International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-6, Issue-3, March 2019

Study On The Behaviour Of Reinforced Concrete Beams Using CFRP Laminates In Flexural Zone

Ramgopal.L, M. Abhinav

Abstract— **Repairing of RC structures has become increasingly important, especially in the last decade. Carbon Fiber Reinforced Polymer (CFRP) is one of the new materials used to strengthen or repair RC structures. This paper presents a study on the behaviour of Carbon Fiber Reinforced Polymer (CFRP) laminates as a flexural repair system for Reinforced Concrete (RC) beams. The objective of the study is to investigate the flexural behaviour of RC beams strengthened by carbon fiber reinforced plastic (CFRP) laminates. The experimental program includes testing of 3 simply supported reinforced concrete beams of which 2 beams are strengthened with CFRP laminates, the remaining 1 beam will be fully solid without CFRP laminates and considered as control beam. The deflection, cracking pattern and ultimate load carrying capacity for RC beams bonded with CFRP laminates will be investigated. Test results in the current study show that the structural performance has been improved and the load carrying capacity increases by 26.4% with respect to control specimen.**

Index Terms— **Carbon Fiber Reinforced Polymer (CFRP) Laminates, Flexural Strengthening, Retrofitting, Semi wrapping, Vertical strips.**

I. INTRODUCTION

In today's growing economy, infrastructure development is also raising its pace. Many. reinforced concrete structures are constructed annually around the globe. With this, there are large numbers of them which deteriorate or become unsafe to use because of the changes in use, changes in loading, change in design configuration, inferior building material used or natural calamities. Thus repairing and retrofitting these structures for safe usage of these structures is on increasing trend. There are several situations in which a civil structure would require strengthening or rehabilitation due to lack of strength, stiffness, ductility and durability. Advanced composites are likely to play a significant role in future construction applications particularly in the strengthening and rehabilitation of existing structures.

Carbon-fiber-reinforced polymer (CFRP) has become a notable material in structural engineering applications. Studied in an academic context as to its potential benefits in construction, it has also proved itself cost-effective in a number of field applications strengthening concrete, masonry, steel, cast iron and timber structures. Its use in industry can be either for retrofitting to strengthen an existing structure or as an alternative reinforcing material instead of steel from the outset of a project. Retrofitting has become increasingly dominant in Civil Engineering, and its applications include increasing the load capacity of old structures that were designed to tolerate far lower service loads than they are experiencing today, seismic retrofitting and repair of damaged structures. Retrofitting is popular in many instances as the cost of replacing the deficient structure can greatly exceed its strengthening using CFRP.

Ramgopal.L, Assistant Professor, Department of Civil Engineering, Chalapathi Institute of Engineering and Technology, Guntur, Andhra Pradesh, India.
M. Abhinav, Assistant Professor, Department of Civil Engineering, Chalapathi Institute of Engineering and Technology, Guntur, Andhra Pradesh, India.

Applied to reinforced concrete structures for flexure, CFRP typically has a large impact on strength but has only a moderate increase in stiffness. This is because the material used in this application is typically very strong but not particularly stiff. As a consequence, only small cross-sectional areas of the material are used. Small areas of very high strength but moderate stiffness material will significantly increase strength, but not stiffness. Wrapping around sections can also enhance the ductility of the section, greatly increasing the resistance to collapse under earthquake loading. Such 'seismic retrofit' is the major application in earthquake-prone areas, since it is much more economical than alternative methods.

