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Numerical Study of R.C. Beams Strengthening by External Steel Plate

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ABSTRACT: *Steel plates are one of the most common materials for strengthening of reinforced concrete beams; it is very effective for increasing the flexural and shear capacity of reinforced concrete beam. The volume of the infrastructure that needs upgrading, strengthening and/or repair is growing worldwide, this method has gained renaissance in the last decades. This paper presents experimental test data with numerical analyses on the effect of using externally steel plate on its cracking pattern, structural deformations and ultimate strength of concrete beams reinforced. The traditional method use the epoxy glues for interfaces bonding while the idea of this study is effect of steel plate length to effective span of tested beam, effect of steel plate ratio and effect of steel plate position. The experimental work includes flexural testing of 250*150*2500mm concrete beams. Numerical analyses implemented by 3-D Flac program for 13-tested beams also presented. The results show that beams reinforced with external steel plate behave as a composite action right up to ultimate load results show good agreement between the experimental and numerical output data. Using external vertical plate outside of cross section restrains the central deflection with considerable increasing of ultimate load capacity, toughness and ductility of tested beam, using steel plate length to effective span of tested beam has a significant effect on the behavior of tested beams up to 0.6, and with steel plate ratios up to 0.017.*

Keywords*: Steel plate, Flexure, Concrete beams, strengthening, bond failure*

I. INTRODUCTION

Concrete and steel are considered to be the prime two construction materials in most countries around that universe. Those numbers of buildings, bridges, pipelines and different cement parts of the infrastructures that need deteriorated in administration What's more done compelling reason from claiming repair shed and upkeep is substantial Also ever expanding. Deterioration or harm to structures may result from different sources, including faulty design and construction practices that ignore the ecological impact, overloading, fire, impact loading, and erosion of steel. On the different hand, a few about these buildings, bridges, pipelines and other parts were initially planned to little span vehicles, lighter loads, What's more level movement volumes over need aid basic today. Restoration can be defined as an operation to bring a structure (or a structural component) that is inadequate in design request to the desired specific execution level. Depending upon the state of the structure and the desired post intervention performance level, rehabilitation can be divided into two categories: repair and strengthening. Repair is the rehabilitation of a harmed structure or a structural component with the aim of restoring the original capacity of the harmed structure. Strengthening, on the different hand, is the process of increasing of the existing capacity of a non-damaged structure (or a structural component) to a specified level. Previously, late years, sticking steel reinforcement method has been developed for structural retrofitting and repairing [1-3]. Strengthening by steel plate will be an well-known technique because of its availability, cheapness, uniform materials properties (isotropic), easy to work, high ductility and high fatigue strength. This system had been used to strengthen both buildings and bridges in countries such as Belgium, France, Japan, Poland, South Africa, Switzerland and United Kingdom [4]. This methodology incorporates enhancing strength (shear, flexure, compression) or improving stiffness of deficient reinforced concrete members by bonding steel plates of calculated thickness with adhesives and anchors to the existing sections. Forces can be transmitted to the external plates from the RC structure through an adhesive bond, bolts or wrapping. Plates can be placed on any surface of the beam or slab and they can have any shape such as flat plates, channels or angle sections. Then again, Steel plate bonding is a cumbersome process requiring extensive work and drilling in the existing section. Steel plates are hard to lift and need to be tailor made to suit to the as-built dimensions of the members resulting in surface finish is unsightly and steel plate retrofit is prone to disintegration About whether. Different rehabilitation techniques have been proposed for essential structures to overcome deficiencies associated with

the aging process, increased loading, change in use, and deterioration. External strengthening gives a practical and cost suitable solution when compared to other traditional rehabilitation methods. Use of steel plates bonded to the tension surface of the concrete structure was the first mode of external strengthening systems [5].
Negligible greater part of the information will be open Likewise insufflate code guidelines are accessible for strengthening concrete structures. In fact, most repair and strengthening designs are based on the assessment of engineers only and, often, empirical knowledge and current practice have an important role in the decisions to be made. Therefore, it is imperative that researches should be done in purpose of providing reliable knowledge about rehabilitation techniques.

