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EFFICIENCY OF INTERNAL STRENGTHENING R.C BEAMS WITH RECTANGULAR OPENINGS IN SHEAR ZONE BY USING STEEL PLATES

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The provision of transverse openings in floor beams to facilitate the passage of utility pipes and service ducts results not only in a more systematic layout of pipes and ducts; but also translates into substantial economic savings in the construction of a multi-storey building. Over the past several decades, many researchers exerted great efforts to predict and interpret the behavior of beams with web openings [3-9]. They recommended convenient methods for the design of such beams. External strengthening by using external steel plates or external CFRP laminates will be a satisfactory method in the case if it is required to provide new opening in existing beams. In this research it was suggested to use internal steel plates to improve the efficiency of beams with opening. Therefore, twelve R.C beams were tested under static loading up to failure; eleven of them were fabricated with rectangular opening through the web in shear zone while the remaining beam had a solid web. Internal steel plates around the opening were used in strengthening them. The effect of internal steel plate's thickness, and configuration, horizontal steel plate length and concrete grade is investigated. The pattern of cracks and modes of failure were observed. The mid span deflection, the inner edge of opening deflection and the difference between deflections of the two opening edges were measured. The crack and ultimate load were recorded. The results were studied and given in shape of plates, tables and curves.

KEYWORDS: *perforated R.C Beams, concrete strength, pattern of cracks, deflections, steel plates and strengthening of web openings*

INTRODUCTION

The trend in recent years toward the systems approach to building has generated a need for web openings in structural members. Web openings provide a passageway for ducts and pipes of air conditioning, water supply, sewage, and other electrical and mechanical services. Passing these services through openings in the webs of the floor beams eliminates a significant amount of dead space and results in a more compact and more economical design. For sure, web openings have a minus effect on both strength and the stiffness of the beams, so these beams must be checked and adequately reinforced to eliminate the weakness.

In 1985, Mansur et-al [4] used a rational design method for reinforced concrete beams with large rectangular opening that are subject to bending moment and shear force. In 1985, Nassef, et-al [7] studied the effect of openings located in the shear zones on the behavior of reinforced concrete beams. In 1998, Mansur [5] studied the effect of introducing a transverse opening on the behaviour and strength of reinforced concrete beams under predominant shear on the basis of observed structural response. Okasha [3] in 2000 studied the effect of CFRP in strengthening and improving the behavior of beams with openings. In 2001, Mansur, et-al. [6] investigate the design of reinforced concrete beams with circular openings. In 2002 Carina N., Martina S.H. [8] studied the behaviour of R.C beams with large openings in shear zone, In 2007. Abdel-Shafy [9] studied the effect of opening dimensions and positions on the static behaviour of high strength R.C perforated beams.

In the current thesis, an experimental study for web openings strengthened internally with steel plates will be presented, the main object of this thesis is to study the availability of providing rectangular web openings in R.C beams with smallest minus effect on both strength and stiffness by means of strengthening openings with internal steel plates.

The mean parameters taken into considerations are:

- Configuration of used steel plates around opening.
- Dimensions of top and bottom steel plates (thickness and length), and
- Concrete grade.

EXPERIMENTAL PROGRAM

Twelve reinforced concrete beams with rectangular cross-section were prepared. The first beam was a solid one with no openings and served as a reference beam. Each one of the rest beams had a rectangular web opening of 30cm length and 12cm height at a distance from the nearest support to its center equals to half its shear span, ten beams of them were strengthened internally by using steel plates around the opening in form of four groups. In group (A), beams (RO3, RO4 and RO5), were provided with the same internal steel plates length (L_h), width (W_h) and configuration type. The only variable parameter was the thickness of the internal steel plates (t_h). It had the values 3, 2 and 4mm respectively. In Group (B), beams (RO3 and RO6), the only variable parameter was the configuration type of the internal steel plates in form of type (1) and type (2) respectively. See Fig. (2). Group (C), consists of two series (C1 and C2). In series C1, beams (RO7 and RO8), and taking beam (RO3) into consideration, the only variable parameter was the internal steel plate's length (L_h). It had the values 50, 40 and 60cm for such group respectively. Series C2, beams (RO9 and RO10) was similar to series C1 except the configuration type of the internal steel plates. The configuration type of the internal steel plates of series C2 was type2. Also taking beam (RO6) into consideration the only variable parameter was the internal steel plate's length (L_h). It had values 50, 40 and 60cm for such group respectively. Group (D), includes beams (RO3, RO11and RO12), the only variable parameter was the grade of concrete (f_{cu}). It had values 30, 60 and 80 MPA respectively.

All the tested beams have the same total length of 1.45m and over all depth and width of 30cm and 12cm respectively. They were simply supported on a span 1.30m apart. All beams were tested under one point static loading at mid span with shear span to depth ratio (a/d) of 2.4. Steel reinforcement of all beams was:

- Four bars 16mm diameter as tension reinforcement.
- Two bars 12mm diameter as compression reinforcement.
- Stirrups 6mm diameter with 14 cm spacing along the solid parts.
- Each vertical side of the opening was reinforced by means of one closed stirrups 6mm diameter.
- Both top and bottom chords of opening length were reinforced by means of 4 closed stirrups of 6mm diameter.

Details of all tested beams are shown in Table (1).

Where

Config. = configuration type of steel plates. (Type1 and type2 = see details in Fig. (2)).

μo % = confinement ratio (Volume of steel plates / volume of confined concrete)

Table. (1) Details of the Tested Beams

Group No.	Beam No.	f_{cu}, (Mpa)	Internal Steel plates (cm)							μo %	Variable included
			horizontal			vertical			Config.		
			L_h	W_h	t_h	L_v	W_v	t_v			
R	SB1	30	---	---	---	---	---	---	---	---	Ref.
	UO2	30	---	---	---	---	---	---	---	---	
A	RO3	30	50	5.0	0.3	---	---	---	Type1	2.78	steel plate's thickness
	RO4	30	50	5.0	0.2	---	---	---	Type1	1.85	
	RO5	30	50	5.0	0.4	---	---	---	Type1	3.7	
B	RO6	30	50	5.0	0.3	25	5.0	0.3	Type2	3.68	Config. of Steel
C – C1	RO7	30	40	5.0	0.3	---	---	---	Type1	2.78	Length of top and bottom steel plates
C – C1	RO8	30	60	5.0	0.3	---	---	---	Type1	2.78	
C – C2	RO9	30	40	5.0	0.3	25	5.0	0.3	Type2	3.87	
C – C2	RO10	30	60	5.0	0.3	25	5.0	0.3	Type2	3.54	
D	RO11	60	50	5.0	0.3	---	---	---	Type1	2.78	Concrete grade
	RO12	80	50	5.0	0.3	---	---	---	Type1	2.78	

MATERIALS

Three concrete mixes were designed to produce concrete having a 28 days cube compressive strength of about 30, 60 and 80 Mpa.

