Experimental Study of Punching Shear Strength of Self Compacting Concrete Slabs with Openings

دراسة عملية لمقاومة القص الثاقب للبلاطات الخرسانية ذاتية الرص ذات الفتحات

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Abstract:

The main purpose of this study is to evaluate the effect of punching shear strength on the behavior of self compacting reinforced concrete two-way slab specimens which have different types of openings. Seven slabs were prepared for this matter divided into two groups, group (A) consists of four slabs, one without opening (S1) and three with square openings (S2,S3, and S4) while group (B) consists of three slabs with circle opening (S5,S6, and S7). The different parameters included in this study are; shapes of opening (square opening, circular opening) and position of opening (for punching failure). The constant parameters considered are; concrete type (self compact) and steel reinforcement ratio. Some of conclusions in this study are; the ultimate punching shear strength of the slab with the larger opening is less than that with smaller one and at the edge for square opening, and the ultimate load capacity for slab specimens were decreased significantly when opening existed, so that the slabs in group (A and B)showed decreasing of the original load of slab (S1), of (38.9%, 44.4%, 33.3%, 30.6%, 38.9%, and 44.4%) for slabs: (S2, S3, S4, S5, S6, and S7) specimens respectively .The percentage of reduction depends mainly on size and position of opening.

Keywords: Punching shear, experimental study, self compacting concrete, slabs opening.

الخلاصة:

إن الهدف من هذا البحث هو دراسة تأثير مقاومة القص الثاقب على سلوك نماذج من البلاطات الخرسانية المسلحة ذاتية الرص والتي تحتوي على فتحات مختلفة. إذ يتضمن هذا البحث إجراء فحص على سبع نماذج من البلاطات تم تقسيمها الى مجموعتين , مجموعة (أ) تتضمن أربعة بلاطات واحدة بدون فتحة وثلاثة تحتوي على فتحة مربعة بأماكن وقياسات مختلفة ومجموعة (ب) تحتوي على ثلاث بلاطات ذات فتحات دائرية وبأماكن مختلفة. هنالك عاملان متغيران رئيسيان هما شكل الفتحة وموقع الفتحة بالنسبة للبلاطة أما العاملان الثابتان هما أولاً نوع الخرسانة المستخدمة والتي تتضمن خرسانة ذاتية الرص وثانياً نسبة حديد التسليح. تم تَحلّل النتائج و رسم منحي التشوه للنماذج ذات الفتحات وقورنت النتائج مع نتائج النموذج الصلد وكذلك سوف تُعرض التشققات الحاصلة في النماذج وكيفية ظهور تأثير القص الثاقب عليها بوضوح. إن بعض الاستنتاجات التي تم التوصل إليه في هذا البحث , 1 : مقاومة القص الثاقب القصوى للبلاطة ذات الفتحة الكبيرة اقل من المقاومة فيما يخص الفتحة الصغيرة والجانبية, 2 : النقصان بسعة الحمل القصوى عند وجود الفتحات بحيث أظهرت البلاطات في المجموعتين (أ,ب) نسبة نقصان (%38.9,%44.4,%33.3,%30.6,%38.9, %44.4) من الحمل الأصلي للبلاطة الصلدة S1 فيما يتعلق بالبلاطات (S2,S3,S4,S5,S6 and S7) على التوالي. وهذا النقصان يعتمد على حجم وموقع الفتحات.

الكلمات المفتاحية: القص الثاقب, دراسه عمليه, خرسانة ذاتية الرص, فتحات السقوف.

1-Introduction:

Suspended reinforced concrete (RC) solid slab has been widely used for the multi-storey building. Small openings are required in the slab to accommodate the mechanical and electrical services such as heating, plumbing and ventilating risers. Meanwhile, substantial size openings are required by lift, stairways and elevator shafts. The structural effect for small openings is often not considered due to the ability of the structure to redistributed stresses. However, for large openings, the static system may be altered when it involves a significant amount of concrete and reinforcement bar that need to be removed. This may lead to decrease in ability of the structure to withstand the imposed loads and the structure needs (1). Fig.(1) shows the opening in slab using for lift (2).

The design of RC slab with opening is not clearly stated in BS 8110 (3). The American Concrete Institute, ACI 318 provides more guidelines for opening size in different location for flat slabs. Fig.(2) illustrates the suggested opening sizes and location on a flat slab. The flat slab is divided into column and middle strips in two perpendicular directions. The opening with any size is permitted in the area where middle strip intersects. For the opening in the area interesting column strip, the allowable opening size is 1/8 the width of column strip in either span. For opening involved in the area intersecting one column and one middle strip, the maximum opening size is where only 1/4 of the slab reinforcement in either strip may be interrupted. In order to apply the ACI 318 guidelines, the total number of reinforcement for slab without opening on both directions must be maintained. Hence, the reinforcement interrupted on the opening must be replaced on each side of the openings (4). Both ACI 318 and BS 8110 share the same idea where all the opening must not be encroach on the column head or drop especially at the edge of column where the shear in the slab is the highest.

This paper study the effect of punching shear on two-way slab with opening using self compacted concrete.

