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Flexure and Shear Strengthening of RCC Beam with Carbon Fiber Reinforced Polymer

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ABSTRACT: Reinforced Concrete is the most widely used construction material all around the World. When the existing structures fail to satisfy the new demand, it is preferable to adopt strengthening techniques. CarbonFibre Reinforced Polymer (CFRP) can be used as one of the materials used for strengthening of RCC Structural members. The strengthening techniques not only results in the increase of load carrying capacity but also ductility of the structural members.

The flexural behaviour of RCC beams strengthened using uni-directional and bi-directional CFRP sheet were experimentally investigated. Two-point loading was adopted for testing. In the experimental investigation twelve under-reinforced concrete beams were tested. Out of twelve beams, four beams were control beams and remaining eight beams were strengthened with uni-directional and bi-directional CFRP sheets with different configurations. The various parameters studied in this experimental investigation are the ultimate load capacity, load-deflection characteristics and energy absorbing capacity. Comparison is also made between controlled and beams strengthened using CFRP.

KEYWORDS: Retrofitting, Uni-directional, Bi-directional CFRP, Two-point loading

I. INTRODUCTION

Generally structures are designed for a specific function. Sometimes due to up gradation of codal provisions, the existing structures fail to satisfy the new codal requirements. Destroying the existing structure and construction of a new one is not economical and feasible solution. So, it is often better to strength or upgrade the structure. Several conventional materials and construction techniques are in practice to strengthen the various concrete structural components. Strengthening or retrofitting increases the load carrying capacity, increase ductility.

Fibre Reinforced Polymer (FRP) sheets are gaining wide acceptance in the construction industry as externally bonded strengthening material. Carbon Fibre Reinforced Polymer (CFRP) has been increasingly used in retrofitting RCC structural members. The use of CFRP provides a cost-effective solution in strengthening structural elements. The CFRP strengthened members gains double the strength, with a moderate increase in stiffness.

Several experimental investigations on retrofitting of RCC beams and columns with CFRP composites reveal the enhancement of strength, confinement and ductility of these members.

II. RESEARCH SIGNIFICANCE

The dynamic changes that occur in our daily lives change the loading type or impose more loads on existing structures. Structures need upgrading due to overload. To keep these deficient structures in service, they are to be upgraded, replaced or their use is restricted. These solutions are usually costly and ineffective. Hence strengthening is usually needed for various reasons to keep the structures at a certain performance level.

During the last decade, strengthening concrete structures with advanced FRP composite materials has gained wide acceptance. FRP sheets are bonded to the surface of deteriorated or deficient structural members to increase their load carrying capacity and ductility. CFRP and GFRP are two common composites with high tensile strength and relatively high stiffness, which are used as additional reinforcement to strengthen RC members

In the present research, the overall behaviour of RC structural members strengthened with CFRP composites was investigated. An experiment investigation was carried to study the behaviour of RCC beams strengthened with different arrangements of CFRP sheets and made comparison on the effect of uni-directional and bi-directional CFRP sheets.



ADVANTAGES OF CFRP

Some of the main advantages of CFRP can be listed below:

Light weight: The FRP is much less dense and therefore lighter than the equivalent volume of steel. The lower weight of FRP makes installation and handling significantly easier than steel. These properties are particularly important when installation is done in cramped locations. The use of fibre composites does not significantly increase the weight of the structure or the dimensions of the member. And because of their light weight, the transport of CFRP materials has minimal environmental impact.

Mechanical strength: CFRP can provide a maximum material stiffness to density ratio of 3.5 to 5 times that of aluminium or steel. CFRP is so strong and stiff for its weight, it can outperform the other materials.

Formability: The material can take up irregularities in the shape of the concrete surface. It can be moulded to almost any desired shape.

Chemical resistance: CFRP is minimally reactive, making it ideal as a protective covering for surfaces where chemical

Corrosion resistance: Unlike metal, CFRP does not rust away and it can be used to make long-lasting structures.

Low maintenance: Once CFRP is installed, it requires minimal maintenance. The materials fibres and resins are durable if correctly specified and require little maintenance. If they are damaged in service, it is relatively simple to repair them, by adding an additional layer.

Long life: It has high resistance to fatigue and has shown excellent durability over the last 50 years.

Easy to apply: The application of CFRP sheet material is like applying wallpaper; once it has been rolled on carefully to remove entrapped air and excess adhesive it may be left unsupported. Fibre composite materials are available in very long lengths while steel plates are general available of limited length.

These various factors in combination lead to a significantly simpler and quicker strengthening process than using steel plate.

III. MATERIALS

Cement

The cement used throughout the experimental investigation was Ordinary Portland Cement (OPC) of grade 53 conforming to IS 8112: 1989 specifications. The properties of cement are shown in Table [1].

