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Flexural Behavior of Slender Reinforced Concrete Beams with Openings

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Abstract:
The precise analysis of reinforced concrete beams is a sophisticated problem, with several opening the problem becomes more complicated. With this in mind, it is essential to provide an intensive experimental information for the analysis of the reinforced slender beams designed with openings. The present study aims to investigate the impact of reinforcement of concrete beam with openings on its flexural behavior in terms of load and deflection. To achieve this goal, set of experimental tests have been conducted on three casted concrete cubes with and without different w/c and plastizer ratios. One layer of steel mesh was used for reinforcement. A concrete mix was designed with a compression strength of 43.6 MPa. The key variables in the present work were shape, location, number and dimension of the openings. The reinforced concrete beams samples were shaped with 400mm height, 1000mm length and 100mm width. The objective functions were mode of failure, the failure load, and the shear strength. The deflection tests revealed that fabrication of a one-layer reinforced concrete with different shapes and locations of the openings provides a better load capacity of the composite and presents a good matrix candidate for the structural applications with openings.

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I. INTRODUCTION

Reinforced concrete deep beams are widely used in diverse applications in structures frames of buildings. Applications such as floor screens, wall footings, caps of foundation pile and girders are good examples of these applications. In addition, it is especially used nowadays for strengthening of the structures of the levels in residential and commercial towers [1]. Though, the presence of openings in the reinforced concrete beam (RCB) diminishes the load strength and stimulate deflection upon service loading [2]. Thus, numerous studies have been conducted to focus on improving the load capacity of these RCBs to extend their utilization to a wider structural application. A deep beam is characterized as a beam possess an observed capacity to transfer the load to the structure supports by a compaction twinge joins the load and the responsive part [3]. The design of deep RCBs has attracted several workers. The design of deep beams with different sizes and shapes of openings have been studies large openings is studied intensively [4-10]. In addition, numerous models were developed to predict the behavior of the RCBs designed with these openings accurately at different conditions [11-17]. Recently, Mohammed et al. [18] studied and analyses the behavior of reinforced high-strength self-compacted concrete deep beams with web opening. They concluded that self-compacting concrete is the most suitable design for casting deep beams. However, they found that all sample tested with web opening have failed in shear test. Jasim et al. [19] studied the influence of the size and the layout of the web

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openings on the load carrying capacity of RCBs. The shear span to overall depth ratio was 1:1. Square openings were used for that study. The strength results proved that the shear capacity of the deep beam is governed by the size and location of web openings. The experimental results indicated that the reduction of the shear capacity may reach (66%). Thus, it can be observed that more improvements are needed for the RCBs with openings and this requires further studies to investigate the impact of reinforcement and how to enhance shear capacity. The goal of the present study is to develop more strength RCBs designed with opening.

II. Experimental

For the present study, several sets of tests have been conducted. Firstly, sieve analysis for the coarse and fine aggregate was conducted according to the ASTM C 136. The output of the test is shown in Figure 1.

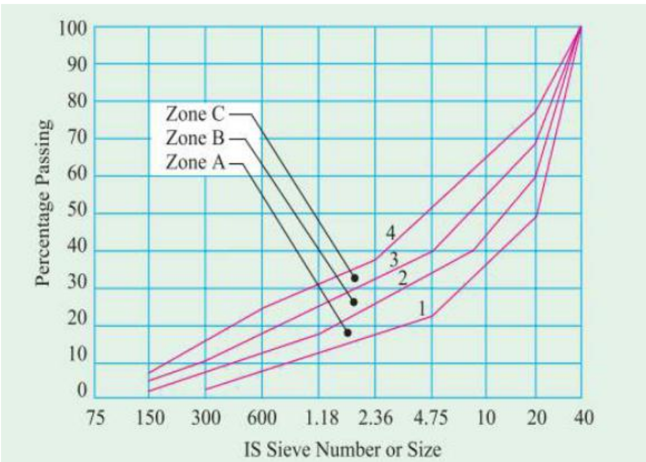

Figure 1. Grading areas for 10 mm aggregate

2.1 Fabrication of cubes

Then preparation of mixes was conducted according to ACI-material code of concrete that is the following mixes were considered for a full scale RCB structure.

