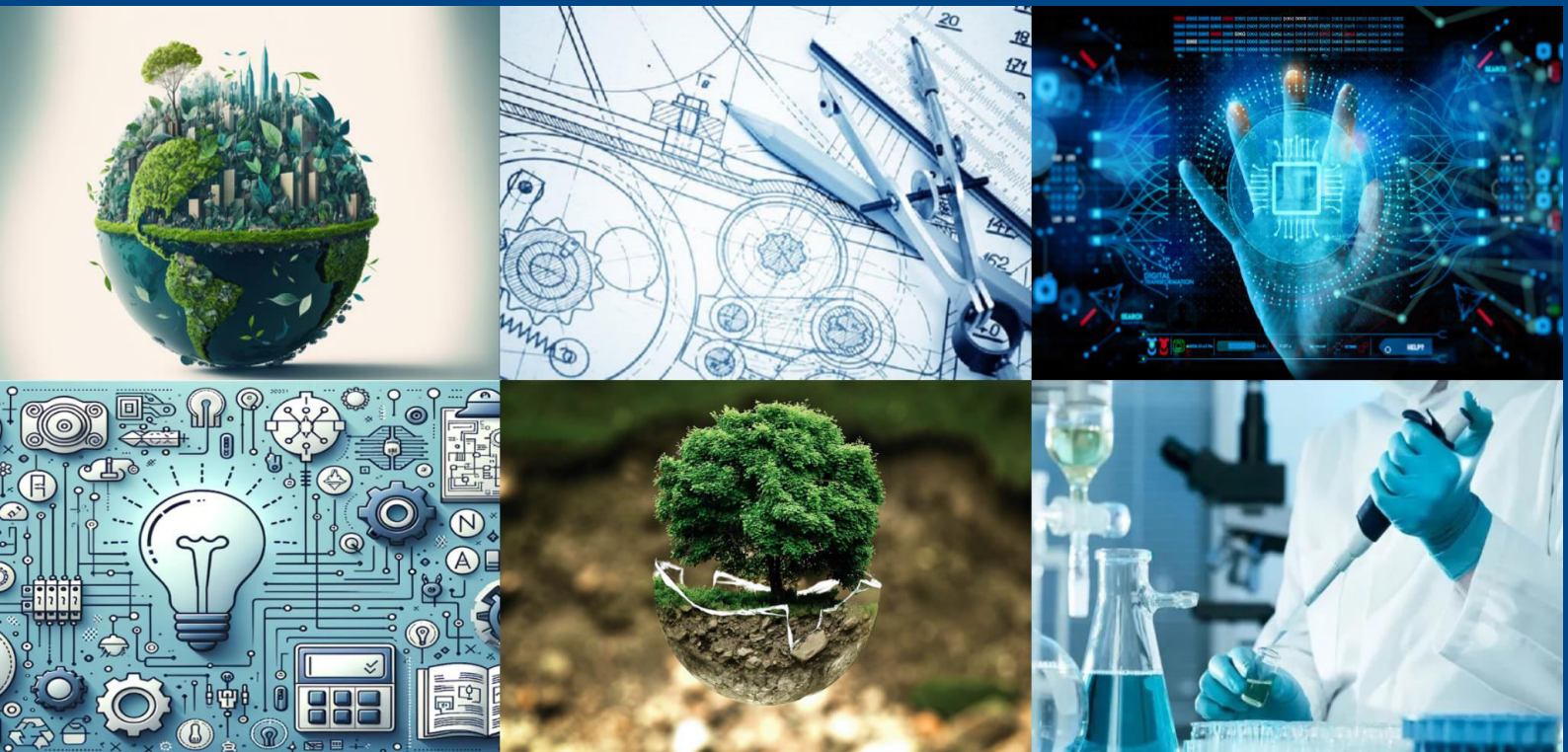




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A Study on the Use of Glass Fiber Reinforced Polymer Composites for Improving the Strength of Reinforced Concrete Beams

Sanjay Kadwasara, Dr. Irfan Kalal

Student, M. Tech. (Structural Engineering), Department of Civil Engineering, Shri JJT University, Jhunjhunu,
Rajasthan, India

Guide, Assistant Professor, Department of Civil Engineering, Shri JJT University, Jhunjhunu, Rajasthan, India

