Experimental Study on Behaviour of RC Beams Reinforced With GFRP

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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.

Fifty-four specimens are tested to detect the compressive behavior of fiber concrete and normal concrete. The mix ratio variations are also adopted for this study. The differences between the compressive behaviors of fiber concrete and normal concrete are recorded. 7, 14 and 28 curing days are considered to investigate this study. Some recommendations are also attached at the end portion of this study.

Experimental investigations on the flexural and shear behaviour 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.

Key words: Glass Fiber Reinforced Polymers (GFRP) and Compressive Behavior.

1. INTRO DUCTION

1.1 General:- 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 a structure.

- Strengthening may be needed to allow the structure to resist load 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).

When dealing with such circumstances, each project has its own set of restrictions and demands. Whether addressing space restrictions, constructability restrictions, durability demands, or any number of other issues, each project requires a great deal of creativity in arriving at a strengthening solution.

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 behaviour between the existing structure and the new strengthening elements.

The selection of the most suitable method for strengthening requires careful consideration of many factors including the following engineering issues:

- Magnitude of strength increase.
- Effect of changes in relative member stiffness.
- Size of project (methods involving special materials and methods may be less cost- effective on small projects).
- Environmental conditions (methods using adhesives might be unsuitable for applications in high-temperature environments; external steel methods may not be suitable in corrosive environments).
- In-place concrete strength and substrate integrity (the effectiveness of methods relying on bond to the existing concrete can be significantly limited by low concrete strength).
- Dimensional/clearance constraints (section enlargement might be limited by the degree to which the enlargement can encroach on surrounding clear space).
- Accessibility.
- Operational constraints (methods requiring longer construction time might be less desirable for applications in which building operations must be shut down during construction).
- Availability of materials, equipment, and qualified contractors.
- Construction cost, maintenance costs, and life-cycle costs, and
- Load testing to verify existing capacity or evaluate new techniques and materials.

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. 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 tensional 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 tensional 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 tensional 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.

1.3. Advantages And Disadvantages Of Fiber Composite Strengthening

*1.3.1. **Advantages***:-Fiber composite strengthening materials have higher ultimate strength and lower density than steel. When taken together these two properties lead to fiber composites having a strength weight ratio higher than steel plate in some case. (though it is often not possible to use this fully). The lower weight makes handling and installation significantly easier than steel. This is particularly important when installing material in cramped locations. Work on soffits of bridges and building floor slabs can often be carried out from man-access platforms rather than full scaffolding. Steel plate requires heavy lifting gear and must be held in place while the adhesive gains strength. Bolts must be fitted through the steel plate into the parent concrete to support the plate while the adhesive cures and to reduce the effects of peeling at the ends. On the other hand, the application of FRP plate or sheet material has been likened to applying wallpaper; once it has been rolled on carefully to remove entrapped air and excess adhesive it may be left unsupported. In general, no bolts are required; in fact, the use of bolts would seriously weaken the material unless additional cover plates are bonded on. Furthermore, because there is no need to drill into the structure to fix bolts or other mechanical anchors there is no risk of damaging the existing reinforcement. Fiber composite materials are available in very long lengths while steel plate is generally limited to 6 m.

The availability of long lengths and the flexibility of the material also simplify installation:

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

The materials fibers and resins are durable if correctly specified, and require little maintenance. If they are damaged in service, it is relatively simple to repair them, by adding an additional layer. The use of fiber composites does not significantly increase the weight of the structure or the dimensions of the member. The latter may be particularly important for bridges and other structures with limited headroom and for tunnels. In terms of environmental impact and sustainability, studies have shown that the energy required to produce FRP materials is less than that for conventional materials. Because of their light weight, the transport of FRP materials has minimal environmental impact.

These various factors in combination lead to a significantly simpler and quicker strengthening process than when using steel plate; This is particularly important for bridges because of the high costs of lane closures and possession times on major highways and railway lines. It has been estimated that about 90% of the market for plate strengthening in Switzerland has been taken by carbon plate systems as a result of these factors.

1.3.2. Disadvantages:- 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. A particular concern for bridges over roads is the risk of soffit reinforcement being hit by over-height vehicles. However, strengthening using plates is generally provided to carry additional live load and the ability of the UN strengthened structure to carry its own self-weight is unimpaired. Damage to the plate strengthening material only reduces the overall factor of safety and is unlikely to lead to collapse.

