Behavior and Strength of Concentrically Loaded Flat Slabs Using Self-Compacting High Strength Concrete With and Without Openings with Steam Curing

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ABSTRACT

Openings in slabs are usually required for plumbing, fire protection pipes, and ventilation ducts and air conditioning.

This study presents an experimental investigation on the influence of openings on the punching shear strength of high reinforced concrete flat plates. Five models of slab-column connection of (1000 x 1000 x 70mm) simply supported along the four edges are tested. The slabs are loaded concentrically by a central stub column. The main variables studied are the size(100x100mm and 200x100mm)and location(at 35 mm , at 135mm from center of slab and at the corner of slab) of the openings and used steam curing method.

Experimental results are recorded and studied at various stages of loading, deflection at the center of the slab, at distance (150mm) from the center of the slab in two directions and at the edge of the tested slab out of support. First cracking load and ultimate load capacity are also recorded.

Keywords: Self-compacting concrete, High strength R.C., Openings in slabs, Steam curing, Effect of size and location of openings and Critical section b_0.

السلوك والتصرف الإنشائي للبلاطات المسطحة محورية التحميل باستخدام المقاومة الخرسانية العالية ذات الرص الذاتي مع و بدون الفتحات المعالجة بالبخار

الخلاصة

الفتحات في السقوف تستخدم عادة للسباكة، أنابيب الحماية من النار، قنوات التهوية و الحرارة و التكيف يقدم هذا البحث دراسة عملية لتأثير الفتحات على مقاومة السقوف الخرسانة المستوية للقص الثاقب.

أجريت الدراسة على خمسة بلاطات بسيطة الاسناد ذات أبعاد ١٠٠٠×١٠٠٠× ٧٠ ملم وتم تسليط الأحمال على العمود ذو المقطع المربع في وسط البلاطة.كانت المتغيرات الأساسية هي:شكل ،أبعاد و موقع الفتحات وتمت معالجة النماذج بأستخدام البخار.

تم قياس و دراسة كل المتغيرات(بأخذ ابعاد مختلفة للفتحات١٠٠×١٠٠ ملم و ٢٠٠× ١٠٠ ملم وأخذ مواقع مختلفة للفتحات على مسافة ٣٥ملم :١٣٥ ملم من مركز البلاطة و في زاوية البلاطة) عند مختلف مراحل التحميل حيث تم قياس الهطول في مركز البلاطة،وعلى مسافة ١٥٠ ملم من مركز البلاطة في كلا الاتجاهين و على الحافة خارج المسند،وتم تسجيل الحمل الذي يظهر به اول تشقق و الحمل الاقصى النهائي ومع ملاحظة التشققات.

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INTRODUCTION

Floors and walls are some of the most commonly existing structural elements in buildings. Nowadays, rebuilding of existing structures has become quite common due to structural and/or functional requirements from the clients as well as the end users. The functional requirements entail often that staircases, elevators, windows, doors and even electrical, heating or ventilation systems, have to be installed. Thus, there exists a great need to introduce sectional openings in floor as well as in walls. The structural effect of small openings is often not considered due to the ability of the structure to redistribute stresses. However, for larger openings the static system may be altered when considerable amounts of concrete and reinforcing steel have to be removed. This leads to a decrease the ability of the structure to resist the imposed loads and the structure needs therefore to be strengthened [1].

Self-Compacting Concrete (SCC)

The Self-Compacting Concrete (SCC) has been characterized as a great evolution in the concrete technology, being able to fill all empty spaces of the formwork and self-compacting only by action of its own weight [7]. From mechanical point of view, the concrete (conventional or self-compacting) presents a lower behavior when subject to the tension stress, when compared to its actuation over efforts of compression [9]. In the present study five samples of two-way RC slab with additive self-compact were tested to investigate the behavior of concentrically loaded slab with and without opening.

Experimental Study

The experimental program consisted of tested five two-way RC slabs loaded up to failure. The objective of the tests was to compare the results between different slab configurations:

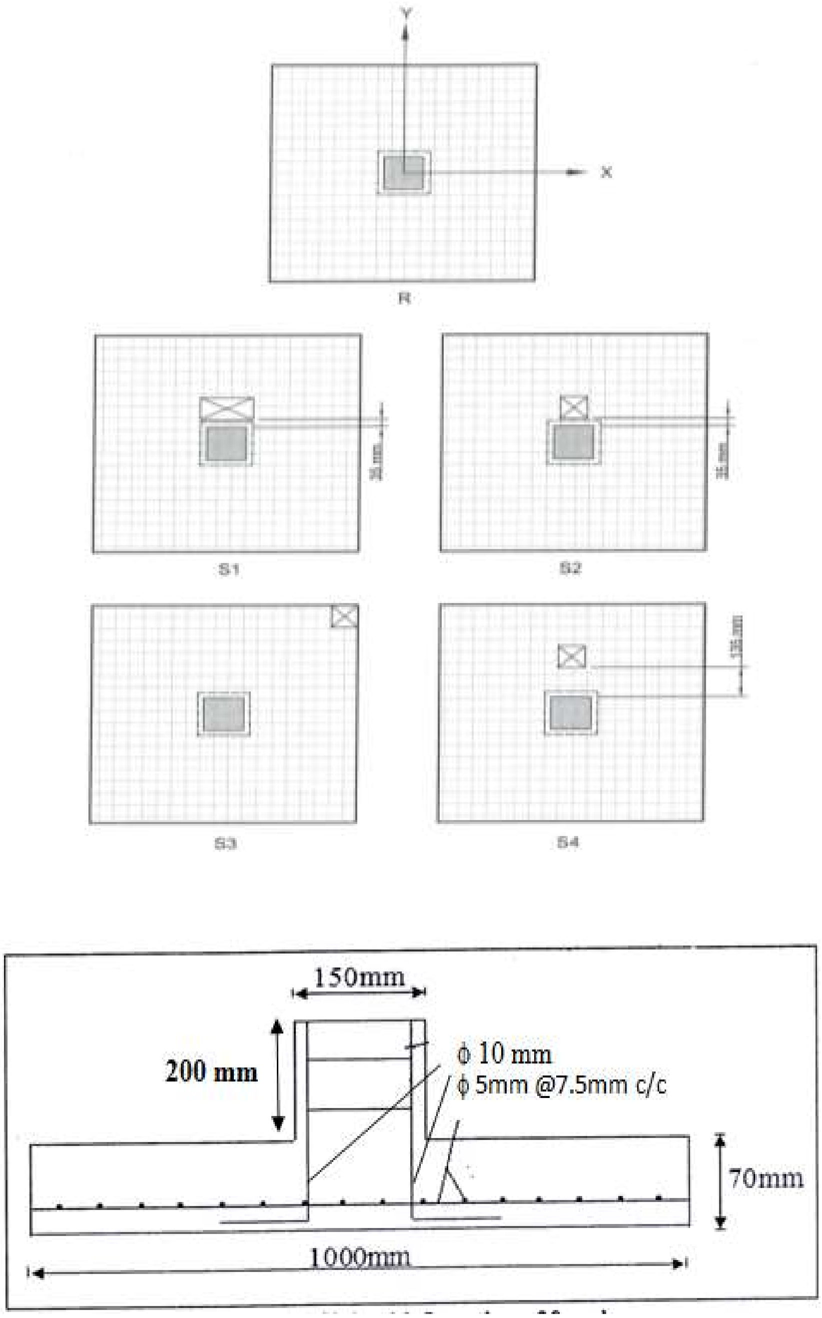
- Slabs without an opening
- Slabs with a cast opening :

