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Flexural Strengthening of R.C. Beams

E. M. Lotfy

Abstract— **Throughout the service life, structural parts would subject to a significant number reason for harm. Repair of such distressed element has been under investigation for various years to accomplish the best, and improvement in the design guidelines. The rehabilitation of structures can be in the form of strengthening, repairing or retrofitting for seismic deficiencies by utilizing two techniques; External steel plating has been applied to flexural elements such as beams and slabs to increase both their strength and stiffness. And externally bonded (EB) 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. The experimental part of the study included testing of ten concrete beams; a total of ten, two-point loading, rectangular cross-sections of 150*250 mm and total length of 2500 mm were tested. Three groups of different reinforced concrete beams; group one contains six beams with reinforcement (A_s=2Φ12mm) and ($A_S^{\backslash}$=2Φ10mm) with using different strengthen techniques. Group two contains two beams with reinforcement (A_s=3Φ16mm) and ($A_S^{\backslash}$=2Φ10mm); control beam and steel plated beam. Group three contains two beams with reinforcement (A_s=3Φ16mm) and ($A_S^{\backslash}$=2Φ4mm); control beam and steel plated beam, All beams have ø6mm @10cm in shear zone and ø6mm@20cm in flexural zone. The experimental outcomes demonstrate that flexural strengthening by steel plate and CFRP sheet has a significant effect on the behavior of tested beams, bottom steel plate and wide side steel plates has a highly effect on the behavior of tested beams, riveted steel plate has a significant effect on the behavior of tested beams more than utilizing epoxy gluing steel plate. Finally flexural strengthening beams by steel plate have a significant effect on the behavior of tested beams with low tensile reinforcement ratio.**

Index Terms— **Behavior, Flexure, Beams, Steel Plate, and Carbon Fiber.**

I. INTRODUCTION

Various rehabilitation techniques have been proposed for civil infrastructure to overcome problems associated with the aging process, expanded traffic, change in use, and deterioration. Among these techniques, external strengthening provides a practical and cost effective solution when compared to other traditional repair methods. The first generation of external strengthening methods utilized steel plates bonded to the tension surface of the structure. The strengthening effectiveness was acceptable; however several problems, including durability, heavy weight, handling, and shoring, had to be resolved; thus the need for alternative materials aroused. The introduction of advanced composite materials, particularly fiber reinforced polymers (FRP), in structural engineering industries, as a second generation of externally bonded retrofit materials, has offered numerous benefits (i.e. corrosion-free, excellent weight to strength ratio, good fatigue resistance, flexibility to conform to any shape, broad applications, and easy manipulations)[1]. Strengthening of RC structures by bonding external steel and composites plates or sheets is an effective method for improving structural performance under both service and ultimate load conditions. Several investigations [2-5] had studied the method of using external steel plates in the repairing or strengthening of RC beams. Externally bonded FRP reinforcement has proven its efficiency in strengthening RC members in flexure through extensive researches and engineering practices in the past decade. A primary concern for this technique is local debonding of FRP/concrete interfaces, which affects negatively the structural integrity and long-term durability of strengthened members. Macro-propagation of the debonding usually leads to a sudden drop in loads and loss of ductility of the whole local interface FRP/RC composite system. In general, stresses in FRP materials are limited in design guidelines to prevent the failure triggered in the bond line [6,7]. However, the stress limitation in the meantime indicates that the advantage of FRP in high strength cannot be fully utilized. Strain limitation in FRP also means reduced deformability and the moment redistribution ability of the whole strengthened systems. Carbon fiber reinforced polymers laminates, CFRP, bonded to the soffit of precracked or uncracked RC rectangular or T-beams was experimentally investigated by several researchers [8,9]. It found that, strengthening beam by bonding CFRP laminates is structurally efficient. Also, it has been shown that plate or sheet bonding reduces crack widths and deflections.

Ehab M. Lotfy, Civil Engineering Department, Suez Canal University / Faculty of Engineering / Associate Professor, Ismaelia, Egypt, 0020552313892/ 00201011790901

II. EXTERNAL STRENGTHENING USING COMPOSITE MATERIALS

Comparison between Steel and Composite Material

In the mid-1980s, it was recommended that fiber reinforced polymer (FRP) plates could prove advantageous over steel plates in strengthening applications [10,11]. Dissimilar steel, FRPs are unaffected by electrochemical deterioration and can resist the corrosive effects of acids, alkalis, salts and similar aggressive materials under a wide range of temperatures [12]. Consequently, corrosion-resistant systems are not required, making preparation prior to bonding and maintenance after installation less arduous than for steel.

