International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 7 Issue 4 Ver. I || April 2018 || PP 81-87

Retrofitting of RCC Beams Weak in Shear with BFRP Wraps

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Abstract: *This paper present an experimental investigation on retrofitting RCC beam weak in shear using BFRP wraps. BFRP stands for basalt fiber reinforced polymer. Six number of RCC beams of size 100x100x750mm were prepared and the reinforcement design was so that they were weak in shear. Of the six beams two were control beams. Control beams were tested up to failure and other beams were preloaded up to70% of the failure load of control beams. Preloaded beams were then retrofitted by using BFRP. BFRP was wrapped in two pattern, one is wrapping in the shear zone in U manner and other pattern is the diagonal wrapping on two side faces at ± 45°. Retrofitted beams were then tested up to failure. All the beams were tested under two point static loading. Load deflection behavior, first crack load, ultimate load, failure mode and crack pattern were analysed. The results depicted that BFRP wraps improved the ultimate load carrying restored the stiffness of the member. BFRP wraps changed the brittle mode of failure to a ductile one.*

Keywords– *BFRP, Diagonal Wrapping, Preloading, Retrofitting, Shear Zone Wrapping*

Date of Submission: 24-03-2018 Date of acceptance: 09-04-2018

I. Introduction

Reinforced concrete structures often have to face modification and improvement of their performance during their service life. This may be due to upgrading of the design standards, increased loading due to change of use, ageing, marginal design, corrosion of the reinforcement bars, construction errors and poor construction, use of inferior material, and accidents such as fires and earthquakes, which renders the structure incapable of resisting the applied service. In such circumstances, there are two possible solutions: replacement or retrofitting. Replacement of full structure might have determinate disadvantages such as high costs for material and labour, a stronger environmental impact and inconvenience due to interruption of the function of the structure e.g. traffic problems. When possible, it is often better to repair or upgrade the structure by retrofitting.

In recent years, retrofitting by bonding of fiber reinforced polymer (FRP) fabrics, plates or sheets on the concrete surface has become very popular. The wide acceptance of FRP is due to its inherent advantages like it has high strength to-weight ratio, high tensile strength, good fatigue resistance, corrosion resistance characteristics, less labour and equipment required for installation, ease in handling, higher ultimate strength, lower density than steel. In this paper RCC Beams were retrofitted using BFRP. Usually beams are retrofitted for enhancing shear capacity, flexural strength, torsional resistance. FRP's are wrapped on the available surface of the beam to enhance required strength. Practically only three sides of the beam are available for wrapping since the fourth side is constructed monolithic with the slab and it is inside the slab. There are specific wrapping pattern for enhancing flexure, shear and torsional capacity of beams. In this paper retrofitting was done to enhance shear capacity.

Shear failure compared to flexural failure is more devastating due to sudden failure. Shear failure start occurring from the critical section at high shear zone near support. The failure is usually occurring without giving any alarming alerts. Therefore, shear failure is considered to be more dangerous for structures than flexural failure. Maximum shear force is at support and the diagonal cracks start from support to applied load. These diagonal cracks were formed on either side or both sides together in RC beam and failure occurred by widening of shear cracks in RC beam. For strengthening, FRP strips have been used on the faces of the RC beam in previous studies. These common types of FRP scheme have been used most frequently in the previous studies i) 90° strip ii) 45° strip and iii) U-shape full length wraps.

II. Related Works

Neto *et al*. (2001) investigated the shear strength of eight T-Reinforced concrete simply supported beams; six of the beams were strengthened with unidirectional layers of CFRP. The main variables investigated were the direction of the CFRP layer (vertical and inclined at 45 degrees) and the number and width of the layers. Four beams were pre-loaded to service load before being strengthened. The beams were 4400 mm in total length, 400 mm of overall height and had a 150 web width. The results showed that ultimate loads of the strengthened beam were from 7 to 35% higher than the control beams. All the strengthened beams failed due to peeling of the CFRP laminates at the ends close to the flange with a thin layer of concrete attached to the laminate [1].

