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Flexural Behavior of RCC Beams Retrofitted with BFRP Wraps

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Abstract—This work presents retrofitting of reinforced concrete beams which are weak in flexure using Basalt fiber reinforced polymer (BFRP) subjected to two point loading. The main aim of this study is to rehabilitate the structurally deficient beam and to make it serviceable in flexure. Experiment consists of six RCC beams. Of the six beams two beams were control beams. Remaining four beams were preloaded to 70% of the ultimate load of the control beam. The beams were then retrofitted by wrapping BFRP on the tension zone and flexural zone. Load–deflection behavior, energy absorption, failure modes and crack propagation patterns are studied extensively. Experimental results are validated with ANSYS software. Parametric study is done in ANSYS for full scaled beams. Various parameters considered are number of layers of wrapping and material of wrapping. Retrofitting with BFRP wraps make structure more efficient and restore stiffness and strength values greater than those of control beams.

Index Terms— Retrofitting, Preloading, Wrapping, BFRP, ANSYS , Flexural behaviour

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1 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.

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 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. 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. In this paper basalt fibre reinforced polymer (BFRP) a natural FRP formed from crushed basalt rock was used as retrofitting material.

Retrofitting can be done to beams, columns, beam column joints, walls etc. In this paper retrofitting was done on beams. 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 flexural capacity. The most frequent failure mechanism in RC beams is a flexural failure under bending stresses. Most of the beams lose their design strength and durability as the load exceeds. It is found from different studies, that the compression zone of the RC beam is safer from failure as the tension zone used to be under pure bending, due to properties of concrete. The critical area for beam under bending stresses is a tension zone of the RC beam. Mostly, the failure initiated by the development of crack from tension zone, and extended up to compression zone before reaching to failure. These cracks usually start from the bottom of applied load, which indicates flexural failure. In this study to enhance flexural strength beams weak in flexure were retrofitted by wrapping BFRP at the tension zone and in the flexural zone.

2 METHODOLOGY

Methodology of this work is divided as methodology for experimental method and methodology for finite element method.

Methodology for experimental method:

1. Material procuring and its testing
2. Mix design
3. Testing of concrete for its fresh and hardened properties
4. Reinforcement design

5. Casting and curing of beams
6. Testing of control beams
7. Preloading other beams (70% ultimate load of control beam)
8. Wrapping BFRP on the pre- loaded beams and its testing.

Methodology for finite element method (using software tool ANSYS):

1. Modeling and analysis of control beams in ANSYS.
2. Modeling and analysis of retrofitted beams in ANSYS.
3. Modeling and analysis of retrofitted full scaled beams in ANSYS.
4. Parametric study is carried out by considering- number of layers of wrapping, material of wrapping.

3 MATERIALS AND METHOD

The materials used for the experimentation were cement, sand, aggregate, steel, water, BFRP. All the materials were tested in the laboratory to obtain its properties. The properties of fresh and hardened concrete were also found out. BFRP was not tested. Its properties were provided by the supplier.

3.1 Concrete

In this 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/mm2. 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, produced a slump value of 36 mm. For finding the properties of hardened concrete, nine number of cubes, three cylinders, three prisms were cast using the stated mix proportion and water cement ratio. 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. Modulus of rupture of the concrete was 3.71N/mm^2 and splitting tensile strength was 2.78 N/mm^2. Modulus of elasticity was found as 21893 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.

3.4 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 (mm)	0.34
Weight (gsm)	300
Tensile strength (MPa)	3000
Elastic modulus (GPa)	180
Poissons ratio	0.30

4 EXPERIMENTAL PROGRAMME

Experiment consists of 6 RCC beams. Beams were designed to study flexural behavior when retrofitted with BFRP wraps. All the beam specimens were of dimension 100x100x750 mm 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.

