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Study the Behavior of Beams with Opening in the Shear Zone Strengthendby Carbon, Glass sheet and Steel Fibers

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Abstract: This study aims to evaluate the improvement of load carrying capacity of reinforced concrete beams with opening in shear zone and strengthened by Steel fiber and Glass, Carbon sheets. Thirteen reinforced concrete (RC) beams with opening in shear zone with a cross section of 150×300 mm and a total length of 1650 mm, were fabricated, strengthened, and loaded up to failure. The results showed that the strengthening with steel fibre and externally bonded glass and carbon strips have obvious enhancement on the general behavior of beams and shear capacity of the opening beams. Also, a reduction in deflection for all strengthened beams was observed.

[Mostafa Abd El Megied Osman, Kholoud Atef Sayed. **Study the Behavior of Beams with Opening in the Shear Zone Strengthendby Carbon, Glass sheet and Steel Fibers.** *Life Sci J* 2019;16(12):136-146]. ISSN: 1097-8135 (Print) / ISSN: 2372-613X (Online). http://www.lifesciencesite.com. 18. doi:10.7537/marslsj161219.18.

Keywords: Study; Behavior; Beams; Shear Zone; Strengthend; Carbon; Glass; sheet; Fiber

1. Introduction

In modern building construction, wide or small openings in reinforced concrete beams are often provided for the use of ducts. These ducts are necessary in order to accommodate needed services such as water pipes, telephone cables, electricity, and air-conditioning ducts. Providing an opening in reinforced concrete beams is often a problem facing the structural engineers. Several studies had been carried out to study the effect of providing opening in beams in the region of shear zone. Currently the most commonly used fiber in strengthening of reinforced concrete beams are steel, synthetic, glass, carbon Fibers. The different types are used to improve performance in different situations. Retrofitting of opening had a significant effect for restore the beam capacity using internal and extranl retrofitting techniques. [1] Some researches examined the effects of loading position, opening locations and opening size on the shear strength of RC beams [2-7]. H. Abdalla, J. Kennedy [8], presented a parametric study using experimental and analytical investigations. They aimed to predict the distribution of shear stresses at the top and bottom chords of openings inreinforced concrete beams.

M. EL-mihilmy and J.W. Tedesco [9] studied the deflection of reinforced concrete beams and strengthened using fiber reinforced polymer plates. Other studies focused on the shear strength of concrete beams bonded with steel plates [10] and bonded using carbon fiber CFRP laminates [11].

2. Objectives

This study concerned about the effect of opening at shear zone on R.C. beams due to four parameters:

- Aspect ratio of opening size. (small or large)
- Percentage of steel Fiber on strength of beams (Percentage of 0.5%- 1.0 %- 1.5% of the volume of concrete).
- Carbon sheets around opening as U shape.
- Glass sheets around opening as U shape.

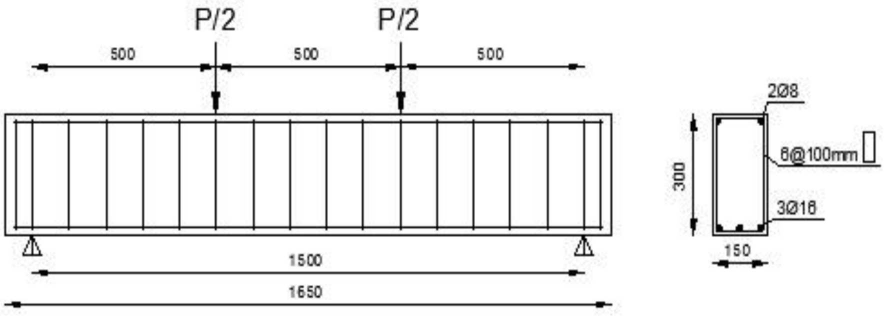
3. Experimental Work

3.1. Program

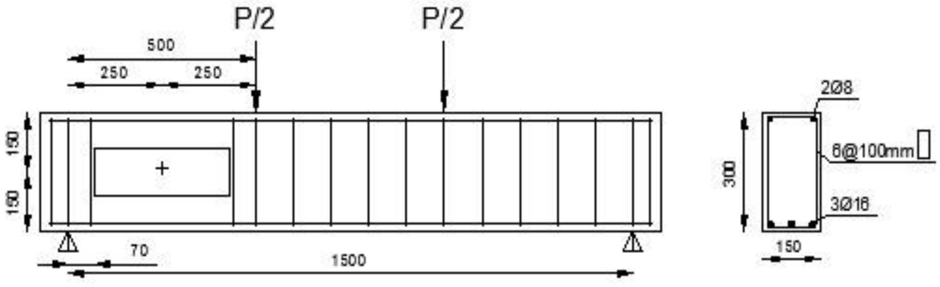
The experimental program included thirteen tested specimens. All the specimens had a typical geometry. The beam length was 1650 mm. The cross section dimensions were 150 mm in width and 300 mm in height. All openings were located at the left side of the beam, at the center between the applied left load and the support. The openings were of the same height of 120 mm at mid height of beam and changed in width, 120 mm and 360 mm. All the tested specimens were reinforced typically for flexure and shear. The bottom longitudinal reinforcement was three bars of nominal diameter of 16 mm with reinforcement ratio of 1.34%. The top longitudinal reinforcement was two bars of nominal diameter of 8 mm, which represent 16.7 % of the bottom bars area. The concrete cover was 15 mm. The stirrups had a nominal diameter of 6 mm, and shaped in closed box form. These stirrups were arranged uniformly along the beam length with internal spacing of 100 mm. Reinforcement of specimens are shown in Figure (1), and the details of the tested specimens are listed in Table (1).