ABSTRACT: Reinforced concrete (RC) structures often require strengthening due to aging, increased loading demands, and environmental deterioration. This study examines the effectiveness of Glass Fiber Reinforced Polymer (GFRP) composites in enhancing the structural performance of RC beams. Experimental investigations were conducted on control and GFRP-strengthened beam specimens subjected to two-point static loading. The behavior of the beams was evaluated in terms of crack development, load-carrying capacity, stiffness, ductility, and deflection. The results demonstrated that GFRP strengthening significantly improved beam performance by delaying crack initiation, reducing crack widths, increasing stiffness, and enhancing ultimate load capacity. The strengthened beams also exhibited better resistance to flexural and shear stresses. The study confirms that GFRP composites offer an efficient, durable, and economical solution for strengthening reinforced concrete structures.

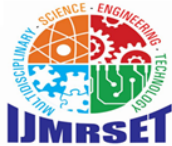
KEYWORDS: Reinforced Concrete Beams, Glass Fiber Reinforced Polymer (GFRP), Structural Strengthening.

I. INTRODUCTION

The strength, durability, adaptability and financial benefits, reinforced concrete buildings are among the most popular types of construction in the contemporary world. Concrete and steel reinforcing bars are used to create reinforced concrete, a composite material commonly known as rebars, to enhance the structural performance of buildings and infrastructure. Concrete possesses high compressive strength, which makes it capable of resisting heavy loads and pressures. However, it has very poor tensile strength and a propensity to fracture under stress. Because steel has a high tensile strength and can withstand bending and stretching pressures, steel reinforcement is included into the concrete to get around this restriction. Because these two materials work together to generate a structural structure that can bear both tensile and compressive loads, reinforced concrete is appropriate for a variety of engineering applications.

Causes of Structural Deterioration and Damage

- Environmental exposure Continuous exposure to moisture, temperature fluctuations, rainfall, humidity, and ultraviolet radiation gradually weakens construction materials such as concrete, steel, and masonry.
- Corrosion of reinforcement steel in reinforced concrete structures occurs when water and chemicals penetrate concrete surfaces. Rust formation increases the volume of steel, leading to cracking, spalling, and reduction in structural strength.
- Poor quality construction materials use of low-grade cement, contaminated aggregates, inferior steel, or improper concrete mix proportions often results in premature deterioration.
- Inadequate design and structural planning may cause excessive stress on structural elements. Errors in load calculations, insufficient reinforcement, and improper detailing can weaken the stability and safety of buildings.
- Faulty construction practices such as improper curing, poor workmanship and inadequate compaction of concrete and incorrect placement of reinforcement contribute to early structural defects and long-term damage.



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II. OBJECTIVES

1. To examine the flexural performance of reinforced concrete beams in loading situations.
2. To evaluate the impact of Glass Fiber Reinforced Polymer (GFRP) establishment on the ultimate load capacity and failure characteristics of reinforced concrete beams.
3. To examine the shear performance and performance of reinforced concrete beams subjected to shear forces.

III. REVIEW OF LITERATURE

Kim, S., Choi, W., & Kim, J. (2025)

The poor flexural performance of unreinforced concrete beams remains a major concern because concrete has a relatively moderate tensile strength but a high compressive strength. Reinforcement bars are typically positioned in the tension zone of reinforced concrete (RC) to get around this restriction beams. However, RC structures often experience problems over time, including deterioration of concrete, corrosion of reinforcing steel, and a decline in live load carrying capacity.

Al-Thairy, H., & Aadi, A. (2024)

This study investigates the structural properties, behaviour, and strength characteristics comprising deep beams made that are near-surface mounted (NSM). Five RC deep beams of 1500 mm in length and 400 × 160 mm in cross-section were produced and tested experimentally. While the other beams were strengthened, one of these specimens was left unstrengthened to act as the control specimen with various configurations of NSM GFRP bars. Every beam specimen underwent four-point loading at different shear span-to-effective depth ratios until it failed.

R, A. (2023)

Extensive For the repair and strengthening of reinforced concrete buildings, fiber-reinforced plastic sheets, laminates, and wraps are the subject of on-going study worldwide. Fiber Reinforced Polymer (FRP) materials have become a popular and effective method for improving the structural performance of deteriorated concrete members during their service life.