Table 1: Properties of Cement

S.No.	Property	Results
1.	Fineness	7%
2.	Specific gravity	3.13
3.	Normal consistency	28%
4.	Setting time i)Initial setting time ii)Final setting time	80min 300min

Sand

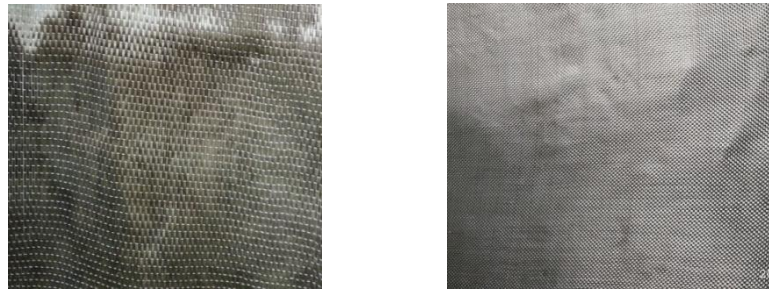
Locally available Swarnamukhi river sand passing through 4.75mm size conforming to IS 383:2016 zone-II grade was used. The specific gravity and fineness modulus values are found to be 2.55 and 3.5 respectively.

Coarse Aggregate

Graded Coarse aggregates of size 20mm was used in the experiment. Specific gravity and fineness modulus of coarse aggregate was 2.55 and 3.5 respectively.

CFRP sheets

CFRP sheets were used for strengthening the RC beams. They were attached to the sides of the concrete beam using epoxy adhesive. Both uni-directional and bi-directional CFRP sheets, as shown in Fig. [1]. were used in different configurations as strengthening material for the beams.



(a) Uni-directional CFRP sheet (b) Bi-directional CFRP sheet

Fig. 1. CFRP Sheets

CFRP

The CFRP used in this project was MBrace Carbon Fibre Wrap-230/50 CF S manufactured by BASF Company. Both Unidirectional and bidirectional carbon fibre sheets with different thickness were used as a retrofiting material for the beams.

CFRP is having high strength, durability and it is easy to install. It is commonly used whenever high strength and rigidity is needed. It can be used for flexural strengthening, shear strengthening and confinement. The properties of Carbon Fibres are shown in Table [2].

Table 2: Properties of Carbon Fibres

Fibre type	Carbon
Fibre weight/Unit Area	230 g/m ²
Fabric thickness	0.131mm
Tensile strength	4900 MPa
Tensile Elongation modulus	230 GPa
Elongation at break	2.1%
Fabric length/roll	100 m
Fabric width	500 mm

Epoxy

Epoxy resin with hardener was used as a bond purpose between concrete surface and carbon fibre sheet. In this project Master Inject 1315, produced by BASF, was used. It is a low viscosity epoxy resin. The epoxy resin primer is mixed as per the manufacturer’s instructions. The mixing was carried out with base: hardener ratio of 3.33: 1. After the uniform mixing, epoxy resin was applied to the concrete surface of RC Beams.

IV. CONCRETE MIX DESIGN

Design concrete mix of grade M25 with proportions of 1:2.14:3.63:0.5 by weight was used. The cement content of 330 kg/cu.m was used. The 28 day cube compressive strength of the concrete mix is 38.6 N/mm². HYSD bars of grade Fe415 were used. 12 mm diameter bars as longitudinal reinforcement and 8mm diameters bars as shear reinforcement were used.

V. RCC BEAM DESIGN

The RCC beams with under-reinforced section were designed based on the limit state method. The longitudinal reinforcement consists of 3-12 mm diameter bars as tension reinforcement, 2- 8 mm diameter bars as compression

reinforcement and 6 mm diameter for stirrups with c/c spacing of 100 mm as shown in Fig.[3].



Fig.3 Reinforcement Details of a Typical RCC Beam Test Specimen

Twelve beams were cast and the dimensions of all the beams are 150mm width, 230mm depth and overall length is 1200mm.

VI. CASTING OF BEAMS

The beams were cast in a mould of size 150 mm × 230 mm × 1200 mm. Initially the reinforcement skeleton was placed in position and the design concrete mix was poured in the mould. Needle vibrator was used for proper compaction and care was taken to avoid the movement of the reinforcement cage inside the form work. The vibration was done until the mould was completely filled with concrete. Then the surface of the concrete beam was leveled by metal trowel and wooden float as shown in Fig.4. The beams were then removed from the mould after 24 hours for 28 days normal curing.