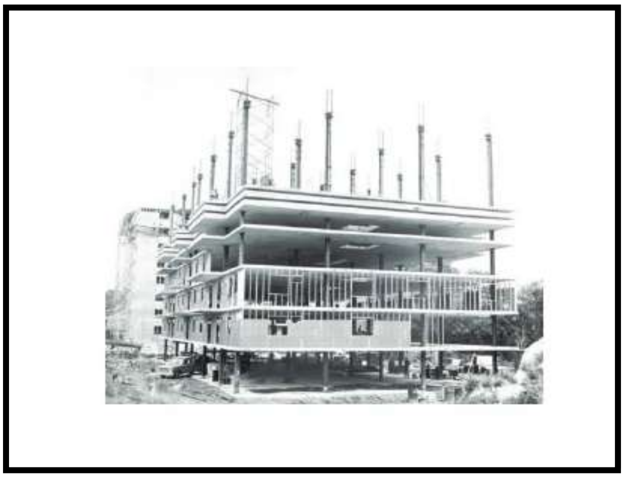

Fig. (1) Lift Slab System (2)

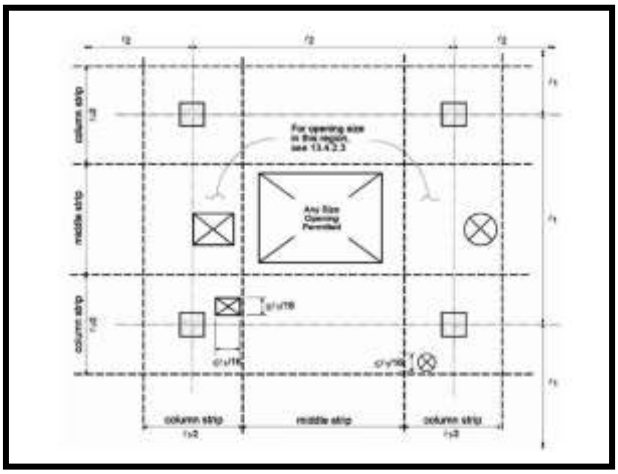

Fig. (2) Suggested Opening Sizes and Locations in Flat Slabs (4)

1.1 The Punching Shear Strength:

One of the major problems in such slabs is the punching shear failure at the connection between the slab and the column. Such type of failure is usually sudden and leads to progressive failure of flat plate structures .Therefore, caution is needed in the design of such slabs and attention should be given to avoid the sudden failure condition (5).

The catastrophic nature of failure exhibited by reinforced concrete flat plates when subjected to concentrated loads has concerned engineers for many years. This localized shear type failure occurs in the immediate vicinity of the load and is usually referred to as a punching shear failure. A failure of this type is undesirable since, for most practical design cases, an overall yield mechanism will not develop before punching. (6)

There are differences in design provisions of punching strength between the two major building codes ACI 318-02(7) and BS 8110 –97(3), since they are based on different empirical formulas. Also, many researches on this problem found many formulas to predict the punching strength. All these differences lead to different predictions of the punching strength of the same specimens.

1.2 Self Compacting Concrete (SCC):

Self compacting concrete (SCC) is distinguished by its special workability. An optimum must be found according to flow ability, self-dearation and homogeneity or stability. The term “self compacting” describes a property of fresh concrete which can be achieved in a variety of ways with different concrete constituent materials and compositions. The nature of the application determines the requisite workability and workability period. It is; therefore, difficult to formulate generally valid specifications for the fresh properties of SCC in the context of technical regulations or to classify them in specific categories or workability classes, as is usually the case with normal concretes. (8)

Concrete that requires little vibration or compaction has been used in Europe since the early 1970s but self-compacting concrete was not developed until the late 1980’s in Japan. In Europe it was probably first used in civil works for transportation networks in Sweden in the mid1990’s. The EC "Testing-SCC project" funded by a multi-national, industry has led project "SCC" 1997-2000 and since then SCC has found increasing use in all European countries. (9)

2-Literature Review:

Mowrer and Vanderbilt (10), investigated the punching shear resistance of slabs. They tested 51 slabs of normal and light weight concrete of which 17 light weight and 8 normal weight slabs which have perforations. On the basis of their tests, they modified Moe’s proposal.

Munahey (11), studied the influence of compressive strength, column size and the amount of flexural reinforcement on the punching shear strength of reinforced concrete 1/2 of scale models of slab-column connection. Twelve slabs of dimensions (850*850*75) mm were loaded concentrically by a square column. The test results indicated that a first crack load and ultimate design punching load increase with the increase in concrete compressive strength or column size, while the increase of strength and column size resulted in decreasing the central deflections of the tested slabs. It was concluded that increasing the size of column or reducing the amount of flexural reinforcement can change the mode of failure from punching to flexural one. Also, the cracks were reduced in number with increasing the amount of flexural reinforcement.

Hong Guan (12), using the numerical analysis of the non-linear Layered Finite Element Method (LFEM) to predict the effect of openings on punching shears failure behavior of slab-column connections with shear stud reinforcement (SSR). All twenty one (21) models are examined through six parametric studies including varying the opening size and location and varying the column aspect ratio. He included in the comparison the empirical predictions recommended by the Standards Association of Australia and the American Concrete Institute. This investigation is an important step towards the determination of the size and location of opening and the size of column for optimum structural performance of flat plate systems.

Chee Khoon, et al (13), studied a simply-supported and fixed-end, square slabs with opening at ultimate limit state using the yield line method. For simply-supported slabs, the analytical study on the ultimate load capacity of the slab shows that the ultimate total load decreases with the size of the opening. However, when the ultimate total load is converted to ultimate area load, the results show otherwise. In the study of fixed-end slabs, the results show that the opening has insignificant effect on the ultimate area load capacity for a small opening size of up to 0.3 times the slab dimension. For opening size of more than 0.5 times the slab dimension, the ultimate area load capacity increases drastically.

