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Experimental Behavior of RC Beams Strengthened by Externally Bonded CFRP with Lap Splice

S. K. Elwan[*1], T. A. Elasayed[2], W. Refaat[3], and A. M. Lotfy[4]
[1]*Department of Civil Eng., The Higher Institute of Engineering, El Sherouk City, Cairo, Egypt*

Abstract:- Carbon fiber-reinforced polymers (CFRP) laminates, or plates, offer very high-strength potential; however, handling of long pieces of these flexible plates can present challenges under field conditions. The development of methods for splicing CFRP plates will enhance the versatility and Practicality of using these materials in field applications. This paper studies the efficiency of CFRP lap splice in externally bonded CFRP flexural strengthened reinforced concrete beams. Seven half-scale beams with different conditions were tested in two-point bending until failure. Two groups were tested; the first one includes control specimens: the first without CFRP strengthening, the second strengthened with full length and without splice, and the third with cut-off at middle of the beam. All specimens in the second group having cut-off at the middle and with lap splice lengths equal 300, 450, 600, 900 mm. respectively on each side of the cut-off. The study illustrates the effect of confinement on the first crack load, failure load, mid-span deflection, and strain in both reinforcement and CFRP.

The failure load was also predicted analytically by CEB-FIP (1993), adopting the traditional sectional analysis for strain compatibility. Instead of strain measuring, three accurate bond-slip models are used to provide accurate prediction for the contribution of CFRP in the flexural capacity of the strengthened beam since all strengthened beams are failed by interfacial debonding of CFRP.

Keywords: Carbon Fiber-Reinforced polymer (CFRP); CFRP Sheets; Debonding Failure; Externally- bonded; Flexure strengthening; Lap Splice; RC Beams.

I. INTRODUCTION

CFRP laminates and fabrics are currently being studied and used for the rehabilitation, repair, and retrofit of concrete structures. FRP composite materials are becoming popular in civil engineering applications due to their high strength to weight ratio, durability, as well as ease of installation. These CFRP materials can be externally bonded to the tension side of concrete structures with any desirable shape with a thin layer of epoxy adhesive and thus enhance stiffness and strength of the structure to be strengthened. Beams flexurally strengthened with conventionally bonded FRP laminates exhibits increased strength and stiffness. Significant improvements in ultimate load capacity, and to a lesser extent, flexural stiffness are seen in many research studies.

Swiss researchers pioneered work on the use of FRP as a replacement for steel in plate bonding applications (Meier and Kaiser, 1991) and numerous researchers have shown that the concrete rehabilitation using FRP is very successful application at retrofit or increasing the strength of reinforced concrete members (El-Badry, 1996; Tamuzs and Tepfers, 2004). The basic concepts in the use of FRPs for strengthening of concrete structures are covered in a review article (Triantafillou, 1998). Some of researches (Meier and Kaiser, 1991; Saadatmanesh and Ehsani, 1991) have shown that Fiber Reinforced Polymer (FRP) composites in strengthening RC members, in the form of sheets, have emerged as a viable, cost effective alternative to steel plates. An overview of twenty – three different studies showed that one third of the strengthened beams showed strength increases of 50 percent or more along with considerable increases in stiffness (Bonacci and Maalej 2001).

Many studies have presented a wide variety of failure modes observed in retrofit concrete beams (Meier et al., 1992); these failure types are FRP rupture, flexural compression crushing, shear failure, FRP interfacial debonding or concrete cover separation as presented by (Ascione and Feo, 2000), and (Bonacci and Maalej, 2000; Bonacci and Maalej, 2001). The criteria for each of these failures are affected by various parameters in the design of a FRP retrofit concrete beam.

Based on experimental results conducted by (Teng et al., 2003), the most common failure mode is due to de-bonding of FRP plate or ripping of the concrete cover. These failure modes are undesirable because the FRP plate cannot be fully utilized. Premature failure modes are caused by interfacial shear and normal stress concentration at FRP cut-off points and at flexural cracks along the beam. The end peel mode starts at the ends of the plates and propagates inwards along the beam. Inclined and horizontal cracks form in the concrete causing it to break away from the beam while remaining firmly attached to the plate. This mode has been investigated experimentally and analytically by many researchers (Jones et al., 1988; Saadatmanesh and Malek, 1997; Rabinovich and Frostig, 2000). The peeling of CFRP composite may cause a sudden and catastrophic failure of the structure.

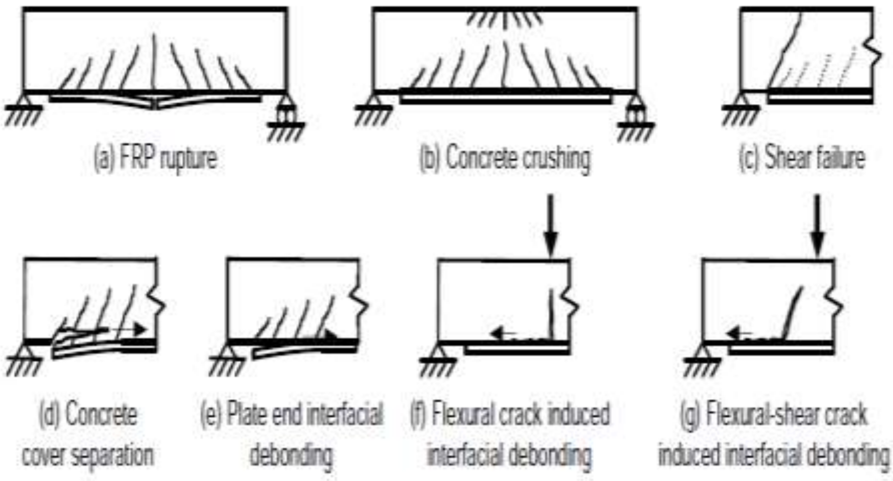


Figure 1: Failure modes of strengthened beams with CFRP laminate

Few studies in the literature have explored the use of butt joints reinforced by lapped splice plates as a means of splicing CFRP plates. The report prepared by Porter M, and Stalling J, (2001) provide a foundation for studying the potential problems associated with the use of splice plates. Eight reinforced concrete beams were used to test the flexural performance of beams externally reinforced with epoxy bonded CFRP primary and splice plate. The major problem identified was the presence of high normal strain levels occurring in the primary plate at the ends of splice plates, which results in high shear stresses in the adhesive bond between the primary and splice plate. During all tests, some degree of splice debonding occurred. As a result for splice debonding, the ultimate capacity of the CFRP sheet was not fully utilized. By the use of dummy plate, it was determined that splice plate debonding was not dependent on the presence of a butt joint in the primary plate. This lead to the fact that an accurate bond slip model is of fundamental importance in the modeling of CFRP strengthened RC structures.