III. EXPERIMENTAL WORK

A. GENERAL

The experimental program had been planned to investigate the behavior of reinforced concrete beams strengthened by external steel plate in flexural to study:

1. Strengthen materials technique; steel plate and CFRP sheet.
2. Positions of flexural strengthen; tension zone and tension zone with different side width plats.
3. Fixing technique of steel plate; gluing and using rivets.

4. Reinforcement ratio of tested beams; tension and compression reinforcement ratio.

B. *DESCRIPTION OF THE TESTED BEAMS*

The main objective of the present work is to enhance the performance of plated beams by arresting the peeling cracks. Different techniques were adopted in this work to arrest the peeling cracks by plate end anchorage rivets and gluing of the steel plate. This study involved testing of ten concrete beams; a total of ten, two-span concrete beams with rectangular cross-sections of 150*250 mm and total length of 2500 mm were tested. Three groups of different reinforced concrete beams; group one contains six beams with reinforcement (A_s=2Φ12mm) and ($A_S^{\backslash}$ =2Φ10mm) with using different strengthen techniques; Control beam, steel plated beam by epoxy gluing, steel plated beam by rivets, Narrow side steel plated 100mm width, Wide side steel plated 200mm width and flexural strengthening beam by CFRP sheet.

Group two contains two beams with reinforcement (A_s=3Φ16mm) and ($A_S^{\backslash}$=2Φ10mm); control beam and steel plated beam. Group three contains two beams with reinforcement (A_s=3Φ16mm) and ($A_S^{\backslash}$=2Φ4mm); control beam and steel plated beam, All beams have ø6mm @10cm in shear zone and ø6mm @20cm in flexural zone and characteristic strength of concrete 50 Mpa as shown in table 1.

The dimensions of the used bottom steel plate were 120 mm width, 3.0 mm thickness, and 2.0 m for long plate. The dimensions of the used side steel plates were 2.0 m length, 3.0 mm thickness, and 10.0 cm width for narrow plate while 20.0 cm for wide plate. Bottom CFRP sheet were 120 mm width, 0.3 mm thickness as shown in figures 1, 2 and 3.

Table (1) Details of tested beams.

Group No	Beam No	Dim. (mm) width	Dim. (mm) depth	Reinforcement Ratio (%) Tens. (ρA_s)	Comp. ($\rho A_s^{\backslash}$)	$\alpha = A_s/A_s^{\backslash}$	Strengthening of RC Beams (flexural zone)
G1	CB1	150	250	0.655	0.45	0.69	Control beam
	PB1						Steel plated beam by epoxy gluing
	RB1						Steel plated beam by rivets
	S1PB1						Narrow side steel plated 100mm width
	S2PB1						Wide side steel plated 200mm width
	FB1						CFRP sheet
G2	CB2			1.74	0.45	0.26	Control beam
	PB2						Steel plated beam by epoxy gluing
G3	CB3			1.74	0.072	0.04	Control beam
	PB3						Steel plated beam by epoxy gluing