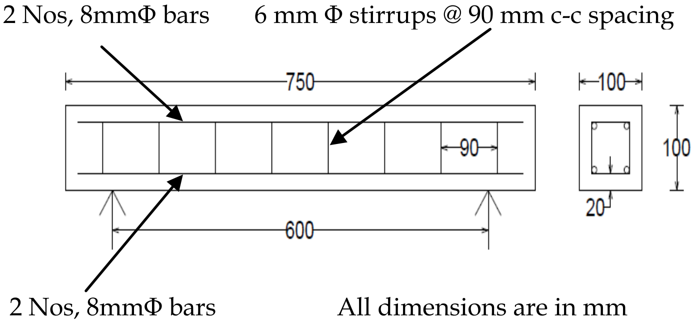


Fig.1 Reinforcement detailing

4.1 Beam Designation

Of the six beams two beams are control beams, with no wrapping and designated as FCB1 and FCB2 ie, flexure control beam one and flexure 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 tension zone wrapping. That is BFRP is wrapped on bottom and two side faces till neutral axis. Designated as FBTW1 and FBTW2 that is, flexural beam with tension wrapping. Next pattern of wrapping is the flexural zone wrapping. BFRP is wrapped on two side faces and bottom in U manner and designated as FBFW1 and FBFW2 that is flexure beam with flexure zone wrapping.

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.

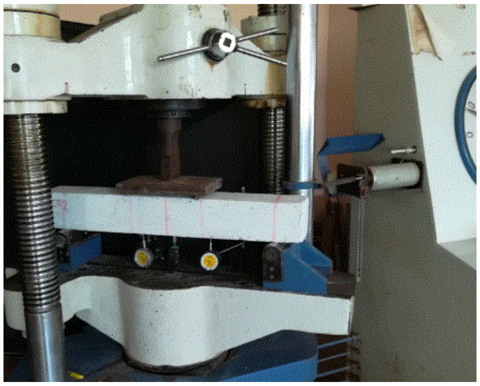


Fig.2 Test setup

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 rquired area was made rough using a coarse sand paper teture 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 was 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. 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. Fig.3 shows the retrofitted specimen.

5 RESULTS AND DISCUSSIONS

The control beams were tested up to the failure and deflection values were 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 tested up to failure and deflection values were 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, ultimate load, crack pattern, energy absorption and failure mode.

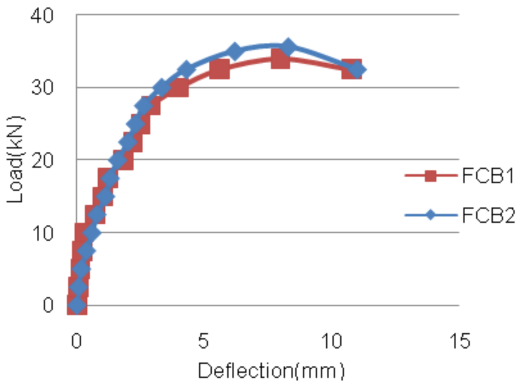
(a) FBFW

(b) FBTW

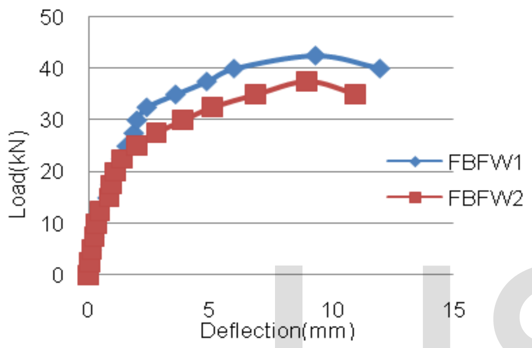
Fig.3 Retrofitted beams

5.1 Load Deflection Behavior

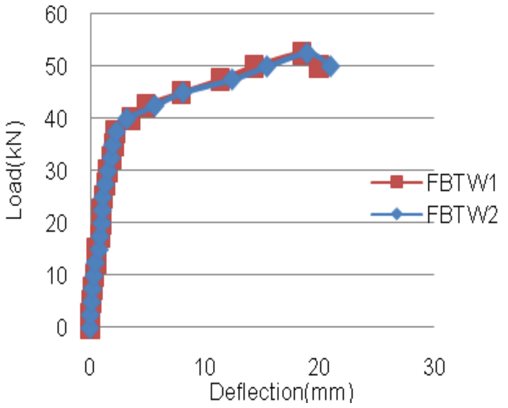
The load deflection histories of all the beams were recorded. Fig.4 shows the load deflection curve for each beam group. From the graph it can be seen that the behavior of each beams in a scheme is identical. This conforms the accuracy of the experimental work. In the case of retrofitted beams, it conforms that the retrofitting was performed in well defined manner. For comparing control beam with the retrofitted beams, curve showing maximum load from each scheme is chosen. Fig.5 shows the load versus mid span deflection of FCB2, FBTW2 and FBFW1. Retrofitted beam show better performance than the control beam. Load carrying capacity of the retrofitted beam is higher than the FCB. It can be seen that the stiffness of the retrofitted beam has increased. Initially all the three beams showed nearly same stiffness. At cracking stage, the stiffness of the control beam decreased notably due to cracking but in retrofitted beams, BFRP come in role and prevent the crack to develop and widen. When a beam is subjected to preloading (70% of ultimate load), later unloaded and then subjected to load again, the stiffness would be lesser second time due to the damage caused in preloading. This shows that the BFRP wraps had improved the beam and restored the stiffness to the level of control beam. The stiffness of the beam



