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CFRP Application in Retrofitting of R.C.C Beam

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ABSTRACT

Deterioration in reinforced concrete structures is a major issue faced by the infrastructures industries all over the world. Since complete replacement of these structures requires high investment, strengthening has become the suitable solution to modify and improve the performance of the structures. The strengthening of RC beams using FRP composites has become a popular structural strengthening technique, due to the well-known advantages of FRP composites such as their high strength-to-weight ratio and excellent corrosion resistance. This study explores the result of an experimental investigation for enhancing the flexure capacity of reinforced concrete (RC) beams with flexure deficiencies, strengthened with Carbon Fiber Reinforced Polymer (CFRP) sheets. Total 18 numbers of specimens were casted. Out of this 9 specimens were tested for control beam and 9 were for deterioration in that three were tested with CFRP wrapping respectively. The geometry of all beams are 1200mm overall length, 1000mm effective length (bearing 100 mm each side), 100 mm width and 150 mm depth with constant reinforcement as per design. The dimensions of all beams are kept same throughout the experiment. Experiments are conducted to study the flexural capacity of RC rectangular beams with and without FRP using local available materials. For the experiment four point bending test was conducted. Deterioration of Concrete is done by using solutions of calcium chloride ($CaCl_2$) with 3 molal ion concentrations. The experimental results demonstrated that the use of CFRP composite strips increases the flexure capacity of the beams significantly by preventing the debonding of CFRP sheets, so that the full strength of the CFRP sheets get utilized.

Keywords: CFRP, $CaCl_2$, Four point bending test, ETABS

I. INTRODUCTION

All civil engineering infrastructures are under goes to degradation or deteriorations. The life of such structures depend up on the continue performance of building which is performed by conducting structural health monitoring techniques. The deterioration of these structures are mainly due to ageing, poor maintenance, corrosion, aggressive environmental conditions, poor initial design or construction errors and accidental situations like earthquakes. In the past a large number of structures were constructed using the older design codes which are structurally unsafe according to today's design standards.so to overcome this problem structural retrofit techniques are used.

Since the complete replacement of such deficient structures requires enormous amount of money and time, strengthening has become the suitable way of improving their load carrying capacity and extending their service lives. . To overcome this problem advanced composite materials such as fibre reinforced polymer (FRP) composites are used for retrofitting of concrete structures. FRP repair is a simple way to increase both the strength and design life of a structure. Because of its high strength to weight ratio and resistance to corrosion, these repair method is ideal for deteriorated concrete structure.

A. Proposed Work

This work is focused on effects of CFRP wrapping for controlled and deteriorated RC rectangular beams with and without CFRP. The scope of study is to compare the Flexural Capacity and deflection of controlled beam wrapped with CFRP and deteriorated beam wrapped with CFRP. To investigate the Failure Patterns for same member. All the beams are designed as per limit state method of design, simply supported at both ends and four point bending test was conducted as per ASTM D6272.

II. EXPERIMENTAL PROGRAMME

To evaluate the performance of existing building, the existing building was modelled and analysed by considering the existing design. The same new building was modelled as per the present code requirement to compare the performance of new building with the existing.

A. Existing Building Properties

Table 1. Existing Building Properties

Types of Structure	G+2 RCC Frame			
Plan Dimension	53.53 m X 6 m			
Story Height	3m			
Grade of Concrete	M15			
Grade of Steel	Fe250			
Column Size	Col. 185X575	Col. 300X400		Col. 320X530
Beam Size Beam	Beam 230X375	Beam 250X500	Beam 270X652	Beam 300X450
Wall Size	450mm	300mm		100mm
Slab Thickness	125mm			

B. New Building Properties

Table 1. New Building Properties

Types of Structure	G+2 RCC Frame			
Plan Dimension	53.53 m X 6 m			
Story Height	3m			
Grade of Concrete	M20			
Grade of Steel	Fe415			
Column Size	Col. 185X575	Col. 300X400		Col. 320X530
Beam Size Beam	Beam 230X375	Beam 250X500	Beam 270X652	Beam 300X450
Wall Size	450mm	300mm		100mm
Slab Thickness	125mm			

From this new properties building is modeled in Etabs and from this results beams are designed for maximum bending moment.

