



BEAM STRENGTHENING USING CARBON FIBER SHEET (WRAPPING)

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Abstract : In day-to-day life, it is important to modify, repair, rehabilitate, or reconstruct existing structures because of various factors like bond failure between beam and column joint, corrosion which leads to deterioration, natural disasters, etc. These factors result in the cracking of our structures, i.e. the structures become inservicable. Hence the modification of these structures is required. This paper shows an experimental study on RC beams retrofitted using unidirectional and bi-directional CFRP sheets. The main objective of this study is to investigate the behavior of RC beams after retrofitting with CFRP sheets.

IndexTerms - Retrofitting, Flexural strength, Crack Pattern, Deflection, RC Beams etc.

I. INTRODUCTION

Retrofitting is the technique of repair and rehabilitation to make structures more resistant to seismic activity, shaking of the earth's surface, etc. Replacement of the full structure leads to various disadvantages like labor charges, cost of the building material, etc. It also leads to inconvenience because of improper function of a structure e.g. traffic jams. This work is about the effect of CFRP sheets having different thicknesses over the RC beams by using experiments.

Corrosion of the reinforcement and deterioration of the structures in RC structures are common problems and many researchers have found alternative materials and techniques of rehabilitation and many solutions have been put forward since a long time and there remains always a demand for looking to use new materials and techniques for repair and rehabilitation of the structures. Retrofitting with the CFRP sheets as external reinforcement plays a great role in a civil engineering.

1.1 Retrofitting, Repair and Rehabilitation

Retrofitting is the technique of repair and rehabilitation to make structures more resistant to seismic activity, shaking of the earth's surface, etc. Replacement of the full structure leads to various disadvantages like labor charges, cost of the building material, etc. It also leads to inconvenience because of the improper function of a structure.

This work is about the effect of CFRP sheets having different thicknesses over the RC beams by using experiments. Corrosion of the reinforcement and deterioration of the structures in RC structures are common problems and many researchers have found alternative materials and techniques of rehabilitation many solutions have been put forward for a long time and there remains always a demand for looking to use new materials and techniques for repair and rehabilitation of the structures. Retrofitting with the CFRP sheets as external reinforcement plays a great role in civil engineering.

1.2 The Scope of Carbon Fibre Strengthening

It is suitable for the strengthening and repair of various structure types and various structural parts, such as beams, slabs, columns, roof trusses, piers, bridges, cylinders, shells, and other structures. The strength grade of the base concrete is not lower than C15, and the carbon fiber cloth strengthening technology has been successfully applied to various beam and slab strengthening and maintenance in China.

In 2014, after Haimen Daxin Bridge tried to use glued steel plates to strengthen the bridge in Haimen. In the Haimen Linjiang Gate Bridge repair, the first attempt to use the method of pasting and wrapping carbon fiber cloth to strengthen the bridge is the first time in the Haimen repair and strengthening bridge construction process.

Carbon fiber strengthening can quickly reinforce the bridge, prevent external moisture from entering the concrete cracks and cause corrosion to the steel bars, ensure the durability of the components, help improve the load-bearing capacity of the bridge, and will not affect the normal operation of the bridge during the strengthening.

1.3 Carbon Fibre Strengthening Features

Carbon fiber strengthening is the use of carbon fiber cloth and structural glue to reinforce the components. The strengthening damage morphology is bonded with carbon fiber sheets as follows:

- The tensile steel bar yields, and then the concrete is crushed under pressure, and the carbon fiber sheet has not yet reached the allowable tensile stress change requirement.
- The stress of the steel bar reaches yield, the carbon fiber has exceeded the allowable tensile strain and has not exceeded the required strain value of the construction project.
- The tensile reaches the ultimate tensile stress, and the concrete in the compression zone is not crushed.
- The strengthening of carbon fiber cloth is too large, the steel bar yields and the concrete in the compression zone is crushed.

1.4 Safety and Precaution of Carbon Fiber Strengthening

Carbon fiber sheets are conductive materials. When using carbon fiber sheets, keep them away from electrical equipment and power sources.

- The bending of the carbon fiber sheet should be avoided during use.
- The raw materials of carbon fiber sheet supporting resin should be sealed and stored away from fire sources and avoid direct sunlight.
- The preparation and use place of resin should be well-ventilated.
- On-site construction personnel should take corresponding labor protection measures based on the use of resin materials.

II. MATERIALS USED

A material is a substance or mixture of substances that constitutes an object. Materials can be pure or impure, living or non-living matter.