Pan *et al.* (2010) investigated eight beams strengthened with GFRP plates including pre-cracked beam (b7) and the results were compared with that of normal beams. Preloaded technique was used to develop multiple cracks for beam type b7. The beams b6 and b8 were normal beams without any cracks or notches. Based on the test results, average ultimate load for beams b6 and b8 was 76.16% and this value was almost equal to that of b7. Also ultimate load for b7 was in between that of b6 and b8. This result shows that an effect of FRP on existing structures with multiple cracks is similar to a new structure [2].

Kim *et al.* (2011) studied RC beams retrofitted with new hybrid FRP system consisting glass FRP (GFRP) and carbon FRP (CFRP). They examined effect of hybrid FRPs on structural behaviour of Retrofitted RC beams and investigated whether different sequences of CFRP and GFRP Sheets Of The hybrid FRPs have influences on improvement of strengthening RC beams. The beams were loaded with different magnitudes prior to retrofitting in order to investigate the effect of initial loading on the flexural behaviour of the retrofitted beams. The main test variables were sequences of attaching hybrid FRP layers and magnitudes of preloads. Test results conclude that strengthening effects of hybrid FRPs on ductility and stiffness of RC beams depend on orders of FRP layers [3]

Weiwen *et.al* (2015) made an experimental investigation on beam to find the effect of a_v/d on behaviors of shear-strengthened RC beams. The six shear-strengthened and six normal beams, used wrapping pattern is U-wrapping with CFRP strips. a_v/d ratios ranging from 1.0 to 3.5 were tested. FRP shear contribution increases initially with a_v/d ratio but decreases slightly when the ratio is beyond 2.0. [4].

Parung Herman *et.al* (2017) made an experimental investigation on the response of reinforced concrete beams strengthened in shear. The beams were tested under three point bending. They considered wire mesh with diameter 4mm, spacing 6 mm, SCC 25 mm. They concluded in retrofitted beam, shear capacity increased by 72%. Both control beam and retrofitted beam failed by shear [5].

III. Materials

3.1. Concrete

In the present work, ordinary Portland cement of 53 grade conforming to IS 12269-1987 was used. Locally available clean river sand have been used in this work. The coarse aggregate used was crushed (angular) aggregate conforming to IS 383:1970. The maximum size of aggregate considered was 20 mm. Based on all the material properties, which were evaluated with the aid of experiments in the laboratory, as per Indian standard specifications, the mix proportion of the concrete was found out, in accordance to IS 10262-2009, in order to achieve the mix design strength of 20 N/mm^2. In accordance the mix proportion by weight of cement:sand:coarse aggregate was found to be 1:1.85:3.1 . The designed water cement ratio was 0.5 and the workability tests performed with this water cement ratio, which produced a slump test value of 36 mm. Nine number of cubes were also casted using the stated mix proportion and water cement ratio, and the average compressive strength for 7 days was 17.25 N/mm^2, for 14 days was 25 N/mm^{2}and for 28 days was 30 N/mm^2.

3.2. Reinforcement

Here Fe 415 HYSD 8 mm diameter, high yield strength, and hot rolled deformed bars having characteristic strength of 415 N/mm^2 were used. Three samples of bars were placed in the universal testing machine one after another and tested for their tensile strength. It was found that the bars had average yield strength of 390 N/mm^2. Thus use of the bar specimen as reinforcement was safe. Fe 415, 8 mm diameter bars were used for the longitudinal reinforcement as well as for providing stirrups

3.3 Epoxy Resin

The success of the strengthening technique primarily depends on the performance of the epoxy resin used for bonding of FRP to concrete surface. Numerous types of epoxy resins with a wide range of mechanical properties are commercially available in the market. These epoxy resins are generally available in two parts, a resin and a hardener. The resin and hardener used in this study are Araldite LY 556 and Hardener HY 951 respectively in a proportion of 10:1.

3.3 Fiber Reinforced Polymer

Basalt fiber reinforced polymer was used is bidirectional twin type. It is natural and is manufactured from basalt rock which is formed by solidification of lava which comes out at the time of volcanic eruption. Table 1 shows the properties of BFRP provided by the supplier.

Table1 Properties of BFRP

Properties	Values
Thickness	0.34mm
Weight	300gsm
Tensile Strength (Mpa)	3000
Elastic Modulus (Gpa)	180
Poissons Ratio	0.30

IV. Experimental Programme

Experiment consists of 6 RCC beams. Beams were designed to study shear behavior when retrofitted with BFRP Wraps. All the beam specimens were of dimension 100mmx100mmx750mm with an effective span of 600mm. The geometry of the test beams are selected based on the parameters like capacity of the loading frame and distance between the loading supports for the beam. All the beams were tested under two point static loading. Fig.1 shows the reinforcement detailing for the beams.

