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EFFECT□ OF OPENING DIMENSIONS AND POSITIONS ON STATIC BEHAVIOUR OF HIGH STRENGTH R.C. PERFORATED T-BEAMS

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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. Eleven beams were tested under static loading up to failure, ten of them were simulated the negative moment regions of reinforced concrete T- beams, were fabricated with large opening through the web and the other beam has solid web. In this study the effect of openings depth, openings length and the distance between the nearest support to the opening and its center is investigated. These beams made from high strength concrete of 90 MPa. The pattern of cracks and modes of failure were observed. The concrete strain and reinforced steel strain around openings were recorded. The maximum midspan deflection, at inner edge of opening and difference between maximum deflections of two edges of the opening were measured. The cracking and ultimate loads as well as crack width were measured. The results were given in shape of photos, tables and curves.

KEYWORDS: *concrete strength, pattern of cracks, deflections, T-beams, opening, and shear stress.*

INTRODUCTION

In most buildings, ducts and pipes for air-conditioning, water supply, sewage and other electrical and mechanical services are accommodated within the floor-ceiling sandwich. Passing these ducts through transverse openings in the floor beams eliminates a significant amount of dead space and results in a more compact design. Several researches had been carried out concerning the behavior of reinforced concrete beams with opening.

In 1985, Nassef, *et-al.* [5] studied the effect of openings located in the shear zones on the behavior of reinforced concrete beams. The main conclusions of this work were that openings can be made in the shear zones of reinforced concrete beams in a way that the beam strength and serviceability conditions are slightly affected, rectangular- shaped openings with fillet corners and diagonal steel bars improved the crack distribution around the corners of openings and increased the shear strength of the beam nearly equal to those corresponding to beam without opening. In 1985, Mansur *et-al.* [3] use a rational design method for reinforced concrete beams, they presented the following formulas, see Fig. (1):

$$v_t = \frac{|M_2| + |M_1|}{l} \qquad v_b = \frac{|M_4| + |M_3|}{l} \tag{1}$$

$$M_t = \frac{|M_2| - |M_1|}{2} \qquad M_b = \frac{|M_4| - |M_3|}{2} \tag{2}$$

$$M = N \; z + M_t + M_b \tag{3}$$

$$\frac{z}{h} N = \frac{\left[M + 1/2\left(|M_1| - |M_2| + |M_3| - |M_4|\right)\right]}{h}$$

$$M^* = M + 1/2\left(|M_1| - |M_2| + |M_3| - |M_4|\right) \tag{4.a}$$

If the top and bottom chords are each symmetrically reinforced:

$$M = N \; z \tag{4.b}$$

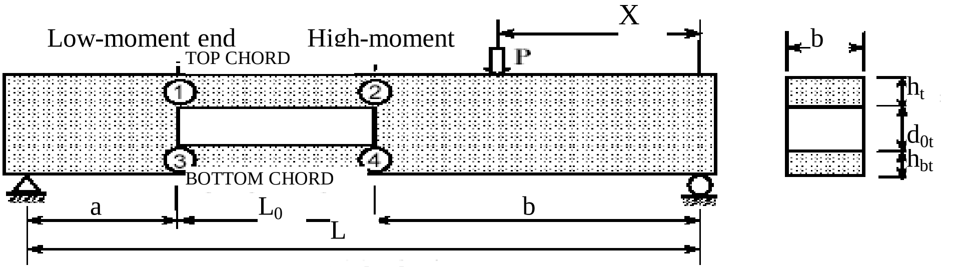
Where

h over all depth of beam.

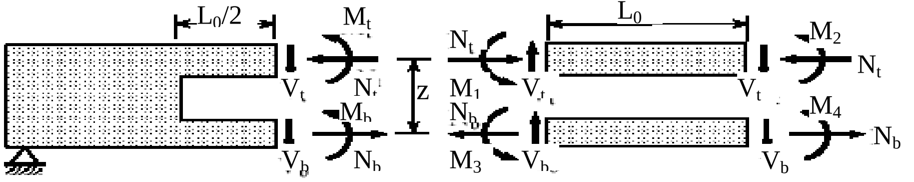
M bending moment at center of opening.

Z distance between the plastic centroids of top and bottom chords.

They concluded that a T-beam containing a large rectangular opening behaves similarly to a Vierendeel panel at the opening segment. Under combined bending and shear, the cord members bend in double curvature with contraflexure points located approximately at their midspan. Total applied shear may be distributed between the top and bottom chord accordance to their flexural stiffness, based on their gross or cracked transformed section. This distribution applies at both service and ultimate loads conditions irrespective of whether the opening is located within the positive or negative moment region of a continuous beam. [Fig. (1)].



(a) The beam



(b) Free-body diagram at opening (c) Free-body diagram of the chords

Fig. (1). Beam with a large opening under bending and shear.

In 1995, Kennedy, and Abdullah [7] published a research on static response of prestressed girders with openings. Their study was theoretical by using nonlinear analysis and experimental, the authors concluded that, cracking load decreases linearly with increase in the length of the opening. The cracking load is also influenced by the position of the external load, reinforcing the sides of the opening can substantially increase the cracking load of prestressed concrete beams and girders.

