



Strengthening of Reinforced Concrete Beams Weak in Shear Using GFRP

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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.

Keywords: Retrofitting, Shear behavior, Shear reinforcement, GFRP Strips, Crack Pattern.

1. 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 the 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 undergone experimental study on beam by the following factors influencing the behavior of shear [1].

- Types of loading conditions and supports
- Finding effective depth ratio by shear span
- Applying transfer reinforcement
- 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 was 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].

2. 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 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.

3. 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.

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

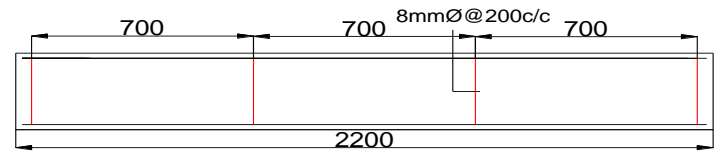
where

- 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°). The GFRP strips are placed in vertical position so that the beams are highly strengthened and accomplish more holding capacity.

4. 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 retrofitted 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 1.



(c) Detailing of BWSC3
Fig. 1: Detailing of Conventional Specimens

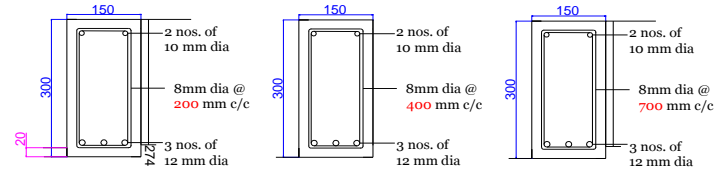
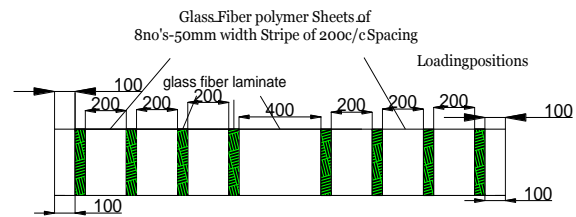


Fig. 2: Cross-sectional Details

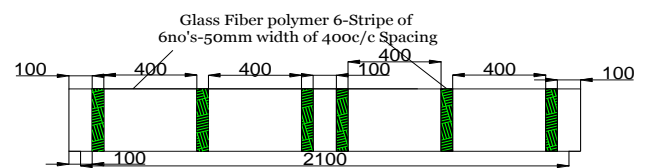
Table 1: Shear Reinforcement Details of Conventional Specimens

Font Size	Beam Specification	Internal Shear Reinforcement Details
1	BWSC1 & BWSRF1	8mm ϕ @ 200mm c/c Spacing
2	BWSC2 & BWSRF2	8mm ϕ @ 400mm c/c Spacing
3	BWSC3 & BWSRF3	8mm ϕ @ 700mm c/c Spacing

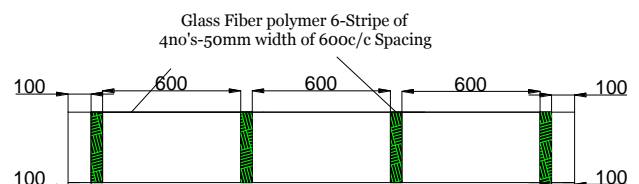
The front view schematic diagrams of the second set of specimens are shown in Fig. 3 and details of the specimens are shown in Table 2



(a) Detailing of BWSRF-1



(b) Detailing of BWSRF-2

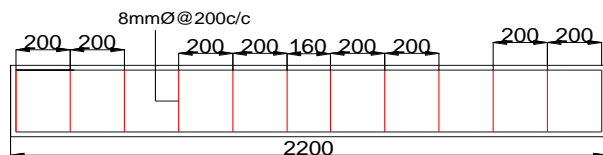


(c) Detailing of BWSRF-3

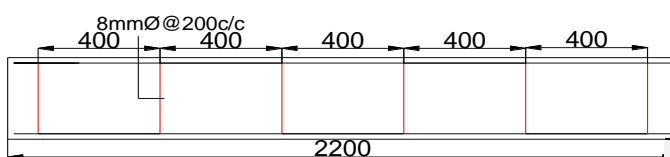
Fig. 3: Detailing of Retrofitted Specimens

Table 2: Shear Reinforcement Details of Retrofitted Specimens

Font Size	Beam Specification	External Bounded GFRP Strips in Shear Span
1	BWSRF1	50 mm wide Strip @ 200mm c/c Spacing
2	BWSRF2	50 mm wide Strip @ 400mm c/c Spacing



(a) Detailing of BWSC1



(b) Detailing of BWSC2

3	BWSRF3	50 mm wide Strip @ 700mm 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 Portland Cement (OPC), the coarse aggregates containing 70% of 20 mm 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 properties compared to others and less expensive. The properties of GFRP are shown in Table 3.