O. Enochsson, et, al (14), presented laboratory tests on 11 slabs with openings, loaded with a distributed load together with analytical and numerical evaluations. Six slabs with openings have been strengthened with carbon fiber reinforced polymers (CFRPs) sheets. These slabs are compared with traditionally steel reinforced slabs, both with (four slabs) and without openings (one slab). The slabs are quadratic with a side length of 2.6 m and a thickness of 100 mm. Two different sizes of openings are used, (0.85 * 0.85) m and (1.2 *1.2) m. The results from the tests show that slabs with openings can be strengthened with externally bonded CFRP sheets. The performance is even better than for traditionally steel reinforced slabs. The numerical and analytical evaluations show good agreement with the experimental results.

3-The Experimental Work:

This experimental study consists examining the use of two types of self-compacting concrete slabs. Group (A) consists four slabs were made of self-compacting concrete, one of them without opening and the other three with square opening, while group (B) consists three slabs were made of self-compacting concrete with circular opening. The experiments had been done in the Structural Lab. of the College of Engineering / AL-Mustansiriya University

3-1 Specimens Details:

The dimensions of all the slab specimens were (450 × 450 × 40 mm) (length × width × thickness), the dimensions were selected according to the dimensions of the used test machine. The dimensions of the slab specimens in group (A) are shown in Fig.(3) and the dimensions of the slab specimens in group (B) are shown in Fig.(4). All specimens have a compressive strength of 70(N/mm2) and steel ratio of (0.005), also they are designed to fail in punching.
The slabs were simply supported along the four edges with a clear span of 420 mm for each direction.

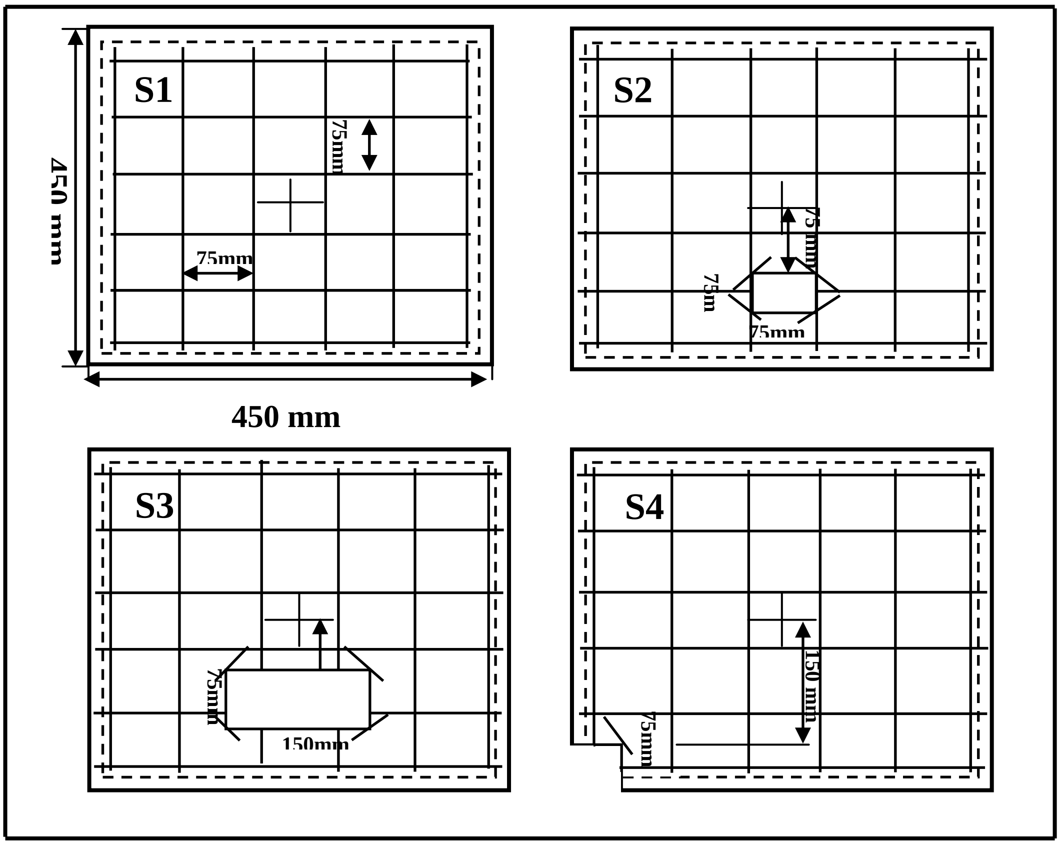

Fig. (3) Dimensions and Reinforcement Details of Slabs in Group (A)