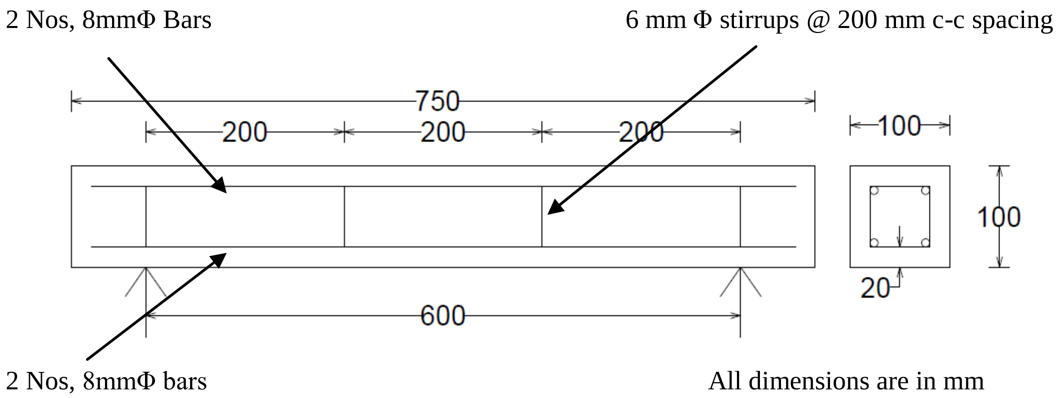


Fig.1 Reinforcement detailing

4.1 Beam Designation

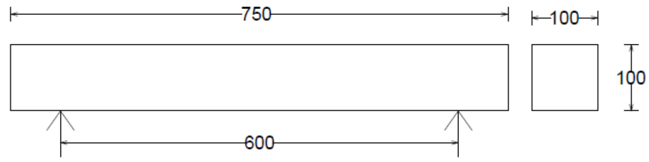
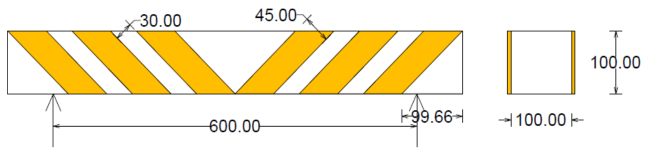
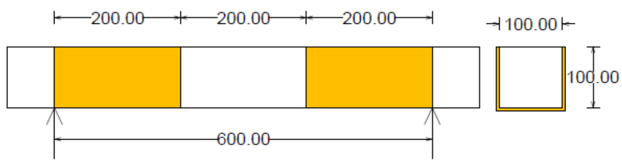
Of the six beams two beam are control beams, where there is no wrapping and designated as SCB1 and SCB2 ie, shear control beam one and shear control beam two. Remaining beams after preloading (70% ultimate load of the control beam) were wrapped with BFRP in two patterns. First pattern is the diagonal wrapping. BFRP strips of width 45mm at ±45° is wrapped at a clear spacing of 30mm on two side faces. Two such specimens were there, designated as SBDW1 and SBDW2 that is shear beam with diagonal wrapping one and shear beam with diagonal wrapping two. Next pattern of wrapping is the shear zone wrapping. BFRP is wrapped on two side faces and bottom in U manner in the shear zones. Such two specimens were there, designated as SBSW1 and SBSW2 that is shear beam with shear zone wrapping one and shear beam with shear zone wrapping two. All beam with designation and wrapped geometry is shown in Table 2.

4.2 Experimental Setup

All the six beams were tested under two point loading. UTM of capacity 600kN is used for testing. LVDT was kept at the mid span of the beam to measure central deflections. Two dial gauges were kept on the tension side of the beam to measure the lateral deflections at L/3 distances. The test setup is shown in Fig.2.

