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Retrofitting Of RCC Beams Weak In Shear Using BFRP –An Analytical Investigation

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ABSTRACT

In this paper analytical investigation was carried out for evaluating the performance of RCC beams retrofitted using BFRP wraps for enhancing shear strength. Numerical analysis tool ANSYS 2015 software was used. Two wrapping pattern considered were, U shape at shear zone and diagonal wrapping on side faces at ±45°. Beams were analysed for two point loading. Load deflection behaviour, ultimate load and deflection at ultimate load were compared. This paper also presents the effectiveness of BFRP as a retrofitting material in comparison to CFRP and GFRP.

Keywords: Retrofitting, BFRP, ANSYS, Shear strength

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

Retrofitting can be done to beams, columns, beam column joints, walls etc. Some conventional retrofitting techniques are steel plate bonding, jacketing by reinforcement cage, using ferrocement and wire mesh. These methods suffer from inherent disadvantages such as it adds additional dead load to the structure, increases size of the section, requires corrosion protection, and in some techniques it require temporary support and curing period. In recent years, retrofitting by bonding of fibre 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 and lower density than steel.

There are artificial and natural FRP. Carbon fibre reinforced polymer, glass fibre reinforced polymer and aramid fibre reinforced polymer are artificial FRP and it is widely used .The problem with this FRP is its high cost and causes skin disease to workers dealing with it. Due to increasing demand and some disadvantages of these materials, it is time to find an alternative material for retrofitting which is eco friendly and pocket friendly. Basalt fibre reinforced polymer (BFRP) a natural FRP formed from crushed basalt rock was used as retrofitting material.

Usually beams are retrofitted for enhancing shear capacity, flexural strength and torsional resistance. FRPs 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, RCC beams were retrofitted for enhancing 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 supports and the diagonal cracks start from support to applied load. These diagonal cracks were formed on either sides together in RCC beams and failure occurred by widening of shear cracks. For strengthening, FRP strips have been used on the faces of the beams in previous studies. The common types of FRP schemes used most frequently in the previous studies were i) 90° strip ii) 45° strip iii) U-shape full length wraps and iv) side faces full length wrapping. In this paper beams were retrofitted with 45° strip wrapping on side faces and U wrapping on shear zone. Numerical analysis tool ANSYS 2015 is used for modelling and analysis.

II. FINITE ELEMENT ANALYSIS USING ANSYS

A. Geometry and Material Data

For the current research, a beam of length 4500mm, width 250mm and depth 300mm is considered. The top longitudinal reinforcement consists of two bars of 10mm diameter (stirrup holder) and the bottom longitudinal reinforcement consists of four bars of 16 mm diameter. Stirrups of 10 mm diameter are provided at 227mm centre to centre spacing. No stirrups were provided in the shear zone so that the beam would fail in shear. Geometry of the RCC beam and loading scheme is shown in Figure 1. These beams are then wrapped in two manners. First type is wrapping in shear zone in U

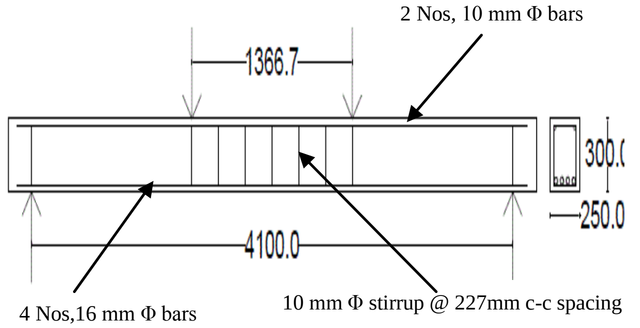
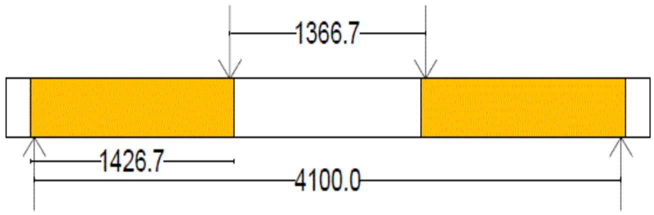
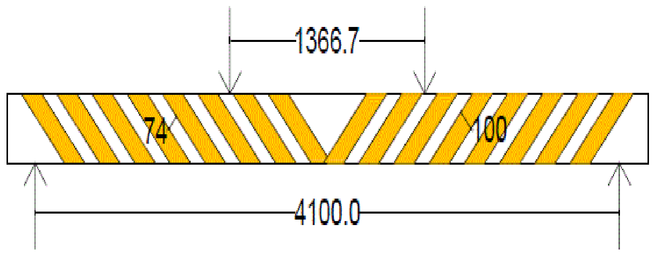


Figure 1. Geometry of RCC beam

manner. That is wrapping on two side faces and at the bottom. Next wrapping is on the side face in diagonal manner at 45°with 100 mm strips at 74 mm spacing. Figure 2 shows the wrapped beams. Beam groups and their designation are shown in table1 and table2 shows the summary of material properties used for analysis.