1. 1:1.5:3 (or M 15)
2. 1:2:4 (or M 20)
3. 1:2:3 (or M 25)

Three cubes were prepared for every mix, casted and cured for 28 days without any admixture. It has been found that the best mix ratio is 1:2:3.8 with a w/c ratio of 48% pressed at 35MPa for 28 days. The mix slump test shows a 57 mm consolidation.

For the plasticized cubes, polycarboxylic polyether (KUT PLAST PCE200) was added to the mix to obtain a super plasticizing concrete admixture. This agent was added to produce a flowing concrete and enable large water reductions for the same workability. In addition, it shows the advantage of revealing a very high early strength, thereby the material becomes suitable for using in precast concrete applications and in areas where higher workability concrete and fast shutter stripping are required.

The optimum quantity of the plastizer was determined by trial and error and it was quantified with a particular concrete mix under prevailing ambient conditions. The ratios are as follow;

0.60-1.00 liters/100 kg cement for flowing concrete.

1.40-2.00 liters/100 kg cement for high strength concrete.

A ratio of 1.1 liters plastizer/100 kg cement was used in the present study. The dosage can be as low as 0.4 liter/100 kg cement and as high as 3 liters/100kg cement depending on the application of concrete involved. Overdosing will result in a very high workability and little retardation. The ultimate compressive strength of the concrete will not be impaired if it is cured properly. Figure 2 shows the cube after molding, this one was marked as SP.

Figure 2. Concrete cube test sample

A one-layer mesh made of minimum steel ration was used for reinforcement. This **layer** is two bars $\emptyset 10mm$ at tension zone and one bar Ø10mm at the

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compression zone with a stirrup of 180 mm spacing. One legged stirrup was used for the opening without any reinforcement bars. Figures 3-8 show the details of the different samples used in this study.

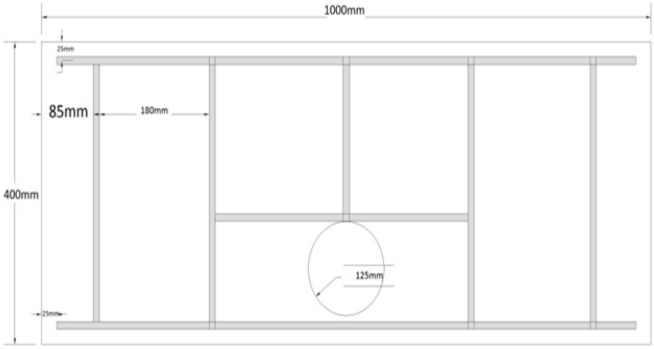


Figure 3. Reinforcements details for the control specimen, main bars : 3Ø10mm, stirrups : Ø10mm@180mm

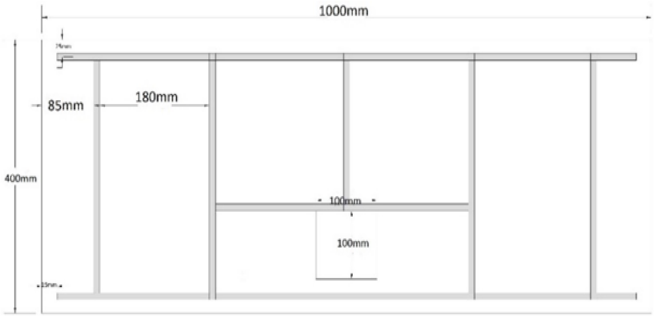


Figure 4. Reinforcement details for small square opening at mid span, main bars : 3Ø10mm, stirrups : Ø10mm@180mm