3.2. Materials

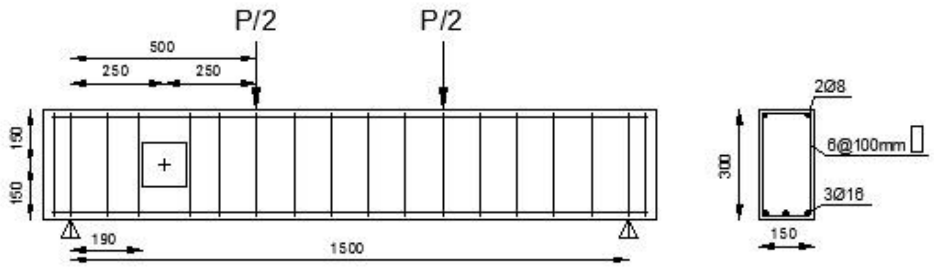
The beams tested of this experimental program were cast of concrete made of local materials in Egypt. Cement was ordinary portland cement, fine and coarse aggregates were composed of good dolomite, well graded and clean from impurities and siliceous sand. Normal mild steel off_y=240 MPa used for stirrups and high grade steel of f_y=360 MPa for longitudinal bars were locally produced bars. Carbon fiber reinforced polymer (CFRP) was unidirectional fabric type. This fabric was 305 mm wide, 0.12 mm thickness, and 220 gm/m^2 density. According to manufacturer's catalogue, CFRP has 4100 MPa tensile strength, and 231 GPa tensile elastic modulus. The elongation of CFRP at break was about 1.7%. Glass fiber reinforced polymer (GFRP) was unidirectional fabricated type. This fabric was 600 mm wide, 0.172 mm thickness, and 445 gm/m^2 density. According to manufacturer's catalogue, GFRP has 2300 MPa tensile strength, and 76 GPa tensile elastic modulus. The elongation of GFRP at break was about 2.8%. Steel fiber had a diameter 0.5 mm and length of 50 mm. Internal electrical strain gauges (Type FLA-6-11-1L) were used in all specimens. The gauge length was 6 mm,120 ohms resistance, and gauge factor 2.10. The strain gauge was fixed at the top of one stirrup faraway 50 mm from support. The electric strain gauge were connected to digital strain instrument. The strain was measured in stirrup at different loading stages.



a- Solid beam



b- Beam with rectangular opening



c- Beam with square opening

Figure (1) Details of Steel Reinforcement (dimention in mm)

Table (1): Details of Tested Specimens

Group	Beam	Opening Shape	Bottom Steel	Top Steel	Stirrups	Strengthen material
Control Group	B1	No opening	3Ø16	2Ø8	Ø6@100mm	without
	B2	Rectangular	3Ø16	2Ø8	Ø6@100mm	without
	B3	Square	3Ø16	2Ø8	Ø6@100mm	without
Steel Fibre Group	B4	Rectangular	3Ø16	2Ø8	Ø6@100mm	S.F 0.5 % In mixture
	B5	Square	3Ø16	2Ø8	Ø6@100mm	S.F 0.5 % In mixture
	B6	Rectangular	3Ø16	2Ø8	Ø6@100mm	S.F 1.0 % In mixture
	B7	Square	3Ø16	2Ø8	Ø6@100mm	S.F 1.0 % In mixture
	B8	Rectangular	3Ø16	2Ø8	Ø6@100mm	S.F 1.5 % In mixture
	B9	Square	3Ø16	2Ø8	Ø6@100mm	S.F 1.5 % In mixture
Glass Fibre Group	B10	Square	3Ø16	2Ø8	Ø6@100mm	G.F
	B11	Rectangular	3Ø16	2Ø8	Ø6@100mm	G.F
Carbon Fibre Group	B12	Square	3Ø16	2Ø8	Ø6@100mm	C.F
	B13	Rectangular	3Ø16	2Ø8	Ø6@100mm	C.F

