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RETROFITTING OF RC BEAM USING CFRP & GFRP WRAPPING

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Abstract - Fibre reinforced polymers (FRP) have become widely used in the aerospace and naval industries over the past few decades. They haven't been applied widely yet because they are more expensive than typical Civil Engineering materials like steel or concrete. However, advancements in our understanding of their limitations and potential uses in construction have resulted in a rise in the use of structural retrofitting. Fibre reinforced polymers seem to be an affordable, effective, and especially time-saving alternative to other retrofit solutions for structures that are in poor condition or need to be able to withstand greater loads than they were originally designed for. This paper presents an experimental study on reinforced concrete beams retrofitted with Carbon Fibre Reinforced Polymer (CFRP) and Glass Fibre Reinforced Polymer (GFRP) externally. The objective of this study is to investigate the improvement of beams after retrofitting using CFRP and GFRP wrapping.

***Key Words*:** FRP, retrofitting, CFRP, GFRP.

1. INTRODUCTION

Retrofitting is the process of developing modifications to already-existing structures to increase their resilience to seismic activity, ground motion, or soil failure caused by earthquakes. Seismic retrofitting is now widely recognized as being necessary due to our improved understanding of the seismic demands and expectations on structures and our recent experiences with large earthquakes close to urban areas.

The main goal of retrofitting is to improve a structure's resistance while it is being repaired so that it will be safer in the event of future earthquakes. The following actions could be part of this work:

a) Increasing the column and wall areas or the quantity of walls and columns to increase the lateral strength in one or both directions.

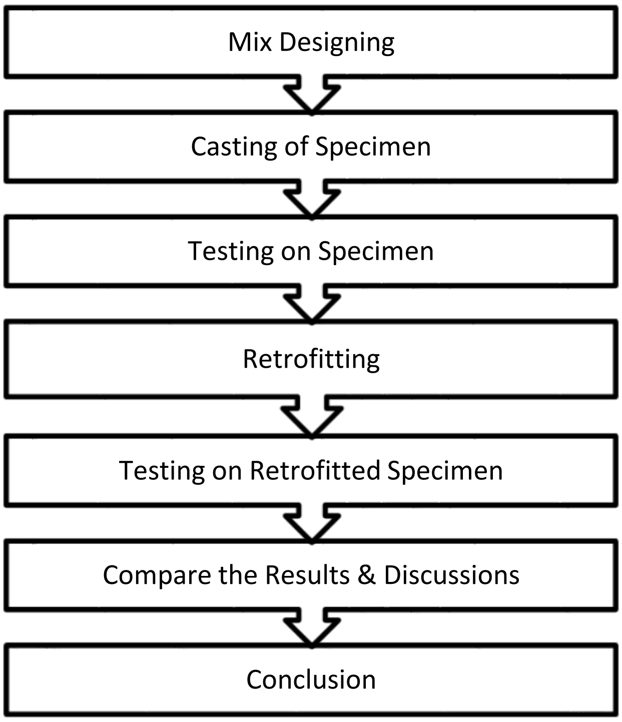
In order for the inertia forces produced by the building's vibration to be transmitted to the members that have the capacity to resist them, the structure must be given unity by creating a proper connection between its resisting elements.

c) Removing elements that cause some members to experience a concentration of stress or are sources of weakness.

d) By properly reinforcing and connecting the resisting members, the potential for brittle modes of failure is reduced.

FRP sheets that are externally bonded are currently being researched and used for the strengthening and repair of structural concrete members all over the world. FRP composite materials are of great interest because, when compared to other repair materials, they have superior qualities like high stiffness and strength as well as ease of installation. Additionally, FRP is a smart choice for external reinforcement due to the materials' non-magnetic and non-corrosive properties as well as their chemical resistance. The addition of externally bonded FRP sheets to RC beams has been actively pursued in recent years to enhance their flexural and shear performance. According to research, strengthening with FRP significantly improves the member's ultimate load carrying capacity as well as their post-cracking stiffness.

2. METHODOLOGY



3. AIM OF EXPERIMENTAL PROGRAM

1) To observed that retrofitting of rc beam after wrapping of CFRP and GFRP.
2) To compare two different results of different material investigation.
3) The main objective of this experimental program is to study the behaviour of under reinforced concrete beam retrofitted with CFRP & GFRP fabric sheets to make comparison of performance of control beam with retrofitted one.