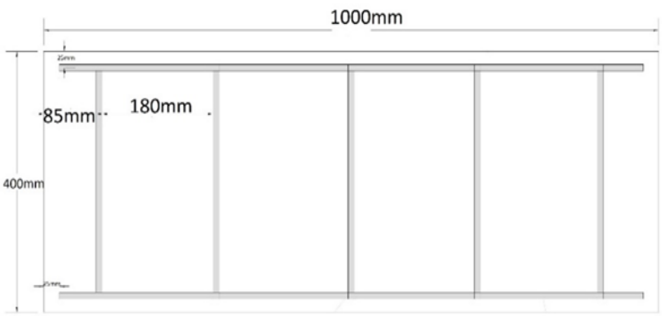
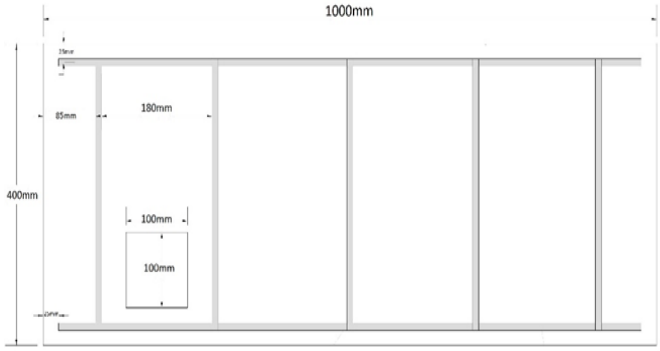


Figure 5. Reinforcement details for small circular opening at mid span, main bars : 3Ø10mm, stirrups : Ø10mm@180mm



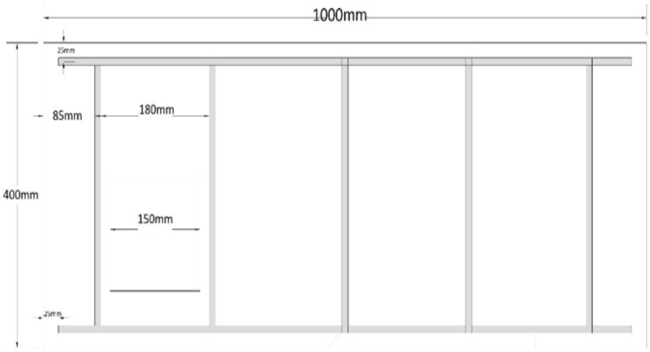


Figure 6. Reinforcement details for small square opening at shear zone, 3Ø10mm, stirrups: Ø10mm@180mm

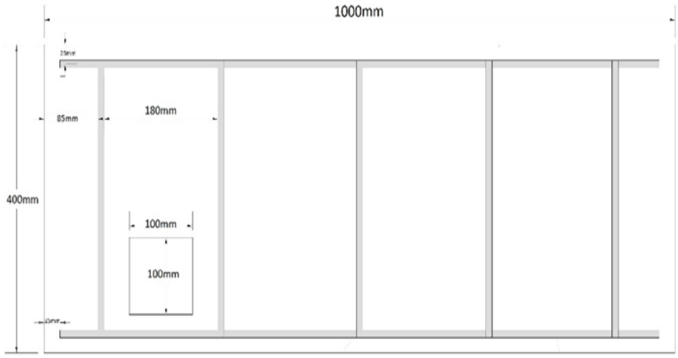


Figure 7. Reinforcement details for two large square opening at shear zone, 3Ø10mm, stirrups: Ø10mm@180mm

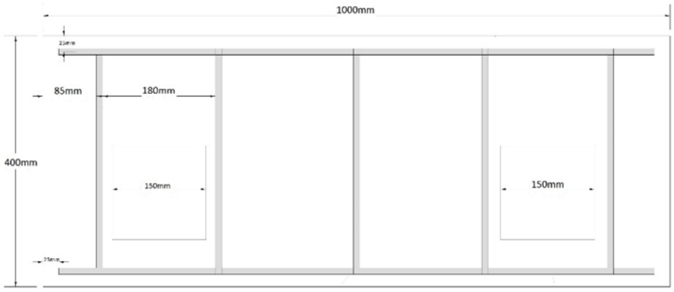


Figure 8. Reinforcement details for two large square opening at shear zone, 3Ø10mm, stirrups: Ø10mm@180mm

The following steps were conducted for sample preparation;