Kassa, H., Melesse, G., & Yabasa, G. (2022)

The concrete construction industry frequently faces challenges related to the low tensile capacity of structural members, brittle failure behaviour, fast crack development, and excessive loading effects. This study focuses on experimentally assessing the flexural performance containing different proportions polymers have gained considerable attention worldwide because of mechanical behaviour structures.

Rafiee, S., Dardae, S., & Bagheri, H. (2021)

Concrete structures are generally considered durable and dependable; however, construction mistakes and negligence during execution can result in various structural deficiencies. These defects often arise from inadequate design procedures, insufficient quality control measures, or improper structural detailing and analysis.

Nwankwo, C., & Ede, A. (2020)

Polymer composites reinforced with fibres are widely applied in the construction sector for the retrofitting of reinforced concrete (RC) structures. However, natural fibres offer a more environmentally sustainable substitute for these conventional synthetic materials. In this research, a kenaf fibre reinforced polymer (KFRP) laminate was developed and manufactured to improve the flexural performance of an RC beam.

Rangari, P. (2019)

The repairing and strengthening structures that have lost their structural capacity over time FRP-based strengthening systems offer a cost-effective and practical substitute for conventional repair methods and materials. This study focuses on examining the flexural and shear performance of concrete beams reinforced with several GFRP sheet layers in various configurations. Understanding how the quantity and orientation of GFRP layers affect the beams' strength and ductility receives particular emphasis.



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IV. METHODOLOGY

All beam specimens to ensure consistency and reliability in the experimental results. After completing each beam was removed from the curing environment, thoroughly cleaned, and washed to remove dust, loose particles, and surface impurities. This preparation helped in the clear observation and recording of crack development during the testing process.

The reinforced concrete beams This loading arrangement is widely used in structural investigations because it creates a large region of nearly constant bending moment between the loading points while producing relatively low shear forces in the central portion of the beam. Such a condition is highly suitable for evaluating the flexural performance and specimens. In cases where shear behavior is of primary interest, the applied load may be positioned closer to the supports to induce higher shear stresses.

A load cell and a spreader beam were used to convey the loading force, distributing it evenly at two specified locations on the specimen. Steel roller bearings placed 150 mm from either end supported the beam sample. Three equal pieces of around 667 mm each made up the effective span of 2000 mm each and the loads were applied at the designated locations accordingly.

Table 1: Various Fiber Properties

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 are commonly preferred in strengthening applications because they are lightweight, economical, and easy to handle during installation. They possess excellent tensile properties and can effectively resist crack propagation in reinforced concrete structures. When externally bonded to concrete surfaces using suitable epoxy adhesives, GFRP fibers improve the stiffness, and service life. The use of GFRP also minimizes additional dead load on the structure because of its lightweight nature.

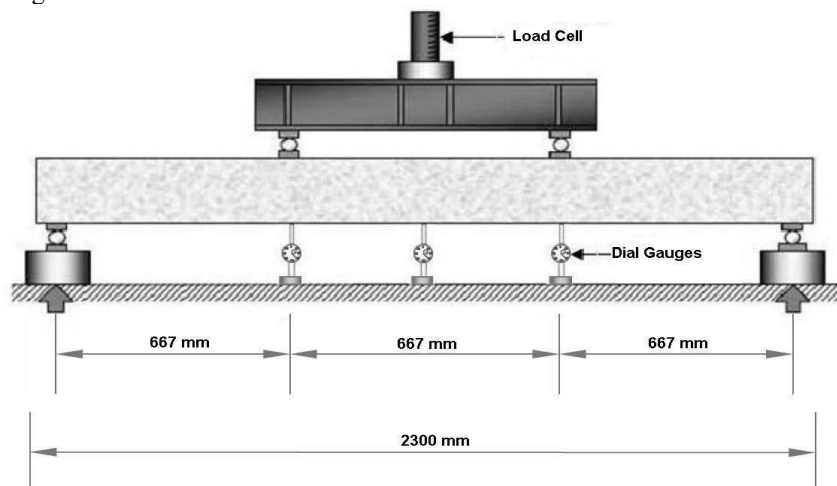


Figure 2: Experimental Setup of Two Point Loading



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The loading frame used in the experiment was sufficiently rigid to withstand the anticipated loads without experiencing significant deformation. Special attention was given to providing easy access to the central region of the beam for observing crack propagation, measuring deflections, and ensuring safe testing conditions. To record vertical deflections accurately, three dial gauges were installed. One gauge was positioned at directly beneath the loading points to monitor the deformation behavior throughout the loading process. This arrangement enabled precise measurement of beam deflections and facilitated a detailed assessment of structural performance under applied loads.

