EXPERIMENTAL STUDY ON EXTERNAL STRENGTHENING OF RC BEAMS USING CFRP COMPOSITES UNDER FLEXURAL LOADING

J. Anto[1], T. Manikandan[2], S. Aravindan[3]
[1]P.G Scholar
Star Lion college of Engineering & Technology
[2] Assistant Professor
M.A.M. college of engineering, Trichy - 621105.
[3] Assistant Professor
M.A.M. college of engineering, Trichy - 621105.

ABSTRACT--- In our country many of the existing reinforced concrete structures are in need of repair or reconstruction, rehabilitation, because of deterioration due to various factors like corrosion, lack of detailing, failure of bonding between beam, column, slab, etc…Strengthening of existing reinforced concrete structures is necessary to obtain an expected life span and achieve specific requirements. The need for efficient rehabilitation and strengthening techniques of existing concrete structures has resulted in research and development of composite strengthening systems. Recent experimental and analytical research have demonstrated that the use of composite materials for existing structural components is more cost-effective and requires less effort and time than the traditional means. Carbon Fiber Reinforced Polymer (CFRP) composite has been accepted in the construction industry as a capable substitute for repairing and strengthening of RCC structures. During past two decades, much research has been carried out on flexural strengthening of reinforced concrete beams using different types of fiber reinforced polymers and adhesives. A detailed Literature review based on the previous experimental and analytical research on reinforced concrete beams is presented. Proposed method of strengthening the RC beam is decided based on the previous experimental and analytical research. Behaviors of reinforced concrete beams with externally bonded CFRP with various types of resins is investigated. Static load responses of all the beams under two point load method had evaluated in terms of flexural strength, crack observation, compositeness between CFRP fabric and concrete, and the associated failure modes.

Keywords: Carbon Fibre Reinforced Polymer, CFRP strengthened beam, Beam flexural behavior, CFRP laminates.

1. INTRODUCTION

The development of external bonding of High-strength Carbon fiber reinforced polymer (CFRP) composites is the potential technique over the steel plates in structural strengthening and upgrades of damaged or deteriorated members. Before the introduction of carbon fiber reinforced polymer strengthening technologies, one popular technique for upgrading reinforced concrete beams was the use of external epoxy-bonded steel plates. This method suffers deterioration problem caused by the corrosion of the steel. There is wide range of techniques available to repair or strengthen structurally deficient and functionally aged structures. One such technique is adding CFRP as external bonded reinforcement to the structure for upgrading reinforced concrete beams was the use of externally epoxy-bonded steel plates.

Repair and strengthening of existing reinforced concrete structures is of great interest for extending their service life as well as for their rehabilitation. Repair of concrete structures can be classified as restoring the original structural shape and strengthening. There are different techniques available for retrofitting and strengthening of various reinforced concrete structural elements. The methods were developed due to different causes, such as inadequate maintenance, overloading of the RC member, corrosion of the steel reinforcement and other reasons. These methods includes

- Steel plate bonding
- External Pre-stressing
- Section Enlargement
- Reinforced concrete jacketing

Carbon Fiber reinforced polymer (CFRP) composites are thin laminates that are externally bonded to structural elements using an epoxy adhesive to increase their load-carrying capacity. CFRP materials are lightweight durable and noncorrosive and can be installed quickly, offering economically and structurally sound alternative in most applications. Repair or strengthening with carbon fiber reinforced polymers has gained acceptance in recent years and has been used to strengthen different construction materials including steel, wood and concrete. Strengthening of RC members usually involves the external bonding of CFRP sheets or plates to RC beams, slabs and column strengthening with CFRP is simple and does not involve heavy equipments.

The wrapping RC members with CFRP sheets may reduce the corrosion by acting as a barrier against the ingress of salt, water and oxygen into the concrete which are the elements required for the corrosion process to continue. Another advantage of using CFRP wraps to repair corrosion damaged members is the external confining pressure provided by the FRP that enhance the bond at the deteriorated concrete cover zone. Recently, carbon fiber reinforced polymers composite was considered as the best strengthening method of reinforced concrete structures. In these strengthening methods, the bond behavior between the concrete and FRP composites is a key issue in design. To externally bond FRP sheets on the tension and also lateral sides of RC beams and columns is a widely used method for repairing and strengthening of the RC structures. Such reinforcing technique is an effective way to improve the flexural and or shear performance of the RC structures reinforced, since FRP has better characteristics than the conventional strengthening material steel, in terms of high tensile strength, lightweight, resistance to corrosion and fatigue.

