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Structural Behavior of Self Compacting Reinforced Concrete Deep Beams Containing Openings

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ABSTRACT

Eleven simple span reinforced self-compacting concrete deep beams were tested under symmetrically two points top load to examine the influence of the transverse circular openings on their behavior. The variables investigated involve shear span to effective ratio a/d, opening sizes and locations and the amount of inclined reinforcement around the openings. All the beams had the same overall dimension, flexural reinforcement and concrete compressive strength. The test results showed that when the opening positioned at the center of the shear span significantly affects the behavior of the beams tested regardless of a/d ratio and size investigated. Also, it was found that when the opening of a large diameter positioned away from the load path either in the top or bottom region of the beam reduces the cracking and ultimate load considerably. The inclined reinforcement around the opening was observed to be very efficient in improving the ultimate load capacities and deflection response.

Keywords: Deep beams, self-compacting concrete, openings, inclined reinforcement, ultimate load capacity

INTRODUCTION

Deep beams are structural members in which most of the applied load transferred directly to the supports by tied arch [1]. In many cases, openings are required in deep beams to provide accessibility to facilitate essential services such as water supply, drainage pipes, and air conditioning ducts. The existence of the opening in shear span zone affect the behavior of such beams especially when the opening positioned to interrupt the load path (that is: the line joining the load bearing edge and support bearing edge)[2-5]. Most of these studies deal with a rectangular opening in shape while few literatures were found in the circular opening [6,7]. Self-compacting Concrete (SCC) is high flow able concrete that can fill the form under its weight without segregation and bleeding [8]. The use of this type of concrete was expected to be effective in the casting of deep beams which usually has significant depth and congested reinforcement.

Research Significance

No literature was found that deals with the self-compacting deep beams containing transverse opening. Also, it is meaningful to provide experimental information about this shape of the opening.

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Experimental Program

An experimental work was carried out to investigate the influence of the circular opening on the behavior of Self-compacting concrete (SCC) deep beams. Eleven deep beam specimens had simple span ℓ 1140 mm, height h of 400 mm and width b of 150 mm were constructed and tested under symmetrically two points top loading as shown in Fig.1. For each specimen, the main tension reinforcement consisted of 3 bars with nominal diameter 16 mm and yield strength of 593 MPa. Furthermore vertical, horizontal web reinforcement made with 4 mm diameter deformed steel wires having a yield strength of 720 MPa spaced at 60 mm C/C which satisfy the minimum spacing recommended by ACI 318M-14.[9]

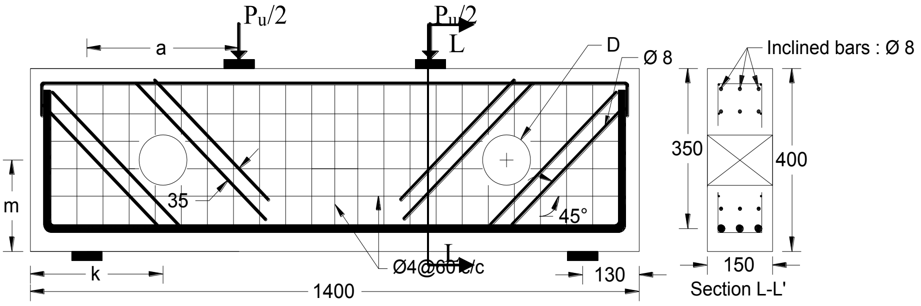


Figure (1)- Specimens details and arrangement of reinforcement

Note: All dimensions in mm

Table 1 illustrates the details of the specimens. The specimens were classified into four groups GA, GB, GC and GD according to selected parameters in addition to the solid reference beam. In GA, an opening of a diameter equal to 110 mm was positioned at the center of the shear span to interrupt completely the assumed load path (Fig. 1) while a/d ratios of 0.8, 1 and 1.2 used. The opening diameter was varied in GB. Two opening diameters were investigated, 70 and 160 mm with a/d ratio equal to 1. Also, the opening positioned at load path center. In GC two opening of a diameter 160 mm were selected to be positioned away from the load path in left upper and right bottom of the shear span. The effect of the inclined reinforcement was examined in GD, three amounts of 8 mm diameter deformed steel wires of 730 MPa yield stress were positioned to make 45 degrees with the horizontal axis of the beams. . The beam notation consisted of three parts; the first part indicates a/d ratio; the second part represents the size of the opening; the third part represents the amount of inclined reinforcement and opening position. Thus, 1-110-2C refer to a beam with a/d equals to 1, opening diameter of 110 mm, two inclined wires of 8 mm diameter above and below the opening and has an opening positioned at the center of the shear span.

