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Strengthening of RC Beam with GFRP Composites in Shear N. B. Bhopale

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Abstract:- The rehabilitation, repair and strengthening of existing reinforced concrete (RC) structures is essential due to factors such as aging, steel reinforcement corrosion, construction/design defects, increased service loads demand, seismic events, and advancements in design guidelines. Fiber-reinforced polymers (FRP) are now being recognized as a promising material for the rehabilitation of such structures, through strengthening or repairing. In buildings and bridges, RC sections are commonly found in the form of beams and girders. Shear failure of RC beams is particularly due to its sudden occurrence without warning. Therefore, the utilization of externally bonded (EB) FRP composites for shear strengthening of RC beams has gathered popularity as a structural enhancement technique, primarily due to advantages of FRP composites, such as high strength-to-weight ratio and exceptional corrosion resistance. In addition, FRP repair systems give a cost-saving choice to traditional repair methods and materials. A study was performed to analyse the shear characteristics of RC beams enhanced with continuous glass fiber-reinforced polymer (GFRP) sheets. Reinforced concrete beams externally bonded GFRP sheets subjected to failure using a symmetrical two-point concentrated static loading system. The experimental data obtained included load, deflection, and failure modes of each beam, along with the effect of the number of GFRP layers on the beams The failures observed in strengthened beams typically commence with the debonding of the FRP sheets, followed by brittle shear failure. The shear capacities of these beams were higher than that of the control beam.

Keywords:- *Rehabilitation, RC, GFRP, Shear Strengthening, Externally Bonded (EB).*

I. INTRODUCTION

A considerable number of existing concrete structures in India fail to meet current design standards due to substandard design, construction, or the need for structural upgrades to comply with new seismic design requirements arising from evolving standards, corrosion-induced deterioration of steel caused by exposure to aggressive environments, and occurrences like earthquakes. The inadequate performance of such structures poses a significant concern from a public safety perspective, leading to the necessity for reinforced concrete structures to undergo modifications and enhancements during their operational lifespan. In such scenarios, two primary solutions emerge: replacement or retrofitting. Deciding for complete structural replacement may entail certain drawbacks, including high material and labour costs, heightened environmental consequences, and operational inconveniences stemming from the disruption of the structure's functionality. Hence, when feasible, repairing or upgrading the structure through retrofitting is often considered more favourable. Retrofitting has increasingly emerged as the predominant approach in civil engineering, with applications including enhancing the load-bearing capacity of aged structures initially designed to withstand lower service loads than presently encountered, seismic retrofitting, and the restoration of weakened structures. The degradation of concrete structures over time, particularly accelerated in aggressive environmental conditions, necessitates various methods for remediation, broadly categorized as structural and non-structural repair. Structural repair involves the comprehensive refurbishment, renovation, and retrofitting of the entire system to bolster structural integrity for accommodating additional loads or retrofitting purposes.

II. METHOD AND MATERIAL

- *Literature Review*

The study by Hamid Saadatmanesh et al. (1991) compared the strength of concrete girders before and after being reinforced with GFRP plates, showing that the plates effectively enhanced the girders' performance [1]. Nanni, A et.al (1993) explores on the lateral confinement of concrete using fibre-reinforced plastic (FRP) composites to enhance compressive strength, pseudo-ductility, and shear resistance. Experimental and analytical studies were conducted on concrete specimens strengthened with FRP lateral confinement, including compression cylinders and column-type specimens. Different types of FRP strips were used for lateral reinforcement, such as braided aramid FRP tapes with varying characteristics. The study aimed to demonstrate how lateral confinement affects the behaviour of concrete specimens under different loading conditions, showing increased compressive strength and pseudo-ductility. The research also discusses the need for an analytical model to predict the performance of confined concrete before developing design procedures for concrete members with FRP lateral confinement [2]. Kachlakev D., McCurry, D. D. (2000) Experimented on four full-scale reinforced concrete beams were replicated from an existing bridge to test the effectiveness of using fibre reinforced polymer (FRP) composite for structural strengthening. The results showed that the use of FRP composites significantly increased the

