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Strengthening of Reinforced Concrete Beams using Fiber Reinforced Polymer Composites

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Abstract: 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. The purpose of this research is to investigate the flexural and shear behavior 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.
Keywords: Strengthening, reinforced concrete beam, glass fiber reinforced polymer, composites, epoxy resin.

I. INTRODUCTION

The use of fiber reinforced polymer (FRP) materials in civil infrastructure for the repair and strengthening of reinforced concrete structures and also for new constructions has become common practice. The most efficient technique for improving the shear strength of deteriorated RC members is to externally bond fiber reinforced polymer (FRP) plates or sheets. External plate bonding is a method of strengthening which involves adhering additional reinforcement to the external faces of a structural member. The success of this technique relies heavily on the physical properties of the material used and on the quality of the adhesive, generally an epoxy resin, which is used to transfer the stresses between the flexural element and the attached reinforcement. The major constituents of FRP are the fiber and the resin. The mechanical properties of FRP are controlled by the type of fiber and durability characteristics are affected by the type of resin. FRP can be applied for strengthening a variety of structural members like beams, columns, slabs and masonry walls. Beams and slabs may be strengthened in flexure by bonding FRP strips at the soffit portion along the axis of bending. Shear strengthening of beams may be achieved by bonding vertical or inclined strips of FRP at the side faces of beams.

II. MATERIAL

A. 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. Ordinary Portland cement (OPC) – 43 grade (Ambuja Cement) was used for the investigation. 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/mm^2. 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 was 31N/mm^2.

B. 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.

C. Fiber Reinforced Polymer (FRP)

Continuous fiber-reinforced materials with polymeric matrix (FRP) can be considered as composite, heterogeneous, and anisotropic materials with a prevalent linear elastic behavior up to failure. Fiber sheet used in this experimental investigation was E-Glass, Bi directional woven roving mat. It was not susceptible to atmospheric agents. It was also chemically resistive and anticorrosive.

D. Epoxy Resin

Epoxy resins are relatively low molecular weight pre-polymers capable of being processed under a variety of conditions. The success of the strengthening technique critically depends on the performance of the epoxy resin used. The resin and hardener are used in this study is Araldite LY 556 and Hardener HY 951, respectively. Araldite LY-556, an unmodified epoxy resin based on Bisphenol-A and the hardener (Ciba-Geig, India) HY 951 (8% of total Epoxy taken) an aliphatic primary amine, were mixed properly.

III.CASTING OF BEAMS

Two sets of beams were casted for this experimental test program. The dimensions of all the specimens are identical. In SET I three beams (F1, F2 and F3) weak in flexure were casted using same grade of concrete and reinforcement detailing. 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 75 mm center to center.

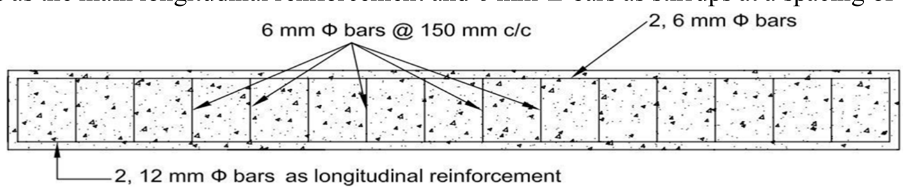

Fig. 1 Reinforcement details of SET I beams

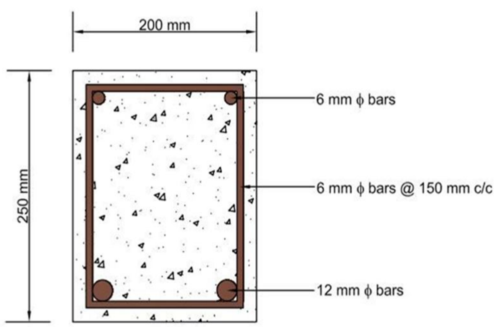

Fig. 2 Section of SET I beams

In SET II three beams (S1, S2 and S3) weak in shear were casted using same grade of concrete and reinforcement detailing. In SET II beams 3, 12 mm □ bars are provided as the main longitudinal reinforcement and without any stirrups.