C. Modeling of Building in ETABS

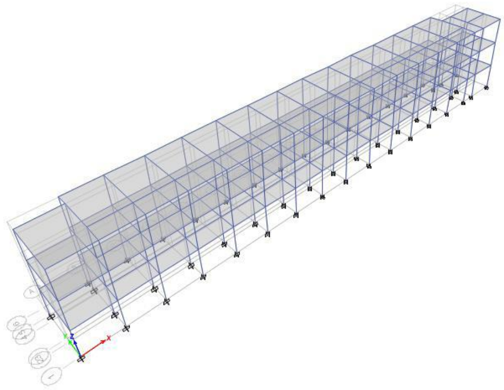

Figure 1. 3D Model of Building

D. Design of Prototype Beam:

Beams are analyzed by using Limit State Method of Design as per IS 456-2000.

Span = 3.5 m = 3500 mm

Load = 54.31kN/m

Width = 300 mm
Depth = 450mm
Effective cover = 25mm
Maximum Bending Moment = 124.74kNm
Maximum Shear Force = 142.55kN
AREA OD STEEL= 964.82mm^2
Use16 mm Φ bars
Number of Bars: 5
Ast provided = 1005.3 mm^2
Shear reinforcement: Use 2 L-8mm stirrups @ 230mm

E. Design of Model Beam:
Assuming Scale Factor 3
Span = 1200 mm
Load = 25.55kN/m = 18.396kN
Width = 100 mm
Depth = 150mm
Effective cover = 20mm
Maximum Bending Moment = 5.51kNm
Maximum Shear Force = 11.0376 kN
AREA OF STEEL= 78.45mm^2
Use 8 mm Φ bars
Number of Bars: 2
Ast provided = 100.52 mm^2
Shear reinforcement: Use 2 L-6mm stirrups @ 140mm

F. Design of CFRP for Model Beam

Table 3. FRP System Properties

Thickness per ply	t_f	1.02mm
Ultimate tensile strength	f^*_{fu}	621N/mm^2
Rupture Strain	ε^*_{fu}	0.015mm/mm
Modulus of elasticity of FRP laminates	E_f	37000N/mm^2
Environment factor	C_E	0.95

Number of Ply: 1
Type of Wrap: U- Wrap CFRP
Design Moment: 3.40 kNm
Design Flexural strength of the section With CFRP: 6.72 kNm
The strengthened section is capable of sustaining the new required moment strength.

III. GEOMETRY OF BEAMS

The geometry of all beams are 1200mm overall length, 1000mm effective length (bearing 100 mm each side), 100 mm width and 150 mm depth with varying reinforcement as per design. The dimensions of all beams are kept same throughout the experiment. All the beams are initially designed as per limit state method of design, simply supported at both ends and applied with multiple concentrated loads equivalent to uniformly distributed load (UDL). Experiments are conducted to study the flexural capacity of RC rectangular beams with and without FRP using local available materials. All the beams are gradually test loaded up to failure. Total 18 numbers of specimens were constructed. Out of this 9 specimens were tested for control beam and 9 were for deterioration in that three were tested with CFRP wrapping respectively.

A. Deterioration of Concrete

Concrete specimens were exposed to weekly cycles of wetting and drying in water and in solutions of calcium chloride (CaCl2) with 3 molal ion concentrations, equivalent in ion concentration to a 7.5% solution CaCl2.Nine Specimens were used to deterioration. The specimens were submerged in solution for 7 days. After 7 days, they were removed from the solution and dried in air. Cycles were repeated for 5weeks.

B. Experimental set up for testing of beams

All the specimens are tested in loading frame of the Applied Mechanics Laboratory, Walchand College of Engineering, Sangli. The testing procedures for all specimens are same. After curing for 7 days and 28 days, control beams and deteriorated beams were tested one by one applying load slowly up to failure. In the testing arrangement, multiple concentrated loads are applied on all the beams gradually increased up to failure. The beam is placed over two steel roller bearings, kept over two steel pedestals at each end; leaving 100mm bearing from either end with an effective span of 1000mm.The loading frame is capable of carrying the expected peak load without significant distortion. Loading is done by hydraulic jacks of 10Tone capacity each. The dial gauge is placed at mid span of beam to measure deflection of the beam.

