, gabbro, diorite, and other dark-colored, fine-grained igneous rocks. Graded crushed stone usually consists of only one kind of rock and is broken with sharp edges. The sizes are from 0.25 to 2.5 in (0.64 to 6.35 cm),

Water
Water fit for drinking is generally considered fit for making concrete. Water should be free from acids, oils, alkalis, vegetables or other organic Impurities. Soft waters also produce weaker concrete. Water has two functions in a concrete mix. Firstly, it reacts chemically with the cement to form a cement paste in which the inert aggregates are held in suspension until the cement paste has hardened. Secondly, it serves as a vehicle or lubricant in the mixture of fine aggregates and cement.

Reinforcement
The longitudinal reinforcements used were high-yield strength deformed bars of 12 mm diameter. The stirrups were made from mild steel bars with 6 mm diameter strength of steel reinforcements used in this experimental program was determined by performing the standard tensile test on the three specimens of each bar. The average proof stress at 0.2% strain of 12 mm bars was 437 N/mm² and that of 6 mm bars was 240 N/mm².

Fiber Reinforced Polymer (FRP)
Fiber reinforced polymer (FRP) is a composite material made by combining two or more materials to give a new combination of properties. However, FRP is different from other composites in that its constituent materials are different at the molecular level and are mechanically separable. The mechanical and physical properties of FRP are controlled by its constituent properties and by structural configurations at micro level. Therefore, the design and analysis of any FRP structural member requires a good knowledge of the material properties, which are dependent on the manufacturing process and the properties of constituent materials.

Fiber
A fiber is a material made into a long filament with a diameter generally in the order of 10 tm.

Glass Fibers
These are fibers commonly used in the naval and industrial fields to produce composites of medium-high performance. Their peculiar characteristic is their high strength.
Glass Fibers:
Glass is mainly made of Silicon (SiO2) with a tetrahedral structure (SiO4). Some aluminium oxides and other metallic ions are then added in various proportions to either ease the working operations or modify some properties (e.g., S-glass fibers exhibit a higher tensile strength than E-glass).

<table>
<thead>
<tr>
<th>Typical Density</th>
<th>Young's Modulus</th>
<th>Tensile Strength</th>
<th>Tensile Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Properties</td>
<td>(g/cm³)</td>
<td>(GPa)</td>
<td></td>
</tr>
<tr>
<td>High Strength</td>
<td>1.8</td>
<td>230</td>
<td>2.48</td>
</tr>
<tr>
<td>High Modulus</td>
<td>1.9</td>
<td>370</td>
<td>1.79</td>
</tr>
<tr>
<td>Ultra-High Modulus</td>
<td>2.0 - 2.1</td>
<td>520 - 620</td>
<td>1.03 - 1.31</td>
</tr>
</tbody>
</table>

Carbon fibers
Carbon fiber is the most expensive of the more common reinforcements, but in space applications the combination of excellent performance characteristics coupled with light weight make it indispensable reinforcement with cost being of secondary importance. Carbon fibers consist of small crystallite of turbostratic graphite.

Carbon Fiber
Carbon fiber is the most expensive of the more common reinforcements, but in space applications the combination of excellent performance characteristics coupled with light weight make it indispensable reinforcement with cost being of secondary importance. Carbon fibers consist of small crystallite of turbostratic graphite.

<table>
<thead>
<tr>
<th>Typical Density</th>
<th>Young's Modulus</th>
<th>Tensile Strength</th>
<th>Tensile Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Properties</td>
<td>(g/cm³)</td>
<td>(GPa)</td>
<td></td>
</tr>
<tr>
<td>High Strength</td>
<td>1.8</td>
<td>230</td>
<td>2.48</td>
</tr>
<tr>
<td>High Modulus</td>
<td>1.9</td>
<td>370</td>
<td>1.79</td>
</tr>
<tr>
<td>Ultra-High Modulus</td>
<td>2.0 - 2.1</td>
<td>520 - 620</td>
<td>1.03 - 1.31</td>
</tr>
</tbody>
</table>

IV. EXPERIMENTAL STUDY
Casting of Beams
Two sets of beams were casted for this experimental test program. In SET I three beams (F1, F2 and F3) weak in flexure were casted using same grade of concrete and reinforcement detailing. In SET II three beams (S1, S2 and S3) weak in shear were casted using same grade of concrete and reinforcement detailing.

