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Retrofitting of Flexural Deficient Beams Using CFRP

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***Abstract:**Retrofitting the Reinforced Concrete (RC) framed structures have been magnifying these days globally. In order to have the up gradation towards the strength of the structural elements which are bounded externally using CFRP along with epoxy resin and hardener. The performance of conventional and retrofitted beams under weak in flexure theoretically and experimentally have been studied in this investigation and also his research emphasizes on the elaborate procedure for effective retrofitting. Total six beams were cast and in which three conventional and three retrofitted by reducing main reinforcement from 100% to 70% and 50%, to assess the flexural strength and damage level of the beams under weak in flexure condition. The design calculations have been considered based on conventional force equilibrium equations as per Indian Standards. The symmetrical two-point loading have been applied along with span at a distance of L/3 on the beam. The performance ofconventional beam's ofresultant which are obtained by ultimate load carrying capacity of retrofitted beams which are need to improve based on the failure mechanism of beam. Hence, theexperimental results are carried out by proposed approaches and evaluated.*

***Index Terms:** Retrofitting, Carbon Fiber Reinforcement polymer (CFRP), Epoxy Resin and Hardener, Beam Weak in Flexure.*

I. INTRODUCTION

Retrofitting of existing reinforced concrete (RC) framed structures are become the major prominence in the construction domain these daysin India are constructed without considering the seismic codal provisions.Therefore, these structures need up gradation or retrofitting, which have become one of the thrust areas in structural engineering globally. Several methods of retrofitting such as construction by attaching plain steel plates have been tried. However, in order to overcome the difficulties and some problems associated with these techniques, namely intensive labour, increased dimension and corrosion protection. Recent research efforts are focused on fibre reinforced polymers (FRP) or fibrous fabrics in order to strengthening or upgrading the elemental property of the existing reinforced concrete (RC) framed structures without distressing the existing structural elements. Retrofitting by using CFRP bonded externally with the help of epoxy resin and hardeners have been considered in this investigation. Many studies have been conducted based on retrofitting of structural elements bonded externally with FRP.

Retrofitting of existing structures has become a major part of the construction activity in many countries. Broadly, this can be attributed to aging of the infrastructure and increased environmental awareness in societies. Some of the structures are damaged by environmental effects, which include corrosion of steel, variations in temperature, exposure to ultra-violet radiation and earthquake. There are always cases of construction-related and design-related deficiencies that need correction. Many structures, on the other hand need strengthening because the allowable loads have increased, or new codes have made the structures substandard. The traditional retrofitting techniques that use steel and cementations materials do not always offer the most appropriate solutions. Retrofitting with fibre reinforced polymers (FRP) to strengthen and repair damaged structures is a relatively new technique. Extensive researches are going on in the areas of application of FRP in concrete structures for its effectiveness in enhancing structural performance both in terms of strength and ductility.

II. THE MODEL DEVELOPMENT PROCEDURE

There is a difference between conventional design procedures to the retrofitted design procedure. For retrofitted specimens at bottom side the CFRP has been attached, where additional resistance may get produce and leads to load carrying capacity of beams. In order to calculate the neutral axis depth of the retrofitted specimen, it need to be equated the equilibrium forces (i.e.,)

$C_u = T_s + T_{cfrp}$ - Eq (1)

Where, C_u is compressive force, T_s is tensile force of steel, T_{cfrp} is tensile force of CFRP. The stress-strain distribution diagram of retrofitted RC beam is shown in Fig. 1.

$$0.36 \times 1.5 \times f_{ck} \times b \times x_u = \left(1.25 \times f_y \times A_{st}\right) + \left(A_{cfrp} \times f_{cfrp}\right)$$

Where, 'f_{ck}'is characteristic compressive strength of concrete; 'b' is width of beam; 'x_u' is neutral axis depth; 'f_y'is characteristic strength of steel; 'A_{st}'is area of main reinforcement; 'A_{cfrp}' is area of CFRP; 'f_{cfrp}' is ultimate stress of CFRP. Table I shows the details of test matrix.