2. CARBON FIBRE REINFORCED POLYMER (CFRP)

Carbon fibres have the highest specific modulus & specific strength of all reinforcing fibre materials.

Carbon fibres are not affected by moisture or variety of solvents, acids, bases.

Fibre & composite manufacturing processes have been developed that are relatively inexpensive & cost effective.

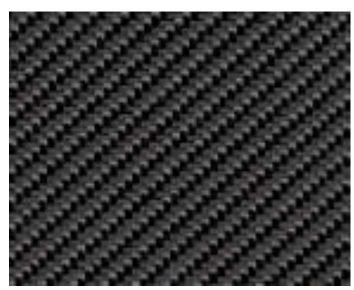

Fig 1. Carbon fibre

3. EXPERIMENTAL PROGRAM MATERIALS USED:

Cement

Ordinary Portland Cement (43 grade) Properties of cement as shown in table 1.

Table 1. Properties of Cement

SI. no	Properties	Results	Requirements as per IS:122689 - 1987
1	Specific gravity	3.16	-
2	Initial setting time(min)	30	Not less than 30
3	Final setting time(min)	430	Not more then 600

Coarse aggregate

Coarse aggregate used here is 20 mm aggregate of good quality. The physical properties and the data’s is given below in table 2.

Table 2 Properties of Coarse aggregate

SI. no	Properties	Results
1	Specific gravity	2.74
2	Water Absorption	4%
3	Fineness modulus	1.96

Fine aggregate

Natural river sand was used as fine aggregate. The properties of sand were determined by conducting tests as per IS: 2386 (Part- I). The results are shown in Table 3.

Table 3 Properties of Fine aggregate

SI. no	Properties	Results
1	Specific gravity	2.80
2	Water Absorption	70%
3	Fineness modulus	2.6

Epoxy resin

Araldite AW106 with Hardener HV 953 IN is used as epoxy resin in order to bind CFRP sheets to concrete.

4. MIX PROPORTION: For M25 Grade of concrete

As per IS-10262 2009

W/C : C : FA : CA

0.45 : 1 : 1.35 : 2.87

Size of Beam = 1.8 x 0.2 x 0.18 m

Water = 11.035 lit

Cement = 24.48 kg

Fine aggregate = 32.94 kg

Coarse aggregate = 68.08 kg

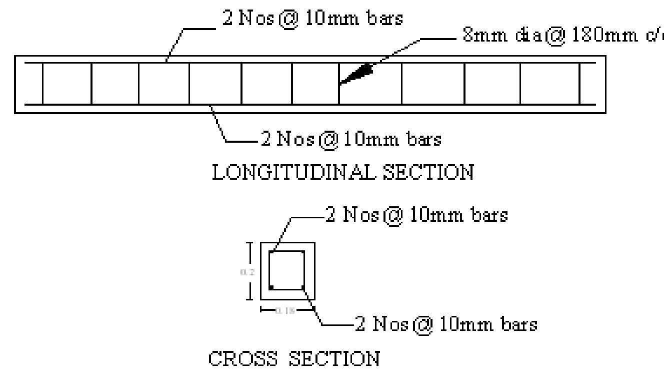

Fig 2. Reinforcement details for beam

5. EXPERIMENTAL SETUP

Bonding of CFRP composites with suitable epoxy adhesive on external surface of structures is the most versatile and widely used technique for strengthening RC beams. Generally, the soffit (bottom) bonding is done for flexural strengthening, while web bonding is preferred for shear strengthening.

Bonding of CFRP composites on beam webs is one of the highly effective methods, since it can provide both the shear and flexural enhancement for concrete beams. The use of lay-up CFRP composites under increased load conditions reveals a reduced deflection and smaller crack widths.

Also, the use of composites offers several advantages like ease of bonding to curved or irregular surfaces, lightweight/ease of application and fiber flexibility to orient in a desired direction for strengthening.