Fig. 5: Specimens Curing



Fig. 6: GFRP strips

Table 3: Properties of GFRP

Properties of Glass fiber	Specifications
Fiber orientation	unidirectional
Density	2.68 g/cm ³
Filament Diameter	13µm
Tensile Strength	3750 N/mm ²
Tensile Modulus	80 N/mm ²
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 hardener 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 application of epoxy resin on the specimen as shown in Fig. 8. The properties of the two materials are shown in Table 2.

Table 4: Properties of Hardener and Resin

Properties	Primer K6	Hardener L-12
Density	1.14g/cc	1.25-1.26g/cc
Pot Life	25 mins @ 270c	2hrs@300c
Cure time	7 days	5days@300c



Fig. 7: A mixture of Epoxy Resin

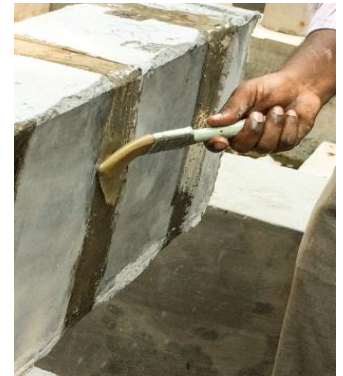


Fig. 8: Application of Epoxy Resin

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.



Fig. 9: Conventional Specimens



Fig. 10: Retrofitted Specimens

All the specimens were tested under the symmetrical two-point loading using loading frame having a capacity of 200 tons. The support conditions are one end was hinge support and the other was roller support. The linear variable differential transducer (LVDT) is placed linearly below the beam at load application using load cell through hydraulic jack of loading frame. The schematic diagram and actual test setup are shown in Fig. 11 and Fig. 12 respectively.

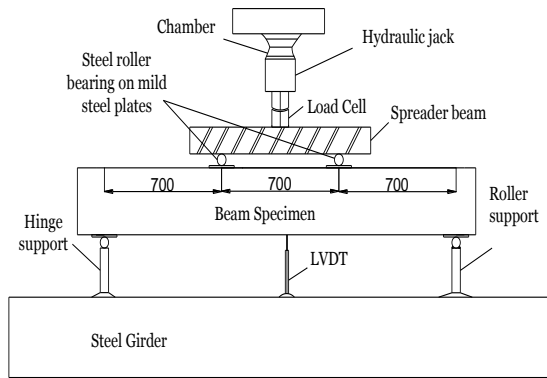


Fig. 11: Schematic Diagram of Test Setup

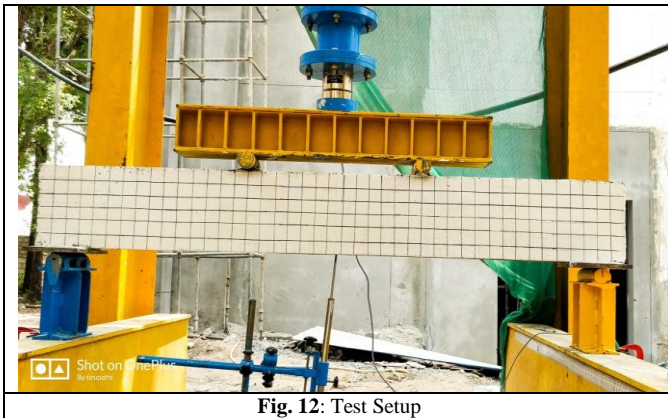


Fig. 12: Test Setup

5. Results and Discussions

Two sets of beams were tested under the loading frame as a four-point loading. Beams are in simply supported condition. The supports were placed on a girder. The load is applied at two places which are 700 mm from the supports and the deflection is measured at the bottom of the beam by LVDT. Different parameters are analyzed after testing such as load versus deflection, mode of failure and crack pattern of all specimens. The comparison of conventional and retrofitted specimens is analyzed from the results.