4. MATERIALS

According to the applicable Indian standard codes of practice, tests were conducted every material used in the investigation to check its physical characteristics. The experimental study for casting the beam used the same sets of materials.

a. Cement

An ordinary Portland cement (OPC) of grade 53 was used for the construction work with specific gravity 3.00. The standard consistency of cement is 32. All the tests were carried out in accordance with the procedure laid down in IS 1489 (Part 1).

b. Fine Aggregate

The sand used for the experimental works was locally procured and passing through 4.75mm IS sieve is classified as fine aggregate as per IS:383-1970. Locally available riverbed sand was used in the present study. The test results for fine aggregate after the calculations are found out that specific gravity of 2.76, water absorption is 1.50% and fineness modulus is 3.88.

c. Coarse Aggregate

Those particles that are predominantly retained on the 4.75 mm sieve are called coarse aggregate. Locally available coarse aggregate of 10mm and 20mm are used throughout the experimental study. The test results for coarse aggregate after the calculations are found out that specific gravity of 2.65, water absorption is 1.02% and fineness modulus is 3.91.

d. Water

Fresh and clean potable water was used for casting and curing the specimens in the study. The water was relatively free from organic matter, silt, oil, sugar, chloride and acidic material as per Indian standard IS: 456-2000.

e. Reinforcing Steel

HYSD steel of grade Fe- 415 conforming to IS: 1786 – 1985 was used in the study. Deformed bars of 10mm and 8mm diameter and mild steel bars of 6mm diameter were used in the experimental program.

f. GFRP Fabric Sheet

Glass Fibre Reinforced Polymer, which is made of glass fibre, was uniaxial which is of 0.20 mm thickness, received as 0.50×30m rolls.

g. CFRP Fabric Sheet

Carbon Fibre Reinforced Polymer, which is made of carbon fiber, was uniaxial which is of 0.13 mm thickness and received as 0.50 × 30 m rolls.

h. Grout

Grout is used for repair of filling cracks on the faces of beam after removal of loading. Monopol and hardner is used for filling cracks with grout. 40ml Monopol liquid is mixed thoroughly with 0.40gm of hardner and applied on cracks with the help of injection.

i. Surface Treatment

The main objective of surface treatment is clean the surface of beam specimen. A two-part surface treatment system Goldbond Primer Part A and B from Krishna Conchem was used.

j. Adhesive

A two-part adhesive system Goldbond Saturant Part A and Part B from Krishna Conchem was used.

5. MIX DESIGN

Concrete mix of M25 and M35 was designed as per Indian standard recommended guidelines IS: 10262:2009. Cube of cross section 150mm×150mm×150mm were casted for both M25 and M35 concrete mixes and after hardening it was placed for curing in curing tank. Then compressive strength test on 3rd and 7th day after curing was conducted.

a. Concrete mix for M25

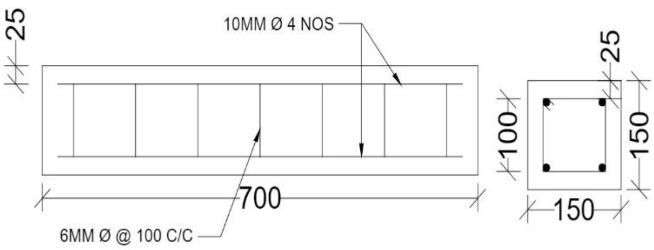
M25 grade concrete mix was designed as per Indian standard recommended guidelines. The water cement ratio achieved in the design was 0.45. The mix proportion of materials adopted was 1:1.82:2.62 by weight (cement: sand: aggregate). Three cube specimens were cast and tested (at the age of 3 and 7 days) to determine the compressive strength. The average compressive strength of the concrete for 3 and 7 day was 21.28N/mm^2 and 25.58N/mm^2 respectively.

b. Concrete mix for M35

M35 grade concrete mix was designed as per Indian standard recommended guidelines IS: 10262:2009, using the materials with properties. The water cement ratio achieved in the design was 0.45. The mix proportion of materials adopted was 1:1.6:1.94 by weight (cement: sand: aggregate). Three cube specimens were cast and tested (at the age of 3 and 7 days) to determine the compressive strength. The average compressive strength of the concrete for 3 and 7 day was 22.28N/mm^2 and 24.05N/mm^2 respectively.