II. RELATED STUDIES

[1] Shahawy et al investigated the flexural behavior of RC rectangular beams with epoxy bonded CFRP laminate. The additional external reinforcement due to the bonding of one, two and three CFRP laminates to the surface of the reinforced concrete beams increased their ultimate flexural capacity by 13%, 66% and 92% respectively. Deflections for the laminated beams exhibit a significant reduction with increasing number of CFRP laminates. [2] Ashour studied the flexural response of 16 RC continuous beams using CFRP laminates. Increasing the CFRP sheet length to cover the entire negative or positive moment zones did not prevent peeling failure of the CFRP laminate and was found to be ineffective when tensile rupture of the CFRP sheets was the failure mode. [3] Rabinovitch and Frostig had done an experimental and analytical comparison of of RC beams strengthened with CFRP composites. Two beams were preloaded up to failure before strengthening and the ability to rehabilitate members that endured progressive or even total damage was examined. The retrofitting process regained the original flexural capacity of the damaged beams and even increased it by more than 90%. [4] Laura Anania et. al investigated the flexural performance of RC beams strengthened with CFRP materials. At the soffit of the original beam, a joist of polyurethane was inserted, connected at its ends to two blocks made of reoplastic mortar, whose function was that of anchorage. There was an increase in the bearing capacity of the beam to more than 70% in respect to the original beam. This technique seemed to be very promising for its short time of execution as well as for its limited cost. [5] Jumaat and Alam investigated the structural behaviour of

externally bonded steel plates and CFRP laminates flexurally strengthened RC beams. The CFRP laminate strengthened RC beam had higher failure load than beam strengthened with steel plate even though both beams were designed for same strength. [6] Alaa morsy and El tony Mahmoud studied the effect of mechanical bonding for the CFRP laminates with the concrete substrate to enhance the flexural beam capacity using square steel plate bonded and pressing on the CFRP laminate surface and fastened with 10 mm steel rivets to prevent laminate de-bonding. Externally bonded CFRP laminates was an effective method to strengthen the reinforced concrete beams and improved the structural load carrying capacity. [7] Asad ur Rehman Khana and Shamsoon Fareeda investigated the behaviour of RC Beams Strengthened by CFRP Wraps with and without End Anchorages. Ultimate load carrying capacities of the strengthened beams increased up to a maximum of 16.7% and 20.8% over control beam respectively. [8] Alnadher ali et. al investigated the use of CFRP mechanical anchorage of CFRP sheets and plates used to externally strengthen reinforced concrete beams under flexure. The beams with anchors generally have higher delamination load than their companion beams without anchors. The beams strengthened with sheets and plates anchored by CFRP anchored have the smallest ductility. A number of strengthening technique of RC beams bonded with various FRP composites were observed in various experimental studies. Based on the experimental studies, using carbon fibre reinforced polymer (CFRP) laminates has proved to be an effective means of upgrading and strengthening reinforced concrete beams.

III. EXPERIMENTAL PROGRAM

Three beams were casted and tested. All beams were of identical rectangular cross-section and of same size. The cross sectional dimensions were 150mm x 200mm and length 1800mm. All beams were tested in two-point bending over a simple span as shown in Fig.1. The load was applied by means of load cell with 40T capacity capable of applying a concentrated load. Variables in the test plan included different pre-damaging level in loading history. One beam was used as control specimen and the two beams were strengthened in flexure using CFRP laminates under different loading level. All beams used in this study had 4#10mm bars in bottom, 2#8mm bar at the top. 15 stirrups of 6mm bars were spaced at 150 mm c/c. The reinforcement details of all beam with cross section is shown in Fig.2.

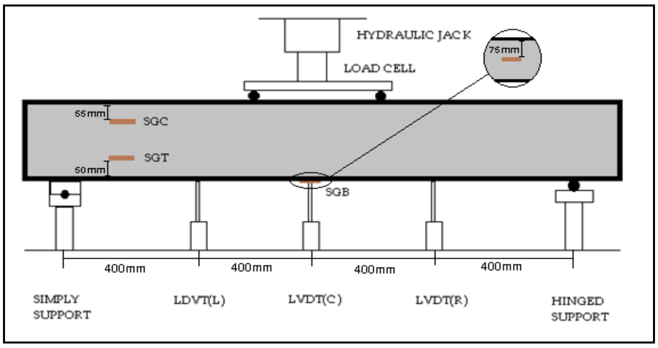

Fig. 1 Experimental Setup of RC beam for testing

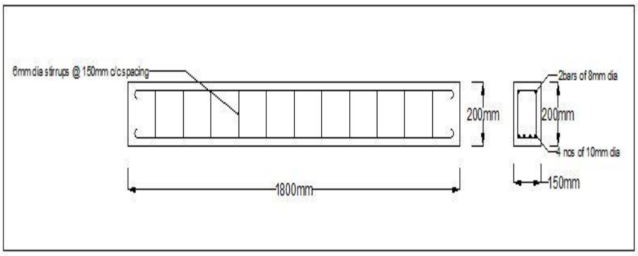

Fig. 2 Reinforcement details of beam

Linear voltage displacement transducers (LVDT) and strain gauges were used to monitor the deflection and strain respectively.