In 1998, Mansur [4] studied the effects of introducing a transverse opening on the behaviour and strength of reinforced concrete beams. Some guidelines are suggested to classify the opening as ‘large” or ‘small”. There are three schools solution for the distribution of the total shear between two chords. The first school assumed the compression chord carries the entire shear, this is probably true in case of the opening is located near the tension face without the use of any short stirrups in the tension chord. The second school distributes the total shear between the chord members in proportion to their cross section, and the third school distributes the total shear between the chord member^{b} n proportion to the flexural stiffness of the cord members. It is obvious that for large openings subjected to combine bending and shear vierendeel action prevails and failure occurs by the formation of a four hinge mechanism.

In 2002 Carina N., Martina S.H. [6] studied the behaviour of beams with large openings, the analysis and the results showed that: Location of the point of contraflexure is not located in the middle of the chords, Therefore a concept has been developed depending on the size and the geometry of the opening, the moment-to shear-force ratio as well as the amount and distribution of the reinforcement in the chords. They concluded that, fore design the stirrups next to the opening depending on the load; the design must concept has been developed in order to choose the number and the location of the stirrups next to the opening. Limitation of the crack width in the corners of the opening in order to limit the crack width an additional diagonal reinforcement bar has to be placed in the opening corners.

EXPERIMENTAL PROGRAM

Eleven reinforced concrete beams with T-section were tested and chosen according to the guide lines presented by Mansur [3]. All tested beams have over all depth 30cm, width of beams 16cm and flange of 8×45cm.Ten beams were provided with large opening through the web, while the other beam has solid web as reference beam. All beams were tested under three points static loading at mid span. The beams were tested considering the flange in tension zone. All beams reinforced with 2 bars 16mm diameter as main reinforcement and around the openings, two bars 10mm diameter as compression reinforcement, two bars 10mm diameter as reinforcement on edge of flange, stirrups 6mm diameter with 15cm spacing on solid parts and one stirrups 12mm diameter as vertical reinforcement around openings . The stirrups along openings were 6mm diameter with 5cm spacing in both top and bottom cords as shown in Fig. (2) and Table (1).

Beams in group (E) having shear span to depth ratio (a/d) equal to 2 with distance from nearest support to center of opening equals to (0.5a) In group (E) the effect of depth of opening is considered, includes two beams having shear span to depth ratio (a/d) equal to 2, having the same length of openings equals to $2.5d_0$. The beam E_1 having depth of openings equals to 0.3t and E_2 having depth of openings equals to 0.5t. In group F the effect of the openings length is considered, includes three beams having the same depth of openings equals to 0.4t, beam F_1 having length of openings equals to $1.5d_0$, F_2 having length of openings equals to $2.0d_0$ and F_3 having length of openings equals to $3.0d_0$.In group G the effect of distance from support is considered, includes four beams, with $0.4t\text{x}2.5d_0$ rectangular opening, having two series with respect to shear span to depth ratio. Series (1): This series contents two beams, having shear span to depth ratio (a/d) equal to 2. The beam G_1 having distance from nearest support to center of opening equals to 0.392a and G_2 having distance from nearest support to center of opening equals to 0.607a.Series (2): these series contents two beams, having shear span to depth ratio (a/d) equal to 4. The beam G_3 having distance from nearest support to center of opening equals to 0.196a and G_4 having distance from nearest support to center of opening equals to 0.303a.

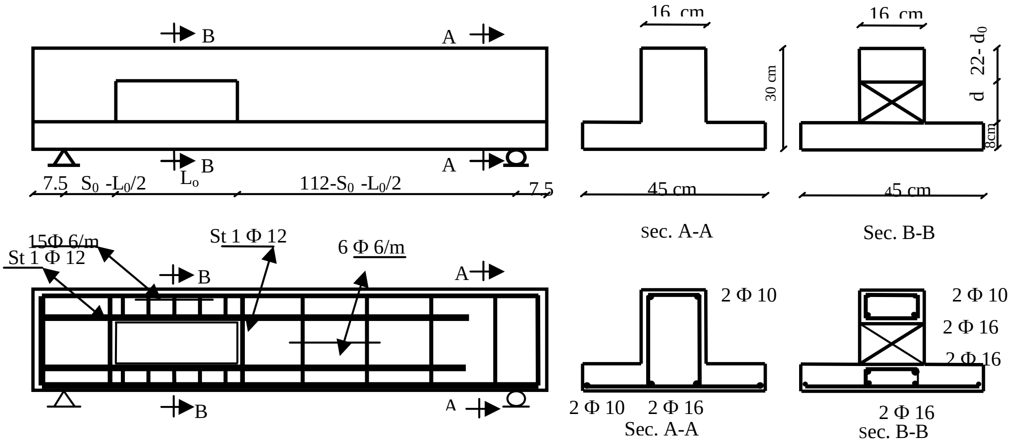


Fig. (2) Details of the tested beams

Table (1): Details of tested beams

Group No.	Beam No.	As	As\	a/d	f_c (Mpa)	d_0	S_0	L_0/d_0	A_0/A_w	Variable included
	R	2Ø16	--	--	90	--	--	2.5	---	Reference beams
	A2	2Ø16	2Ø16	2	90	0.4t	0.5a	2.5	0.273	
E	E1	2Ø16	2Ø16	2	90	0.3t	0.5a	2.5	0.204	Depth of opening
	E2	2Ø16	2Ø16	2	90	0.5t	0.5a	2.5	0.341	
F	F1	2Ø16	2Ø16	2	90	0.4t	0.392a	1.5	0.164	Length of opening (L_0)
	F2	2Ø16	2Ø16	2	90	0.4t	0.446a	2	0.218	
	F3	2Ø16	2Ø16	2	90	0.4t	0.553a	3	0.327	
G	G1	2Ø1	2Ø16	2	90	0.4t	0.392a	2.5	0.273	Position of opening (So)
	G2	2Ø1	2Ø16	2	90	0.4t	0.607a	2.5	0.273	
	G3	2Ø16	2Ø16	4	90	0.4t	0.196a	2.5	0.273	
	G4	2Ø16	2Ø16	4	90	0.4t	0.303a	2.5	0.273	

Where:

A_s Main steel reinforcement.
$As^\backslash$ longitudinal reinforcement around openings.
do opening depth,
L_0 opening length,
S_0 Distance from nearest support to center of opening.
t over all beam depth,
A_0 area of open,
A_w area of web.
a effective shear span.