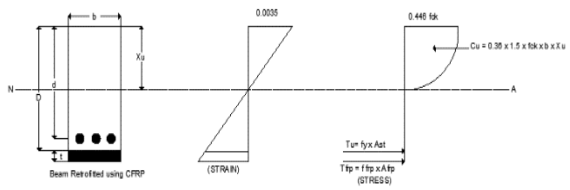

Fig. 1: Stress-Strain Distribution Diagram of Retrofitted RC Beam

Table I: Details of test matrix

Beam	A_{st} (mm^2)	Thickness (t_{cfrp})(mm)	Applied Load (Theoretical) (kN)
BWFC100	339.12	0	56
BWFC70	237.384	0	41.23
BWFC50	169.56	0	31

III. Experimental Programme

All the six beams were cast by M20 grade of concrete Fe 500 steel. The retrofitted beams were wrapped using CFRP of thickness 0.317N/mm^2, bonded externally by using epoxy resin and hardener in the ratio of 1:5. In this study three beams are considered as conventional beams which are weak in flexure by reducing the main reinforcement from 100% to 70% and 50%. All the beams were having the span of 2200 mm, and the cross section was considered as 150 mm × 300 mm. The conventional beam designated as beam weak in flexure control specimen with 100% flexural reinforcement (BWFC100) is shown in Fig. 2(a). The control beam designated as beam weak in flexure control specimen with 70% flexural reinforcement (BWFC70) is shown in Fig. 2(b), whereas the conventional beam with 50% main reinforcement (BWFC50) is shown in Fig. 2(c).

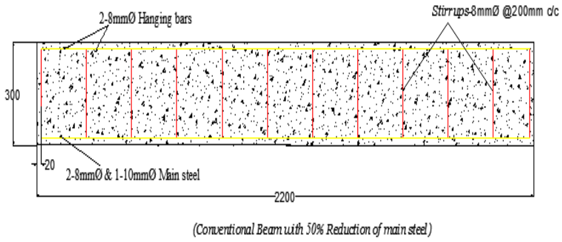

Fig. 2(a): Detailing of BWFC100

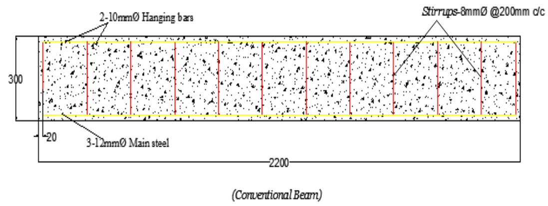

Fig. 2(b): Detailing of BWFC70

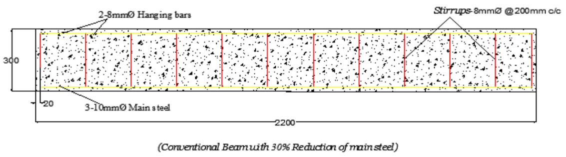

Fig. 2(c): Detailing of BWFC50

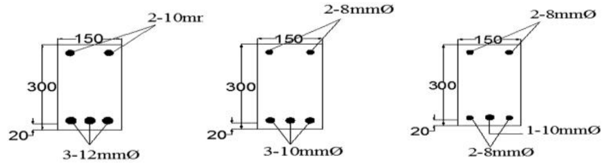

Fig. 2: Cross-Sectional Details

The retrofitted beam designated as beam weak in flexure retrofitted specimen with 100% flexural reinforcement (BWFR100) is shown in Fig.3(a). The retrofitted beam designated as beam weak in flexure retrofitted specimen with 70% flexural reinforcement (BWFR70) is shown in Fig.3(b), whereas the retrofitted beam with 50% main reinforcement (BWFR50) is shown in Fig. 3(c).

Fig. 3 shows the specimens values based on Table II.