C. Loading Pattern

The Figure 2 given below shows the typical test arrangement under multiple concentrated loads applied on all the beams in the structural laboratory. The geometry of all beams are 1200 mm overall length, 1000 mm effective length (bearing100 mm each side), 100 mm width and 150 mm depth.

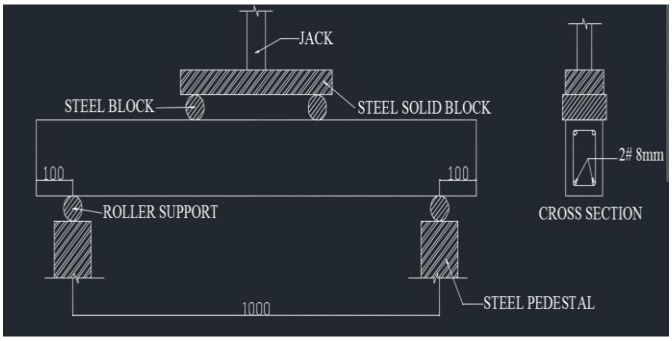

Figure 2. Test setup

IV. TEST RESULTS AND DISCUSSIONS

A. Introduction

This chapter interprets the results obtained from the experimental investigation which Comprises of testing of eighteen RC beams. The behaviour of the RC beams with respect to ultimate load carrying capacity, crack pattern, deflection is studied throughout the test and their failure modes are described.

B. Control Beam

The control beam is not strengthened with CFRP composites to study the behaviour of the bending failure without strengthening. It is a bending deficient beam and is tested under the four point static loading system by applying the point loads gradually. The experimental setup for the control beam under four-point static loading frame is shown in previous chapter. The first hair line crack appeared at a load of 18 kN in the bending region of the beam for 28th days testing. As the load increased, additional tension cracks are developed and the primary visible crack undergoes widening and propagated. With the further increase in load, the beam exhibited a wider diagonal bending crack and finally failed in bending at a load of 25kN for 28th days testing

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Table 4. Test Result of Control Beam for 28th Days

Specimen	Failure Load (kN)	Maximum Deflection (mm)	Average Flexure Strength (MPa)
Beam A	25	4.4	6.66
Beam B	24.5	4.2	
Beam C	25.5	4.5	

C. Deteriorated Beam

The beams are deteriorated by using in solutions of calcium chloride ($CaCl_2$) with 3 molal ion concentrations as explain in previous chapter. The testing of beams are same as above. The first hair line crack appeared at a load of 15 kN in the bending region of the beam for 28th days testing. As the load increased, additional tension cracks are developed and the primary visible crack undergoes widening and propagated. With the further increase in load, the beam exhibited a wider diagonal bending crack and finally failed in bending at a load of 22.3 kN for 28th days testing.

Table 5. Test Result of Deteriorated Beam for 28th Days

Specimen	Failure Load (kN)	Maximum Deflection (mm)	Average Flexure Strength (MPa)
Beam A	23	4.1	5.95
Beam B	21	4.2	
Beam C	23	4.4	

D. Load Vs Deflection Graph for Beams without strengthening

Specimens are tested after 28 days curing and 5 weeks cycle in loading frame for Control beam and for deteriorated beam respectively. The beams are tested one by one by applying load slowly up to the failure load and deflection is measured by using gauge at mid span.