MATERIALS

Concrete mixes were designed to produce concrete having a 28 days cubic compressive strength of 90 Mpa.

The used materials were:

a) Ordinary Portland cement conforms with E.S.S [2].
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) Local sand was used, 2.60, 1.58 and 2.58 specific gravity, volume weight and fineness modules respectively.
d) Drinking water.
e) Superplastisizer; the used additive was SIKAMENT (FF3) product by SIKA Industries Co. for SIKA Egypt Co., having a density 1.21 t/m^3.
f) Silica fume; the average particle size is 0.1µm, the specific surface area is (12-15 m^2/g) and the specific gravity is 2.2.
g) The longitudinal reinforcing steel was high tensile one of grade 40/60; while normal mild steel of grade 24/35 was used for stirrups having 6mm diameter. Steel reinforcing confirm with E.S.S [2].

Mix proportion by weight was presented in table (2).

Table (2) Mix proportion by weight

Amount of constituent materials/m3					
Cement (kg)	Sand (kg)	Broken Bazalt (kg)	Water (litre)	Silica fume ((kg)	Add. .(kg)
500	500	1200	145	110	20

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. The 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 curing in the same manner.

TEST PROCEDURE

The beams were tested under one point static loading on increments. Before cracking load each increment was 0.50 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 electrical strain gauges of steel and concrete strains, dial gauges, crack width and the crack propagation were recorded at the beginning and at the end of each increment of loading. At the same time, three control cubes were tested in compression. The beam maximum deflection was measured using dial gauge fixed at mid span, and another dial gauge in the two edges of openings. The strains were measured by using electrical strain gauges connecting to a digital strain indicator. For all beams, the strain in concrete was measured in mid span at compression zone and strain in steel was measured in longitudinal reinforcement around openings, in top chord was measured in corner beside applied load, in bottom chord was measured in corner beside support. The cracks that appeared were measured by using an optical micrometer with a 40X magnification factor. Measurements were taken on both sides of beam and at several spaces along the crack and marked by number (load value). At the end of each test the crack pattern was sketched and measured.

GENERAL BEHAVIOUR OF TESTED BEAMS

Generally, the load-deflection curve of the tested beams can be divided into three district stages, first stage I, the beam was uncracked and hence it had a relatively high flexural rigidity. Consequently, the slope of the load-deflection curve in this stage was steeper than that for the other stages. Second stage II, flexural cracks started to form, as the applied load was increased, cracks propagated and their width and height increased. Hence, the slope of the load-deflection curve became smaller than that of the first stage. Third stage III, the beams started to show signs of failure and the slope of the load-deflection curve became more flat.

INFLUENCE OF OPENING DEPTH (d_0):

W.R.T. Pattern of cracks, modes of failure and width of cracks

From investigation of plates (1) to (11), it is clear that increasing of opening depth don't change the mode of failure but increasing number and width of cracks at the same load level. This is due to the fact that increasing of opening depth means decreasing the top chord depth leading to decreases strength of the beams chords. In beam having opening depth equal to 0.5 times over all beam depth, the number of cracks in solid part is lower than the number of cracks in solid part of beam having depth equals to 0.4 times over all beam depth. This is due to the fact that failure load of beam having higher opening depth is lower than failure load of beam having lower opening depth, and the several cracks appeared in solid part at later stages of loading. The modes of failure of beams having difference opening depth were shear compression failure at upper chord of opening. As shown in Fig. (4) and Table (3).

W.R.T. Cracking and ultimate loads.

The theoretical values of ultimate loads ($P_{u.th}$) given in the table (3) is calculated based on consideration of Mansur [3] in second school, the ACI code [1] is used to calculate the ultimate shear strength of the tested beam. This school gives good calculation for the tested beam better than other two schools. From Table (3) and Figs. (5) , increasing of opening depth decreased the cracking and ultimate loads. This is due to the increases in depth of upper chord increasing stiffness of the beams. Decreasing opening depth from 0.4 to 0.3 times the over all beam depth increased the cracking and ultimate load by 12.5 % and 25 % respectively. Increasing opening depth from 0.4 to 0.5 times the over all beam depth decreased the cracking and ultimate load by 25 % and 27 % respectively. Beam having opening depth equals to 0.3 times the over all beam depth the cracking and ultimate loads were 45% and 96% respectively of beam without opening. Also, beam having opening depth equals to 0.5 times the over all beam depth the cracking and ultimate loads were 30% and 59% respectively of beam without opening. As shown in Fig. (5).

W.R.T. Maximum Induced deflections.

Increasing of opening depth increased the maximum deflections at mid span, at inner edge of opening and difference between maximum deflections of two edges of the opening. This is due to the fact that the increasing depth of upper chord is usually accompanied with increasing stiffness of beam. As shown in Fig. (8) and Table (4).

W.R.T. Maximum Induced strains.