II. OBJECT AND SCOPE

The study also aims to confirm the applicability of numerical analysis by the finite difference method FDM to these plate bonded beams. A total of 13 RC beams were strengthened by bonding thin steel plates of varying depth and thickness to the web using an epoxy adhesive. The results of tests on these beams were compared with those of control beams not reinforced with steel plates. Furthermore, numerical analysis based on a non-linear FDM was also performed to simulate the behavior of these beams, and the applicability of FDM to these plate bonded beams was confirmed.
The study presents tests results on the performance of plate bonding with different parameters:
1- Effect of steel plate length to effective span of tested beam (L_{sp}/L_e).
2- Effect of used steel plate ratio ($\rho_{sp} = \frac{A_{sp}}{bd}$)
3- Effect of steel plate position

III. EXPERIMENTAL WORK

Experimental study involved testing of concrete beams with rectangular cross-sections of 150*250 mm, total length of 2500 mm and effective span 2300mm. Flexural reinforcement (As=2Φ12mm) and (AS$^{\backslash}$ =2Φ10mm) and characteristic strength 50 Mpa were tested under two-point loads about 10 tested beams [6].

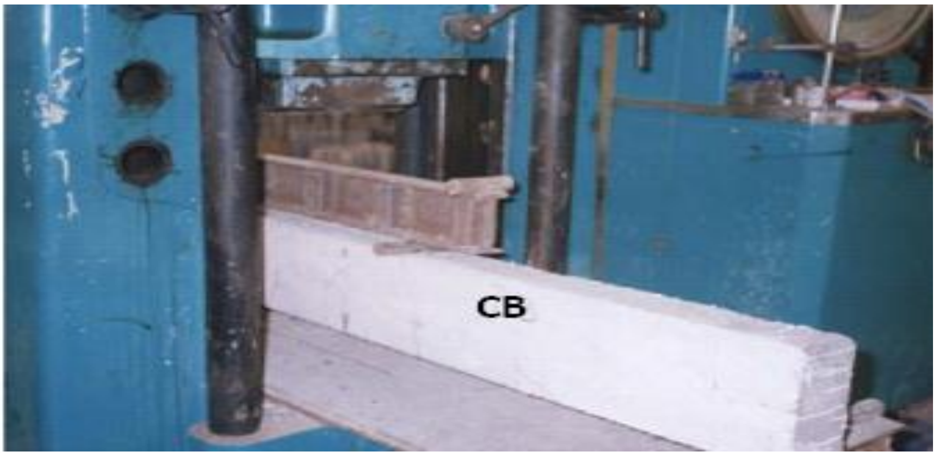

Fig. 1: The used universal testing machine

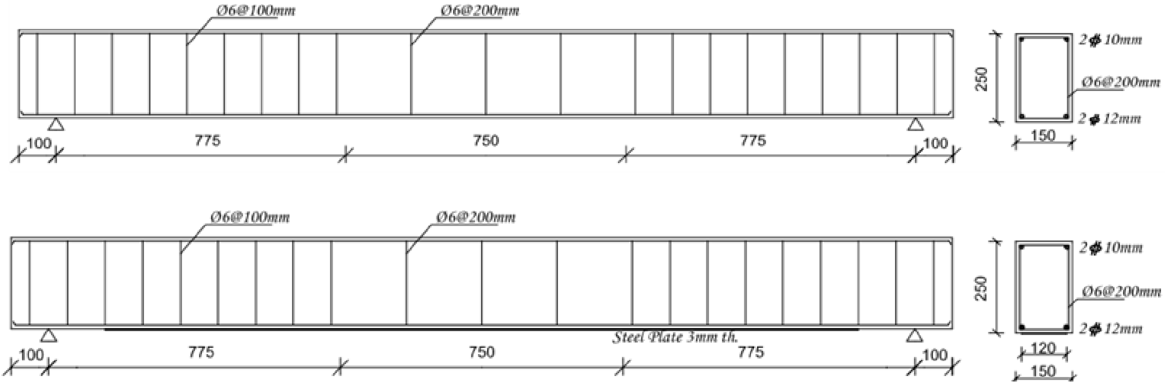

FIG.2: Details of Reinforcement and Dimensions in Mm

IV. Theoretical Analysis

Calculation of theoretical ultimate load:

The ultimate load of strengthened beams could be obtained using the stress block of BS 8110 (British Standard, 1985) [7]. Fig. 3 shows the cross section and the stress and strain distribution of strengthened beams. Assuming full composite action of steel plate and beam, the failure load of steel plate strengthened beams by the BS 8110 could be written as follows:

$$M_u = \frac{\left\{A_s f_t \left(d - \frac{0.9x}{2}\right) + A_p f_{tp} \left(d_p - \frac{0.9x}{2}\right)\right\}}{0.65} \qquad (1)$$

where, A_s, A_p equal to the area of rebar and steel plate, f_y and f_{yp} equal to the yield stress of rebar and steel plate and f_t and f_{tp} equal to the tensile stress of rebar and steel plate, respectively.