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static capacity of the beams by approximately 150% compared to unstrengthen sections. Retrofitted beams with both carbon fibre reinforced polymers (CFRP) and glass fibre reinforced (GFRP) composites shows more load carrying capacity minimizes deflection. Fibre optic gauges were successfully used to monitor strain [3]. Externally bonded Glass Fiber Reinforced Polymer (GFRP) sheets have been investigated as a method for shear strengthening of reinforced concrete (RC) beams by Dong et al., (2012) & Sundarraja & Rajamohan, (2008). Research shows that this method can effectively improve the shear capacity of RC beams up to 50% [4]. M. A. A. Saafan (2006) Examines shear strengthening of RC beams using GFRP wraps and significant improvement in shear strength was observed [5]. Pannirselvam, N et al. (2008) Develops strength models for RC beams with externally bonded FRP and models provide accurate and reliable predictions for the strength of FRP-reinforced RC beams [6]. Khalifa, E. S (2013) studied multilayer wraps which provide substantial improvement in the flexural capacity of RC beams [7]. Compares the effectiveness of CFRP and GFRP in strengthening RC beams. Both CFRP and GFRP significantly improved the beam strength, with CFRP showing slightly better performance [8].

Dong et al. (2012) studied shear strengthening of RC deep beams with highly ductile fiber-reinforced concrete jackets, showing improved shear capacity by 13.6%–145.5% through various reinforcement configurations [9]. Todupunoori Shiva Sai et al. (2020) concluded in that the beams with a higher thickness of Glass Fiber Reinforced Polymer (GFRP) and beams with a higher thickness of Carbon Fiber Reinforced Polymer (CFRP) shows more deflections than Reinforced Cement Concrete (RCC) beam. Results indicate that beams reinforced with CFRP sheets demonstrate superior performance when contrasted with those reinforced with GFRP. Specifically, the beam strengthened with a 1mm thick GFRP sheet controls deflection by 17.09%, while the 1mm thick CFRP sheet strengthens the beam to control deflection by 22.49% in relation to the control beam. Moreover, the beam enhanced with a 2mm thick GFRP sheet manages deflection by 29.5%, while the beam supported by a 2mm thick CFRP sheet controls deflection by 34.79% compared to the control beam. In a similar fashion, the beam reinforced with a 3mm thick GFRP sheet limits deflection by 41.5%, while the beam upheld by a 3mm thick CFRP sheet oversees deflection by 46.78% relative to the control beam. The results indicate that beams strengthened with CFRP sheets have a greater ability to manage deflection compared to those reinforced with GFRP sheets [10]. The behaviour of GFRP-strengthened beams in shear is complex and influenced by various factors such as the configuration of the reinforcement, the interaction with internal steel reinforcement, and the failure modes at ultimate load [11]. Junaid et al., (2021) Studies have shown that the effectiveness of GFRP for shear strengthening can be affected by the width and spacing of the strips, the presence of internal steel stirrups, and the type of concrete used [12]. Additionally, the interaction between internal GFRP bars and stirrups and externally bonded CFRP sheets can influence the shear strength gain, which may be reduced when internal and external reinforcements are in close proximity [12]. Moreover, the efficiency of shear strengthening with GFRP is also dependent on the axial stiffness of the FRP, the existing steel reinforcement ratio, and the concrete strength [13]. The externally bonded GFRP is a viable solution for increasing the shear capacity of RC beams, but the design must consider the interaction between GFRP and internal reinforcement, as well as the specific characteristics of the beam and the GFRP material. The complexity of the failure mechanisms and the influence of various parameters on the efficiency of shear strengthening highlight the need for a comprehensive understanding and careful design when implementing GFRP shear strengthening solutions[11], [13].

➢ *Materials*

- *Cement:*

The properties of cement are determined in accordance with IS12269:2015[14], [15], with specifications outlined in IS4031-1988[16].