Fig: 4 RCC Beams Test Specimen

VII. STRENGTHENING OF BEAMS




The surfaces of the beam were prepared by rubbing with sandpapers and then washed with water to remove any dust or oil. Then the primer was applied after the beams were dried completely. The epoxy resin primer was mixed as per the manufacturer's guidelines. The epoxy primer was applied within 30 minutes and it was allowed to dry for 6 hours. The MBrace primer was allowed to cure until tack free. The first coat of fully mixed saturant was applied to the well finished concrete surface using roller or brush. Immediately after the application of epoxy saturant, the fiber sheet was attached to the surface of the member by the application of uniform pressure across the entire width of the fiber sheet as shown in Fig. [5]. All the air bubbles or air pockets were squeezed out of the CFRP sheet to give uniform and smooth surface by using rollers. Care was taken to ensure that no entrapped air was left in the CFRP before the epoxy sets. The fibers were coated with another layer of epoxy saturant for aesthetic blending and protecting the layers from the environmental weathering. The specimen with CFRP composites was allowed to cure in atmosphere for about seven days.



Fig: 5. Application of Epoxy Resin on the Surface of the Beam

The beam strengthening methods adopted in the present experimental investigation for flexural and shear are shown in Table [3].

Table: 3 Details Test Specimens

Beam ID	Strengthening Configuration	Type of Strengthening	CFRP type	Strengthening Scheme
GROUP A (Control Beams) Beams 1 to 4		-	-	-
GROUP B				
Beam 5		Flexure Strengthening	Uni-directional Wrap	At bottom Surface.
Beam 6		Flexure Strengthening	Uni-directional Wrap	At bottom Surface.
Beam 7		Flexure Strengthening	Bi-directional Wrap	At bottom Surface.
Beam 8		Flexure Strengthening	Bi-directional Wrap	At bottom Surface.
GROUP C				
Beam 9		Shear Strengthening	Uni-directional Wrap	U-wrap (Three-sided Wrap)
Beam 10		Shear Strengthening	Uni-directional Wrap	U-wrap (Three-sided Wrap)
Beam 11		Shear Strengthening	Bi-directional Wrap	U-wrap (Three-sided Wrap)
Beam 12		Shear Strengthening	Bi-directional Wrap	U-wrap (Three-sided Wrap)

The flexural strengthening and shear strengthening of the test specimens using CFRP is shown in Fig.6 and Fig. [7], respectively.



Fig 6: Beams with Flexural Strengthening



Fig 7: Beams with Shear Strengthening

VIII. TESTING OF BEAMS

Both control and strengthened beams were tested under flexure. Twelve beams were cast. For all the beams, the test procedure was same. The beams were cured for 28 days. Out of the twelve beams, four control beams and remaining eight beams were strengthened with CFRP sheets. All the beams were tested up to failure. Total four beams were strengthened for flexure with two-beams were of uni-directional CFRP sheets and two more were of bi-directional CFRP sheets. Remaining four beams were strengthened for shear using CFRP strips. Two beams with uni-directional CFRP strips and two more with bi-directional CFRP strips.

The beams were tested under simply supported end conditions. Two-point loading was adopted for testing. The test setup is as shown in Fig. 8. The displacements were obtained by using LVDTs. Three LVDTs were used in the setup, i.e.,

one at the center and the other two under the loading points. The load was applied through a hydraulic jack. The load was applied in regular equal increments i.e., 2 kN. At every increment of load, the LVDT reading was recorded. All transducers were connected to the data acquisition system. Load at first crack was noted down. Also, subsequent crack patterns were marked on the beam surface as they develop during the application of load from first crack until the failure of the beam. Load-deflection curve was then drawn. This same test procedure was adopted for all the beams.



Fig 8: Experimental Test Setup

IX. RESULTS AND DISCUSSIONS

The deflections of the beams retrofitted with uni-directional and bi-directional CFRP sheets were compared with the control RCC beams. The load-deflection behaviour of beams retrofitted with unidirectional and bi-directional CFRP sheets was also compared. It can be observed that the behaviour of the beams retrofitted with CFRP sheets is better than the control beams. The deflection was reduced when retrofitted with CFRP sheets. It can also be observed that beams retrofitted with bi-directional CFRP sheets shows less deflection and high load bearing capacity than the beams retrofitted with uni-directional CFRP sheets as shown in Fig. [9]. The use of CFRP sheet shows delayed growth of crack formation.