a. Using different size of openings (two size 100x100mm and 200x100mm).

b. Using different location for openings (at 35 mm , at 135mm from center of slab and in the corner of slab).

Test Specimens

The slabs specimens used in this study consist of a square reinforced concrete slab (1000x1000mm) in size, with a total thickness of (70mm) and (150x150mm)square stub column with (200mm) high cast monolithically at the center of the slab. The tested specimens were reinforced with deformed wires of (5mm) diameter distributed across the section, as shown in Fig.1. Two different sizes of openings are used, (100x100 mm) and (200x100 mm) ,for the slabs with a cast opening. The needed amount of reinforcement was equal to the amount in a reinforced homogeneous slab that would pass through the opening and three different location (at 35 mm , at 135mm from edge of column and in the corner of slab).



Figure(1) Model Slab With Location of Operation

Materials Used

Cement: ordinary Portland cement Type (I) manufactured in Lebanon (Turbat Alsabaa) is used.

Fine Aggregate: AL-Ukhaidher natural sand is used which has fineness modulus (F.M) of (2.72), bulk specific gravity (S.G.)of this aggregate is (2.61). The grading of fine aggregate is listed in Table (1).

Coarse Aggregate: Crushed gravel from AL-Nibaee with maximum size of (14 mm) is used. The bulk specific gravity (S.G.) of this aggregate is (2.59). The grading of coarse aggregate is listed in Table (2).
Water: Tap water is used for mixing concrete.
Admixture: For high strength concrete production, the water cement of mix is reduced by using a superplasticizer (SP), which is a chemical admixture that compensates for the associated reduction in workability. The (SP) used in this study is commercially known as (Glenium 51) which complies with ASTM C 469-86[4]. The typical properties of Glenium 51 are listed in Table (4).
Reinforcement: Welded wires fabric mesh is used as flexural reinforcement placed in tension or in the tension and compression faces of the slabs. The average yield strength is (610 MPa) and the average ultimate strength is (728 MPa). The deformed wires are (5mm) in diameter. The test is made in the material laboratory/ Al-Mustansiriya University, Figuer. 2 shows the test set up.

Table (1) Grading of Fine Aggregate.

Sieve Size (mm)	% Passing by Weigh	
	%Fine Aggregate Passing	IOS 45/1984 Limits [12]
10	100	100
4.75	91.6	90-100
2.36	87.2	75-100
1.18	73.6	55-90
0.6	43.6	35-59
0.3	9.10	8-30
0.15	0.05	0-10

Table (2) Grading of Coarse Aggregate.

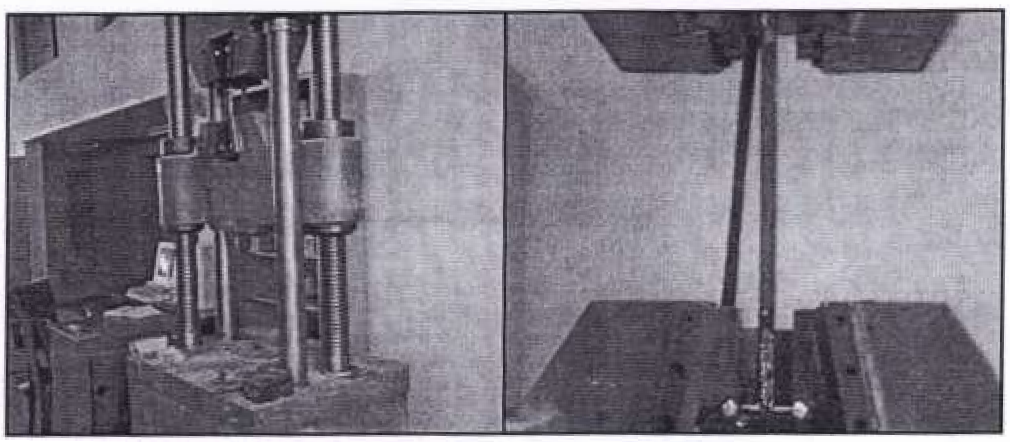
Sieve Size (mm)	% Passing by Weigh	
	%Coarse Aggregate	
12.5	100	100
9.5	96	85-100
4.75	27	10-30
2.36	2.8	0-10
1.18	0.7	0-5

Table (3) Chemical Analysis of the Limestone Powder.

Oxide	Content %
CaO	56.10
SiO2	1.38
Fe2O3	0.12
Al2O3	0.72
MgO	0.13
SO3	0.21
L.O.I	4.56

Table (4) Typical Properties of Glenium 51.

Form	Viscous Liquid
Colour	Light Brown
Relative Density	1.1 @ 20 0C
pH	6.6
Viscosity	128+/-30 cps @ 20 0C
Transport	Not Classified as Dangerous
Labeling	No Hazard



Figure(2)Test Setup for Steel bar

Mix Proportions

The mix design was done according ASTM C 469-86.(1 : 1.6 : 1.5) [4]with water cement ratio of 0.3. Cement: 535 kg/m^3, sand:863 kg/m^3, graval:794 kg/m^3, water:155L/m^3 , (Glenium 51)18 L/m^3,Lim:64 kg/m^3.after selecting the mix for high strength concrete , cylinders(raduis 15 cm and high 30 cm)cubes (15cmx15cmx15 cm) were cast and tested at age of (28 days) to determine the properties of concrete: average of cube strength f_{cu}=65.36 MPa and average of cylindrical compressive strength f'_c=60.27 MPa.