- *Fine Aggregate:*

The fine aggregate passed through a 4.75 mm sieve and exhibited a specific gravity of 2.65. As per Indian Standard specifications, the fine aggregate belonged to zone III in terms of grading according to IS 383-1970 confirms Zone-III [17].

- *Course Aggregate:*

The maximum size of coarse aggregates is 20 mm, with a relative density of 2.89. The choice of crushed stones with a maximum size of 20mm was made for the aggregates. The tests on aggregate are conducted as per IS 2386 Part III-1963[18]. Aggregate comes under Grading zone III as per IS: 383-1970 specifications [17].

- *Mix Proportions of Concrete*:

Concrete mix design as per IS 10262-1983 [19].Mix Proportion of concrete (by weight) was 1:1.51:3.56:0.5. Cube compressive strength after 28 days cube was 21.87Mpa.

- *Steel Reinforcement:*

The longitudinal reinforcements that were used comprised of high-yield strength deformed bars with a diameter of 12mm at bottom and 8mm Dia. for top as a anchor bars. The stirrups were used from mild steel bars of 6mm in diameter. The yield strength of the steel reinforcements has been determined by performing the standard tensile test on three samples of each bar. The average proof stress at 0.2% strain for the 12mm and 8 mm diameter bars was 415 N/mm2, and for the 6mm diameter bars, it was 245 N/mm2.The Tests are conducted as per IS 1786(2008) and IS 432-1(1982)[20], [21].

- *Fiber Reinforced Polymer (FRP)*:

Fibre sheet used in this experimental investigation was E-Glass, Bidirectional woven roving mat. It was not susceptible to atmospheric agents. It was also chemically resistive and anticorrosive. The manufacturer of E-Glass fiber woven sheet used for the experimental work.

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- *Epoxy Resin:*

The success of the strengthening technique mostly depends on the performance of the epoxy resin used for bonding of FRP to concrete surface. Various types of epoxy resins with a varying range of mechanical properties are available in the market. These epoxy resins are generally available in two parts, as resin and a hardener.

Fig 1 Bidirectional Woven Glass Fiber Sheet

Fig 2 Hand Layup Method of Preparation of GFRP for Test

- *Fabrication of GFRP Plate for Tensile Strength*

The hand-made contact moulding in an open mould was used to combine the plies of woven rope in the prescribed sequence. A flat and rigid plywood platform has been selected. A plastic sheet is placed on the plywood platform and a thin polyvinyl alcohol film is applied as a release agent using spray guns. The lamination begins with a brush-deposited gel coating (Epoxy and Hardener) on the mould, whose main purpose is to provide a smooth outer surface and protect fibres from direct exposure to the environment. The ply was cut from a roll of woven roving. The reinforcement layer was placed on the form at the top of the gel layer and the gel layer was again applied by brush. All air bubbles caught were removed with serrated steel rollers. The hand laying process is the continuation of the above-mentioned process before the gel layer is completely hardened. The plastic sheet was covered again with polyvinyl alcohol as a release agent, applied to the top of the plate.

Table 1 Modulus of Elasticity of GFRP Specimens

GFRP plate of	Ultimate Load (N)	Ultimate Stress (MPa)	Change In Length mm	Ultimate Strain	Modulus of elasticity
2 layers	4500	310.34	4.00	0.027	11637.93
	5250	362.07	4.50	0.030	12068.97
	5000	344.83	5.00	0.033	10344.83
	4500	310.34	4.50	0.030	10344.83
	4750	327.59	4.00	0.027	12284.48
Average	4800	331.03	4.40	0.029	11336.21

Subsequently, a heavy flat metal solid platform was mounted on the plate to compress. The plate was left for at least 48 hours. and cut in size 150mmx25mm for the test, five specimens were tested.

- *Casting of Beams*

- *Description of Specimens :*

The experimental work consists of 8 number of RC rectangular beams of same longitudinal reinforcement of three numbers of 12mm φ as tension reinforcement and two number of 8mm φ was provided at top with 6mm φ 160 mm spacing stirrups as shear reinforcement.