(a) Control beam



(b) Flexural wrapped beam



(c) Tension wrapped beams
Fig.4 Load deflection behavior

depends on the length of FRP. Longer the length of the beam, stiffer the beam will be. The main difference between tension zone wrapping and flexural zone wrapping is the length of wrapping. Hence it can be note that as the length of wrapping increases the load carrying capacity, stiffness and ductility of the member increases. The results indicate that retrofitting increases the stiffness, ultimate load and reduces the deflection. Comparing tension zone and flexural zone wrapped beams beam with flexural wrapping shows somewhat a sudden failure but tension zone wrapped beams yields before failure. FBTW show outstanding bahaviour and it increases the ductility of the beam to a high extends than FBFW.

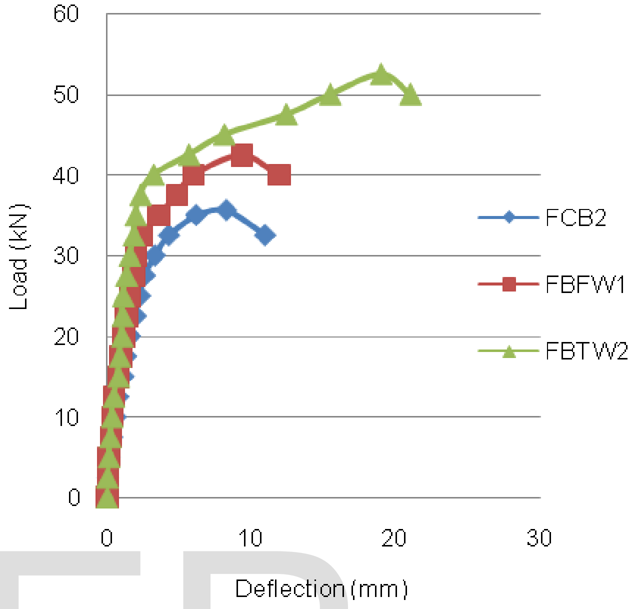


Fig.5 Load deflection behaviour

5.2 First Crack Load and Ultimate Load

First crack load and ultimate load of all beams with their increases with respect to control beam were noted and tabulated in Table 3. Load at the change of slope at the initial portion of load deflection curve is the first crack load. There is an increase of 14.3 % for flexural zone retrofitted beams and 57.14% for tension zone retrofitted beam in case of first crack load. Ultimate load carrying capacity of tension zone retrofitted beam is 50.86% more and flexural zone retrofitted is 14.94% more than control beams.

Table 3 First crack load and Ultimate load

Designation	First crack load (kN)	Mean (kN)	Percentage increase (%)	Ultimate load (kN)	Mean (kN)	Percentage increase (%)
FCB1	10	8.75	-	34	34.8	-
FCB2	7.5			35.6		
FBFW1	10	10	14.3	42.5	40	14.94
FBFW2	10			37.5		
FBTW1	15	13.75	57.14	52.5	52.5	50.86
FBTW2	2.5			52.5		

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 flexural zone is 29.7 % and that at tension zone wrapping was 265.15% more than reference beam.

Table 4 Energy absorption

Designation	Energy absorption (kN -mm)	Mean (kN -mm)	Percentage increase (%)
FCB1	212.15	222.09	-
FCB2	232.03		
FBFW1	315.96	288.10	29.7
FBFW2	260.25		
FBTW1	799.99	810.98	265.15
FBTW2	821.98		

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, at the early load stages flexural cracks were initiated at the soffit of the beam. As the load increased, cracks propagated in vertical direction and for further increase in load cracks started propagating in inclined direction. Which means the mode of failure was flexural shear failure. Fig.6 shows the failure pattern of flexural control beam. Both the beams FCB1 and FCB2 failed in same manner.