Experience of the long-term durability of fiber composites is not yet available. This may be a disadvantage for structures for which a very long design life is required but can be overcome by appropriate monitoring.

A perceived disadvantage of using FRP for strengthening is the relatively high cost of the materials. However, comparisons should be made on the basis of the complete strengthening exercise; in certain cases the costs can be less than that of steel plate bonding.

A disadvantage in the eyes of many clients will be the lack of experience of the techniques and suitably qualified staff to carry out the work. Finally, a significant disadvantage is the lack of accepted design standards.

1.4 Present Investigation:- The purpose of this research is to investigate the flexural and shear behaviour of reinforced concrete beams strengthened with varying configuration and layers of GFRP sheets. More particularly, the effect of the number of GFRP layers and its orientation on the strength and ductility of beams are investigated. Two sets of beams were fabricated and tested up to failure. 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.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1.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 *moulded* into any form or *towelled* 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, the full hardening period of concrete is at least 7 days. The gradual increase in strength is 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. The stone is usually sharply broken. The weight of concrete varies with the type and amount of rock and sand. A concrete with trap rock may have a density of 2,483 kg/m2. Concrete is stronger in compression than in tension, and steel bar, called rebar or mesh is embedded in structural members to increase the tensile and flexural strengths. In addition to the structural uses, concrete is widely used in precast units such as block, sewer, and water pipe, and ornamental products.

Ordinary Portland cement (OPC)-43 grade (Bharathi 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 4.75mm sieve with specific gravity of 2.68. The grading zone of the 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 20mm 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 20mm. nominal concrete mix of 1:1.5:3 by weight is used to achieve the strength of 20N/mm2. The water cement ratio 0.5 is used. Three cubes specimens were cast and tested at the time of beam. Test Fifty-four specimens are tested to detect the compressive behavior of fiber concrete and normal concrete. The mix ratio variations are also adopted for this study. The differences between the compressive behaviors of fiber concrete and normal concrete are recorded. 7, 14 and 28 curing days are considered to investigate this study. Determine the compressive strength of concrete. The average compressive strength of the concrete was 31 N/mm2.

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. 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. The Grade 43 Portland cement was generally used in reinforced cement concrete construction which also called as R.C.C. The grade 43 is also used in R.M.C which is also called ready mix concrete and also use in Pre cast structure concrete for construction purposes.

Fineness will be = **225 kg/m2**

Crushing strength 3 days later = **23 N/mm2**

After 7 days later strength = **33 N/mm2**

After 28 days later strength = **43 N/mm2**

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. 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 Godavari 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.

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. 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. Thedensity is 2,723 kg/m3, the specific gravity 2.72, and the crushing strength 158 to 220 MPa.

2.1.1.4. 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.

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 □ bars was 437 N/mm^2 and that of 6 mm □ 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 behaviour 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.

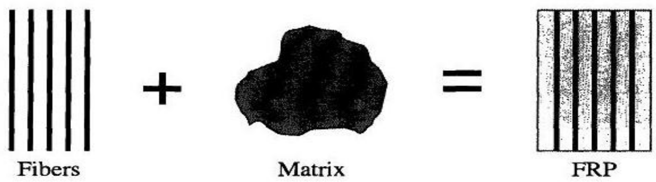

Fig. 2.1 Formation of Fiber Reinforced Polymer Composite.

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.

To perform these desirable functions, the fibers in FRP composite must have:

- high modulus of elasticity for use as reinforcement;
- high ultimate strength;
- low variation of strength among fibers;
- high stability of their strength during handling; and
- high uniformity of diameter and surface dimension among 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 □ bars are provided as the main longitudinal reinforcement and 6 mm □ bars as stirrups at a spacing of 150 mm center to center where as in SET II beams 3, 12 mm □ bars are provided as the main longitudinal reinforcement and without any stirrups.