2.1. Cement

An OPC of Grade 43 satisfying all the requirements of IS 8112:1989 is utilized in this context. It was tested for its physical properties as per Indian Standard specifications.

S.NO	Characteristics	Value obtained	As per IS: 8112
1	Specific gravity	3.15	2.5-3.5
2	Standard Consistency (%)	32	30
3	Fineness (kg/m ²)	245	275
4	soundness(mm)	3	10
5	Initial setting time (min.)	50	30
6	Final setting Time (min.)	260	600
7	Compressive strength 7days (N/mm2)	26	23 (Min)
	14 days(N/mm2)	35	33 (Min)
	28 days(N/mm2)	46	43 (Min)

Table 1 Characteristics of cement

2.2. Sand

The sand used in this study was locally available with a fineness modulus of 2.19 and specific gravity of 2.69 has been used.

2.3. Coarse Aggregate

Maximum size of Aggregates of 20mm having a specific gravity of 2.74 were used and the grading zone of aggregates was Zone II as per IS specifications.

2.4. Water

Clean tape water that was free from suspended particles and chemical substance admixture was also used during mixing.

2.5 Mix Design

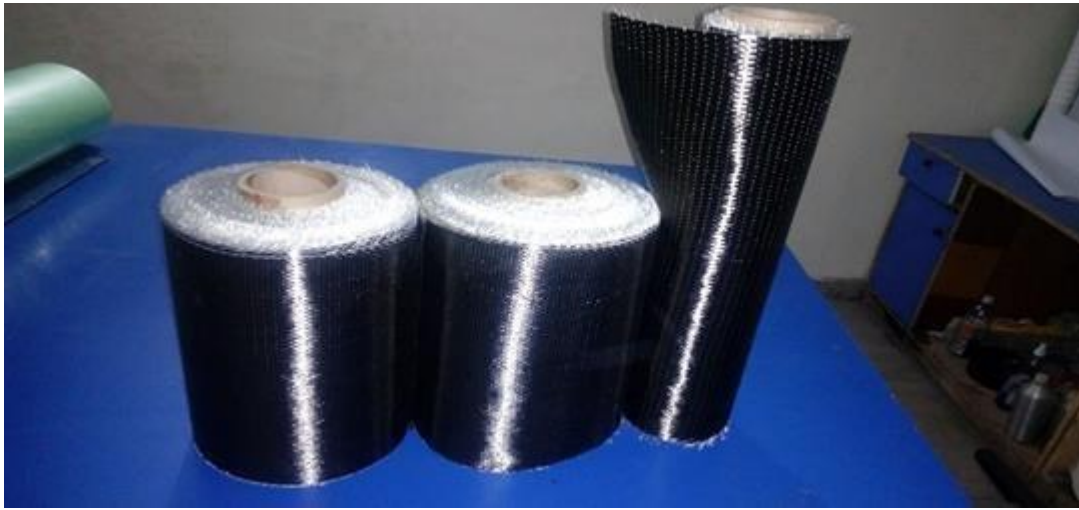
Design concrete mix M30 of 1:1.77:2.89 by weight is used. In this context, the water-amentaceous ratio of 0.45 was used. Before the casting of RC beams, only three cubes were cast and were tested for compressive strength (at the age of 28 days). The average compressive strength of the three concrete cubes was 26.81 N/mm2. HYBD bars of 12 mm dia diameter in the tension zone and 10mm diameter in the compression zone were used and 8mm diameters were used as shear reinforcement.

2.6 Carbon Fibre Sheets

CFRP has high strength, durability and one more thing it is easy to install. It is commonly used whenever high strength and rigidity are needed. Both Unidirectional and bidirectional carbon fiber sheets with different thicknesses were used as retrofitting material for the beams.

Fiber material	High strength carbon
Areal Weight	245 gm/m2

Fabric width	500 mm
Ultimate Tensile Strength	3800 Mpa
Tensile Modulus	>2750Mpa

Table 2 Properties of CFRP sheet.**Figure 1** Uni-directional and bi-directional Carbon fibre sheets.