6. CASTING OF BEAMS

Twenty-four reinforced concrete beam specimen of cross section 150mm×150mm with length of 700mm were cast. From these twenty-four beam specimens, twelve specimens are of M25 concrete mix and twelve specimens are of M35 concrete mix. For all the twenty-four reinforced concrete beam specimen, four deformed bars of 10mm diameter were used as longitudinal reinforcement and 6mm diameter mild steel stirrups at a spacing of 100mm c/c were provided as shown in figure 1.



ALL DIMENSIONS ARE IN MM

Fig-1: Detailing of Beam

The steel mould for the beam was made with dimensions 150mm × 150mm and length of 700mm. Cover blocks of 25mm were placed under the reinforcement cage to provide a uniform cover. The coarse aggregates, fine aggregate, cement and water were mixed in concrete mixer as per proportion obtained from the design concrete mix. The beam specimen as cast dimensions/ reinforcement details are shown in Figure 2.

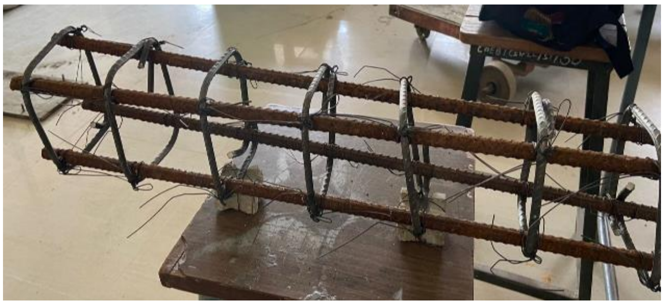


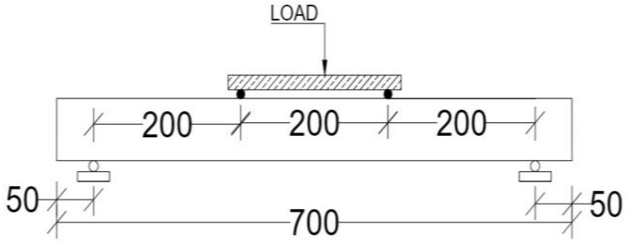
Fig-2: Reinforcement for Beam

The moulds were oiled before concreting to ease the demoulding process. The concrete mix was poured into the moulds and compacted using a compaction rod. The compaction was done until the concrete mix was totally compacted and the mould was completely filled. The beam specimens were demoulded after twenty-four hours. After demoulding, the beam specimens were cured for 28 days in curing tank.

7. TESTING OF BEAMS

The testing procedure for the entire beam specimens in the experimental study for controlled beams and retrofitted beams was same. The controlled beams and retrofitted beams were tested for the flexural strength. After the curing period of 28 days was over, the beam was washed and its surface was cleaned for clear visibility of cracks.

The two-point loading arrangement is used for testing of beams. This has the benefit of a considerable area of nearly uniform moment coupled with very small shears, allowing the central portion's bending capacity to be evaluated. The test beam was supported on roller bearings acting as supports. The specimen was placed over the two steel rollers bearing leaving 50 mm from the ends of the beam. The remaining 600 mm was divided into three equal parts of 200 mm as shown in the figure 3.



ALL DIMENSIONS ARE IN MM

Fig-3: Schematic Diagram of Test Setup for Beams

Fig-4: Two Point Loading System Test Setup for Beam

Loading was done by hydraulic jack of UTM. The deflections of the beams were noted till the appearance of the first crack. After the appearance of the crack and the load was further applied till ultimate load. The ultimate load or fracture load was taken as the load at which the load on the display screen on the UTM returned back. Cracking and failure mode was checked visually.

8. RETROFITTING OF BEAMS

The bonding surface of the concrete beam is made rough to a coarse sand paper texture by scarifying it with the help of a toothed grinder. Edges were made rounded and cleaning it with an air blower. Cracks on surface of beam were repaired by injecting low viscous grout (monopol liquid and hardner) and allowed to set grouted cracks for 60 minutes. All visible moisture was removed from the concrete surface.

A two-component epoxy primer (Goldbond Primer Part A and Part B) is mixed thoroughly and applied to the concrete surface, and allowed to dry for thirty minutes. A thick layer of two-component saturating epoxy which acts as an adhesive for FRP fabric (Goldbond Saturant Part and Part B) is applied over the primer on the concrete surface using a paint roller. The FRP fabric is rolled on the concrete surface, and pressed into place at the centre and moved toward the ends. The FRP fabric is kept tight and wrinkles free. The paint roller is used to remove any trapped air pockets and to work the saturating epoxy into the fabric. The beam specimens wrapped with FRP fabric, are allowed to cure for seven days at room temperature. The procedure for wrapping of CFRP and GFRP is same the only differ was in the material of fabric.