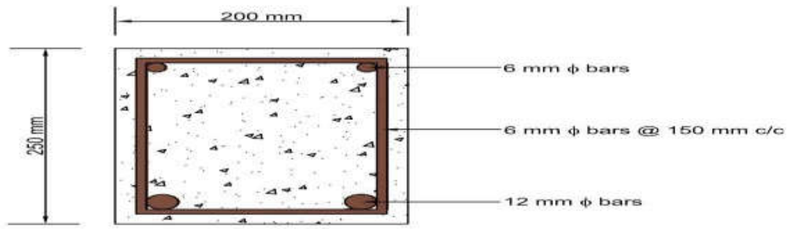

Fig. 2.6 Reinforcement details of SET I beams.

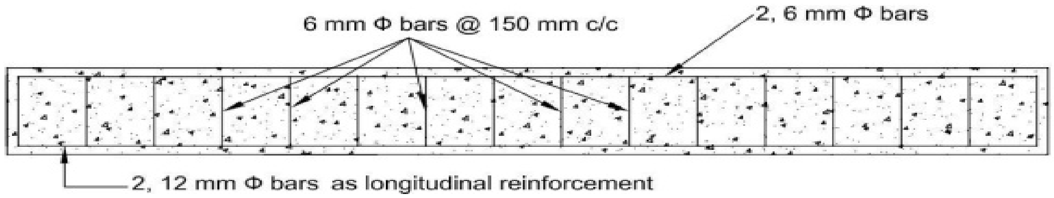

Fig. 2.7 Section of SET I beams.

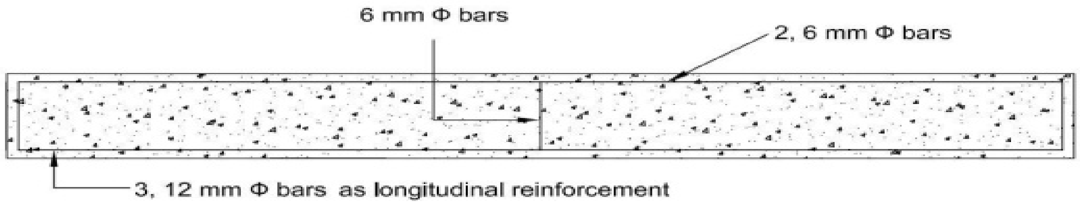

Fig. 2.8 Reinforcement details of SET II beams

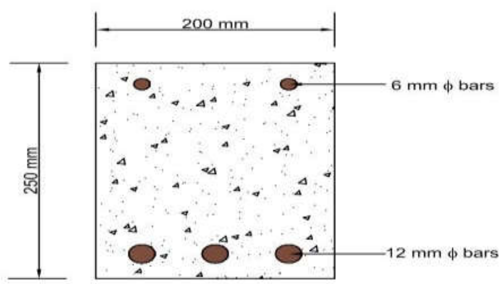

Fig. 2.9 Section of SET II beams

2.5.1. MIX DESIGN FOR M20 CONCRETE:- The mix design of M20 concrete is conducted according to the ACI guidelines [ACI-211] 8-inch height, 4-inch diameter cylinder is considered in this investigation. The area of this cylinder is computed as 1.6×10-3 m3. Table 2.7 shows the mix proportions of M20 concrete according to ACI guidelines.

Ingredients	Required amount according to ACI guidelines (Kg/m3)
Cement	355
Coarse aggregate	1016
Fine aggregate	799
Water	185

Table2.7. Mix proportions of M20 concrete according to ACI guidelines

The amounts of ingredients which are used to cast the cylinder are estimated. So, Table 2.8 shows the estimated amount of ingredients which are used to cast the cylinder.

Ingredients	The Required amount of single cylinder according to ACI guidelines (Kg)
Cement	0.56
Coarse aggregate (C.A.) ¾ inch downgrade black stone (70% of C.A.) ½ inch black stone chips (30% of C.A.)	1.62 1.13 0.48
Fine aggregate	1.27
Water	0.29
GFRP (2% of total weight of cylinder)	0.07

Table2.8. Estimated amount of ingredients which are used to cast the cylinder

Six sets of the cylinder are cast where each set consists of three cylinders. First three sets are cast without Fiber which is considered as normal concrete. But second three sets are cast with Fiber which is considered as fiber concrete. So, compressive strength tests are performed on the normal concrete on different days of these nine cylinders where first three samples at 7 days, second three samples at 14 days and last three samples at 28 days. And all day are counted according to curing condition. Table 2.9 shows the compressive strength test results of M20 normal concrete, and Table 2.10 shows the compressive strength test results of M20 Fiber concrete (F.C.).