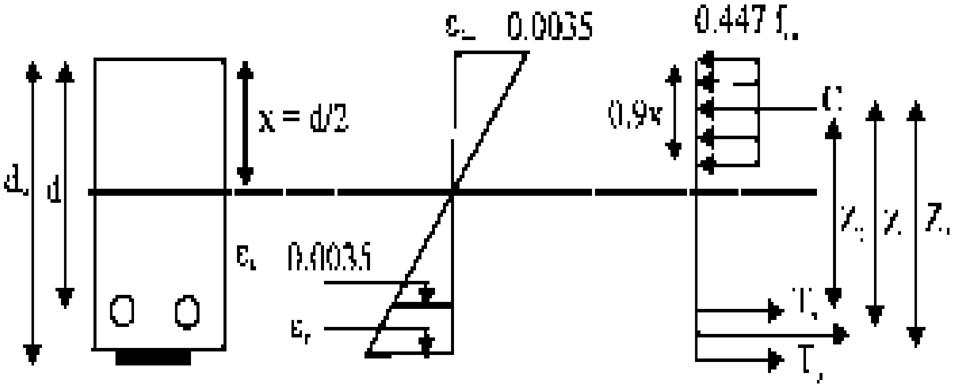

Fig. 3: Strain-stress diagram of strengthened beam

Finite Difference Method (FDM) Analysis

The nonlinear finite difference approach can be used to predict the behavior of plated beam structure at elastic stage, plastic stage, cracking load, post-cracking stage and ultimate load. The finite difference models used in the current study was described by using the available elements in 3D-Flac

3-D solid elements of cube shape were used to model the reinforced concrete beams while strengthening plates were represented using the structural type of elements (beam element). The beam elements of the steel plate are attached to the bottom face of the concrete beam directly as shown in Fig. 4. Perfect bonding between strengthening plate and the concrete was considered. Figure 5 shows the stress–strain relationships for used materials, concrete and steel. The yield strength, tensile strength and modulus of elasticity of the steel plates were 360 MPa and 200GPa, respectively. Figure 2 shows the position of strengthened steel plate for groups 1 &2 at the bottom of cross section whereas figure 6 shows details of steel plate orientation for group 3. Numerical model contains 13 beams divided into three groups as shown in table (1)

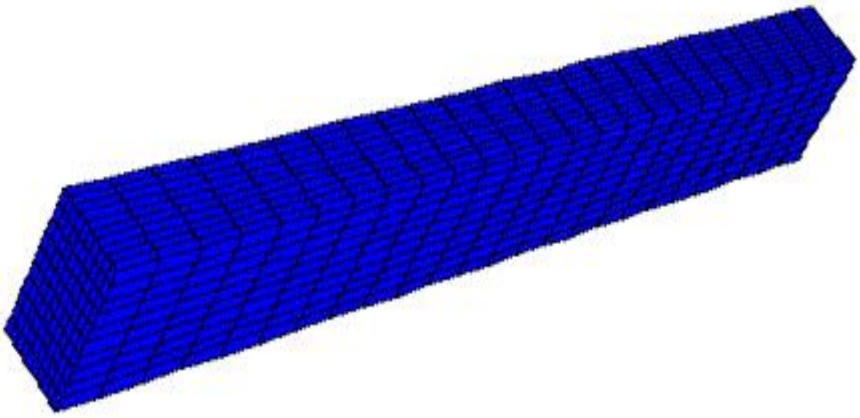

Fig. 4: Discretized concrete beam

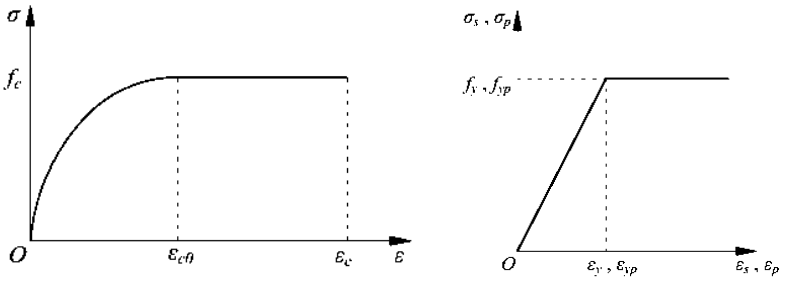

Fig. 5: Stress–strain relationships for materials, showing: (a) concrete; (b) steel