Fig-5: Grinding of beam with grinder

Fig-6: Cracks on Beam

Fig-7: Drilling of Beam for Crack Repair

Fig-7: Injecting of Viscous Grout for Crack Repair

Fig-8: Primer Part A & Part B

Fig-9: Application of Primer on Beam

Fig-10: Saturant Part A & Part B

Among all 24 beam specimens, 3 beams were treated as control beam, 3 beams were retrofitted with fully wrapped GFRP as well as CFRP and 3 beams were retrofitted with partially wrapped CFRP. 50 mm of strips were used on beam in partially wrapping technique. Figure 11 showing all three retrofitted beams of CFRP and GFRP fully wrapped and CFRP partially wrapped.

Fig-11: Fully wrapped CFRP & GFRP and Partially wrapped CFRP Beam Specimen

After the wrapping of FRP fabric on beam specimens are allowed to cure for seven days at room temperature.

After the curing of retrofitted beam specimens for 7 days at room these beams specimens were tested on UTM as explained in chapter 7 of these paper.

Fig-12: Testing GFRP Wrapped Beam on UTM

Fig-13: Testing CFRP Fully Wrapped Beam on UTM

Fig-14: Testing CFRP Partially Wrapped Beam on UTM

9. RESULTS

1. TEST ON CONTROL BEAMS

Three numbers of control beam of M25 and M35 were tested under flexure.

Table-1: Test Results of Control Beams under Flexure

Specimen Designation	Material Description	Concrete-Mix Grade	First Cracking Load	Deflection at First Crack	Ultimate Load	Ultimate Load Deflection
Beam 01	**Control Beam**	**M25**	75 kN	2.8 mm	102 kN	6.0 mm
Beam 02			73 kN	2.5 mm	100 kN	5.2 mm
Beam 03			70 kN	2.2 mm	97 kN	4.8 mm
Beam 04		**M35**	78 kN	4.0 mm	105 kN	8.4 mm
Beam 05			80 kN	4.5 mm	106 kN	9.0 mm
Beam 06			76 kN	3.2 mm	103 kN	8.0 mm

2. TEST ON RETROFITTED GFRP BEAMS

Three numbers of beam of M25 and M35 were retrofitted with GFRP wrapping and tested under flexure.

Table-2: Test Results of GFRP Wrapped Beams under Flexure

Specimen Designation	Material Description	Concrete-Mix Grade	First Cracking Load	Deflection at First Crack	Ultimate Load	Ultimate Load Deflection
GFRP 01	**Glass Fibre Reinforced Polymer (Fully wrapped)**	**M25**	110 kN	3.9 mm	125 kN	9.4 mm
GFRP 02			115 kN	4.2 mm	131 kN	9.7 mm
GFRP 03			118 kN	4.5 mm	134 kN	10.5 mm
GFRP 04		**M35**	128 kN	4.4 mm	150 kN	10 mm
GFRP 05			133 kN	5.7 mm	159 kN	11.4 mm
GFRP 06			135 kN	7.0 mm	162 kN	13 mm

3. TEST ON RETROFITTED CFRP BEAMS

Three numbers of beam of M25 and M35 were retrofitted with CFRP fully (all four faces) as well as partially (at 50mm spacing) wrapping and tested under flexure.

Table-3: Test Results of CFRP Fully Wrapped Beams under Flexure

Specimen Designation	Material Description	Concrete-Mix Grade	First Cracking Load	Deflection at First Crack	Ultimate Load	Ultimate Load Deflection
CFRP 01	**Carbon Fibre Reinforced Polymer (Fully wrapped)**	**M25**	98 kN	4.8 mm	124 kN	13.6 mm
CFRP 02			101 kN	6.2 mm	138 kN	16.2 mm
CFRP 03			105 kN	7.0 mm	145 kN	18.0 mm
CFRP 04		**M35**	130 kN	8.0 mm	168 kN	14.1 mm
CFRP 05			129 kN	7.6 mm	165 kN	13.3 mm
CFRP 06			127 kN	6.0 mm	158 kN	11.2 mm

