Strength Analysis of RC Beams using Glass Fiber Reinforced Polymer Composite

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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.

1. 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, filing systems, planters, or other items are being added to astructure.

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).

The majority of structural strengthening involves improving the ability of the structural element to safely resist one or more of the following internal forces caused by loading: flexure, shear, axial, and torsion. Strengthening is accomplished by either reducing the magnitude of these forces or by enhancing the member's resistance to them. Typical strengthening techniques such as section enlargement, externally bonded reinforcement, post-tensioning, and supplemental supports may be used to achieve improved strength and serviceability.

Strengthening systems can improve the resistance of the existing structure to internal forces in either a passive or active manner. Passive strengthening systems are typically engaged only when additional loads, beyond those existing at the time of installation, are applied to the structure. Bonding steel plates or fiber-reinforced polymer (FRP) composites on the structural members are examples of passive strengthening systems. Active strengthening systems typically engage the structure instantaneously and may be accomplished by introducing external forces to the member that counteract the effects of internal forces. Examples of this include the use of external post-tensioning systems or by jacking the member to relieve or transfer existing load. Whether passive or active, the main challenge is to achieve composite behavior between the existing structure and the new strengthening elements.

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.

Among many options, this reinforcement may be in the form of preformed laminates or flexible sheets. The laminates are stiff plates or shells that come pre-cured and are installed by bonding them to the concrete surface with a thermosetting resin. The sheets are either dry or pre-impregnated with resin (known as pre-preg) and cured after installation onto the concrete surface. This installation technique is known as wet lay-up. FRP materials offer the engineer an outstanding combination of physical and mechanical properties, such as high tensile strength, lightweight, high stiffness, high fatigue strength, and excellent durability. The lightweight and formability of FRP reinforcement make FRP systems easy to install. Since these systems are non-corrosive, non-magnetic, and generally resistant to chemicals, they are an excellent option for external reinforcement.

2. Literature review

A review of some significant experimental investigations conducted using steel plates is presented to demonstrate some of the structural implications of external plating.

Research work into the performance of members strengthened with steel plates was pioneered simultaneously in South Africa and France in the 1960s (L'Hermite and Bresson, 1967; Fleming and King, 1967; Lerchenthal, 1967; Gilibert et al., 1976). Continued development of suitable adhesives and the increased use of the technique in practice stimulated further research work. Eberline et al. (1988) present a literature review on research and applications related to steel plate bonding.

Structural investigations

The history of bonded external reinforcement in the UK goes back to 1975 with the strengthening of the Quinton Bridges on the M5 motorway. This scheme followed a number of years of development work by the Transport and Road Research Laboratory (TRRL), (now TRL), in association with adhesive manufacturers and the Department of Transport. In terms of testing programmes, research and development work continued at the TRRL and at several academic institutions in the UK, most notably at the University of Sheffield. Theoretical investigations and the evaluation of suitable adhesives were allied to the extensive beam testing programmes which were undertaken.

Preliminary studies were conducted by Irwin (1975). Macdonald (1978) and Macdonald and Calder (1982) reported four point loading tests on steel plated RC beams of length 4900mm. These beams were used to provide data for the proposed strengthening of the Quinton Bridges (Raithby, 1980 and 1982), and incorporated two different epoxy adhesives, two plate thicknesses of 10.0mm and 6.5mm giving width-to-thickness(b/t) ratios of 14 and 22, and a plate lap-joint at its centre. In all cases it was found that failure of the beams occurred at one end by horizontal shear in the concrete adjacent to the steel plate, commencing at the plate end and resulting in sudden separation of the plate with the concrete still attached, up to about mid-span. The external plate was found to have a much more significant effect in terms of crack control and stiffness. The loads required to cause a crackwidthof0.1mmwereincreasedby95%,whilstthedeflections underthisloadwere substantially reduced.

The post cracking stiffness was found to be increased by between 35– 105% depending upon the type of adhesive used and the plate dimensions. The features of this work became the subject of a more detailed programme of research at the TRRL (Macdonald, 1982; Macdonald and Calder, 1982), in which a series of RC beams of length 3500mm were tested in four point bending. The beams were either plated as-cast or plated after being loaded to produce a maximum crack width of 0.1mm. The effect of widening the plate whilst maintaining its cross-sectional area constant was studied. It was found that the plated as-cast and the pre-cracked beams gave similar load/deflection curves, demonstrating the effectiveness of external plating for strengthening purposes.

An extensive programme of research work carried out at the University of Sheffield since the late 1970s has highlighted a number of effects of external, epoxy-bonded steel plates on the serviceability and ultimate load behaviour of RC beams. A brief summary of some of the research findings is presented by Jones and Swamy (1995).