Table (1)- Details of the test specimens

Group No.	Designation	a/d	D mm	k mm	m mm	Inclined reinforcement
Solid beam	1-S	1	0	0	0	-
GA	0.8-110-OC	0.8	١١٠	270	200	-
	1-110-OC	1		305	200	-
	1.2-110-OC	1.2		340	200	-
GB	1-75-OC	1	70	305	200	-
	1-160-OC		١٦٠			-
GC	1-160-OT			220	260	-
	1-160-OB			390	153	-

GD	1-110-2C		١١٠	305	200	2Ø8 mm (Fig. 1)
	1-110-4C					4Ø8 mm (Fig. 1)
	1-110-6C					6Ø8 mm (Fig. 1)

Mix proportions of SCC were selected according to EFNARC [10] Guidelines using ordinary Portland cement, coarse aggregate with a nominal size of 14 mm, fine aggregate lies in zone 2 according to IQS 45/1984[11]. Silica fume was added to the mixture by 10 % of the weight of cement to enhance the fresh, and hardened properties of SCC [8,12]. Superplasticizer type A and F according to ASTM C494[13] clasification commercially named Glenuim was used added to SCC mixture to desired slumpflow. The mix proportions per cubic meter were 500 kg of cement, 50 kg of silica fume, 850 kg of Coarse aggregate, 800 kg of fine aggregate, 10 liters of superplasticizer and 187 liters of water results in water to the cementitious ratio of 0.34. To ensure the used concrete is self-compacting, Slump Flow, T_{50}, and L-box tests were performed as shown in plate 1. Furthemore, the results were compared with the limitation of EFNARC [10] and ACI 237R-07[8] as indicated in Table 2. Concrete compressive strength f'_c was determined by testing four 100 × 200 mm cylinders. Moreover, splitting tensile strength f_t was determined using the same number and type of cylinders. The average of f'_c and f_t were 65.57 MPa and 4.57 MPa respectively.

Plate 1-Fresh tests of SCC

Table(2)-Tests results of Fresh SCC

Test method	**Result**	**EFNARC Limits**	**ACI237R-07 Limits**
Slump flow (mm)	670	650-800	450-760
T_{50} (sec)	4.5	2-5	2-5
L-box (H_2/H_1)	0.9	0.8-1	0.8-1

Every specimen was casted using two batches of SCC in vertically positioned steel molds then cured for 28 days using wet burlaps after removing the molds.

Testing Procedure and Instruments

The beams tested using the universal testing machine (AVERY) of 2500 KN capacity at the structural laboratory of building and construction department of the university of technology. During the test midspan, vertical deflection was recorded using analogue dial gage of 0.01 mm accuracy. The first cracking load was observed, and the crack patterns were marked. Bearing plates of 70 × 150 mm with a thickness of 20 mm were placed at load points to prevent local crushing of concrete.

Test Results

Results and Discussions

Table 3 shows the first shear cracks loads and experimental shear capacities. Except beams 1-S and 1-110-4C the inclined cracks formed at low load levels from 80 to 120 KN from the diagonal edges of the openings then propagated toward the load and support points with few increments in the applied loads. All beams failed in shear except beam 1-110-6C that which was failed in flexure. The shear failure of the beam 1-S accompanied with flexural effect results in a flexure-shear mode of failure. All beams with opening the failure occurred along diagonal crack joining the bearing plate edge and opening tangents opposite to them. For GA beams, it was observed that when a/d ratio increased, the shear capacity was decreased linearly (Fig. 2) as a result of increasing the applied moment while the shear cracks loads did not significantly affected. The increase of opening diameter from 75 to 160 mm decreases the cracking and failure loads by 33 and 29% respectively due to a reduction in the area at which the load would be transmitted directly to the supports. In GC beams, it was seen that the positioning of the large diameter opening decreases the ultimate shear strength although it located clear from the load path. Also, the results show that the positioning of the opening in the bottom right panel of the shear span increases the shear capacity slightly rather than when it positioned in the upper left panel. This might be attributed to the occurred decrease in compression area. From the tests results of GD beams, it was concluded that the inclined reinforcement was very efficient in improving the ultimate shear capacity of the pierced beams. [14, 15] It can increase the failure loads to that of corresponding solid beams.