Fig.2 Test setup

Table 2 Beam designation

Wrapping scheme	Wrapping configuration	Beam designation
No wrapping		SCB1, SCB2
Diagonal wrapping on sides		SBDW1, SBDW2
Shear zone wrapping		SBSW1, SBSW2

4.3 Retrofitting of RCC Beams

After preloading to 70% of ultimate load of control beam, they were marked corresponding to the wrapping pattern to which they have to be wrapped. All the loose particles of concrete surface at the required area was made rough using a coarse sand paper texture and cleaned with dry clothes to remove all dirt and debris particles and prepared to the required standard. The fabrics were then cut according to the size. Epoxy resin was then mixed in accordance with manufacturer's instructions. The mixing is carried out in a plastic container (100 parts by weight of Araldite LY 556 to 10 parts by weight of Hardener HY 951) and was continued until the mixture was uniform. Then the epoxy resin is applied to the concrete surface. Then the BFRP sheet is placed on top of epoxy resin coating and the resin is squeezed through the roving of the fabric with the roller .air bubbles entrapped at the epoxy/concrete or epoxy/fabric interface are eliminated. Fig.3 shows the retrofitted specimen. During hardening of the epoxy, a constant uniform pressure is applied on the fabric surface in order to extrude the excess epoxy resin and to ensure good contact between the epoxy, the concrete and the fabric. This operation is carried out at room temperature. Concrete beams retrofitted with basalt fiber fabric were cured for six hours at room temperature before testing.

(a) Diagonal wrapping (b) shear zone wrapping

Fig.3 Retrofitted beam specimens

V. Results and Discussions

The control beams were tested up to the failure load and deflection values are noted for each load increment of 2.5 kN. The beams to be retrofitted were preloaded up to 70% of the failure load of the control beams. After retrofitting preloaded beams, they were also tested up to failure and deflection values are noted for each load increment of 2.5 kN. The behavior of each beam in the group were analysed by considering its load deflection behavior, first crack load and ultimate load, deflection at ultimate load, crack pattern, energy absorption and failure mode .

5.1 Load Deflection Behavior

The load deflection histories of all the beams were recorded. The deflection at one third span and mid span were noted. For comparing load deflection behavior mid span deflection was considered. Load Vs mid span deflection of each beam in a scheme was compared. Fig.4 shows the load deflection curve for each beam in scheme. From the graph it can be seen that the behavior of each beams in a scheme is identical. This conforms the accuracy of the experiment. In the case of retrofitted beams, it conforms that the retrofitting was performed in well defined manner. For comparing control beam with the retrofitted beams, beam with maximum failure load from each scheme was chosen. The mid-span deflection of retrofitted beam was compared with that of control beam. Fig.5 shows the comparison of load deflection behavior of control beam, and retrofitted beams.