IV. MATERIAL PROPERTIES

Concrete was designed with M20 grade according to Indian Standard code for *Concrete mix design* of IS 10262-2009. Nine concrete cube specimens of dimensions 150mm x 150mm x 150mm were made at the time of casting and were kept with the beams during curing. The average 28 days concrete cube strength was 25.4 Mpa.

Nitowrap CFP 50 and Nitowrap CFP 100 CFRP laminates were used as repair material for strengthening the damaged RC beams. The properties of CFRP laminates is shown in Table 1. Adhesive used for bonding CFRP laminates to RC beams is Nitowrap 40. The compression of adhesive Nitowrap 40 is 40N/mm^2 at 1 day and 75 N/mm^2 at 7days, shear strength was 13 N/mm^2. The mix ratio of adhesive agent of base and harderner is 2:1 and the pot life of mix is 30 min. @ 40^{o}c. Initial cure of adhesive is 4-6 hours and full cure is 7 days.

Nitowrap CFP50/100	CFP 50	CFP 100
Nominal thickness	1.2mm	1.2mm
Nominal width	50mm	100mm
C/S area	60mm^2	120mm^2
Young's modulus	>165000 N/mm^2	>165000 N/mm^2
Tensile strength	>2800 N/mm^2	>2800 N/mm^2
Elongation at break	1.7%	1.7%

Table 1. Properties of CFRP

V. STRENGTHENING TECHNIQUE

The first beam is damaged at ultimate load and the second beam is damaged at factored load. Control beam was fully damaged in flexure. Grouting was done to repair the cracks. Three holes were drilled on side face of RC beam with diameter of 19mm upto depth of 100mm. Cera Fill 45 Premium and Cera plug was used as an agent for grouting process. Grouting was done by manually using high pressure cement grout pump. Cera polly crack filler and Cera latex SBR was used as an agent of repairing and filling cracks. After the cracks were repaired, surface preparation was done for bonding CFRP laminates with RC beams. For bonding the CFRP laminates with the RC beams, Nitowrap 40 epoxy primer was used.

VI. DETAILS OF SPECIMEN

After all the beams were repaired, CFRP laminates were used for strengthening the RC beam with different wrapping schemes as shown in Fig.3(a)-(c). Table 2 shows the details of all test specimen.

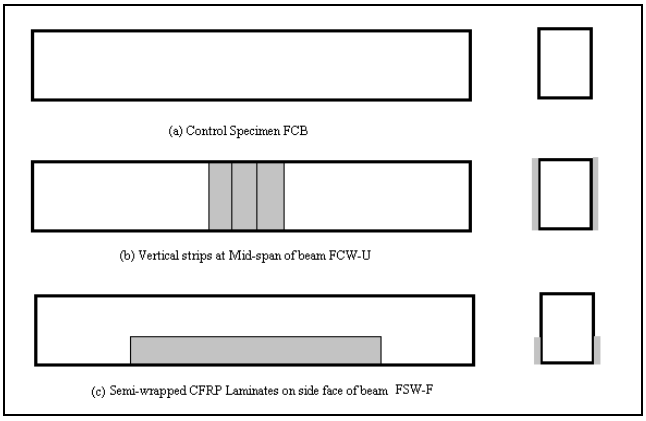

Fig.3 Wrapping of CFRP laminates

Beam Designation	Pre-Damaged Level	Retrofitting scheme	CFRP laminates
FCB	None	None	
FCW-U	Ultimate load (100kN)	vertical strips of Nitowrap CFP 100 at mid-span	6 strips of dimension 100mm x 200mm x 1.2mm each
FSW-F	Factored load (90kN)	Semi wrapping of Nitowrap CFP 50 on both sides	4 strips of dimension 1000mm x 100mm x 1.2mm each