(a) Beam with shear zone wrapping



(b) Beam with diagonal wrapping

Figure 2. Geometry of retrofitted beams

Table 1. Beam designation

Beam group	Material of wrapping	Beam designation
Control beam	-	BC
Beam with shear zone wrapping	BFRP	BSWB
	CFRP	BSWC
	GFRP	BSWG
Beam with diagonal wrapping	BFRP	BDWB
	CFRP	BDWC
	GFRP	BDWG

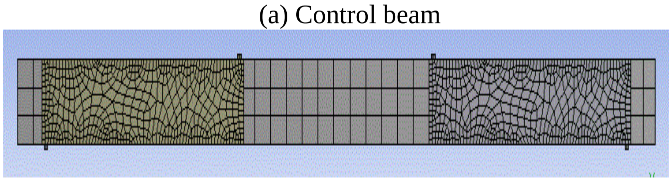
Table 2. Summary of material properties

Material	Dimensions (mm)	Compressive strength (Mpa)	Tensile strength (Mpa)	Yield strength (Mpa)	Young's modulus (Gpa)	Poisson's ratio
Concrete	-	30	3.71		27.83	0.15
Steel	10Φ, 16Φ	-	-	415	200	0.3
BFRP	0.34	-	3000		108	0.3
CFRP	0.22	-	3500		242	0.2
GFRP	0.27	-	1800		69	0.22

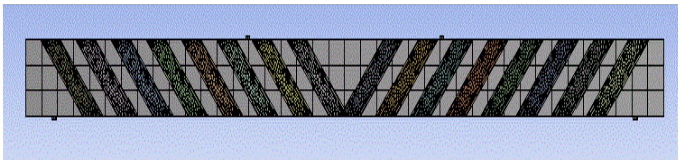
B. Numerical Modeling

The concrete was modeled with a 3-D reinforced concrete 8-noded SOLID65 element which is capable of cracking in tension and crushing in compression having three degrees of freedom at each node (translation in x, y, z directions). Beam 188 is a linear beam element and is used for steel reinforcement. The FRP sheet was modelled with 4-noded SHELL181 (membrane only option) element with six degree of freedom at each node (translation in x, y, z direction and rotation in x, y, z direction). The element accommodates option for defining the material number, orientation, thickness and number of integration points through the thickness of each layer. Figure 3 shows the meshed model control beam, shear zone wrapped beam and diagonal wrapped beam respectively.

(a) Control beam



(b) Shear wrapped beam



(c) Diagonal wrapped beam

Figure 3. Meshed models

C. Non - Linear Solution and Failure Criteria

In this study the total load applied was divided in to a series of load increments (or) load steps. Newton – Raphson equilibrium iterations provide convergence at the end of each load increment within tolerance limits. The automatic time stepping in the ANSYS program predicts and controls load step sizes for which the maximum and minimum load step sizes are required. After attempting many trials number of load steps, minimum and maximum step size was determined. After that each beam was analysed.

III. RESULTS AND DISCUSSION

D. Load Deflection Behaviour of Beams

The load deflection behaviour is shown in Figure 4.It is very evident that stiffness of the retrofitted beam is increased. The contribution of shear wrapping to stiffness is less as there is no wrapping in flexural zone, where cracks may propagate easily. Diagonal wrapping increases stiffness of the beam, which means it prevent the growth of cracks. From the graph it is seen that the retrofitting introduces more ductility to the beam.