3.3 Concrete Mix

A normal concrete mix was used to cast all the tested concrete beams, the mix proportion by weight is given in Table (2). Concrete constitutes were added separately, while water was added by volume. Mixing was performed using a concrete drum mixer. First, cement, aggregate and sand were dry mixed, then the water was gradually added and mixed thoroughly. Mixing operation continued after adding water for a period of about 3-minutes until a uniform colour obtained. The concrete was cast in steel shutters and compacted using vibrator to insure a good compaction. Steel shutters were chosen to achieve regular dimensions, right angle corners and fair face surfaces. Six cubes of 150×150×150 mm were cast and tested to determine the compressive strength for each group beam specimen. The average compressive strength considered for all specimens was 33 MPa.

Table (2): Concrete Mix Proportion (unit kg/m^3)

Cement (kg/m^3)	**Coarse Aggregate** (kg/m^3)	**Fine Aggregate** (kg/m^3)	**Water lit/m^3**	**W/C**
350	1200	600	175	0.50

4. Strengthening Procedures

The external strengthening (Glass, Carbon sheets and epoxy adhesives) was performed as follows:

(a) Preparation of concrete surface by using grinding disk.

(b) The surface was leveled and corners had been rounded to a radius of 10 mm by diamond grinding disk.

(c) Epoxy resin was mixed separately, then, the two used components was added to each other using special spatula.

(d) Stir with an electric mixer for about 3 minutes until all the colors streaks disappeared, then the mix was poured into clean container and stir again for about extra two minutes at a low speed to keep air entertainment at a minimum.

(e) The mixed resin was applied to the prepared concrete beam surface by brush in a rate of 1.2 kg/m^2.

(f) Carbon and glass fiber fabrics with width of 100 mm were placed onto the epoxy coating and squeezed with plastic roller.

5. Test Procedure and Set-up

All specimens were tested as simple beams with clear span of 1500 mm using a two point loading. The load was applied by means of a hydraulic reversed pump. This load was monotonically increased gradually from zero up to failure load. Each specimen was supplied with internal electrical-strain gauge before casting. Deflection was recorded at different loading stages by the use of two linear variable differential transducer LVTD gauges which were applied at midspan and under center of opening. The structural testing frame in the concrete testing laboratory of the faculty of Engineering at Mataria, Helwan University has been used for test beams. The specimens are simply supported on two I-beams where they are supported on the frame by welding to produce two line supports. The clear span between the two supports is 1500 mm; one hydraulic loading jack and load cell with a capacity of 500 KN is used. The load cell is connected to a digital display screen to read the applying loads. Vertical deflection was measured at the mid- span of the beams and at the third of the beam by linear variable differential transducer (LVDT). The data acquisition system used to record the deflection measurment underneath the bottom of the beam at mid and third of the span.

6. Test Results

6.1. General Behavior and Cracking Patterns

Figure (2) and (3) show the cracking patterns for all tested beams after failure. In the Figure, each crack is marked by a line representing the direction of cracking. Comparing the crack patterns between control specimens revealed that they were largely different. The effect of having opening on beams in shear zone changed the behavior of beams and changed the path of cracks and transformed simple beam behavior into a more complex behavior. The small opening represent source of weakness which caused more cracks and decreasing in capacity of beam and its stiffness but not similar to the large opening which caused early break down.

6.2. Experimental Failure Loads

The failure loads and failure mechanism ofbeams aresummarized in Table (3). Opening location (in shear zone) may be considered the greatest parameter affecting the beam capacity so represented a huge decreasing of beam capacity. The opening length may be considered on of the important parameters effecting both cracking and failure load. Comparing with the opening height and opening length, represented in the difference between the percentage of decreasing of beam capacity between rectangular wide opening and square opening.

6.3. Load-Deflection Curves

Two points of deflection for each specimen were measured, one at the mid-span (at 750 mm from support) and the other under the center of opening (at 250 mm from support). Figures (4), (5) and (6) show the load deflection curves at mid span for all tested beams. Figures (7), (8) and (9) show the load deflection curves under opening for all tested beams. The load capacity decresed by 67.6 %, and 63 % for square opening and large opening beams, respectively to that of control beam. Figures show that strengthened beams with steel fiber and having rectangle opening with different ratios of (0.5 %,1.0 % and 1.50 %), the load capacity increased by 7 %, 17 % and 25 % more than the capacity of control beam with rectangle opening, respectively. And those capacity ratios in case of square opening beams were 6 %, 47.5 % and 56 %, respectively more than tthat of the control beam with square opening.

However, as the opening represents a source of weakness, the beam recorded a big value of deflection at mid span or under the center of opening because of the beam with opening has less stiffeness as solid one, therefore the breaking was occurred.

Table (3): Cracking load, Failure Load and Failure Mechanism of all Tested Beams.