Curing

After casting, the specimens and their cubes and cylinders were left under polythene sheets for (24 hours) in the laboratory. Then, it was stripped off the mould and placed in steam curing setup for (48 hours) under 55 C^0 and then tested.

Testing and Results

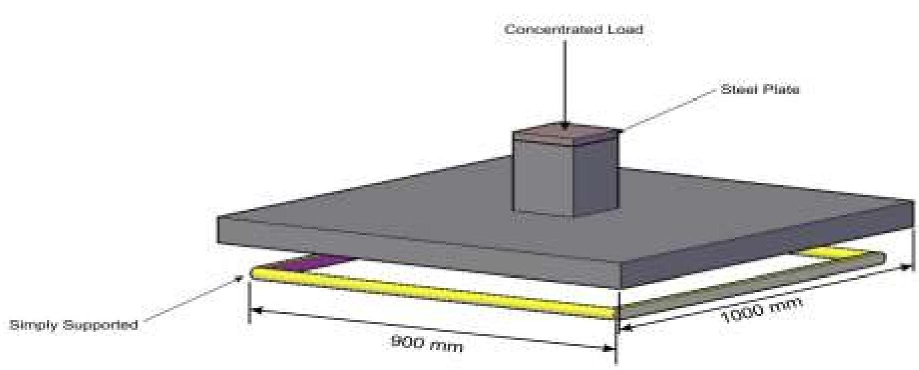
The slab specimens are simply supported along their four edges of 900 mm from center to center. The loading area is 150x150mm as shown in Fig.3.while Fig.4 show the preparation for loading test machine.

The deflection measurement is taken at several points. Four dial gages of (0.01mm) sensitivity are mounted on a steel frame, three of them put under the slab (tension face) in the center and X,Y direction at spacing (150mm) from the center (openings are along Y direction). The fourth one was put on the compression face to measure the uplift of the freely supported slab.

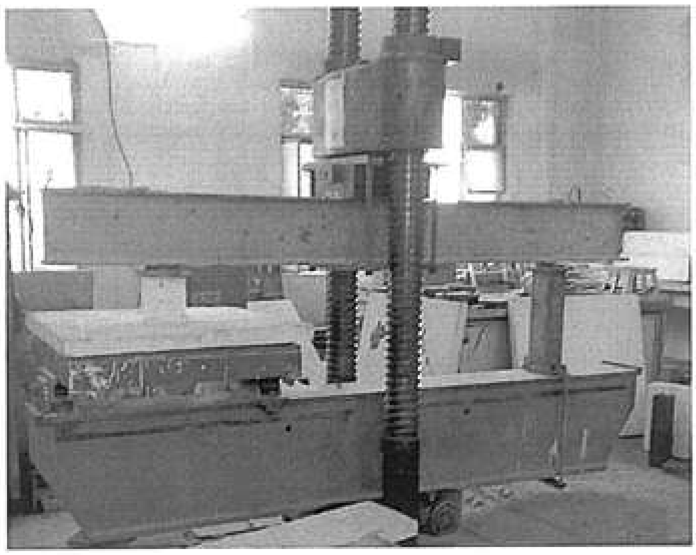
The general response for all tests specimens was similar. First, the contact between the support and the slab was developed until a load of approximately 2.5 kN where a small bump can be noticed. The bump was believed to be due to adjustment of the bolted joints in the test rig during the initial loading phase. The first crack in the slabs is observed between 7-8.5 kN. For reference slab, the cracking starts in the middle of the slab, in contrast to the slabs with openings where the first crack is initiated in 45^0 in the vicinity of one corners of the opening. As the load increases, more cracks initiate and continue to grow. For the slabs with openings, the cracks were narrower and more widely spread in comparison to the cracks in the slab without opening as shown in Figures (5, 6, 7, 8 and 9). In general, the effect of openings used (in most cases), decreases the first cracking load and the percentage of decrease reaches (21.4%) with respect to reference slab (R) as listed in Table (5). The presence of openings leads to decrease the slab area, therefore; the stress on slab-column connection will increase.

Table(5)Test result for cracking and ultimate loads

Specimens	Size and locationof openings	Cracking load kN	% Decrease in cracking load	Ultimate load kN	% Decrease in ultimate load	Typeof failure
R	Without openings	8.5	-	130	-	punching
S1	200x100 at 35 mm	7.5	13.33	80	62.5	punching
S2	100x100 at 35 mm	7	6.25	86	51.2	punching
S3	100x100 at corner	8.5	-	126	3.17	punching
S4	100x100 at 135 mm	8	21.4	92	41.3	punching



Figure(3) Loading and supporting of the slab



Figure(4) Preparation for loading test machine.