Fig.6 Failure pattern of flexural control beams

For the beams retrofitted in flexural zone, at the initial stages of loading there was no crack formation. As the load increased a small diagonal hair crack was visible near the support in the shear zone of the flexural retrofitted beam. Suddenly this inclined hair crack propagates from loading point to the support point leading to the failure of the retrofitted beams. Which means that mode of failure was shear failure. Both the beams FBFW1and FBFW2 failed in same manner. There was no rupture or debonding of the BFRP. Fig.7 shows the failure pattern of flexural wrapped beam. Here the mode of failure changed from flexural shear to pure shear failure. The failure is usually occurring without giving any alarming alerts. Therefore, shear failure is considered to be more dangerous for structures than flexural failure. For beams retrofitted in tension zone, there were no visible cracks. There was debonding at the left top portion of the BFRP. The failure was by complete bending failure. Fig.8 shows the tension zone retrofitted beams after testing.

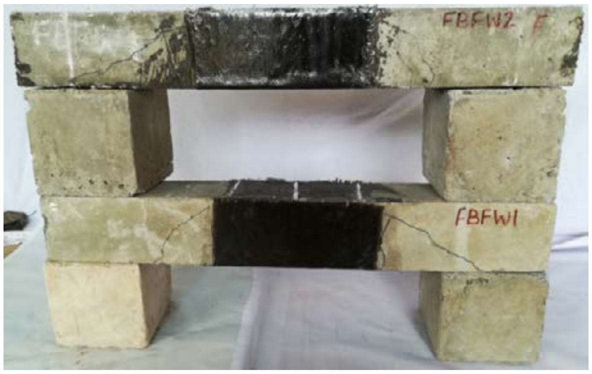


Fig.7 Failure pattern of flexural zone retrofitted beams

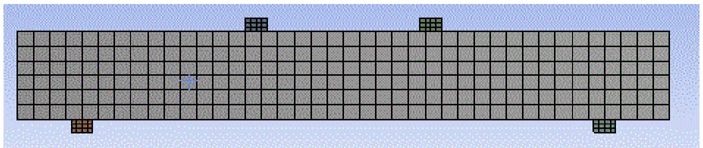
Fig.8 Failure pattern of flexural zone retrofitted beams

6. VALIDATION OF THE EXPERIMENTAL RESULTS USING ANSYS

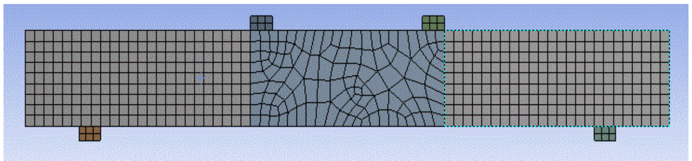
Experimental results were validated using numerical analysis tool ANSYS 2016. For validating experimental results, geometry of the beams was exactly similar to the experimental conditions. Properties of the material obtained by material testing were input in ANSYS. In experimentation, beams were preloaded prior to retrofitting. During preloading, stiffness of the beam reduces. To account this reduction in stiffness, elasticity of concrete corresponding to 70% of ultimate load of control beam were found from load deflection curve of control beams. For retrofitted beams, this elasticity is input as the elasticity of concrete. Table 5 shows the material properties. Results were validated by comparing load deflection behavior, ultimate load, deflection, energy absorption and failure modes.

6.1 Numerical Modeling

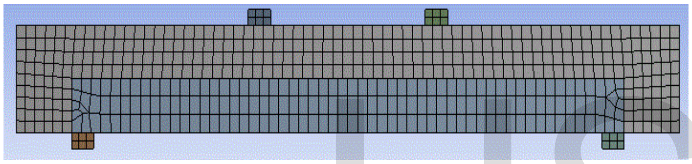
The concrete was modeled with a 3-D reinforced concrete 8-noded SOLID65 element which is capable of cracking in tension and crushing in compression having three degrees of freedom at each node (translation in x, y, z directions). Beam 188 is a linear beam element and is used for steel reinforcement. The FRP sheet was modelled with 4-noded SHELL181 (membrane only option) element with six degrees 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. Fig.9 shows the meshed model control beam, flexural zone wrapped beam and tension zone wrapped beam respectively.