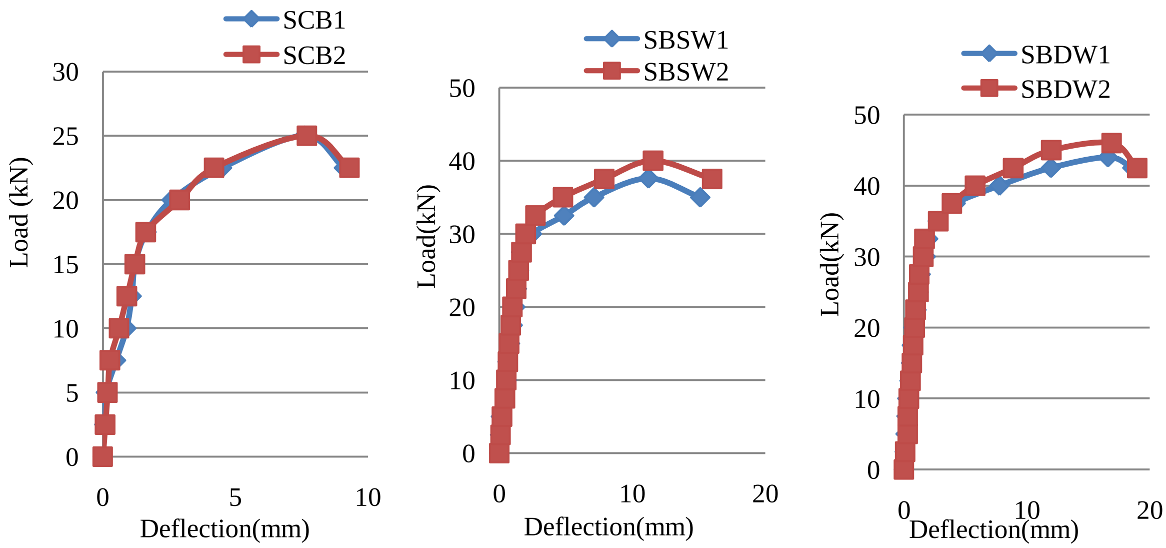


Fig.4 Load deflection curve of each beam

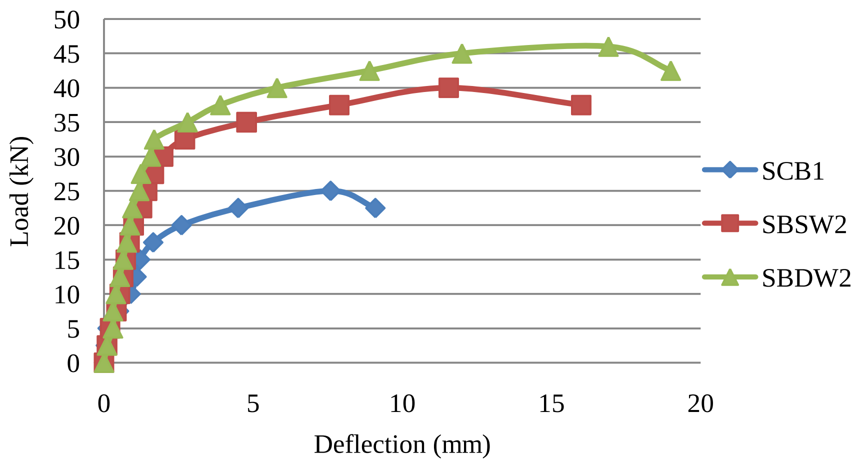


Fig.5 Comparison of load deflection behavior of control beam and retrofitted beams

Control beam failed in brittle manner. Retrofitted beams shows higher load carrying capacity and showed large deflection before failure. The failure mode changes from brittle nature to ductile nature. It can be seen that the stiffness of the retrofitted beam has increased. At the initial stages of loading the BFRP wraps restore the stiffness of the retrofitted beams to the level of control beam. At later loading stages stiffness of the retrofitted beams was high. Stiffness of the diagonal wrapped beam was very high compared to control beams because diagonal wrap prevents the propagation of crack. Diagonal wraps provide lateral confinement to the beam specimens. Stiffness of the beam wrapped in shear zone is less than that of the diagonally retrofitted beam. This may be due to the absence of any wrapping in the flexural zone, where crack may initiate and propagate.

5.2 First Crack Load and Ultimate Load

First crack load and ultimate load of retrofitted beams and control beam were noted and tabulated in Table 2. First crack load is obtained from the load deflection curve. Load at the change of slope at the initial portion of load deflection curve is the first crack load. It can be seen that there is no increase in the first crack load for beams retrofitted in shear zone. This is because that crack may start at the flexural zone as there is no wrapping in the flexural zone. There is an increase of 60% in the first crack load for beam retrofitted by diagonal wrapping. The ultimate load carrying capacities of retrofitted beams were higher than that of the control specimens. For beams retrofitted in shear zone, load carrying capacity is 55.2 % more than control beams. For diagonal wrapped beam there is an increase of 80% in the load carrying capacity.

Table 3 First crack load and Ultimate load beams

Designation	First crack load (kN)	Mean (kN)	Percentage increase (%)	Ultimate load (kN)	Mean (kN)	Percentage increase (%)
SCB1	5	6.25	-	25	25	-
SCB2	7.5			25		
SBSW1	5	6.25	0	37.6	38.8	55.2
SBSW2	7.5			40		
SBDW1	10	10	60	44	45	80
SBDW2	10			46		

5.3 Energy Absorption

Energy absorption is the area under the load deflection curve. Energy absorption of each specimen were found and tabulated in Table 4. Energy absorption of beams retrofitted at shear zone is 141.78 % and that of diagonal wrapping was 330.67 % more than reference beam.