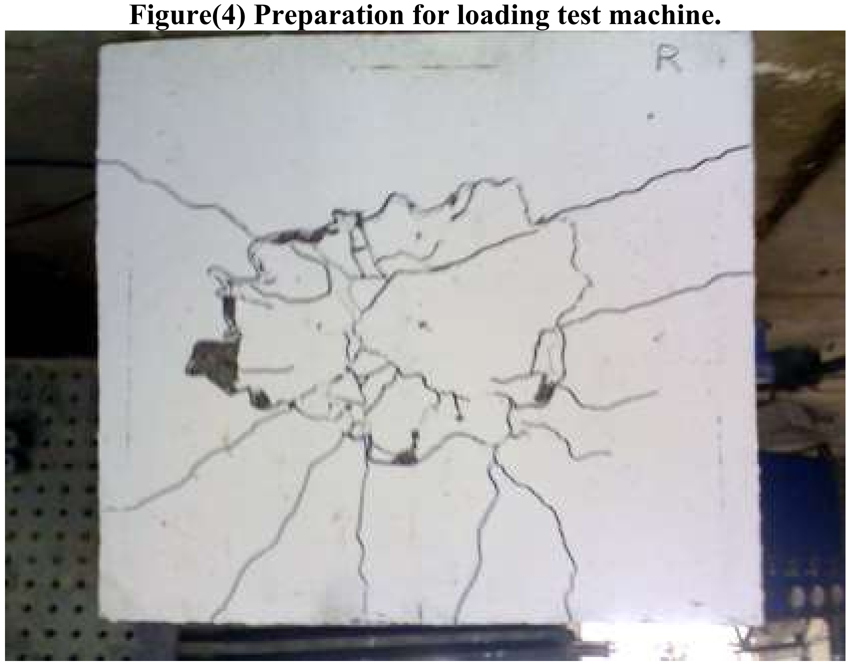
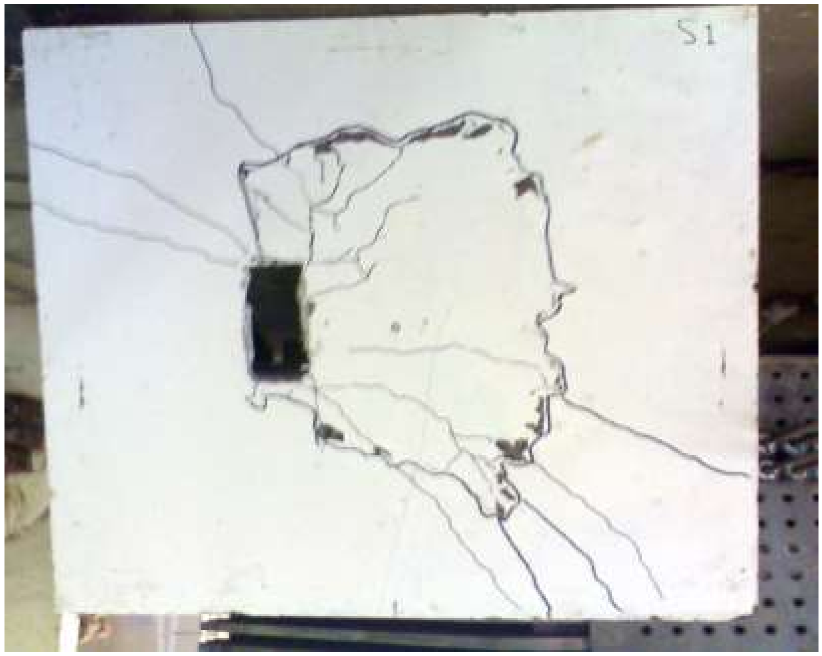