Increasing of opening depth increased the maximum strain at upper steel around opening, strain at lower steel around opening and strain at concrete under point of loading at the same load level. This is due to the decreased the depth of upper chord decreased the compression zone in cross section accompanied with a decrease in the neutral axis depth in tension zone too. As shown in Fig. (9) and Table (4).

Table (3): Test results

Group No.	Beam No.	Theoretical(ACI)		Experimental		Δ_1	Δ_2	Δ_3	W_{max} (mm)	Mode of failure
		Pu(t) shear	P_u(t) bending	P_{cr} (t)	P_u (t)					
D	R	24.33	21.66	10	25.4	1	-	1.04		S.C
	A_2	20.53	21.66	4	19.6	0.77	1	0.95	1	S.C
E	E_1	23.78	21.66	4.5	24.5	0.96	1.25	1.03	1	S.C
	E_2	18.06	21.66	3	15	0.59	0.77	0.83	1.4	S.C
F	F_1	20.80	21.66	8.5	23	0.91	1.17	1.1	1.1	S.C
	F_2	20.80	21.66	6	22.6	0.89	1.15	1.09	1.1	S.C
	F_3	20.80	21.66	3	16	0.63	0.82	0.77	1.6	S.C
G	G_1	20.80	21.66	3.5	20	0.79	1.02	0.96	0.88	S.C
	G_2	20.80	21.66	3	15	0.59	0.76	0.72	0.84	S.C
	G_3	20.53	10.83	3	14.5	-	-	1.34	0.57	F.T.
	G_4	20.53	10.83	3	13	-	-	1.2	0.88	F.T.

Where

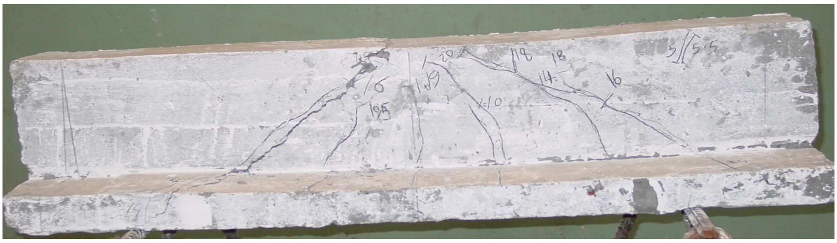
P_{cr} = cracking load for the tested beams (t), P_u= ultimate load for the tested beams (t).

Δ_1=experimental ultimate load of tested beams/ experimental ultimate load of beam without opening.

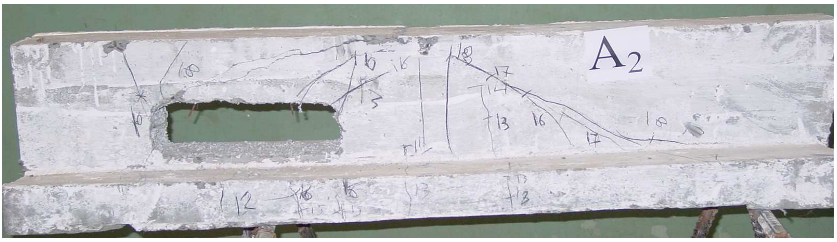
Δ_2=experimental ultimate load of tested beams/experimental ultimate load of beam A_2. Δ_3 = theoretical load of tested beams / experimental load tested beams.

S.C= Shear compression failure. F.T= Flexural tension failure.

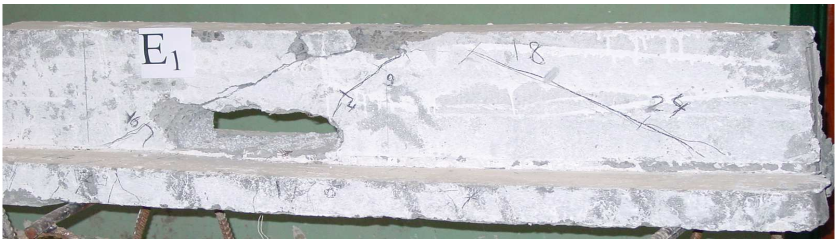
W_{max} =width of cracks in (mm) at 85% of ultimate load.