(a) Control beams



(b) Flexural zone wrapped beam



(c) Tension zone wrapped beams

Fig.9 Meshed models

Table5 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		21.89	0.15
Concrete (pre-loaded beams)	-	30	3.71		0.673	0.15
Steel	8Φ	-	-	390	200	0.3
BFRP	0.34	-	3000		108	0.3

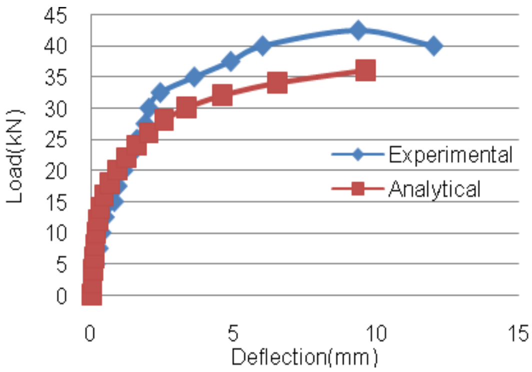
6.2 Non - Linear Solution and Failure Criteria

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.

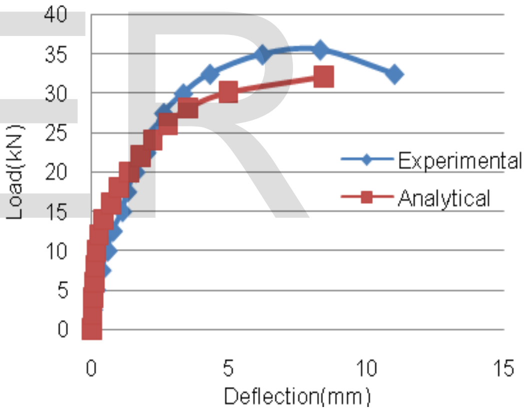
6.3 Load Deflection Behaviour

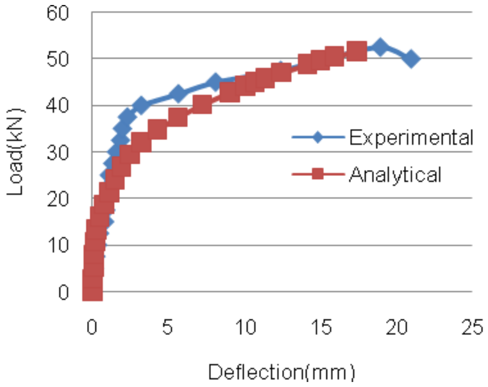
Load deflection curve for beams in each scheme were drawn. For comparing with analytical result beam with maximum ultimate load was chosen from the experimental part. Fig.10 shows the load deflection behaviour of experimental and analytical beams. From the graph it is very clear that behaviour was very similar to the experimental results.

(a) Control beam



(b)Flexural zone wrapped beam





(c) Tension zone wrapped beam

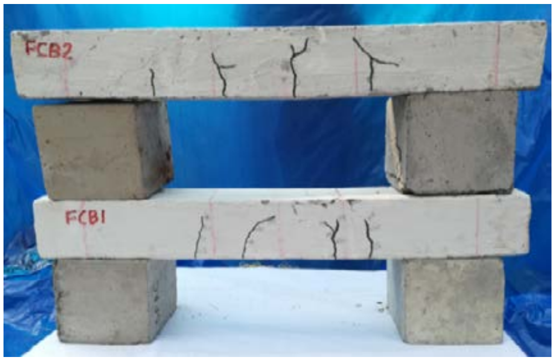
Fig.10 Comparison of load deflection behaviour

6.4 Ultimate Load, Deflection and Energy Absorption

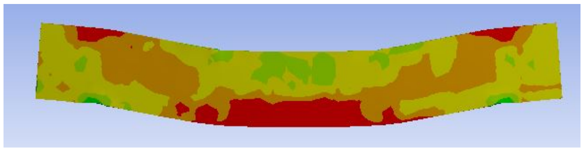
Ultimate load, deflection and energy absorption of each beams and their percentage difference from the experimental value is tabulated in Table6. It is seen that in all the cases the percentage difference from the experimental results is less than 10%. Hence it is acceptable.