- *Strengthening of Beams with GFRP Sheet and testing*

The concrete surfaces were prepared by chiselling and roughening, followed by cleaning with an air blower. An epoxy resin mixture, made by combining 100 parts resin with 10 parts hardener, was uniformly applied to the beam in shear zone. Glass fiber woven sheet was then positioned onto the epoxy layer, and pressure was applied with a roller to ensure resin penetration and eliminate air bubbles. Another resin layer was applied before placing a second sheet, repeating the pressure application with steel roller. This process ensured the composite laminate was well-affixed, with consistent pressure maintained to expel excess resin and ensure proper bonding. The beams, bonded with glass fiber fabric in shear zone, were cured at room temperature for at least a week before testing. Specimens were tested using a universal testing machine. Beam tested under two-point loads to measure shear capacities. Deflection readings were taken two dial gauges placed at center at center of beam specimen and L/3 distance from end support.

Table 2 Beam Strengthening Systems

Beam ID	Sheet Thickness (mm)	No. of layers of sheet	Strengthening system with GFRP sheets
CB	Control Beam (No sheets)		
SSB1	0.58	1	U warping with one layer on shear zone
SSB2	0.58	2	U warping with two layers on shear zone
SSB3	0.58	3	U warping with three layers on shear zone

III. RESULTS AND DISCUSSION

The beam U warped with three layers of GFRP performed better than the Control beam and all other beams strengthen (SSB1, SSB2, and SSB3). It is observed from above fig.5 that, the ultimate load carrying capacity of all strengthened beams is higher than the control beam. All reinforced beams (SSB1 to SSB3) demonstrate superior ultimate capacities in comparison to the reference beam (CB).

Fig 3 Test Setup

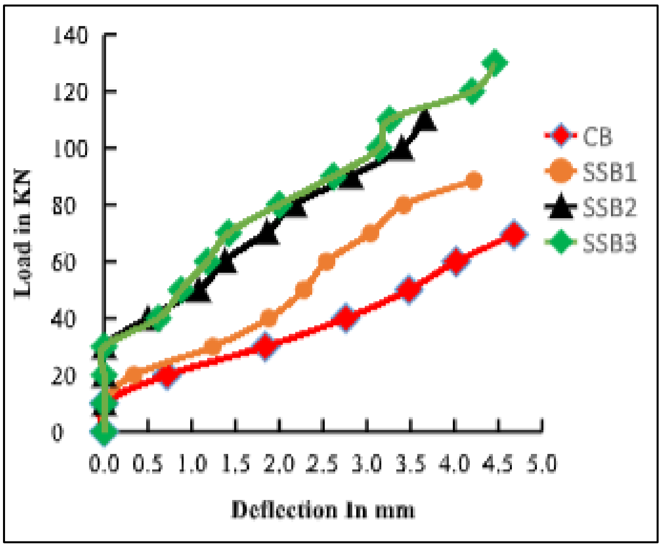

Fig 4 Load Vs Deflection

The enhancement ratio of ultimate load (λ) varies from 1.27 (SSB1) to 1.82 (SSB3), signifying a noteworthy advancement in load-bearing ability as a result of the reinforcement with GFRP. SSB3 displays the most significant advancement in ultimate load (1.82 times that of the reference beam) and the greatest shear contribution from GFRP. The advancement in ultimate load carrying capacity and shear contribution escalates with multiple layers of GFRP The utmost shear contribution is evident in SSB3 at 45.06%, whereas the minimum is in SSB1 at 21.47%. The reference beam (CB) failed exclusively in shear. All reinforced beams failed due to delamination of GFRP in conjunction with concrete crushing followed by shear collapse. From the fig.4 SSB1 and SSB2 demonstrate the most effective reduction in deflection at midspan, each showing an 11% reduction compared to the control beam. SSB3, although having the highest ultimate load capacity, shows a lesser reduction in deflection at midspan (5%).The reinforcement technique utilizing GFRP proves to be efficacious in amplifying both the ultimate load capacity and shear effectiveness of the beams.

