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EXPERIMENTAL INVESTIGATION OF STRENGTHENING OF REINFORCED CONCRETE BEAMS USING GLASS FIBRE REINFORCED POLYMER COMPOSITES

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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. Experimental data on load, deflection and failure modes of each of the beams were obtained. The detail procedure and application of GFRP sheets for strengthening of RC beams is also included. The effect of number of GFRP layers and its orientation on ultimate load carrying capacity and failure mode of the beams are investigated.

1. INTRODUCTION

1.1GENERAL

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. 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 loadcarrying capacity is needed. This can also occur if additional mechanical equipment, filing 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.

1.2 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

2. MATERIALS AND METHODS

2.1 MATERIALS

2.1.1 Concrete

Concrete is a construction material composed of portland cement bubbles for porosity or light weight. Normally, the full hardening period of concrete is at least 7 days. The gradual increase in strength due to the hydration of the tricalcium aluminates and silicates. Sand used in concrete was originally specified as roughly angular, but rounded grains are now preferred..

2.1.1.1 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

2.1.1.2 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.zone of fine aggregate was zone III as per Indian Standard specifications.

2.1.1.3 Coarse aggregate

Coarse aggregate are the crushed stone is used for making concrete. The commercial stone is quarried, crushed, and graded texture and consisting largely of quartz and feldspar with often small amounts of mica and other minerals.

2.1.1.4 Water

Water it for drinking is generally considered fit for making concrete.

2.1.2 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. The yield 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 φ bars was 437 N/mm^2 and that of 6 mm φ bars was 240 N/mm^2. 2.1.3 FIBER REINFORCED POLYMER (FRP) Continuous fiber-reinforced materials with polymeric matrix (FRP) can be considered as composite, heterogeneous, and anisotropic materials with a prevalent linear elastic behavior up to failure. Fiber reinforced polymer (FRP) is a composite material made by combining two or more materials to give a new combination of properties. FRP composite is a two phased material, hence its anisotropic properties. It is composed of fiber and matrix, which are bonded at interface. Each of these different phases has to perform its required function based on mechanical properties, so that the composite system performs satisfactorily as a whole. In this case, the reinforcing fiber provides FRP composite with strength and stiffness, while the matrix gives rigidity and environmental protection.

Reinforcement materials

A great majority of materials are stronger ad stiffer in fibrous form than as bulk materials. A high fiber aspect ratio (length: diameter ratio) permits very effective transfer of load via matrix materials to the fibers, thus taking advantage of there excellent properties. Therefore, fibers are very effective and attractive reinforcement materials.

2.1.3.1 Fiber

A fiber is a material made into a long filament with a diameter generally in the order of 10 tm. The aspect ratio of length and diameter can be ranging from thousand to infinity in continuous fibers. The main functions of the fibers are to carry the load and provide stiffness, strength, thermal stability, and other structural properties in the FRP.

- Glass fibers

- Carbon fibers
- Aramid fibers

2.2 EXPERIMENTAL STUDY

The experimental study consists of casting of two sets of reinforced concrete (RC) beams. 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 by using continuous glass fiber reinforced polymer (GFRP) sheets in shear. The strengthening of the beams is done with varying configuration and layers of GFRP sheets. Experimental data on load, deflection and failure modes of each of the beams were obtained. The change in load carrying capacity and failure mode of the beams are investigated as the amount and configuration of GFRP sheets are altered. The following chapter describes in detail the experimental study.

2.3 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. The dimensions of all the specimens are identical. The cross sectional dimensions of the both the set of beams is 250 mm by 200 mm and length is 2300 mm. In SET I beams 2, 12 mm φ bars are provided as the main longitudinal reinforcement and 6 mm φ bars as stirrups at a spacing of 75 mm center to center where as in SET II beams 3, 12 mm φ bars are provided as the main longitudinal reinforcement and without any stirrups.

2.4 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. This operation was carried out at room temperature. Concrete beams strengthened with glass fiber fabric were cured for 24 hours at room temperature before testing.

2.5 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.

2.6 FABRICATION OF GFRP PLATE

To meet the wide range of needs which may be required in fabricating composites, the industry has evolved oven a dozen separate manufacturing processes as well as a number of hybrid processes. Each of these processes offers advantages and specific benefits which may apply to the fabricating of composites. Hand lay-up and spray-up are two basic molding processes. The hand lay-up process is the oldest, simplest, and most labour intense fabrication method. The process is most common in FRP marine construction. In hand layup method liquid resin is placed along with reinforcement (woven glass fiber) against finished surface of an open mould. Chemical reactions in the resin harden the material to a strong, light weight product. The resin serves as the matrix for the reinforcing glass fibers, much as concrete acts as the matrix for steel reinforcing rods. The percentage of fiber and matrix was 50:50 in weight.