Figure (5) Crack patterns at tension face of slab R



Figure(6) Crack patterns at tension face of slab S1

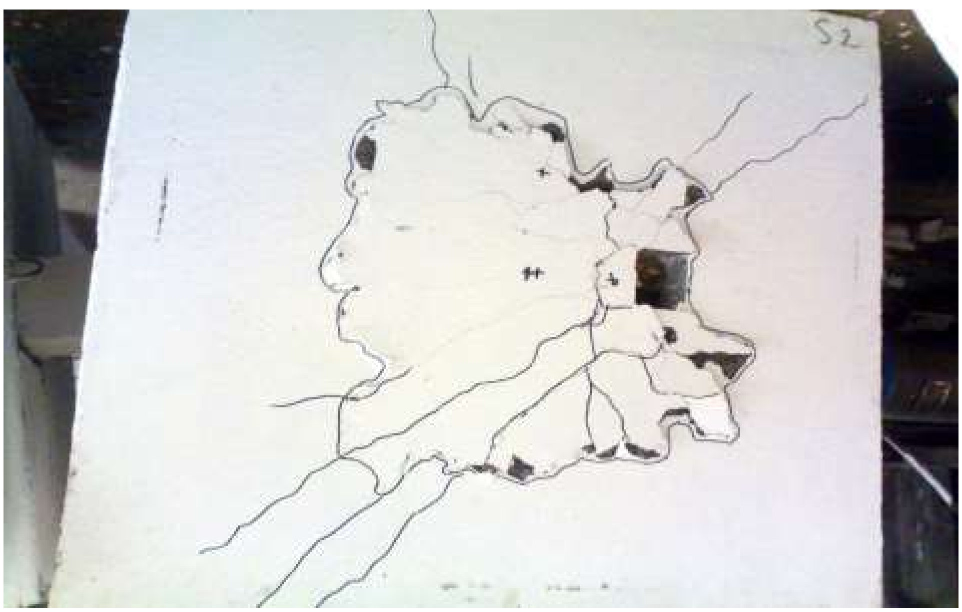


Figure (7) Crack patterns at tension face of slab S2

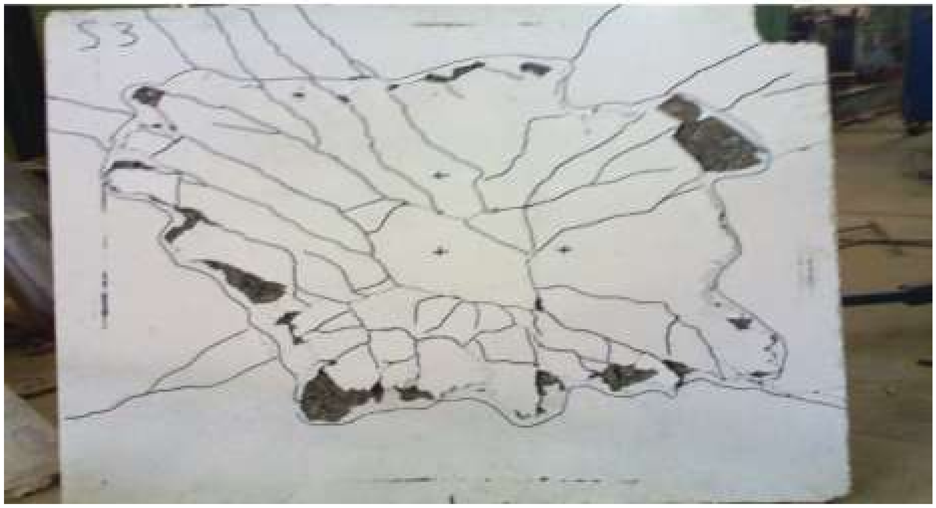


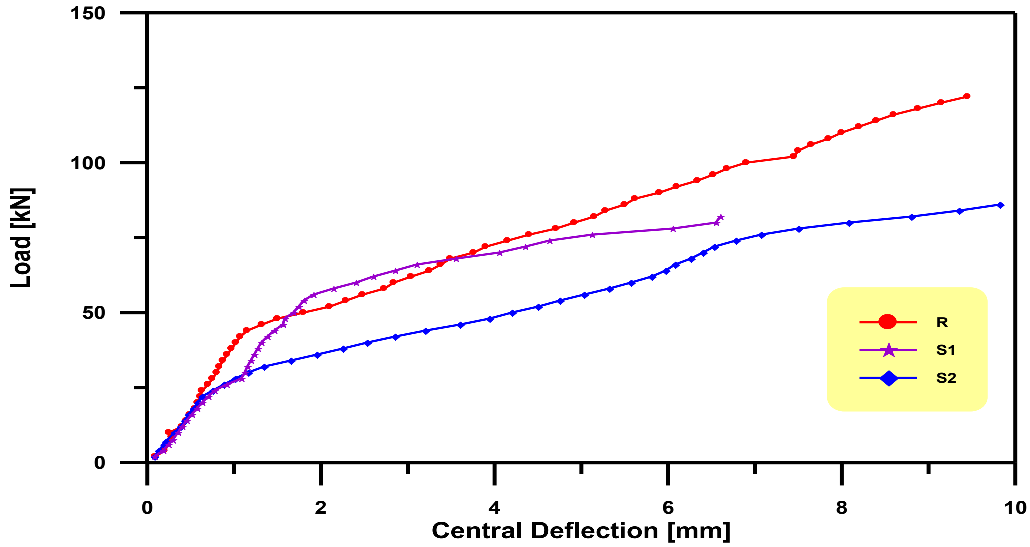
Figure (8) Crack patterns at tension face of slab S3

Figure(9) Crack patterns at tension face of slab S4

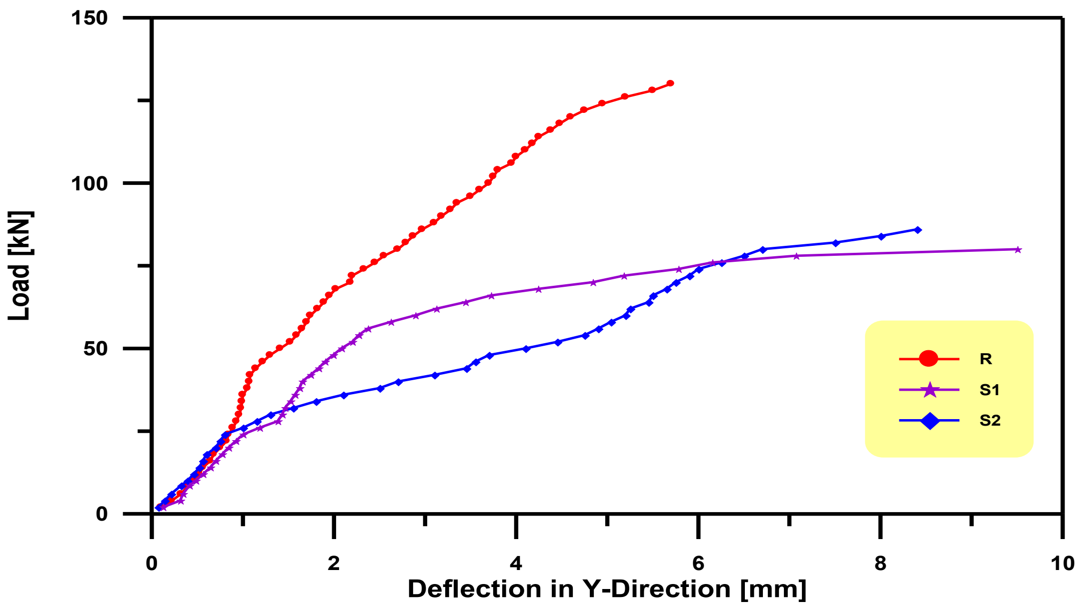
Parametric Study

Effect of Size Of The Openings

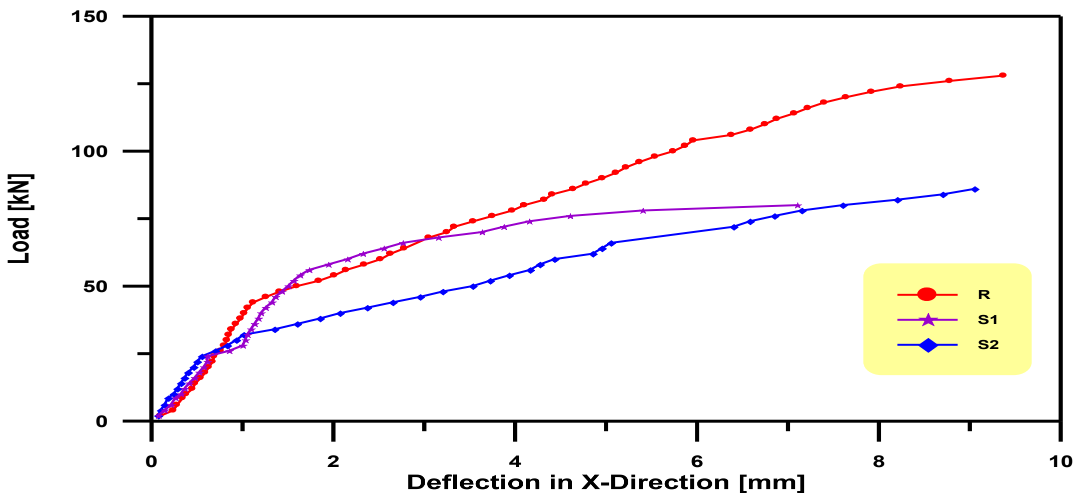
In order to inspect the effect of size of openings on the behavior of slab, two dimensions of openings have been carried out, (100x100 mm) and (200x100 mm) in slabs (S2) and (S1) respectively. It was found that, a decreases the first cracking load from (8.0 kN) for (S2) to (7.5 kN) for (S1) about (6.66%) and an increase in dimension of opening decreases about (15%) the ultimate load capacity at failure from (92 kN) for (S2) to (80 kN) for (S1). In case of opening dimensions increased, the cracks propagation starting from tensile face of slab near the supports and concentrated toward the opening, so that the ultimate stresses developed make the slab reach to failure because of the presence of large opening, beside large openings lead to decrease the loaded area, therefore; the stress on slab-column connection will increase as shown in Figures (10, 11, 12 and 13).