1. Casting and testing of concrete cubes (150mm ×150mm ×150mm) with and without PCE200
2. Designing and analyzing of the samples for flexural and shear strength with and without openings
3. Proposing of openings locations and dimensions.
4. Molding of samples

Figure 9 shows the molded sample. The concrete cube was strengthened over 28 days and was tested at 35 MPa using a ready mix admixture (superplasticizer) PCE 200 was added to the mix by percentage of 1.5% of the weight of the cement, this percentage based on trial mixes yielded cube strength at 28 days 6323.654 psi (43.6 MPa) . Steel used yield at (375 MPa) and has diameter of 3/8 inch for longitudinal steel and for transverse steel. About the specimen mold we built a steel mold with the sample dimensions.

Figure 9. The sample in a mold

2.2 Fabrication of beams

Seven beams have been casted with dimensions of h=400 mm, L=1000mm , and b=100mmusing a steel mold for the proposed locations of the openings. The matrix of beams being cast were as follow;

1- Hollow section with a square opening (100×100)mm at mid- span
2- Hollow section with a circular opening (125mm in dia.) at mid-span
3- Hollow section with square opening (100×100)mm at shear zone
4- Hollow section with square opening (150×150) mm at shear zone
5- Hollow section with two square opening (150×150) mm placed at 0.5D from the face of the support
6- Hollow section with one large rectangular opening (150×600) mm .

After removing the specimen from the mold, the bolts removed, and the specimen was immersed in a curing clean water tank for 28 days. Upon completion of curing, the specimens were tested for visible cracks by painting, then labeled to be ready for testing.

2.3 Specimen evaluation

A universal hydraulic machine (Haida HD-B616-2,China) was employed for specimen evaluation. A 200 Tons load cell capacity and a dial gauge was used for measuring the deflection. Figure 10 shows the control specimen without opening under testing. Figure 11 shows the specimens with different shape and location of openings under testing.

Figure 10. Control specimen without opening under testing

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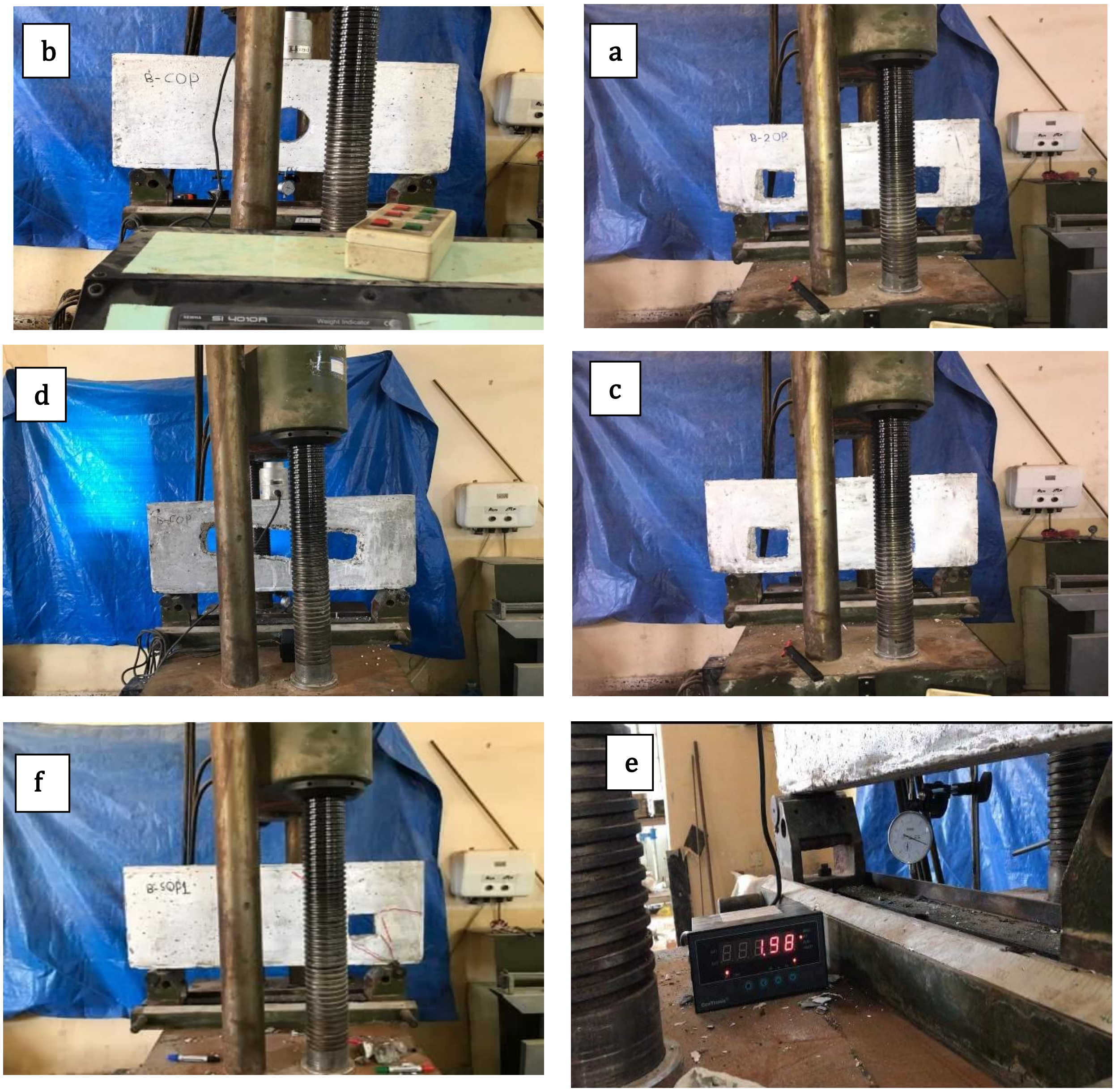