Beam	Opening Shape	Cracking load (KN)	Failure load (KN)	Failure Shape
B1	No opening	106	216	Shear failure happened
B2	Rectangle	30	70	Cracks around opening only
B3	Square	55	80	Cracks around opening and along the beam
B4	Rectangle	15	75	Cracks around opening only
B5	Square	55	85	Cracks around opening and along the beam
B6	Rectangle	20	82	Cracks around opening only
B7	Square	25	118	Cracks around opening and along the beam
B8	Rectangle	20	88	Cracks around opening only
B9	Square	35	125	Cracks around opening and along the beam
B10	Square	58.5	147	Cracks around opening and along the beam
B11	Rectangle	15	90	Cracks around opening only
B12	Square	50	180	Cracks around opening and along the beam
B13	Rectangle	25	100	Cracks around opening

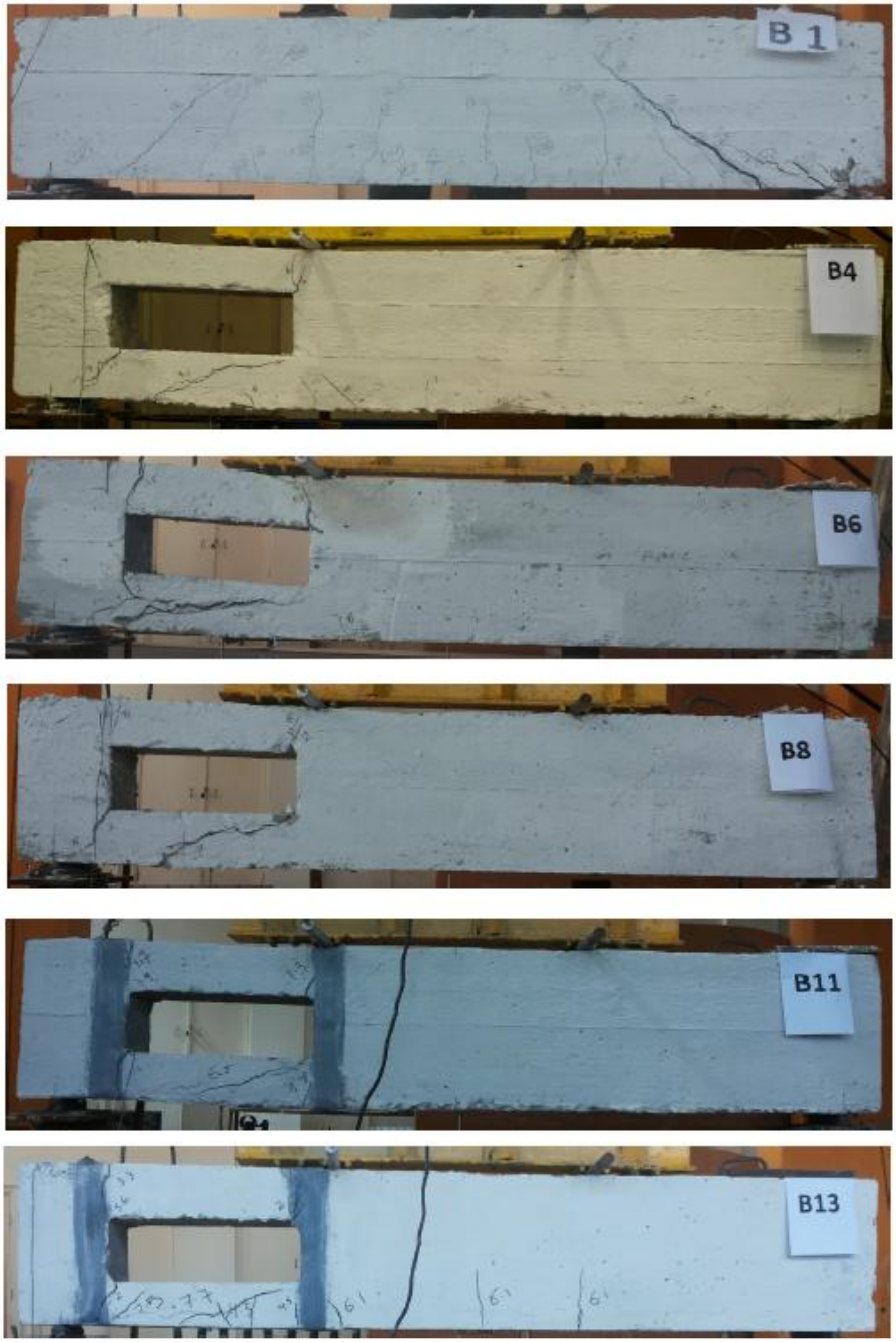
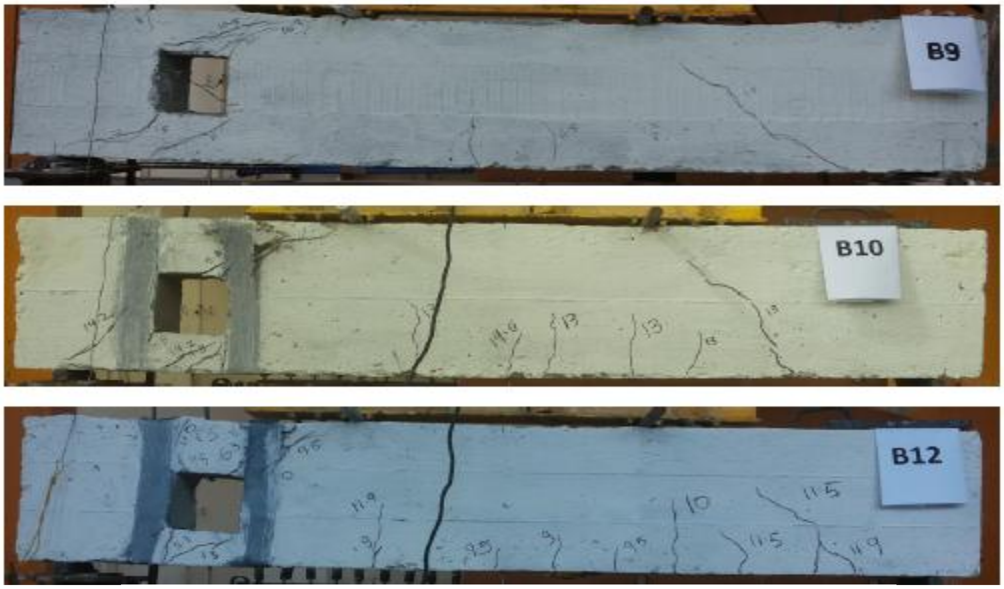


