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Effect of Separation Distance between the Columns on Punching Pattern for Flat Plates with High Strength Concrete

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Abstract

When a reinforced concrete slab is supported by coupled columns, these columns may behave as one column or as separated two columns according to the separation distance between them. Therefore, this study investigates the effect of separation distance of the columns on punching pattern for flat plates with high strength concrete and compares their results with other results of flat plates with normal strength concrete. Eight reinforced concrete slab specimens with coupled columns are cast with dimensions (length, width and thickness) equal to (850,470 and 50mm) by using a single high strength concrete mix with average compressive strength ($f`_c$) that equals (55MPa) supported by coupled circular cross-section columns (diameter=85mm), these columns are located at the centerline of the slab in long direction; while in the short direction ,the positions of the columns are variable with respect to the centerline of the slab. However, the problem remains symmetric about the two axes.

The specimens are tested over a simply supported span at four edges. The variable of this study is the clear distance between columns which takes the values (0.05 ,0.5 ,1 ,1.5 ,3 ,5 ,7 and 9)d ,where d is the effective depth. The test results show that ,the ultimate load reaches the maximum value when the clear distance between columns equals 9d and decreases by about (17.3 to 44.5) % of the maximum ultimate load when the clear distance between columns decreases from 7d to 0.05d .Also it is noticed that when the clear distance between columns is in the range (0.05d to 7d) ,the failure zone behaves as one zone; while when the clear distance between columns is equal to 9d , the failure zone separates into two zones. When the test results are compared with other results of flat plates with normal strength concrete($f`_c$=24MPa),it is concluded that ;when the concrete compressive strength factor ($\sqrt{f`_c}$)is increased by about 50% ($f`_c$ is increased from 24 to 55MPa),the ultimate loads increase by (16,17.5,20.7,21.4,31.67,31.74 and 32.84) % for the specimens from 0.05d to 9d respectively. So this study investigates the effect of separation distance of the columns on punching pattern for flat plates with high strength concrete.

KEY WORDS: punching shear, flat plate, coupled columns, high strength concrete.

الخلاصـــــــة

عندما يكون السقف الخرساني المسلح مسند بواسطة عمودين متقاربين ,فان هذين العمودين إما أن يتصرفان كعمود واحد أو كعمودين منفصلين حسب المسافة الفاصلة بينهما . لذلك فان هذه الدر اسه تبحث تأثير مسافة الفصل ما بين الاعمده على نمط الفشل لبلاطات مسطحه ذات خرسانه عاليه ألمقاومه و مقارنتة مع بلاطات ذات خرسانة اعتيادية ألمقاومه . تتضمن الدر اسه صب ثمانية نماذج من البلاطات الخرسانية المسلحة بأبعاد (الطول , العرض والسمك) مساوية إلى(470,850و50)ملم بخرسانة ذات مقاومه تساوي 55ميغا باسكال مسنده بواسطة عمودين متقاربين مقطعهما دائري قطره يساوي 85ملم , هذين العمودين يقعان على الخط المحوري للسقف بالاتجاه الطويل , بينما بالاتجاه القصير فان موقع العمودين يكون متغير بالنسبة للخط المحوري للسقف مع الاحتفاظ بالتناظر حول المحورين. تم فحص النماذج على فضاء بسيط الإسناد من إضلاعه الأربعة. المتغير لهذه الدراسة هو المسافة ألصافيه بين العمودين والتي أخذت القيم التالية (9,7,5,3,1.5,1,0.5,0.05) من العمق الفعال .