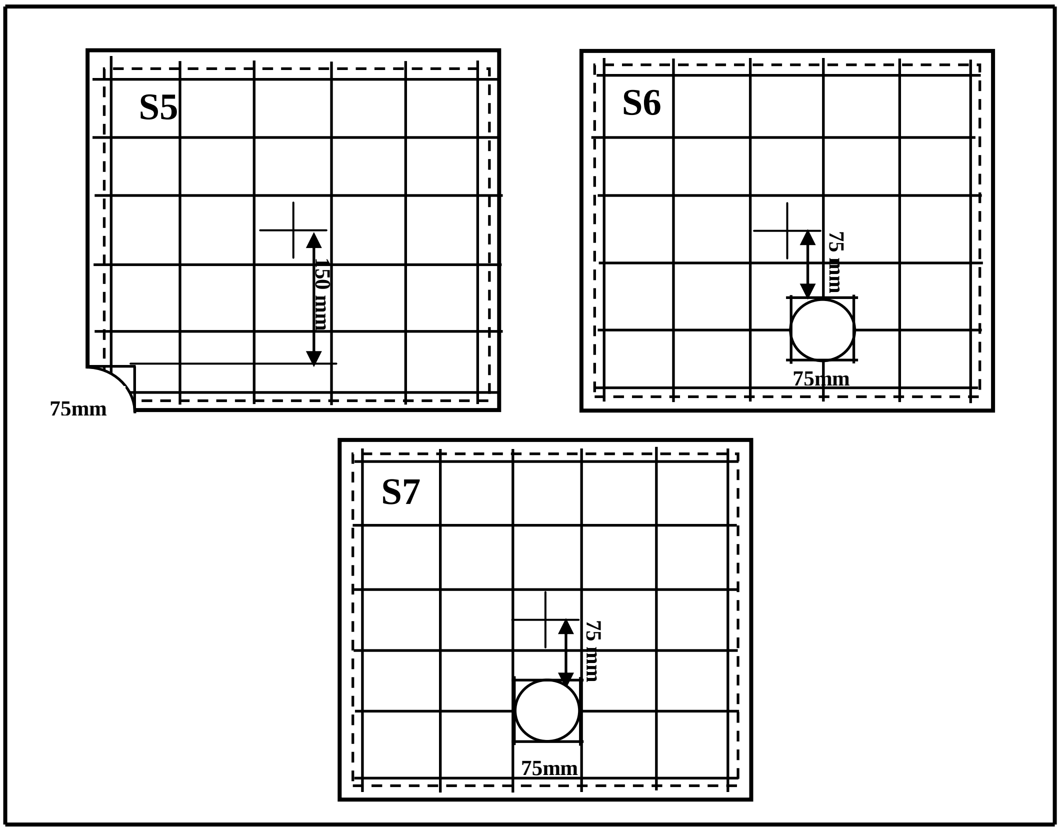

Fig. (4) Dimensions and Reinforcement Details of Slabs in Group (B)

3-2 Materials:

The materials used in the experiments of this study are described as below:

3-2-1 Concrete:

Ordinary Portland cement (type I) according to ASTM C150-89(15) produced in Lebanon was used throughout this study. The coarse aggregate was a 12.5mm maximum size crushed gravel and the fine aggregate was natural river sand with a 2.72 fineness modulus according to the Iraqi standard specification No. 45/ 1984(16). For self compact concrete production, super plasticizer (high range water reducing agent HRWRA) based on poly carboxylic ether is used, and the cement is generally partial replaced by filler limestone powder in order to improve certain properties. Cylinders and prisms for control tests were cast and stored with each slab and then tested at the same time of slab testing. The average results of cylinder strength test 70 (N/mm2). The test was conducted at age of (28) days. Then, one mix was chosen to cast the specimens used in this study. Details of the chosen mixes are shown in Table (1).

Table (1) Mix Proportions

Group	W/C ratio	Mix Proportions					
		Water kg /m3	Cement kg/ m3	Sand kg/ m3	Gravel kg/ m3	Super plasticizer l/m3	Limestone Powder L.S.P kg/ m3
A and B	0.289	155	535	863	784	18	64

3-2-2 Steel Reinforcement:

Plain wires 6 mm in diameter were used as flexural reinforcement placed in the tension face of the slab. The yield strength was determined from tensile test at the Structural Lab. of the College of Engineering / AL-Mustansiriya University, and the average yield strength was 382 N/mm^2. The wires were cut to the desired length, and 90-degree hook is formed at the ends of each bar dimensioned according to sections 7.1 and 7.2 of the ACI 318/02 Building code (7). The wires were uniformly spaced and placed in two directions at 75 mm c/c spacing each way to obtain the desired steel ratios of (0.005). A clear cover of 15 mm was provided for the mesh.

3-3 Specimen Preparation and Testing:

The moulds used for casting the slab specimens were wooden moulds. Each mould consists of a bed and four movable sides. The sides were fixed to the bed by screws. The clear dimensions of the moulds were 450 × 450 × 40 mm. Before placing concrete in the molds, steel wire mesh reinforcement was placed in the bottom face of the panel's mould, as shown in Fig. (5.a)

The opening was made by using two wooden cubes with the size of [75 mm×75 mm×40mm] for S2,S4 , [75 mm×150 mm×40mm] for S3 , and wooden circle with diameter 75 mm for S5,S6,S7, the cubes and circle were fixed in their correct positions using bolts. The bolts can be easily removed to take off the wooden cubes and circles from the mold after casting. The wooden cubes and circles were covered with a paper and wide tape and oiled before casting, to prevent bonding between the wooden cubes or circles and the concrete.

After casting and curing procedure, the slabs will be tested by subjected to concentrated load which are provided by a central column of dimension (30 * 30) mm. The load is applied in increments in this test.

Before testing the specimens, positions of supports, central applied load and dial gauge were marked. The central deflection of the slab specimen was measured at the center of the slab by using a dial gauge of (0.01mm) sensitivity. Fig.(5.b) illustrates the testing setup. The machine which was used in the test of specimens is one of the hydraulic types available in the structural laboratory in the Civil Engineering Department, College of Engineering, Al-Mustansiriya University.

a. Steel Bars & Mould

b.Testing Setup

Fig. (5) Specimen Preparation & Testing Setup

4- Analysis of the Results:

All the slabs of this study are designed to fail in punching, and test results recorded during this test included (first crack, ultimate load and the deflection at ultimate load) are given in Table (2).