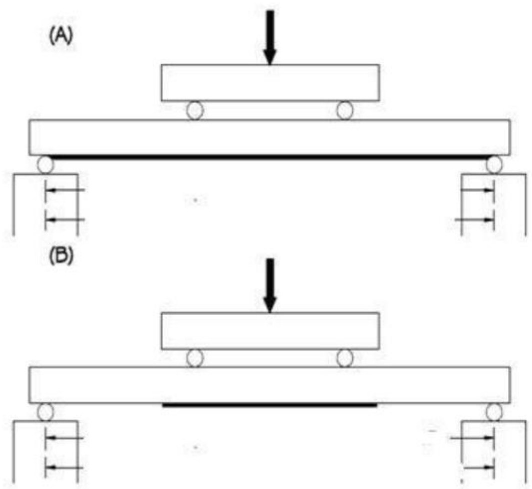

Fig 3. Wrapping scheme

6. TEST METHODS

The flexural behavior of the reinforced concrete beam is observed under two point loading. The test data are recorded and it will be interpreted for further comparison with CFRP wrapped beams. The reinforced concrete beam with glass fibre mixes is tested under the same loading conditions. The point at which the cracks occurred is noticed and the flexural strength of the beam is noted. The precracked beams are wrapped with CFRP laminates by using epoxy resins. Then the wrapped concrete samples are allowed to cure for one week. This concrete specimen is again tested with the same loading setup. The result data are tabulated, interpreted and the discussions are made based on the observed results. The test process of control beam and retrofitted beams are shown in figures.

Fig 4. Testing of control beam

Fig 5. Deflection and Crack patterns observed in control beam under loading

Fig 6. CFRP partially wrapped on its tension zone

Fig 7. Crack patterns observed in partially wrapping beam

Fig 8. CFRP fully wrapped on its tension zone

Fig 9. Crack patterns observed in fully wrapping beam

7. RESULTS

A result shows that as the addition of CFRP increases the strength.

Table 4. Load – Mid Span Deflection CONTROL BEAM

LOAD	LEFT	MID	RIGHT
0	0	0	0
0.5	0.15	0.65	0.15
1	0.61	0.99	0.61
1.5	1.33	1.72	1.33

Ultimate load = 2 TON

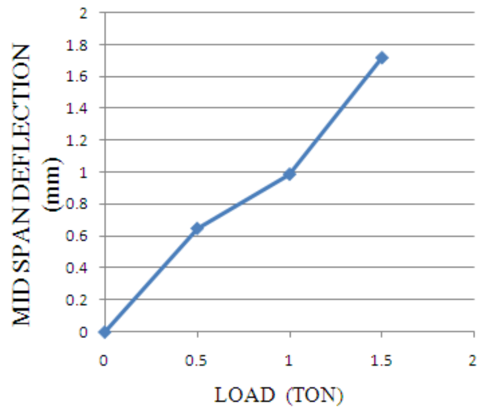

FIG 10. Load – Mid Span Deflection(CB)

Table 5. Load – Mid Span Deflection PWB FOR SINGLE LAYER

LOAD	LEFT	MID	RIGHT
0	0	0	0
0.3	0.08	0.2	0.08
0.6	0.15	0.37	0.15
0.9	0.36	0.70	0.36
1.2	0.55	1.10	0.55
1.5	0.77	1.47	0.77
1.8	1.15	2.14	1.15
2.1	1.46	2.63	1.46
2.4	1.79	3.18	1.79
2.7	2.30	3.72	2.30
3	2.89	4.49	2.89
3.3	3.37	5.13	3.37
3.6	3.70	5.68	3.70
3.9	4.22	6.25	4.22
4.2	4.74	7.09	4.74
4.5	5.10	7.68	5.10

Ultimate load = 5.4 TON

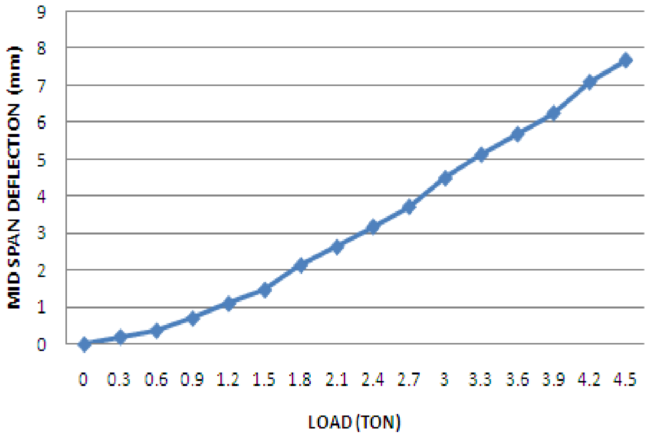

FIG 10. Load – Mid Span Deflection (PWB FOR SINGLE LAYER)