(1) Beam R



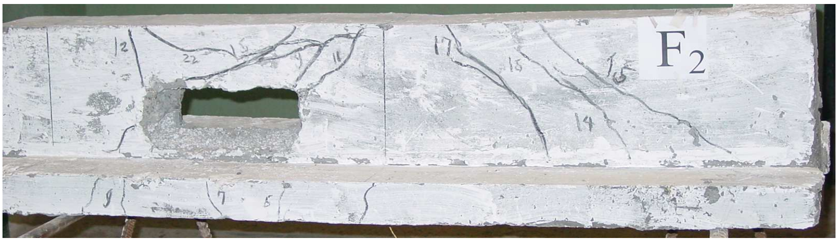
(2)Beam A_2



(3)Beam E_1

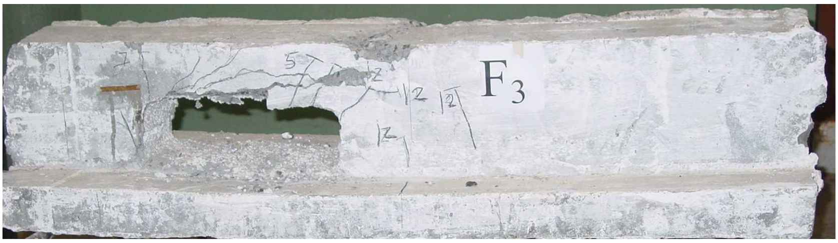
(4)Beam E_2

(5) Beam F_1

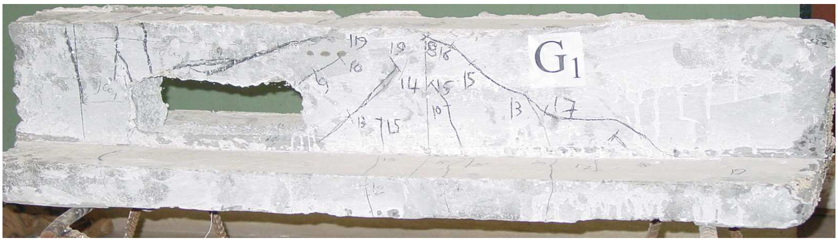


(6) Beam F_2

Fig. (3) Pattern of cracks of tested beams

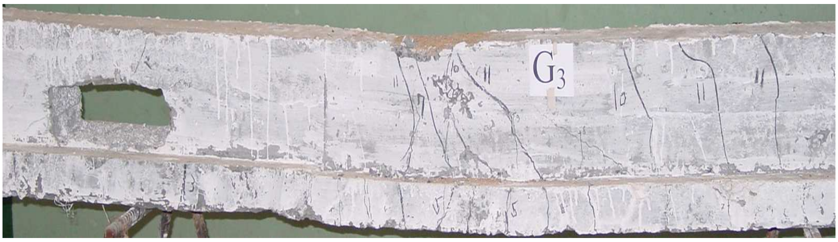


(7)Beam F_3



(8) Beam G_1

(9)Beam G_2



(10)Beam G_3

(11) Beam G_4

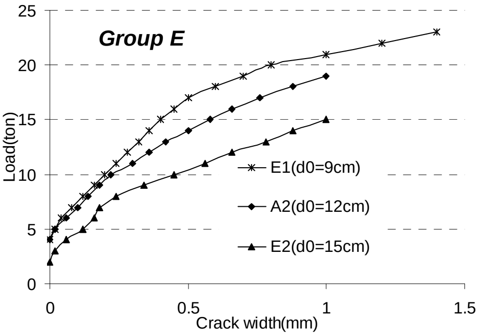
Fig. (3) Pattern of cracks of tested beams (cont.)

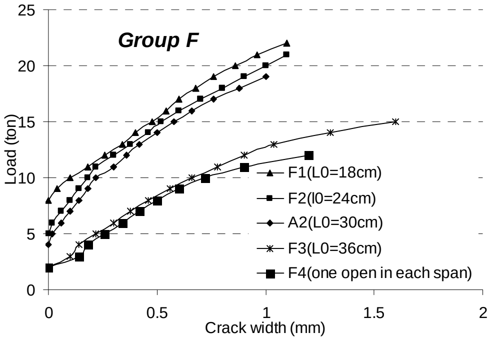
Table (4) Test results

Group No.	Beam No.	$-\delta_{1max}$	$-\delta_{2max}$	$-\delta_{3max}$	$-\varepsilon_{s1*10}^{-5}$	$-\varepsilon_{s2*10}^{-5}$	$-\varepsilon_{c*10}^{-5}$
D	R	6.20	5.90	1.80	----	----	----
	A_2	6.70	6.60	3.20	200	193	57
E	E_1	6.10	4.40	2.10	305	225	------
	E_2	5.20	5.30	3.30	215	74	179
F	F_1	5.70	4.80	2.70	297	------	------
	F_2	6.10	6.00	2.80	178	------	------
	F_3	8.50	7.80	4.55	1810	1120	84
G	G_1	4.83	4.62	1.47	180	87	------
	G_2	6.35	6.01	3.64	303	------	124
	G_3	41.05	16.17	11.38	189	------	86
	G_4	49.30	20.9	17.10	96	76	118

Where

δ_{1max} maximum deflections at mid span of beams in mm at 85% of ultimate load.
$-\delta_{2max}$ maximum deflections at inner edge of opening in mm at 85% of ultimate load.
$-\delta_{3max}$ difference between maximum deflections of two edges of the opening in mm at 85% of ultimate load.
$-\varepsilon_{s1}$ maximum strains at upper steel around opening at 85% of ultimate load.
$-\varepsilon_{s2}$ maximum strains at lower steel around opening at 85% of ultimate load.
$-\varepsilon_{c}$ maximum strains at concrete under point of loading at 85% of ultimate load.