For normal strength concrete f_{cu} of 30 Mpa, the constituent materials were:

a) Ordinary Portland cement. Its properties are according to E.S.S. [2].
b) Local sand was used, 2.60 specific gravity, 1.58t/m^3 volume weight and 2.59 fineness modulus.
c) Local gravel was used, 2.66 specific gravity, 1.7 t/m^3 volume weight, 6.42 fineness modulus and 20mm maximum nominal size.
d) Drinking water was used for both mixing and curing.

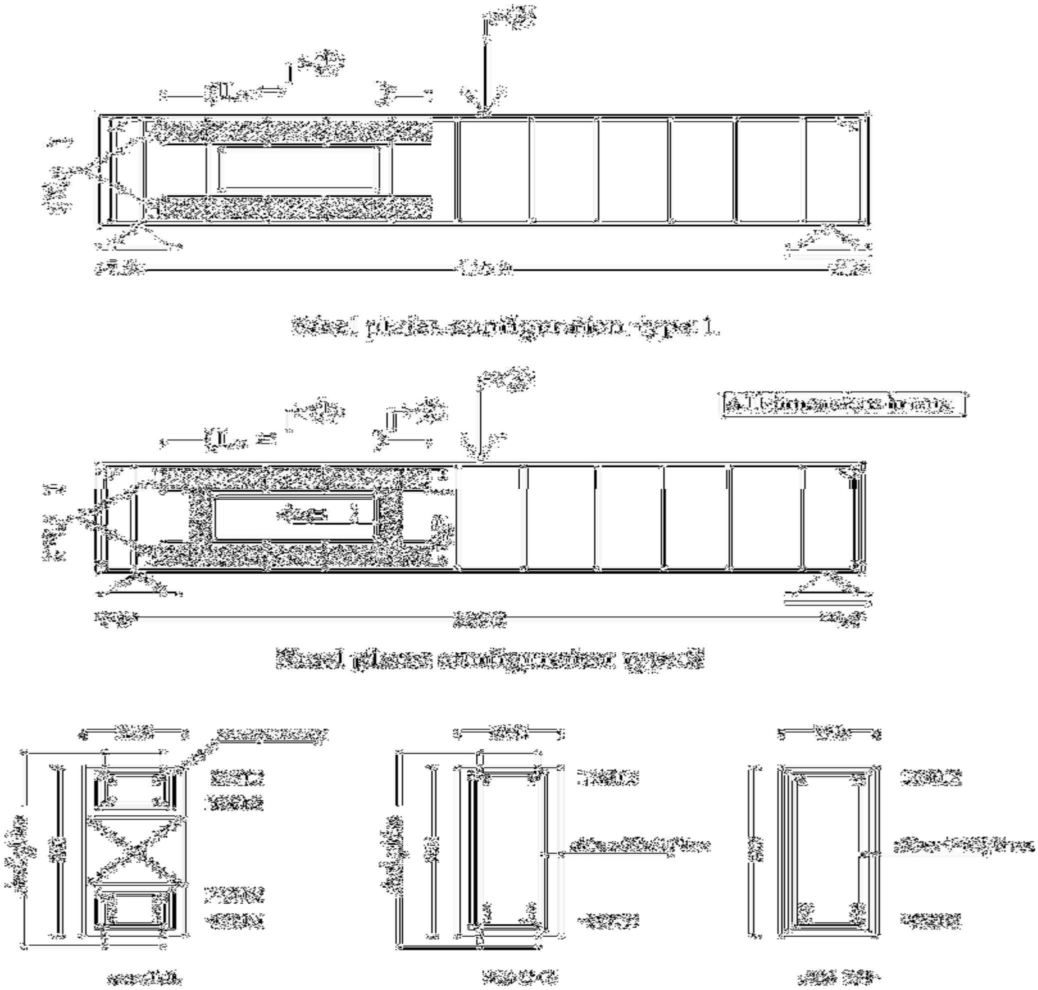


Fig. (2) Details of tested beams

For high-strength concrete f_{cu} of 60 and 80 Mpa, the constituent materials were:

a) Cement, Sand and water were the same types and qualities that used in normal strength concrete mixes.

b) Crushed basalt; the used crushed basalt was 20mm maximum nominal size, 2.70 specific gravity and 2.35 t/m^3 volume weight
c) Superplastisizer; the used additive was SIKAMENT (NN) produced by SIKA Industries Co. for SIKA Egypt Co., having a density 1.2 t/m^3.
d) Silica fume, the specific surface area is (12-15 m^2/g) and the specific gravity is 2.2.

The amounts of the constituent materials used in each mix by weight (kg/m^3) are given in table (2).

The mechanical properties of the used steel plates were presented in table (3).

Table (2): Amounts of the Constituent Materials by Weight Required for One Cubic Meter of Concrete for the Used Different Mixes.

Mix No.	**Amount of constituent materials/m3**							**f_{cu} Mpa**
	Cement (kg)	**Sand (kg)**	**Coarse aggr. (kg)**		**Water (litre)**	**Silica fume ((kg)**	**Add. .(kg)**	
			Gravel	**Broken Bazalt**				
1	400	620	1220	-----	190	----	----	30
2	450	600	---	1200	155	70	15	60
3	500	600	--	1200	145	80	20	80

Table (3): Mechanical Properties of the Used Steel Plates.

Commercial thickness (mm)	4	3	2
Actual thickness (mm)	4.2	3.1	2.1
Yield strength (kg/cm^2)	2525	2402	2461
Ultimate strength (kg/cm^2)	3527	3700	3516
% of elongation	27.1	28.3	29.1

FABRICATION OF THE TESTED BEAMS

This program was carried out in reinforced concrete laboratory, Assiut University. The concrete was mixed by means of horizontal pan mixer of 0.1 m^3 capacity. Concrete was placed in a steel forms. The openings were achieved using wooden parts of the same opening size. Concrete was compacted by electrical internal vibrator. Control specimens including three cubes 15 cm side length were cast with each beam at the same time. The beams and cubes were cured in the same manner.

TEST PROCEDURE

The beams were tested under one point static loading on increments. Before cracking load each increment was 0.5 ton but after cracking, each increment was 1.0 ton. The load was kept constant between two successive increments for about five minutes. During this period, reading of dial gauges and the crack propagation were recorded. At the same day, three control cubes were tested in compression.