2.7 DETERMINATION OF ULTIMATE STRESS, ULTIMATE LOAD AND YOUNG'S MODULUS

The ultimate stress, ultimate load and Young's modulus are determined experimentally by performing unidirectional tensile tests on specimens cut in longitudinal and transverse directions, and at 45° to the longitudinal direction, as described in ASTM standard: D 638-08 and D 3039/D 3039M - 2006. A thin flat strip of specimen having a constant rectangular cross section was prepared in all cases**.**

3. RESULTS AND DISCUSSION

3.1 INTRODUCTION

This chapter describes the experimental results of SET I beams (weak in flexure) and SET II beams (weak in shear). Their behavior throughout the static test to failure is described using recorded data on deflection behavior and the ultimate load carrying capacity. The crack patterns and the mode of failure of each beam are also described in this chapter. Two sets of beams were tested for their ultimate strengths. In SET I three beams (F1, F2 and F3) weak in flexure are tested. In SET II three beams (S1, S2 and S3) weak in shear are tested. The beams F1and S1 were taken as the control beams. It was observed that the beams F1 and S1 had less load carrying capacity when compared to that of the externally strengthened beams using GFRP sheets. In SET I beams F2 is strengthened only at the soffit of the beam and F3 is strengthened up to the neutral axis of the beam along with the soffit of the beam. SET II beams S2 is strengthened only at the sides of the beam in the shear zone and S3 is strengthened by U-wrapping of the GFRP sheets in the shear zone of the beam. Deflection behavior and the ultimate load carrying capacity of the beams were noted

3.4 LOAD AT INITIAL CRACK

Two point static loading was done on both SET I and SET II beams and at the each increment of the load, deflection and crack development were observed. The load at initial crack of all the beams was observed, recorded and is shown in figure 5.9 and 5.10. Under two point static loading of SET I beams, at each increment of load, deflection and crack development were observed. In beam F1 initiation of the crack takes place at a load of 30 KN which is lower than beam F2 in which crack initiation started at 34 KN. The crack initiation of beam F3 was not visible due to application of GFRP sheet up to the neutral axis of the beam. The cracks were only visible after a load of 90 KN.

3.5 ULTIMATE LOAD CARRYING CAPACITY

The load carrying capacity of the control beams and the strengthen beams were found out and is shown in fig. 5.11 and 5.12. The control beams were loaded up to their ultimate loads. It was noted that of all the beams, the strengthen beams F2, F3 and S2, S3 had the higher load carrying capacity compared to the controlled beams F1 and S1.An important character to be noticed about the usage of GFRP sheets is the high ductile behaviour of the beams. The shear failure being sudden can lead to huge damage to the structure. But the ductile behaviour obtained by the use of GFRP can give us enough warning before the ultimate failure. The use of FRP can delay the initial cracks and further development of the cracks in the beam. SET I beams F1, F2 and F3 were loaded under two point static loading. As the load was increased incrementally development of cracks takes place and ultimately the beam failed. The ultimate load of F1 beam was 78 KN which is lower than F2 beam which carried an ultimate load of 104 KN and further lower than F3 beam which carried an ultimate load of 112 KN.

3.6 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. In SET II beam S1 the shear cracks started at the centre of short shear span. As the load increased, the crack started to widen and propagated towards the location of loading. The cracking patterns show that the angle of critical inclined crack with the horizontal axis is about 45°.For strengthened reinforced concrete beams S2 and S3, the numbers of vertical cracks were increased compared to controlled beam S1.

3.7 COMPARISION OF RESULTS

The results of the two set of beams tested are shown in Table 5.1. The failure mode, load at initial crack and ultimate load of the control beams without strengthening and the beams strengthen with two layers GFRP sheet are presented. The difficulties inherent to the understanding of strengthen structural member behavior subjected to flexure and shear have not allowed to develop a rigorous theoretical design approach. The complexity of the problem has then made necessary an extensive experimental research. Moment of resistance of the SET I beams was calculated analytically and was compared with the obtained experimental results

SET I Beams	from analytical study	from experimental study
F1	17.12 KN-m	26.00 KN-m
F2	24.60 KN-m	34.68 KN-m

Table 5.2 Comparision of value obtained from analytical and experimental study

CONCLUSION

In this experimental investigation the flexural and shear behaviour of reinforced concrete beams strengthened by GFRP sheets are studied. Two sets of reinforced concrete (RC) beams, in SET I three beams weak in flexure and in SET II three beams weak in shear were casted and tested. From the test results and calculated strength values, the following conclusions are drawn:

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.
3. Analytical analysis is also carried out to find the ultimate moment carrying capacity and compared with the experimental results. It was found that analytical analysis predicts lower value than the experimental findings.
4. When the beam is not strengthen, it failed in flexure but after strengthening the beam in flexure, then flexure-shear failure of the beam takes place which is more dangerous than the flexural failure of the beam as it does not give much warning before failure. Therefore it is recommended to check the shear strength of the beam and carry out shear strengthening along with flexural strengthening if required.
5. Flexural strengthening up to the neutral axis of the beam increases the ultimate load carrying capacity, but the cracks developed were not visible up to a higher load. Due to invisibility of the initial cracks, it gives less warning compared to the beams strengthen only at the soffit of the beam.By strengthening up to the neutral axis of the beam, increase in the ultimate load carrying capacity of the beam is not significant and cost involvement is almost three times compared to the beam strengthen by GFRP sheet at the soffit only.

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 un-strengthen 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.
4. When the beam is strengthen by U-wrapping in the shear zone, the ultimate load carrying capacity is increased by 48 % compared to the control beam S1 and by 13% compared the

beam S2 strengthen by bonding the GFRP sheets on the vertical sides alone in the shear zone of the beam.

5. When the beam is strengthen in shear, then only flexural failure takes place which gives sufficient warning compared to the brittle shear failure which is catastrophic failure of beams.

6. The bonding between GFRP sheet and the concrete is intact up to the failure of the beam which clearly indicates the composite action due to GFRP sheet.

7. Restoring or upgrading the shear strength of beams using GFRP sheet can result in increased shear strength and stiffness with no visible shear

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