Strengthening of Beams
Before bonding the composite fabric onto the concrete surface, the required region of concrete surface was made rough using a coarse sand paper texture and cleaned with an air blower to remove all dirt and debris. Once the surface was prepared to the required standard, the epoxy resin was mixed in accordance with manufacturer’s instructions. Mixing was carried out in a plastic container (Araldite LY 556 – 100 parts by weight and Hardener HY 951 – 8 parts by weight).
and was continued until the mixture was in uniform colour. When this was completed and the fabrics had been cut to size, the epoxy resin was applied to the concrete surface. The composite fabric was then placed on top of epoxy resin coating and the resin was squeezed through the roving of the fabric with the roller. Air bubbles entrapped at the epoxy/concrete or epoxy/fabric interface were to be eliminated. Then the second layer of the epoxy resin was applied and GFRP sheet was then placed on top of epoxy resin coating and the resin was squeezed through the roving of the fabric with the roller and the above process was repeated. During hardening of the epoxy, a constant uniform pressure was applied on the composite fabric surface in order to extrude the excess epoxy resin and to ensure good contact between the epoxy, the concrete and the fabric.

V. EXPERIMENTAL SETUP

All the specimens were tested in the loading frame of the “Structural Engineering” Laboratory of National Institute of Technology, Rourkela. The testing procedure for the entire specimen was same. After the curing period of 28 days was over, the beam as washed and its surface was cleaned for clear visibility of cracks. The most commonly used load arrangement for testing of beams will consist of two-point loading. This has the advantage of a substantial region of nearly uniform moment coupled with very small shears, enabling the bending capacity of the central portion to be assessed. If the shear capacity of the member is to be assessed, the load will normally be concentrated at a suitable shorter distance from a support.

VI. RESULTS AND DISCUSSIONS

Failure Modes
The flexural and shear strength of a section depends on the controlling failure mode. The following flexural and shear failure modes should be investigated for an FRP-strengthened section:
1. Crushing of the concrete in compression before yielding of the reinforcing steel;
2. Yielding of the steel in tension followed by rupture of the FRP laminate;
3. Yielding of the steel in tension followed by concrete crushing;
4. Shear/tension delamination of the concrete cover (cover delamination); and
5. Debonding of the FRP from the concrete substrate (FRP debonding).

<table>
<thead>
<tr>
<th>Sr. 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>Beam weak in flexure (SET I)</td>
<td>F1</td>
<td>30</td>
<td>78</td>
<td>Flexural failure + GFRP rupture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F2</td>
<td>34</td>
<td>104</td>
<td>GFRP rupture + Flexure-shear failure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F3</td>
<td>112</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Beam weak in shear (SET II)</td>
<td>S1</td>
<td>35</td>
<td>82</td>
<td>Shear failure + Flexural failure + Crushing of concrete</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S2</td>
<td>39</td>
<td>108</td>
<td></td>
</tr>
</tbody>
</table>

Crack Pattern
The crack patterns at collapse for the tested beams of SET I and SET II are shown in Fig. 5.13 to 5.18. In SET I the controlled beam F1 exhibited widely spaced and lesser number of cracks compared to strengthened beams F2 and F3. The strengthened beams F2 and F3 have also shown cracks at relatively close spacing. This shows the enhanced concrete confinement due to the GFRP strengthening. This composite action has resulted in shifting of failure mode from flexural failure (steel yielding) in case of controlled beam F2 to peeling of GFRP sheet in case of strengthened beams F2 and F3. The debonding of GFRP sheet has taken place due to flexural-shear cracks by giving cracking sound. A crack normally initiates in the vertical direction and as the load increases it moves in inclined direction due to the combined effect of shear and flexure. If the load is increased further, cracks propagate to top and the beam splits. This type of failure is called flexure-shear failure.
VII. CONCLUSION

A) SET I Beams (F1, F2 and F3)
1. Initial flexural cracks appear at a higher load by strengthening the beam at soffit. The ultimate load carrying capacity of the strengthen beam F2 is 33% more than the controlled beam F1.
2. Load at initial cracks is further increased by strengthening the beam at the soffit as well as on the two sides of the beam up to the neutral axis from the soffit. The ultimate load carrying capacity of the strengthen beam F3 is 43% more than the controlled beam F1 and 7% more than the strengthen beam F2.

B) SET II Beams (S1, S2 and S3)
1. The control beam S1 failed in shear as it was made intentionally weak in shear.
2. The initial cracks in the strengthen beams S2 and S3 appears at higher load compared to the unstrengthen beam S1.
3. After strengthening the shear zone of the beam the initial cracks appears at the flexural zone of the beam and the crack widens and propagates towards the neutral axis with increase of the load. The final failure is flexural failure which indicates that the GFRP sheets increase the shear strength of the beam. The ultimate load carrying capacity of the strengthen beam S2 is 31% more than the controlled beam S1.

REFERENCES