In the work done by Lu X.Z. et al. (2005), a set of three bond-slip models with different levels of sophistication is proposed. These three models are not based on axial strain measurements on the FRP plate; instead, they are based on the prediction of a meso-scale finite element model, with appropriate adjustment to match their predictions with the experimental results for a few key parameters. Through the comparison with the large test database, all three bond-slip models are shown to provide accurate predictions of both the strength (i.e the ultimate load) and the strain distribution in the FRP plate.

In this paper, particular emphasis is directed towards investigating the efficiency of CFRP lap splice in externally bonded CFRP flexural strengthened reinforced concrete beams. Also, the study aimed at developing analytical model for predicting the failure load caused by interfacial debonding, using section analysis based on strain compatibility, and bond-slip models.

II. TESTING PROGRAM

This section describes the experimental work performed through this study beginning with the used materials, specimen's details, measurement devices, test setup, and specimen's grouping.

2.1. Materials Used

All specimens are made from one concrete mix of compressive strength, f_{cu} = 25 MPa, and according to the EN the equivalent compressive cylinder strength, $f_c^{'}$ = 20 MPa. The specimen's main reinforcement (longitudinal) is high grade deformed steel bars with 360 MPa nominal yield stress while the lateral reinforcement (stirrups) is mild smooth bars with 240 MPa nominal yield stress. The mechanical properties of the used CFRP plates for structural strengthening (Sika CarboDur S512) and the adhesive for bonding laminates with concrete (Sikadur 30) are illustrated in Table (1).

Table 1: Mechanical properties of used CFRP plates and adhesive

Material Property	*Sikadur 30*	*Sika CarboDur S512*
Dimensions (mm.)	-	*50 x 1.20*
Compressive Strength (MPa)	*62.00*	-
Tensile Strength (MPa)	*24.80*	*2800*
*Shear Strength (MPa) to F.I.P**	-	*15.00 (Concrete Failure)*
*Adhesive Strength (Mpa) to F.I.P**	*18.60 (Bond Strength)*	*4.00 (Concrete Failure)*
Flexural Strength (Mpa)	*46.80*	-
Young's Modulus (MPa)	*4482*	*165000*
Ultimate Tensile Strain	-	*0.0155*

2.2. Specimens Details

Seven half-scale RC beams, of 400 mm deep by 200 mm wide cross section, were statically tested to failure in two-point bending. All beams were 2200 mm long over 2000 mm clear span, and were reinforced by two 12 mm diameter bottom bars, two 10 mm diameter top bars (stirrups hanger), and 8 mm diameter stirrup every 166 mm, as shown in Fig. 2.

Tested beams were divided in two groups. Fig. 3 shows that group (A) consisted of three beams; the first (B_C) is the control one without strengthening, and the second (B_F) strengthened in flexure by one soffit plate (500 mm wide x 1.20 mm thick), symmetrically positioned about the middle of the span covering the full unsupported length. The third (B_{FC}) is the same as the second but with CFRP sheet having cut-off at the middle of the beam. Group (B) consisted of four beams (B_{FC300}, B_{FC450}, B_{FC600}, B_{FC900}) having middle cut-off and with total lap splice plate lengths equal 300, 450, 600, and 900 mm., respectively.

The CFRP plates were applied according to the manufacturer's specifications and the ACI 440.2R-08. They were traditionally installed by the application of the epoxy resin adhesive to the concrete substrate, after grinding and smoothing the concrete surface, followed by manual sheets' placement and pressing onto the adhesive with a rubber roller.

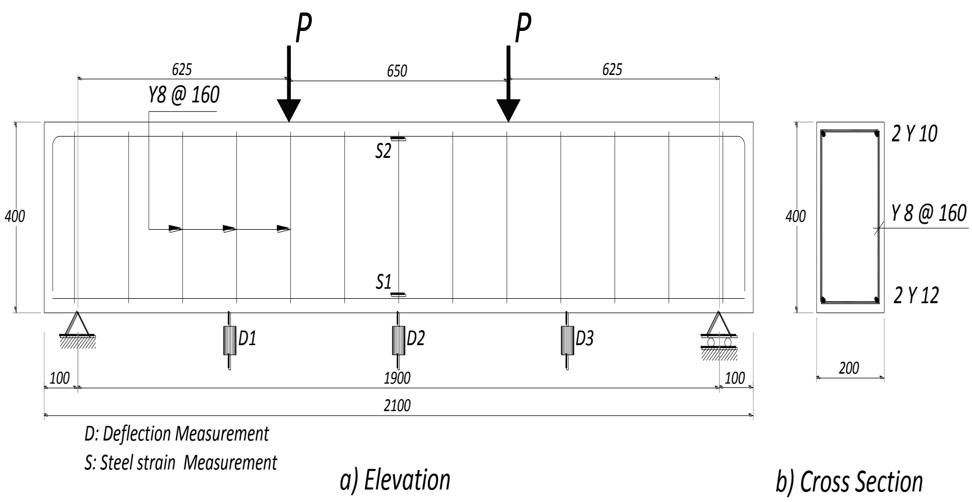


Figure 2: Reinforcement details of beams, deflection and steel strain measurement locations