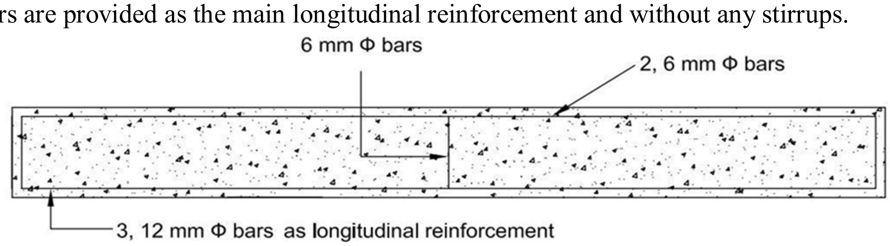

Fig. 3 Reinforcement details of SET II beams

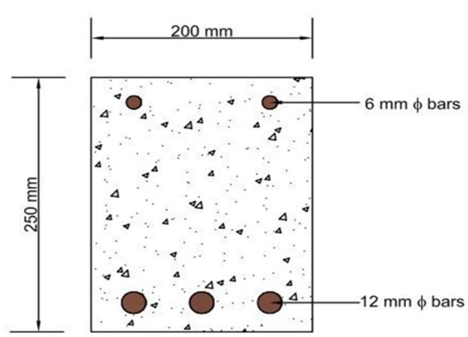

Fig. 4 Section of SET II beams

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IV. STRENGTHENING OF BEAMS

Before bonding the composite fabric onto the concrete surface, the required region of concrete surface was made rough using a coarse sand paper texture and cleaned with an air blower to remove all dirt and debris. Once the surface was prepared to the required standard, the epoxy resin was mixed. Mixing was carried out in a plastic container and was continued until the mixture was in uniform color. When this was completed and the fabrics had been cut to size, the epoxy resin was applied to the concrete surface. The composite fabric was then placed on top of epoxy resin coating and the resin was squeezed through the roving of the fabric with the roller. This operation was carried out at room temperature. Concrete beams strengthened with glass fiber fabric were cured for 24 hours at room temperature before testing.

Fig. 5 Application of epoxy and hardener on the beam

Fig. 6 Fixing of GFRP sheet on the beam

V. EXPERIMENTAL SETUP

All the specimens were tested in the loading frame of the Standard Precision Testing Laboratory, Nagpur. 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. Load arrangement for testing of beams will consist of two-point loading. 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. 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.

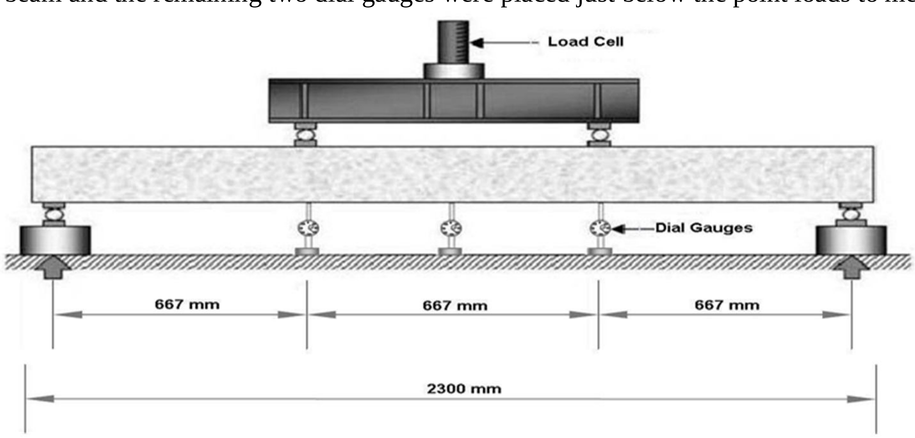

Fig. 7 Two point loading experimental setup

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Fig. 8 Experimental setup for testing of beams

VI. PROCEDURE

Before testing the member was checked dimensionally, and a detailed visual inspection made with all information carefully recorded. After setting and reading all gauges, the load was increased incrementally up to the calculated working load, with loads and deflections recorded at each stage. Loads will then normally be increased again in similar increments up to failure, with deflection gauges replaced by a suitably mounted scale as failure approaches. This is necessary to avoid damage to gauges, and although accuracy is reduced, the deflections at this stage will usually be large and easily measured from a distance. Similarly, cracking and manual strain observations must be suspended as failure approaches unless special safety precautions are taken. If it is essential that precise deflection readings are taken up to collapse. Cracking and failure mode was checked visually, and a load/deflection plot was prepared.

