Strengthening of Shear Deficient Beams Using GFRP

P. Vijaya Kumar, P. Poluraju

Abstract: Due to lateral forces acting on the structure, stresses are generated in the beam which causes beam failure. To overcome those stresses in the existing structures, retrofitting is one of the techniques to increase the lateral strength. In this study, an experimental investigation was done on RC beams to check the shear behavior by comparing control RC beams with strengthened RC beams. To observe the shear behavior considered RC Beams were made weak in shear and then Retrofitted. Two sets of beams were considered, out of which, set-1 consists of three control specimens with shear reinforcement of 100%, 50%, and 30%. Set-2 consists of three retrofitted specimens with GFRP Strips with shear reinforcement of 100%, 50%, and 30%. GFRP strips were provided around the beam with different spacing. The results concluded that the retrofitted specimens have more load carrying capacity compared to control specimens. Thus, the retrofitting is a feasible solution to overcome the stresses developed in the structure. The study also involves the behavior of shear having several GFRP layers and orientation of ultimate load carrying capacity, failure mode and crack pattern of the beam are also investigated.

Index Terms: Retrofitting, GRPF, Shear strength, Load carrying capacity, Crack pattern.

I. INTRODUCTION

In recent years, various research works are being carried out to know the shear behavior of various reinforced structural elements. The beam is weak in shear is due to some additional horizontal forces acting which is parallel to beam surface will generate some stress on the beam. This happens due to lack of required shear reinforcement. Since most of the construction works are going with reinforced concrete structures, failures will occur commonly in beams and in various structural components caused by shear. While some research works were going by considering different parameters and loading conditions, to observe how the beams are behaving in the shear zone. Most of the researchers have under-gone experimental study on beam by the following factors influencing the behavior of shear [1].

a. Types of loading conditions and supports.
b. Finding effective depth ratio by shear span.
c. Applying transfer reinforcement.
d. Increase the strength of concrete by taking less percentage of steel.

The reason behind all this research work is to know the shear strength (or) shear failure deriving various equations with different code provisions. In order to overcome all these problems, various retrofitting techniques came into existence. One of them is using of Fiber Reinforced Polymer (FRP) and composite sheets. It helps in giving strength for already existing structures. The primary reason for the retrofitting technique is to overcome the harmed construction and gives the protection. Also, the main goal is to secure the structures under future seismic conditions. The FRP is a composite material consisting of high-quality carbon and glass strands. These FRPs are the laminated sheets which are firm plates that come pre-cured and are introduced by holding them to the solid surface with a thermosetting pitch [1]. These FRPs are very much fascinated in view of its predominant properties. While coming to economy perspective, the glass fiber sheets are most commonly utilized in many research works. By using FRPs, the RC beams enhance its shear strength capacity. It also increases the stiffness and ductility behavior of the beam. It concluded that FRP wrapping systems can be used for shear strengthening and shear repair of RC beams when considering various parameters [2]. The result was high for the vertical U-wrap strips than side vertical strips. The development of the cracks was due to the presence of vertical strips. The load carrying of the retrofitted beams was greater than the control beams. The shear strength and stiffness were increased with a substantial reduction in shear cracking [3]. When the GFRP strips are used in the shear deficient beams, the initial cracks occur at higher loads than control beams. This shows the use of GFRP strips is effective when the strengthening of the structures in shear was done. The flexural failure was prominent than shear failure when the beams bonded with inclined GFRP. This avoids catastrophic failure of the beams [4]. The flexural strength and ultimate load capacity of the beams improved due to the external strengthening of the beams [5]. There was an increase of 9-14% in shear load and 10-14% in flexural load. There was a decrease in stiffness of the beam after retrofitting due to ductile nature [6]. The cracks in the shear zone were very less, so the application of GFRP increased the shear strength and concluded that retrofitting is effective technique [7]. The retrofitting RC beams with shear deficiency were more effective for full-loop CFRP wrapping due to the lack of stirrups [8]. There was an increase in ultimate loads between 49 to 57% for the all repaired beams. The proper crack repair techniques can reduce the effect of existing shear cracks [9].

II. RESEARCH SIGNIFICANCE

A broad research has been significantly noticed in the field of retrofitting in recent years. The present work is focused mainly on the strengthening of beams, which are

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P. Vijaya Kumar, Research Scholar, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation (Deemed to be University), Guntur-522502, Andhra Pradesh, India.

P. Poluraju, Associate Professor, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation (Deemed to be University), Guntur-522502, Andhra Pradesh, India

not having ability towards shear resistance when the structure experiences sudden impacts like earthquakes. Strengthening was done to the beams which beam weak in shear. The beam weak in shear concept was achieved by reducing the percentage of shear reinforcement. The failure behavior of beams and ultimate shear load carrying capacity of beams were observed.