5.1. Load versus Deflection Response

The Fig. 13 shows the load vs. deflection response of both BWSC1 and BWSRF1. The load carrying capacity for retrofitted specimen was more when compared to conventional specimen. The retrofitted beam was shown less deflection at higher loads. The ultimate load was significant for BWSRF1 about 167.24 kN and deflection was 10 mm whereas for BWSC1 the ultimate load was about 129.6 kN and the corresponding deflection was 30 mm. Therefore, the retrofitted specimen shows significant performance than conventional specimen.

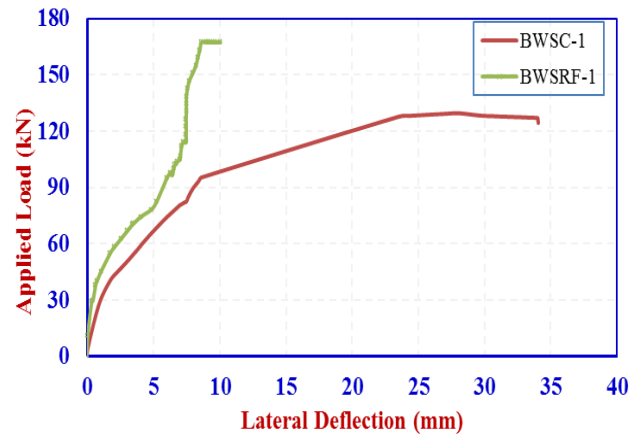


Fig. 13: Load vs. Deflection curves for BWSC1 and BWSRF1.

The Fig. 14 shows the 50% shear reinforcement reduction specimens designated as BWSC2 and BWSRF2. The BWSRF2 shows significant load carrying capacity even though the shear reinforcement was reduced as parameter in this study. The load deflection curve is gradually drops down after reaching the ultimate load. For BWSC2, the load carrying capacity was 125 kN and its deflection was about 13 mm whereas for BWSRF2, the ultimate load was 102.2 kN and the corresponding deflection is 11 mm. It shows that retrofitted specimen has significant load carrying capacity.

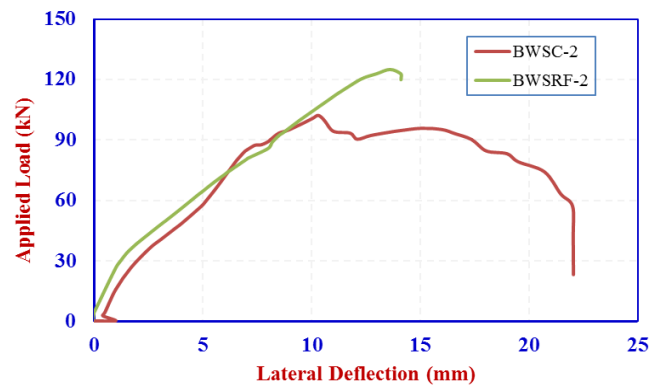


Fig. 14: Load vs. Deflection curves for BWSC2 and BWSRF2.

Fig. 15 shows the 30% shear reinforcement reduction specimens BWSC3 and BWSRF3. The BWSC3 specimen shows the load carrying capacity was 95.4 kN and its corresponding deflection was 11 mm. For BWSRF3 specimen, the ultimate load was 104.4 kN and its deflection was 9 mm. Therefore, retrofitted specimen shows significant strength than the conventional specimen.

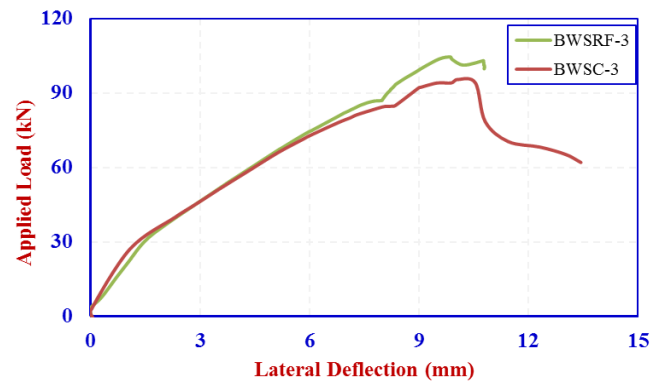


Fig. 15: Load vs. Deflection curves for BWSC3 and BWSRF3.

Fig. 16 shows the set-1 specimens BWSC1, BWSC2, and BWSC3. The BWSC1 showed significant load carrying capacity than specimens BWSC2 and BWSC3. The BWSC1 showed load carrying capacity of 129.6 kN which was higher than BWSC2 and BWSC3 shown loads of 102.2 kN and 95.4 kN respectively.

