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STRENGTHENING OF REINFORCED CONCRETE BEAMS USING GLASS FIBER REINFORCED POLYMER

GUGULOTHU RAMBABU[1], PUSHADAPU PRUDHVIJA[2], KUSUMA SUNDAR KUMAR[3]

[1](MTECH (SE) student department of civil engineering Usha Rama college of engineering and technology)

[2](ASSISTANT PROFESSOR department of civil engineering Usha Rama college of engineering and technology)

[3](PROFESSOR & HEAD OF THE Department of civil engineering Usha Rama college of engineering and technology)

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

KEYWORD: *Fiber-reinforced polymer, glass fiber reinforced polymer (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. 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.

- Additional strength may be needed to allow for higher loads to be placed on the structure. This 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 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.

2. STRENGTHENING USING FRP COMPOSITES: 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 Strengthening with externally bonded FRP sheets has been shown to be applicable to many types of RC structural elements. FRP sheets may be adhered to the tension side of structural members (e.g., slabs or beams) to provide additional flexural strength. They may be adhered to web sides of joists and beams or wrapped around columns to provide additional shear strength.

3.ADVANTAGES AND DISADVANTAGES OF FIBERCOMPOSITESTRENGTHENING:

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 cases (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. 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.

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 unstrengthen 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. 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.

4. APPLICATIONS OF FRP STRENGTHENING:

The applications of FRP strengthening reported in the literature, the majority occur in Switzerland where the concept was first proposed and developed. In these cases, which are considered in more detail by Meier (1995), pultruded carbon fiber/epoxy laminates have been used exclusively. The first reported application was the repair in 1991 of the Ibach Bridge in the canton of Lucerne, for which several prestressing tendons had been severed during the installation of traffic signals. The bridge was repaired with three CFRP sheets of dimensions 150 mm wide by 5000 mm long and of thickness 1.75 mm or 2.0 mm. The total weight of the CFRP used was only 6.2 kg, compared with the 175 kg of steel which would have been required for the repair. In addition, all work was carried out from a mobile platform, eliminating the need for expensive scaffolding. A loading test with an 840 KN vehicle demonstrated that the rehabilitation work had been satisfactory. The wooden bridge at Sins in Switzerland was stiffened in 1992 to meet increased traffic loading (Meier et al., 1993). Two of the most highly loaded cross beams were strengthened using 1.0mm thick CFRP laminates. The appearance of the historic structure was unaltered by the strengthening technique. Other CFRP strengthening applications in Switzerland include slab reinforcement around a newly installed lift shaft in the City Hall of Gossau St. Gall, the upgrading of a supermarket roof using laminates 15.5m in length to allow the removal of a supporting wall, ground floor strengthening of the Rail Terminal in Zurich, and the strengthening of a multistory car park in Films. A chimney wall at the nuclear power plant in Leibstadt has also been post strengthened for wind and seismic loading after the installation of ducts. The following five examples of FRC strengthening were cited by Nanni (1995), carbon fiber composites having been used in all cases:

- Strengthening of a cantilever slab of the Hata Bridge along the Kyushu Highway in order to accommodate large parapet walls which caused elevated bending moments due to the higher wind force.
- Increase of the load rating of the Tokando Highway bridge at Hiyoshikura, a reinforced concrete deck supported on steel girders, causing a 30–40% reduction of stress in the internal rebar's
- Arrest of the internal steel reinforcement corrosion of the concrete beams in the waterfront pier at the Wakayama oil refinery.
- Strengthening and stiffening of the concrete lining of the Yoshino Route tunnels on Kyushu Island, necessary due to cracking which arose from unexpected fluctuations in the underground water pressure.
- No loss of tunnel cross-sectional area occurred and the road remained open during the bonding work.
- Longitudinal strengthening of the sides and soffit of a culvert at the Fujimi Bridge in Tokyo.

5. 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.

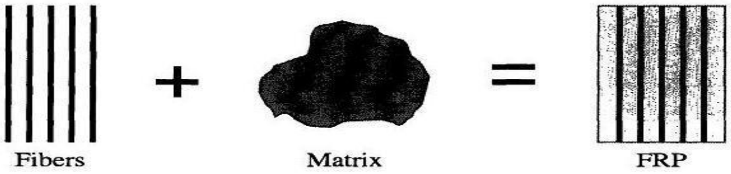


Fig.1: Formation of Fiber Reinforced Polymer Composite

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:

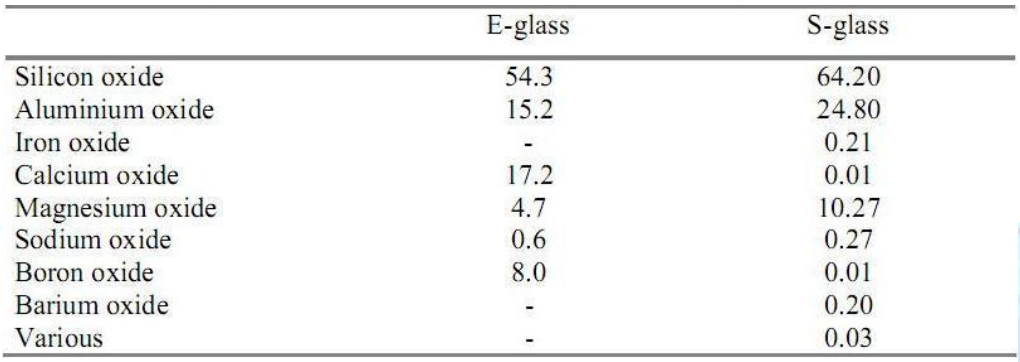
i) high modulus of elasticity for use as reinforcement;
ii) high ultimate strength
iii) low variation of strength among fibers;
iv) high stability of their strength during handling; and
v) High uniformity of diameter and surface dimension among fibers.

Types of fibers used in fiber reinforced polymer composites:

- Glass fibers
- Carbon fibers
- Aramid fibers

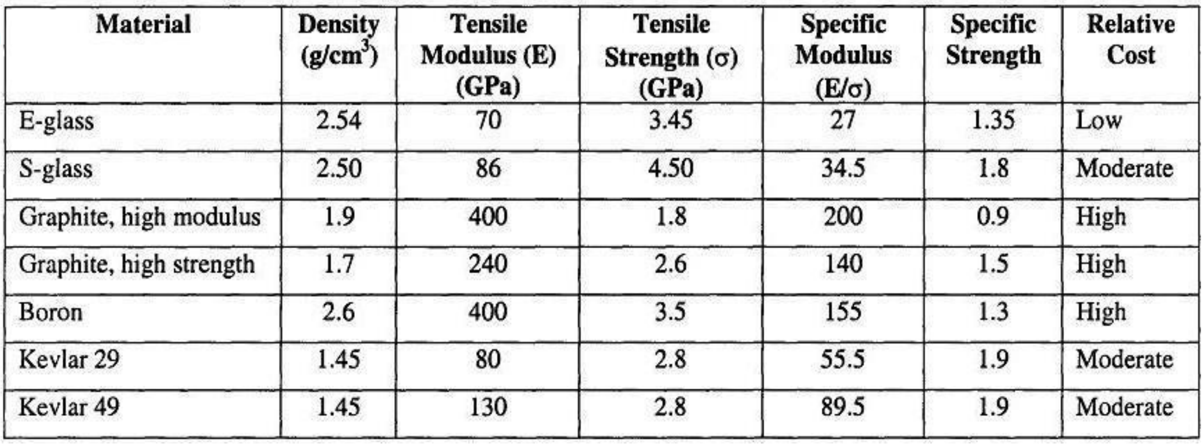
Glass fibers: These are fibers commonly used in the naval and industrial fields to produce composites of medium-high performance. Their peculiar characteristic is their high strength. Glass is mainly made of silicon (SiO_2) with a tetrahedral structure (SiO_4). Some aluminum oxides and other metallic ions are then added in various proportions to either ease the working operations or modify some properties (e.g., S-glass fibers exhibit a higher tensile strength than E-glass).The production technology of fiberglass is essentially based on spinning a batch made of sand, alumina, and limestone. The constituents are dry mixed and brought to melting (about 1260 °C) in a tank. The melted glass is carried directly on platinum bushings and, by gravity, passes through ad hoc holes located on the bottom. The filaments are then grouped to form a strand typically made of 204 filaments. The single filament has an average diameter of 10 µm and is typically covered with a sizing. The yarns are then bundled, in most cases without twisting, in a roving.

Table 1: Typical composition of fiberglass (% in weight)



	E-glass	S-glass
Silicon oxide	54.3	64.20
Aluminium oxide	15.2	24.80
Iron oxide	-	0.21
Calcium oxide	17.2	0.01
Magnesium oxide	4.7	10.27
Sodium oxide	0.6	0.27
Boron oxide	8.0	0.01
Barium oxide	-	0.20
Various	-	0.03

Table 2: properties of different fibers



Material	Density (g/cm^3)	Tensile Modulus (E) (GPa)	Tensile Strength (σ) (GPa)	Specific Modulus (E/σ)	Specific Strength	Relative Cost
E-glass	2.54	70	3.45	27	1.35	Low
S-glass	2.50	86	4.50	34.5	1.8	Moderate
Graphite, high modulus	1.9	400	1.8	200	0.9	High
Graphite, high strength	1.7	240	2.6	140	1.5	High
Boron	2.6	400	3.5	155	1.3	High
Kevlar 29	1.45	80	2.8	55.5	1.9	Moderate
Kevlar 49	1.45	130	2.8	89.5	1.9	Moderate

Glass fibers typically have a Young modulus of elasticity (70 GPA for E-glass) lower than carbon or aramid fibers and their abrasion resistance is relatively poor; therefore, caution in their manipulation is required. In addition, they are prone to creep and have low fatigue strength. To enhance the bond between fibers and matrix, as well as to protect the fibers itself against alkaline agents and moisture, fibers undergo sizing treatments acting as coupling agents. Such treatments are useful to enhance durability and fatigue performance (static and dynamic) of the composite material. FRP composites based on fiberglass are usually denoted as GFRP.