6.5 FAILURE MODE AND CRACK PATTERN

Failure mode of beams after experimental testing and software analysis were compared. Fig.11 shows the failure mode of control beams. The crack pattern of experimentally tested beam was compared with the strained region obtained after software analysis. For experimentally tested beams, it was failed by flexural shear crack in the flexural zone. Similar trend was seen in analytical part. The red colour shows the maximum strained area. It is seen that maximum strained area is the flexural zone and it starts from bottom and moving upward. For beams retrofitted in flexural zone the experimental result showed that failure is by diagonal shear crack. Analytical result showed a similar trend. Fig.12 shows failure mode of experimental models and analytical model. In the case of analytical model, there was maximum strain in the flexural zone and in the shear zone. But crack in flexural zone is bridged BFP wrapping. In the shear zone, diagonal crack may form there. For beams wrapped in the tension zone, experimentally there were no visible cracks and analytically there were no maximum strained region outside BFRP wrapping. Maximum strain is near the bottom side. BFRP wrapping confines the body and arrest the propagation of cracks. Fig.13 shows the failure mode of tension zone wrapped beam.



(a) Beams after experimental testing



(b) Beam after software analysis
Fig.11 Failure mode of control beams

Table 6 Comparison of ultimate load, deflection and energy absorption

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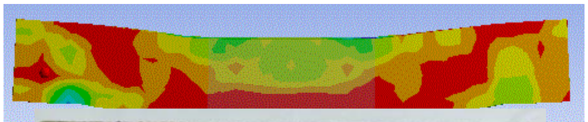
Designation	Ultimate load (kN)			Deflection at ultimate load (mm)			Energy absorption (kN-mm)		
	Experimental	Analytical	% difference	Experimental	Analytical	% difference	Experimental	Analytical	% difference
FCB	34.8	32.2	7.4	8.1	8.4	3.6	222.09	224.09	0.90
FBFW	40	36.130	9.6	9.1	9.6	4.9	288.10	288.04	0.02
FBTW	52.5	51.7	1.5	18.7	17.4	6.7	810.98	798.33	1.55

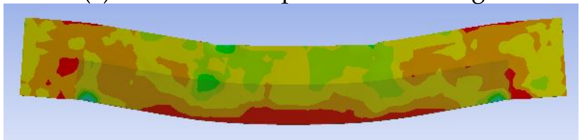
(a) Beams after experimental testing



(b) Beam after software analysis
Fig.12 Failure mode of flexure zone wrapped

(a) Beams after experimental testing

(b)



Beam after software analysis
Fig.13 Failure mode of tension zone wrapped beams

In all the cases the experimental results and analytical results were very close to each other .the maximum percentage difference in the result were 9.6% which less than 10%. Hence experimental results were validated

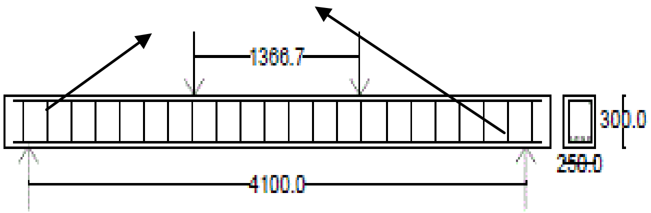
7 PARAMETRIC STUDY

Parametric study was done on full scaled beams. The considered parameters were number of layers of BFRP wrapping and material of wrapping.

7.1 Geometry and Material Data

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 200mm centre to centre spacing. Geometry of the RCC beam and loading scheme is shown in Fig.14. Table 7 shows the material properties input in ANSYS. Meshed models of the control and retrofitted beams were shown in Fig.15.

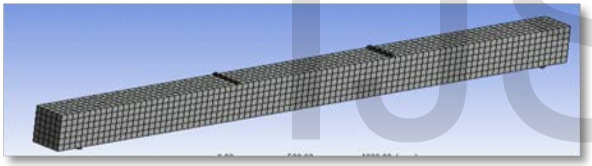
2 Nos, 10 mm Φ bars



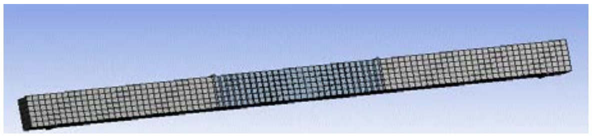
4 Nos, 16 mm Φ bars

10 mm Φ stirrup @ 200mm c-c spacing

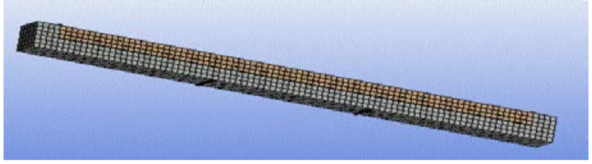
Fig.14 Geometry of full scaled RCC beam



(a) Control beam



(b) Flexural zone wrapped beam



(c) Tension zone wrapped beam

Fig.15 Meshed model of full scaled beam

Table 7 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		21.89	0.15
Concrete(retrofitted beams)	-	30	3.71		0.5	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