Figure 11. Control specimens with different openings under testing

III. Results and Discussion

Flexural test been conducted on six specimens to examine the influence of the openings on mechanical strength of the RCBs. Table 1 shows a description of the labeled samples and a summary of the measurements obtained in the present work.

Table 1. Experimental results

Beam Label	Beam description	Opening Shape	Opening Dimension (mm)	Opening location	Max. Load Capacity (kN)	Max. Deflection Reading (mm)
B-S	Solid	-	-	-	200	5.2

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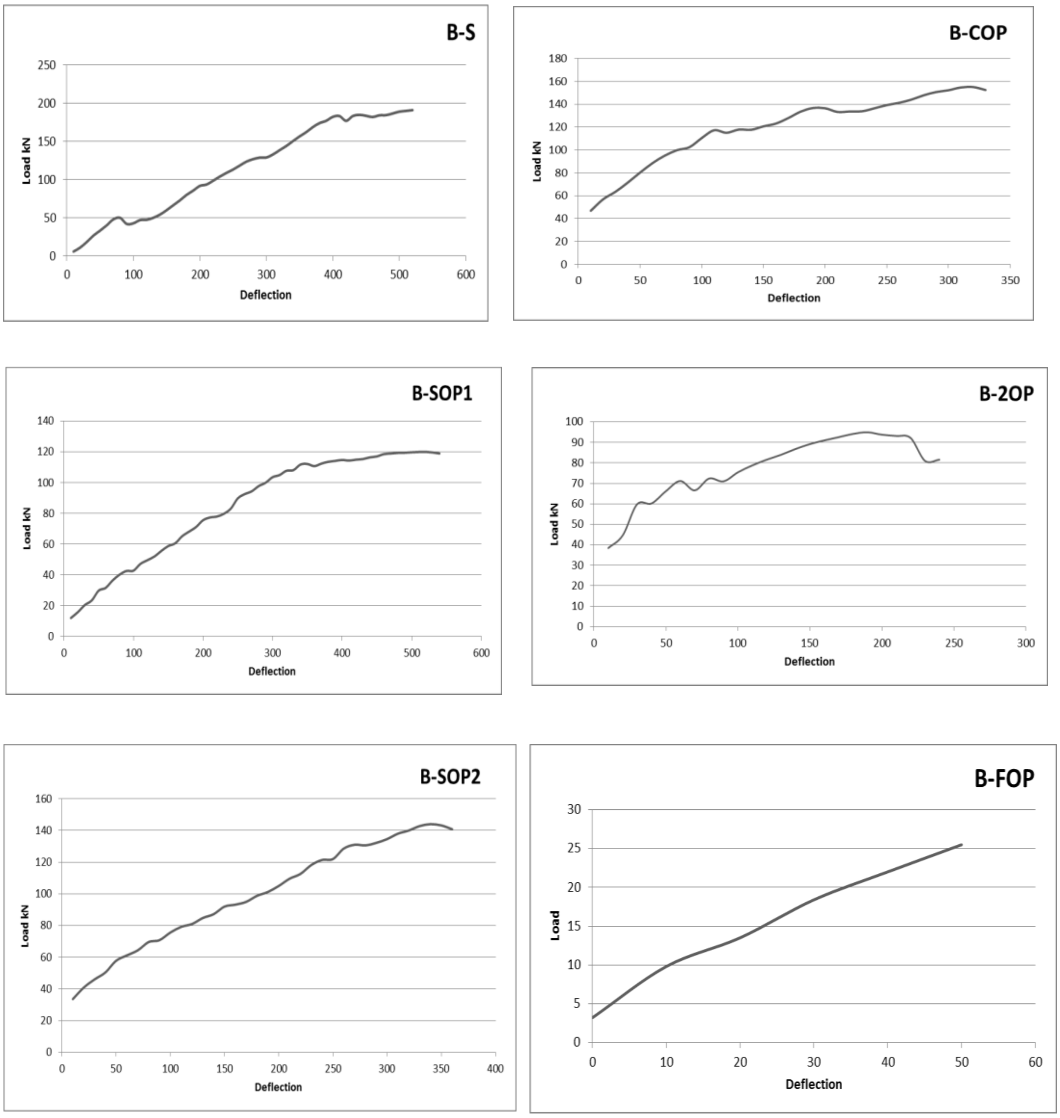
B-2OP	Two openings	Square	(150×150)	shear zone	95	1.9
B-COP	One opening	Circular	125 dia.	Mid-span	155	3.2
B-SOP1	One opening	Square	(100×100)	Shear zone	129.2	2.9
B-SOP2	One opening	Square	(150×150)	Shear zone	113.6	2.6
B-MSO	One opening	Square	(100×100)	Mid-span	144	3.4
B-FOP	One large opening	Rectangular	(600×100)	Mid span	25	0.5

Figure 12 shows a load-deflection relationship for the different samples fabricated in the present study and described in Table 1.



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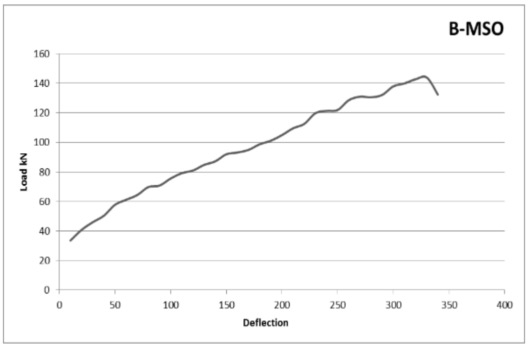


Figure 12. Load- deflection curves for different samples labled in Table 1

It can be observed from the responses shown in Figure 12 that the presence of openings diminishes the strength against deflection (sample B-S vs. the other samples except B-FOP). This increase in deflection resulted in a remarkable reduction in the failure load capacity of the beams fabricated. The range of reduction depicted was 32-54 % in case of one and two regular openings. But the strength drops to less than 10 % with B-FOP where the opening is single and large. It can also depict from these responses that changing the shape of the opening from circular (B-COP) at mid span to a square shape opening at shear zone (B-SOP2) does not affect the behavior of load-deflection curve significantly. The same negligible difference in behavior was observed for the single square shape opening (B-MSO) at mid span. However, when the opening was increased to two openings with the same shape (square) and location (shear zone), the load capacity was reduced from 113.6 to 95 kN. Also, Figure 12 characterize the influence of opening sizes on the corresponding crack failure. It shows that for RCBs fabricated with the same opening size, the reduction in the failure load due to the change in load location from mid span shear zone to point is significant, the percent of reduction is about 15%. Table 2 shows all percent of failure reduction.