Discontinuous fibers.
Discontinuous fibers *mat.*

Fig .2: Discontinuous Glass Fibers

Carbon fibers: consist of small crystallite of turbostratic graphite. These resemble graphite single crystals except that the layer planes are not packed in a regular bonds. Between the basal planes only weak Van-der-waal forces exist. Therefore the single crystals are highly anisotropic with the plane moduli of the order of 100 GPA whereas the molecules perpendicular to the basal plane are only about 75 GPA. It is thus evident that to produce high modulus and high strength fibers, the basal planes of the graphite must be parallel to the fiber axis. They have lower thermal expansion coefficients than both the glass and aramid fibers. The carbon fiber is an anisotropic material, and its transverse modulus is an order of magnitude less than its longitudinal modulus. The material has a very high fatigue and creep resistance. Since its tensile strength decreases with increasing modulus, its strain at rupture will also are much lower. Because of the material brittleness at higher modulus, it becomes critical in joint and connection details, which can have high stress concentrations. As a result of this phenomenon, carbon composite laminates are more effective with adhesive bonding that eliminates mechanical fastened

Table 3: Typical properties of carbon fibers

Typical Properties	Density (g/cm^3)	Young's Modulus (GPa)	Tensile Strength (GPa)	Tensile Elongation (%)
High Strength	1.8	230	2.48	1.1
High Modulus	1.9	370	1.79	0.5
Ultra-High Modulus	2.0 - 2.1	520 – 620	1.03 - 1.31	0.2

Kevlar fibers: Kevlar (poly-paraphenylene terephthalamide) is the DuPont Company's brand name for a synthetic material constructed of para-aramid fibers that the company claims is five times stronger than the same weight of steel, while being lightweight, flexible and comfortable. It is also very heat resistant and decomposes above 400 °C without melting. It was invented by Stephanie Kwolek of DuPont from research into high performance polymers, and patented by her in 1966 and first marketed in 1971. Kevlar is a registered trademark of E.I. du Pont de Nemours and Company. Kevlar fibers can be bonded to one another or to other materials to form a composite. Kevlar's main weaknesses are that it decomposes under alkaline conditions or when exposed to chlorine. While it can have a great tensile strength, sometimes in excess of 4.0 GPA, like all fibers it tends to buckle in compression

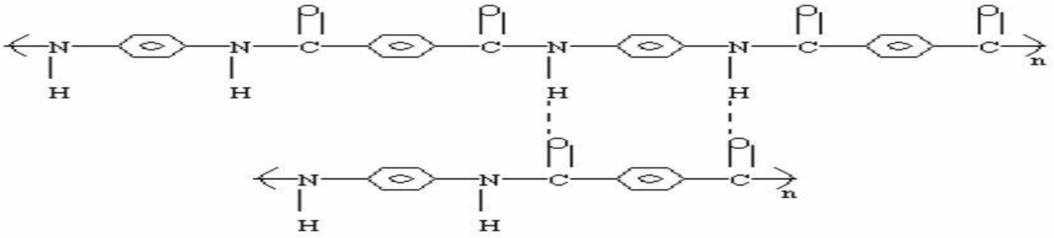


Fig. 3: Structure of aramid fiber

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.

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.