Type of cylinder specimen	Compressive strength (MPa)					
Symbol	7 days	Avg.	14 days	Avg.	28 days	Avg.
C-1	18	19	21	23	26	26
C-2	19		25		25	
C-3	20		23		27	

Table2.9. Compressive strength test results of M20 fiber concrete.

Type of cylinder specimen	Compressive strength (MPa) (With 2% Fiber)					
Symbol	7 days	Avg.	14 days	Avg.	28 days	Avg.
S-1	23	24	28	28	31	32
S-2	24		26		33	
S-3	25		30		30	

Table2.10. Compressive strength test results of M20 fiber concrete (F.C.).

From the analysis of Table 2.11, it is clearly understood that the compressive strength of fiber concrete is more than normal concrete. This is considered as a good use of the symbol of the Fiber in concrete. Figure 8 also narrates that the use of fiber in concrete can easily possible to get approximate M30 concrete mix strength in the M20 concrete mix which may be taken as a great achievement in concrete history.

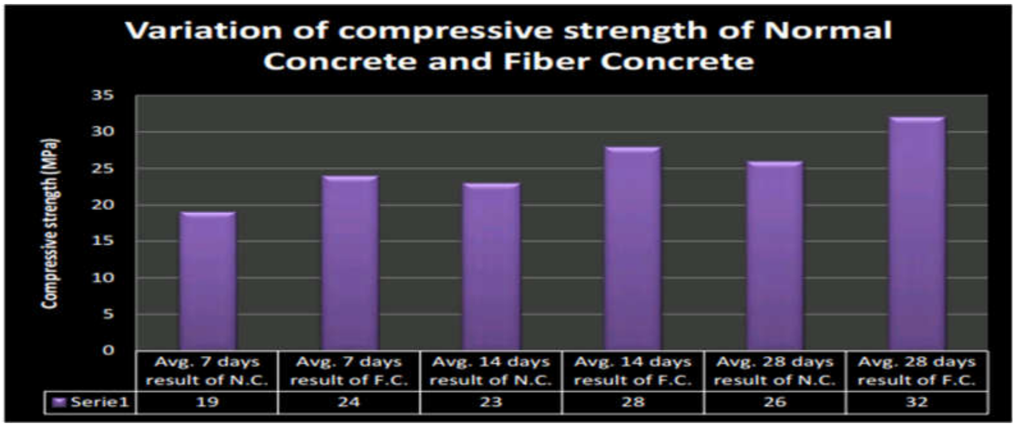

Table2.11. Graphical representation of overall compressive strength results

From the analysis of Figure 8, it is clearly understood that the compressive strength of fiber concrete is more than normal concrete. This is considered as a good use of the symbol of the Fiber reinforced in concrete. Figure 8 also narrates that the use of fiber in concrete can easily possible to get approximate M30 concrete mix strength in the M20 concrete mix which may be taken as a great achievement in concrete history.

2.6. 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.

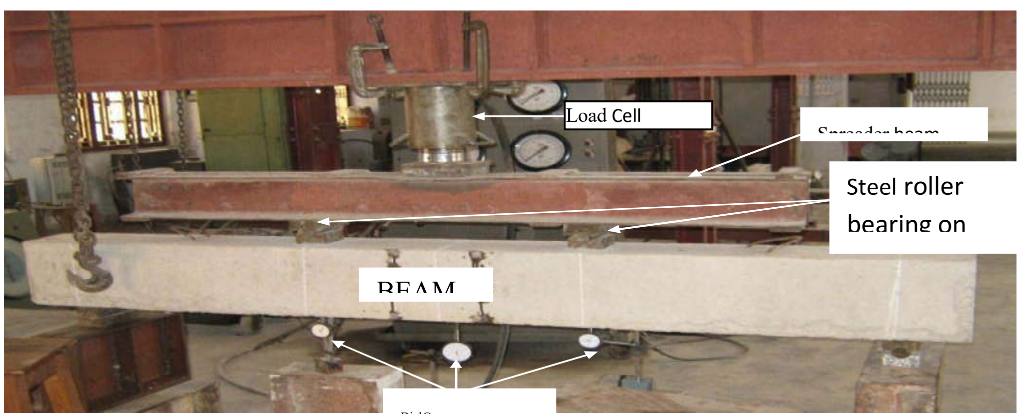

Fig.2.26. Experimental setup for testing of beams @ (Annaram Barrage Lab)

Two-point loading can be conveniently provided by the arrangement shown in Figure. The load is transmitted through a load cell and spherical seating on to a spreader beam. This beam bears on rollers seated on steel plates bedded on the test member with mortar, high-strength plaster or some similar material. The test member is supported on roller bearings acting on similar spreader plates.