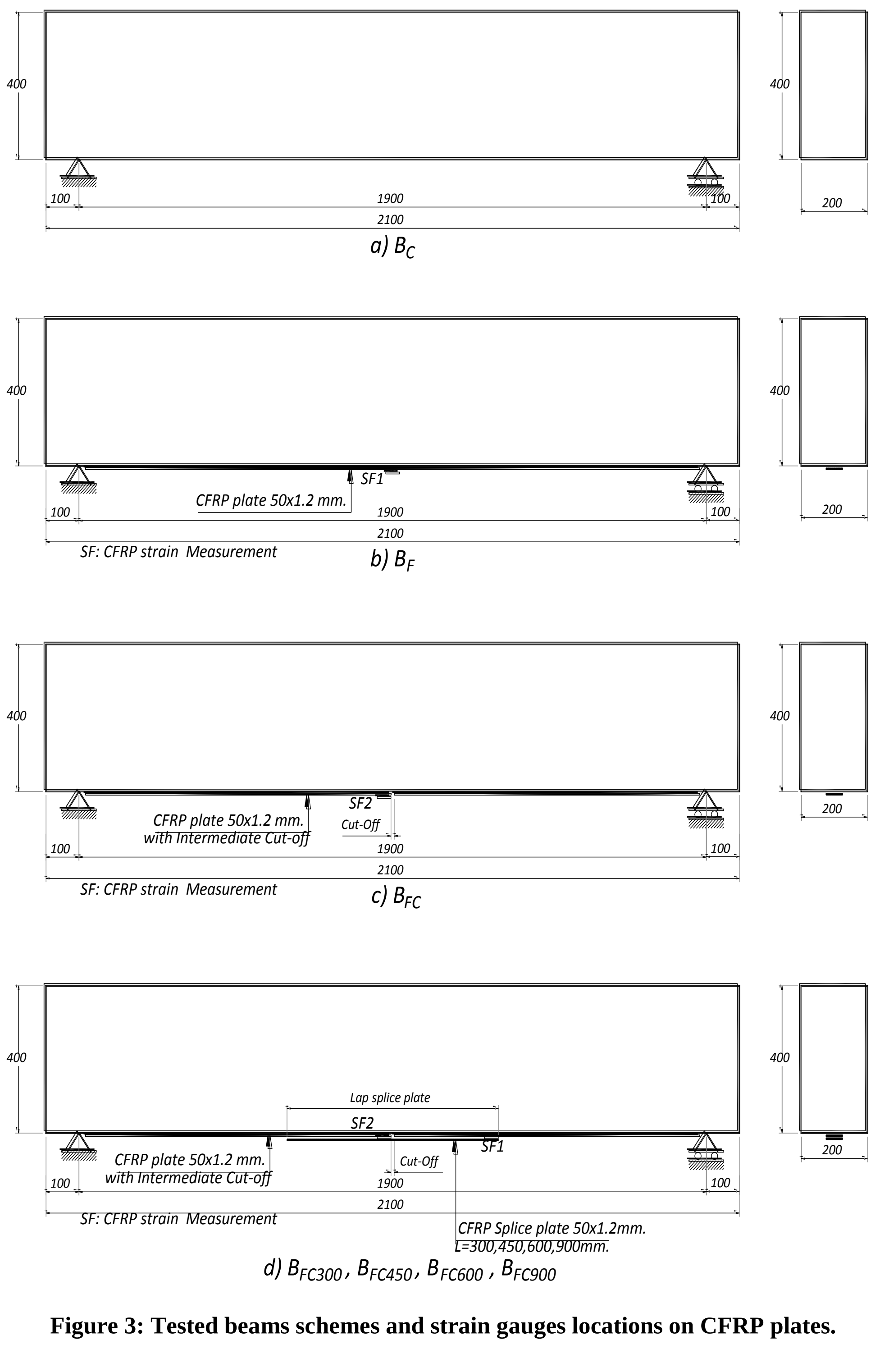


Figure 3: Tested beams schemes and strain gauges locations on CFRP plates.

2.3. Test Setup and Instrumentation

All specimens were statically tested using rigid steel frame. The load was manually and monotonically increased up to failure using a hydraulic jack of 1000 kN capacity. Each increment (5 kN) was applied for 2 minutes and at the end of which the load was held constant for measurements and observations. Three dial gauges with accuracy 0.01 mm was used to measure the quarters (D1 and D3) and mid span (D2) deflections as shown in Figure (3). The mid-span tensile steel strain (S1) was measured by one electrical strain gauge of 20-mm length and 120-Ohm resistance. Another three similar gauges (SF1, SF2, and SF3) were used to measure the CFRP tensile strains as shown in Fig.(2). Cracks were also detected and marked.

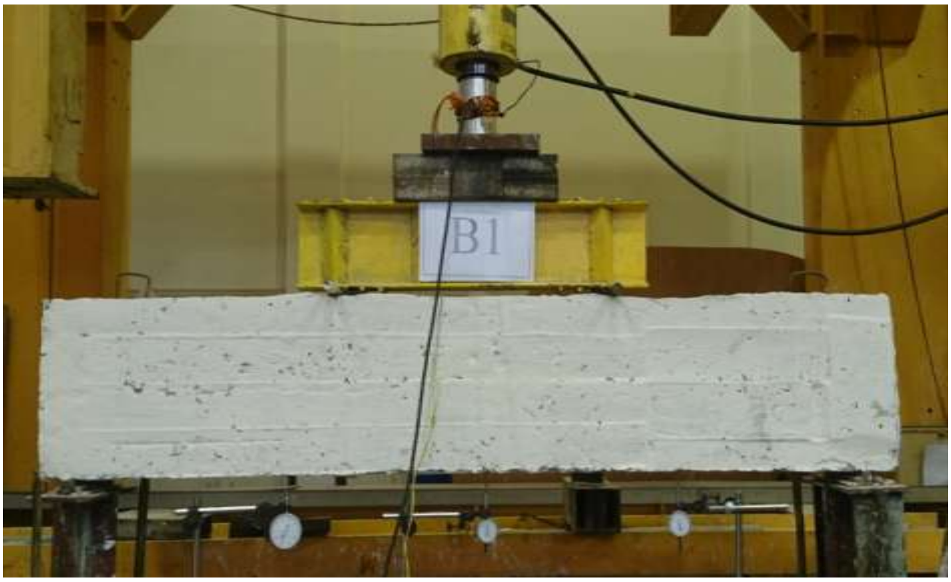


Figure 4: Typical Test setup

III. TEST RESULTS AND DISCUSSIONS

This section describes the experimental test results and discussion concerning ultimate loads, load-deflection relationship, strain in steel rebar and CFRP laminate, and failure patterns. Table (2) shows the experimental results of the tested specimens.