Steel plate strengthening of existing structures has also been investigated in Switzerland at the Swiss Federal Laboratories for Material Testing and Research (EMPA) (Ladner and Weder, 1981). Bending tests were carried out on RC beams 3700mm in length, and the plate width-to-thickness (b/t) ratio was studied whilst maintaining the plate cross-sectional area constant. The external plate continued through and beyond the beam supports, with which they were not in contact, for a distance such that the bonded area (48000mm2) was the same for each plate width. The external plate was not bonded to the concrete beam except in the anchorage areas beyond the supports. The results clearly showed that thin plating was more effective than thick narrow plating, as noted in studies conducted in the UK. The effective anchorage length la which allowed the plate to reach yield before shear failure adjacent to the bonded areas was found to be inversely proportional to the b/t ratio. Therefore, as b/t increased (wide, thin plates), the anchorage length is decreased.

3. Materials and methods

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. Concrete may be produced as a dense mass which is practically artificial rock, and chemicals may be added to make it waterproof, or it can be made porous and highly permeable for such use as filter beds. An air-entraining chemical may be added to produce minute bubbles for porosity or light weight. Normally, thefullhardeningperiodofconcreteisatleast7days.

Portland slag cement (PSC) – 43 grade (Kornak Cement) was used for the investigation. It was tested for its physical properties in accordance with Indian Standard specifications. The fine aggregate used in this investigation was clean river sand, passing through 4.75 mm sieve with specific gravity of 2.68. The grading zone of fine aggregate was zone III as per Indian Standard specifications. Machine crushed granite broken stone angular in shape was used as coarse aggregate. The maximum size of coarse aggregate was 20 mm with specific gravity of 2.73. Ordinary clean portable water free from suspended particles and chemical substances was used for both mixing and curing of concrete.

For concrete, the maximum aggregate size used was 20 mm. Nominal concrete mix of 1:1.5:3 by weight is used to achieve the strength of 20 N/mm2. The water cement ratio 0.5 is used. Three cube specimens were cast and tested at the time of beam test (at the age of 28 days) to determine the compressive strength of concrete. The average compressive strength of the concrete was31N/mm2.

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. It is a bluish-gray powder obtained by finely grinding the clinker made by strongly heating an intimate mixture of calcareous and argillaceous minerals. The chief raw material is a mixture of high-calcium limestone, known as cement rock, and clay or shale. Blast-furnace slag may also be used in some cements and the cement is called portland slag cement (PSC). The color of the cement is due chiefly to iron oxide. In the absence of impurities, the color would be white, but neither the color nor the specific gravity is a test of quality. The specific gravity is at least 3.10. Portland slag cement (PSC) – 43 grade (Kornak Cement) was used for the investigation.

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. Usually commercial sand is obtained from river beds or from sand dunes originally formed by the action of winds. Much of the earth’s surface is sandy, and these sands are usually quartz and other siliceous materials. The most useful commercially are silica sands, often above 98% pure. Beach sands usually have smooth, spherical to ovaloid particles from the abrasive action of waves and tides and are free of organic matter. The white beach sands are largely silica but may also be of zircon, monazite, garnet, and other minerals, and are used for extracting various elements.

Sand is used for making mortar and concrete and for polishing and sandblasting. Sands containing a little clay are used for making molds in foundries. Clear sands are employed for filtering water. Sand is sold by the cubic yard (0.76 m3) or ton (0.91 metric ton) but is always shipped by weight. The weight varies from 1,538 to 1,842 kg/m3, depending on the composition and size of grain. Construction sand is not shipped great distances, and the quality of sands used for this purpose varies according to local supply. Standard sand is a silica sand used in making concrete and cement tests. The fine aggregate obtained from river bed of Koel, clear from all sorts of organic impurities was used in this experimental program. The fine aggregate was passing through 4.75 mm sieve and had a specific gravity of 2.68. The grading zone of fine aggregate was zone III as per Indian Standard specifications.

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), although larger sizes may be used for massive concrete aggregate. Machine crushed granite broken stone angular in shape was used as coarse aggregate.

The maximum size of coarse aggregate was 20 mm and specific gravity of 2.78. Granite is a coarse-grained, igneous rock having an even texture and consisting largely of quartz and feldspar with often small amounts of mica and other minerals. There are many varieties. Granite is very hard and compact, and it takes a fine polish, showing the beauty of the crystals. Granite is the most important building stone. Granite is extremely durable, and since it does not absorb moisture, as limestone and sandstone do, it does not weather or crack as these stones do. The colors are usually reddish, greenish, or gray. Rainbow granite may have a black or dark- green background with pink, yellowish, and reddish mottling; or it may have a pink or lavender background with dark mottling. The density is 2,723 kg/m3, the specific gravity 2.72, and the crushing strength 158 to 220MPa.