TEST RESULTS

i- Pattern of Cracks and Mode of Failure of Tested Beams:

In reference beam (SB1) which was a solid one the first crack was initiated at the bottom surface under point of load application (in mid-span). This crack grew very slowly vertically up to a distance more than three quarter of the height of the beam. With increasing the load, diagonal tension cracks formed between the point of load application and the support, the major crack was formed with an inclination ranges between 35° and 47° to the horizontal. The final mode of failure was shear failure accompanied with concrete crushing adjacent to the load application. In reference beam (UO2), without internal strengthening, the first crack was initiated at the top corner at inner edge of the opening. At this time small cracks formed at opposite opening corner. By load increasing, other cracks initiated in top chord and grew in length and width, near failure few cracks appeared in bottom chord. The major crack leading to failure was occurring in the top chord with an inclination to horizontal of about 20°. The final mode of failure was shear at opening. For all beams with strengthened opening, the first crack appeared in top chord at high moment end of the opening. Almost, at the same load small cracks appeared in bottom chord at low moment end of opening. After that, vertical cracks at bottom chord at the inner edge of the opening were observed. By load increasing further other cracks at inner side of the opening initiated and grew in length towards the point of loading. At outer side of the opening cracks propagated towards the nearest support. At later stage of loading diagonal cracks initiated at the solid side of the beam, in addition to small cracks near the center of the beam. Few minutes before failure small horizontal cracks were appeared in the middle of top chord, then diagonal cracks at top and bottom chords appeared suddenly accompanied with failure occurrence. Concrete crushing was occurred near point of loading. The mode of failure of these beams was due to shear at opening region. At failure the compression chord of the opening of these beams have been splitted diagonally with crushing of concrete at the high moment end. See Fig. (3).

In general, it can be seen that, crack number of the beam having opening without internal strengthening were smaller than those in beams having strengthened opening. The inclination of the major cracks of beams with strengthened opening was closed to horizontal compared with those of beams having opening without strengthening. The mode of failure of either beams having strengthened opening or beam having opening without strengthening was shear at opening region. Meanwhile, the failure of beams having strengthened opening was accompanied with concrete crushing at the point of load application and at the inner edge of the opening.

(1) Beam SB1

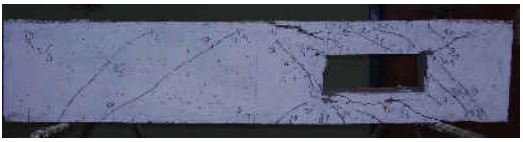
(2)Beam UO2

(3)Beam RO3

(4)Beam RO4

(5) Beam RO5

(6) Beam RO6



(7) Beam RO7

(8) Beam RO8

(9)Beam RO9

(10)Beam RO10

(11) Beam RO11

(12) Beam RO12

Fig. (3) Pattern of cracks of tested beams.

ii- Loads and Deflections of Tested Beams at Both Cracking and Ultimate Level:

Table (4) summarizes the obtained and recorded test results for the tested beams in form of cracking and ultimate load levels.

Where:

$f_{c\ u}$ = concrete grade.

$P_{cr.}$ = cracking load.

P_ul. = ultimate load.

δ_{cr} = deflection at cracking load.

δ_{mid} = mid span deflection at 90% of ultimate load.

S.F = shear failure.

δ_{inn} = inner edge deflection at 90% of ultimate load.

S.F.O = shear failure at opening region.

δ_{diff} = difference between deflections of two opening edges at 90% of ultimate load

Table (4) The Obtained Test Results for Tested Beams.

Group No.	Beam No.	f_{cu} (Mpa)	Internal Steel plates (cm)							Pcr (ton)	Pul (ton)	δcr (mm)	δmid (mm)	δin(mm)	δdif (mm)	Mode of failure
			horizontal			vertical			Config.							
			L_h	W_h	t_h	L_v	W_v	t_v								
R	SB1	30.3	---	---	---	---	---	---	---	5	15.9	0.77	2.95	2.94	0.79	S.F
R	UO2	32.5	---	---	---	---	---	---	---	2.5	8.3	0.6	2.12	2.62	1.38	S.F.O
(A)	RO3	28.5	50	5.0	0.3	---	---	---	Type1	2.5	11.6	0.47	4.16	4.34	2.7	S.F.O
(A)	RO4	29.1	50	5.0	0.2	---	---	---	Type1	2.5	9.8	0.52	3.11	3.21	1.96	S.F.O
(A)	RO5	31.6	50	5.0	0.4	---	---	---	Type1	2.5	11.9	0.43	3.45	3.81	2.54	S.F.O
(B)	RO6	33.6	50	5.0	0.3	25	5.0	0.3	Type2	2.5	11.6	0.55	4.46	4.93	3.4	S.F.O
(C) C1	RO7	33.6	40	5.0	0.3	---	---	---	Type1	2.5	11.3	0.53	4.29	4.98	2.96	S.F.O
(C) C1	RO8	31.2	60	5.0	0.3	---	---	---	Type1	2.5	12	0.44	3.95	4.25	2.64	S.F.O
(C) C2	RO9	29.8	40	5.0	0.3	25	5.0	0.3	Type2	2.5	11	0.54	4.47	4.91	3.24	S.F.O
(C) C2	RO10	30	60	5.0	0.3	25	5.0	0.3	Type2	2.5	12.3	0.48	3.81	4.1	2.6	S.F.O
(D)	RO11	59.4	50	5.0	0.3	---	---	---	Type1	5.5	17	1.14	4.88	5.13	3.16	S.F.O
(D)	RO12	77	50	5.0	0.3	---	---	---	Type1	6	19.5	1.2	6.27	7.54	3.69	S.F.O

The relation between load and mid-span deflection for tested beams are presented in figure (4) through Figure (8).

DISCUSSION OF TEST RESULTS

The obtained test results were analysed to declare the effect of various included parameters taken in this work on strength, deformation as well as upon absorbed strain energy up to failure. These properties were measured by means cracking and ultimate load, cracking and ultimate defections as well as by toughness respectively. As follows:

i- Effect of Steel Plates Thickness "Confinement Ratio"

It is clear from Fig. (4) and Fig. (9), that increasing confinement ratio (μo %) (Volume of steel plates / volume of confined concrete) has no effect on cracking load (Pcr.). Increasing confinement ratio increased the ultimate load, but increasing confinement ratio after a certain value has slight effect on ultimate load. Increasing confinement ratio from 0 % to 1.85 % increased the ultimate load by 18 %. Increasing confinement ratio from 1.85 % to 2.78 % increased the ultimate load by 22 %. Increasing confinement ratio from 2.78 % to 3.7 % increased the ultimate load by 3 %.

This may be related to that the failure occurred due to concrete crushing rather than yielding of steel plates. Thus the ACI limits on maximum shear appears to apply to beams with opening, provided Vc is calculated on basis of net section through the opening, this results was agreed with that given in ref. [6].

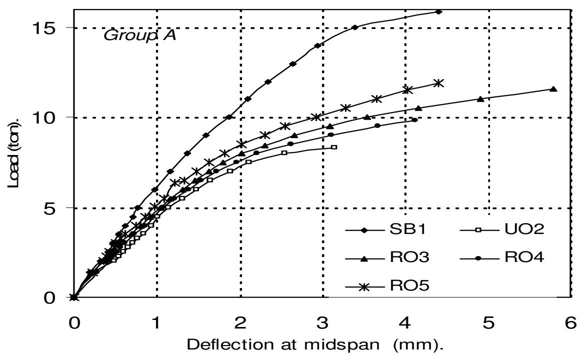


Fig. (4).