3.1 First Cracking and Ultimate Loads

From the experimental investigation, the first cracking load and the ultimate capacity of the strengthened (control) tested beams are as in Table 2. The control beam failed by yielding of steel tension reinforcement in a traditional flexural failure. In general, different CFRP strengthened reinforced concrete beams without and with lap splice plates (B_F, B_{F300}, B_{F450} , B_{F600} and , B_{F900}) showed significant increases in first cracking and ultimate capacities as compared to that of control beam. From the experimental results, it is identified that the average percentage increase of cracking and ultimate loads of CFRP strengthened beams are 22.6% and 40.5% respectively.

The increase in first crack load of strengthened beams can be attributed to the increase of stiffness due to the laminates restraining effects. On the other hand the strengthened beam with cut-off at the middle without lap splice shows almost the same cracking load of the control beam. This was due to the effect of cut-off which allows and not prevents the first tensile crack in the middle of the beam (the cut-off location). However, for beams with lap splice, a slight increase in the ultimate capacity compared to the beam with continous CFRP laminate was recorded. Thus, it is concluded that the strengthened beams with CFRP laminate having cut-off with lap splice plate can back up the flexural enhancement of the strengthened beam with CFRP laminate having full length without cut-off.

Table 2: Experimental results

Beam Code	Cracking Load P_{cr} (kN)	Failure Load P_u (kN)	Deflections (mm)			Max. Steel strain (*10 $^{-6}$)	Max. CFRP Strain (* 10 $^{-6}$)		Failure mode
			D1	D2	D3	(S1)	(SF1)	(SF2)	
B_C	48.3	112	-	4.43	-	2142	-	-	Flexural
B_F	58.4	155.8	-	5.42	-	2148	2995	-	Debonding
B_{FC}	47.4	128.5	-	4.98	-	3240	119	477	Flexural
B_{FC300}	61	156.5	-	5.35	-	2464	1230	1030	Debonding
B_{FC450}	57.4	155	-	5.40	-	2084	1490	2950	Debonding
B_{FC600}	61	159.7	-	5.31	-	2329	1451	730	Debonding
B_{FC900}	58.2	160	-	5.55	-	2304	2930	1290	Debonding

3.2 Load-Deflection Relationship

The load-deflection relationship of the control beam and beams strengthened with CFRP laminates are shown in Fig.5. It is observed that initially all the strengthened beams have almost the same load deflection curve except that having cut-off at the middle without lap splice. The average percentage of increase in the deflection of strengthened beams compared to the control one equal 22%. The strengthened beam having cut-off without lap splice exhibits a slight increase in the deflection compared to the control one equal 12.4%. It can be clearly seen from Fig. 5, when the internal steel yields, the additional tensile force is carried by the FRP system and an increase of the load capacity and deflection of the beam is obtained. The failure modes which are observed on the CFRP strengthened beams are different from that of the classical reinforced concrete control beam. CFRP reinforced beams behaves in a linear elastic fashion nearly up-to the failure.

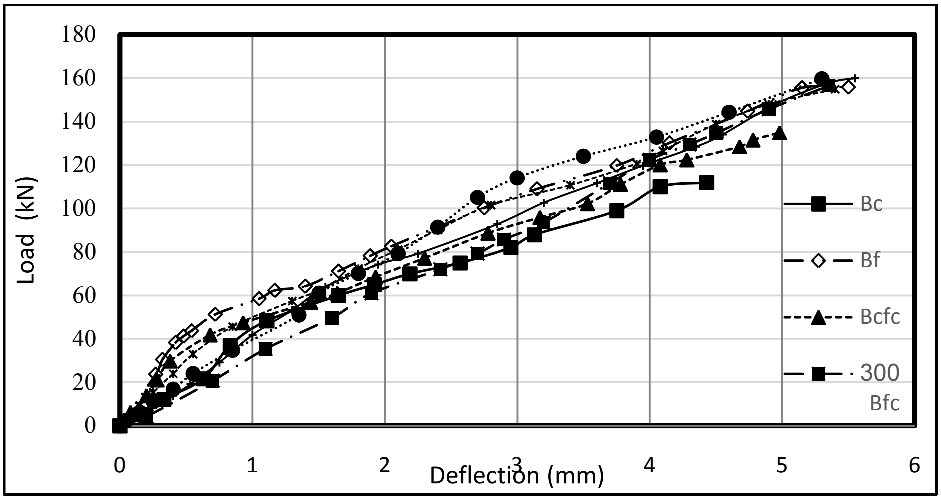


Figure 5: Load-Deflection at mid-span

3.3 Load-Steel Strain Relationship

Fig. 6 shows the load- internal tensile steel strain curves of the control beam and beams strengthened with CFRP laminates. The curves show bi-linear and nearly similar stiffness load–tensile steel strain, (S1), for all strengthened beams with lap splice plates. Curve of control beam (B_c) shows less stiffness and strain at failure compared to strengthened beams. The strengthened beam with cut-off and without lap splice shows different behaviour since the cracking started earlier due to cut-off which control the crack in the mid-span and a rapid increase in the tensile strain is happened after cracking. Then, the effect of laminate sheets results in increasing the stiffness of the beam until failure happen with high strain value compared to control beam.