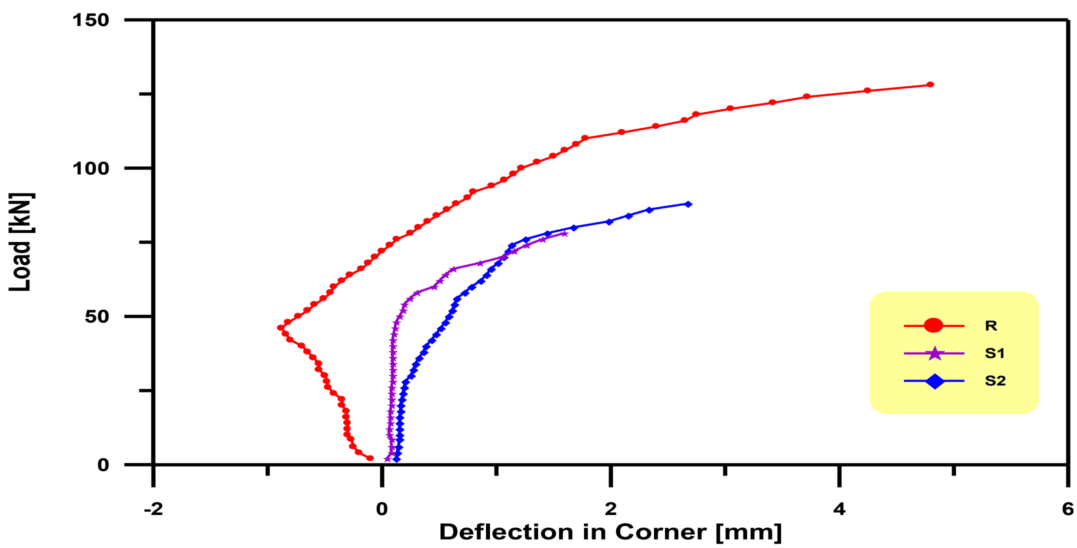
Figure(10) Load – central Deflection Curve for Slabs specimens R,S1 and S2



Figure(11) Load –Deflection Curve in Y-Direction for Slabs specimens R,S1 and S2



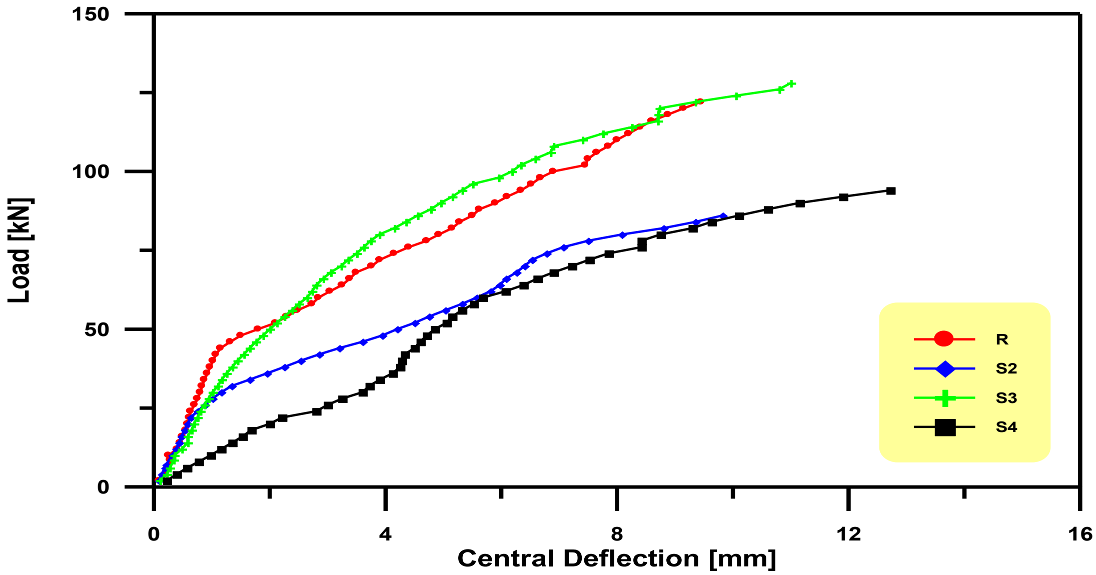
Figure(12) Load –Deflection Curve in X-Direction for Slabs specimens R,S1 and S2



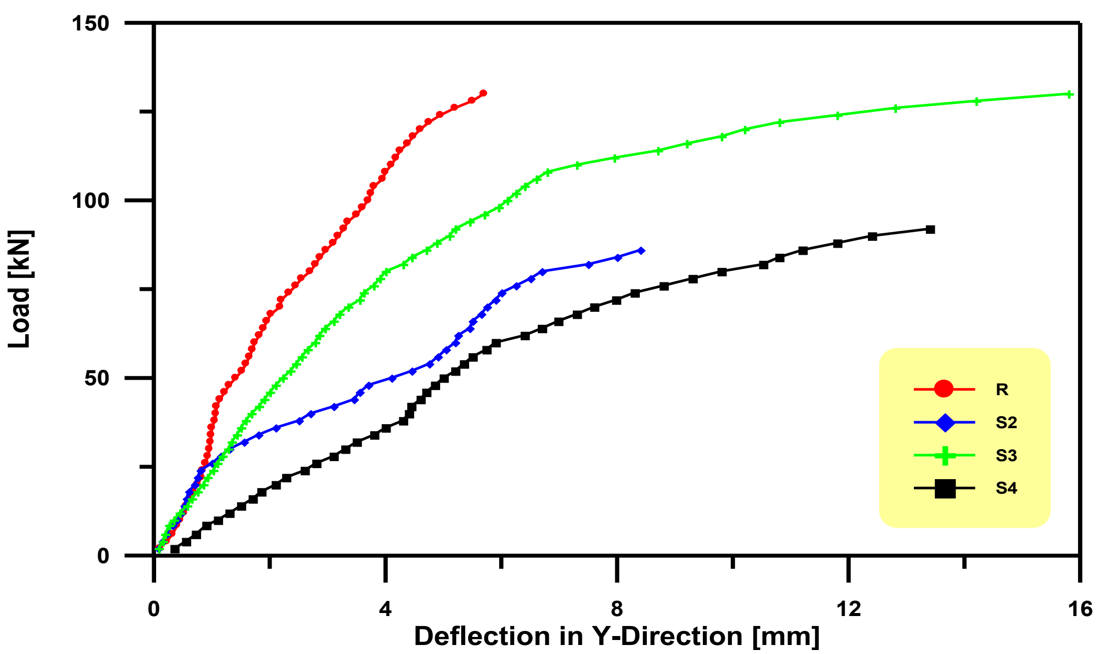
Figure(13) Load –Deflection Curve in Corner for Slabs specimens R,S1 and S2