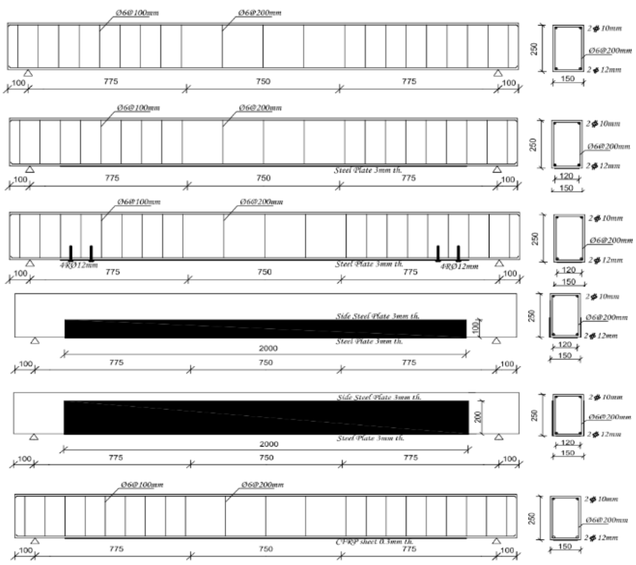

Figure 1. Details of reinforcement and dimensions in mm for group 1

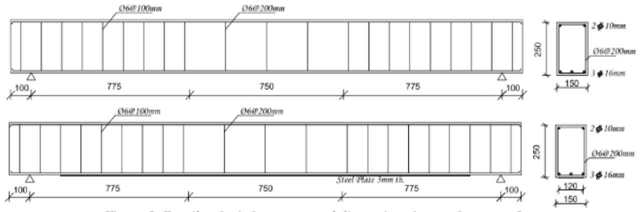

Figure 2. Details of reinforcement and dimensions in mm for group 2

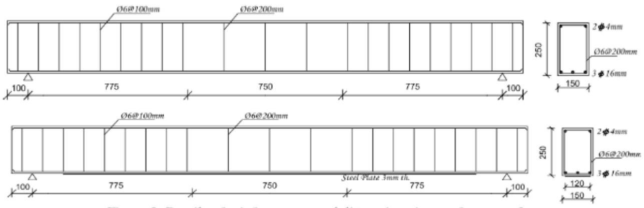

Figure 3. Details of reinforcement and dimensions in mm for group 3

C. *Loading Arrangement:*

The load was applied by universal testing machine of 1000 KN. Full capacity through a loading plate and a spreader beam to give two-point loading (75 cm).

IV. RESULTS AND DISCUSSION

The experimental program included testing of 10-RC beams; the parameters of study were

1. Strengthen materials technique; steel plate and CFRP sheet.
2. Positions of flexural strengthen; tension zone and tension zone with different side width plats.
3. Fixing technique of steel plate; gluing and using rivets.
4. Reinforcement ratio of tested beams; tension and compression reinforcement ratio.

Table 2 demonstrates the actual f_{cu}, cracking Load, ultimate Load, maximum deflection of tested specimens and Type of failure.

Table 2. The Results of tested Specimens

Group No.	Beam No.	Actual f_{cu} (Mpa)	Cracking Load (kN)	Ultimate Load (kN)	Deflection (mm)	Type of failure
G1	CB1	49	12.5	65	12	flexure
	PB1	50	17	90	13.5	flexural-shear
	RB1	52	20	110	18	flexural-shear
	S1PB1	49	42.5	140	16	Compression
	S2PB1	50	45	185	17.5	Compression
	FB1	51	21	95	16	flexural-shear
G2	CB2	48.5	12	150	18	flexural
	PB2	50	17	156	21	flexural-shear
G3	CB3	49	11.5	110	14.5	flexural
	PB3	51	15.5	140	15.5	flexural-shear

A. *Strengthen materials technique; steel plate and CFRP sheet.*

Figure 4 shows the load-deformation of beams FB1, PB1 and CB1 respectively; strengthening by CFRP sheet leads to increase in toughness of tested beam, where strengthening by steel plate increase ductility of tested beam. From table 2, it can be seen that, ultimate loads, and maximum deflection of FB1, PB1 to CB1 are (146% and 138%), and (133% and 113%) respectively.

Flexural strengthening by steel plate and CFRP sheet has a significant effect on the behavior of tested beams. Where ultimate loads and of tested beams increase by 138% to 146% of control beam respectively, and of tested beams increase by 113% to 133% of control beam respectively

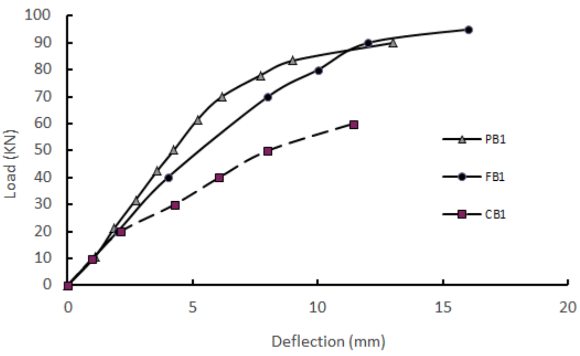

Figure 4. Load-deflection curve of beams FB1, PB1&CB1

B. Positions of flexural strengthen; tension zone and tension zone with different side width plats.

Figure 5 shows the load-deformation of beams S2PB1, S1PB1, PB1and CB1 respectively; strengthening by bottom plate with side steel plates leads to increase in toughness of tested beam more than bottom plate only. From table 2, it can be seen that, ultimate loads, and maximum deflection of S2PB1, S1PB1, PB1 to CB1 are (285%, 215 and 146%), and (146%, 133 and 113%) respectively.