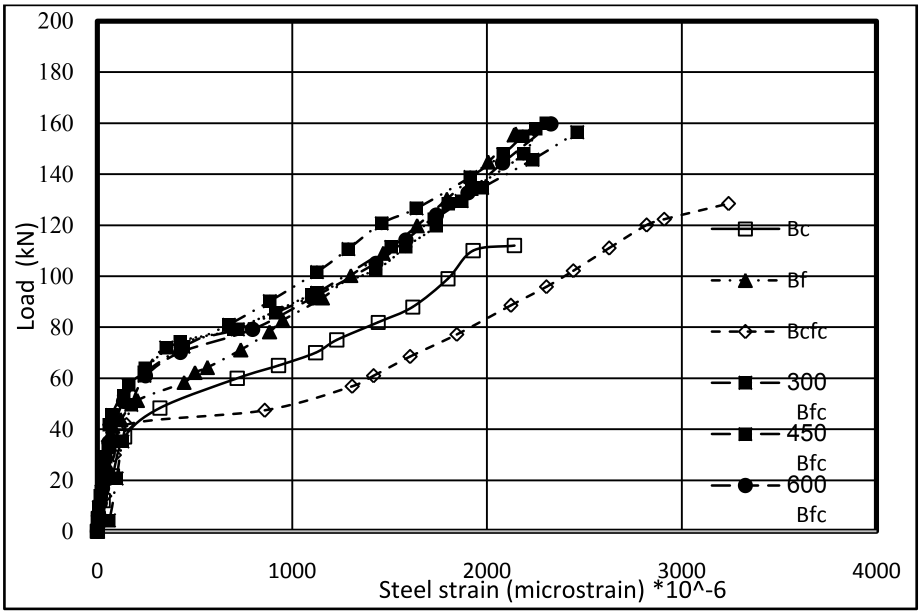


Figure 6: Load-tensile steel strain at mid-span

3.3 Load-CFRP Strain Relationship

Figures 7 and 8 show the load- external tensile CFRP strain curves of the strengthened beams with CFRP laminates, at mid span and at end of lap splice plate respectively. The first curve shows that strengthened beams B_{FC} , B_{FC450} have almost the same CFRP strain at mid span with higher stiffness compared to other strengthened beams B_{FC300} , B_{FC600}, and B_{FC900} whose have almost the same trend. While strengthened beam with cut-off and without lap splice B_{CFC} have small CFRP strain since the failure is governed by tensile crack at the location of the cut-off and the strain in the CFRP strain is not activated. The second curve shows that all strengthened beams with lap splice plate B_{FC300} , B_{FC450}, and B_{FC600} have similar CFRP strain behaviour at the end of splice plate except the beam with 900mm lap splice plate B_{FC900} ,which have higher strain value at failure.