Effect of Location Of the Openings

Three slabs specimens were cast with different opening location as shown in Fig.1 to study the effect of opening position. Compression with reference slab specimen it is found that, there is little effect when the location of opening in the corner of slab specimen (S3). Because the size of opening is small compare with slab's thickness beside opening's location at the edge. While, the increase in distance of openings from the edge of column as (35mm)to(135mm) in slabs specimens (S2) and (S4) respectively, increases the first cracking load from (7 kN) to (8 kN) about (14.28%). Also increases about (7%) in the ultimate load capacity at failure from (86 kN) for slab specimen (S2) to (92 kN) for slab specimen (S4), because the response slab specimen (S2) is softer as compared with the response of slab specimen (S4). In general the reduction in slab shear strength when the opening is located anywhere within 10 times the of slab thickness from concentrated load or reaction area and these reduction increased when the distance between opening location and face of column decreased as shown in Figures (14, 15, 16 and 17).



Figure(14) Load – central Deflection Curve for Slabs specimens R,S2,S3 and S4



Figure(15) Load –Deflection in Y-Direction Curve for Slabs specimens R,S2,S3 and S4

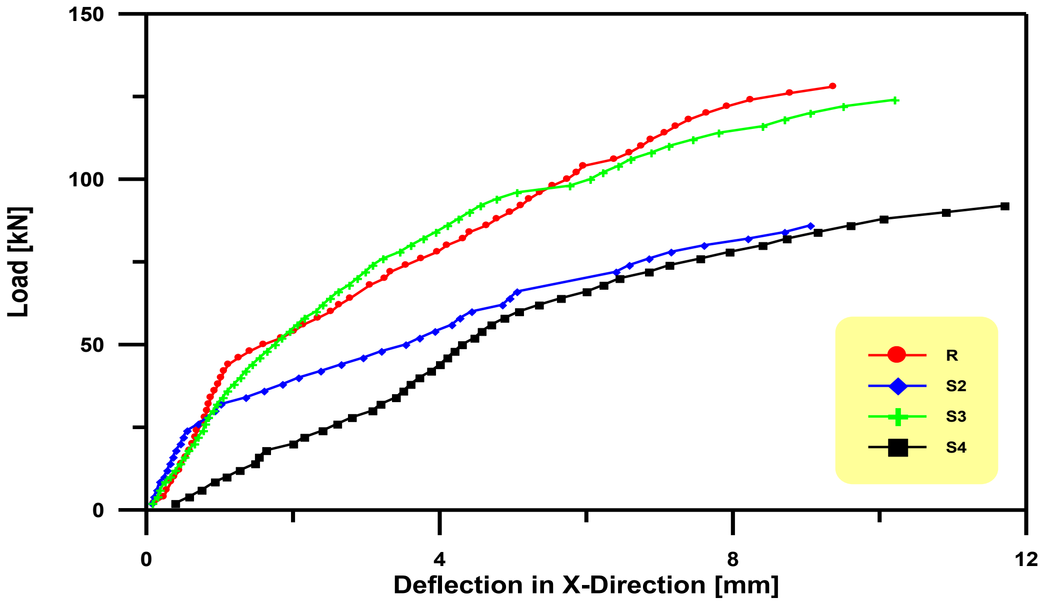


Figure.16 Load –Deflection in X-Direction Curve for Slabs specimens R,S2,S3 and S4

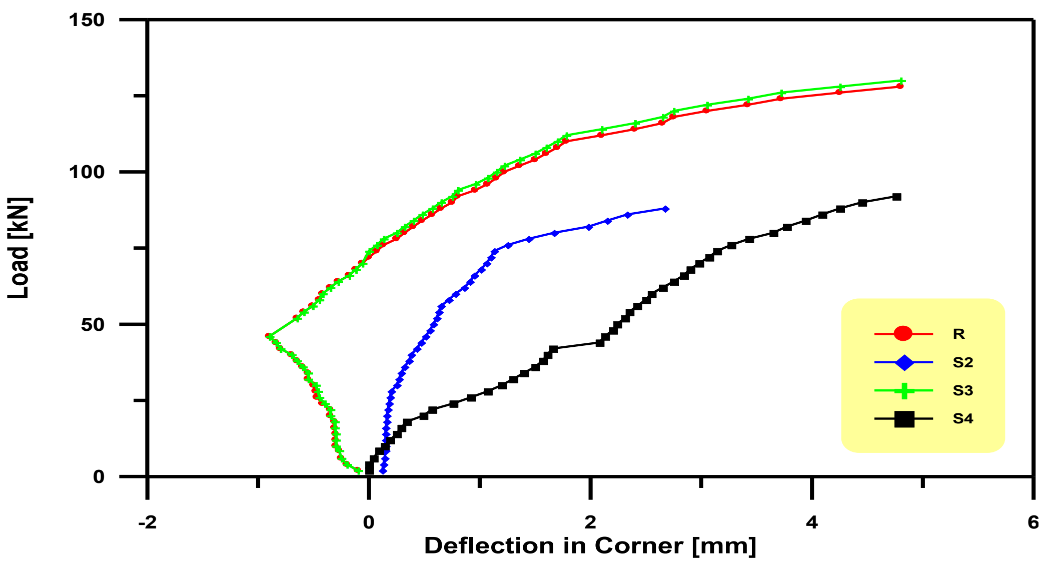


Figure (17) Load –Deflection in Corner Curve for Slabs specimens R,S2,S3 and S4

Effect Of Openings on Shear Stress

A reduction in shear strength is made by considering from ineffective that portion of the critical section b_0 which is enclosed by straight lines drawing from the column centroied to the edge of the opening as shown in Fig.18. So the value of b_0 will be different from specimen to another depending on the location and size of openings.