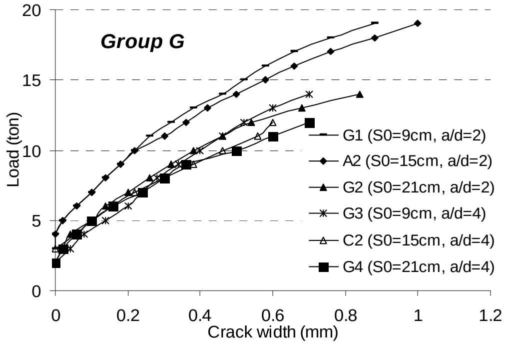


Fig.(4) Relation between applied load and crack width

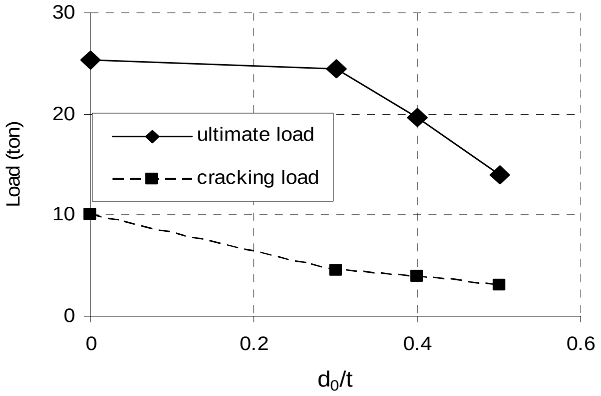


Fig.(5):Influence of opening depth on the cracking and ultimate loads

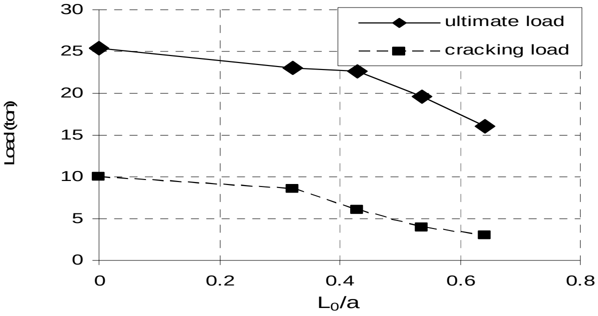


Fig.(6) Influence of opening length on the cracking and ultimate loads

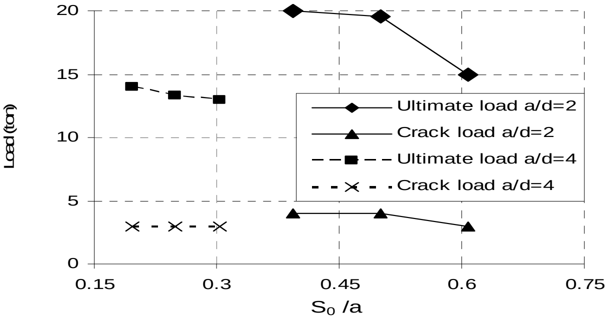
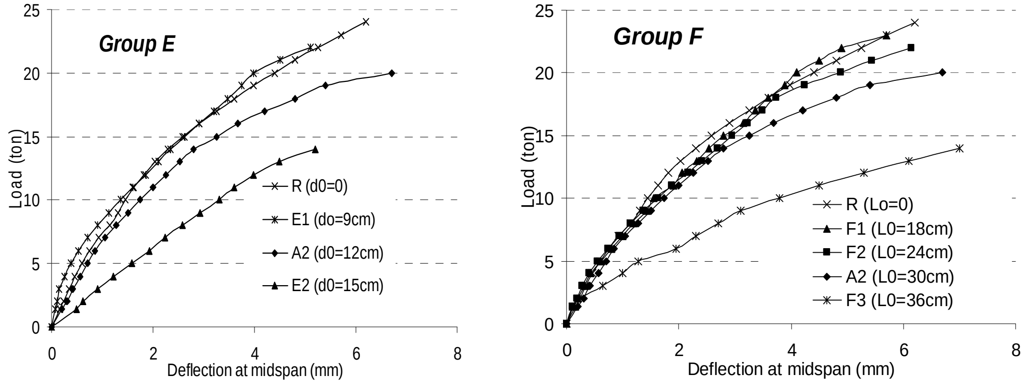


Fig.(7):Influence of the distance between the nearest support to the opening and its center on the cracking and ultimate loads



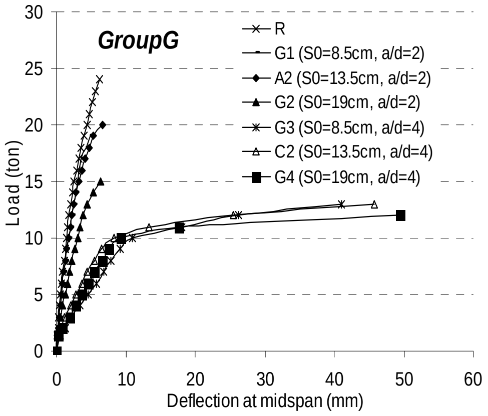


Fig. (8) Relation between applied load and maximum deflection.

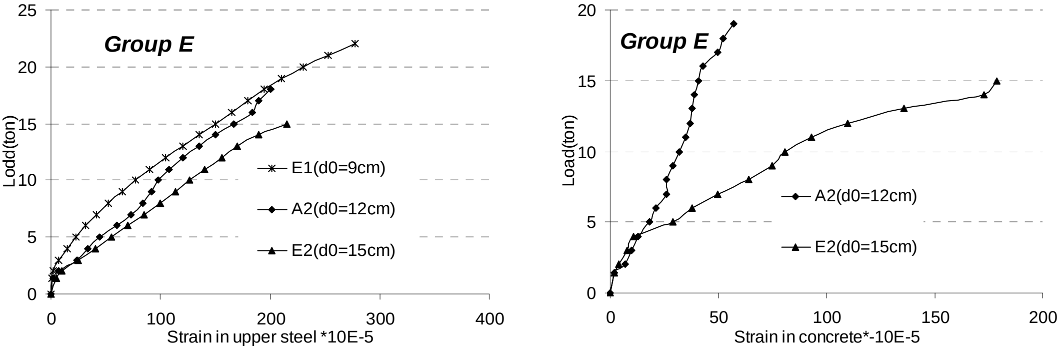


Fig.(9) Relation between applied load and maximum strains.