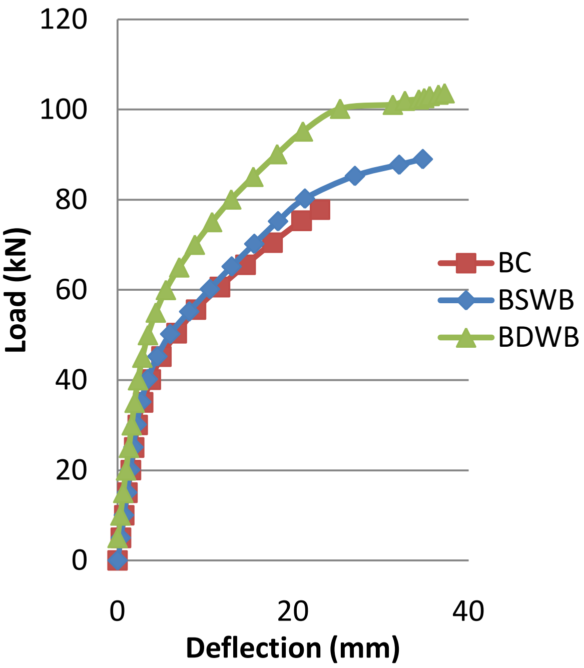


Figure 4. Load deflection curve

E. Ultimate Load and Deflection

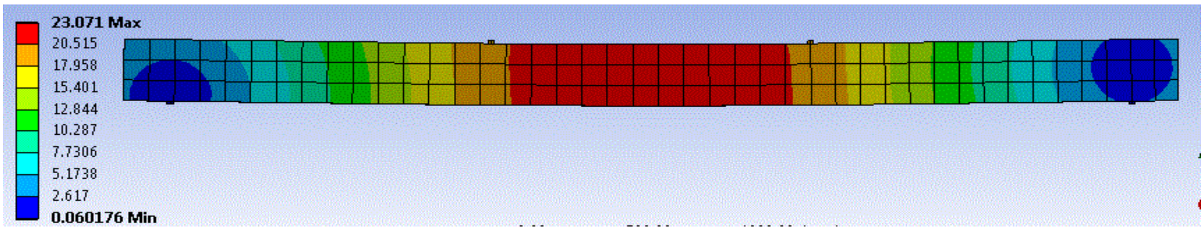
Ultimate load and deflection of wrapped beam and its percentage increase with control beams was tabulated in table3. Deflected beams after analysis are shown in Figure 5. BSWB shows 33.29 % increase in load carrying capacity than control beam. Shear wrapped beam show an increase of 14.4 % than BC. It is seen than beam with diagonal wrapping out performed beam with shear zone wrapping.

Table 3. Ultimate load and Deflection

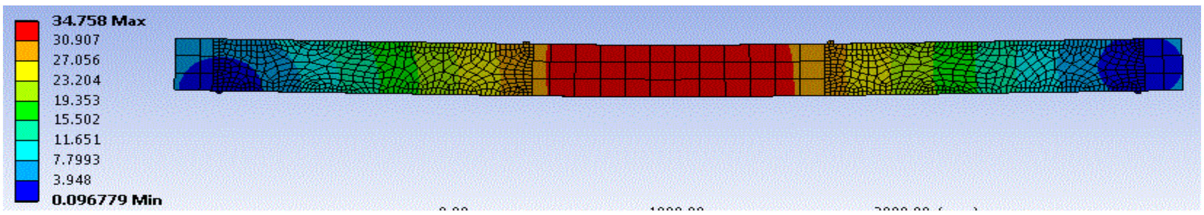
Beam designation	Ultimate load (kN)	Percentage increase %	Deflecion at ultimate load(mm)	Percentage increase %
BC	77.71	-	23.07	-
BSWB	89.06	14.4	34.75	50.6
BDWB	103.68	33.29	37.96	64.54

F. Effectiveness of BFRP Compared to CFRP and GFRP

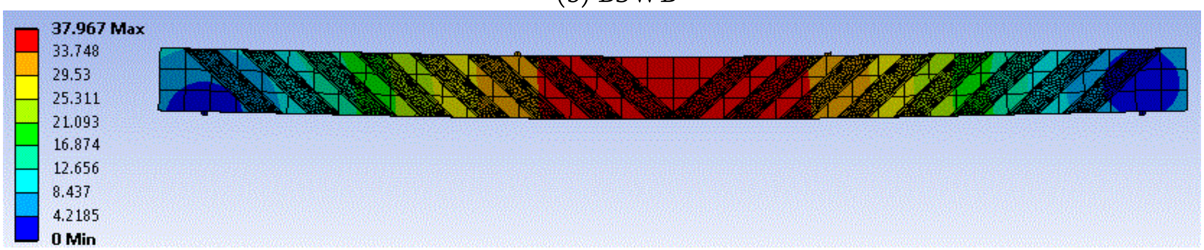
Ultimate load and deformation at ultimate load for both types of wrapping with these three different FRPs was tabulated. Graph is plotted for diagonally wrapped beam and shear wrapped beam with these materials. Figure 6 and Figure 7 shows the load deflection graph for diagonal wrapped beams and shear wrapped beams respectively.