7.2 Number of Layers of Wrapping

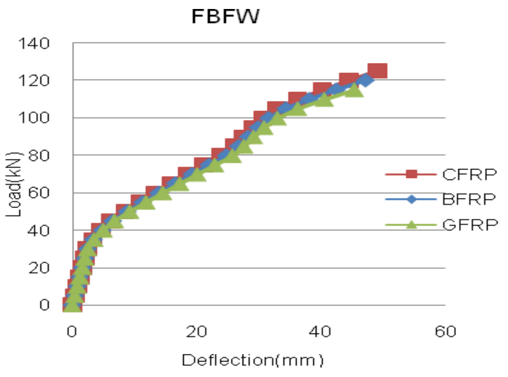
Analysis has been done with one layer and two layers of BFRP. The results after analysis have been tabulated in Table8. From table it is clear that as the number of layers of wrapping increases the performance of the retrofitted beam increases.

Table 8 Ultimate load and deflection

Beam designation	No of layers of BFRP wrapping	Ultimate load (kN)	Percentage increase (%)	Ultimate deflection (mm)	Percentage increase (%)
FCB	-	101.33	-	38.40	-
FBFW	1	120.26	18.68	47.13	22.73
	2	130.39	28.67	51.65	34.50
FBTW	1	140.34	38.49	69.59	81.22
	2	153.42	51.40	80.64	110

7.3 Materials of Wrapping

The materials considered were CFRP, GFRP and BFRP. Graph has been plotted for FBFW and FBTW separately for different materials. Fig.16 shows the load deflection graph. From both the graph it is seen than performance of beam retrofitted with BFRP is comparable that with GFRP and CFRP. Table 9 gives the percentage increase in ultimate load and deflection due to retrofitting with this three FRP with respect to control beam. The performance of BFRP is comparable to that of CFRP and GFRP. It can be used as an alternative to CFRP and GFRP.



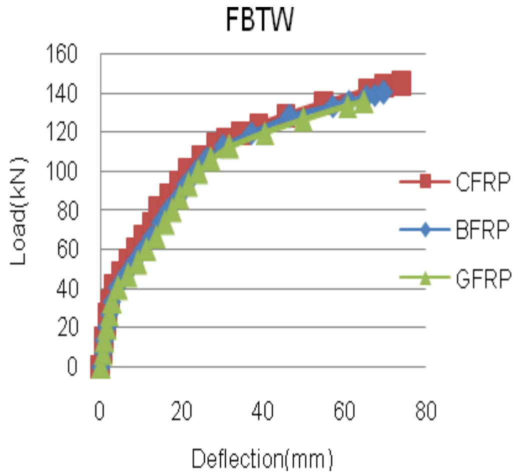


Fig.16 Load deflection behaviour

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Table 9 Ultimate load and deflection for different materials of wrapping.

Beam designation	Material of wrapping	Ultimate load (kN)	Percentage increase (%)	Ultimate deflection (mm)	Percentage increase (%)
FCB	-	101.33	-	38.40	-
FBFW	BFRP	120.26	18.68	47.13	22.73
	CFRP	125.34	23.69	49.08	27.81
	GFRP	115.20	13.68	45.42	18.28
FBTW	BFRP	140.34	38.49	69.59	81.22
	CFRP	144.10	42.20	74.15	93.09
	GFRP	135.56	33.78	64.87	68.93