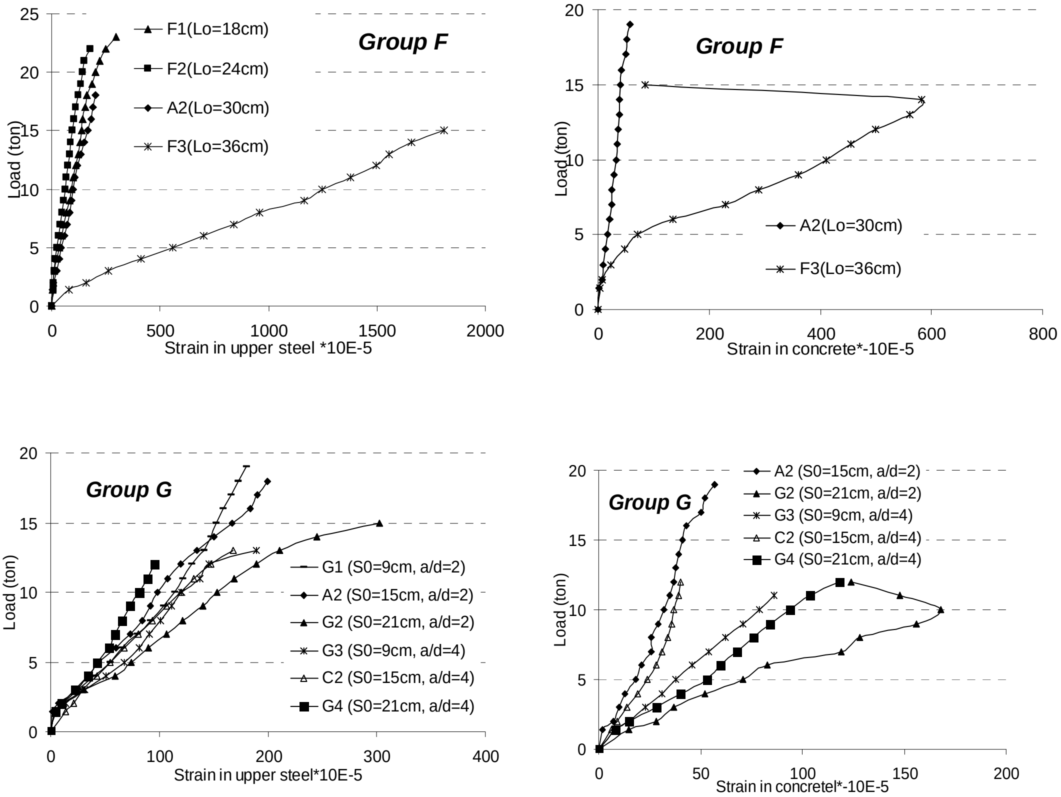


Fig.(9) Relation between applied load and maximum strains.

INFLUENCE OF OPENING LENGTH (L_0):

W.R.T. Pattern of cracks, modes of failure and width of cracks

The opening length has the same influence of opening depth from the points of views of pattern of cracks, mode of failure and cracks width. The modes of failure of beams having opening length equals to 0.32 to 0.64 times of shear span length were shear compression failure at upper chord of opening. The top chord of beam having opening length 0.64 times of shear span length was fully crushed, this is due to the distance between point of load application and opening edge is very small. This means that, this chord is subjected to high value of bending moment (high value of compressive stress). Solid part of beam having opening length equals to 0.64 times of shear span length have the same pattern of cracks of beam having opening depth equal to 0.5 times over all beam depth for the same reason. As shown in Fig. (4) and Table (3).

W.R.T. Cracking and ultimate loads

Increasing of opening length has the same effect of increasing of opening depth on both cracking and ultimate loads. Decreasing opening length from 0.54 to 0.32 times the shear span length increased the cracking and ultimate loads by 112.5 % and 17 % respectively. And decreasing opening length from 0.54 to 0.43 times the shear span length increased the cracking and ultimate loads by 50 % and 15 % respectively. Increasing opening length from 0.54 to 0.64 times the shear span length decreased the cracking and ultimate loads by 25 % and 18 % respectively. Beam having opening length equals to 0.32 times shear span length the cracking and ultimate loads were 85% and 91% respectively compared with that of beam without opening. Beam having opening length equals to 0.43 times shear span length the cracking and ultimate loads were 60% and 89% respectively respect to beam without opening. Beam having opening length equals to 0.64 times shear span length the cracking and ultimate loads were 30% and 63% respectively respect to beam without opening. As shown in Fig. (6) and Table (3).

W.R.T. Maximum Induced deflections

Increasing of opening length increased the maximum deflections at mid span, at inner edge of opening and difference between maximum deflections of two edges of the opening. This is due to the increasing length of opening is accompanied with a decreasing of stiffness of beam. As shown in Fig. (8) and Table (4).

W.R.T. Maximum Induced strains

Increasing opening length increased the maximum strain at upper steel around opening, strain at lower steel around opening and strain at concrete under point of loading at the same load level. As shown in Fig. (9) and Table (4).