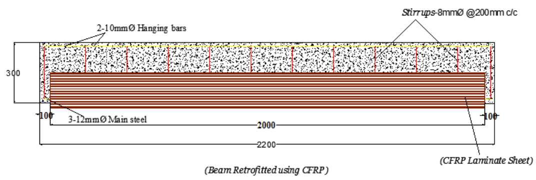

Fig. 3(a):BWFR100

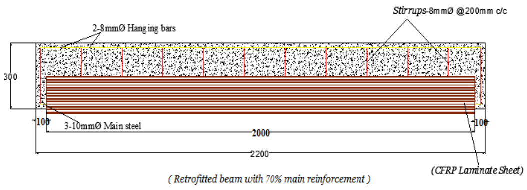

Fig. 3(b):BWFR70

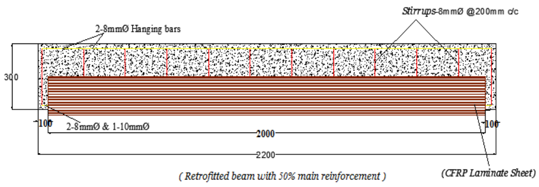

Fig. 3(c):BWFR50

Fig. 3: Retrofitted Specimensdetails

Table II: load pattern

Beam	A_{st} (mm^2)	Thickness (t_{cfrp}) (mm)	Applied Load (Theoretical) (kN)
BWFR100	339.12	0.317	75
BWFR70	237.384	0.317	64
BWFR50	169.56	0.317	57.2

A. Casting of beams

Firstly, all the six beams are needed to be cast as per the design consideration. In which three beams are considered as conventional and the remaining three beams are considered as retrofitting beams. Here all the beams are cast according to the mix design and also the materials which are required to cast the beams are shown in chapter-3. After material procurement the next step of the process is to weigh the materials of the required quantity per meter cube. The volume of the beam is obtained as 0.26 m^3, since from Table I we can observe the concrete mix proportions per meter cube. So, it is necessary to measure the required volume of material quantities before cast of beams. After weighing of materials as per the required quantities, now all the coarse aggregates, fine aggregates and cement are need to be mix thoroughly by adding of water content after providing of steel reinforcement in Fig. 4(a).

Fig. 4(a): Providing of Steel reinforcement in beam mould

After placing the beam reinforcement cage in to the beam box, the concrete mix which is mixed thoroughly need to be poured in to the beam box in the form of layers. After filling of first two layers we need to place the vibrator inside the concrete in order to avoid air voids. And after filling the next layer of concrete mix again it is required to keep the vibrator to avoid the air voids. At last we need to level the top surface of the beam with the help of a trowel. The beams are needed to be demoulded within 24 hours of cast as shown in Fig. 4(b). And after demould all the control and retrofitted specimens need to be covered with the help of gunny bags in order to perform curing up to 28 days.

Fig. 4(b): Cast concrete beam

B. Detailed Process for Fixing of CFRP

In order to start the first step of the process, the surface of the beams have to be polished using concrete grinding machine in order to make the surface even for fixing of CFRP as shown in Fig. 4(c). And also, the required safety precautions we need to maintain while using the grinding machine like by wearing the gloves on the hands, safety apron and protection mask. Now, the surfaces of the beams have to be cleaned by using brush or blower thoroughly. The CFRP has to cut as per dimensions required for retrofitting, for each beam the required sheet dimensions are 450mm × 2000mm. the next step of the process is the mixture of epoxy resin by following the CFRP cutting sheet and hardener with ratio of 1:5 may mixed systematicallyfrom 10 to 15 min. Then applying on the cleaned surface of the beam at place where the CFRP have to be attached.

Fig. 4(c): Application of CFRP sheet

As per specifications and guidelines of the supplier of epoxy resins after application on the surface, around 180 sec

Table III: Properties of CFRP

Type of fibre	**CARBON FIBRE**
Fibre orientation	UNIDIRECTIONAL
Weight of fibre	400 g/mm^2
Density of fibre	1.80 g/cc
Fibre thickness	0.317 mm
Ultimate elongation (%)	1.5
Tensile strength	3400 N/mm^2
Tensile modulus	230000 N/mm^2

(30 min) of pot life must and should maintained.The CFRP need to be attached over the surface and roll the CFRP sheet with the help of steel roller in order to observe no air voids. All the three retrofitted beams were kept for 7 days dry curing in order to gain the bonding strength. The control and retrofitted beams have to be white washed and grids have to be drawn by 5 cm × 5 cm grid box in order identify the crack pattern.