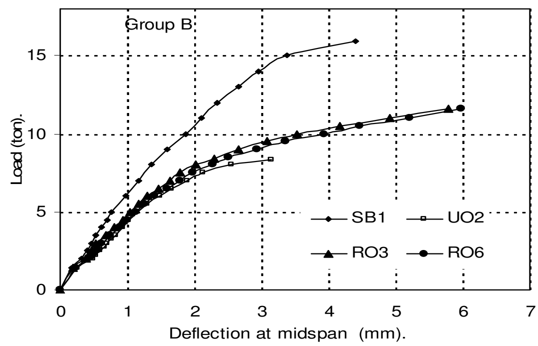


Fig. (5).

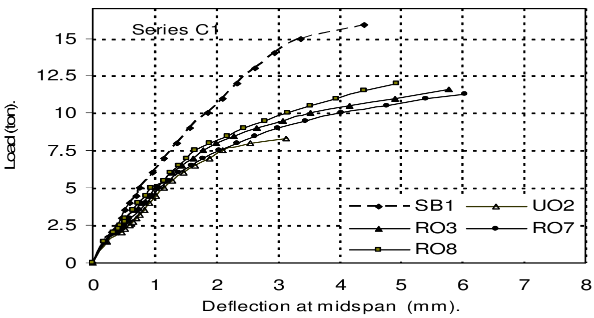


Fig.(6).

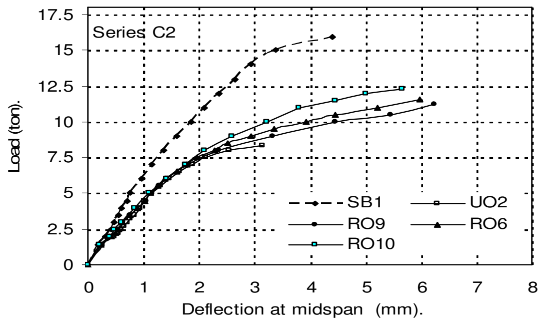


Fig.(7).

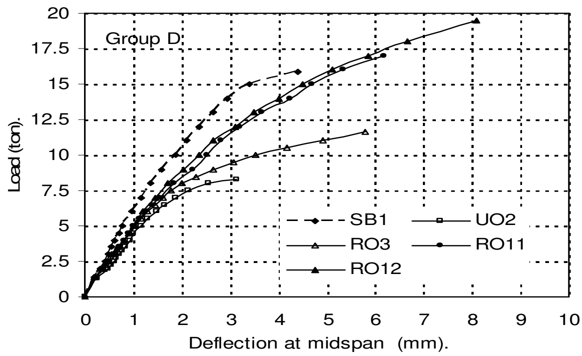


Fig.(8).

From Fig. (4) and Fig. (10), it can be seen that increasing confinement ratio (μo %) decreased the deflection at cracking load (δcr). This may be due to increasing of the stiffness at the opening region. It can be obvious from Fig. (11) that, due to load increasing, the deflection at mid span, inner edge deflection and difference between deflections of two opening edges for all strengthened beams at 90% of the ultimate load were more than those of beam having unstrengthened opening. Meanwhile, Fig. (4) indicates that at the same load, increasing confinement ratio (μo %) decreased mid span deflection, inner edge deflection and the difference between deflections of two opening edges. This may be related to increasing beam stiffness at opening region. Increasing confinement ratio from 0%, 1.85% increased the mid span deflection, inner edge deflection and difference between deflections of two opening edges by 47%, 23 %and 42 % respectively. Increasing confinement ratio from 1.85% to 2.78% increased the mid span deflection, inner edge deflection and the difference between deflections of two opening edges by 49%, 43% and 54% respectively. Increasing confinement ratio from 2.78% to 3.7% decreased mid span deflection, inner edge deflection and the difference between deflections of two opening edges by 33%, 21% and 12% respectively.

Figure (12) indicates that confinement ratio has considerable effect on beam toughness. The toughness of beams was evaluated by means of area under load-deflection diagram. In general, increasing confinement ratio increased beam toughness. However, due to deflection decreasing, beams having almost the same ultimate load the beam toughness decreased by increasing confinement ratio. Increasing confinement ratio from 0 % to 1.85 % increased beam toughness by 59 %. Increasing confinement ratio from 1.85 % to 2.78 % increased beam toughness by 116 %. Increasing confinement ratio from 2.78 % to 3.7 % decreased beam toughness by 64 %.

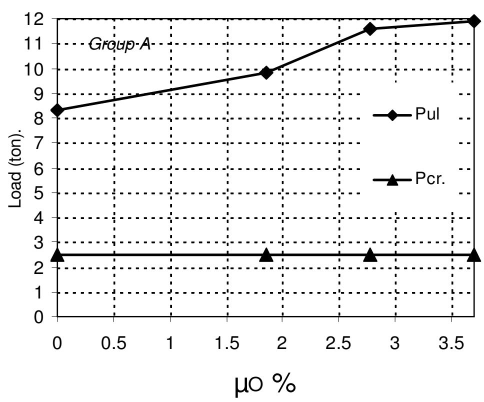


Fig. (9). Effect of confinement ratio on cracking and ultimate load

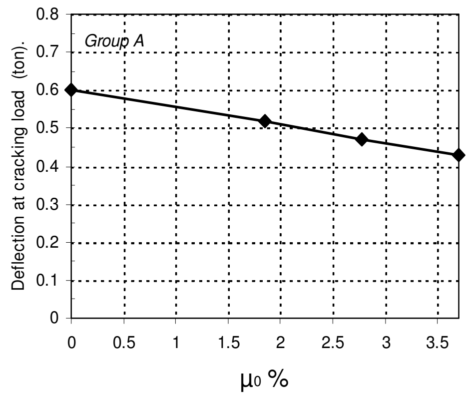


Fig.(10) Effect of confinement ratio on deflection at cracking load.

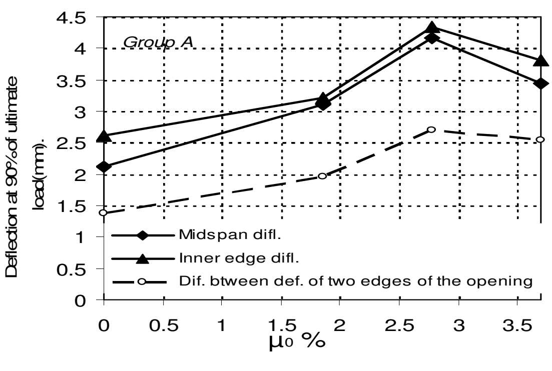


Fig. (11). Effect of confinement ratio on the deflections.

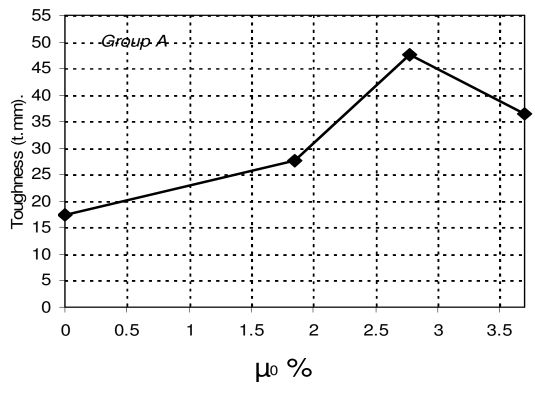


Fig. (12). Effect of confinement ratio on the beam toughness.