Table (1): Details of tested beams

Groups	Beams	F_{cu} Mpa	Plate Thickness (mm)	Plate Width (mm)	L_{sp}/L_e (Le=2300mm)	Steel Pate Ratio ($\rho_{sp} = \frac{A_{sp}}{bd}$)	note
G1	CB1	50	3	120	0	0	Steel plate at the bottom of cross section (Fig.2)
	B2				0.4	0.01	
	B3				0.5		
	B4				0.6		
	B5				0.7		
	B6				0.8		
G2	B7		1	120	0.6	0.003	Steel plate at the bottom of cross section (Fig.2)
	B8		5			0.017	
	B9		7			0.024	
	B10		10			0.03	
G3	B11		6	60	0.6	0.01	one notch in middle by 6mm/w &60mm/H (Fig.6)
	B12		3	60			two notch with 3mm/w & 60mm/H (Fig.6)
	B13		3	60			outside cross section (Fig.6)

L_{sp} : Steel plate length Le: Effective length of tested beams A_{sp} : Steel plate area

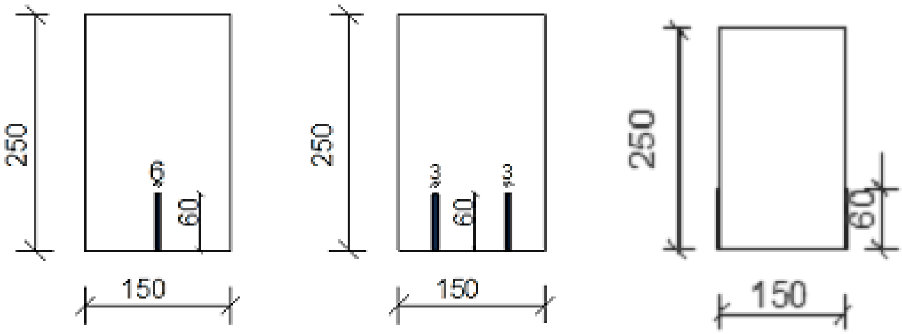

Fig.6: Details of steel plate orientation, mm

V. RESULTS AND DISCUSSION

Table 2 shows the comparisons between the numerical, experimental results of tested beams and theoretical failure load. The theoretical failure was calculated from BS 8110, based on full composite action Eq. 1

Table 2: The numerical, experimental results of tested beams and theoretical failure load.

Group No.	Beam No.	Numerical Results			Experimental Results			Theoretical Ultimate Load* (kN.m) BS 8110	Mode of Failure
		1st crack Load (kN)	Ult. Load (kN)	Def. (mm)	1st Crack Load (kN)	Ult. Load (kN)	Def. (mm)		
G1	CB1	14	70	12.5	12.5	65	12	32.23	Flexural
	B2	17	85	16				89.76	Flexural
	B3	23	95	16.5					Flexural
	B4	25	103	19	17	90	13.5		Flexural
	B5	26	109	20.5					Flexural
	B6	27	113	21					Flexural
G2	B7	23	90	15.1				51	Flexural
	B8	26	110	20				128.6	Flexural

G3	B9	28	114	21.5				167.8	Compression
	B10	30	118	22				227.35	Compression
	B11	28	115	22				80.96	Compression
	B12	32	120	22.4					Compression
	B13	33	122	22.5					Compression

Theoretical ultimate load* according to BS 8110 (British Standard, 1985)

Comparison of Experimental and Numerical Results

Mode of failure and failure load: Table 2 shows the failure loads and modes of failure of the beams based on experimental and numerical results. The results for the nonlinear finite Difference analysis shows that the failure modes for all the beams were of flexural in nature. This is because of the assumption of perfect bond between strengthening materials and concrete surface. The numerical value of failure load of the control beam was almost similar with the experimental result. However, the failure loads of strengthened beams from numerical result are higher when compared to the experimental results.

