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Retrofitting of RC Beams Using FRP and FRCM

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Abstract

The deterioration of reinforced concrete (RC) structures due to various factors such as aging, aggressive environments, or increased loads poses significant challenges to structural integrity and safety. Retrofitting techniques have emerged as effective solutions to enhance the structural performance of existing RC members. Among the retrofitting options, the use of Fibre Reinforced Polymer (FRP) and Fibre Reinforced Cementitious Matrix (FRCM) systems have gained considerable attention in recent years. The study encompasses a comprehensive review of the underlying principles, design considerations, and implementation techniques associated with these retrofitting methods. The work presents experimental investigations that demonstrate the successful application of FRP and FRCM retrofitting techniques in strengthening RC beams. This report summarizes the outcomes of these studies, including the enhanced load carrying capacity, increased stiffness, and improved ductility achieved through the retrofitting process.

Keywords: Fibre Reinforced Polymer, Fibre Reinforced Cementitious Matrix, Retrofitting, Reinforced Concrete Beam, T-beam

INTRODUCTION

Recent research has primarily concentrated on using FRP and epoxy resin to improve the durability of pre-existing RC structures [1–3]. In case of fire hazards and places with high temperatures, an innovative material called FRCM is used nowadays for retrofitting as a good alternative [4]. The FRP system uses organic epoxy resin whereas the FRCM system uses inorganic cement-based mortar binder. In this study, RC specimens comprising slab, beam, and column were cast and tested by wrapping with different FRP and FRCM layer patterns and comparisons made of them and studied [5, 6]. The tests were carried out under two-point bending and loads and corresponding deflections were recorded.

DETAILS OF EXPERIMENTAL WORK

The experimental investigation consisted of five beams for retrofitting and one beam for conventional concrete testing to serve as a comparison. This setup includes T-beams on both sides and a C-frame with two columns [7, 8]. The slab measures 1700 mm × 350 mm × 50 mm reinforced with 2 bars of 8 mm diameter at the top and bottom, along with 12 bars of 8 mm diameter stirrups spaced at 150 mm intervals (Figure 1). The beam has dimensions of 1700 mm × 150 mm × 100 mm with reinforcement comprising 2 bars of 8 mm diameter at the top, 3 bars of 12 mm diameter at the bottom, and 18 bars of 8 mm diameter stirrups at 100 mm spacing (Figure 2). The column is designed with 4 bars of 8 mm diameter, and 100 mm stirrup spacing is provided (Figure 3) [9].

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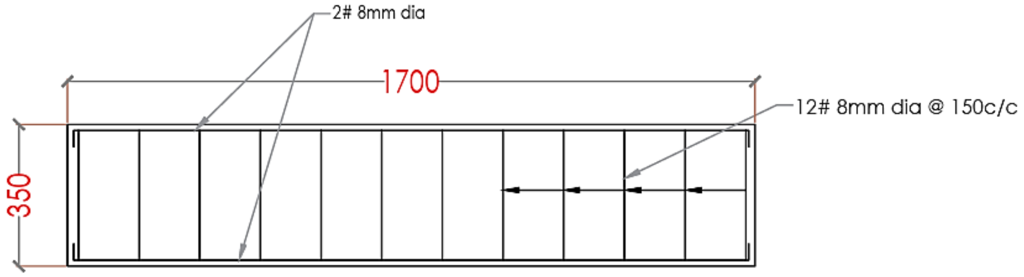

Figure 1. Plan of the slab with reinforcement details.

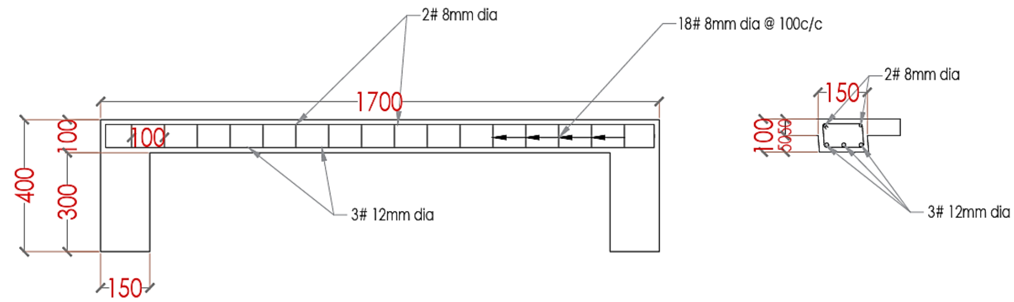

Figure 2. Longitudinal-section and cross-section of the beam with reinforcement details.