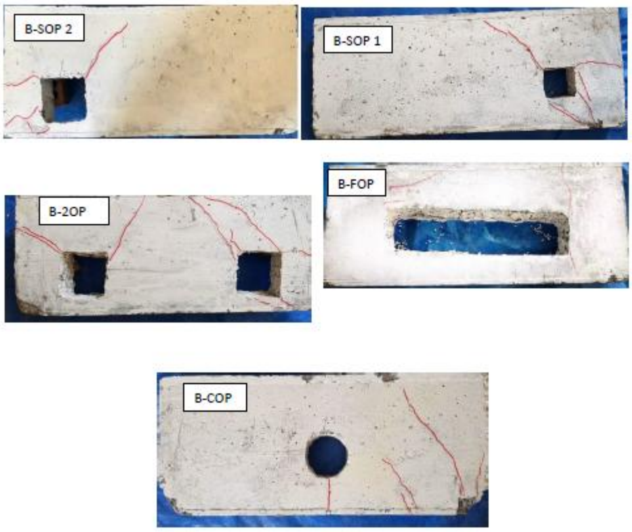
Figure 13 illustrates different modes of failure for the samples examined in the present work. The failure of the examined beams can be specified by one of the following patterns; shear-compression pattern of failure that was happened and shown with B-COP sample as a result of the growth of diagonal crack in shear span that due to concentrated strains in the chord of compression above opening near the applied intensive load, the other possible mode of failure would appear as a diagonal cracks locate in the other corner of the openings continuously grow and extended along the twinge merging with the point where load were applied which is obviously illustrated in the other sample shown in Figure 13, B-S, B-SOP 1, B-SOP 2, B-2OP, B-FOP and B-MSO. Thus, it can be seen that these cracks in the shear regions for samples B-SOP 1, B-SOP 2, and B-2OP

Table 2. Percent of load failure reduction

Sample	**Percent of load failure reduction**
B-SOP 1	63.46%
B-SOP 2	38.45%
B-MSO	44.23%
B-COP	50%
B-2OP	34.61%
B-FOP	90.38%

negatively impact the performance of the RCBs investigated in the present work, substantially, in serviceability. It is noticed that, the failure resistance of these RCBs with different shapes and locations of opening in terms of strength against crack propagation was less than the resistance of the solid beam, sample B-COP, against the generation of the failure cracks as defined elsewhere [19].

For the ultimate load capacity of the RCBs, it was observed that the increase is due to the strength. Ultimately, the circular opening showed the least reduction in the ultimate load capacity among all RCBs fabricated.



IV. CONCLUSION

Based on the present study, it is concluded that the fabrication of a slender (one-layer) reinforced concrete deep beams with different shape and sizes of the opening is a complex problem. This requires an intensive study to figure out the suitable design and ingredients to obtain a high shear strength RCBs to overcome lack of such high strength composite with openings. The most substantial conclusions of the implemented study can be summarized as follows:

The fabricated RCBs show a significant improvement regarding load-deflection behavior compared to the most recent works;

The openings cause a reduction in load capacity approaches 32% as an average for the examined samples of RCBs

The enforcement with the plasticizing agent improves the shear strength significantly when the shape of the opening was circular with the smallest dimensions;

Large opening showed more effect on the load capacity than the small opening and this seemed logical because of the big amount of the concrete been taken off the section ,since concrete is the main factor in facing the shear stresses , so large openings have a larger effect than small ones .

The number of the opening also showed a big impact on the failure mechanism with the biggest decrease in the ultimate load off all the shear zoned openings , but it has showed no flexural crack either, so from all shear zoned openings we have to ensure that shear reinforcement must dealt with carefully so no shear failure are encountered.

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