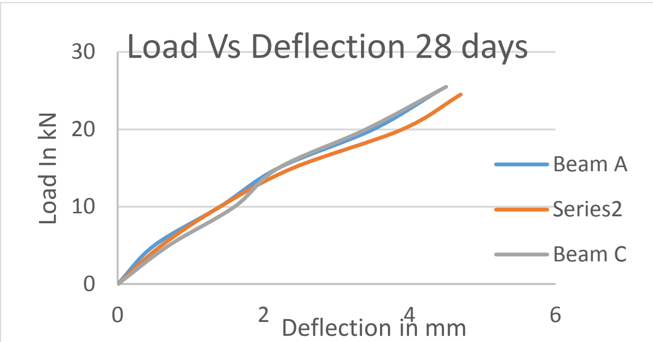

Figure 3. Load Vs Deflection Graph of control beam

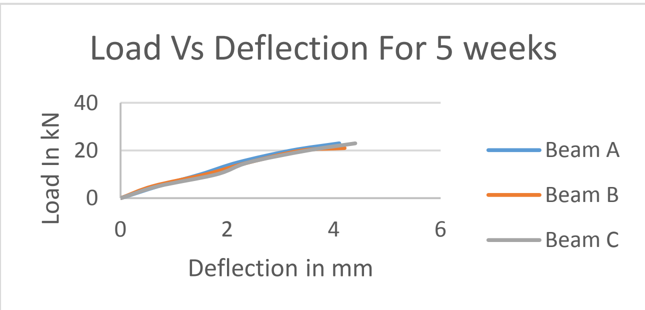

Figure 4. Load Vs Deflection Graph of deteriorated beam

E. Control Beam with CFRP Wrapping

The control beam is strengthened with CFRP composites to study the behaviour of the bending failure. The beams are strengthened with bidirectional woven CFRP U-strips of 1 layer bonded to the bottommost and side portions with 3 strips of equal width of 200 mm and spacing between the strips is 200 mm. The testing of beams are same as above. The first hair line crack appeared at a load of 22 kN in the bending region of the beam. As the load increased, additional tension cracks are developed and the primary visible crack undergoes widening and propagated. With the further increase in load, the beam exhibited a wider diagonal bending crack and finally failed in bending at a load of 34 kN.

Table 6. Test Result of Control Beam with CFRP Wrapping

Specimen	Failure Load (kN)	Maximum Deflection (mm)	Average Flexure Strength (MPa)
Beam A	35	4.6	9.33
Beam B	35	4.7	
Beam C	32	4.5	

F. Deteriorated Beam with CFRP Wrapping

The deteriorated beam is strengthened with CFRP composites to study the behaviour of the bending failure. The beams are strengthened with bidirectional woven CFRP U-strips of 1 layer bonded to the bottommost and side portions with 3 strips of equal width of 200 mm and spacing between the strips is 200 mm. The testing of beams are same as above. The first hair line crack appeared at a load of 20 kN in the bending region of the beam. As the load increased, additional tension cracks are developed and the primary visible crack undergoes widening and propagated. With the further increase in load, the beam exhibited a wider diagonal bending crack and finally failed in bending at a load of 31.3 kN.

Table 7. Test Result of deteriorated Beam with CFRP Wrapping

Specimen	Failure Load (kN)	Maximum Deflection (mm)	Average Flexure Strength (MPa)
Beam A	32	4.6	8.36
Beam B	30	4.5	
Beam C	32	4.7	

G. Load Vs Deflection Graph for Beams with strengthening

Strengthened specimens are tested after 28 days curing and 5 weeks cycle in loading frame for Control beam and for deteriorated beam respectively. The beams are tested one by one by applying load slowly up to the failure load and deflection is measured by using gauge at mid span.