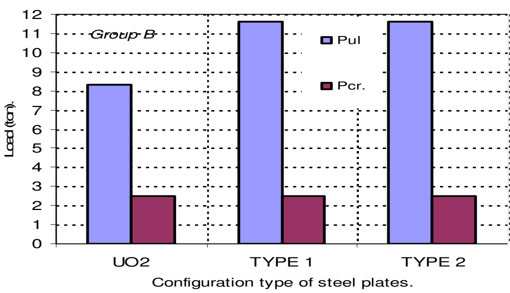
ii- Effect of Coniguration Type of Steel Plates

Cracking load of beam having steel plate's configuration type 1 was the same one as for beam having steel plate's configuration type 2. This may be attributed to the fact that the cracking load is mainly affected by concrete grade rather than by configuration type of steel plates.

The ultimate loads were not affected by steel plates configuration type (i.e. the vertical steel plates at the opening sides not affect the ultimate load value). The failure of two beams having different steel plates configurations was designated by what so called frame type failure "splitting of top and bottom chords of opening", consequently the effect of vertical steel plates on the ultimate load did not appear. See Fig. (5) and Fig. (13). For beams strengthened with any of two steel plates configuration types the ultimate load were 140 % of beam having unstrengthened opening.

Figure (14) shows that, the deflection at cracking load for beam with steel plate's configuration type 2 is approximately similar to the deflection at cracking load for beam with steel plate's configuration type 1. It can be noticed from Fig. (15) that the deflection at mid span, inner edge deflection and the difference between deflections of two opening edges for beam with steel plate's configuration type 2 were slightly more than those for beam with steel plates configuration type 1. This may be occurred due to that the presence of horizontal and vertical steel plates at opening corners without strong connection between them lead to reduction of the amount of concrete at these positions. In addition, the presence of vertical steel plates at the inside face of the horizontal steel plates vanish the bond between concrete and horizontal steel plates at these positions. All of these tend to make the opening corners to be weak and hence increase the deflections. The mid span deflections of beams having steel plates configurations type 1 and type 2 were 196 % and 210 % respectively of beam having unstrengthened opening, their inner edge deflections were 166 % and 188 % of beam having unstrengthened opening and their difference between deflections of two opening edges were 196 %and 246 % respectively of beam having unstrengthened opening.

Figure (16), indicates that, the toughness of beams strengthened with steel plates configuration type 1 or type 2 were greater than that of beam having unstrengthened opening. However, the toughness of beams with steel plate's configuration type 1 and type 2 were approximately similar to each other. The toughness of beam with steel plates configuration type 1 and type 2 were 275 % and 278 % respectively of beam having unstrengthened opening.



]Fig. (13). Effect of configuration type on cracking and ultimate load

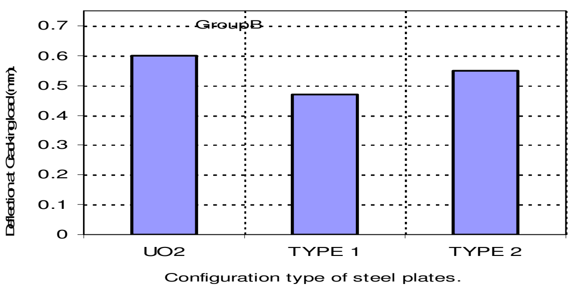


Fig. (14) Effect of configuration type on deflection at cracking load.

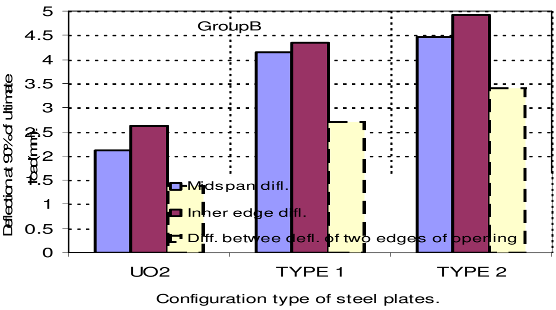


Fig. (15). Effect of configuration type on the deflections.

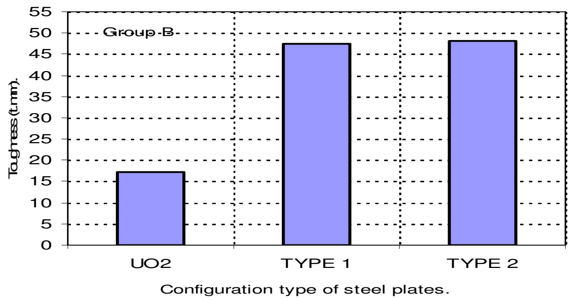


Fig. (16). Effect of confinement ratio on the beam toughness.

iii- Effect of Horizontal Steel Plates Length

From Fig.(6, 7, 17 and 18), it was clear that for two types of steel plates configurations the cracking load was not affected by increasing the length of internal horizontal steel plates.

Increasing steel plate length, for both two types of steel plate configurations, increased the ultimate load. Increasing the length of steel plates more than 4/3 of opening length increased the ultimate load slightly. This was because, as mentioned before, the failure occurred due to concrete crushing rather than yielding of steel plates, hence the force in steel plates did not increased more than certain value and so the anchorage length after this value was not required. The ultimate loads of beams having steel plate's configurations type 1 with horizontal steel plate's lengths of 0, 1.33, 1.67 and 2.00 of opening length were 100 % , 136 % , 140% and 145% respectively of beam having unstrengthened opening. However, the ultimate loads of beams having steel plates configurations type 2 with horizontal steel plates lengths of 0, 1.33, 1.67 and 2.00 of opening length were 100 %, 135 % , 140 % and 148 % respectively of beam having unstrengthened opening.

From Fig.(19) and (20), it can be observed that, increasing the length of internal steel plates, for both two types of steel plates configurations, decreased the deflection at cracking load.

It is obvious from Fig. (21) and (22), that all strengthened beams with any one of configuration types and with different lengths of steel plates showed that the mid span deflection, inner edge deflection and difference between deflections of two opening edges were greater than those of beam having unstrengthened opening. However, increasing the length of internal steel plates for beams with any type of steel plate configuration decreased mid span deflection, inner edge deflection and the difference between deflections of two opening edges. This may be due to the fact that the rigidity of opening corners usually increased by increasing the length of steel plates. The mid span deflection of strengthened beam with configuration type 1 having steel plates lengths of 1.33, 1.67 and 2 of opening length was 202%, 196% and 186% respectively of that unstrengthened opening, their inner edge deflections were 190%, 166% and 162% respectively of beam having unstrengthened opening and their difference between deflections of two opening edges were 214%, 196% and 191% respectively of beam having unstrengthened opening. The mid span deflection of beam with configuration type 2 having steel plates lengths of 1.33, 1.67 and 2 of opening length was 218%, 210% and 180% respectively of that for beam having unstrengthened opening, their inner edge deflections were 195%, 188% and 156% respectively of beam having unstrengthened opening and their difference between deflections of two opening edges were 249%, 246% and 188% respectively of beam having unstrengthened opening.