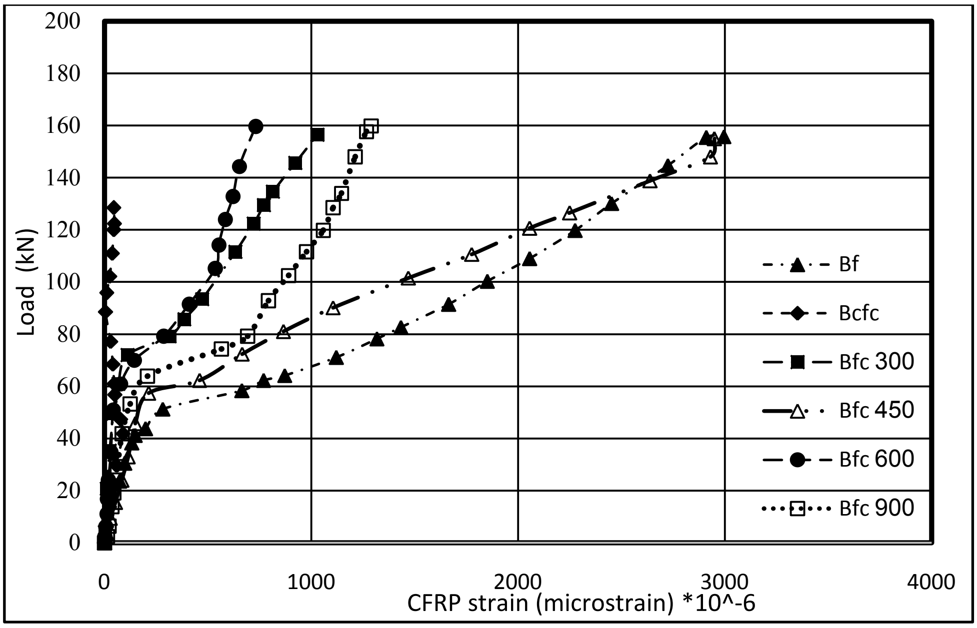


Figure 7: Load-CFRP strain at mid-span

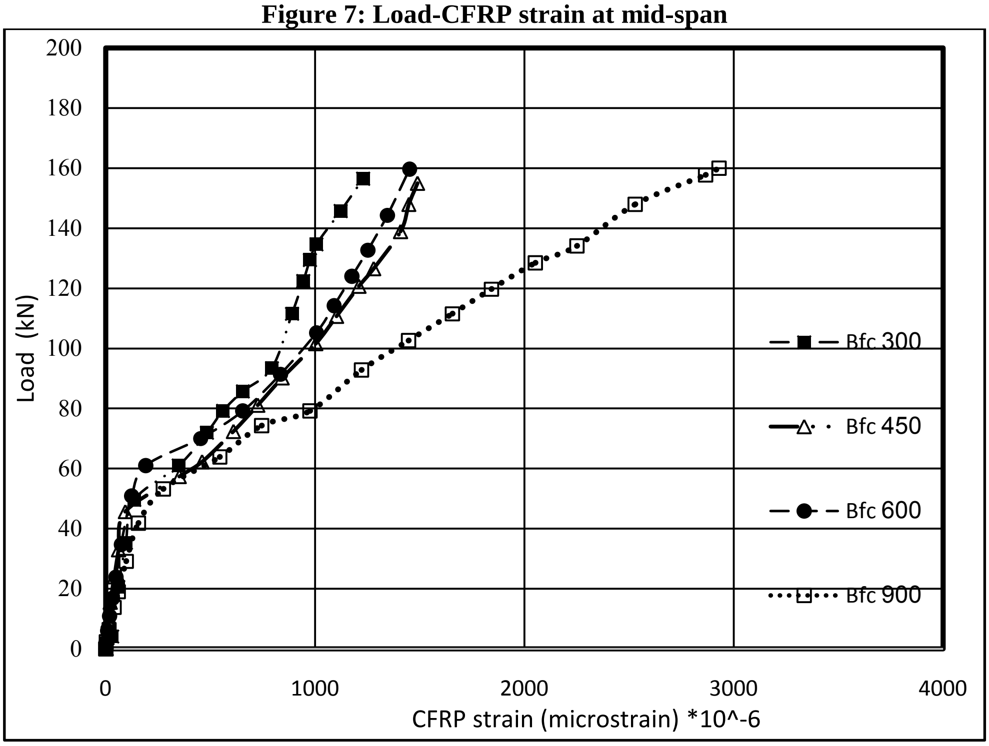


Figure 8: Load-CFRP strain at end of lap splice plate

3.4 Crack pattern and Failure Modes

The failure modes which are observed on the CFRP strengthened beams are different from that of the control beam. The crack patterns and failure modes of the tested beams are shown in Fig. 10. It is observed that the control beam together with the strengthened beam with cut-off and without lap splice have failed in flexural. While, all beams strengthened with CFRP laminates have failed in the same manner by interfacial debonding between CFRP and concrete. This mode of failure has been attributed to the flexural cracks in the tension side of the beam which induced interfacial debonding. During the testing, the unstrengthened (control) beam exhibited widely spaced and greater number of banded cracks compared to the strengthened beams. The strengthened beam with cut-off and without lap splice exhibited wide crack at the location of cut-off. The cracks have appeared on the surface of the strengthened beams at relatively close spacing. This behaviour shows the enhanced concrete confinement due to the influence of the CFRP laminates. Also the composite action had resulted in shifting of failure mode from flexural failure (steel yielding) in case of control beam and strengthened beam with cut-off and without lap splice plates to peeling of CFRP laminates for the strengthened beams. A crack normally initiates in the vertical direction and as the load increases it extended upward drastically due to the combined effect of shear and flexure. With further load increase, cracks propagate to top and the beam splits. This type of failure is called flexure-shear failure. Finally, the strengthened beam failed due to the separation of CFRP sheet by giving cracking sound along with the flexural-shear cracks.

IV. ANALYTICAL APPROACH FOR FLEXURAL STRENGTHENING

Analytical approach to evaluate the contribution of FRP composites laminates to concrete structures in flexural behaviour is described in the code CEB-FIP (1993). The code uses a rectangular stress block to determine the equilibrium forces those are acting on the reinforced concrete beams. The code adopt the traditional sectional analysis called "plane sections remain plane" for strain compatibility, and the stress strain relationships of concrete, steel and FRP laminates are used for equilibrium equations as shown in Fig. 9.

According to the code provision CEB-FIP (1993), the ultimate moment capacity of the strengthened beams is calculated using equivalent rectangular stress block of the beam cross section and then calculated the failure load. Taking moment at the centroid of the tension steel, A_{st} , ultimate bending moment is expressed by the following equation:

$$M_u = F_{SC}(d - d^{'}) + F_{CC}(d - 0.45x) + F_f(d^{''})$$

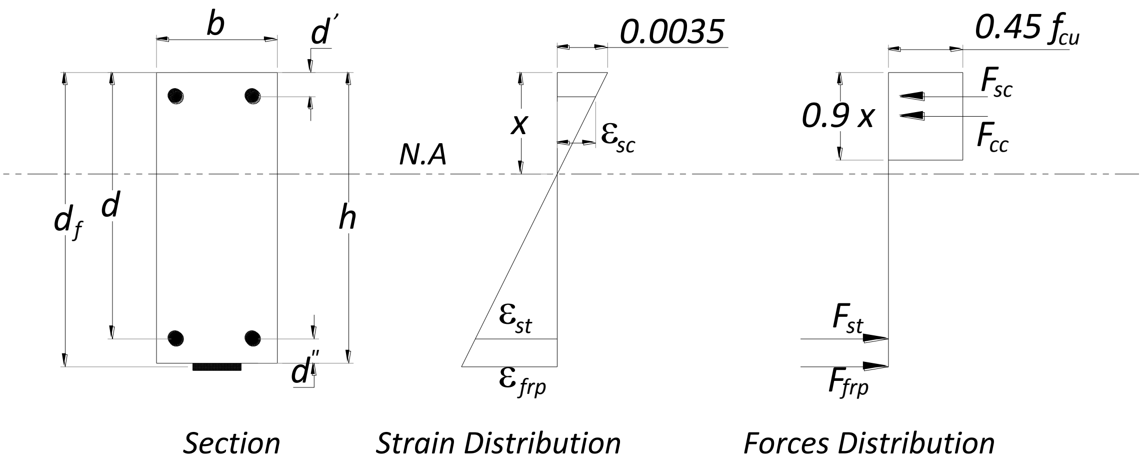
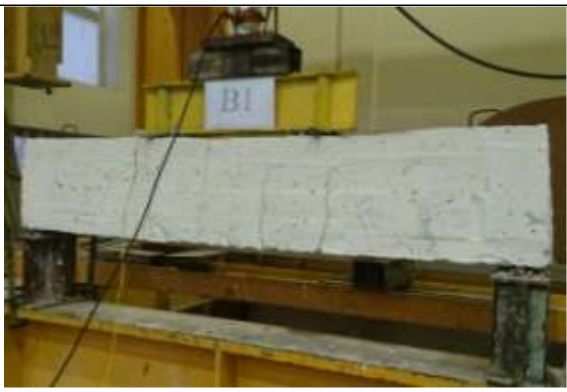
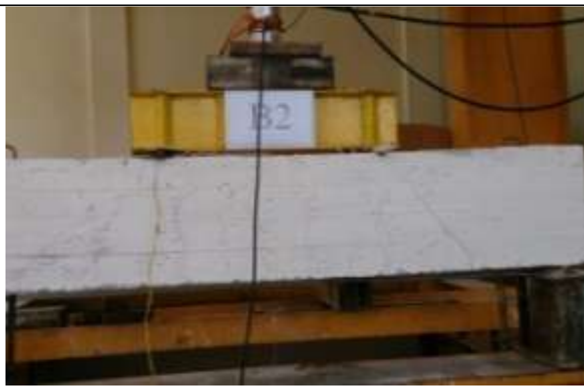