Table 2. Details of all test specimen

VII. TEST RESULTS

Beams were tested under two point bending. Control beam FCB failed in flexure-shear with initial crack occurring at 22.3kN and ultimate load at 100.1kN. Flexural failure occurred due to yielding of steel followed by crushing of concrete in compression zone as shown in Fig.4(a). The beam FCW-U which was strengthened with vertical strips of CFRP laminates at mid-span of beam on both faces of beam failed in flexure by laminates rupture with initial crack occurring at 25.1kN and ultimate load at 120.1kN. The cracks have evenly occurred along the edges of CFRP laminates as shown in Fig.4(b). The beam FSW-F which was strengthened by semi-wrapping of CFRP laminates on both side faces of the beam had higher initial crack load of 47.8kN and higher ultimate load capacity of 126.5kN compared to contol beam. The structural performance of the beam increases by 26.4% in ultimate load capacity and 114% in initial crack load compared to control beam. This particular beam failed in shear by laminates rupture with cracks occurring along the edges of CFRP laminates and in shear zone as shown in Fig.4(c).

Fig.4(a) FCB specimen

Fig.4(b) FCW-U specimen

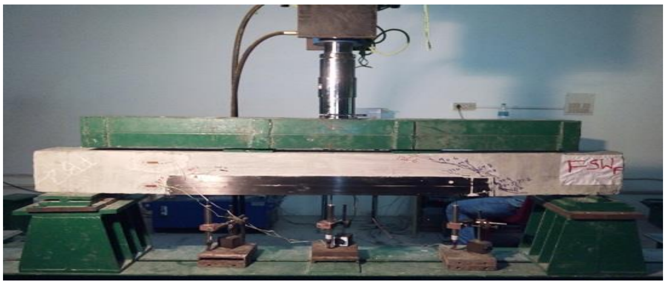

Fig.4(c) FSW-F Specimen

A. Load-Deflection graph

Three Linear Voltage displacement transducers (LVDT) have been used to monitor deflection in each beam. One LVDT-C was kept at mid-span and the other two LVDT-R and LVDT-L were kept at 400mm from each support end. Control beam FCB failed in flexure with deflection of 10.9mm as shown in Fig.5(a). The beam FCW-U strengthed with CFRP laminates showed higher deflection upto 23.8mm as shown in Fig.5(b). The beam FSW-F with semi-wrapped CFRP laminates in both sides of beam showed lesser mid-span displacement than other beams as shown in Fig.5(c). Table 3 shows the experimental results of all the tested beam.