Water

Water fit for drinking is generally considered fit for making concrete. Water should be free from acids, oils, alkalies, 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.

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. They are widely used for strengthening of civil structures. There are many advantages of using FRPs: lightweight, good mechanical properties, corrosion-resistant, etc. Composites for structural strengthening are available in several geometries from laminates used for strengthening of members with regular surface to bi- directional fabrics easily adaptable to the shape of the member to be strengthened. Composites are also suitable for applications where the aesthetic of the original structures needs to be preserved (buildings of historic or artistic interest) or where strengthening with traditional techniques cannot be effectively employed.

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.

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.

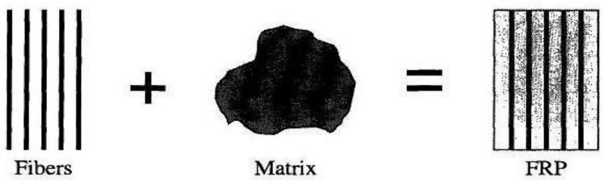

Fig. 1: Formation of Fiber Reinforced Polymer Composite

4. Results and discussions

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. The ultimate load carrying capacity of all the beams along with the nature of failure is given in Table 1.

Table 1: Ultimate load and nature of failure for SET I and SET II beams

Sr. No.	Type of Beam	Beam designation	Load at initial crack (KN)	Ultimate load (kN)	Nature of failure
1	Beams weak in flexure (SET I)	F1	30	78	Flexural failure
		F2	34	104	GFRP rupture + Flexure-shear failure
		F3	Not visible	112	GFRP rupture + Flexure-shear failure
2	Beams weak in shear (SET II)	S1	35	82	Shear failure
		S2	39	108	Flexural failure + Crushing of concrete
		S3	40	122	Flexural failure + Crushing of concrete

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, deflect ion and crack development were observed. The load at initial crack of all the beams was observed, recorded and is shown in figure 2 and 3.

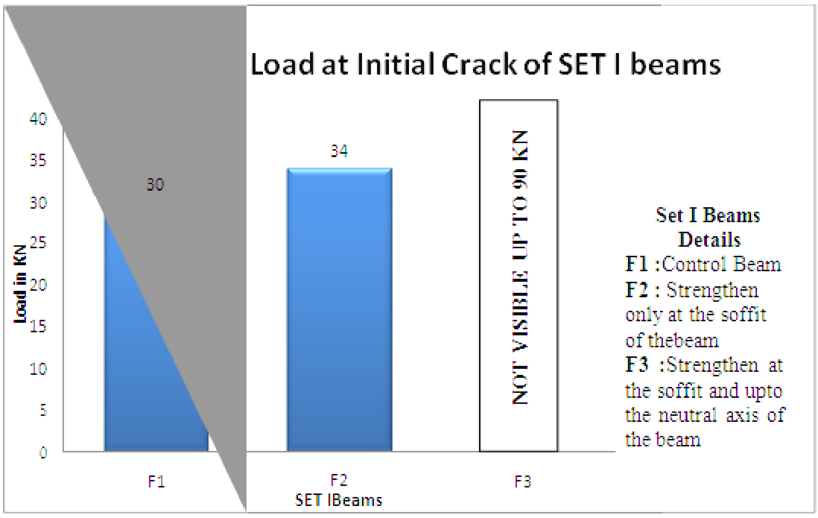

Fig. 2: Load at initial crack of beams F1, F2 and F3.

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.

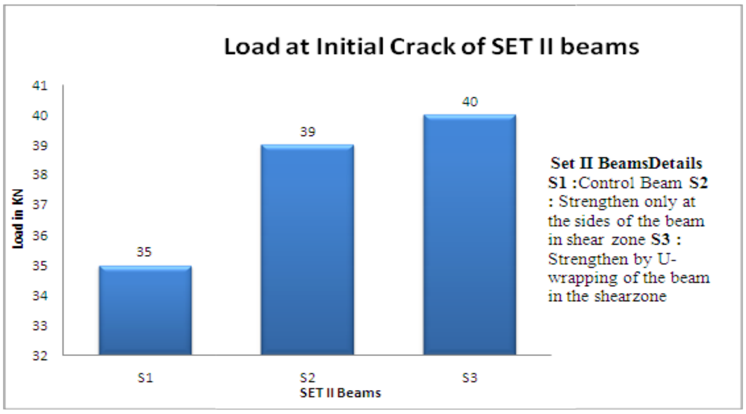

Fig. 3: Load at initial crack of beams S1, S2 and S3.