Table (2) Load and Deflection Characteristics at First Crack and Ultimate Loads of Slabs

Group	slab	First crack load (F.C.L) (kN)	Ultimate load (U.L) (kN)	$\frac{F.C.L}{U.L}$ (%)	Deflection at ultimate load (mm)	Mode of failure
Group (A)	S1	7.5	36	20.8	5	Punching
	S2	7.5	22	34	2.45	Punching
	S3	7.5	20	37.5	2.2	Punching
	S4	7.5	24	31.3	3	Punching
Group (B)	S5	7	25	28	4.0	Punching
	S6	7	22	31.8	3.8	Punching
	S7	7.5	20	37.5	3.1	Punching

4-1 Load-Deflection Curve:

The load–deflection relationships of slab models, with steel ratio (0.005), for self compacting slabs with opening models, groups A and B respectively are presented in Figs. (6) to (12). Also, load versus deflection relations at the center of the loaded area are recorded for each slab specimen, for each loading increment. Failure loads are measured.

With reference to the below curves, it can be seen that the load-deflection curves at (different size of opening or at most specimens) exhibit three stages each with different slope. The first stage is the elastic or uncracked stage, the second stage is multiple cracking stages; and the third is the plastic stage, which represents the yielding of reinforcement and widening of cracks.

In general, when one sees the Figs. (6 to 12) he notices a decreasing in the ultimate load capacity and the percentage of decreasing becomes about (38.9%,44.4%,33.3%) from the original load (S1) specimen for (S2,S3,S4) specimens, while it becomes about (30.6%,38.9%,44.4%) from original load (S1) specimen for (S5,S6,S7) specimens respectively.

Finally, the comparison between the results for solid slab (S1) and the results for other slab tested with opening of group (A and B) shown in Fig.(13 and 14). From Fig.(13), it can be seen that the slab specimens (S2, S3, and S4) was failed at less load than load which of the solid slab (S1) was failed at, due to exist of openings. From the comparing the behavior of these specimens with the behavior of solid slab, we notice that specimen (S4) is recorded a small different in behavior comparing with the solid slab. This is due to that the effect of edge opening in slab is small comparing with other openings. From Fig.(14), we can see that the load-deflection relations of slab specimens (S5, S6,and S7) are flatter, representing softer load-deflection behavior than the solid slab specimens (S1) and the behavior of slab specimen S5 shows approximate nearly from S1 which more than slap specimens S6 and S7. This can be attributed to both the reduction of modulus of elasticity of concrete and the moment of inertia due to the increase in the amount of cracks.

We notice the results the deflection for specimens in group (B) more than the deflection for specimens in group (A) comparing with specimen (S1). These differences changes obviously with opening (location and size).

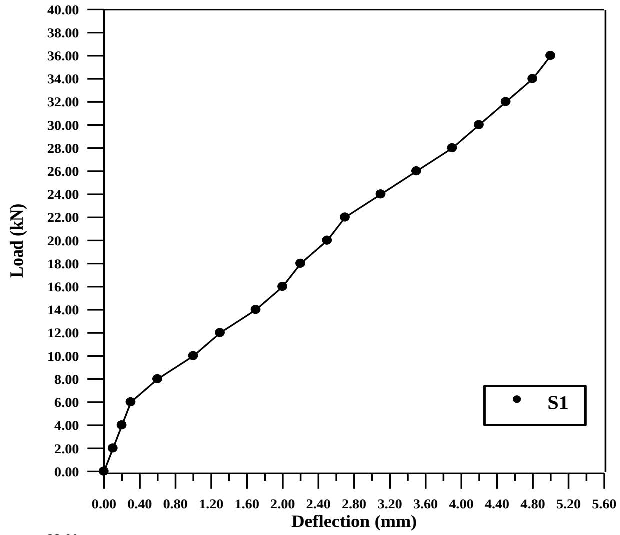

Fig. (6) Load-Deflection Curve of Slab (1)

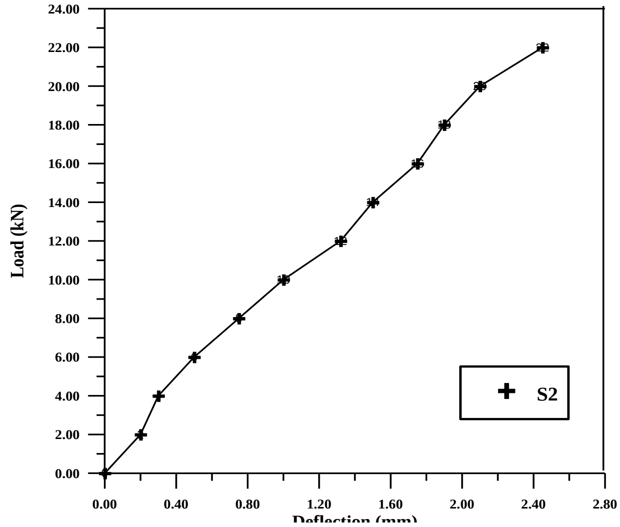

Fig. (7) Load-Deflection Curve of Slab (2)

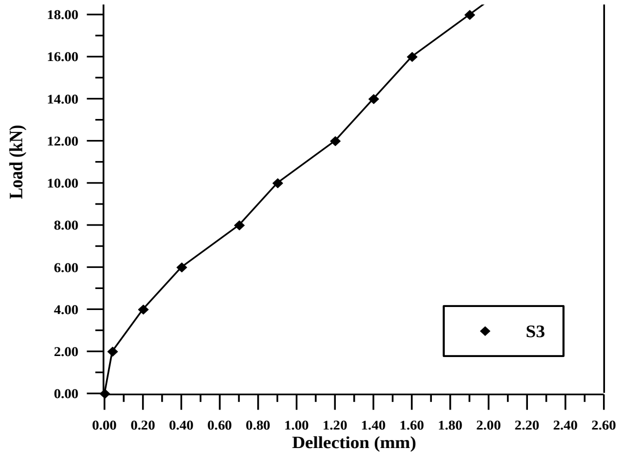

Fig. (8) Load-Deflection Curve of Slab (3)