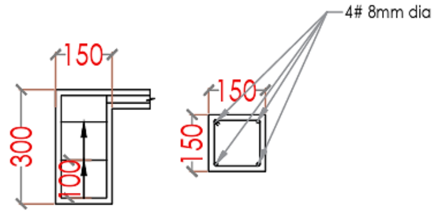

Figure 3. Section and plan of the column with reinforcement details.

TESTS FOR MATERIAL PROPERTIES

The materials used for this experimental work are as given in Table 1.

Table 1. Details of material properties.

Materials	Properties
Cement	OPC 53 grade
Coarse Aggregate	12.5 mm
Fine Aggregate	Crushed stone (M sand)
Reinforced bars	8 mm bars and 12 mm bars

Initial tests were conducted to assess the cement's specific gravity, as well as the specific gravity and water absorption properties of both fine and coarse aggregates [10, 11]. Additionally, sieve analysis was performed on both fine and coarse aggregates.

CASTING AND CURING OF TEST SPECIMENS

Materials such as cement, fine and coarse aggregates were used for the trial mix and a proper mix design was framed according to the design provisions [12]. Then the materials were weighed, batched, and mixed and finally, the desired concrete mix was achieved. For each batch of mix sample, cubes of size 100 mm were cast for determination of compressive strength, i.e., two numbers of 100 mm cubes. The specimens were cured by covering the concrete surface with wet gunny bags and allowed to cure for 28 days. After curing, the beams were exposed to the atmosphere till they were wrapped with FRP and FRCM using wrapping agents, and testing was carried out (Figure 4).

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APPLICATION OF FRCM

Before applying FRCM, the surface was grooved for proper adhesion. In the first specimen, a base layer of cementitious mortar (1700 mm × 500 mm) was applied Figure 6(a), followed by carbon fibre mesh (Figure 5) and Figure 6(b) and a final mortar layer in Figure 7(a). The second specimen had mortar applied in 300 mm × 500 mm sections on each side, with carbon fiber mesh and 100 mm FRCM strips (Figure 8). The third specimen had a longer first mortar layer (700 mm × 500 mm) on each side, two layers of carbon fibre mesh, and 100 mm FRCM strips (Figure 9). Specimens two and three focused on support spans for shear strengthening and flexural failure study.

APPLICATION OF FRP

The surface was prepared by smoothening and cleaning it. Then, a 3:1 epoxy primer coat was applied and left to dry for a day. Carbon FRP strips Figure 10(a) and Figure 10(b) were applied for shear strengthening using a 2:1 epoxy saturant. The first specimen was air-cured for seven days. In the second specimen, sand sprinkling on surface was done before applying FRCM, combining FRP and FRCM.

Figure 4. T-Beam and C-frame specimen.

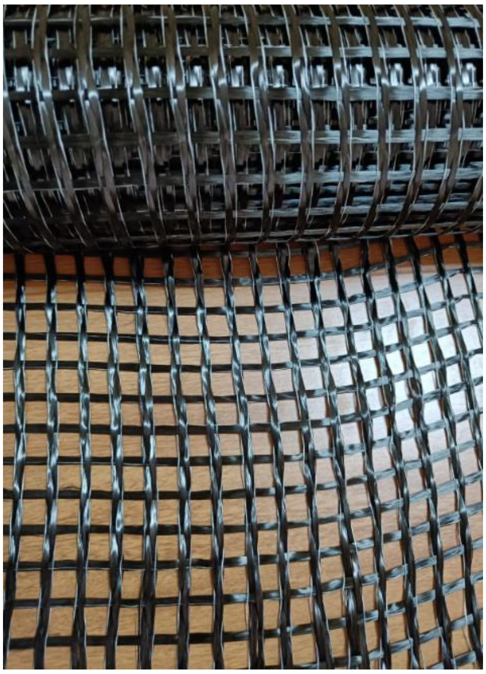

Figure 5. FRCM mesh used in the present study.