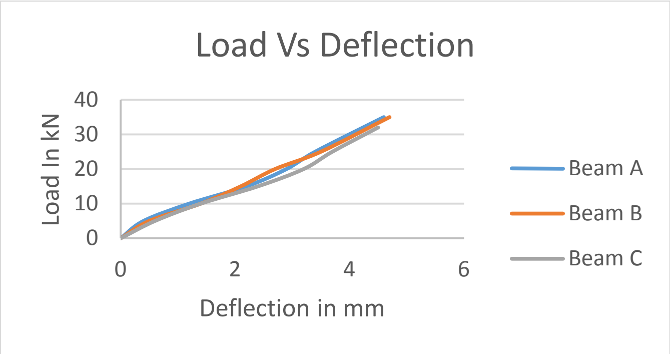

Figure 5. Load Vs Deflection for CFRP Wrap Beam

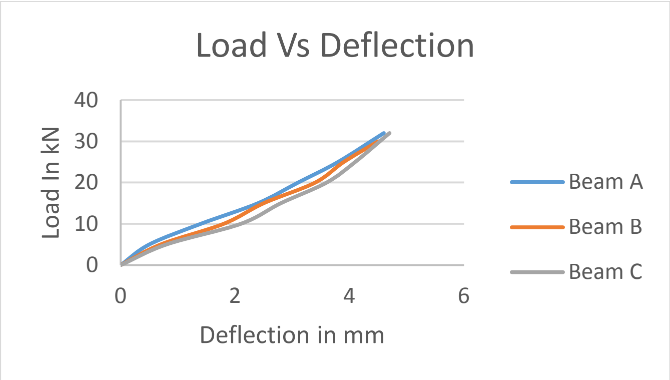

Figure 6. Load Vs Deflection for Deteriorated Beam with CFRP Wrap

H. COMPARISON OF LOAD FOR CONTROL BEAM WITH CFRP WRAP BEAM

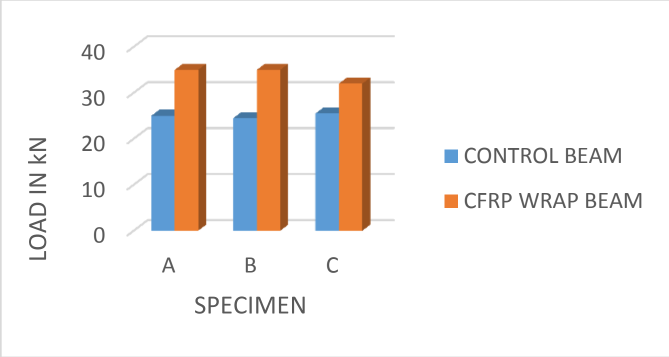

Figure 7. COMPARISON OF LOAD for Control Beam with CFRP Wrap Beam

Graph shows that Flexure strength of Control beam enhanced by 40.45% due to CFRP wrapping.

I. COMPARISON OF LOAD FOR DETERIORATED BEAM WITH CFRP WRAP DETERIORATED BEAM

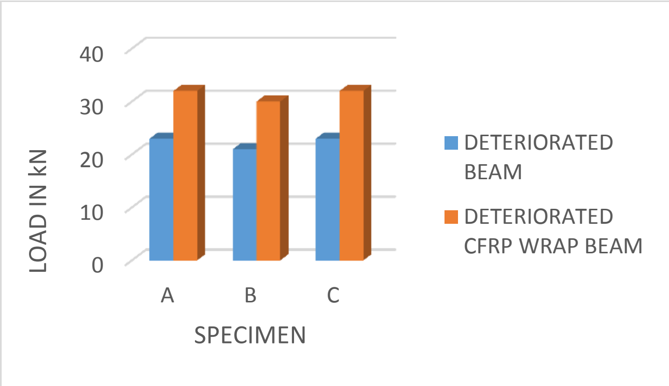

Figure 8. Comparison Of Load For Deteriorated Beam With Cfrp Wrap Deteriorated Beam

Graph shows that Flexure strength of Deteriorated beam enhanced by 40.50% due to CFRP wrapping.

J. FAILURE PATTERNS of BEAMS

Figure 9

Small hair cracks appeared at mid span bottom and progressed upwards at mid span top.

Figure 10

Due to wrapping of CFRP to beam failure of beams is shifted from mid span to span between two CFRP strips

V. CONCLUSIONS

1) From test results Flexure strength of Deteriorated beam decreased by 10.66 % as compared to Control beam.
2) Graph shows that for deteriorated beam at same load deflection is more as compare to control beam.
3) From test results Flexure strength of Control beam enhanced by 40.45% due to CFRP wrapping.
4) From test results Flexure strength of Deteriorated beam enhanced by 40.50% due to CFRP wrapping.
5) The initial cracks in the strengthened beams are formed at a higher load compared to the control beams.
6) Small hair cracks appeared at mid span bottom and progressed upwards at mid span top. It is purely a flexural failure.
7) Due to wrapping of CFRP to beam failure of beams is shifted from mid span to span between two CFRP strips.

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