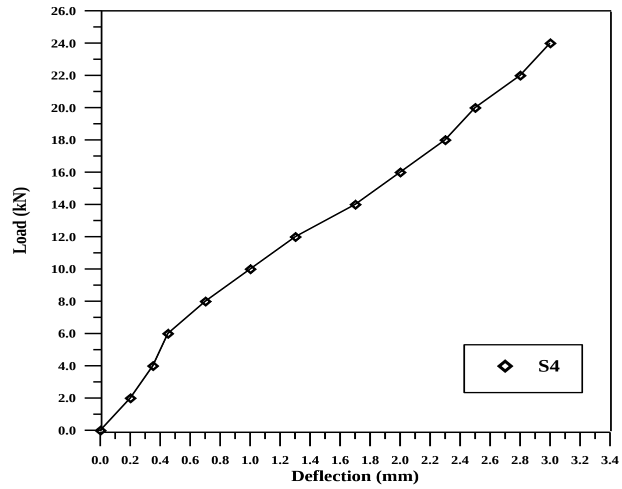

Fig. (9) Load-Deflection Curve of Slab (4)

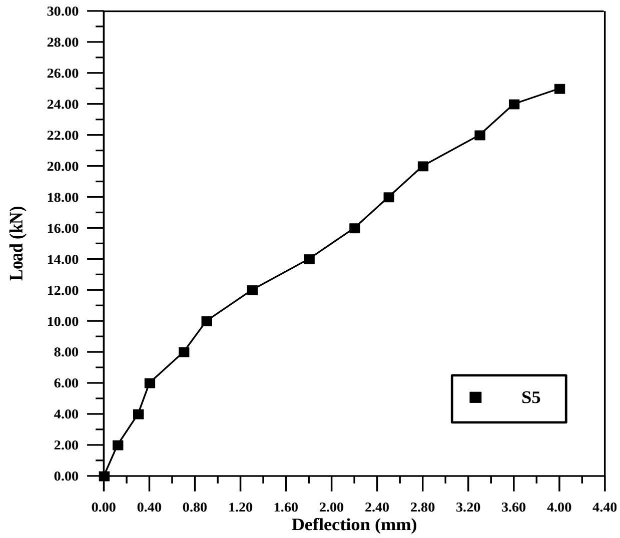

Fig. (10) Load-Deflection Curve of Slab (5)

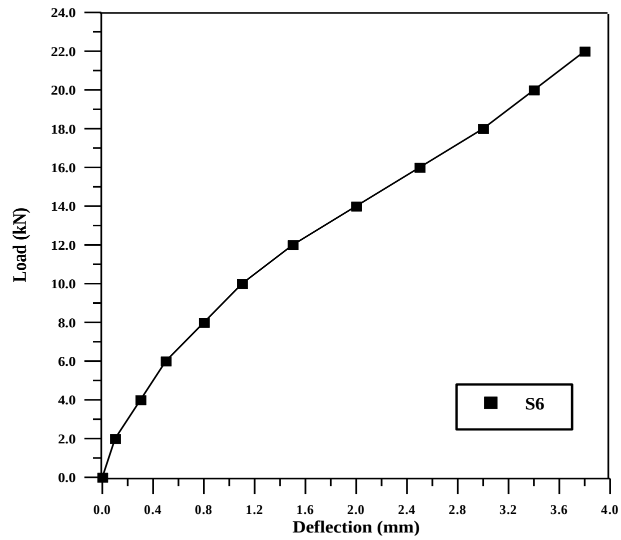

Fig. (11) Load-Deflection Curve of Slab (6)

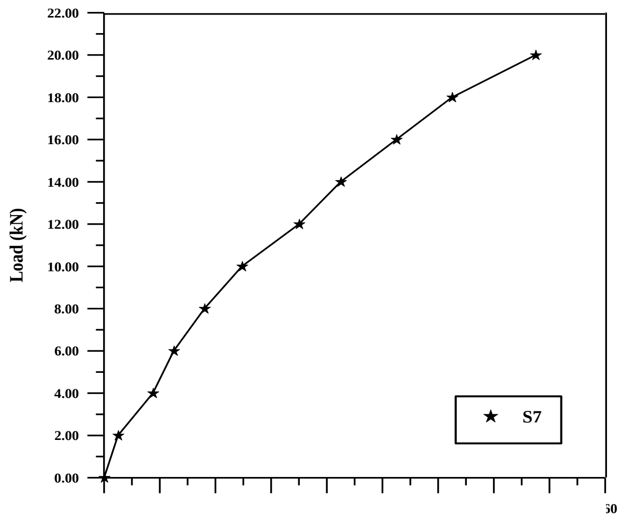

Fig. (12) Load-Deflection Curve of Slab (7)