From Figs. (23) and (24), it can be observed that, for two types of configurations, the toughness of all strengthened beams in this group was greater than those of beam having unstrengthened opening. While, increasing steel plates lengths than certain limit, for two types of configurations, decreased beam toughness. Beams with steel plates configurations type 1 having horizontal steel plates of lengths of 1.33, 1.67 and 2.00 of opening length their toughness were 279%, 275% and 231% respectively of that for beams with unstrengthened opening. Meanwhile, beams with steel plates configurations type 2 having the same steel plates lengths their toughness was 283%, 278% and 275% respectively compared with that of beam having unstrengthened opening

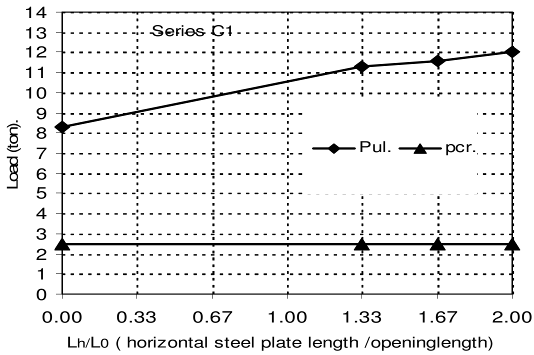


Fig. (17) Effect horiz. Steel pates length with config. Type 1 on cracking and ultimate load

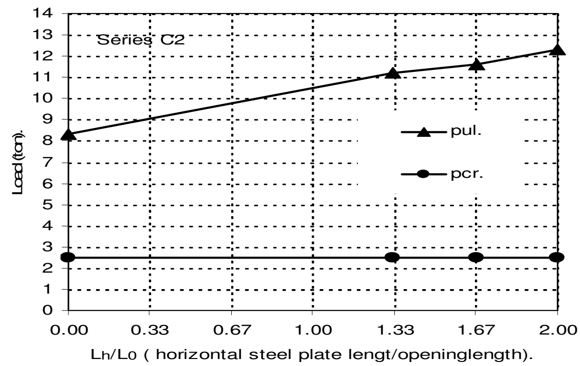


Fig. (18) Effect horiz. Steel pates length with config. Type 2 on cracking and ultimate load

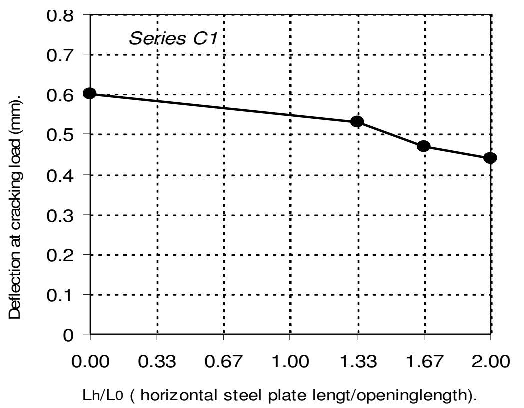


Fig. (19). Effect horiz. Steel pates length with config. Type 1 on deflection at cracking load.

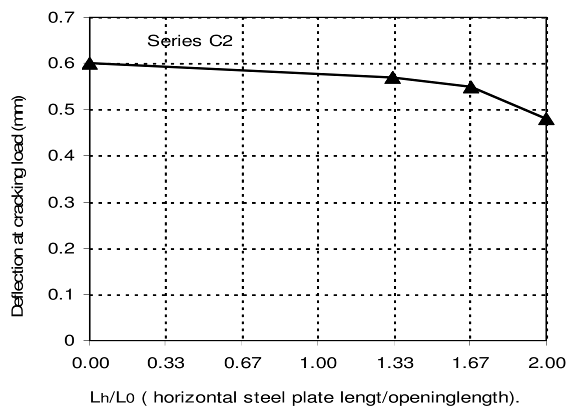


Fig. (20) Effect horiz. Steel pates length with config. Type 2 on deflection at cracking load.

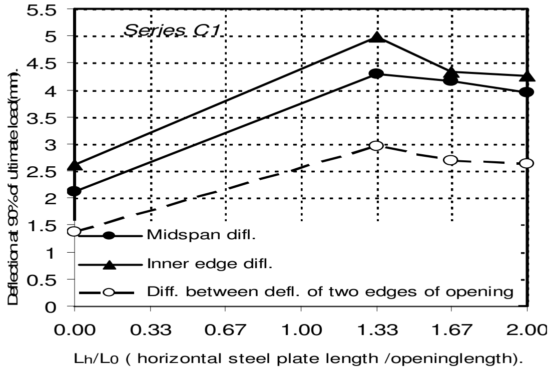


Fig. (21). Effect horiz. Steel pates length with config. Type 1 on deflections.

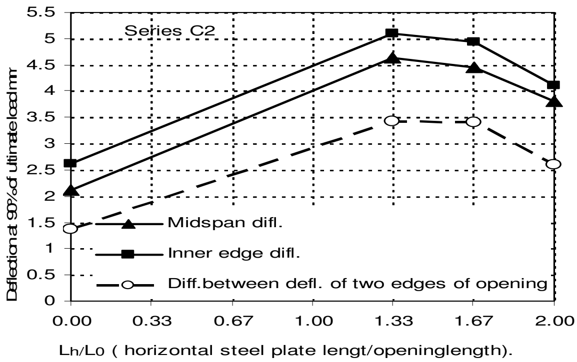


Fig. (22). Effect horiz. Steel pates length with config. Type 2 on deflections.

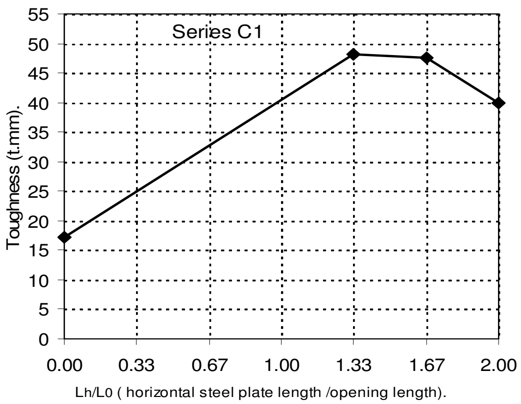


Fig. (23). Effect horiz. Steel pates length with config. Type 1 on toughness.