Table-4: Test Results of CFRP Partially Wrapped Beams under Flexure

Specimen Designation	Material Description	Concrete-Mix Grade	First Cracking Load	Deflection at First Crack	Ultimate Load	Ultimate Load Deflection
CFRP 07	**Carbon Fibre Reinforced Polymer (Partially wrapped)**	**M25**	77 kN	3.6 mm	118 kN	10.0 mm
CFRP 08			70 kN	3.0 mm	113 kN	9.2 mm
CFRP 09			82 kN	4.3 mm	121 kN	10.7 mm
CFRP 10		**M35**	112 kN	3.3 mm	136 kN	6.8 mm
CFRP 11			120 kN	4.5 mm	143 kN	9.2 mm
CFRP 12			118 kN	4.0 mm	141 kN	8.0 mm

10. COMPARATIVE STUDY

In Comparative study, first crack loading and ultimate loading strength of control beams were compared with GFRP and CFRP wrapped beams as per the concrete mix of M25 and M35.

1. **Comparative study on Control Beam with FRP Wrapped Beam of Concrete Mix M25**

Table-5: Control Beam vs FRP Wrapped Beam of Concrete Mix M25

Sr. No.	Beam Designation		First Cracking Load	% Increase in First Cracking Load	Ultimate Load	% Increase in Ultimate Load
1.	**Control Beam**	Beam 01	75 kN	-	102 kN	-
		Beam 02	73 kN	-	100 kN	-
		Beam 03	70 kN	-	97 kN	-
2.	**Glass Fibre Reinforced Polymer Wrapping**	GFRP 01	110 kN	47	125 kN	23
		GFRP 02	115 kN	58	131 kN	31
		GFRP 03	118 kN	69	134 kN	39
3.	**Carbon Fibre Reinforced Polymer Wrapping (Fully Wrap)**	CFRP 01	98 kN	31	124 kN	22
		CFRP 02	101 kN	39	138 kN	38
		CFRP 03	105 kN	50	145 kN	50
4.	**Carbon Fibre Reinforced Polymer Wrapping (Partially Wrap)**	CFRP 07	77 kN	3	118 kN	16
		CFRP 08	70 kN	-4	113 kN	13
		CFRP 09	82 kN	18	121 kN	25