Under two point static loading of SET II beams, at each increment of load, deflection and crack development were observed. InbeamS1 initiation of the crack takes place at a load of 35KN which is lower than beam F2 in which crack initiation started at 39KN and Further lower than beam F3 in which crack initiation started at 40KN. There was not much difference in load for crack initiation in beam S2 and S3.

Ultimate Load Carrying capacity

The load carrying capacity of the control beams and the strengthen beams were Found out and is shown in fig. 4 and

5. The control beams were loaded upto 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.

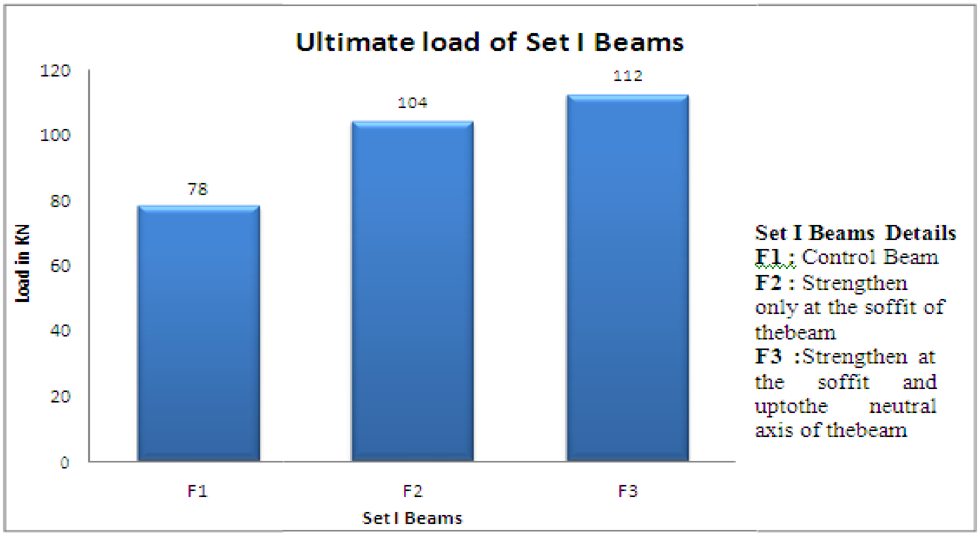

Fig. 4: Ultimate load of beams F1, F2 and F3

SET I beams F1, F2 and F3 were loaded under two point static loading. As the load Was increased incrementally development of crack stakes 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 104KN and further lower than F3 beam which carried an ultimate load of 112 KN.

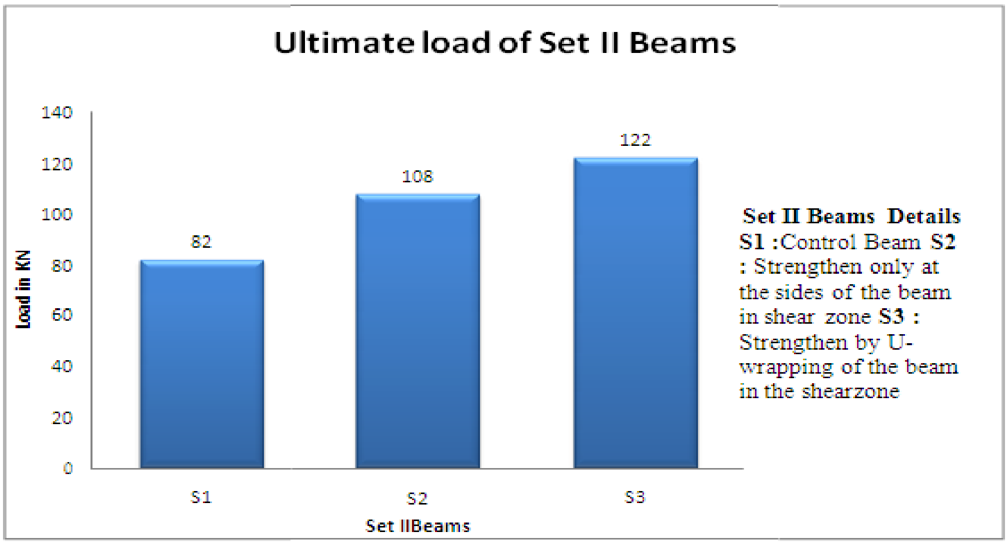

Fig. 5: Ultimate load of beams S1, S2 and S3

SET II beams S1, S2 and S3 were loaded under two point static loading. As the load Was increased incrementally development of crack stakes place and ultimately the beam failed. The ultimate load of S1 beam was 82 KN which is lower than S2 beam which carried an ultimate load of 108KN and further lower than S3 beam which carried an ultimate load of 122 KN.

5. Conclusion

In this experimental investigation the flexural and shear behavior 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:

- 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.
- 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 beamF2.
- 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.
- 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.
- 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.

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