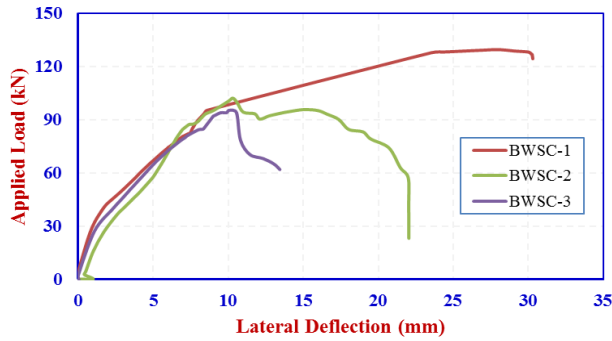


Fig. 16: Comparison of all Conventional specimens.

The Fig. 17 shows the set-2 specimens BWSRF1, BWSRF2 and BWSRF3. The BWSRF1 showed significant load carrying capacity than specimens BWSRF2 and BWSRF3. The BWSRF1 shown load carrying capacity of 167.24 kN which was higher than BWSRF2 and BWSRF3 having loads of 125 kN and 104.4 kN respectively.

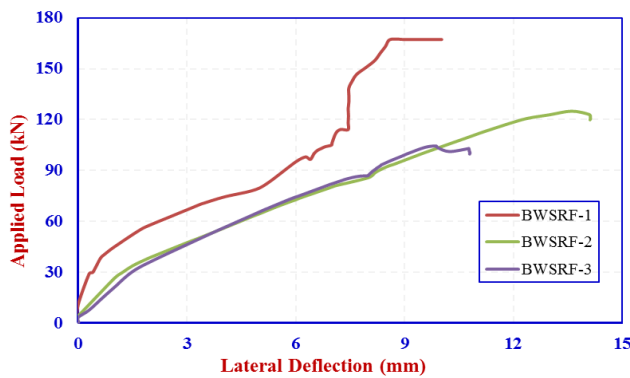


Fig. 17: Comparison of all Retrofitted specimens

5.2. Mode of Failure

Various modes of failure were observed in the experiments. The shear failure, flexural failure and crushing of concrete was observed in case of conventional specimens whereas, in case of retrofitted specimens, the flexural cracks were developed. Initially cracks developed at the supports later it propagates from supports to the centre of the beam at the point of application of load. The ultimate load carrying capacity, load at the initial crack, critical shear angle and mode of failure were shown in Table 5.

Table 5: Mode of Failure of all specimens

Beam Designation	Ultimate Load (kN)	Load at Initial Crack (kN)	Critical Shear Angle, θ (Degrees)	Mode of Failure
BWSC1	129.6	72	55	Flexure failure Shear failure
BWSC2	102.2	69	40	Shear failure + Crushing of concrete
BWSC3	95.4	70	52	Shear failure
BWSRF1	167.24	88.2	37	Flexure failure Shear failure

BWSRF2	125	84.1	42	Shear failure
BWSRF3	104.4	85.2	22	Shear failure + Crushing of concrete

5.3 Failure Mechanism

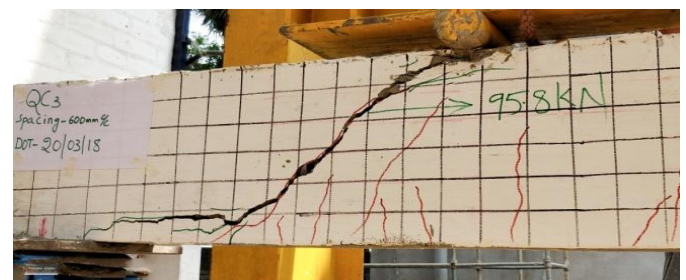
Failure mechanism of all the set-1 and set-2 specimens is shown in Figs. 18 and 19 respectively. Majorly shear cracks were developed with various orientation angles for set-1 specimens whereas for set-2 specimens flexural cracks were occurred. The concrete gets crushed and bending occurs for shear reduction specimens because of more spacing of stirrups in set-1 specimens. Based to these shear cracks, the critical shear angle was observed in all set-1 specimens. Whereas for set-2 specimens, due to heavy stress, the GFRP strips resists the maximum loads coming on the beam. Due to strips, no cracks were encountered in the retrofitted area. Hence, retrofitted specimens with GFRP strips show significant strength and it is a very feasible solution for retrofitting the structure.