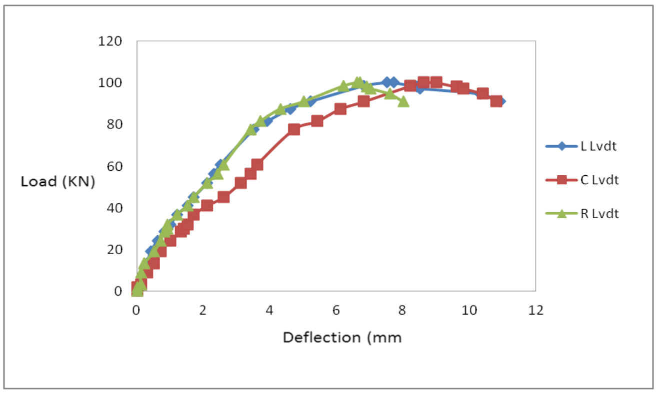

Fig.5(a) Load Vs Deflection of FCB specimen

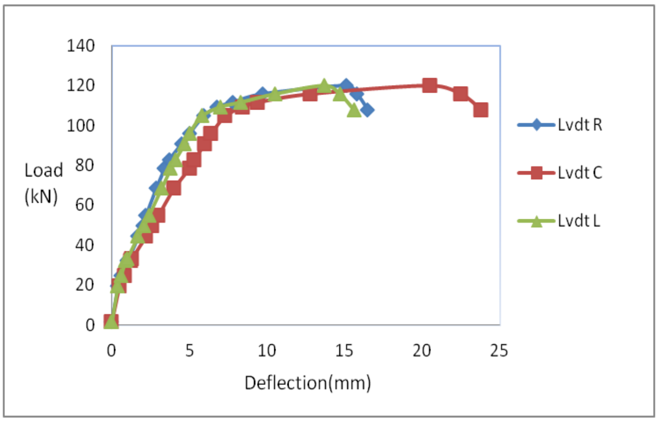

Fig.5(b) Load Vs Deflection of FCW-U specimen

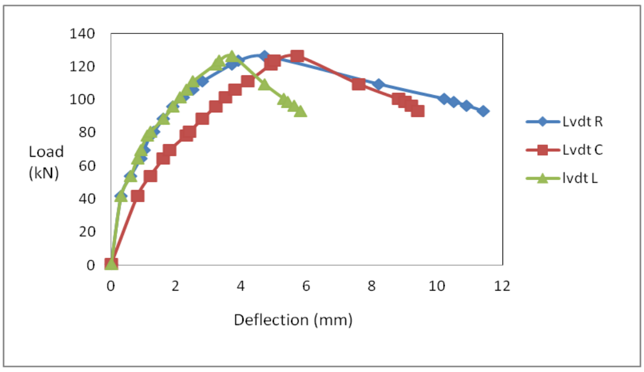

Fig.5(c) Load Vs Deflection of FSW-F specimen

The load Vs mid-span deflection of all the beam are shown in Fig.6

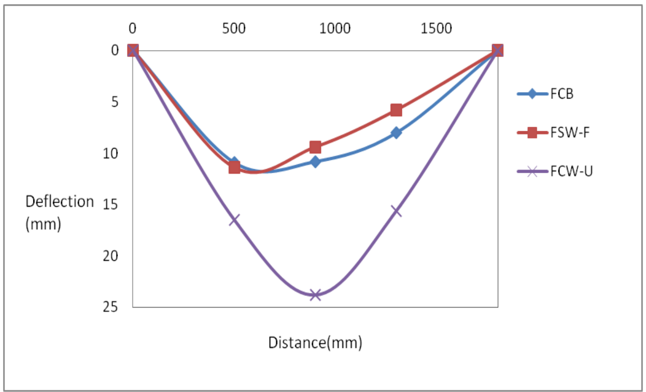

Fig.6 Load Vs Mid-span deflection

Beam Specimen	**Initial crack load (kN)**	**Ultimate load (kN)**	**% increase**	**Deflection at mid-span (mm)**
FCB	22.3	100.1	-	10.8
FCW-U	25.1	120.1	19.9	23.8
FSW-F	47.8	126.5	26.4	9.4

Table 3. The experimental results of all the beams tested.

B. Load- Strain graph

Three Strain gauges were used to monitor the strain in all beams. The strain gauges is placed in compression zone SGC on side face of beam, tension zone SGT on side face of beam and bottom tension face of beam SGB. Fig.7(a)-(c) shows the Load Vs strain graph for all the beams. Fig.8 shows the load-bottom tension strain graph for all the beams.