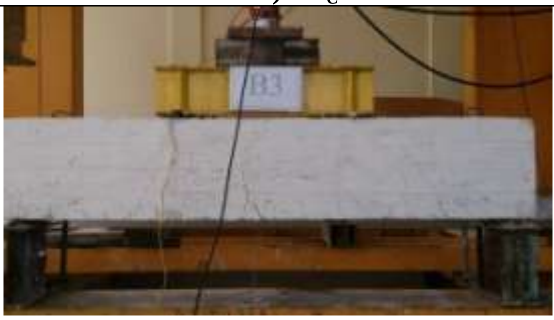
Figure : Strain distribution and force equilibrium for strengthened RC section with CFRP



a) B_C



b) B_F

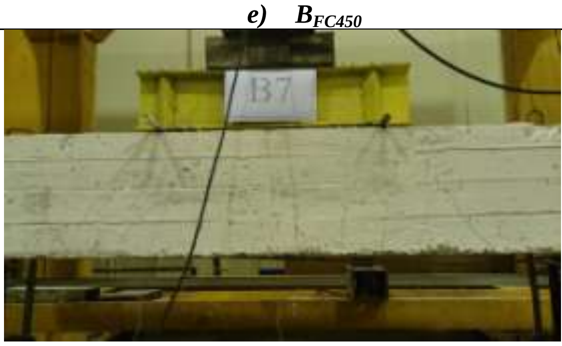


c) B_{FC}

d) B_{FC300}

e) B_{FC450}

f) B_{FC600}



g) B_{FC900}

Figure 10: Crack patterns of tested beams

Since all strengthened beams failed by interfacial de-bonding between CFRP and concrete, a reliable local bond-slip model is of major importance for the determination of the ultimate load of the CFRP to concrete interface (F_{frp}) which governs the failure of the strengthened section. Three accurate bond-slip models are used to provide accurate prediction for the contribution of CFRP in the flexural capacity of the strengthened beam. These models are not based on axial strain measurements on the CFRP plate, but instead they are based on the predictions of a meso-scale finite element model, with appropriate adjustment to match the experimental results of a few key parameters. These key parameters are much more reliable than local strain measurements on the CFRP plate. Bond-slip models do not suffer from the random variation associated with strain measurement nor the indirectness of the load-slip curve.

The first bond-slip model is developed by Yuan et al (2004), the second one is described in recent JCI report (2003) and the third one developed by Yang et al (2001) in China. The following units are used: N for forces, MPa for stresses and elastic modulus, and mm for lengths.

4.1 Yuan's Model

The bond strength model given by Yuan et al (2004) is described by the following equations

$$P_u = \beta_1 b_f \sqrt{2E_f t_f G_f}$$

Where β_1 = bond length factor, b_f = width of CFRP plate, E_f = elastic modulus of CFRP, t_f = thickness of CFRP , and G_f = interfacial fracture energy $= 0.308\beta_w^2\sqrt{f_t}$

where f_t = concrete tensile strength, β_w = width ratio factor = $\sqrt{\dfrac{2.25 - b_f/b_c}{1.25 + b_f/b_c}}$

b_f = width of CFRP plate, and b_c = width of concrete prism

4.2 Iso's Model

The bond strength model proposed by M.Iso (JCI Techniqal report, 2003) is given by $\tau_u = 0.93 f_c^{'0.44}$,

$L_e = 0.125(E_f t_f)^{0.57}$, If $L_e \succ L$ then $L_e = L$

$P_u = \tau_u b_f L_e$

4.3 Yang's Model

The bond strength model proposed by Yang et al (2001) is

$P_u = (0.5 + 0.08\sqrt{\dfrac{E_f t_f}{100 f_t}})b_e L_e \tau_u$, Where $\tau_u = 0.5 f_t$, $L_e = 100mm$

The results of the three bond-slip models are illustrated in Table 3. The ultimate load of the CFRP to concrete interface (P_u) is then used in calculating the ultimate bending moment and consequently the analytical failure load of the beam. This was in order to examine the validity of the used models in describing the effect of CFRP flexural strengthening.

Table 3: Analytical results of bond-slip models

Bond – slip model	***CFRP Plate***			***Concrete***			τ_u *(MPa)*	L_e *(mm)*	P_u *(KN)*
	t_f	b_f	E_f *(GPa)*	f_{cu} *(MPa)*	$f_c^{'}$ *(MPa)*	f_t *(MPa)*			
Yuan's model	*1.2*	*50*	*165*	*25*	*20*	*2.32*	*9.66*	*248*	*24.88*
Iso's model	*1.2*	*50*	*165*	*25*	*20*	*2.32*	*3.47*	*131*	*22.69*
Yang's model	*1.2*	*50*	*165*	*25*	*20*	*2.32*	*1.16*	*100*	*16.45*

Substituting by the ultimate load of the CFRP to concrete interface (P_u) in calculating the ultimate moment of the strengthened section in terms of (F_{frp}), the ultimate moment and consequently the analytical failure load of the beam can be estimated and compared with the experimental result as seen in Table 4.