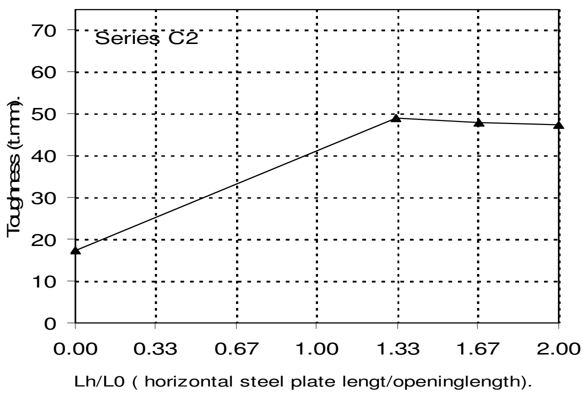


Fig. (24). Effect horiz. Steel pates length with config. Type 2 on toughness.

iv- Effect of Concrete Grade

It can be observed from Figs. (9) and Fig.(25), that the cracking load of strengthened beams increased by increasing grade of concrete. This may be due to increasing of compressive strength of concrete which accompanied by increasing its tensile strength. Beams with concrete grade of 28.5 MPa, 59.4 MPa and 77 MPa the cracking loads were 100%, 220% and 240% respectively of beam with 32.5 MPa as concrete grade. Increasing concrete grade considerably increased the ultimate load. This may be due to delaying concrete crushing in top and bottom chords of opening and hence promise to increase the load carried by horizontal steel plates and then increased the ultimate load. The ultimate loads of beams having opening with concrete grads of 28.5 MPa, 59.4 MPa and 77 MPa were 140%, 205% and 235% respectively of beam having unstrengthened opening with concrete grade of 32.5 MPa .

It can be seen from Fig. (26) that increased concrete grade increased the deflection at cracking load. It can be obvious from Fig. (27) that, increasing concrete grade increased mid span deflection, inner edge deflection and the difference between deflections of two opening edges. The mid span deflections of beams with concrete grades of 28.5 MPa, 59.4 MPa and 77 MPa were 196%, 230% and 296% respectively of that for beam having unstrengthened opening with concrete grade of 32.5 MPa, their inner edge deflections were 166%, 196% and 288% respectively of beam having unstrengthened opening with concrete grade of 32.5 MPa and their difference between deflections of two opening edges were 196%, 229% and 267% respectively of beam having unstrengthened opening with concrete grade of 32.5 MPa.

Figure (28) indicates that, increasing concrete grade considerably increased beam toughness.

Toughness of beams having concrete grade 28.5MPa, 59.4MPa and 77MPa were 275%, 379% and 595% respectively of beam having unstrengthened opening with concrete grade of 32.5MPa.

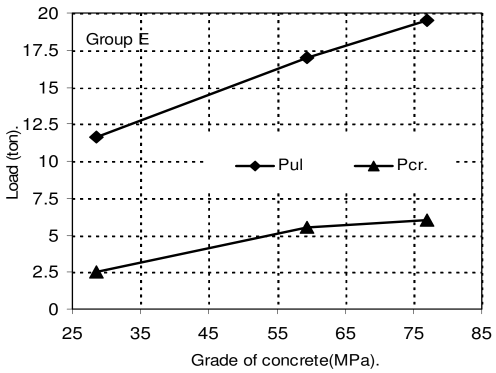


Fig. (25) Effect of concrete grade on cracking and ultimate load

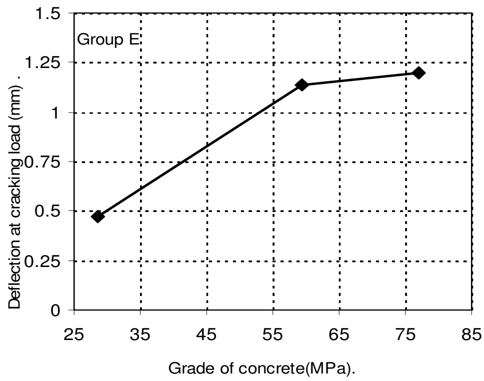


Fig. (26) Effect of concrete grade on deflection at cracking load.

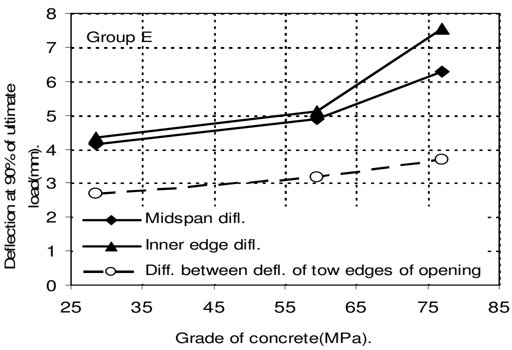


Fig. (27). Effect of concrete grade on deflections.

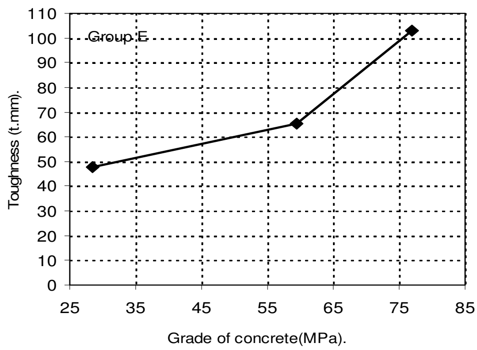


Fig. (28) Effect concrete grade on toughness.

<u>vi-Comparison of the Experimental Ultimate Load with that Predicted In Reference [9]:</u>

To compare the experimental results with the predicted ultimate load using some equations found in the literature, the ultimate expected theoretical load for tested beams was estimated using the following equation proposed by Abdel-Shafy [9].

$$P_u = 0.0083 \frac{\mu^{0.085} f_c^{0.3} A_{t+b}}{\left(\frac{d_0}{d}\right)^{0.7} \left(\frac{l_0}{a}\right)^{0.72} \left(\frac{S_0}{a}\right)^{0.58} \left(\frac{a}{d}\right)^{0.5}}$$

Where;

P_u = The predicted ultimate load in (ton).

μ =ρ+ 2μt+2 μb

ρ = Main reinforcement ratio.

μ_t = Horizontal reinforcement ratio around opening in top chord (A_{st}/ A_{ct}).

μ_b = Horizontal reinforcement ratio around opening in bottom chord(A_{sb}/ A_{cb}).

A_{st} = Area of horizontal reinforcement around opening in top chord (cm^2).

Ast = Area of horizontal reinforcement around opening in bottom chord (cm^2).

A_{ct} = Concrete area of top chord (cm^2).

A_{cb} = Concrete area of bottom chord (cm^2).

A_{t+b} = Σ of concrete area of top and bottom chords (cm^2).

d = Depth of beam (cm).

a = Shear span length of beam (cm).

d_0 = Opening depth (cm).

S_0 = Distance between nearest support and center of opening (cm).

L_0 = Opening length (cm).

Figure (29), shows the relation between the experimental ultimate load and the predicted ultimate load for the tested beams by Abdel-Shafy equation [9]. It can be notice that Abdel-Shafy equation satisfactory for predicting of the ultimate load for normal strength R.C beams having rectangular web opening and strengthened internally by using steel plates, but it is not satisfactory for the same beams with high strength concrete grade.