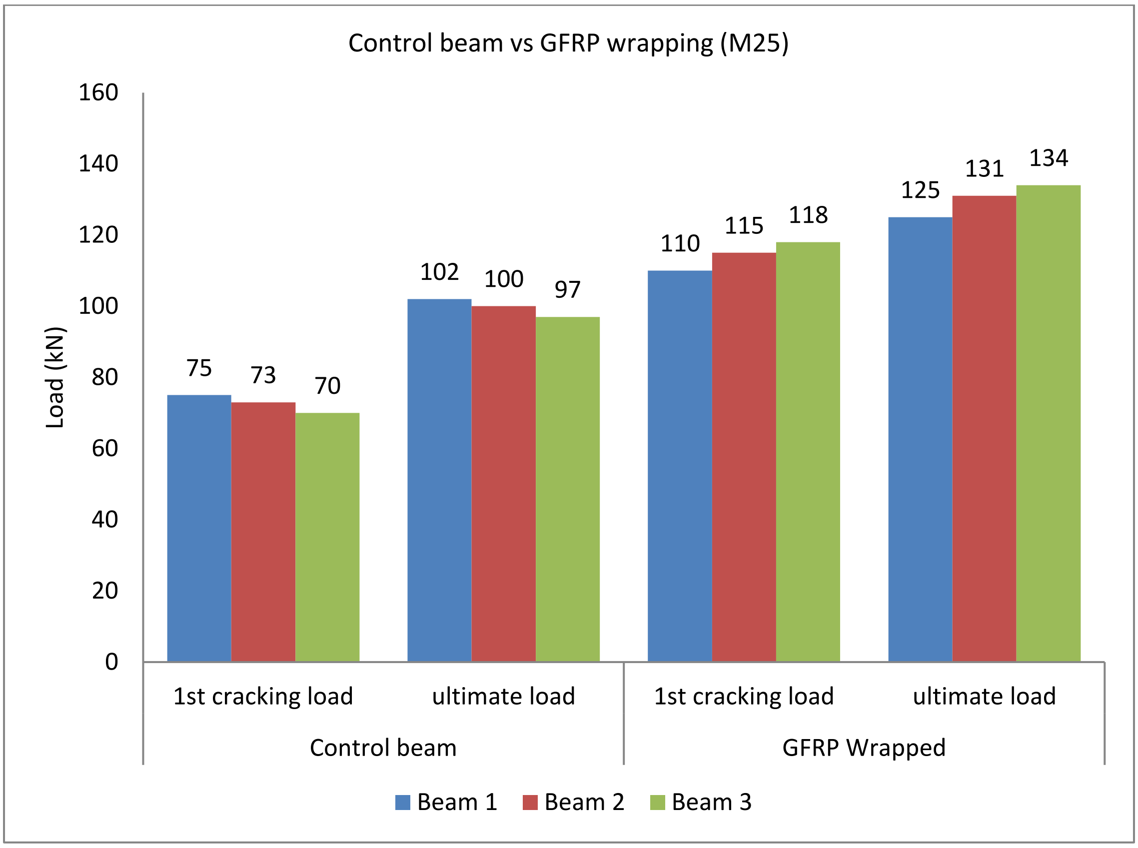


Fig-15: Control Beam vs GFRP Wrapped Beam of Concrete Mix M25

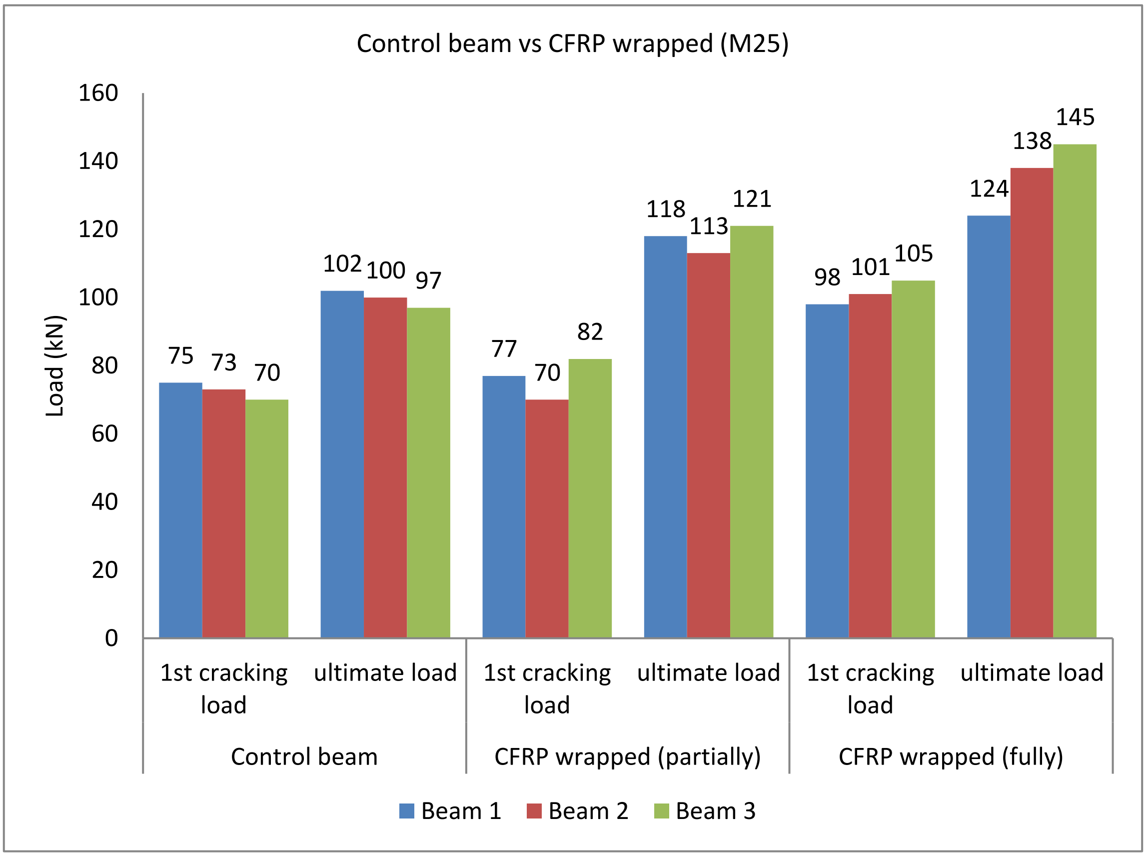


Fig-16: Control Beam vs CFRP Wrapped Beam of Concrete Mix M25

2. <u>**Comparative study on Control Beam with FRP Wrapped Beam of Concrete Mix M35**</u>