Table 4: Comparison between analytical and experimental load of strengthened beam

Bond – slip model	***Analytical Failure Load (kN)***	***Exp. Failure Load***	*% Anal./Exp.*
Yuan's model	*13.73*	*15.58*	*88.13%*
Iso's model	*13.44*		*86.26%*
Yang's model	*12.73*		*81.70%*

V. CONCLUSIONS

Experimental work on the behavior of a concrete beams strengthened with externally bonded CFRP plates with and without lap splice at the mid span has been carried out. This was in order to examine the efficiency of splice plate in rehearsing the ultimate capacity of the strengthened beam. It was shown that all lap splices with lengths 150,300,450,600, and 900 mm are effective in backing up the capacity of the original beam strengthened with continous CFRP plate. Also, the analytical approach described in the code CEB-FIP (1993) to evaluate the contribution of FRP composites laminates to concrete structures in flexural behavior is used to verify the experimental results. Instead of stress strain relationship of CFR laminates, three accurate bond-slip models are used to provide accurate prediction for the contribution of CFRP in the flexural capacity of the strengthened beams since all of them are failed by interfacial debonding between CFRP and concrete. Based on the study, several findings are presented as follows:

1- Different CFRP strengthened reinforced concrete beams with full length and with lap splice plates ($\boldsymbol{B_F}$, $\boldsymbol{B_{F300}}$, $\boldsymbol{B_{F450}}$, $\boldsymbol{B_{F600}}$ and , $\boldsymbol{B_{F900}}$) showed significant increases in first cracking and ultimate capacities as compared to that of control beam. From the experimental results, it is identified that the average percentage increase of cracking and ultimate loads of CFRP strengthened beams are 22.6% and 40.5% respectively. On the other hand the strengthened beam with cut-off at the middle without lap splice ($\boldsymbol{B_{CFC}}$) shows almost the same cracking load of the control beam. However, a slight increase in the ultimate capacity compared to the control beam equal to 20.5%.

2- From the previous finding, strengthened beams with CFRP laminate having cut-off with lap splice plate can back up the ultimate capacity of the strengthened beam with CFRP laminate having full length without cut-off. While, the strengthened beam with cut-off at the middle without lap splice cannot backup the flexural strength with the same enhancement value.

3- The average percentage of increase in the deflection of strengthened beams (with full length and with splice plates) compared to the control one equal 22%. The strengthened beam having cut-off without lap splice exhibits a slight increase in the deflection compared to the control one equal 12.4%.

4- The ultimate load- steel strain curves show bi-linear and nearly similar stiffness for all strengthened beams with full length and with lap splice plates. Curve of control beam (B_c) shows lesser stiffness and strain at failure. The strengthened beam with cut-off and without lap splice shows different behaviour since the cracking started earlier due to cut-off which control the crack in the mid-span and a rapid increase in the tensile strain is happened after cracking.

5- all beams strengthened with CFRP laminates have failed in the same manner by interfacial debonding between CFRP and concrete.

6- A comparison has been made between the experimental results and analytical results based on three bond-slip models. Generally, the agreement is good especially the result calculated using Yuan's model.

REFERENCES

[1]. Meier, U. and Kaiser, H. (1991). “Strengthening structures with CFRP laminates.” Proc., Advanced Composite Materials in Civil Engineering Structures., ASCE, New York, 224–232.

[2]. Tamuzs, V., and Tepfers, R (2004), “Strengthening of concrete structures with advanced composite materials: Prospects and problems”, J. Mater. Civ. Eng, 16(5), pp 391–397.

[3]. El-Badry, M (1996), “Advanced composite materials in bridges and structures”, Canadian Society for Civil Engineering, Montreal.

[4]. Triantafllou, T. C. (1998). “Shear Strengthening of reinforced concrete beams using epoxy-bonded FRP composites.” ACI Structures J., 95(2), 107–115.

[5]. Saadatmanesh, K., Ehsani, M.R (1991), “R/C Beam Strengthened with GFRP Plates 1: Experimental Study”, Journal of Structural Engineering, pp 3434-3455.

[6]. Bonacci, J.F., Maalej, M (2001), “Behavioral trends of RC beams strengthened with externally bonded FRP”, Journal of Composite for Construction, 5(2), pp 102–113.

[7]. Ascione, L., Feo, L (2000), “Modeling of composite/concrete interface of RC beams strengthened with composite laminates”, Composites Part B: Engineering, 31, pp 535–540.

[8]. Bonacci, J.F., Maalej, M (2000), “Externally bonded fiber-reinforced polymer for rehabilitation of corrosion damaged concrete beams”, ACI Structural Journal, 97(5), pp 703–11.

[9]. Teng, J.G. Smith, S.T., Yao, J. Chen, J.F (2003), “Intermediate crack-induced de-bonding in RC beams and slabs”, Construction and Building Materials, 17, pp 447–462.

[10]. Jones, R., Swamy, R.N., Charif, A (1988), “Plate separation and anchorage of reinforced concrete beams strengthened by epoxy-bonded steel plates”, Struct. Eng., 66(5), pp 85–94.

[11]. Saadatmanesh, H. Malek, A.M (1997), “Prediction of shear and peeling stresses at the ends of beams strengthened with FRP plates”, Proc., 3rd Int. Symposium on Non-Metallic

[12]. (FRP) Reinforcement for Concrete Structures., 1, Japan Concrete Institute, Sapporo, Japan, pp 311–318.

[13]. Rabinovich, O., Frostig, Y (2000), “Closed-form high-order analysis of RC beams strengthened with FRP strips”, J. Compos for Constr. ASCE, 4(2), pp 65–74.

[14]. Lu, X.Z., Teng, J.G., Ye, L.P., and Jiang, J.J (2005), "Bond-slip models for FRP sheets/plates bonded to concrete" Engineering Structures 27 (2005) 920-937. doi:10.1016/j.engstruct.2005.01.014
[15]. Meier, U., Deuring, M., Meier, H., and Schwegler, G. (1992). "Strengthening of Structures with CFRP Laminates: Research and Applications in Switzerland." Advanced Composite Materials in Bridges and Structures, CSCE, Montreal 1992, 243-250.
[16]. Porter, N.M., and Stallings, J.M. (2001). "Flexural Strengthening of Reinforced Concrete Beams with Externally Bonded CFRP Plates with LAP splices." Research submitted to Highway Research Center, Auburn University, AL.
[17]. Yuan, H., Teng, J.G., Seracino, R., Yao, J. (2004). "Full-range behaviour of FRP-to-concrete interface." Engineering Structures 2004, 26(5):553-64.
[18]. JCI. Technical report of technical committee on retrofit technology. In: Proc., International symposium on latest achievement of technology and research on retrofitting concrete structures. 2003.
[19]. Yang, Y.X., Yue, Q.R., Hu, Y.C. (2001). "Experimental study on bond performance between carbon fiber sheets and concrete." Journal of building structures 2001; 22(3):36-42 [in Chinese].