Deflection: The load versus deflection curves based on the experimental and numerical results of beams CB1& B4 (beam PB1: [4]) are shown in Fig. 7. It can be seen form the Fig. 7 shows that deflections based on numerical analysis are almost identical with the experimental results and all the beams gave linear, elastic portions of the curves at the initial stages.

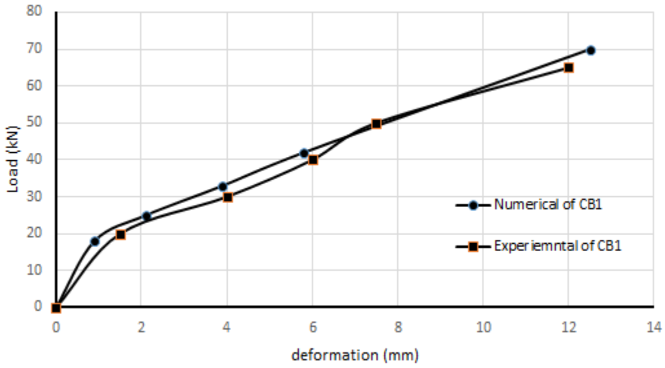

Fig.7-a: load-deflection curve of experimental and numerical results of control beam CB1

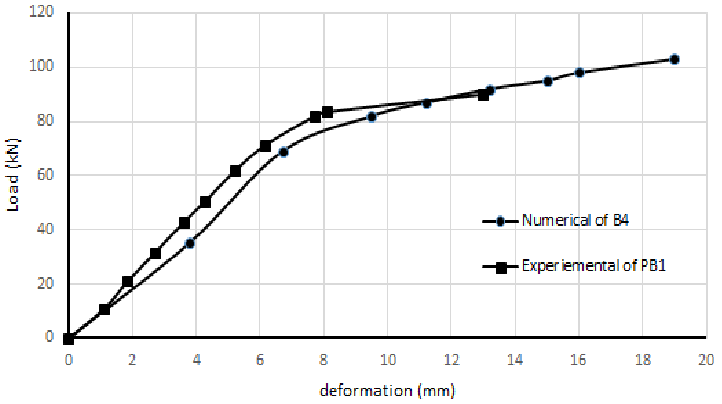

Fig.7-b: load-deflection curve of experimental and numerical results of Beam B4

Effect of steel plate length to effective span of tested beam (L_{sp}/L_e):

Figure 8 shows the load-deformation of beams CB1, B2, B3, B4, B5 and B6; strengthening by steel plate with different length to effective span ratios 0,0.4,0.5,0.6,0.7and 0.8 respectively. Increase steel plate length leads to increase in toughness of tested beam. From table 2, it can be seen that, ultimate loads, and maximum deflection of B2, B3, B4, B5 & B6 to CB1 are (121%, 136%, 147%, 156% and 161%), and (128%, 132%, 152%, 164% and 168%) respectively.

Figure 9 shows the load-max. comp. stress for beams CB1, B2, B3, B4, B5&B6. Figure 10 shows ultimate load and max. deflection of tested beams to control beam with different steel plate length ratios to effective span, and also shows that using steel plate length to effective span of tested beam has a significant effect on the behavior of tested beams up to 0.6. Where ultimate loads and maximum deflection of tested beam B4 (with L_{sp}/L_e=0.6) increased by 147% and 152% of control beam, respectively.