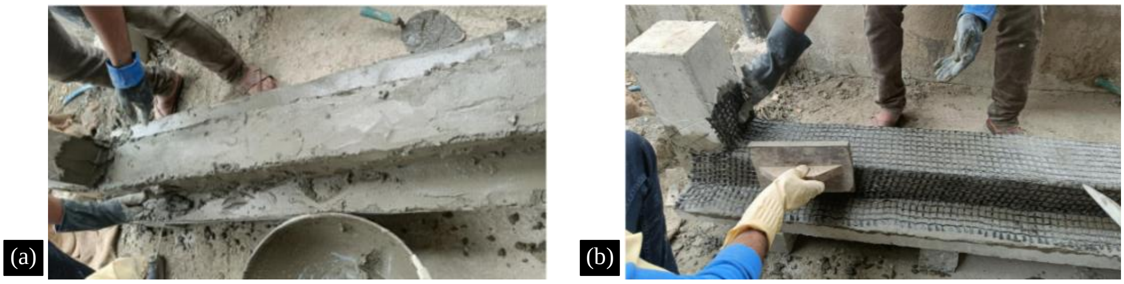

Figure 6. (a) Application of first layer of mortar and (b) Placing of fibre mesh.

Figure 7. (a) Application of second layer of mortar and (b) Beam wrapped with FRCM.


Figure 8. Application of FRCM in one layer-strip form.


Figure 9. Application of FRCM in two layers.

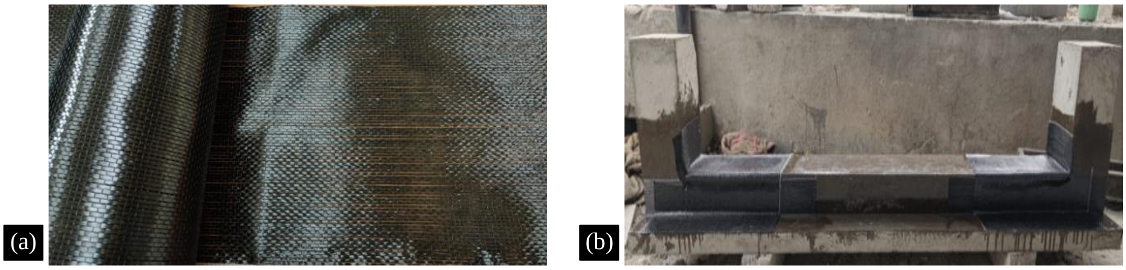

Figure 10. (a) CFRP wrap and (b) Beam wrapped with CFRP.


Figure 11. Set-up of control beam specimen (CB-0).

EXPERIMENTAL SETUP AND INSTRUMENTATION

The specimens were tested in the loading frame fixed with a hydraulic jack of maximum loading of 2000 kN. In the present testing, a loading jack of 1000 kN capacity with a 500 kN load cell was used. Two-point loading method of testing was adopted. At every 0.1 sec interval, loads and corresponding deflections were recorded using a Linear Variable Differential Transformer (LVDT).

Description of Specimens

Control Beam (CB-0):

The control beam is a normal concrete beam that is subjected to two-point loading till beam failure is observed. This specimen was used as a comparison for all the other beams which were retrofitted (Figure 11). Curing was done for seven days and testing was done after that period.

Beam with One Full FRCM Layer (FRCM-1LF)

The beam was wrapped in FRCM in one continuous layer and tested after seven days.

FRCM Beam in Strips (FRCM-1L-S):

The beam was applied with one layer of FRCM in strip form at regular intervals of 100 mm spacing.

Double Layer FRCM in Supports (FRCM-2L)

Beam with two layers of FRCM in support spans.

FRP two layered beam (FRP-2LS):

The beam was applied with FRP in two layers in support spans.

One Layered FRCM and Two-layered FRP (1L-FRCM+2L-FRP):

The beam was wrapped with two layers of FRP at support spans and a complete layer of FRCM throughout.

RESULTS AND DISCUSSION

Ultimate Load Carrying Capacity

All the tests were conducted till the specimens failed. Load, deflection and failure patterns were recorded. Table 2 gives the ultimate load taken by each beam specimen. CB-0 has a load-carrying capacity of 118.8 kN. With reference to CB-0, the load-bearing capacity of all the specimens have been compared. FRCM-1LF has taken a load of 125.9 kN which is 7 kN more than that of the control beam. FRCM-1L-S has failed at a load of 118.7 kN which is -0.1 kN less than that of the control beam. FRCM-2L has taken a load of 119.5 kN which is 0.7 kN more than that of the control beam. FRP-2LS has failed at a load of 129.6 kN which is 11 kN more than that of the control beam. 1L-FRCM + 2L-FRP has collapsed at a load of 125.4 kN which is 6 kN more than that of the control beam.