VII. ANALYTICAL STUDY

Analytical study is devoted to the development of an analytical model to analyze and design reinforced concrete beams strengthened in flexural by means of externally bonded glass fiber reinforced polymer composite sheets. The purpose of this analytical model is to accurately predict the flexural behavior of reinforced concrete beams strengthened with GFRP sheet. The moment of resistance of the SET I and SET II beams are obtained from the calculations.

Table 1
Analytical calculations of beams F1 and F2

Beam	X_u (mm)	M_u (kN□m)
F1	36.59	17.12
F2	54.54	24.6

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VIII. RESULTS AND GRAPHS

A. Failure Modes

Table 2
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	LoadinKN 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

B. Load Deflection Curve

From the load and deflection of data of SET I beams F1, F2 and F3, it is clear that beam F1 has lower ultimate load carrying capacity compared to beams F2 and F3. Beam F1 had also undergone higher deflection compared to beams F2 and F3 at the same load. Beam F2 had higher ultimate load carrying capacity compared to the controlled beam F1 but lower than beam F3. Beam F3 had higher ultimate load carrying capacity compared to the beams F1 and F2. Both the beams F2 and F3 had undergone almost same deflection up to 65 KN load. After 65 KN load beam F3 had undergone same deflection as beam F2 but at a higher load compared to beam F2. The deflection undergone by beam F3 is highest. Beam F2 had undergone higher deflection than beam F1.

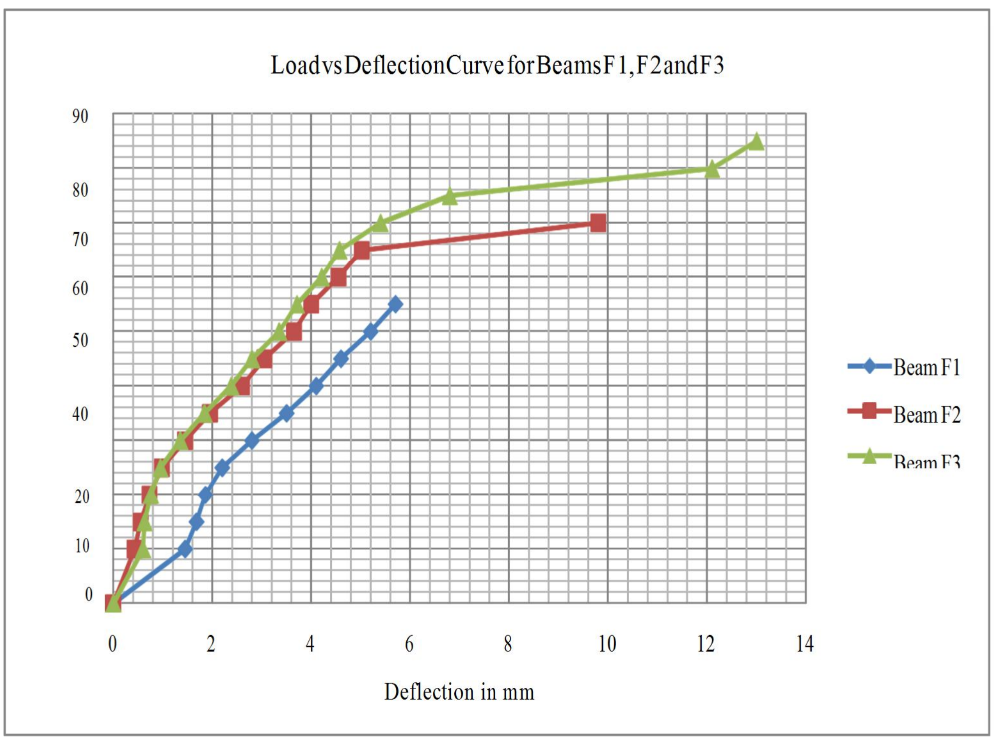

Fig. 9 Load vs Deflection Curves for Beams F1, F2 and F3.