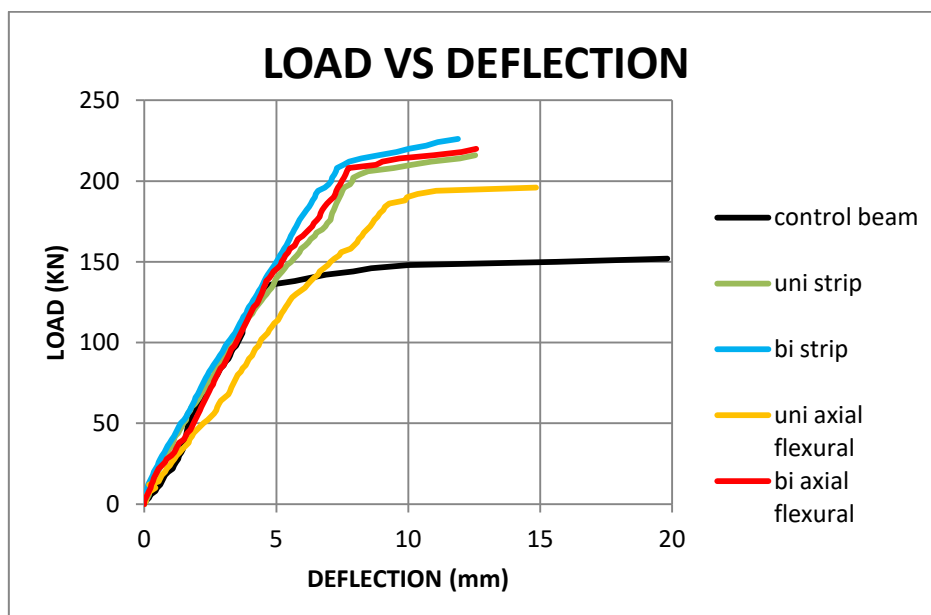


Fig: 9 Comparison of LoadVs. Deflection curve for all beams

The control beams exhibits the more deflections and less ultimate load carrying capacity. It is clear from the graph that the beams retrofitted with CFRP sheets possess better load and deflection characteristics than the control beams. The ultimate load capacity of the beams retrofitted with uni-directional and bi-directional CFRP sheet is increased by 93% and 120% respectively, compared to the control RCC beam.

The typical observations and results of the experimental investigation are shown in Table No. [4].

Table: 4 Details Test Specimens

Specimen	Yield Load (kN)	Ultimate Load (kN)	Deflections at yield load of the Observed points (L,M,R)* (mm)	Maximum Deflection at Observed points (mm)	Initial Stiffness (N/m)	Post-Yield Stiffness (N/m)	Energy Absorbed (kN/m)	shear strength (kN/m ²)	
Control Beam 1	122	154	3.92,4.06, 3.92	18.86,18.26, 17.88	31.98	1.99	2380	855.6	
Control Beam 2	126	152	4.62,5.1, 4.6	19.82,20.04, 19.68	30.53	1.40	2539	844.4	
Control Beam 3	132	156	4.78,5.16, 4.74	19.02,18.62, 18.98	27.30	1.30	2427	866.7	
Control Beam 4	130	154	5.74,4.42, 4.48	19.68,19.62, 19.88	31.05	1.55	2415	855.6	
Flexural Strengthening									% Increase in Flexural Strength
Uni-directional beam 1	182	196	9.06,8.98, 9.04	14.84, 14.36, 14.52	20.19	1.83	2003	1088.9	1.27
Uni-directional beam 2	180	200	8.64,8.68, 8.62	15.16,14.26, 15.14	21.25	2.47	2053	1111.1	1.29
Bi-directional beam 1	200	220	7.48,7.88, 7.48	12.58,12.66, 12.36	26.9	3.04	1879	1222.2	1.43
Bi-directional beam 2	198	218	7.5,8.04, 7.64	12.3,12.42, 12.26	26.88	3.25	1738	1211.1	1.41
Shear Strengthening									% Increase in Shear Strength
Uni-directional beam 1	198	216	7.8,7.34, 7.78	12.54,12.26, 12.62	24.5	3	1767	1200	1.40
Uni-direction	202	220	8.38,9.08, 8.46	12.22,12.68, 12.42	22.68	3.01	1840	1222.2	1.43

al beam 2									
Bi-directional beam 1	204	228	8.32,8.4, 8.32	11.8,11.68, 11.62	24.43	5.01	1619	1266.7	1.48
Bi-directional beam 2	206	226	7.3,7.28, 7.48	11.88,11.62, 11.6	27.8	3.55	1818	1255.6	1.47

*L-Left LVDT, C - Central LVDT and R-Right LVDT

X. CONCLUSION

The behaviour of reinforced concrete beams strengthened for flexure and shear by uni-directional and bi-directional CFRP sheets was studied in the present experimental investigation. Based on the strength characteristics obtained from the experimental investigation, the following conclusions can be drawn:

- The ultimate load carrying capacity and the flexural strength of the beams increases with CFRP sheets bonded to the bottom surface of the beams.
- Increased ultimate load capacity beams strengthened with uni-directional and bi-directional CFRP sheet can be observed.
- The use of CFRP strips, bonded on three sides, results in enhanced shear strength of the beam.
- The rate of Cracks propagation and increase in width of the crack during the gradual increase in the loads were reduced by the use of CFRP sheets bonded on the bottom surface of beams.
- Deflections are reduced in case of beams strengthened with uni-directional and bi-directional CFRP sheets.

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