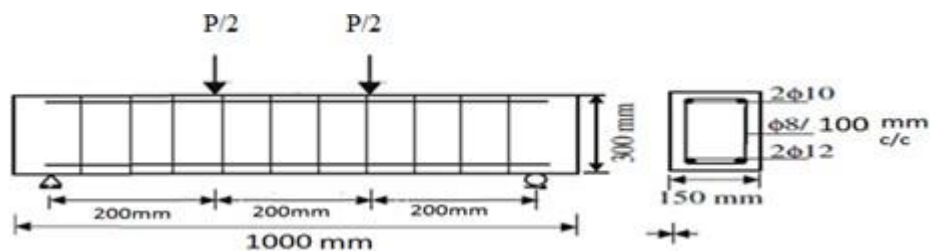
2.7 Epoxy

Epoxy resin with hardener was used as a bond purpose between the concrete surface and carbon fiber sheet. The epoxy resin primer is mixed as per the guidance of the manufacturer's instructions. The mixing is carried out in a plastic container having a base hardener ratio (Base: Hardener =3.33Kg: 1Kg) i.e., hardener 30% of epoxy resin. After the uniform mixing, epoxy resin is applied to the concrete surface of RC Beams.

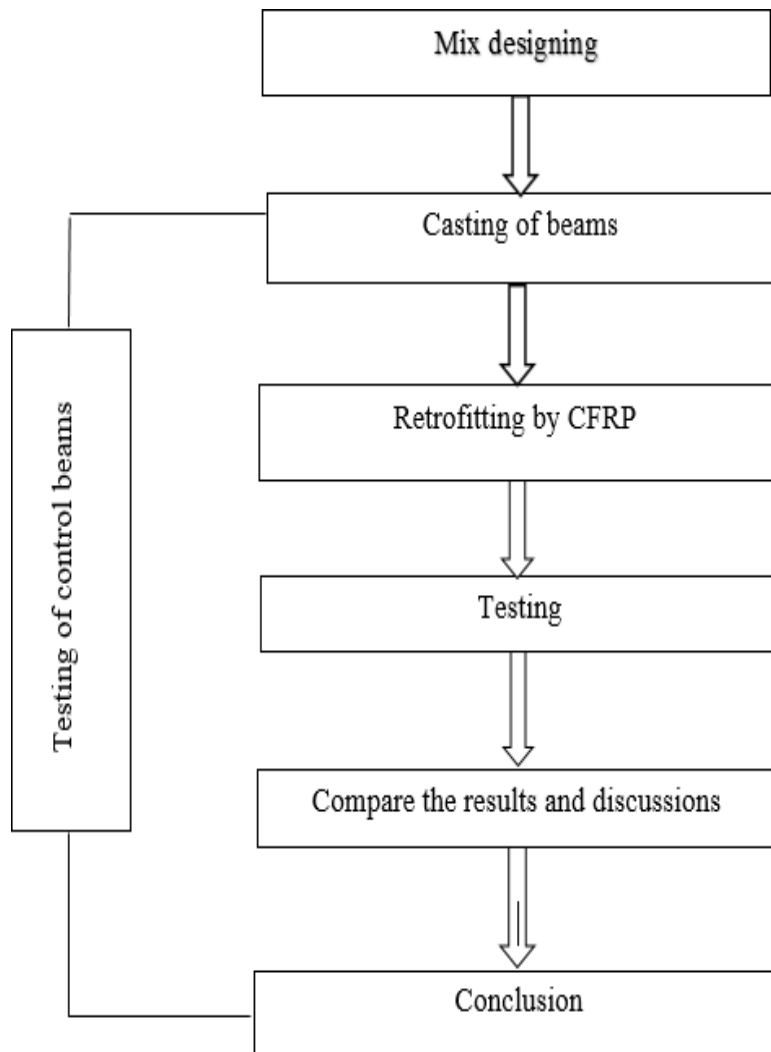
2.8 Detail Reinforcement of Beam

The molds were prepared using plywood. The dimensions of all the specimens were identical. The length of beams was 1000mm and the cross-sectional dimensions were 150 mm x 150 mm. The design mix ratio was adopted for designing the beam.

Twelve beams were cast in three of them as control beams and other beams were retrofitted. The first beams were tested in four points loading for failure. The rest of the beams were tested in four-point loading until cracks appeared on them and these cracked beams were unloaded and retrofitted the cracked beams with unidirectional and bi-directional CFRP sheets having different thicknesses.

**Figure 2** Geometry, Detail of reinforcement and loads of the beams.

III. METHODOLOGY



Design concrete mix M30 of 1:1.77:2.89 by weight is used. In this context, the water-cementitious ratio of 0.45 was used. Before the casting of RC beams, only three cubes were cast and were tested for compressive strength (at the age of 28 days). The average compressive strength of the three concrete cubes was 26.81 N/mm². HYBD bars of 12 mm dia diameter in the tension zone and 10mm diameter in compression zone were used and 8mm diameters were used as shear reinforcement.