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From the load and deflection of data of SET II beams S1, S2 and S3, it is clear that beam S1 has lower ultimate load carrying capacity compared to beams S2 and S3. Beam S1 had also undergone higher deflection compared to beams S2 and S3 at the same load. Beam S2 had higher ultimate load carrying capacity compared to the controlled beam S1 but lower than beam S3. Beam S3 had higher ultimate load carrying capacity compared to the beams S1 and S2. Both the beams S2 and S3 had undergone almost same deflection up to 70 KN load. After 70 KN load beam S3 had undergone same deflection as beam S2 but at a higher load compared to beam S2. The deflection undergone by beam S3 is highest. Beam S2 had undergone higher deflection than beam S1.

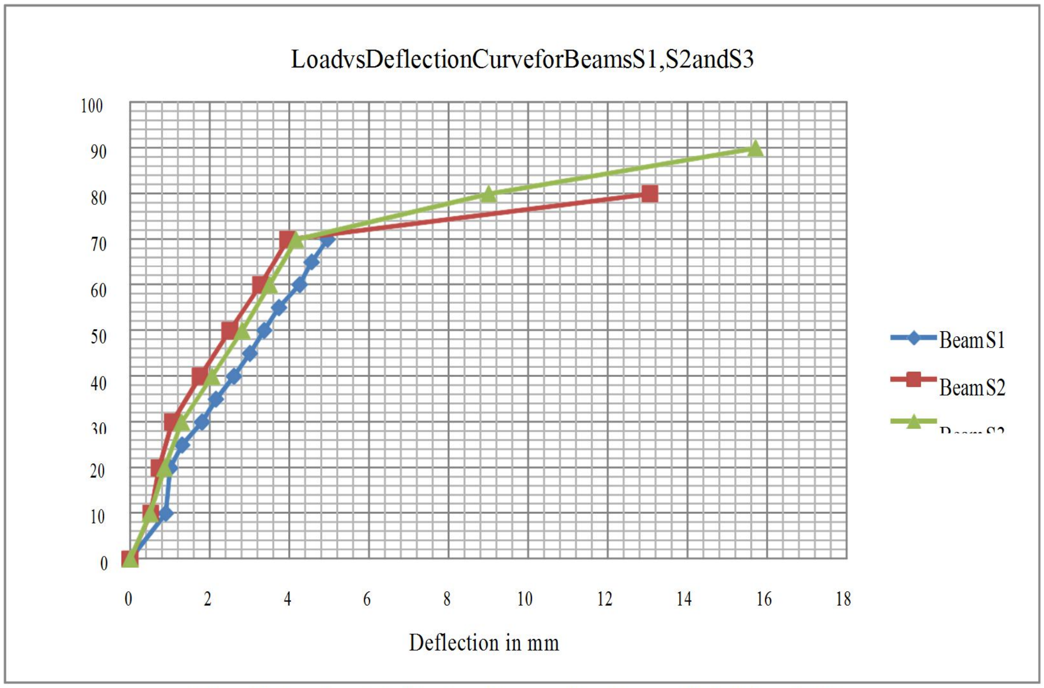

Fig. 10 Load vs Deflection Curves for Beams S1, S2 and S3.