The specimen was placed over the two steel rollers bearing leaving 150 mm from the ends of the beam. The remaining 2000 mm was divided into three equal parts of 667 mm as shown in the figure. Two point loading arrangement was done as shown in the figure. Loading was done by hydraulic jack of capacity 100 KN. Three number of dial gauges were used for recording the deflection of the beams. One dial gauge was placed just below the center of the beam and the remaining two dial gauges were placed just below the point loads to measure deflections.

3.2.2. Calculation Of Moment Of Resistance Of The Beams:-

The moment of resistance of the SET - I beams are obtained from the following calculations:

$$f_{ck} = 31 \text{ MPa} \qquad b = 200 \text{ mm}$$

$$f_y = 415 \text{ N/mm}^2 \qquad A_{st} = 226.19 \text{ mm}^2$$

As per IS: 456 : 2000, Clause 38.1, ANNEX G, the total force due to compression is equal to the total force due to tension, hence

$$C = T \qquad C_c = T_s$$

$$0.36 \text{ X } f_{ck} \text{ X } x_u \text{ X } b = 0.87 \text{ X } f_y \text{ X } A_{st}$$

$$x_u = 36.59 \text{ mm}$$

$$M_u = 0.36 \times f_{ck} \times x_u \times b\,(d - 0.42 \times x_u)$$

$$M_u = 17.12 \text{ KN - m}$$

Hence, the moment of resistance of beam **F1** is **17.12 KN - m.**

Now considering the effect of strengthening of beam F2 using two layers of GFRP sheets, so along with the tensile force T_s an addition tensile force T_{frp} will be also acting. The value of $T_{frp} = f_{frp} \times A_{frp}$ i.e. stress of GFRP $\times$ area of GFRP. The value of f_{frp} is obtained from the experimental testing.

$$f_{frp} = 334.5 \text{ N/mm}^2 \qquad A_{frp} = 120 \text{ mm}^2$$

$$C = T, C_c = T_s + T_{frp}$$

$$0.36 \times f_{ck} \times x_u \times b = 0.87 \times f_y \times A_{st} + f_{frp} \times A_{frp}$$

$$x_u = 54.54 \text{ mm}$$

$$M_u = 0.36 \times f_{ck} \times x_u \times b\,(d - 0.42 \times x_u)$$

$$M_u = 24.6 \text{ KN -m}$$

Hence the moment of resistance of beam **F2** is **24.6 KN - m**.

Due to application of two layers of GFRP sheet at the soffit of the F2 beam, the moment of resistance of the beam F2 is higher than moment of resistance of beam F1. The depth of neutral axis and the moment of resistance of both the beams is presented in table 3.1.

Beam	x_u (mm)	M_u (KN - m)
F1	36.59	17.12
F2	54.54	24.6

Table 3.1 Analytical calculations of beams F1 and F2

4.2. 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:

- Crushing of the concrete in compression before yielding of the reinforcing steel;
- Yielding of the steel in tension followed by rupture of the FRP laminate;
- Yielding of the steel in tension followed by concrete crushing;
- Shear/tension de-lamination of the concrete cover (cover de-lamination); and
- De-bonding of the FRP from the concrete substrate (FRP de-bonding).

5. CONCLUSIONS:-

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:

SET I Beams (F1, F2 and F3)

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 beam F2.

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.

SET II Beams (S1, S2 and S3)

The control beam S1 failed in shear as it was made intentionally weak in shear.

The initial cracks in the strengthen beams S2 and S3 appears at higher load compared to the un-strengthen beam S1.

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.

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.

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.

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.

Restoring or upgrading the shear strength of beams using GFRP sheet can result in increased shear strength and stiffness with no visible shear cracks. Restoring the shear strength of beams using GFRP is a highly effective te.

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