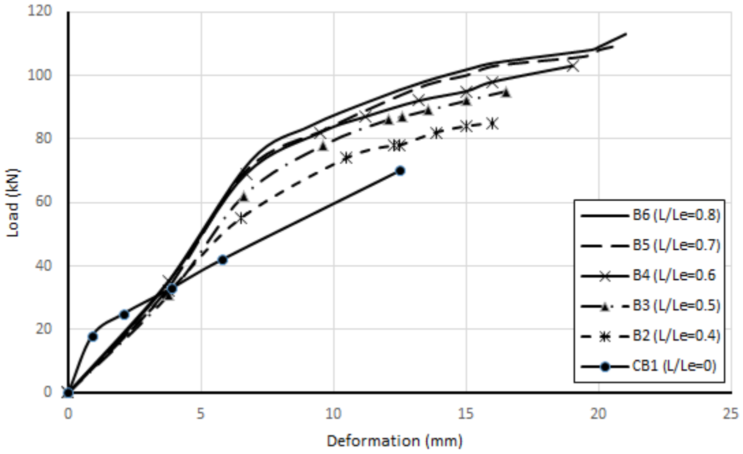

Figure 8: Load-deflection curve of beams CB1, B2, B3, B4, B5&B6

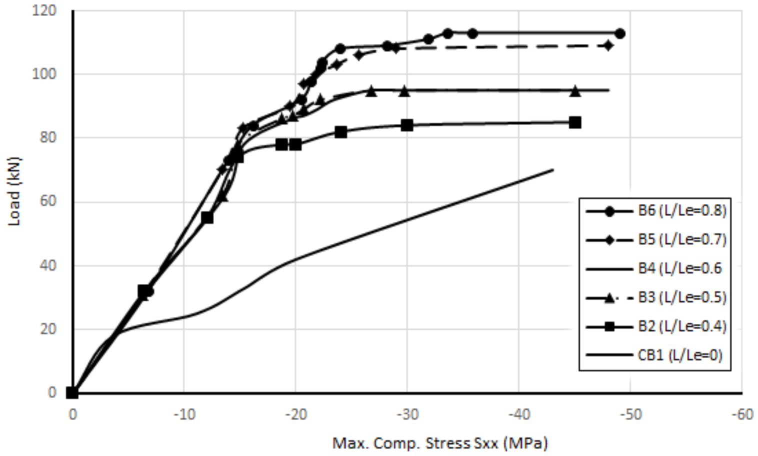

Figure 9: Load-Max. Comp. stress for beams CB1, B2, B3, B4, B5&B6

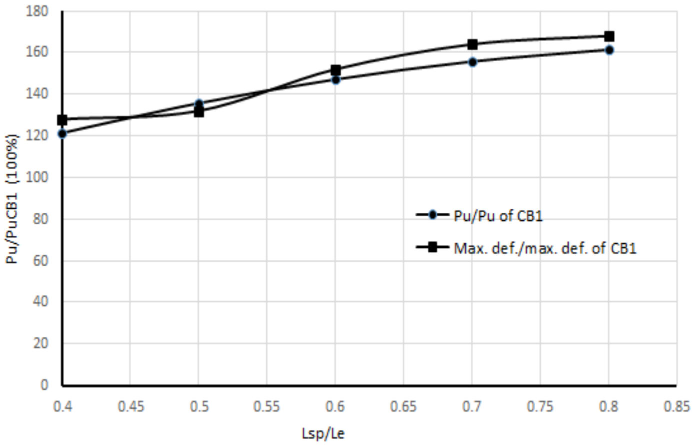

Figure 10: Ultimate load and Max. Deflection of tested beams to control beam with steel plate length to effective span of tested beam (L_{sp}/L_e)

Effect of Steel Plate Ratio ($\rho_{sp} = \frac{A_{sp}}{bd}$)

Figure 11 shows the load-deformation of beams CB1, B7, B5, B8, B9 and B10; strengthening by steel plate with different ratios 0, 0.003, 0.01, 0.017, 0.024 and 0.035 respectively with length to effective span ratios 0.6. Increase steel plate ratio leads to increase in toughness and ductility of tested beam. From table 2, it can be seen that, ultimate loads, and maximum deflection of B7, B4, B8, B9 & B10 to CB1 are (129%, 147%, 157%, 163% and 168%), and (121%, 152%, 160%, 172% and 176%) respectively.

Figure 12 shows the Load-Max. Comp. stress for beams CB1, B7, B5, B8, B9 and B10. Figure 13 shows ultimate load and Max. deflection of tested beams to control beam with different steel plate ratios, and also shows that using steel plate ratios of tested beam has a significant effect on the behavior of tested beams up to 0.017. Where ultimate loads and maximum deflection of tested beam B8; (with ratio=0.017) increase by 157% and 160% of control beam, respectively.