INFLUENCE OF DISTANGE BETWEEN NEAREST SUPPORT TO CENTER OF OPENING (S_0):

W.R.T. Pattern of cracks, modes of failure and width of cracks

The distance between nearest support to center of opening has the same effect of opening length from the points of views of pattern of cracks, mode of failure and cracks width. Increasing the distance between nearest support to center of opening in both short beams having a/d=2 and slender beams having a/d=4 increased the number and cracks width at the same load level. This is due to in short beams the opening is more near of point of load application. Beams having distance between nearest support to center of opening varied from 0.39 and 0.61 times shear span length with a/d=2 have the same modes of failure and pattern of cracks. Also, beams having distance between nearest support to center of opening varied 0.2and 0.31 times shear span length with a/d=4 have the same pattern of cracks and modes of failure tension flexural failure at solid span. This means that slender beams, (a/d=4) are more affected by this distance. The best location of opening is 0.195 and 0.4 times shear span length for slender beams (a/d=4) and short beams (a/d=2) respectively. As shown in Fig. (4) and Table (3).

W.R.T. Cracking and ultimate loads

When the distance between nearest support to center of opening is increased the cracking and ultimate loads are usually decreased. In short beams having a/d=2, decreasing the distance between the nearest support to center of opening from 0.5 to 0.39 times shear span length increased both the cracking and ultimate load by 12.5 % and 2 % respectively. And increasing the distance between the nearest support and center of opening from 0.5 to 0.61 times shear span length decreased the cracking and ultimate load by 25 % and 24 % respectively . Also, beam having distance between nearest support to center of opening equals to 0.39 times shear span length the cracking and ultimate loads were 35% and 79% of that beam without opening, and beam having distance between nearest support to center of opening equals to 0.61 times shear span length the cracking and ultimate loads were 30% and 59% of that beam without opening. In slender beams having a/d=4, decreasing distance between the nearest support to center of opening from 0.25 to 0.2 times shear span length increased the ultimate load by 3.6 %. Increasing distance between the nearest support to center of opening from 0.25 to 0.31 times shear span length decreased the ultimate load by 7.1 %. The cracking load of slender beams is not affected by this distance because the initiation of the cracking was of flexural cracking type under point of loading. Investigation of the effect of both shear span to depth ratio and distance between nearest support to center of opening indicates that the distance between center of opening to point of loading more critical and has a pronounced effect than the distance between nearest support to center of opening. As shown in Fig. (7) and Table (3).

W.R.T. Maximum Induced deflections

Increasing the distance between nearest support to center of opening increased the maximum deflections at mid span, at inner edge of opening and difference between maximum deflections of two edges of the opening. As shown in Fig. (8) and Table (4).

W.R.T. Maximum Induced strains

Increasing the distance between nearest support to center of opening increased the maximum strain at upper steel around opening, strain at lower steel around opening and strain at concrete under point of loading, for the same reason as the effect of opening length. As shown in Fig. (9) and Table (4).

CONCLUSIONS

The following conclusions may be drawn from the experimental investigation of reinforced HSC T-beams that contain large openings through the web and are subjected to combined bending and shear:

1- The opening depth, opening length and the distance between nearest support to center of opening has a pronounced effect on both cracking and ultimate loads of the tested T-beams.

2- The opening dimension and its position significantly affect the maximum induced deflections and strains more than the cracking and ultimate loads of the tested T-beams.

3- The ultimate loads of the tested beams calculated from ACI [1] of second school of distributing the total shear between the chords members in proportion to their cross section gives the best confirmation for beams failed in shear mode failure.

4- In beams failed in shear mode failure it is possible for simplicity neglect the opening in design when the opening depth is less than 0.3 times the over all depth of beam or the opening length is less than 0.33 times the shear span of beam.

5- The best location of opening is 0.195 and 0.4 times shear span length for slender beams (a/d=4) and short beams (a/d=2) respectively.

6- The distance between the point of loading and center of opening is more critical and has a pronounced effect than that distance between nearest support to center of opening.

7- In slender beams (a/d=4) when opening is near from support it was observed that there is no effect on cracking and ultimate loads but a significant effect on maximum induced deflections and strains was noticed**.**

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تأثير أبعاد الفتحة ومكانها على السلوك الاستاتيكى للكمرات الخرسانية المسلحة ذات المقاومة العالية المثقوبة وذات حرف T

في المنشآت الحديثة حيث توجد فتحات كثيرة في الكمرات الخرسانية لدخول أنابيب المياه والكهرباء والتكييف. هذه الكمرات تحتاج إلى طرق تحليل خاصة لأن نتيجة وجود هذه الفتحات يؤدى إلى النقص في مقاومة ومتانة هذه الكمرات وتركيز الشروخ وزيادتها في منطقة الفتحات.

لهذا الغرض تم إعداد وصب أحد عشر كمرة خرسانية مسلحة ذات قطاع على شكل حرف **T** و ذات تسليح أقل من المتوازن وتم اختبارهم تحت تأثير حمل استاتيكى. إحدى هذه الكمرات ليس بها فتحات وعشر كمرات أخرى بكل واحدة منهم فتحة واحدة كبيرة في عصبها في منطقة العزم السالب. وفي هذه الدراسة تم أخذ تأثير كل طول وعرض هذه الفتحة بالإضافة إلى بعد مركز الفتحة عن الركيزة القريبة منها. تم قياس عرض الشروخ مع تحديد شكلها ومكانها وكيفية انتشارها مع قياس الانفعالات في كل من الخرسانة والحديد الأفقي حول الفتحة وكما تم رصد قيم حمل التشريخ وأقصى حمل بالإضافة إلى قيم أقصى هبوط للكمرات في منتصف الكمرات وعلى جانبى الفتحة. أعطيت النتائج في صورة منحنيات وجداول وتوصيات للتعرف علي سلوك هذا النوع من الكمرات ذات الفتحات والمصنوعة من الخرسانة العالية المقاومة.