C. Testing Procedure

The controlled and retrofitted beams were tested under four point bending load in order to know the ultimate load carrying capacity. From the left edge of the beam at a distance of 100 mm hinge support was placed and from the right edge of the beam at a distance of 100 mm roller support was placed. The support conditions are same for all tested specimens as shown in Fig. 4(d). The capacity of testing frame is 200 tons at structural engineering laboratory Koneru Lakshmaiah Education Foundation(Deemed to University).

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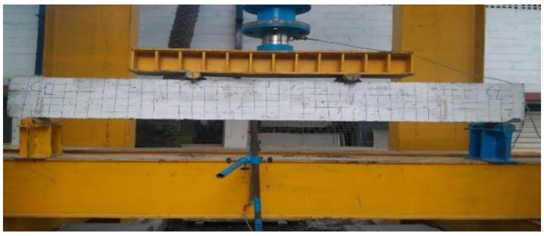

Fig. 4(d) : Testing of beams

The setup which was used for the testing of controlled and retrofitted beams. The beams are lifted with the help of crane and placed on the supports. Further, it is important to provide the plate and then mortar to maintain even surface to avoid eccentricity. Two loading points were provided with equal distance in form of steel solid billets. Then I sectional girder beam was placed to apply the two point loading on the beam. The loading cell was placed above the girder in order to record the load values. To measure the mid displacement the LVDT has been maintained at the middle bottom surface of the beam.

D. Failure Mechanism of Tested Specimens (Conventional)

The BWFC100 has been tested, and the ultimate load carrying capacity of beam was obtained as 135.4 kN and maximum deflection was 25.97 mm. The crack pattern of the tested specimen shown in Fig. 5(a). The cracks were generated from the bottom surface of the beam and the major crack were obtained at the middle portion of the beam and it was observed that some of the shear cracks were also encountered, hence it can be stated that BWFC100 consists a failure mechanism of both flexural and shear failure.

Fig. 5(a): Failure Pattern of the BWFC100

The BWFC70 has been tested and the ultimate load carrying capacity was obtained as 93.7 kN and the maximum deflection was obtained as 21.93 mm. In this case, the beam was affected majorly due to flexural cracks and shear cracks. The deflections were recorded at each interval of load. The failure pattern has been shown in Fig. 5(b). Also, the shear cracks were noticed near to the supports and propagates at an angel of 45^0 towards the compression zone, hence it can be stated that BWFC70 is obtained a combined failure flexure and shear failure.

Fig. 5(b): Failure Pattern of the BWFC70

BWFC50 has been tested, and the ultimate load carrying capacity of beam was obtained as 75.2 kN and maximum deflection was obtained as 25.9 mm. As a parameter the percentage of main steel reinforcement has been reduced in this specimen from 100% to 50% to assess the flexural strength deficiency. The observed failure pattern of this specimen was purely flexural as shown in Fig. 5(c). The significant flexure cracks observed at the middle portion of the beam with visible crack width.

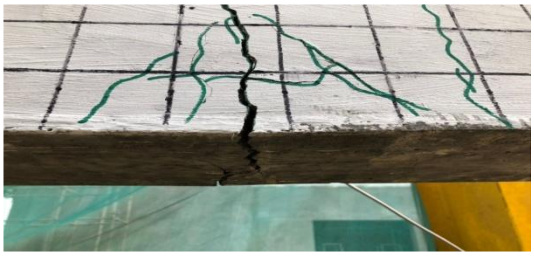

Fig. 5(c): Failure Pattern of the BWFC50

E. Failure Mechanism of Tested Specimens (Retrofitted)

BWFR100 has been tested and the ultimate load carrying capacity was obtained as 193 kN and the maximum deflection was obtained as 19.51 mm. The beam was affected majorly due to shear cracks and fewer amounts of flexural cracks have been observed. Since, the BWFR100 was designed to resist flexural strength. It has been clearly observed that the retrofitting was helped to enhance the flexural strength. From Fig. 5(d), it was noticed that the shear crack from the left support of the beam was propagated at an angle of 45^0.