Table-5: Control Beam vs FRP Wrapped Beam of Concrete Mix M35

Sr. No.	Beam Designation		First Cracking Load	% Increase in First Cracking Load	Ultimate Load	% Increase in Ultimate Load
1.	**Control Beam**	Beam 04	78 kN	-	105 kN	-
		Beam 05	80 kN	-	106 kN	-
		Beam 06	76 kN	-	103 kN	-
2.	**Glass Fibre Reinforced Polymer Wrapping**	GFRP 04	128 kN	67	150 kN	43
		GFRP 05	133 kN	66	159 kN	50
		GFRP 06	135 kN	67	162 kN	58
3.	**Carbon Fibre Reinforced Polymer Wrapping (Fully Wrap)**	CFRP 04	130 kN	44	168 kN	60
		CFRP 05	129 kN	62	165 kN	56
		CFRP 06	127 kN	68	158 kN	54
4.	**Carbon Fibre Reinforced Polymer Wrapping (Partially Wrap)**	CFRP 10	112 kN	44	136 kN	30
		CFRP 11	120 kN	50	143 kN	35
		CFRP 12	118 kN	55	141 kN	37

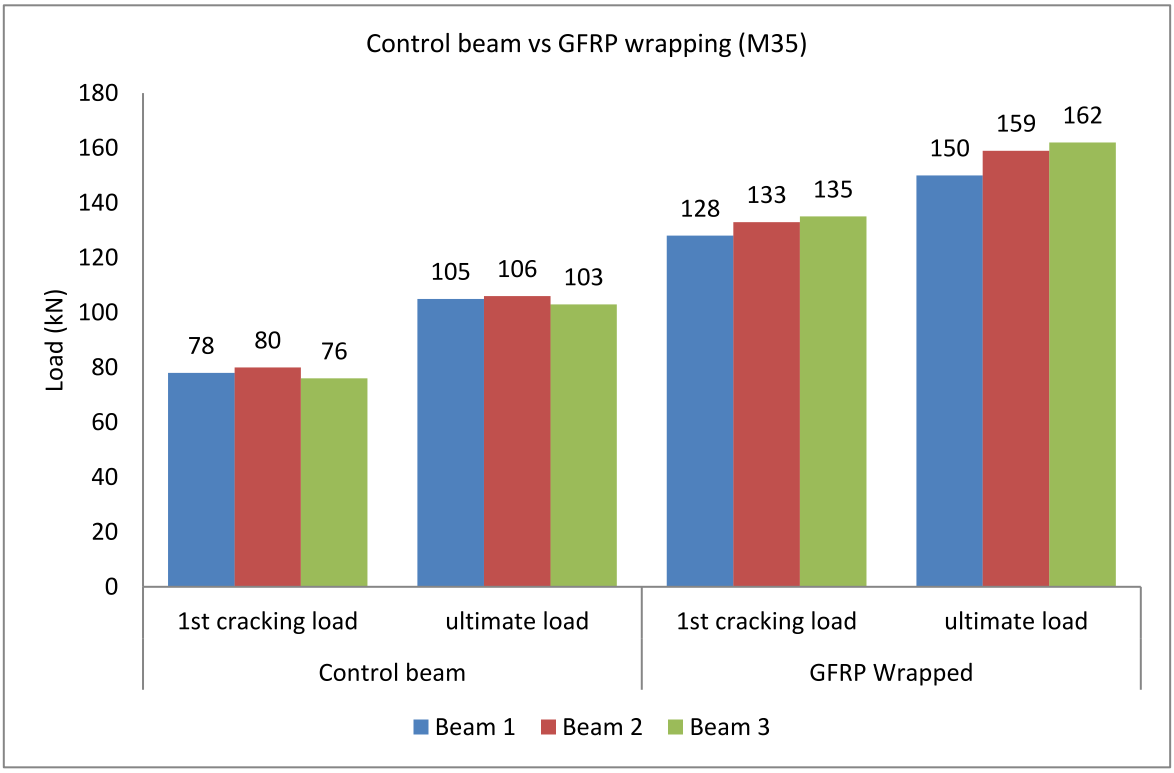


Fig-17: Control Beam vs GFRP Wrapped Beam of Concrete Mix M35

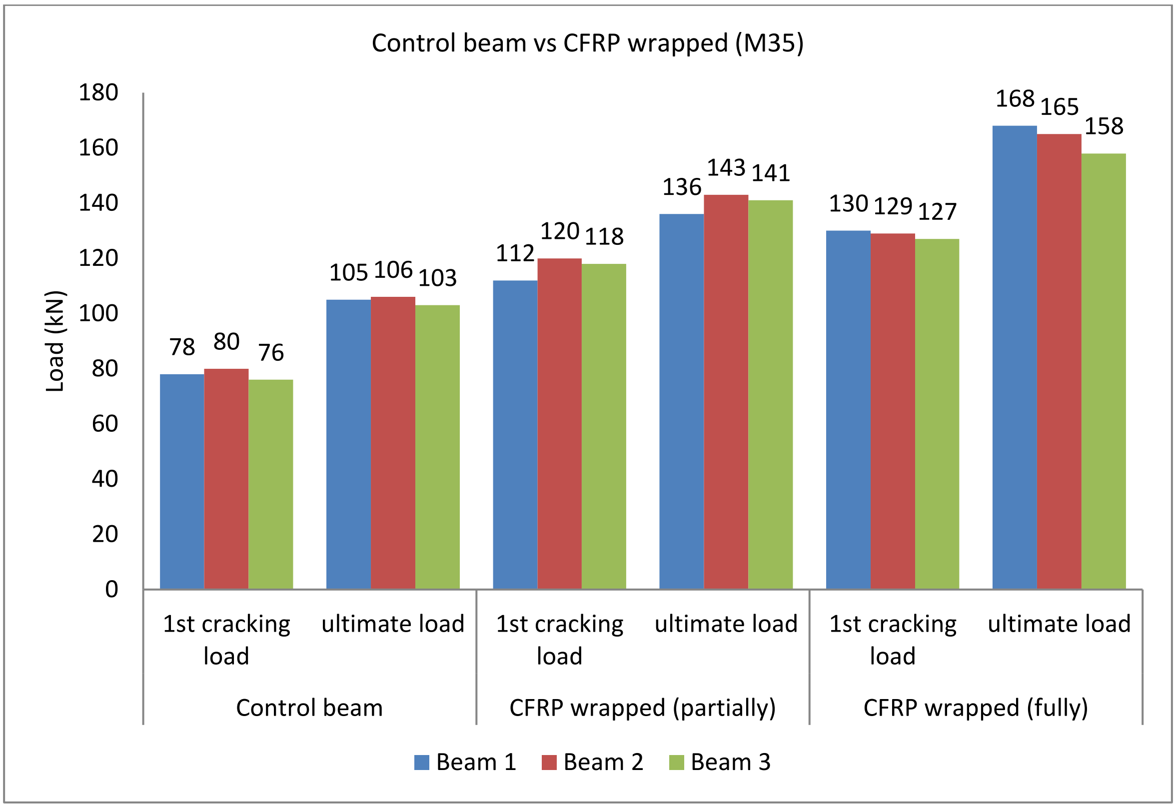


Fig-18: Control Beam vs CFRP Wrapped Beam of Concrete Mix M35

11. CONCLUSIONS

The behaviour of reinforced concrete beams specimen retrofitted by wrapping of GFRP and CFRP fabric are studied and investigated and following conclusions were made:

1. Due to the entire wrapping method used on all four sides of the beam, the deflections of the beams are kept to a minimum.
2. When compared to the control beams, the early cracks develop at a higher load in the retrofitted beams.
3. Due to external frp wrapping on beam, the flexural strength and ultimate load capacity of the beams improved.
4. The flexural strength and ultimate load capacity of beams can be improved more effectively by wrapping them with carbon fibre sheets.
5. The breakdown of the beam clearly shows the composite action caused by the FRP sheets because the link between the FRP sheet and the concrete was intact up until that point.
6. The wrapping of beams on all four sides increases their strength and bearing capacity. As the demand for load increases, it raises the resistance capacity.
7. The ultimate strength of GFRP wrapping increase 48% more than the control beam and GFRP wrapping increases 60% more than the control beam.
8. It was found that both FRP fabric CFRP and GFRP are good for corrosion resistance.
9. The cost of GFRP fabric is more than CFRP fabric.
10. CFRP fabric has better adhesion bonding as compared to GFRP fabric.

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