Table 4 Energy absorption

Designation	Energy absorption (kN -mm)	Mean (kN -mm)	Percentage increase (%)
SCB1	148.95	150.92	-
SCB2	152.90		
SBSW1	347.41	364.90	141.78
SBSW2	382.40		
SBDW1	631.34	649.97	330.67
SBDW2	668.60		

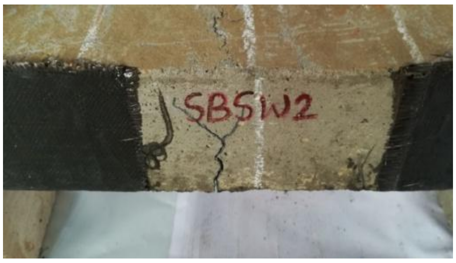
5.4 Failure Mode and Crack Pattern

Failure mode and crack pattern of control beam and retrofitted beams were noted and explained separately. For control beams, since the beam specimens were weak in shear, the shear crack tends to propagate at the initial stages of loading itself. Very small flexural cracks were observed in the flexural zone at later loading stages. As the load increases, shear crack widens and propagates rapidly. The specimens clearly failed in a brittle manner with sudden destruction. Both the control beams failed in same manner. Fig. 6 shows the failure patter of all beams. For beams wrapped in the shear zone, at the initial loading stage a small vertical crack regenerated in the flexural zone. As the loading increases, these crack started to propagate slowly in vertical direction. At later loading stages, this crack started to propagate in inclined direction. The failure mode was flexural shear failure. That is BFRP wraps on the shear zone changed the mode of failure from brittle to ductile which gives sufficient warning before failure. In both the beams only single crack was seen, which widened as load increased and both the beams failed in similar manner. There was no rupture or debonding of the BFRP. There was no concrete crushing. Fig.7 (a) shows the enlarged view of the crack pattern.

(a) Control beam (b) Shear zone wrapped beam (c) Diagonal wrapped beam

Fig. 6 Failure pattern

For beams wrapped in diagonal manner, there were no cracks at the initial loading stages. As the load increased small cracks started to form in the flexural zone. At the initial loading stage there started a small vertical crack in the flexural zone. As the loading increased, additional cracks were formed and start to propagate vertically. Diagonal wraps arrested the cracks from widening. At later loading stages, these cracks tend to propagate in inclined direction. The failure mode was flexural shear failure. Both the beam showed similar failure bahaviour. The crack width of both beams was very less compared to other beams. There was concrete crushing at the loading points and debonding of BFRP strips from the concrete surface. Fig .7 (b) shows the enlarged view of failed beam.



(a) Shear zone wrapped beam (b) Diagonal wrapped beam

Fig.7 Cracks in retrofitted beams

VI. Conclusions

This paper projects the shear behavior of reinforced concrete beams retrofitted with basalt fiber polymer sheets after preloading. The conclusion drawn from the entire study were

- The stiffness of the retrofitted beams considerably increased when compared to the control beams. BFRP wraps restores the stiffness to the same level of the control beam in the initial stage. And further increases the stiffness in later stages of loading.
- The load carrying capacity of the retrofitted beams is increased. Retrofitted beam with shear zone wrapping showed a percentage increase of 55.2% and that with diagonal wrapping is 80%. Diagonal wrapped bean out performed shear zone wrapped beams
- There was no increase in the first crack load in shear zone wrapped beam. This may be due to small flexural cracks in flexural zone at the time of preloading. When loaded again after retrofitting crack may easily form there since there were no wrapping in the flexural zone. But there is an increase of 60% in first crack load for diagonal wrapped beams.
- Energy absorption of shear zone wrapped beam was 141.78% more and diagonal wrapped beam was 330.67% more than the reference beam.
- Diagonal strips arrest the crack from widening and propagation. It provides lateral confinement to the retrofitted beams.
- Retrofitted beams were failed after undergoing a very huge deflection compared to control beams. Mode of failure of retrofitted beams is by flexural shear cracks. That is mode of failure had changed from brittle to ductile.
- The test result show that diagonal wrapping tends to give the maximum efficiency when compared to shear zone wrapped beams. In all the cases diagonal wrapped beams out performed shear zone wrapped beams.
- BFRP is very effective material for retrofitting. It can used as an alternative to the commonly used retrofitting materials like GFRP and CFRP

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Jasmin S.P."Retrofitting of RCC Beams Weak in Shear with BFRP Wraps" International Journal of Engineering Science Invention (IJESI), vol. 07, no. 04, 2018, pp 81-87