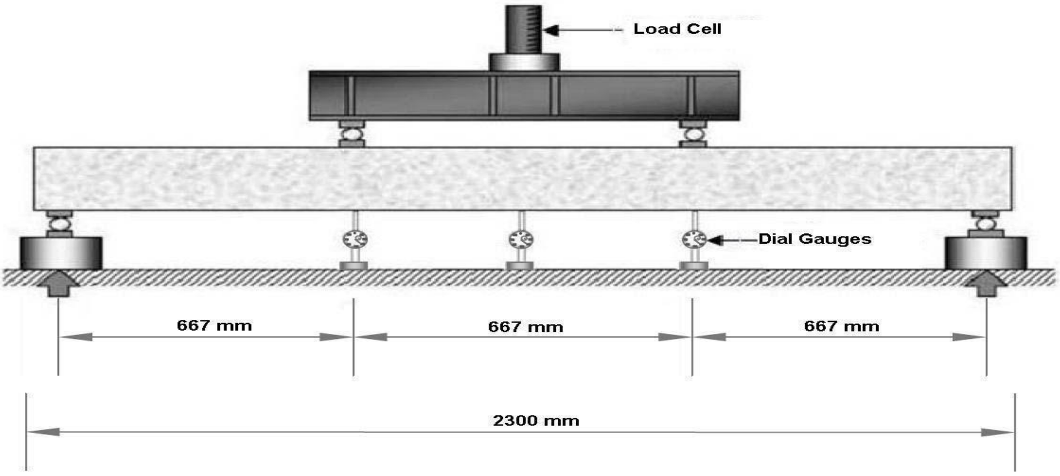


Fig. 4: Two point loading experimental setup

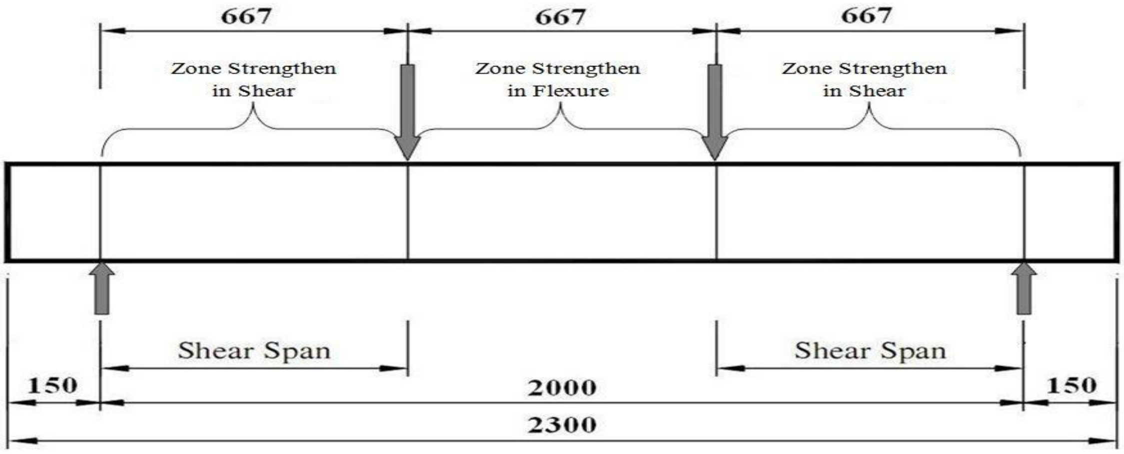


Fig. 5: Shear strengthening zone and flexure strengthening zone of the beam

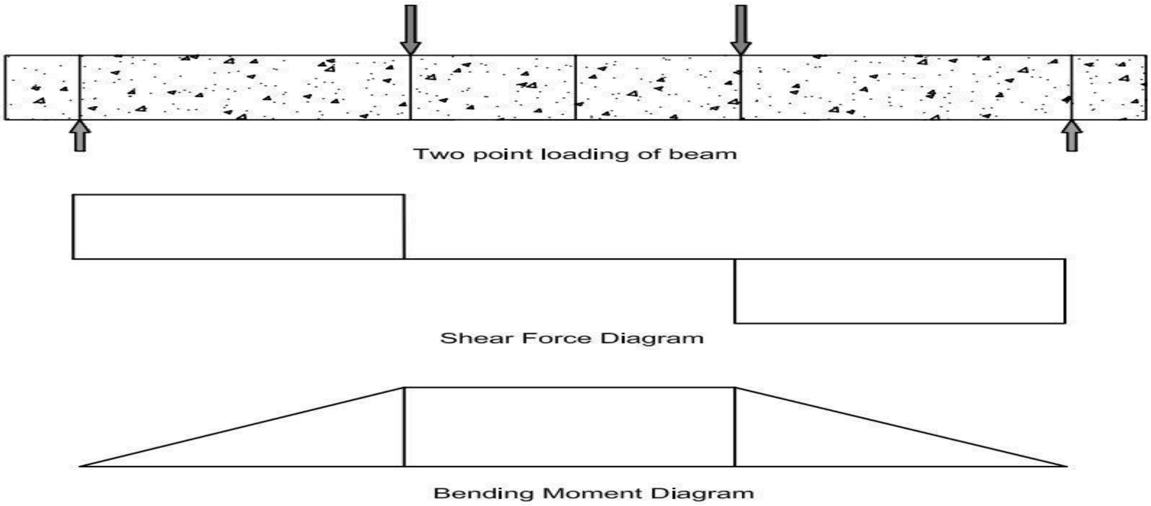


Fig. 6: Shear force and bending moment diagram for two point loading

7. 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.

8. 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:

A) 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.

B) 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 beam.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 technique.

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