Flexural strengthening of tested beam by bottom steel plate and wide side steel plates 200mm width has a significant effect on the behavior of tested beams more than beams with bottom steel plate and narrow side steel plates 100mm or beams with bottom steel plate only.

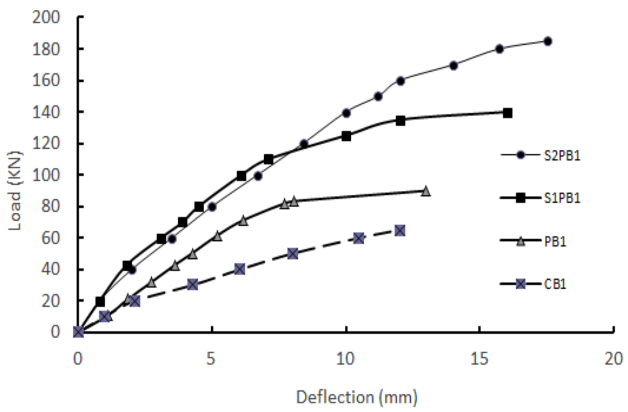

Figure 5. Load-deflection curve of beams S2PB1, S1PB1, PB1and CB1

C. Fixing technique of steel plate; Epoxy gluing and using rivets.

Figure 6 shows the load-deformation of beams RB1, PB1 and CB1 respectively; using riveted steel plate increase toughness of tested beam more than using epoxy gluing steel plate or control beam. From table 2, it can be seen that, ultimate loads, and maximum deflection of RB1, PB1 to CB1 are (169% and 138%), and (150% and 113%) respectively.

Flexural strengthening by riveted steel plate has a significant effect on the behavior of tested beams more than using epoxy gluing steel plate or control beam. Where ultimate loads of tested beams increase by 169% and 138% of control beam respectively, and maximum deflections of tested beams increase by 150% and 113% of control beam respectively

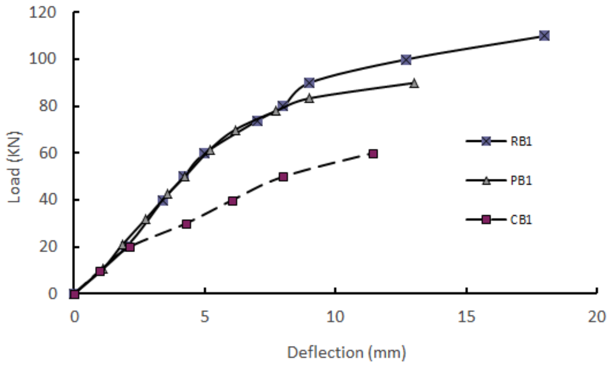

Figure 6. Load-deflection curve of beams RB1, PB1&CB1

D. Reinforcement ratio; tension and compression reinforcement ratio.

Figures 7, 8 and 9 show the load-deformation of beams (PB1& CB1 with ρA_s = 0.655% and α=0.69), (PB2& CB2 with ρA_s = 1.74% and α=0.26), and (PB3& CB3 with ρA_s = 1.74% and α=0.04), respectively; using steel plate increase toughness of tested beams more control beams. From table 2, it can be seen that, ultimate loads, and maximum deflection of (PB1& CB1, (PB2& CB2), and (PB3& CB3) are (138% and 113%), (104% and 117%), and (127% and 107%) respectively.

Figure 10 shows that flexural strengthening beams by steel plate has a significant effect on the behavior of tested beams with low tensile reinforcement ratio; where ultimate load and maximum deflection of tested beam with (ρA_s = 0.655% & $\rho A_{s\backslash}$ = 0.45%) increase to 138% and 113% respectively. Also has highly effects on tested beams with low compression reinforcement ratio; where ultimate load and maximum deflection of tested beam with (ρA_s = 1.74% & $\rho A_{s\backslash}$=0.0.07%) increase to 127% and 107% respectively.