III. DESIGN PROCEDURE

All the RC beam specimens are designed as per IS 456:2000 [10]. And the shear for the FRP was contributed by the following expression.

$$V_{frp} = \frac{fos \times F_y \times \text{Area Of FRP} \times d}{\text{Spacing}}$$

Where

F_y = tensile strength of steel
Fos = factor of safety
d = width of GFRP strip

The factor of safety should be taken as 0.8 times of V_{frp}

The beams were retrofitted in shear by bonding with strips of GFRP all around the specimen (360^0). The GFRP strips are placed in vertical position so that the beams are highly strengthened and accomplish more holding capacity.

IV. EXPERIMENTAL PROGRAMME

The total six numbers of specimens were cast. The dimensions of all the specimens are same i.e., 150 mm × 300 mm. The length of all the specimens is also same i.e., 2.2 m. The difference in the specimens is the spacing of the stirrups. These six specimens are divided into 2 sets. The first set contains three conventional specimens which are designated with beam weak in shear conventional (BWSC1, BWSC2 and BWSC3). The second set contains three specimens which are designated with beam weak in shear retrofit-ted with fiber (BWSRF1, BWSRF2 and BWSRF3). The schematic diagrams of front view and cross-sectional view of the first set of specimens are shown in Figs. 1 & 2 and details are shown in Table I.

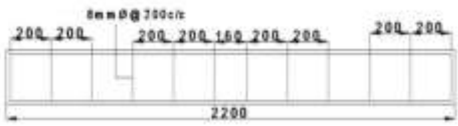

Fig. 1(a): Detailing of BSC1

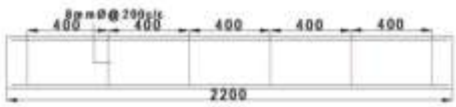

Fig. 1(b): Detailing of BSC2

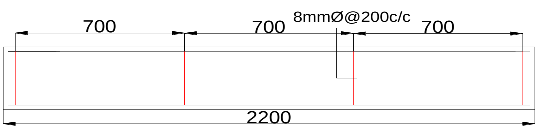

Fig. 1(c): Detailing of BWSC-3
Fig. 1: Detailing of Conventional Specimens

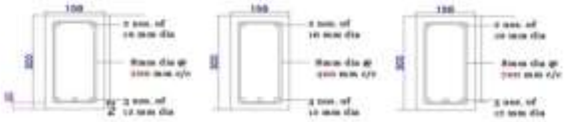

Fig. 2: Cross-Sectional Details

Table I: Shear Reinforcement Details of Conventional Specimens

S.NO	BEAM SPECIFICATION	INTERNAL REINFORCEMENT DETAILS
1	BWSC-1&BWSRF-1	8mm dia @200mm c/c spacing
2	BWSC-2 & BWSRF-2	8mm dia @ 400mm c/c spacing
3	BWSC-3& BWSRF-3	8mm dia @ 700 mm c/c spacing

The front view schematic diagrams of the second set of specimens are shown in Fig. 3 and details of the specimens are shown in Table II.

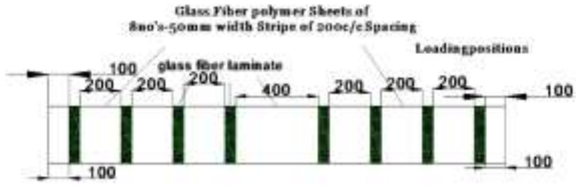

Fig. 3(a): Detailing of BWSRF-1

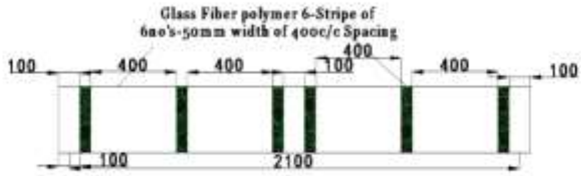

Fig. 3(b): Detailing of BWSRF-2

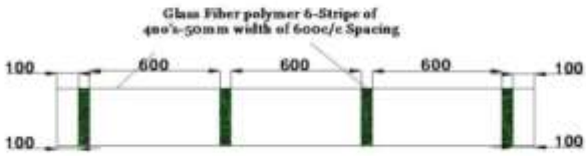

Fig. 3(c): Detailing of BWSRF-3
Fig. 3: Detailing of Retrofitted Specimens

Table II: Shear Reinforcement Details of Conventional Specimens

S.NO	BEAM SPECIFICATION	EXTERNAL BOUNDED GFRP STRIP IN SHEAR SPAN
1	BWSRF-1	50mm wide strip @ 200mm c/c spacing
2	BWSRF-2	50 mm wide strip @ 400 mm c/c spacing
3	BWSRF-3	50 mm wide strip @ 700 mm c/c spacing

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The fabricated moulds (Fig. 4) are prepared using Galvanized Iron (GI)-Sheets to get the mould in required shape and plaster powder was applied at corners of the mould to avoid slurry leakages.