Figure (2) Crack Patterns for Control Beam and Beams with Rectangular Opening

Figure (3) Crack Patterns for Beams with Square Opening



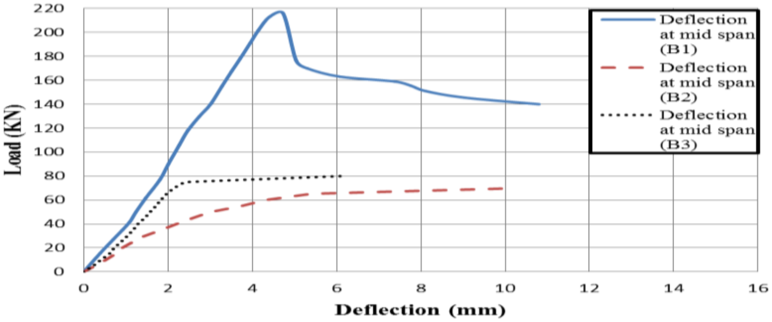


Figure (4) Deflection at mid span for specimens (B1, B2 and B3)

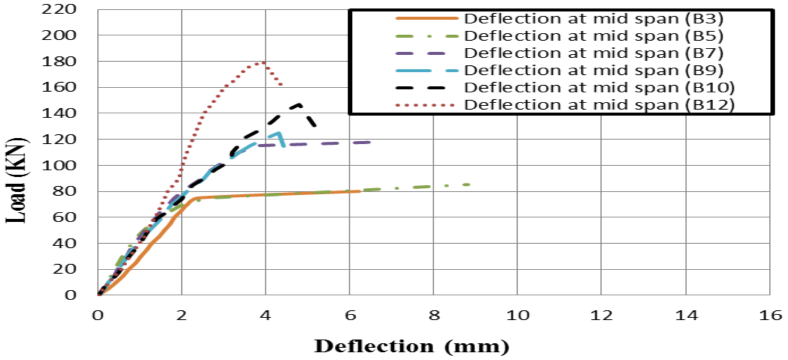


Figure (5) Deflection at mid span for specimens (B3, B5, B7, B9, B10 and B12)

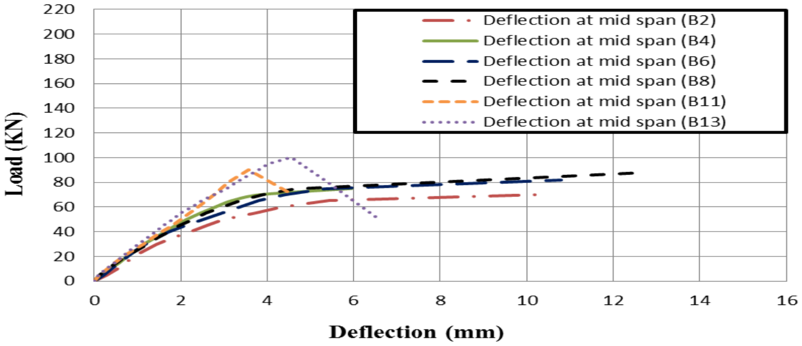


Figure (6) Deflection at mid span for specimens (B2, B4, B6, B8, B11 and B13)