8. CONCLUSIONS

This paper projects the flexural 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 flexural zone wrapping showed a percentage increase of 14.94% and that with tension zone wrapping is 50.56%. Tension zone wrapped beams out performed flexural zone wrapped beams.
- There was an increase of 14.3% for flexural zone wrapped beams and 57.14% for tension zone wrapped beams in first crack load.
- Energy absorption of flexure zone wrapped beam was 29.7% and tension zone wrapped beam was 265.15% more than the reference beam.
- Tension zone wraps 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 flexure zone retrofitted beams is by diagonal shear cracks. That is mode of failure had changed from ductile to brittle.
- The test results show that tension zone wrapping tends to give the maximum efficiency when compared to flexure zone wrapped beams. In all the cases tension zone wrapped beams out performed flexural zone wrapped beams.
- The Experimental results and analytical results show a maximum percentage difference of 9.6 % which is less than permissible hence results are validated.
- For full scaled beams tension zone wrapped beam show better performance than flexural wrapped beams
- As the number of layers of wrapping increased ultimate load and ultimate deformation increased.
- The performance of beam retrofitted with BFRP showed a similar behaviour of that retrofitted with CFRP and GFRP. Hence BFRP, which is eco friendly can be used as an alternative of CFRP and GFRP for retrofitting

REFERENCES

[1]. Tara sen and H.N. Jagannatha Reddy, "A Numerical Study of Strengthening of RCC beams using Natural Jute Fiber and its comparative study with CFRP and GFRP strengthening system" *International journal of sustainable build environment,*vol.3,pp.12-22,2014.

[2]. Tara sen and H.N. Jagannatha Reddy, "Confining concrete with sisal and jute FRP as alternatives for CFRP and GFRP" *International journal of sustainable build environment,* vol.4, pp.248–264, 2015.

[3]. Tara sen and H.N. Jagannatha Reddy, "Application of sisal, bamboo, coir and jute natural composites in structural up gradation", *International journal of Innovation, Management andTechnology,*vol4, pp.43-55, 2012.

[4]. J.Poornima and M.Sivaraj "Performance Enhancement of Concrete Structures using Natural Fibre Composites" *European Journal of Scientific Research,* vol.3, pp.22-30, 2012.

[5]. Battula Sudheer Kumar and Rajalapati, "Tensile Properties of Long Jute Fiber Reinforced Polypropylene Composites" ,*International Journal of Engineering Inventions,*vol.3, pp.45-56, 2012.

[6]. Rohit Vasudeva And Mandeep Kaur , "Retrofitting of RC beams using glass fiber reinforced polymer sheets" *Indian journal of science and technology* , vol.9,pp.12-22,2016.

[7]. Poorna Prasad Rao.O.L, Rama Mohan Rao .P, "Retrofitting of RC beams using rubberised coir fiber sheets " *International journal of civil engineering,*vol.3.,pp.20-28,2016 .

[8]. Sandeep Kumar L.S , Dr.H.N. Jagannatha Reddy ,Rumina Nizar , "Retrofitting of RC beams using natural FRP", *International journal of emerging trends in engineering and developments,*vol.3,pp.168-178,2013.

[9]. K.R. Yoganathan , Dr.N. Mahendran, "Retrofitting of geopolymer beam using carbon fiber mat", *International journal of innovative research in science ,engineering and technology,* vol.3, pp.1251-1257,2014.

[10]. J.Gopi Krishna ,S.Reddemma , "Retrofitting of RC beams with externally bonded CFRP" *International journal of innovative research in science ,engineering and technology,* vol.7, pp.6-17,2015.

[11]. Dr . Ragheed Fatehi Makki , " Response RC beams retrofitted by ferrocement" *,International journal of scientific technology ,* vol.9, pp.27-33,2014 .

[12]. A.Arwin Amiruddin , Parung Herman And Riswal.K (2017), "Shear capacity of RC beam retrofitted with wire mesh and SCC", *APRN journal of engineering and applied science,*vol.7 pp.,2012-2076,2017.

[13]. R. Santhakumar , R.Dhanaraj ,E. Chandrasekaran , "Behaviour of retrofitted RC beams under combined bending and torsion ", *Electronic journal of structural engineering*, vol .7, pp.1-6, 2007.

[14]. Abhishek Sharma ,Tara Sen , Joyanta Pal , "Effect of shear span-depth ratio on mechanical performance of RC beams strengthened in shear with u-wrapping FRP strips" , *journal of mechanical and civil engineering* , pp.2278-1684,2016.

[15]. IS 456-2000, *code of practice for plain and reinforced concrete* , New Delhi :Indian Standards Institutions.

[16]. IS 10262-2009, *Guidelines for concrete mix design proportioning,* Bureau of Indian standards.