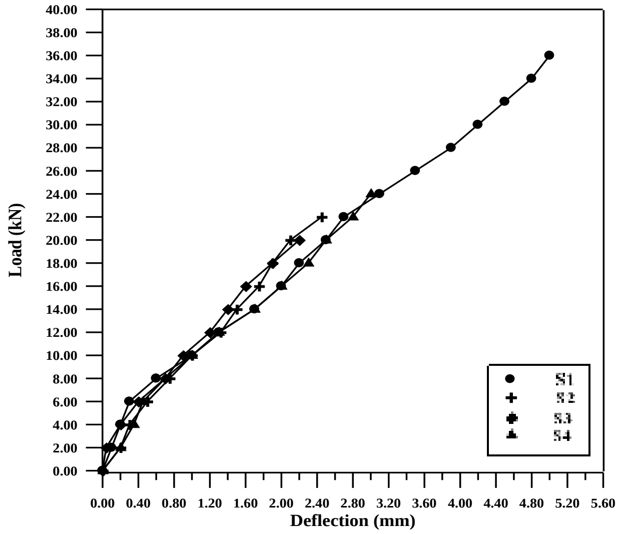

Fig. (13) Load-Deflection Curve of Specimens, S1,S2,S3,S4

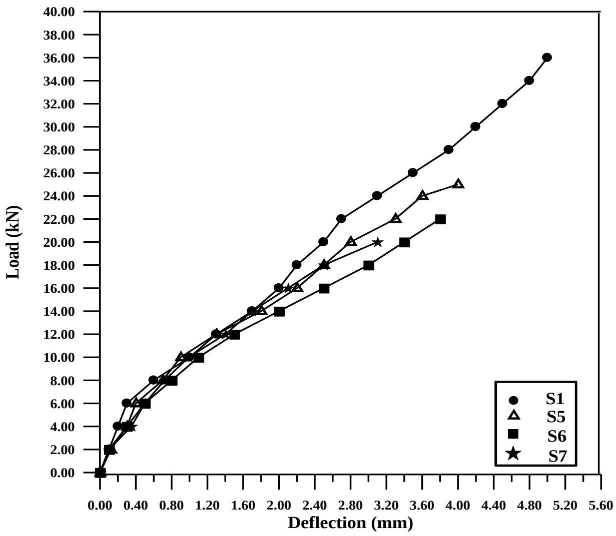

Fig. (14) Load-Deflection Curve of Specimens, S1, S5, S6, S7

4-2 Crack Patterns:

When the load is applied to the reinforced concrete (punching) slab specimens, with steel ratio (0.05), the first crack forms in the tension surface of the slab specimens under the loaded area. As the load is increased, radial cracks in the tension surface start to appear and extend from the perimeter below the loaded area towards the slab specimen edges included the opening cracks noticed inside the opening and also some cracks appeared at the openings edges as a punching perimeter progressed these cracks also depending on the opening type and size, for square openings the small opening have the less cracks and the large opening have the more and wide cracks, while for circle openings the opening at the front of the column have less cracks compare with the edge and side openings.

At the same time, the cracks increase in number at the central region of the slab specimen. Cracking at the supports of the panels is also noticed at this stage. A complete punching shear failure occurs by increasing the load. Figs.(15 to 21) shows the tested slab specimens and their cracking patterns. Fig. (22 and 23) explains the crack patterns within the opening.

Fig.(15) Crack Pattern at Failure for Specimen S1.

Fig.(16) Crack Pattern at Failure for Specimen S2.

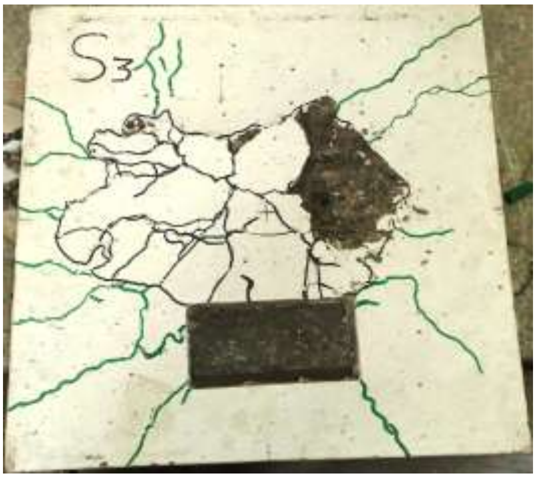

Fig.(17) Crack Pattern at Failure for Specimen S3.

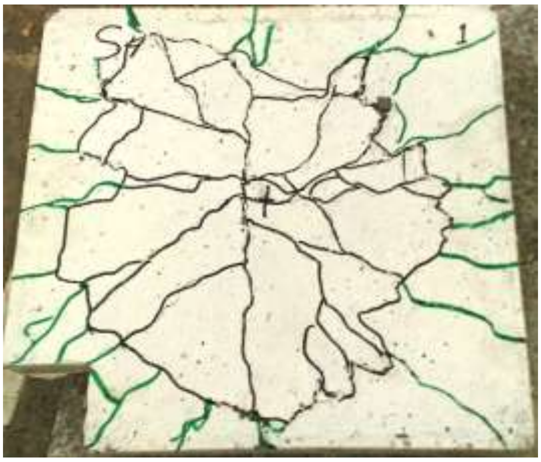

Fig.(18) Crack Pattern at Failure for Specimen S4.

Fig.(19)Crack Pattern at Failure for Specimen S5.

Fig.(20) Crack Pattern at Failure for Specimen S6.

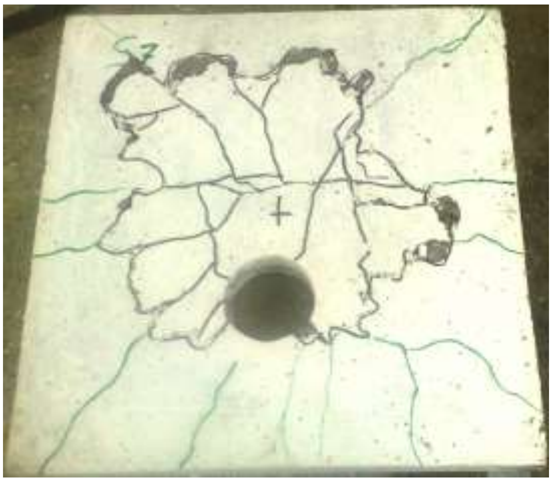

Fig.(21) Crack Pattern at Failure for Specimen S7.

Fig.(22) Crack Pattern at Failure for Specimen S3 within The Opening.