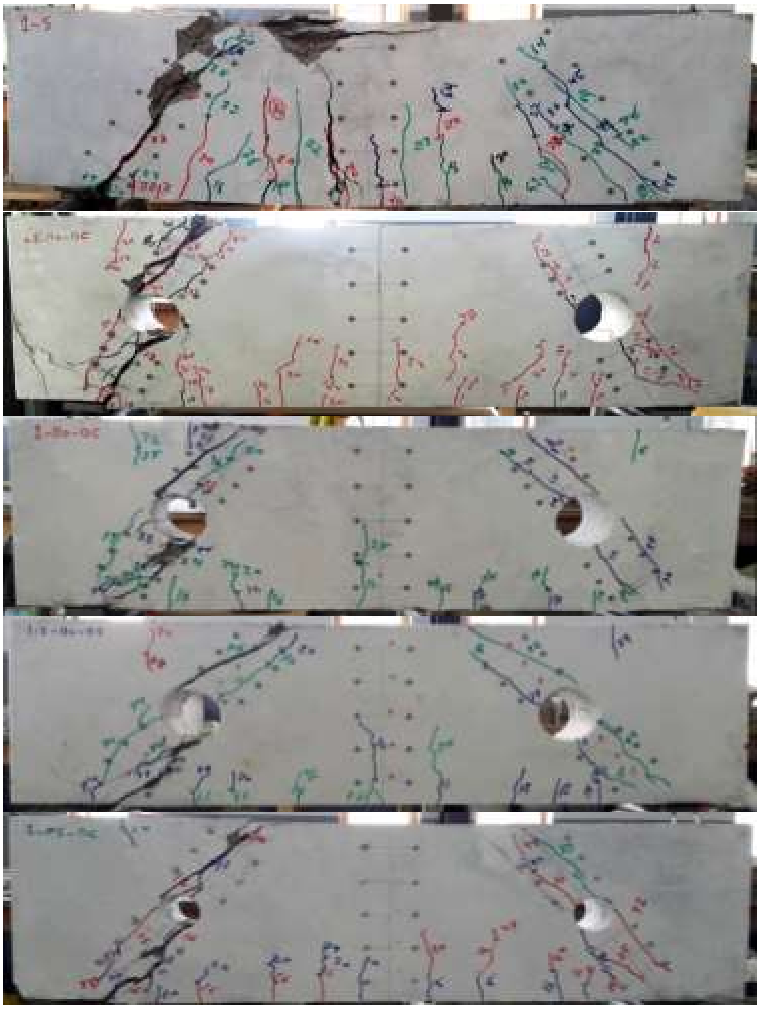
Table (3)-Test results of deep beam specimens

Group no.	**Beam designation**	**The first shear cracking load $P_{cr(s)}$ (kN)**	**Ultimate load capacity P_u (kN)**
Solid beam	1-S	200	870
GA	0.8-110-OC	100	470
	1-110-OC	100	410
	1.2-110-OC	80	360
GB	1-75-OC	120	410
	1-160-OC	80	290
GC	1-160-OT	120	580
	1-160-OB	120	620
D	1-110-2C	100	660
	1-110-4C	120	840
	1-110-6C	120	890

Load-Deflection Response

Figs. 2-6 explains the load-deflection relationship of the beams tested. It can be easy to observe that when a/d ratio increased the mid span deflection also increased.

The increase of opening diameter increases the deflection slightly at the same load stages of GB beams. In GC beams, the deflection seems to be not affected by the location of the opening but it was smaller than of beams with opening interrupts the load path. The increase of the inclined reinforcement improves the deflection response of the beams tested and it similar to that of a corresponding solid one as a result of restraining of the cracks widths.