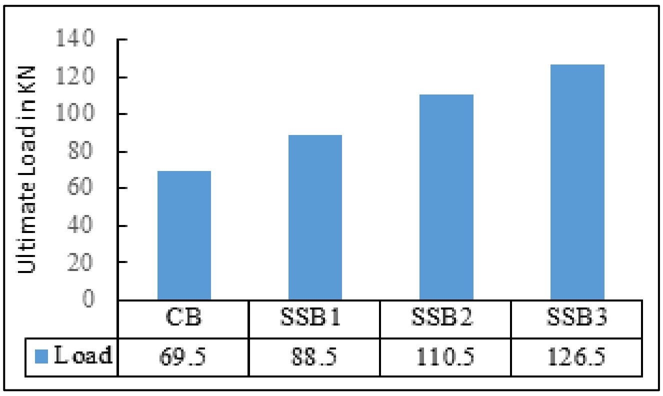

Fig 5 Ultimate Load Vs Warping System

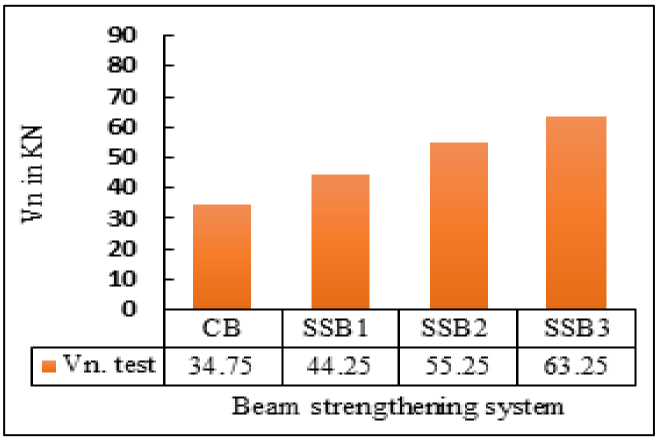

Fig 6 Shear strength Vs Warpping System

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Table 3 Ultimate Load, Shear Contribution by Fiber and Load Enchancement Pattern, Natureof Failuer

Specimen	Experimental Results					Load Enhancement Factor = P (Strengthen Beam) / P(Control Beam)	Nature of Failure
	Load at failure P in (KN)	***Vn, test (kN)***	***Vc,test +Vs,test (kN)***	***V_f,test (kN)***	***(V_f,test/ Vn,test)* 100 (%)***		
CB	69.5	34.75		-	-	-	Shear failure
SSB1	88.5	44.25	34.75	9.5	21.47%	1.27	Delamination of GFRP followed by crushing of concrete & shear failure
SSB2	110.5	55.25	34.75	20.5	37.10%	1.59	Delamination of GFRP followed by crushing of concrete & shear failure
SSB3	126.5	63.25	34.75	28.5	45.06%	1.82	Delamination of GFRP followed by crushing of concrete & shear failure

IV. CONCLUSION

The control beam (CB) failed at an ultimate load of 69.5 KN with shear failure. Strengthened beams (SSB1, SSB2, and SSB3) showed significant improvements in ultimate load compared to the control beam: as 27%, 59%, and 82% respectively. The shear strength was increased due to GFRP strengthening of beams SSB1. SSB2, SSB3 by 21.47% 37.10%, 45.06% respectively. All strengthened beams (SSB1, SSB2 and SSB3) exhibited a similar failure pattern: Initial delamination of the GFRP (Glass Fiber Reinforced Polymer) followed by crushing of concrete and shear failure. The control beam (CB) failed purely by shear. The results determines that the use of GFRP significantly enhances the load-carrying capacity and shear resistance of beams with reduction in deflection. The increase in ultimate load and the fiber's contribution to shear strength are evident in the strengthened specimens.

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