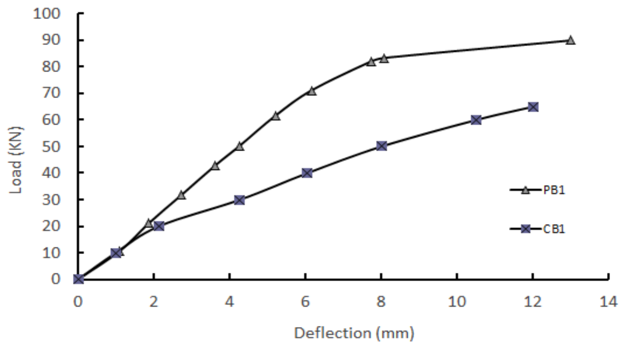

Figure 7. Load-deflection curve of beams PB1 &CB1

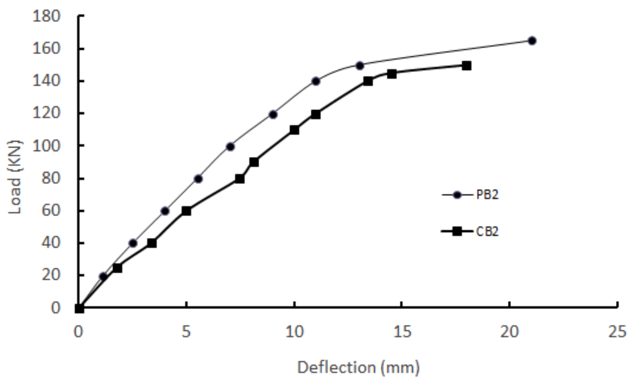

Figure 8. Load-deflection curve of beams PB2 &CB2

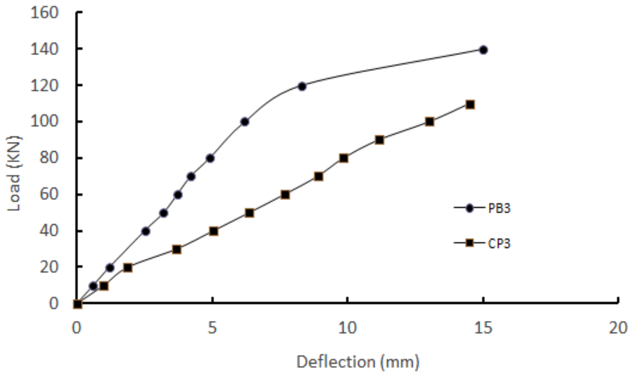

Figure 9. Load-deflection curve of beams PB3 &CB3

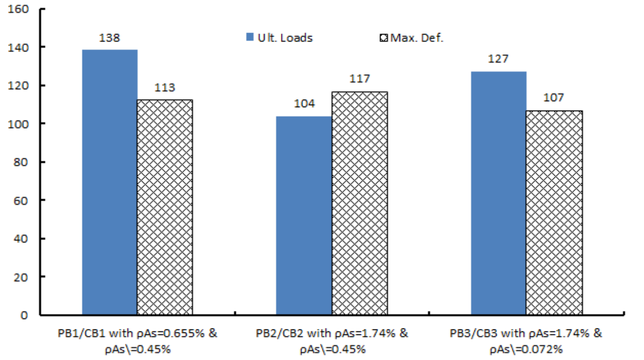

Figure 10. The relation of ultimate load and maximum deflection of flexural strengthening beams and control beams

V. CONCLUSIONS

The experimental results from 10 reinforced concrete beams demonstrate the influences of strengthen materials technique, positions of flexural strengthen, fixing technique of steel plate and reinforcement ratio of tested beams; tension and compression reinforcement ratio. Based on the experimental results presented in this study the following conclusions can be drawn:

1. Flexural Strengthening by steel plate and CFRP sheet has a significant effect on the behavior of tested beams. Where ultimate loads and of tested beams increase by 138% to 146% of control beam respectively.
2. Flexural strengthening of tested beam by bottom steel plate and wide side steel plates has a significant effect on the behavior of tested beams more than beams with bottom steel plate and narrow side steel plates or beams with bottom steel plate only. Where ultimate loads and of tested beams varied from 285%, 215% & 146% of control beam respectively.
3. Flexural strengthening by riveted steel plate has a significant effect on the behavior of tested beams more than using epoxy gluing steel plate or control beam. Where ultimate loads of tested beams increase by 169% and 138% of control beam respectively, and maximum deflections of tested beams increase by 150% and 113% of control beam respectively.
4. Flexural strengthening beams by steel plate has a significant effect on the behavior of tested beams with low tensile reinforcement ratio; where ultimate load and maximum deflection of tested beam with (ρA_s = 0.655% & $\rho A_{s\backslash}$ = 0.45%) increase to 138% and 113% respectively. Also has highly effects on tested beams with low compression reinforcement ratio; where ultimate load and maximum deflection of tested beam with (ρA_s = 1.74% & $\rho A_{s\backslash}$=0.0.07%) increase to 127% and 107% respectively

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