V. RESULT AND DISCUSSIONS

The structural performance of reinforced concrete (RC) beams was significantly improved by the use of composites. GFRP composites' use improved the strengthened beams' load-carrying capability in comparison to the control, according to experimental findings specimens. The strengthened beams exhibited enhanced resistance to flexural and shear stresses, enabling them to sustain higher loads before the onset of cracking and ultimate failure.

The results further indicated that the first crack load was considerably higher in beams retrofitted with GFRP composites. The development and propagation of cracks were effectively controlled due to the confinement and reinforcement provided by the GFRP layers. As a result, the strengthened beams showed reduced improved crack distribution and crack widths during the loading procedure. This contributed to greater durability and serviceability of the structural members.

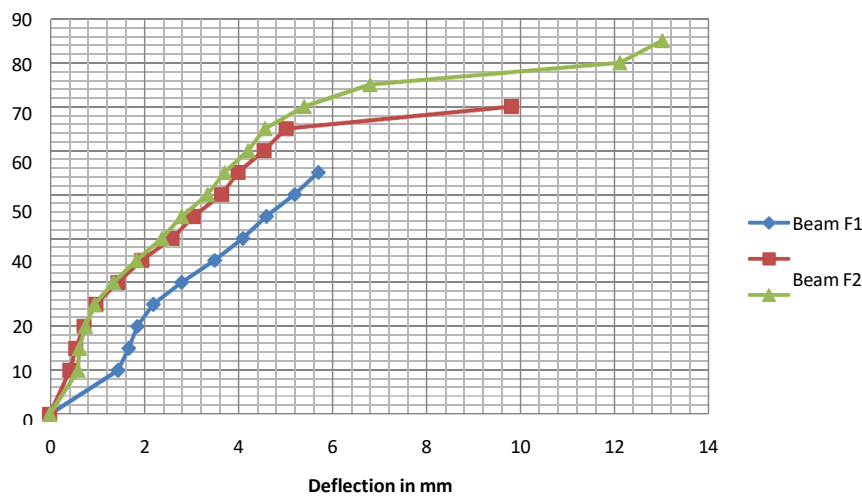


Figure 3: Deflection vs. Load for Beams F1, F2 and F3

Based on load versus deflection data collected for the SET I beam (F1, F2, and F3) curves were developed specimens. The analysis of these curves indicates notable differences in their structural performance. Beam F1 exhibited the lowest among the three beams and experienced greater deflection than beams F2 and F3 under identical loading conditions. Beam F2 demonstrated an improvement in to the control beam F1; however, its capacity remained lower than that of beam F3. Among all specimens, beam F3 showed the highest ultimate load-carrying capacity, reflecting superior structural strength.



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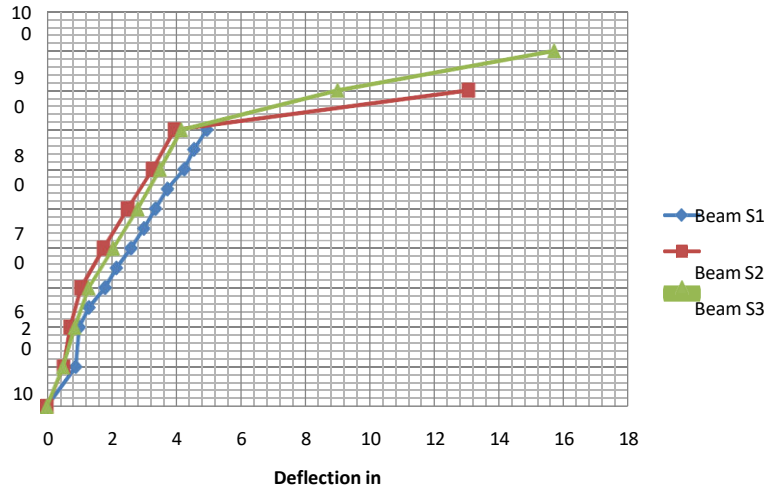


Figure 4: Deflection vs. Load for Beams S1, S2 and S3

Beam S2 demonstrated and the control beam S1, although its capacity remained lower than that of beam S3. Among all the specimens, beam S3 achieved the highest ultimate load capacity, indicating superior structural performance. Up to a load of approximately 70 kN, beams S2 and S3 displayed nearly identical deflection characteristics. Beyond this load level, beam S3 sustained higher loads while exhibiting deflections comparable to those of beam S2. The maximum deflection was observed in beam S3 at failure. Furthermore, beam S2 experienced greater deflection than beam S1, indicating enhanced ductility despite its increased load-bearing capacity.