C. Ultimate Load Carrying Capacity

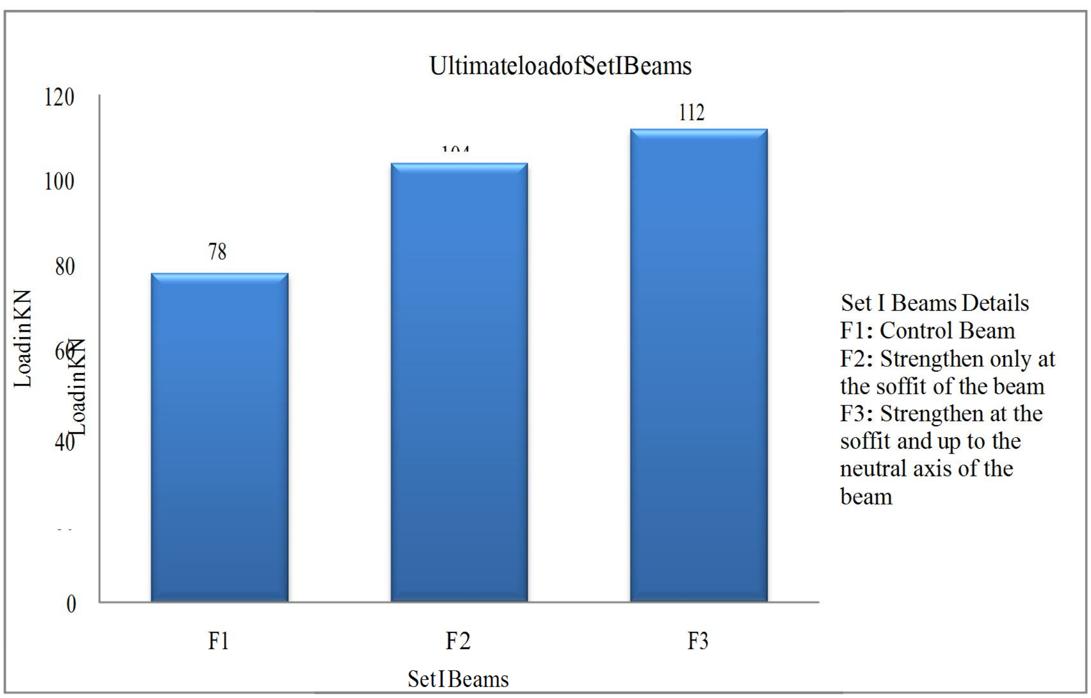

Fig. 11 Ultimate load of beams F1, F2 and F3.

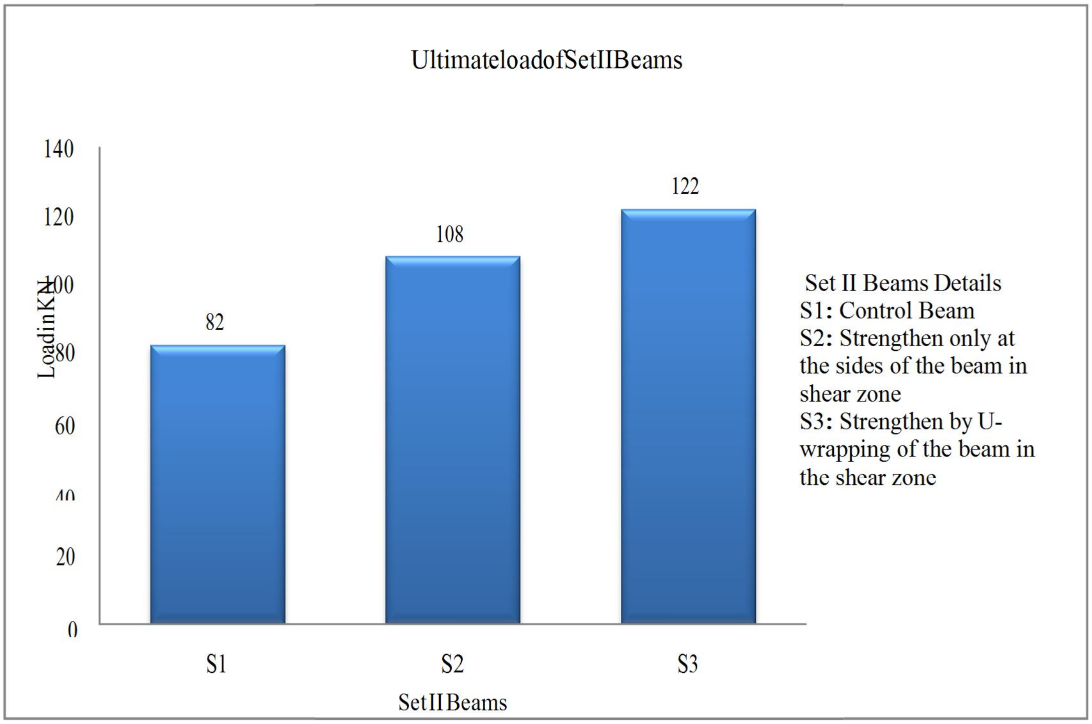

Fig. 12 Ultimate load of beams S1, S2 and S3.