Fig. 5(d): Failure Pattern of the BWFR100

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BWFR70 has been tested and the ultimate load carrying capacity is obtained as 146.7 kN and maximum deflection was obtained as 17.79 mm. The beam was affected majorly due to shear cracks rather than flexural cracks because the beam was retrofitted at the tension surface of the beam in order to get resistance over flexure as shown Fig. 5(e).

Fig. 5(e): Failure Pattern of the BWFR70

BWFR50 has been tested and ultimate load carrying capacity was obtained as 142.5 kN and the maximum deflection was obtained as 24.43 mm. Since the main reinforcement was reduced to 50% in this specimen. From the Fig. 5(f), it can be observed that the CFRP was delaminated from the surface of the beam. Also, it can be observed that the sheet was tearing horizontally along the length. It means pure flexural failure of the laminated sheet was occurred during the test. Few shear cracks were also observed. The test results of all specimens are presented in Table IV.

Table IV: Summary of Test Results

Beam	Ultimate Load (kN)	Failure Mode
BWFC100	135.4	Flexural & Shear
BWFR100	193	Shear
BWFC70	93.7	Flexural & Shear
BWFR70	146.7	Shear
BWFC50	75.2	Flexural
BWFR50	142.5	Delaminating& Flexural Rupture

IV. The Experimental Results

The comparison of conventional and retrofitted specimens are evaluated from the experimental results based on the following different parameters are analyzed after testing such as load versus deflection, mode of failure and crack pattern of all specimens.

A. Load versus Deflection Response

The Fig. 6 shows the comparison of flexural strength of BWFC100 and BWFR100. The load carrying capacity of BWFR100 is 42.54% greater than BWFC100 and the deflection wascomparatively less with control beam having 100% main reinforcement. It indicatesthat the retrofitted beam has shown significant strength and stiffness with less magnitude of deflection.

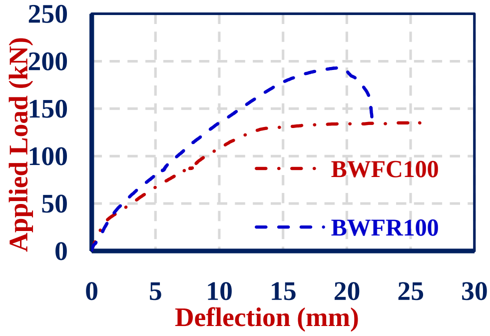

Fig. 6: Comparison of Flexural Strength of BWFC100 and BWFR100.

The comparison of flexural strength of BWFC70 and BWFR70 is shown in Fig. 7. The load carrying capacity of BWFR70 is 56.56 % greater than BWFC70 and the deflection wascomparatively lesswith control beam having 70% main reinforcement. It shows that the retrofitted beam has significant strength and stiffness with less magnitude of deflection.

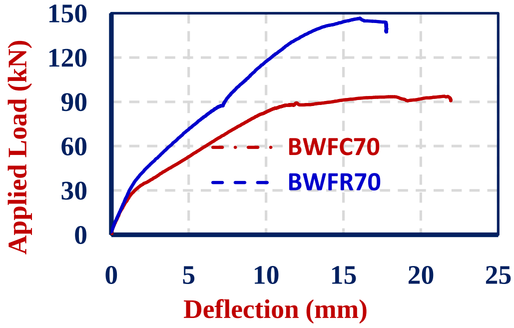

Fig. 7: Comparison of Flexural Strength of BWFC70 and BWFR70.