1-S

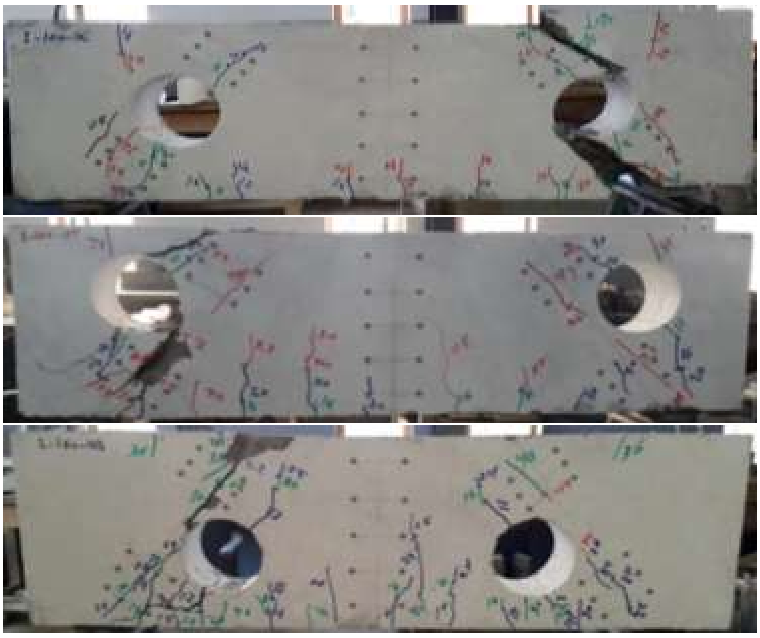
0.8-110-OC

1-110-OC

1.2-110-OC

1-75-OC

Plate 2-Deep beams after failure



1-160-OC

1-160-OT

1-160-OB

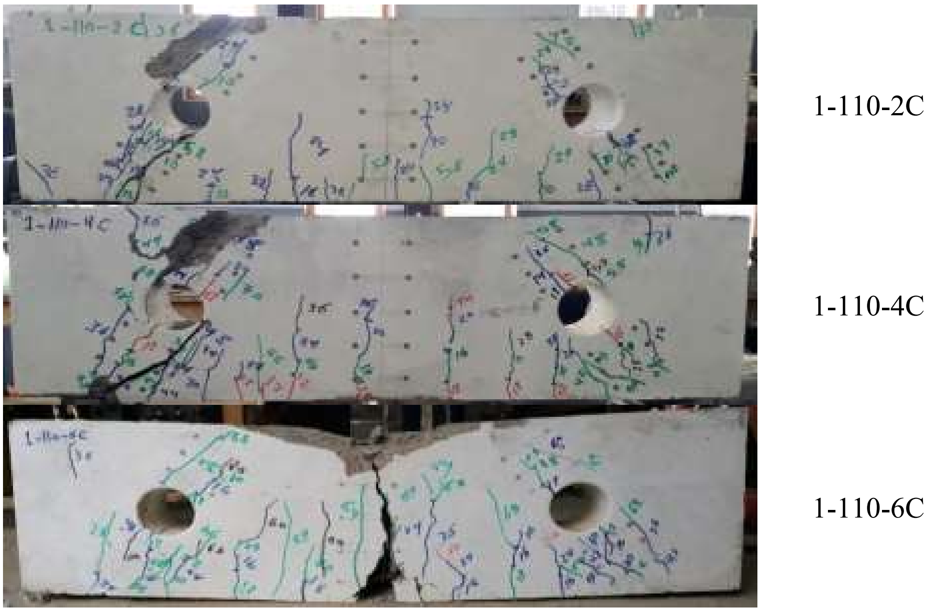


Plate 2-(continued) Deep beams after failure

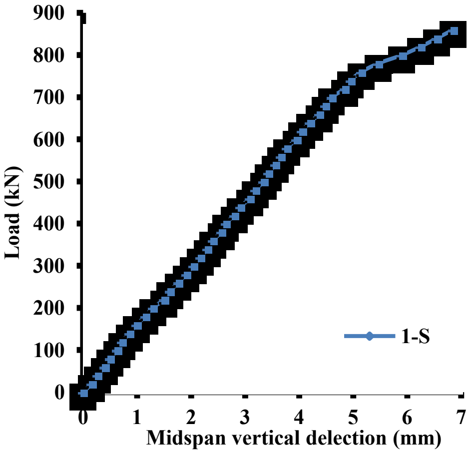
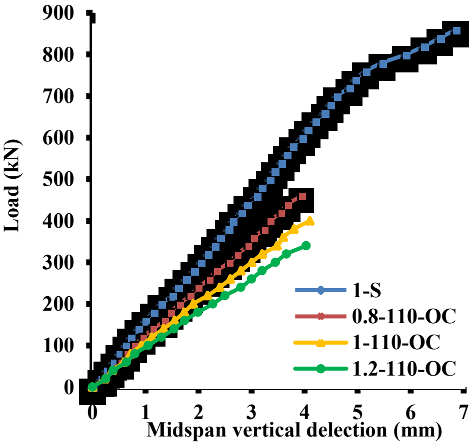
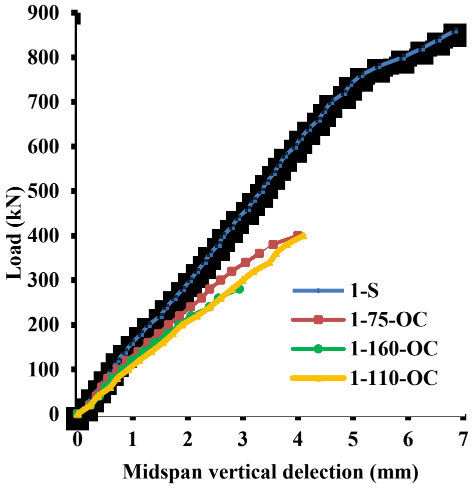