Deflection at Ultimate Load

The maximum deflection value corresponding to the ultimate bearing capacity of the control beam specimen is shown in Table 3.

Comparison of Ultimate Load Carrying Capacity of Different Beams

As shown in Table 3, Control Beam CB-0 has taken a load of 118.8 kN. Specimen FRCM-1LF has shown an increase of 5.97%, reaching 125.9 kN, suggesting enhanced load-bearing potential. FRCM-1L-S has a slight -0.08% variation, with 118.7 kN, indicating a minor dip in performance. FRCM-2L shows a 0.58% increase at 119.5 kN. FRP-2LS impressively increases by 9.09% to 129.6 kN. Lastly, 1L-FRCM + 2L-FRP achieves 125.4 kN, a 5.55% improvement. Overall, FRCM-1LF and FRP-2LS excel in boosting load-carrying capacity.

FAILURE MODES

The Failure Mode of the Control Beam (CB-0)

The control beam has undergone shear failure**.** Shear cracks and minute flexural cracks have been noted at the bottom of the beam (Figure 12). Therefore, it is a combination of shear and flexure failure. This could likely be attributed to inadequate shear reinforcement, deficient load carrying capacity, or insufficient confinement of the beam's concrete, indicating a compromised ability to withstand the applied loads and resulting in a combined failure scenario.

Table 2. Ultimate load-carrying capacity and deflection of beams.

S.N.	Designation	No. of layers	Load carrying capacity (kN)	Corresponding deflection (mm)
1	CB-0	0	118.8	51.59
2	FRCM-1LF	1	125.9	68.92
3	FRCM-1L-S	1	118.7	33.75
4	FRCM-2L	2	119.5	30.66
5	FRP-2LS	2	129.6	7.52
6	1L-FRCM + 2L-FRP	1,2	125.4	40.17

Table 3. Comparison of load carrying capacity of beam.

S.N.	Designation	Load carrying capacity (kN)	Percentage variation in load carrying capacity	Factor increase in load carrying capacity
1	CB-0	118.8	-	-
2	FRCM-1LF	125.9	+ 5.97%	0.94
3	FRCM-1L-S	118.7	- 0.08%	1
4	FRCM-2L	119.5	+ 0.58%	0.99
5	FRP-2LS	129.6	+ 9.09%	0.909
6	1L-FRCM + 2L-FRP	125.4	+ 5.55%	0.95

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Figure 12. Close-up view of shear cracks in specimen CB-0.

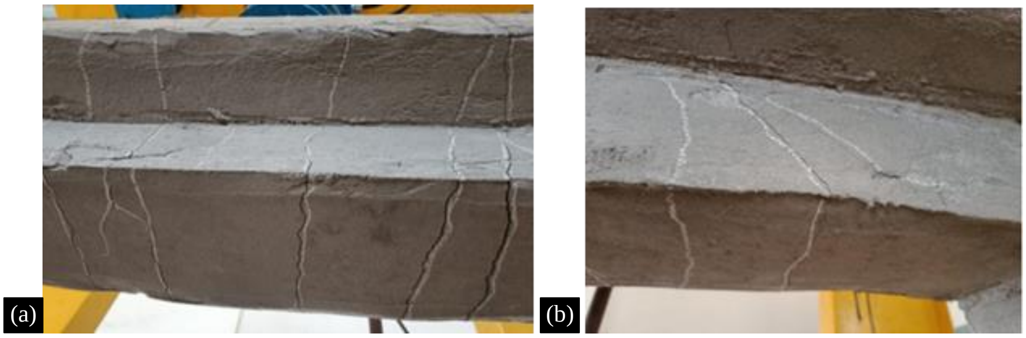

Figure 13. Close-up view of flexure and shear cracks in specimen FRCM-1LF.


Figure 14. Shear cracks in specimen FRCM-1L-S.