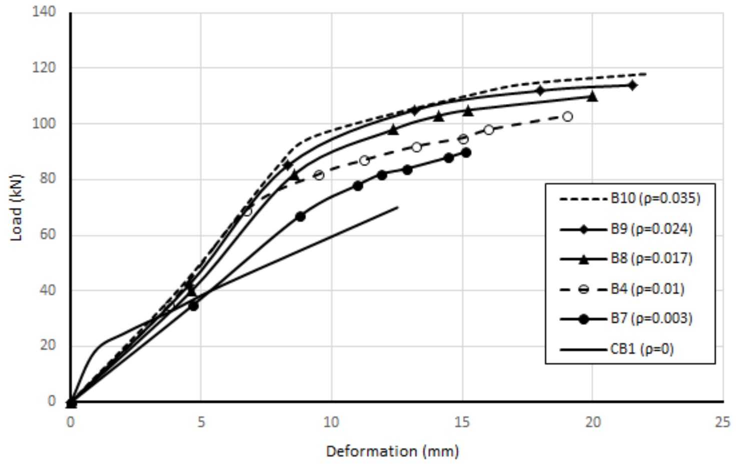

Figure 11: Load-deflection curve of beams CB1, B7, B4, B8, B9&B10

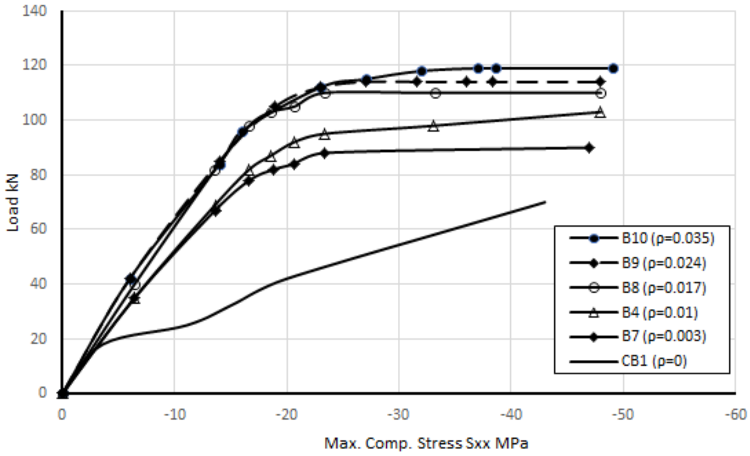

Figure 12: Load-Max. Comp. stress for beams CB1, B7, B4, B8, B9&B10

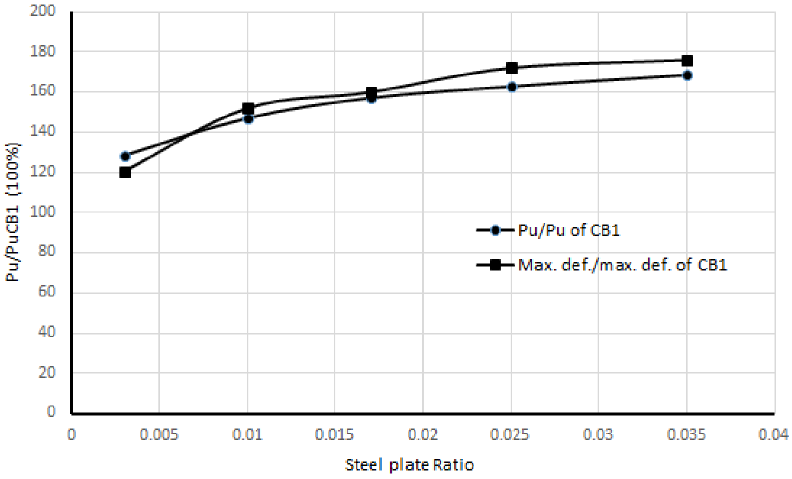

Figure 13: Ultimate load and Max. Deflection of tested beams to control beam with steel plate thickness

Effect of steel plate position

Figure 14 shows the load-deformation of beams CB1, B4, B11, B12 and B13; strengthening by steel plate with different position; horizontal plate under cross section 3mm thickness, vertical plate with 1-notch inside cross section 6mm thickness, vertical plate with 2-notch inside cross section 3mm thickness, and vertical plate outside cross section 3mm thickness every side. Using vertical steel plate in strengthening beam leads to increase in toughness of tested beam. From table 2, it can be seen that, ultimate loads, and maximum deflection of B4, B11, B12 & B13 to CB1 are (147%, 164%, 171% and 174%), and (152%, 176%, 179% and 180%) respectively.