4. CASTING OF RC-BEAMS

Twelve beams were cast. The dimensions of all the specimens were identical and were identical in shape i.e. 'rectangular having dimensions 1000mm in length and 300mm x 150mm in cross-section. The rectangular moulds were prepared using boiling water-proof plywood as shown in figure 3. For designing the beams, the design mix ratio was used. Fig.2 shows a rectangular reinforcement cage that consists 12 mm diameter of two bars as tension reinforcement at the soffit of the beam and 10 mm diameter of two bars as compression reinforcement and an 8mm diameter for rings as shear reinforcement with a c/c spacing of 100mm.



Fig 3 Reinforcement cage



Fig 4 Plywood Mould

Twelve beams were cast three of them as control beams and rest nine beams were retrofitted. The first three beams were tested in four points loading for failure. The rest nine beams were tested in four-point loading until cracks appeared on them and these cracked beams were unloaded and retrofitted the cracked beams with unidirectional and bi-directional CFRP sheets having different thicknesses.



Fig 5 Casting of Beams

V. RETROFITTING OF BEAMS

All four sides of the beams were wrapped with CFRP sheets and used full wrapping technique as the method of retrofitting. Before applying the epoxy primer, the surface of the beams was made rough to get a better bond between the concrete surface and the CFRP sheet. A wire brush was used for roughing the surface of the RC- beam and then the surface was cleaned with clean water to remove the dirt. The mixing is carried out in a plastic container having a base hardener ratio (Base: Hardener =3.33Kg: 1Kg) i.e., hardener 30% of epoxy resin.

The epoxy resin primer is mixed in a plastic container as shown in Fig. 6 as per the guidance of the manufacturer's instructions. After the uniform mixing, epoxy resin was applied to the concrete surface of RC Beams. After that, CFRP sheets were applied on the top coating of the epoxy resin and the sheet on the beam was pressed to eliminate entrapped air bubbles. This retrofitting of beams is done at room temperature. Before testing the Retrofitted beams, they were cured for 2 days at room temperature.



Mixing Epoxy Resin



Application of Resin



Carbon Fibre Wrapping

Fig 6 Retrofitting of Beams

VI. TESTING OF BEAMS

Both control and retrofitted beams were tested for flexural strength. Twelve beams were cast. For all the beams, the test procedure was the same. The beams were cured for 28 days. In twelve beams three beams were tested for failure and nine beams were retrofitted with CFRP sheets six beams were retrofitted with uni-directional CFRP sheets having thicknesses of 0.2mm and 0.3mm and three beams were retrofitted with bi-directional CFRP sheets having thicknesses 0.4mm. For clear visibility of cracks on the surfaces of the beams, the surface of the beams is cleaned with cotton. The arrangement of Four-point Loading is used for testing beams because, in arrangement, the maximum flexural stress is spread over the section of the beam between loading points and four-point loading tends to be the best choice if the material is not homogenous.

Four four-point loading arrangements were done as shown in Fig. 6 which consists of a beam supported on the two steel rollers bearing 200mm from the ends of the beams. The remaining portion of 600 mm was divided into three equal parts of 200 mm as shown in the fig 7. Till the appearance of the first crack recorded on automatic UTM, the deflections of the beams were noted. Then the fracture load was recorded as the load at which load on the automatic UTM returned. The average load of the three control specimens and average of nine retrofitted beams were taken and the load-deflection graph was obtained. The deflection curve of each beam in four points of loading is analyzed.



Fig 7 Experimental test setup

The deflections of each type of beams retrofitted with uni-directional and bi-directional CFRP sheets were compared with the control RC beams. Also, the behavior of load-deflection was compared between beams retrofitted with unidirectional and bi-directional CFRP sheets having different thicknesses and the same reinforcement. It has been found that the behavior of the beams retrofitted with CFRP sheets is better than the control beams. The deflection lowers when retrofitted externally with CFRP sheets. It has also been found that beams retrofitted with bi-directional CFRP sheets show less deflection and high load-bearing capacity than the beams retrofitted with uni-directional CFRP sheets. Also load bearing capacity increases with the thickness of CFRP sheets. The use of CFRP sheets shows less growth of crack formation. Since the full wrapping technique was used for strengthening of the beams, initially the cracks were not visible. As the increase in loading increases the propagation of the cracks due to the wrapping of CFRP sheets around the beams (uni-directional and bi-directional) leads to crack formation. The result shows that the application of the CFRP sheets around the beams is beneficial not only in flexure but shear in strengthening also. Fig. 7 shows the failure pattern.