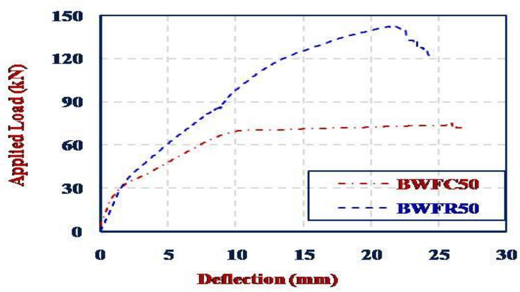

Fig. 8: Comparison of BWFC50 and BWFR50 Flexural Strengths

Fig. 8 shows the 89.59% shear reinforcement reduction specimens BWSC50 and BWSRF50. The evaluation of flexural concentration of BWFC50 and BWFR50 is shown in Fig. 8. The load carrying capacity of BWFR50 is 89.59 % greater than BWFC50 and the deflection wascomparatively lesswith control beam having 50% main reinforcement. It shows that the retrofitted beam has significant strength and stiffness with less magnitude of deflection.

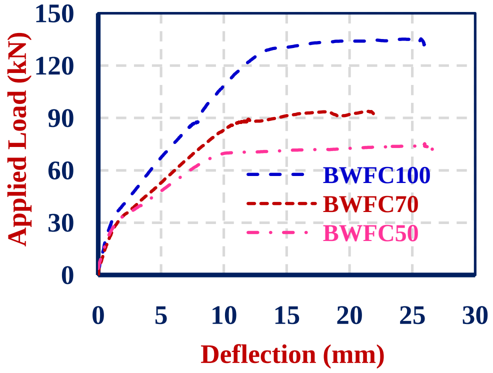

Fig. 9: Conventional specimens are evaluate

Fig. 9 shows the set-1 specimens BWFC100, BWFC70, and BWFC50. The comparison of flexural strengths of three controlled specimen has been shown in Fig. 9. The load carrying capacity of BWFR100 isgreater than BWFC70 and BWFC50. The deflection washigher when compared to the BWFC70 and BWFC50.

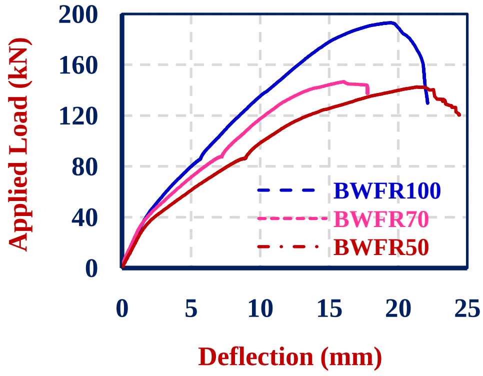

Fig. 10: Evaluation of flexural strengths of BWFR100, BWFR70 and BWFR50.

V. CONCLUSION

The theoretical and experimental study on control and retrofitted reinforced concrete beams using CFRP. As a parameter all beams made weak in flexure by reducing the main reinforcement from 100% to 70% and 50% have been studied and the beam failure mechanism also observed. The following conclusions are drawn from present study:

i. The control beams were shown high magnitude of deflections when compared to the retrofitted beams.
ii. The load carrying capacity of retrofitted beams is significant when compared with control beams.
iii. The enhancements of flexural strength of retrofitted beams have been increased due to externally bonded CFRP.
iv. The visibility of flexural cracks has been noticed much higher in conventional beams when compared to the retrofitted beams at early intervals of load application. Few shear cracks were also noticed.
v. The major shear cracks have been observed in BWFR100 at an ultimate load of 193kN.
vi. The delamination and flexural rupture of CFRP sheet was occurred in BWFR50 at an ultimate load of 142.5kN.
vii. The ultimate capacity of BWFR100 was increased by 42.54% compared with BWFC100.
viii. The ultimate capacity of BWFR70 was increased by 56.56% compared with BWFC70.
ix. The ultimate capacity of BWFR50 was increased by 89.59% compared with BWFC50.
x. Retrofitting using CFRP sheets has been recommended in order to enhance the flexural strength of beams.

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