Figure 15 shows the Load-Max. Comp. stress for beams CB1, B4, B11, B12 and B13. Figure 16 shows ultimate load and Max. deflection of tested beams to control beam with different position of steel plate, and also shows that best position of using steel plate for strengthen beams is vertical plate and outside cross section. Where ultimate loads and maximum deflection of tested beam B13; increased by 174% and 180% of control beam, respectively.

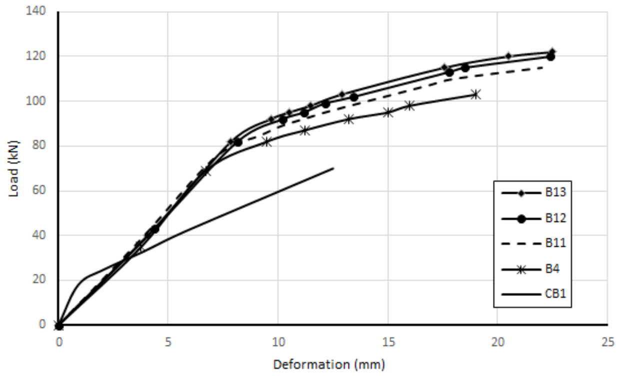

Figure 14: Load-deflection curve of beams CB1, B4, B11, B12 and B13

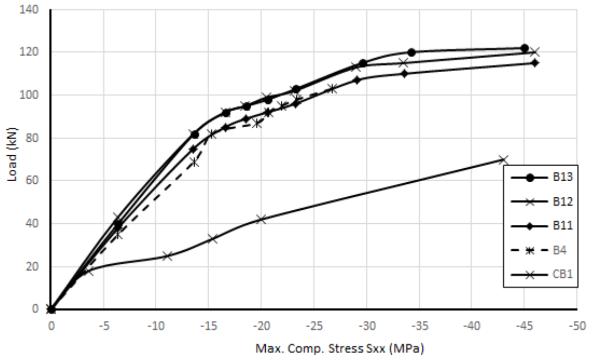

Figure 15: Load-Max. Comp. stress for beams CB1, B4, B11, B12 and B13

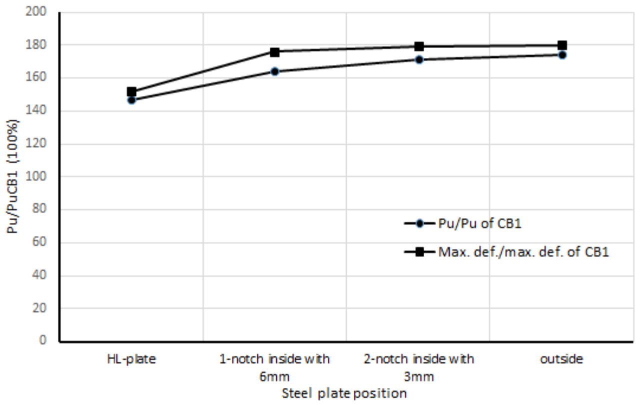

Figure 16: Ultimate load and Max. Deflection of tested beams to control beam with different position of steel plate

VI. CONCLUSIONS

Experimental and numerical studies were conducted on the flexural strengthening of RC beams with epoxy bonded continuous steel plates to confirm the effectiveness of this strengthening technique and to study the effects of plate depth and thickness on the ultimate flexural strength of plated beams. From the results of experiments and the numerical analysis, the following conclusions can be drawn.

1- Using external steel plate restrains the central deflection with considerable increasing of ultimate load capacity.
2- Strengthening beams by steel plate leads to increase the toughness and ductility of tested beam.
3- Using steel plate length to effective span of tested beam has a significant effect on the behavior of tested beams up to 0.6. Where ultimate loads and maximum deflection of tested beam with $L_{sp}/L_e=0.6$ increased by 147% and 152% of control beam, respectively.
4- Using steel plate ratios of tested beam has a significant effect on the behavior of tested beams up to 0.017, where ultimate loads and maximum deflection of tested beam with ratio=0.017 increased by 157% and 160% of control beam, respectively.
5- Best position of using steel plate for strengthen beams is vertical plate and outside cross section, where ultimate loads and maximum deflection of tested beam increased by 174% and 180% of control beam, respectively.

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