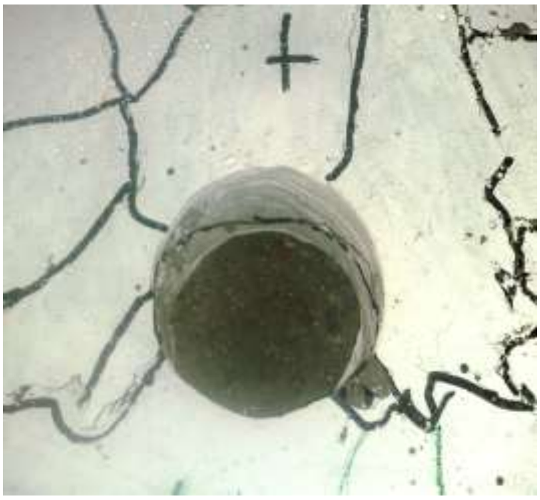

Fig.(23) Crack Pattern at Failure for Specimen S7 within The Opening.

5- Conclusions:

1. The ultimate punching shear strength of the slab with the larger opening is less than that with smaller one and corner square openings represented at the percentages of 55%, 61%, and 67%.
2. The ultimate punching shear strength of the slab with the corner opening and side opening is more than that with front one for circle opening represented at the percentages of 69%, 61%, and 55%.
3. An opening located at the front of the column decreases the punching shear capacity of the connection more than the same size opening located at the side of the column at percentage of 6%.
4. The ultimate load capacity for slab specimens decreases significantly when opening existed as the slabs in group (A and B) exhibit decrease of (38.9%, 44.4%, 33.3%, 30.6%, 38.9%, and 44.4%) from the original load of slab (S1) for (S2, S3, S4, S5,

S6, and S7) specimens respectively. The percentages of reduction depend mainly on the size and location of opening.

5. In the solid slab the punching shear zone is greater than that zone in slab with small opening, while is approximate similar in slab with side and large opening for the square opening. But the punching shear zone in the sold slab is approximating similar to all specimens with circle opening.

6. Cracks at the openings sides appeared at different percentages from the ultimate load according to opening type and this effect on the reduction in ultimate load and increase the deflection.

References:

1. Koh Heng Boon, Abu Bakar Mohamad Diah, Lee Yee Loon," Flexural Behavior of Reinforced Concrete Slab with Opening", Malaysian Technical Universities Conference on Engineering and Technology ,June 20-22, 2009, MS Garden, Kuantan, Pahang, Malaysia
2. Piotr Rusinowski, "Two-Way Concrete Slabs with Openings, Experiments, Finite Element Analysis and Design", M.Sc. Thesis, College of Engineering, Luleå University of Technology, 2005.
3. British Standards Institution BS 8110: Part1:1997, London, "Code of Practice for Design and Construction".
4. Basile G. Rabbat and Mahmoud E. Kamara (2005). "Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (ACI 318R-05): Building Code Requirements for Structural Concrete and Commentary." US: ACI Publication. Section 13.4.2.
5. Long, A.E. "Punching Failure of Slabs, Transfer of Moment and Shear" Journal of the Structural Division, St.4, April, 1973, pp. 665-685.
6. Marzouk, H.; and Hussein, A., "Experimental Investigation on the Behavior of High-Strength Concrete Slabs ", ACI Structural Journal, Vol.88, No.6, Nov-Dec 1991, pp.701-713.
7. ACI Code (318-2002),"Building Code Requirements for Reinforced Concrete", American Concrete Institute, Detroit, Mich.2002.
8. Kordts, Stefan and Breit, Wolfgang," Assessment of Fresh Concrete Properties of Self Compacting Concrete", FTB (Ready-mixed Concrete Research Association), 2004,pp. 113-124 (Internet)
9. "The European Guidelines for Self-Compacting Concrete Specification Production and Use, May 2005, www.efca.info.or. www.efnarc.org, p (68).
10. Mowrer, R.D.; and Vanderbilt, M.D.,"Shear Strength of Lightweight Aggregate Reinforced Concrete Flat Plates", Journal of the American Concrete Institute, Vol.64, Nov. 1967, pp.722-729.
11. Munahey, A.A., "Punching Shear in Reinforced Concrete Flat Plates Made with ABU- GHAR Limestone", M.Sc. Thesis, College of Engineering , University of Basrah, Iraq, 1995. p. (97).
12. Hong Guan," Prediction of Punching Shear Failure Behavior of Slab-Edge Column Connections with Varying Opening and Column Parameters " , Journal of the Advances in Structural Engineering, Vol. 12, No. 1 , February, 2009, pp. 19-36.
13. Chee Khoon Ng, Timothy Julius Edward, and Daniel Kim Tee Lee," Theoretical Evaluation on Effects of Opening on Ultimate Load-carrying Capacity of Square Slabs", Electronic Journal of Structural Engineering, Vol. (8), 2008, pp.12-19.
14. Ola Enochsson , Joakim Lundqvist , Bjo¨rn Ta¨ljsten ,Piotr Rusinowski ,and Thomas Olofsson , " CFRP strengthened openings in two-way concrete slabs –An experimental and numerical study", Construction and Building Materials Journal, Vol. 21, 2007, pp.810-826.
15. ASTM C150-1989, "Standard Specification for Portland cement", "Annual Book of ASTM Standards, Vol.04.02, 1989, p (4).
16. المواصفة القياسية العراقية رقم (45) ,"ركام المصادر الطبيعية المستعملة في الخرسانة و البناء" , الجهاز المركزي للتقييس و السيطرة النوعية , بغداد,1984, 13 صفحة.