(a) Flexural and shear cracks in BWSC-1

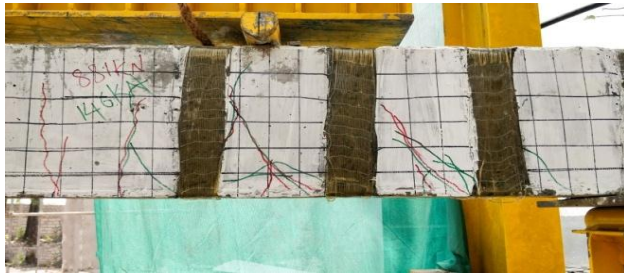


(b) Crushing of concrete in BWSC-2

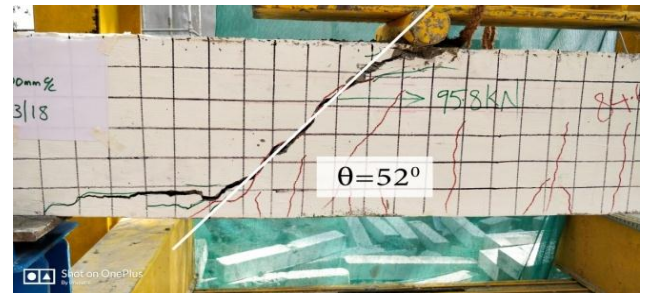


(c) Typical Shear crack occurs diagonally in BWSC-3

Fig. 18: Failure Mechanism for Conventional Specimens



(a) Flexural failure in BWSRF-1



(c) The crack pattern of BWSC-3



(b) Shear failure in beam BWSRF-2



(d) The crack pattern of BWSRF-1



(c) Typically shear failure in BWSRF-3



(e) The crack pattern of BWSRF-2

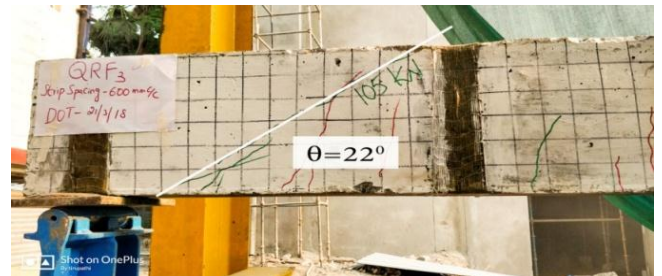
Fig. 19: Failure Mechanism for Retrofitted Specimens

5.4. Crack Pattern

The crack pattern with their orientation angle for all the specimens is shown in Fig. 20. The crack pattern for conventional specimens lies within 40 to 55 degrees. While the crack pattern for retrofitted specimens lies within 20 to 45 degrees.

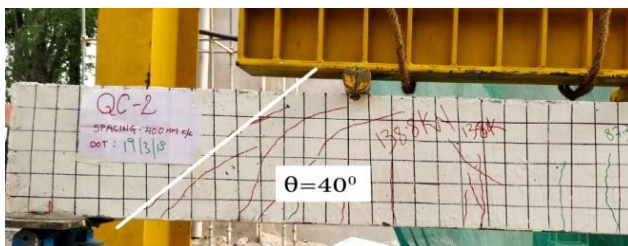


(a) The crack pattern of BWSC-1



(f) The crack pattern of BWSRF-3

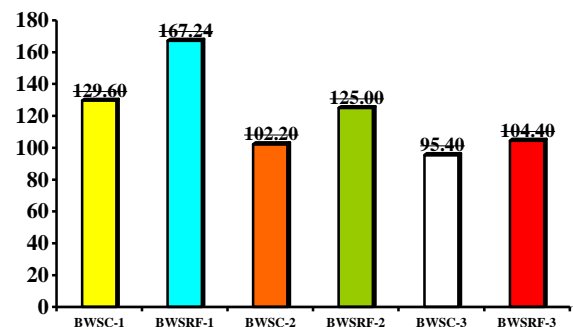
Fig. 20: Crack pattern for all specimens



(b) The crack pattern of BWSC-2

5.5. Ultimate Load

Fig. 21 shows the comparison of ultimate load carrying capacity of all the specimens. From Fig. 21, it was clearly noticed that BWSRF1 shown significant ultimate load carrying capacity. Comparing set-1 specimens with set-2 specimens, set-1 specimens have the more ultimate load carrying capacity i.e., BWSRF1, BWSRF2, and BWSRF3.



6. 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 increased load.
- 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 increased 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 retrofitted 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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