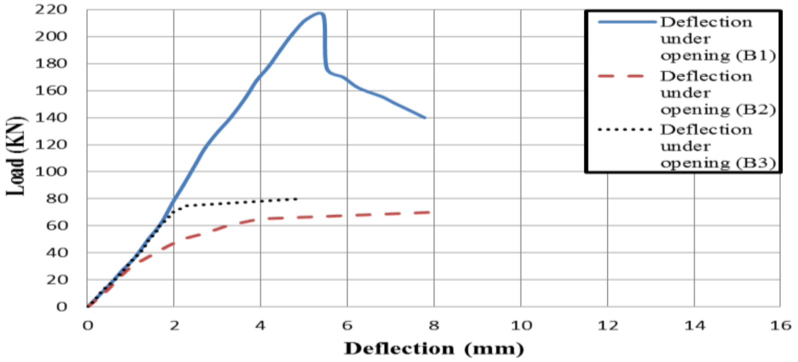


Figure (7) Deflection under opening for specimens (B1, B2 and B3)

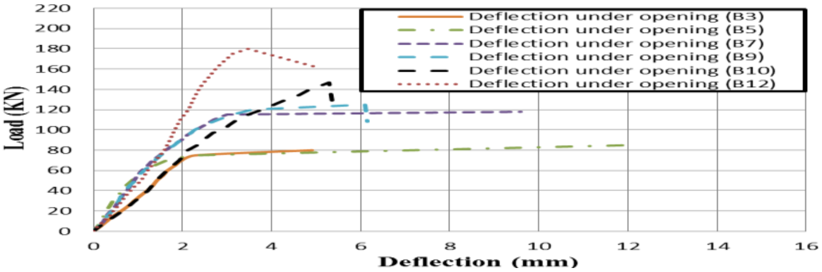


Figure (8) Deflection under opening for specimens (B3, B5, B7, B9, B10 and B12)

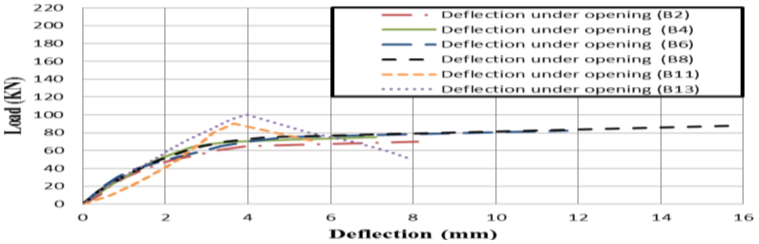


Figure (9) Deflection under opening for specimens (B2, B4, B6, B8, B11 and B13)

6.4. Deflection Profile Curves

Deflection profile of beam with opening had a change of line of slope, not the normal curvature deflection in comparison of normal beam without opening. Figures (10), (11) and (12) show the values of deflection for beams at 250 mm from support (Δ1 under opening) and at 750 mm from support (Δ2 mid span) at failure load. It is clear that the large opening represent a source of weakness and caused to break the beam and recorded the big value of deflection, but the effect of small opening on the deflection profile at peak load did had obvious difference regard to the case of beam without opening.

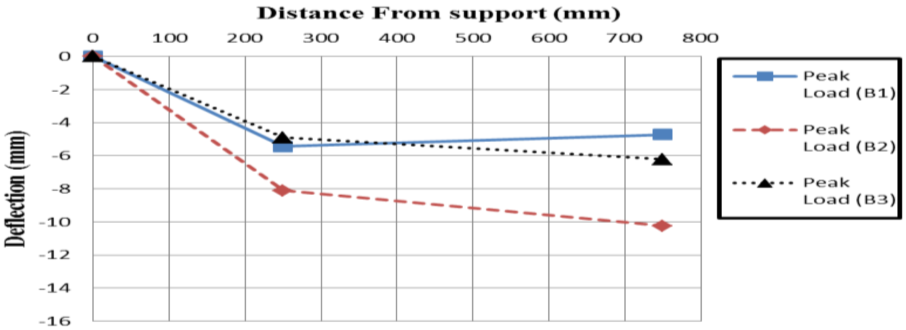


Figure (10) Deflection Profile for specimens (B1, B2 and B3)