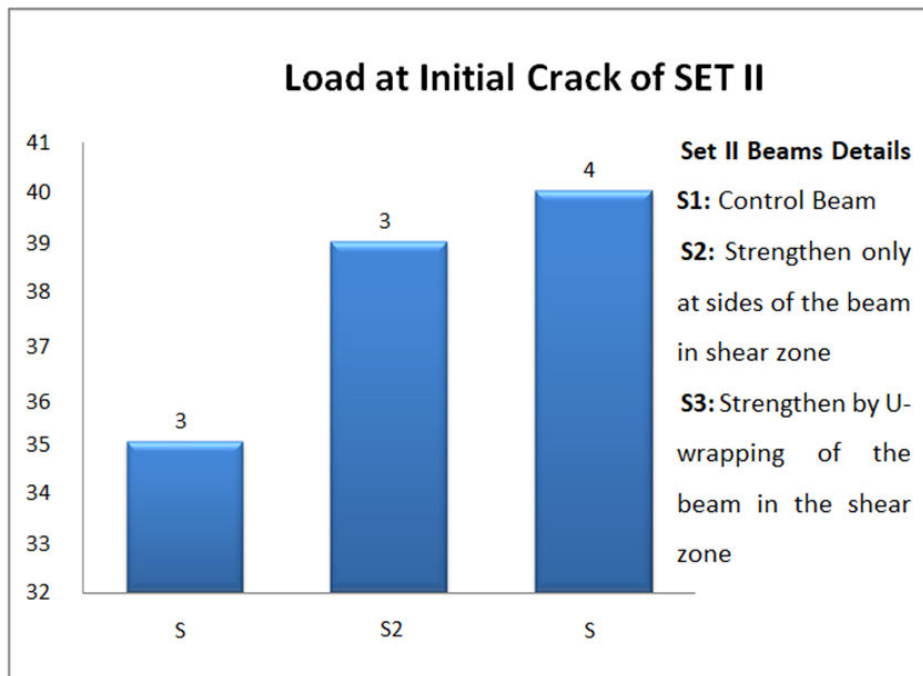
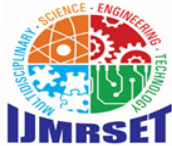


Figure 5: Crack of beams S1, S2 and S3

Beam S1 exhibited the earliest crack formation, of 35 kN. In comparison, Beam F2 showed crack initiation at a higher load of 39 kN, indicating improved resistance to cracking. Beam F3 demonstrated the best performance among the three, with the first crack observed at 40 kN. This suggests that the strengthening measures adopted in beams F2 and F3 enhanced their load-carrying capacity and delayed crack formation. However, the variation in crack initiation loads



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between beams S2 and S3 was minimal, indicating that both beams exhibited nearly similar cracking behavior and structural response under the applied loading conditions.

VI. CONCLUSION

The experimental results obtained Table two sets of reinforced concrete beams. The failure, load corresponding to the first apparent fracture, the maximum load-bearing capacity of the beams reinforced with two layers of Glass Fiber Reinforced Polymer (GFRP) sheets as well as the control beams are among the crucial data shown in the table. A comparison of these metrics offers important information about how well GFRP strengthening enhances the reinforced concrete beams' structural performance.

Strengthened structural components' reactions to combined flexural and shear actions is highly complex. The interaction between concrete, steel reinforcement, adhesive materials, and externally bonded GFRP sheets makes it difficult to establish a comprehensive and rigorous theoretical design methodology. Due to these complexities, extensive experimental investigations are essential for understanding the actual response of strengthened beams under loading conditions. Experimental studies help in evaluating crack development, stiffness characteristics, load-deflection behavior, and ultimate strength with greater accuracy.

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