(a) BC



(b) BSWB



(c) BDWB

Figure 5. Deflected profile of (a) BC, (b) BSWB, (c) BDWB

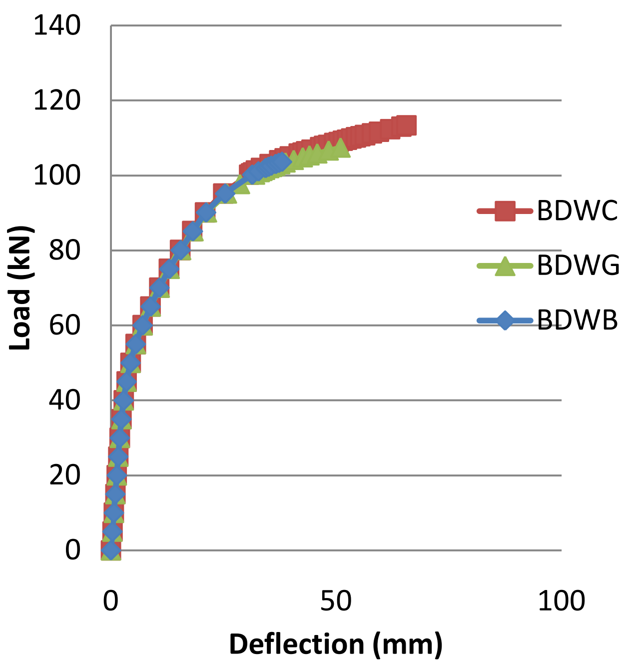


Figure 6. Load deflection curve for diagonally retrofitted beams

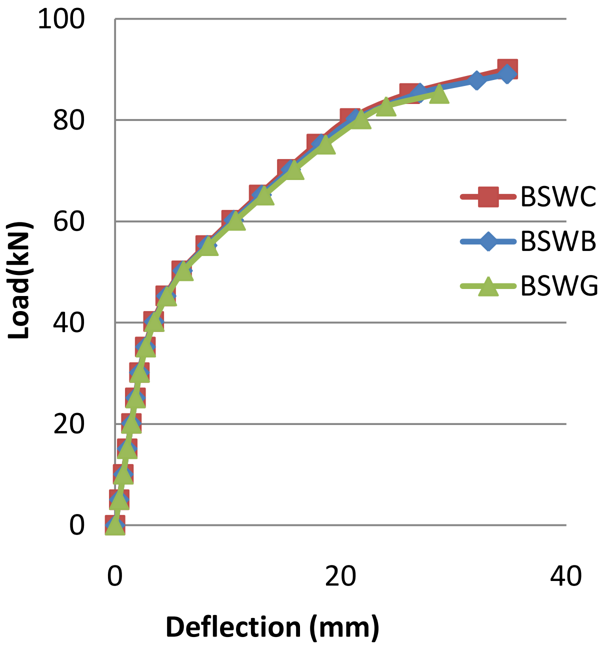


Figure 7. Load deflection curve for shear zone retrofitted beams

From both the graph it is seen than performance of beam retrofitted with BFRP is comparable that with GFRP and CFRP. Table 4 gives the percentage increase in ultimate load and deflection due to retrofitting with this three FRP with respect to control beam. Diagonal wrapping increased load carrying capacity by 103.6-113 .3 % and shear zone wrapping increased ultimate load by 82.25- 89.05%. As the performance of BFRP is comparable, it can be used as an alternative to CFRP and GFRP.

Table 4. percentage increase in ultimate load and deflection for retrofitted beams

Pattern of wrapping	Material of wrapping	Beam designation	Ultimate load (kN)	Percentage increase %	Deflection ultimate load (mm)	Percentage increase %
Diagonal wrapping	BFRP	BDWB	103.68	33.29	37.96	64.54
	CFRP	BDWC	113.34	45.71	65.58	184.26
	GFRP	BDWG	107.44	38.13	50.95	120.84
Shear zone wrapping	BFRP	BSWB	89.05	14.4	34.75	50.6
	CFRP	BSWC	90.09	15.82	34.79	50.8
	GFRP	BSWG	82.25	5.74	28.74	24.57

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