Table 6. Load – Mid Span Deflection PWB FOR TWO LAYERS

LOAD	LEFT	MID	RIGHT
0	0	0	0
0.3	0.23	0.26	0.23
0.6	0.38	0.42	0.38
0.9	0.55	0.65	0.55
1.2	0.88	1.12	0.88
1.5	1.25	1.89	1.25
1.8	1.73	2.35	1.73
2.1	2.28	3.05	2.28
2.4	2.68	3.63	2.68
2.7	3.24	4.48	3.24
3	3.62	5.12	3.62
3.3	4.20	5.75	4.20
3.6	4.66	6.50	4.66
3.9	5.24	7.14	5.24
4.2	5.65	8.15	5.65

Ultimate load = 5.7 TON

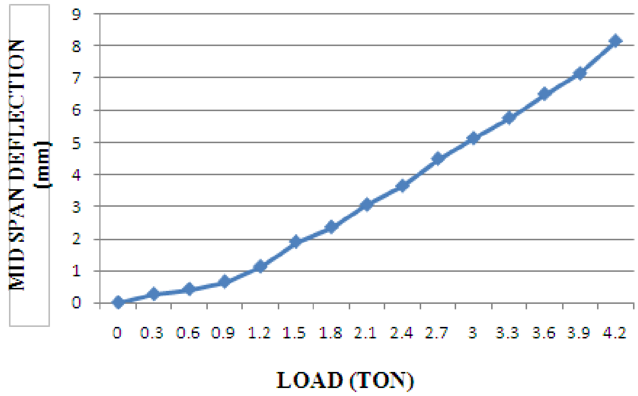

FIG 10. Load – Mid Span Deflection (PWB FOR TWO LAYERS)

Table 7. Load – Mid Span Deflection PWB FOR THREE LAYERS

LOAD	LEFT	MID	RIGHT
0	0	0	0
0.3	0.21	0.19	0.21
0.6	0.45	0.38	0.35
0.9	0.54	0.64	0.54
1.2	0.85	1.12	0.85
1.5	1.28	1.86	1.22
1.8	1.71	2.32	1.71
2.1	2.2	3.01	2.2
2.4	2.75	3.6	2.65
2.7	3.2	4.46	3.2
3	3.68	5.1	3.58
3.3	4.1	5.71	4
3.6	4.58	6.48	4.58
3.9	5.26	7.1	5.2
4.2	5.73	8.1	5.63

Ultimate Load-6.5 TON

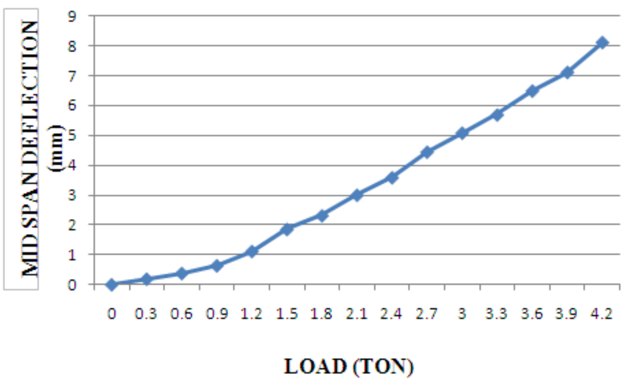

FIG 11. Load – Mid Span Deflection

(PWB FOR THREE LAYERS)

Table 8. Load – Mid Span Deflection FWB FOR SINGLE LAYER

LOAD	LEFT	MID	RIGHT
0	0	0	0
0.3	0.24	0.26	0.24
0.6	0.47	0.56	0.47
0.9	0.73	0.84	0.67
1.2	0.87	1.14	0.87
1.5	1.47	1.94	1.42
1.8	1.58	2.17	1.58
2.1	1.98	2.75	1.98
2.4	2.45	3.3	2.35
2.7	2.82	4.02	2.82
3	3.18	4.58	3.18
3.3	3.42	5.03	3.4
3.6	3.83	5.54	3.83
3.9	4.28	6.15	4.28
4.2	4.68	6.74	4.68
4.5	5.24	7.52	5.17
4.8	5.75	8.22	5.6