Fig. 4: Moulds

All the specimens are cast and cured for 28 days. The grade of the concrete was M20. The design mix proportion was 1:2.35:3. The mix proportion was achieved as per design calculations considered in IS 10262:2009 [11]. The materials used were Ordinary Port-land Cement (OPC), the coarse aggregates containing 70% of 20mm aggregates and 30% of 10 mm aggregates, and the fine aggregates conforming to Zone-II. The water-cement ratio was 0.5. The specimens are cured with gunny bags as shown in Fig. 5. The laminated sheets are cut into required shapes are shown in Fig. 6. The GFRP laminated sheets which are having very good proper-ties compared to others and less expensive. The properties of GFRP are shown in Table III.

Fig. 5: Specimens Curing

Fig. 6: GFRP strips

Table III: Properties of GFRP

S.NO		
1	Fiber Orientation	Unidirectionl
2	Density	2.68g/cm3
3	Filament Diametre	13mm
4	Tensile Diametre	3750N/mm2
5	Tensile Modulus	80N/mm2
6	Elongation	4.8%

Grinding process has been achieved using grinding machine at appropriate location on beams for GFRP sheets wrapping. The crucial part of strengthening procedure was done which was epoxy sap utilization. The epoxy resin consists of harder and resin which was lapox L-12 and Lapox K6 respectively. The mixture of epoxy resin and hardener with a ratio of 2:1 has to be mixed thoroughly stir for 10 to 15 minutes as shown in Fig. 7. The appropriation of epoxy resin on the specimen as shown in Fig. 8. The properties of the materials are shown in Table II.

Fig. 7: A mixture of Epoxy Resin

Fig. 8: Application of Epoxy Resin

After application of epoxy resin, the pot life should be maintained for 30 minutes and ensure that the epoxy solution was formed into sticky form. Then, the GFRP strips are wrapped on the beams at required places. Application of GFRP was done using steel roller to avoid air voids. After 30 minutes of GFRP application, again apply the epoxy resin to the outer surface. To appear cracks clearly, whitewash has done to the specimens. The conventional and retrofitted specimens are shown in Fig. 9 and Fig. 10 respectively.

V. CONCLUSION

The experimental work was done on RC beams weak in shear, by reducing the vertical stirrups with different spacing. The same procedure was done in the case of retrofitted beams. The beam was retrofitted with GFRP strips. These strips were placed in different spacings according to the shear reinforcement. However, different behavior was observed for the GFRP wrapped specimens subjected to four-point loading condition. The following conclusions were made based on experimental work.

a. As expected, the load carrying capacity was significant for strengthened beams when compared to conventional beams.
b. At initial load, various flexural and shear cracks were observed, later the crack width was increases with in-creased load.

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c. Due to GFRP wrapping on all four sides, the crack was not visible in GFRP layer and the remaining area was cracked diagonally.
d. The maximum ultimate load shown for BWSRF1 was 166 kN.
e. The beam which was considered 100% with 200 mm c/c spacing, the load carrying capacity of that beam has in-creased by 32.3% compared to strengthened beams.
f. In case of 400 mm c/c spacing, the load increased by 22.8% compared to the retrofitted beam. Same in the case of 700 mm c/c spacing load increased by 25.5% compared to the retrofitted beam.
g. The concrete was failed in tension zone for the retrofit-ted beam because of hardened FRP.
h. It is easy to keep up a moderated uniform thickness of epoxy resin all through the bounding length.
i. Restoring the shear quantity of beam using GFRP was exceeded the normal strategy.

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AUTHORS PROFILE

P. Vijay Kumar is working as HoD for Construction Department and Associate Dean P&D at Koneru Lakshmaiah Education Foundation (Deemed to be University), Vaddeswaram, Guntur District, Andhra Pradesh, India. He is pursuing PhD from Koneru Lakshmaiah Education Foundation (Deemed to be University). He has completed Master of Technology in Structural Engineering from JNTU and Bachelor of Technology from Anna University. He has 25 years of experience in construction.

Dr. P. Poluraju is working as Associate Professor and HoD in Civil Engineering Department at Koneru Lakshmaiah Education Foundation (Deemed to be University), Vaddeswaram, Guntur District, Andhra Pradesh, India. He has completed Master of Technology in Structural Engineering from IIT Guwahati in 2009 and Ph.D. in Structural Engineering from IIT Madras in 2017. His research interests include Sandwich Panels, Rehabilitation and Retrofitting of RC structures. He has published 32 research papers in international journals and conferences and guiding 8 numbers of Ph.D. scholars guided 20 numbers of P.G. dissertations and 10 number of U.G. project works. He is a lifetime permanent member of ICI (Indian Concrete Institute) & ISRD.