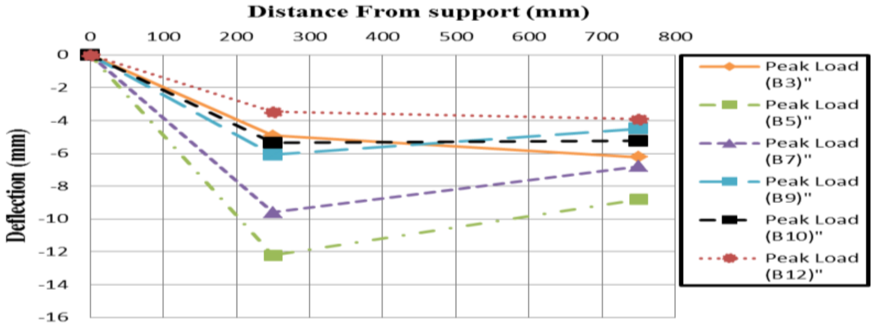


Figure (11) Deflection Profile for specimens (B3, B5, B7, B9, B10 and B12)

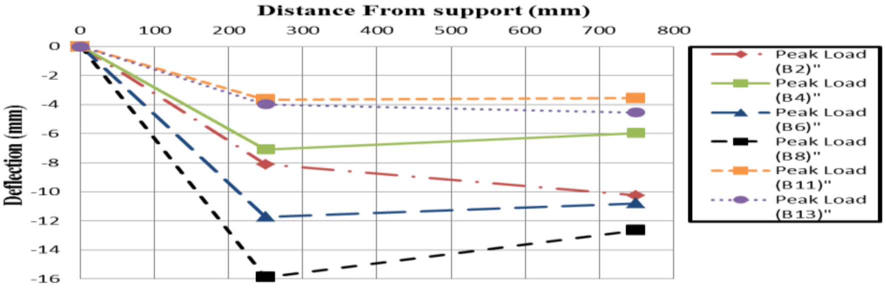


Figure (12) Deflection Profile for specimens (B2, B4, B6, B8, B11 and B13)

6.5. Steel Strains

For steel fiber in mixture of ratio 1.5%, the measured strain of steel stirrups reached the yield value. For large opening of tested beams and strengthened with glass and carbon fiber sheets, the strain of steel stirrups did not reached to yield point, while for small opening of beams and strengthed with glass and carbon fiber sheets the strain reached to yield poimt.

7. Prediction Equations and Comparison with Test Results

In the next part, a comparison between test results of beams and prediction equations of shear strength according to ACI Code [12] formula are presented. It is noticed that ACI code does not take into consideration the presence of steel fibre added to the concrete paste.

7.1. ACI Code-Shear Equations

According to the ACI Code, the design of beams for shear is to be based on the following relation:

$V_u \leq \varphi V_n$ Eq. (1)

Where: Vu is the total shear force applied at a given section of the beam due to factored loads.

$Vn = Vc + Vs$ Eq. (2)

$V_u \leq \varphi V_c + \varphi A_v f_y d / S$ Eq. (3)

The nominal shear strength contribution of the concrete can be simplified as shown in Eq. (4)

$V_c = 0.17 \lambda \sqrt{f'c}\, b_w d$ Eq. (4)

In case of having opening

Mainly there are no steel stirrups at large opening, so shear strength provided by shear reinforcement "Vs" can be neglected.

$V_u \leq \varphi V_c$ Eq. (5)

$V_c = 0.17 \lambda \sqrt{f'c}\, b_w d_{eff}$ Eq. (6)

$d_{eff} = d - d_{opening} - c_c$ Eq. (7)

7.2. Strengthening Equations

Beams (B10, B11, B12 and B13) will be solved for FRP shear strengthening "U-wrap" according to the ACI Code. The design of beams for shear is to be based on the following relation:

$\phi V_n = \phi (V_c + V_s + \phi_f V_f)$ Eq. (8)

$V_f = A_{fv} * F_{fe} * d_{fv} / S_f * \gamma_f$ Eq. (9)

$A_{fv} = 2 * n * t_f * w_f$ Eq. (10)

$F_{fe} = \xi_{fe} * E_f$ Eq. (11)

7.3. Test Results and Prediction Equations

The presence of openings in reinforced concrete beams needs special attention in the analysis and design equations because of the reduction in both stiffness and strength of the beam and excessive cracking around the opening due to high stress concentration.

The comparisons of beams are listed in Table (4) and are shown in Figures (13) and (14) outlining the differences between the ACI code values and experimental shear strength values. It should be noticed that the ACI code shear equation does not take into consideration adding of steel fiber pieces with different ratios on the final shear strength, which may give variations between the values of the test results and code prediction as the case of the present study.

Table (4): The Analytical and test results for all tested beams.