For nonprestressed slabs V_c shall be the smallest of (a),(b) and (c) [3] : (11.12.2.1)

(a) $V_c = [1+\frac{2(4)}{\beta c}]\frac{b_0 d\sqrt{fc}}{6}$ … (1)

Where βc is the ratio of the long side to short side of column, concentrated load or reaction area;

(b) $V_c = [\frac{d\, a_s}{b_0}+2]\frac{b_0 d\sqrt{fc}}{12}$ ….. (2)

Where a_s is 40 for interior columns, 30 for edge columns, 20 for corner columns.

(c) $V_c = \frac{b_0 d\sqrt{fc}}{3}$ ….(3)

$\Phi V_n = \Phi V_c / b_0 d$ ….(4)

Where:

Φ=Strength reduction factor

F_c=Cylinder compressive strength of concrete

b_0=Perimeter of the critical section for punching shear, mm

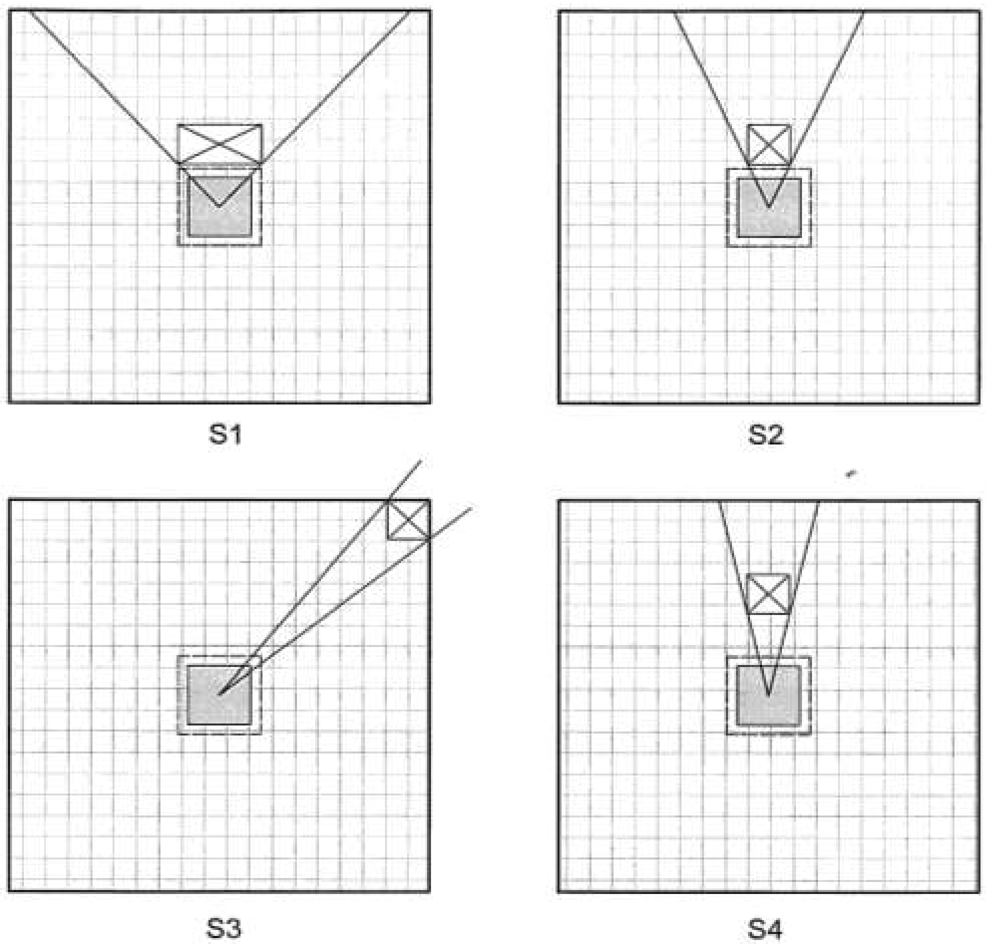
d=Effective depth, mm

V_c=Shear strength

From Table 6 it is found that, there is little effect when the location of opening in the corner of slab specimen (S3) decrease the shear strength about 0.51% from reference slab specimen (R). Because the size of opening is small compare with slab's thickness beside opening's location at the edge. While, the increase in distance of openings from the edge of column from (35mm)to(135mm) in slabs specimens (S2) and (S4) respectively, decreases the shear strength about (1.02%) and (0.63%) respectively. A reduction in critical section b_0 increases when the opening becomes near to the edge of column. While largest decreases recorded for slab specimen (S1) about (2.15%) in the shear strength, Because large openings leads to increase the ineffective portion of the critical section b_0 .

Table(6) shear strength values for the slab specimens

Slabs Specimens	Size and location of openings	b_o mm	(a)V_c kN	(b)V_c kN	(c)V_c kN	% Decrease in shear strength
R	Without openings	792	442.7	108.81	98.38	-
S1	200x100 at 35 mm	775	433.19	107.74	96.27	2.15
S2	100x100 at 35 mm	784	438.22	108.30	97.38	1.02
S3	100x100 at corner	788	440.46	108.55	97.88	0.51
S4	100x100 at 135 mm	787	439.9	108.49	97.76	0.63



Figure(18) critical section of slabs

CONCLUSIONS

From the tested specimens it may be conclude:

1. All tested slab specimens with openings have a lower ultimate load carrying capacity reaches to (62.5%) than the reference slab specimen without opening.
2. The slabs with the smaller openings have a noticeable higher load carrying capacity reaches to (15%) and a stiffer load-deflection response than the slabs with larger openings.
3. As far as possible, opening in slabs should be located in zone where shear stresses are small and bending moment are below maximum, but small opening can be made anywhere in slab.
4. All slabs with openings have a lower shear strength reaches to (2.15%) than the reference slab and this decreases small because the size of opening is small compare with slab's thickness.
5. Also the amount of reinforcement which excite in the panel without openings, in two directions, must be maintained; thus, half of the reinforcement must be replaced on every side of the opening.

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