Ultimate Load-5.74 TON

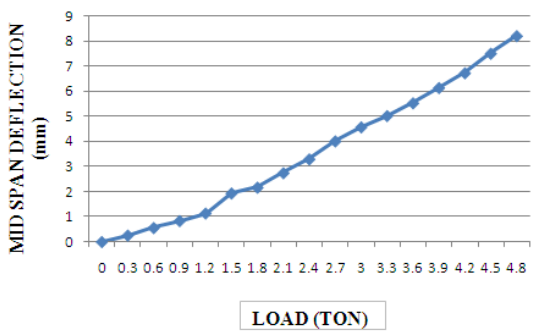

Fig 12. Load – Mid Span Deflection FWB FOR SINGLE LAYER

Table 9. Load – Mid Span Deflection FWB FOR TWO LAYERS

LOAD	LEFT	MID	RIGHT
0	0	0	0
0.3	0.25	0.29	0.25
0.6	0.44	0.48	0.44
0.9	0.63	0.68	0.63
1.2	0.84	0.93	0.84
1.5	1.22	1.35	1.22
1.8	1.52	1.83	1.52
2.1	1.92	2.36	1.92
2.4	2.37	2.96	2.37
2.7	3.62	3.66	3.62
3	3.82	3.92	3.82
3.3	4.43	4.34	4.43
3.6	4.93	4.95	4.93
3.9	5.34	5.64	5.34
4.2	5.59	5.94	5.59
4.5	6.20	6.54	6.20
4.8	6.34	6.96	6.34
5.1	6.78	7.54	6.78
5.4	7.32	8.19	7.32

Ultimate Load- 6.3 TON

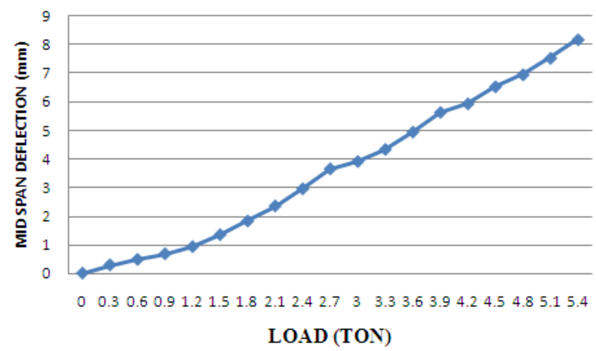

Fig 13. Load – Mid Span Deflection FWB FOR TWO LAYERS

Table 10. Load – Mid Span Deflection FWB FOR THREE LAYERS

LOAD	LEFT	MID	RIGHT
0	0	0	0
0.3	0.12	0.16	0.12
0.6	0.22	0.25	0.22
0.9	0.43	0.48	0.43
1.2	0.56	0.60	0.56
1.5	0.72	0.84	0.72
1.8	0.81	1.88	0.81
2.1	0.95	1.98	0.95
2.4	1.04	2.04	1.04
2.7	1.13	2.55	1.13

3	1.44	2.92	1.44
3.3	1.86	3.50	1.86
3.6	2.27	3.96	2.27
3.9	2.62	4.57	2.62
4.2	2.94	5.06	2.94
4.5	3.42	5.62	3.42

Ultimate Load-6.6 TON

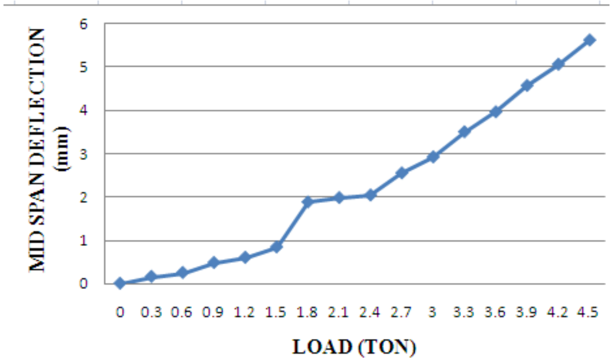

Table 10. Load – Mid Span Deflection FWB FOR THREE LAYERS

8. CONCLUSION

Based on the results obtained from experiments, following conclusions are drawn:

The external bonding of CFRP fabrics offers an externally effective means of strengthening Reinforced Concrete (RC) beams flexure.

CFRP fabric property bonded to the tension face of RC beams can enhance the flexural strength substantially the strengthened beams exhibit an increase in flexural strength for 40 to 45 percent for three layers static loading respectively.

A flexible system will ensure that bond line three layers CFRP strengthened beam does not break before failure and participate fully in structural resistant of the strengthened beams.

In flexural (FB) beams, the use of CFRP on the RC beam increased its ultimate load capacity.

It was found that the ultimate load bearing capacity of CFRP strengthened flexural beams with different reinforcement layouts were similar, while their failure mechanisms were different.

In this investigation CFRP strengthened beam gives appreciable strength and stability when compared to control beam.

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