D. Comparison of Results

Table 3

Comparison of M_u value obtained from analytical and experimental study

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

IX. CONCLUSIONS

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. 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. 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. It was found that analytical analysis predicts lower value than the experimental findings. 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.

X. ACKNOWLEDGMENT

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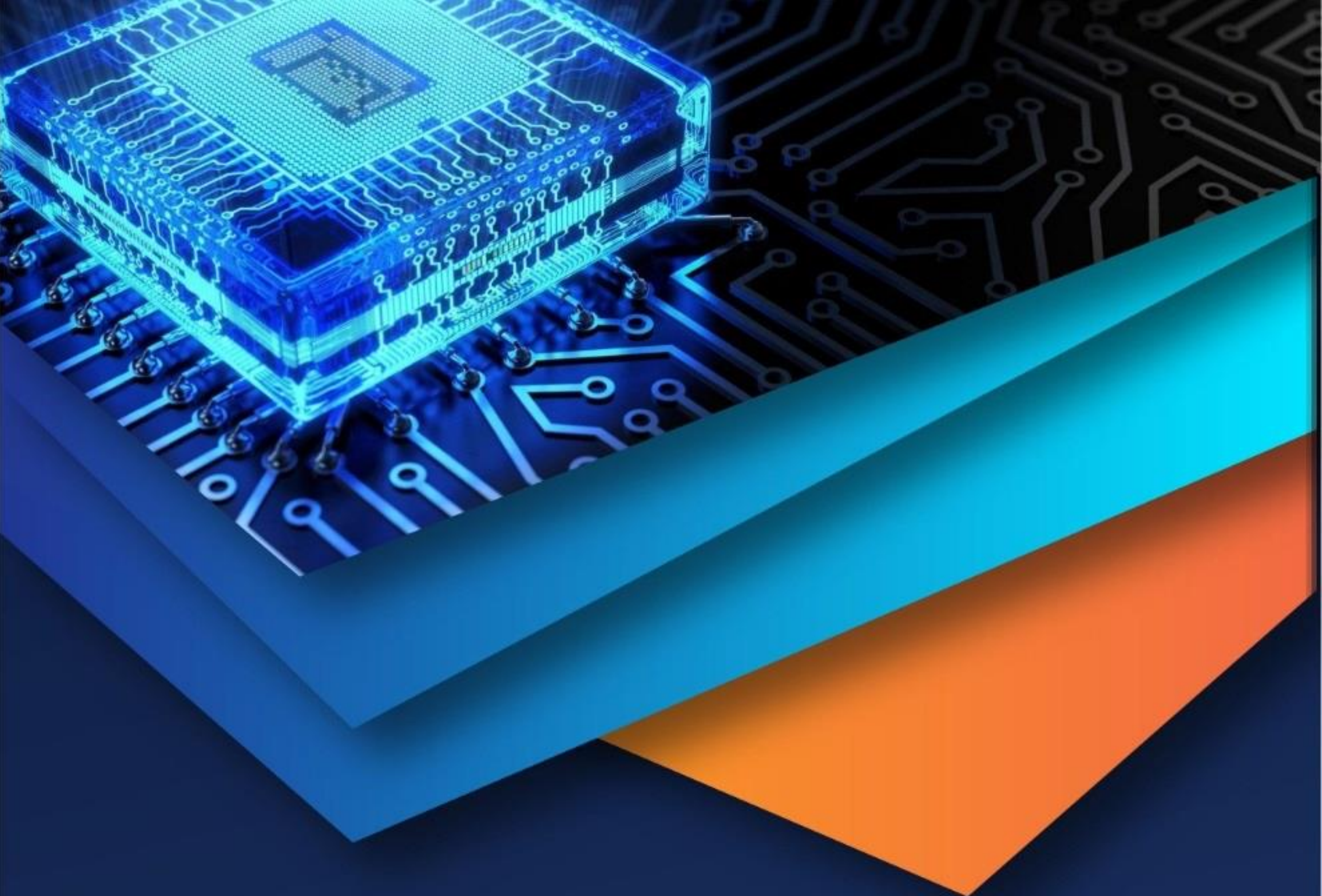

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