Figure (2)-Load-deflection relationship beam 1-S



Figure(3)-Load-deflection curve of GA beams



Figure(4)-Load-deflection curve of GB beams

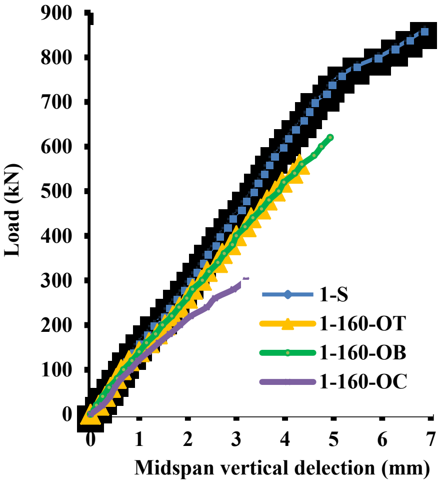
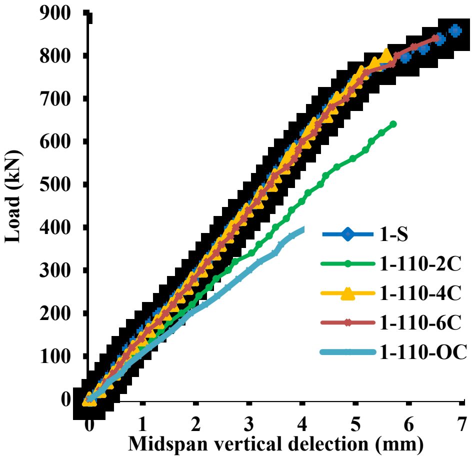


Figure (5) load deflection- curve of GC beams

CONCLUSIONS

I. All beams tested were failed in shear except beam 1-110-6C where its failure occurred in flexure. The shear failure was accompanied by flexure effect in the deep solid beam while it was occurred by splitting along the diagonal crack joining the load and support bearing edges with opening tangents opposite to them in beams with openings.

II. When the opening interrupts the assumed load path, the ultimate shear was severely decreased. For a beam with the opening of 160 mm diameter, the reduction in the ultimate load capacity was 66.7 % when it compared with corresponding solid one.



Figure(6)-Load-deflection curve of GD beams

III. In general, the behavior of beams tested influenced by a/d ratio. It was found that the increase of a/d ratio from 0.8 to 1.2 decreases the failure load by about 23 %. This decrement was observed to form a linear relationship with a/d ratio. Also, the mid span deflection exhibited the same relationship while the shear and cracking loads decreased slightly when the a/d ratio equals to 1.2.

IV. Increase the opening diameter decreases the shear cracking load and the ultimate shear strength of the beams while mid span deflection was not considerably influenced. The results showed that when opening diameter increased from 75 to 160 mm the drop in the shear cracking and failure loads were about 33 and 29 % respectively.

V. The positioning of the opening in the lower right panel of the shear span panel increases the ultimate load capacity by 6.9 % rather than when it positioned in the upper left panel while the shear cracking load and mid-span deflection did not affect. Also, the increment was 66.7 % when the same opening size positioned at the center of the shear span.

VI. The incorporation of the inclined reinforcement around openings was found very effective in improving the shear strength and the deflection of the beams tested. It was observed that when the number of the inclined reinforcement increased from 2 to 6 bars of 8 mm diameter above and below the opening, the ultimate load capacity of the deep beam with opening exceeded that of a solid beam. Furthermore, the deflection response became similar too.

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