Control Beam

Retrofitted Beam

Fig 8 Failure pattern of the beams

It has been found that fewer cracks appeared on the beams retrofitted with bi-directional CFRP having a thickness of 0.4 mm as compared with the beams retrofitted with that of the unidirectional CFRP sheets having a thickness of 0.2mm and 0.3mm. The control beams show the maximum deflections and less ultimate load-carrying capacity. It is clear from the graph that all the beams retrofitted with CFRP sheets have better load deflection characteristics than the control beams.

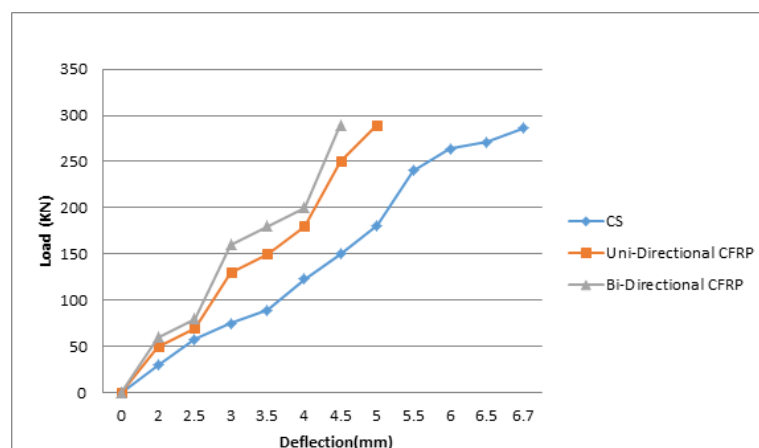


Fig 9 Load vs Deflection Graph

When all the beams retrofitted with CFRP sheets are considered it is found that the beams with 0.4mm CFRP sheet wrapping had a better load-deflection behavior compared to the other retrofitted beams. It is found that retrofitting with CFRP sheets is more effective in improving the flexural strength of the beam. The first crack appeared at the load of 252 KN on the beam. Also

to some extent, retrofitting of beams by using CFRP sheets (uni-directional and bi-directional) reduced the deflections of the beams.

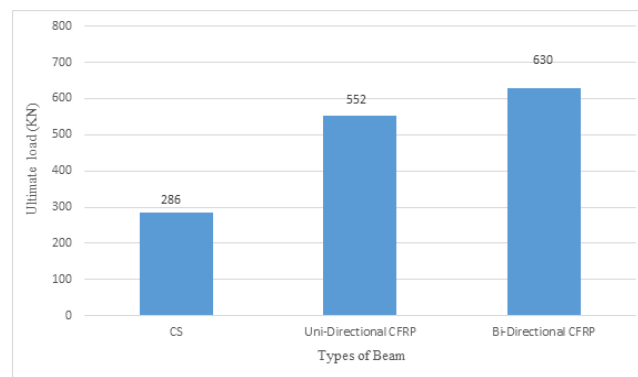


Fig 10 Comparison of Ultimate Load Capacity

VII. CONCLUSION

The flexural behavior of reinforced concrete beams externally strengthened by CFRP sheets (uni-directional and bi-directional) having different thicknesses are studied in this experimental investigation. From the calculated strength values and the test results, the following conclusions are drawn:

- Due to the strengthening of beams with CFRP sheets externally, The ultimate load-bearing capacity and the flexural strength of the beams increased.
- The first Average crack load of control beams and retrofitted beams was found at 252 kN and above 500 kN respectively. The initial cracks in the retrofitted beams appeared at a higher load as compared to control beams.
- Due to the full wrapping technique around all four sides of the RCC beams, the deflections of the beams were also reduced.
- When comparing the control RCC beams with the beams retrofitted with unidirectional and bi-directional CFRP sheet CFRP sheets, there increased ultimate load capacity by 93% and 120% respectively.
- Of course, the cost of the material is high but the beams retrofitted with CFRP sheets show the maximum ultimate load capacity.
- Debonding between CFRP sheet and concrete occurs at high loads, there occurs at 530 kN in the case of uni-directional CFRP sheets whereas at 597 kN in bi-directional CFRP sheet, CFRP sheets shows composite action.
- Cracks due to the loads were minimized by the application of the CFRP sheets externally on the beams that indicates serviceability of the cracked beams increased.
- It is found that the wrapping of CFRP sheets around all four sides of beams is more effective in improving the ultimate load capacity of beams and their flexural strength.

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