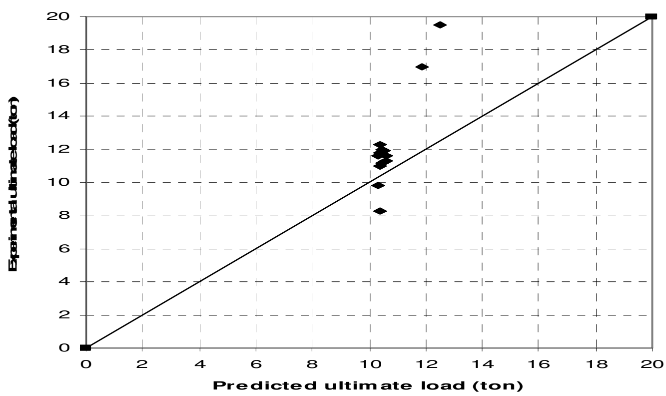


Fig. (29), Comparison between experimental ultimate loads and predicted ultimate load based on Abdel-Shafy equation [9].

CONCLUSIONS

The following conclusions may be drawn from the experimental investigation of R.C Beams having rectangular openings through the web at shear zone and strengthened internally by using steel plates:

1. The mode of failure of beams with a/d = 2.4 and having opening in shear zone with height 0.4 of the beam depth and with length of 2.5 of its depth is usually of shear failure at opening region.
2. The presence of an opening in shear zone of R.C concrete beam with height of 0.4 the beam depth and with length of 2.5 its depth significantly decreases its cracking and ultimate load. The ultimate loads of beams with openings may be reduced by about 50% compared to similar beam without openings.
3. The cracking load of beams having opening in shear zone strengthened internally with steel plates is not affected by any of steel plates thickness, steel plates configurations type, and horizontal steel plates length.
4. Increasing the thickness of steel plates around the shear zone openings increased the ultimate loads up to limited value depending on concrete grade beyond which the ultimate load may be constant or slightly decreased.
5. Beams having rectangular opening in shear zone strengthened with internal steel plates with configuration type 1 or type2 have the same ultimate load.
6. The ultimate load of beams having rectangular opening in shear zone strengthened internally with steel plates with configurations used in this research slightly increased by increasing the length of horizontal steel plates.
7. Increasing the thickness of steel plates and the length of horizontal steel plates decreases mid span deflection, inner edge deflection and difference between deflections of two opening edges.
8. Mid span deflection, inner edge deflection and difference between deflections of two opening edges for beams with steel plates configuration type 2 were greater than those for beams with steel plate's configuration Type 1.
9. Increasing concrete grade of beams having rectangular opening in shear zone strengthened with internally steel plates considerably decreased mid span deflection, inner edge deflection and the difference between deflections of two opening edges.
10. The presence of an opening in shear zone of R.C concrete beam with height of 0.4 the beam depth and with length of 2.5 its depth usually reduces beam toughness by about 60% compared to similar beam without openings.
11. Increasing the thickness of steel plates, the length of horizontal steel plates around the opening decreased beam toughness.
12. Increasing concrete grade of beams having rectangular opening in shear zone strengthened with internally steel plates considerably increased beam toughness.
13. Abdel-Shafy equation [9] can be satisfactorily used only for predicting the ultimate load for normal strength R.C beams rather than for high strength R.C beams having rectangular web opening and strengthened internally by using steel plates.

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كفاءة التقوية الداخلية للكمرات الخرسانية المسلحة ذات الفتحات المستطيلة فى منطقة القص باستخرام الواح الصلب

ظهرت فى الا عمال الانشائية الحاجة الى عمل فتحات باشكال مختلفة خلال اعصاب الكمرات الخرسانية المسلحة لاستخدامها كممرات للتوصيلات الكهربية والميكانيكية وخلافه. ان وجود هذه الفتحات يؤثر بالسلب على مقاومة وصلابة هذه الكمرات، مما دعا العديد من الباحثين لدراسة السلوك الانشائى للكمرات الخرسانية المسلحة ذات الفتحات لتحديد مدى كفاءتها وكيفية تقويتها وتسليحتها لمقاومة الاجهادات المتولدة فيها نتيجة الاحمال الواقعة عليها.

وقد توصل الباحثون فى هذا المجال الى نتائج طيبة من حيث قدرتهم علي تحديد الشكل والمقاس المثالي للفتحة وكذلك الموقع المناسب لهذه الفتحات سواء بالنسبة لموضعها في الاتجاه الطولي لمحور الكمرة او خلال عمقها. كذلك توصل الباحثون الي انسب الاساليب لكيفية تسليح وتقوية هذه الفتحات.

كل الابحاث والجهود السابقة كانت منصبه علي التقويه الداخلية للفتحة من خلال التسليح المعتاد مثل الكانات اعلي واسفل الفتحة وكذلك علي جانبيها بالاضافة الي الحديد المكسح علي جانبي الفتحة وايضا التسليح الطولي حول الفتحة. ولم يلجأ احد الي التفكير في استخدام الواح الصلب للتقوية الداخلية للفتحة. البحث القائم بين ايدينا يحاول دراسة تاثير استخدام الواح الصلب في تقوية منطقة الفتحات علي مقاومتها وتشكلها. لهذا الغرض تم اعداد وصب إثنتي عشرة كمرة خرسانية مسلحة ذات قطاع مستطيل وذات تسليح اقل من المتوازن وتم اختبارها تحت تأثير حمل استاتيكي. إحدي هذه الكمرات ليس بها

فتحات وباقي الكمرات بكل واحدة منهم فتحة واحدة مستطيلة في عصبها في منطقة القص، عشر كمرات من هذه الكمرات ذات الفتحات تم تقويتها داخليا باستخدام الواح من الصلب. وفي هذه الدراسة تم اخذ تأثير سمك الواح الصلب المستخدمة وكذالك الطراز والهيئة التي وضعت بها هذه الالواح حول الفتحة بالاضافة الي تاثير طول الواح الصلب الافقية كما تم دراسة تأثير رتبة الخرسانة علي المتغيرات التي تم دراستها. تم قياس شكل الشروخ ومكانها وكيفية انتشارها مع رصد قيم حمل التشريخ وأقصي حمل بالاضافة إلي قيم الهبوط المناظرة الي حمل التشريخ وايضا قيم اقصي هبوط لللكمرات في منتصف الكمرات وعلي جانبي الفتحة. أعطيت النتائج في صورة منحنيات وجداول وتوصيات للتعرف علي سلوك هذا النوع من الكمرات والمقواه داخليا باستخام الواح الصلب والتي توصلت الي أن سلوك مثل هذه الانواع من الكمرات ذات الفتحات المستطيلة في منطقة القص تتأثر بكلا من سمك وأبعاد وموضع الواح الصلب المستخدمة حول الفتحة سواء رأسيا أو أفقيا بالاضافة الي رتبة الخرسانة المستخدمة.