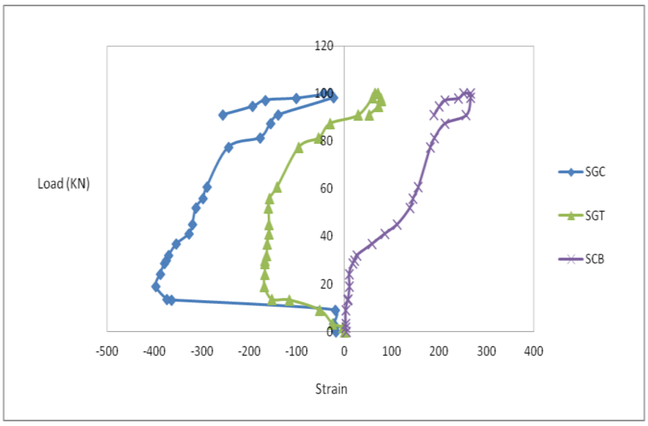

Fig.7(a) Load Vs Strain for FCB specimen

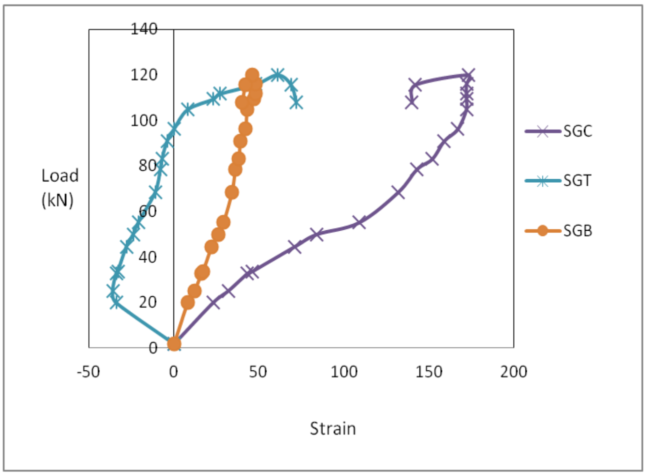

Fig.7(b) Load Vs Strain FCW-U specimen

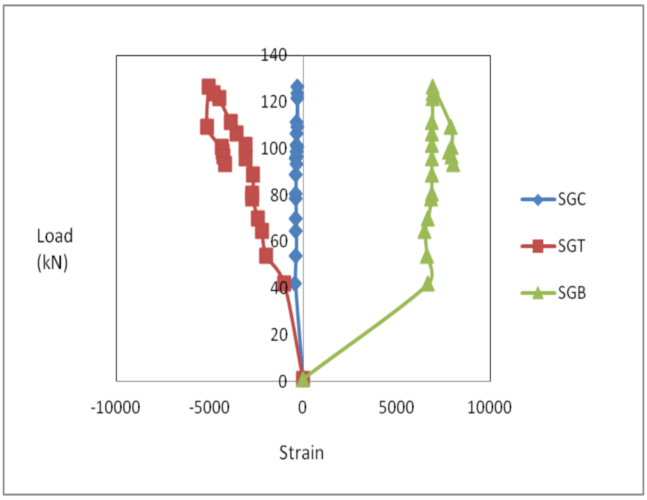

Fig.7(c) Load Vs Strain for FSW-F specimen

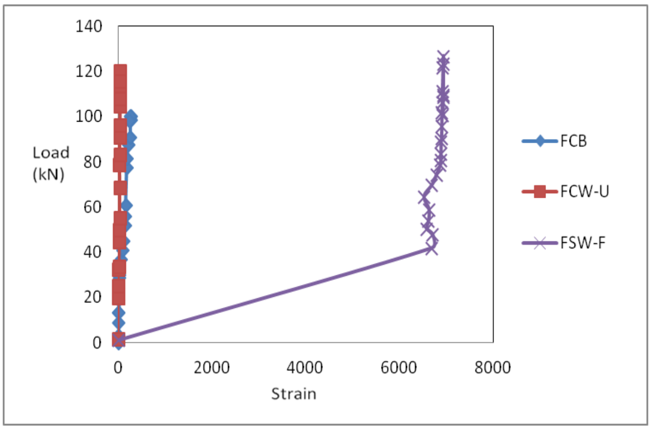

Fig.8 Load Vs Bottom Strain for all specimen

As the load increases upto ultimate load capacity, the strain measured in all the beams become non-linear. The Beam FSW-F showed maximum strain variation compared to other other beams. The beam FCW-U showed lesser strain variation than the control beam.