The Failure Mode of the FRCM Specimen (FRCM-1LF)

In this specimen, more flexural cracks and few shear cracks have been observed especially at the bottom of the beam (Figure 13). Beam experienced higher bending stresses, possibly due to increased loads or inadequate reinforcement in the flexural direction. The limited occurrence of shear cracks could indicate a relatively better shear capacity, but the predominance of flexural cracks implies that the beam's design might be more sensitive to bending moments and insufficient in terms of flexural reinforcement.

The failure mode of the FRCM specimen (FRCM-1L-S)

In this specimen, shear failure had taken place. Shear cracks have occurred in the support span (Figure 14). Debonding has taken place in the slab element. The shear cracks in the support span might indicate a deficiency in shear reinforcement or inadequate transfer of shear forces within the structure.

The Failure Mode of the FRCM Specimen (FRCM-2L)

In this specimen, slight flexural and shear cracks have appeared due to inadequate reinforcement in both flexural and shear directions, or insufficient structural stiffness. Debonding has taken place in the slab and column portion (Figure 15) possibly due to poor adhesive bonding or inadequate surface preparation.

Figure 15. Debonding of the slab and column element in specimen FRCM-2L.

The Failure Mode of FRP specimen (FRP-2L-S)

In this specimen, flexural cracks have been observed. Wider cracks have taken place at the bottom of the beam and no cracks are to be seen on the FRP wrap pasted portion. The wider cracks observed at the bottom of the beam can be attributed to higher tensile forces in that region. The absence of cracks on the FRP wrap pasted portion indicates the effectiveness of the FRP material in confining and strengthening the beam.

The Failure Mode of FRCM and FRP Specimen (1L-FRCM + 2L-FRP)

Flexural failure was observed in this specimen, with cracks propagating until the maximum load was reached; eventually, slight shear cracks also developed. This could likely be attributed to the excessive bending stresses imposed on the beam.

Effect of CB, FRCM and FRP

A comparison is made between the Control Beam (CB-0), all three FRCM specimens (FRCM-1LF, FRCM-1L-S, and FRCM-2L), one FRP specimen (FRP-2LS) and a combination of FRP and FRCM specimen (1L-FRCM+2L-FRP) (Figure 16). When compared to CB-0, FRCM-1LF has shown shear failure more quickly whereas CB-0 has taken some amount of time for failure. FRCM-1L-S has more load-carrying capacity when compared to FRCM applied in one layer full. FRCM-2L has sustained a greater load in all three FRCM specimens and has performed way better than CB-0. FRP-2LS has reached the heights of taking up the maximum load out of all the specimens and produced a complete flexure failure.

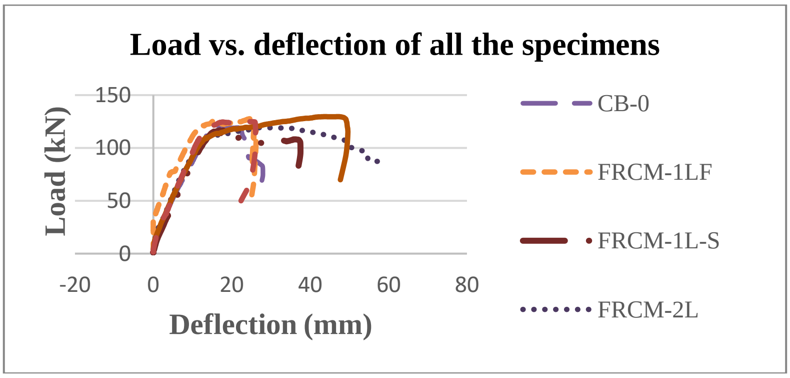

Figure 16. Load vs. deflection of all the specimens.

CONCLUSIONS

Based on the experimental results, the following conclusions are drawn:

- Inclusion of FRCM and FRP wraps gave better results in terms of improved failure behaviour of the beams, in comparison with the control beam.
- The load bearing capacity of the fully wrapped FRCM beam exhibited higher strength and resulted in ductile failure.
- Specimens CB-0, FRCM-1LF, FRCM-1L-S and 1L-FRCM+2L-FRP demonstrated combined shear and flexural failures.
- A complete flexural failure was observed in the FRP beam specimen FRP-2L-S, featuring a two-layer wrap of FRP, which contributed to both strength and stiffness at the support locations.
- Shear strengthening interventions, such as single or double-layer wraps of FRCM, FRP, or both, resulted in flexural failures in select specimens.

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