Group	Beam	Opening Shape	Strengthing Material	ACI Code (KN)	Exp. Shear strength (KN)	Exp. / ACI ratio
Control Group	B1	No opening	-------	73.89	108.00	1.46
	B2	Rectangular	-------	20.61	35.00	1.70
	B3	Square	-------	37.44	40.00	1.07
Steel Fibre Group	B4	Rectangular	S.F 0.5 % In mixture	18.70	37.50	2.00
	B5	Square	S.F 0.5 % In mixture	35.53	42.50	1.20
	B6	Rectangular	S.F 1.0 % In mixture	18.70	41.00	2.20
	B7	Square	S.F 1.0 % In mixture	35.53	59.00	1.66
	B8	Rectangular	S.F 1.5 % In mixture	18.70	44.00	2.35
	B9	Square	S.F 1.5 % In mixture	35.53	62.50	1.76
Glass Fibre Group	B10	Square	G.F U shape	128.21	73.50	0.57
	B11	Rectangular	G.F U shape	51.69	45.00	0.87
Carbon Fibre Group	B12	Square	C.F U shape	154.30	90.00	0.58
	B13	Rectangular	C.F U shape	60.63	50.00	0.82

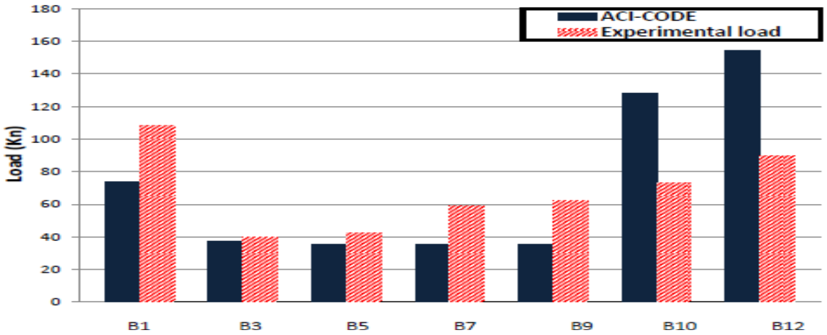


Figure (13) Theoretical (ACI) and Test Results for specimens (B1, B3, B5, B7, B9, B10 and B12)

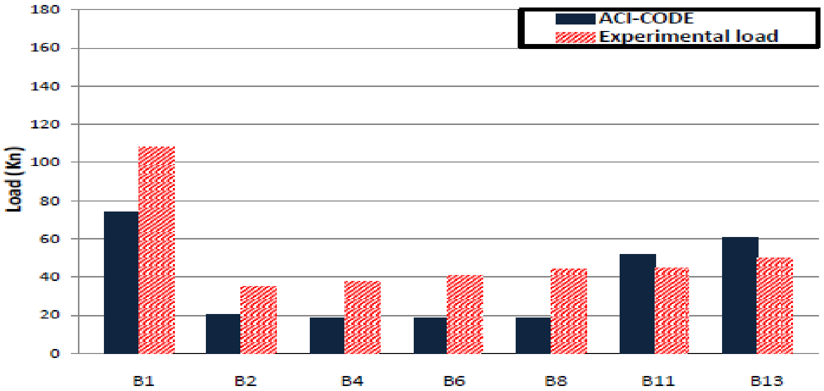


Figure (14) Theoretical (ACI) and Test Results for specimens (B1, B2, B4, B6, B8, B11 and B13)

8. Conclusions

According to the results of the present study, following conclusions can be drawn:-

1. The existence of the openings in the shear zone may transform simple beam behavior into a complex behavior, as they induce an effective change in the dimension of the beams cross sections.
2. Openings in the shear zone for tested RC beams caused decreasing in the load capacity by 67.6 %, and 63 % with small square opening and large opening, respectively.
3. Deflection profile of beam with opening had a change of line of slope, not the normal curvature deflection in comparison of normal beam without opening.
4. The strengthened beams with steel fiber and having rectangle opening with dimension (0.4t × 1.2t) with different percentage (0.5 % - 1.0 % - 1.50 %) of volume of concrete, the capacity of loads increased by 7 %, 17 % and 25 % more than those of control beam with rectangle opening, respectively.
5. The strengthened beams with steel fiber and having square opening with dimension (0.4t × 0.4t) with different ratios (0.5 % - 1.0 % - 1.50 %), the capacity of loads increased by 6 %, 47.5 % and 56 % more than those of control beam with square opening, respectively.
6. Beams strengthened with glass and carbon fiber sheets and having rectangle opening with dimension of (0.4t × 1.2t), the capacity of load ioncresed by 28.5 % and 42.8 % more thanthat of the control beam with rectangle opening, respectively.
7. Beams strengthened with glass fiber and carbon fiber sheets with square opening of dimension of (0.4t×0.4t), the capacity of load incresed by 83.7 % and 125 %, repectively more than the control beam with square opening.
8. ACI code equations do not take into consideration the effect of steel fiber ratio in mixture, so there was an obvious difference between the test results of this study and the prediction equations of the code.

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