VIII. CONCLUSION

The following conclusions are drawn from the experimental study on the behaviour of RC beams strengthened with CFRP laminates in flexure

- All the beams strengthened with CFRP laminates showed improvement in the structural performance.
- The ultimate load carrying capacity of strengthened RC beams FSW-F increased up to a maximum of 26.4% over the control specimen.
- Beam FSW-F was expected to fail in flexure but failed in shear. This beam obtained the maximum load carrying capacity and lesser displacement compared to other beams.
- Beam FSW-F showed increase in first crack load as much as 114% than that of respective control beam.
- CFRP laminates proved to be effective material for repair and strengthening of beam. Further investigation can be done with even more wrapping schemes for better improvement in structural performance of beam.

REFERENCES

[1] Shahawy M.A, Arockiasamy M, Beitelmant T and Sowrirajan R, ‘Reinforced concrete rectangular beams strengthened with CFRP laminates’, *Composites: Part* B 27B (1996) pg. 225-233

[2] Ashour A.F, El-Refaie S.F, Garrity S.W, ‘Flexural strengthening of RC continuous beams using CFRP laminates’ *Cement & Concrete Composites, vol. 26 (2004), pg. 765–775*

[3] Rabinovitch O, Frostig Y, ‘Experiments and analytical comparison of RC beams strengthened with CFRP composites’, *Composites: Part B 34 (2003) pg.663–677*

[4] Laura Anania, Antonio Bada, Giusy Failla, ‘Increasing the flexural performance of RC beams strengthened with CFRP materials’, *Construction and Building Materials vol 19 (2005) pg. 55–61*

[5] Jumaat M.Z, Alam A, ‘Experimental and Analytical Investigation on the Structural behaviour of Steel plate and CFRP laminate flexurally strengthened reinforced concrete beams’, *Journal of Applied Sciences, vol 8(23) (2008) pg. 4383-4389*

[6] Alaa Morsy, El Tony Mahmoud, Bonding techniques for flexural strengthening of R.C.beams using CFRP laminates’, *Ain Shams Engineering Journal , vol 4 (2013), pg.369–374*

[7] Asad ur Rehman Khan, Shamsoon Fareed, ‘Behaviour of Reinforced Concrete Beams strengthened by CFRP Wraps with and without End Anchorages’, *Procedia Engineering vol 77 (2014) pg. 123 – 130*

[8] Alnadher Ali, Jamal Abdalla, Rami Hawileh, Khaled Galal, ‘CFRP mechanical anchorage for externally strengthened RC beams under flexure’, *Physics Procedia vol. 55 (2014) pg.10 – 16*

[9] Barros J.O.S, Fortes A.S, ‘Flexural strengthening of concrete beams with CFRP laminates bonded into slits’, *Cement & Concrete Composites 27 (2005) pg.471–480*

[10] Dai J.G, Ueda T, Sato Y and Ito T,’Flexural strengthening of RC beams using externally bonded FRP sheets through flexible adhesive bonding’ *Proceedings of the International Symposium on Bond Behaviour of FRP in Structures (2005) pg. 205-214*

[11] Esfahani M.A, Kianoush M.R, Tajari A.R, ‘Flexural behaviour of reinforced concrete beams strengthened by CFRP sheets’, *Engineering Structures vol 29 (2007) pg. 2428–2444*

[12] El-Ghandour A.A, ‘Experimental and analytical investigation of CFRP flexural and shear strengthening efficiencies of RC beams’ *Construction and Building Materials vol 25 (2011) pg. 1419–1429*

[13] Hiroki Sakurabaa, Takashi Matsumoto and Toshiro Hayashikawa,’A Study on the Flexural Behavior of CFRP Box Beams with Different Laminate Structures’*Procedia Engineering vol. 14 (2011) pg. 1845–1854*

[14] Taerwe L, Vasseur L & Matthys S, ‘External strengthening of continuous beams with CFRP’ *Concrete Repair, Rehabilitation and Retrofitting II – Alexander et al (eds) (2005) pg. 43-53*

[15] Moatasem M. Fayyadh, Hashim Abdul Razak, ‘Assessment of effectiveness of CFRP repaired RC beams under different damage levels based on flexural stiffness’, *Construction and Building Materials vol. 37 (2012) pg.125–134*