بينت نتائج الفحوصات أن حمل الفشل وصل إلى أعلى قيمة عندما أصبحت المسافة بين الأعمدة مساوية إلى 9d وتتناقص هذه القيمة بنسبة تتراوح بين (44.5-17.3)% من أقصى حمل للفشل عندما تناقصت المسافة بين الأعمدة من 7d إلى 0.05d. كذلك لوحظ انه عندما تكون المسافة الصافية بين الأعمدة بحدود 0.05 d إلى 7d فأن منطقة الفشل تنفصل عن البلاطة كجزء واحد، لكن عندما تكون المسافة الصافية ما بين الأعمدة تساوي 9d فأن عندما تم مقارنة نتائج هذا الفحص مع نتائج أخرى لبلاطات مسلحه ذات خرسانه اعتيادية المقاومة فقد تم استنتاج أن معامل مقاومة الانضغاط ($\sqrt{f`_c}$ ) عندما يزداد بنسبة حوالي 50% (أي عندما تزداد $f`_c$ من 24 إلى 55 ميغا باسكال) فان تحمل ألبلاطه يزداد بنسب (16.2, 17.54, 20.76, 21.37, 31.67, 31.75, 32.85, 34.15)% للنماذج من d 0.05 إلى 9d على التوالي.

Notations

D = Effective depth of slab;

$f`_c$= Ultimate cylinder compressive strength;

f_y = Yield tensile strength;

f_u= Ultimate tensile strength;

X= Clear Distance between columns;

ϕ = Diameter of reinforced bars, mm.

1- Introduction

A reinforced concrete flat plate system is a widely used structures .Its formwork is very simple as no beams, drop panels or column capitals are used .One of the major problems in such system is the punching shear failure at the connection between the slab and the column .The production of high strength concrete is one of the main developments in the concrete technology that have made major impacts on structural systems. Husain (1) studied the punching shear strength of flat plates with high strength concrete supported by single column. She found that the punching shear strength increases by about 17% when concrete compressive strength increases by about 11.6% (104.8-117.0 MPa).

Nobari and Ejlaly (2) studied the punching shear resistance of high strength concrete slabs. The experimental results from four researches show that the punching shear strength is assumed to be proportional to $\sqrt{f`_c}$ up to 100MPa.

In some cases of flat plate structures, the slab has two or more convergent columns. The purpose of this state is either for architectural design or for structural requirements such as when the foundation has two convergent piles and when combined foundation supports two columns separated by expansion joint. The punching shear behavior of the convergent columns may be either as one column or as separated columns, this is unknown .Al-Hafiz (3) studied the punching shear strength of flat plates with normal strength concrete supported by double columns. He found that when the clear distance between columns is 0.05d, the ultimate load is 52.5 MPa and this load reaches 82 MPa when the clear distance between columns equals 9d . This study investigates the effect of separation distance of the columns on punching pattern for flat plates with high strength concrete.

2-Experimental Work

2-1 Experimental Program

The test program consists of fabricating and testing of eight reinforced concrete slabs with coupled columns using concrete mix with average cylinder compressive strength ($f`_c$) equal to (55 MPa). All slab specimens have the same dimensions (length, width and thickness) equal to (850, 470 and 50mm) and concrete cover of (15 mm); see Figures 1 and 2. The variable investigated in this study is the distance between columns in the slab specimen. Deformed welded wire fabric mesh (WWF) with (6mm) diameter and (75mm) c/c spacing each way are used as flexural reinforcement placed in tension faces. The average yield strength (f_y) of deformed wires is (438MPa), Table 1 shows the detail of the distance between columns.

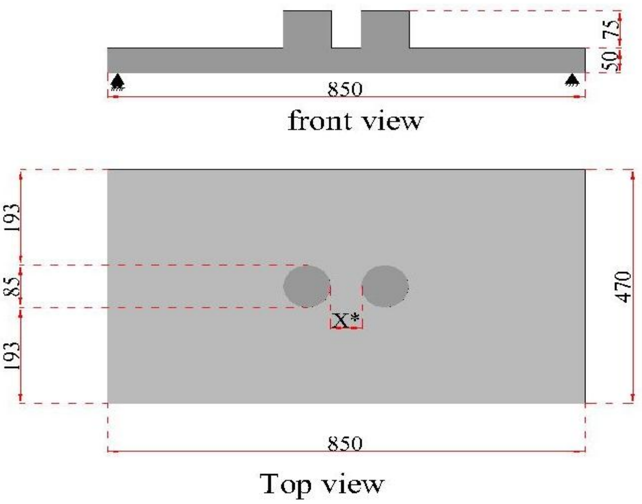

Fig. 1: Details of Slab dimensions

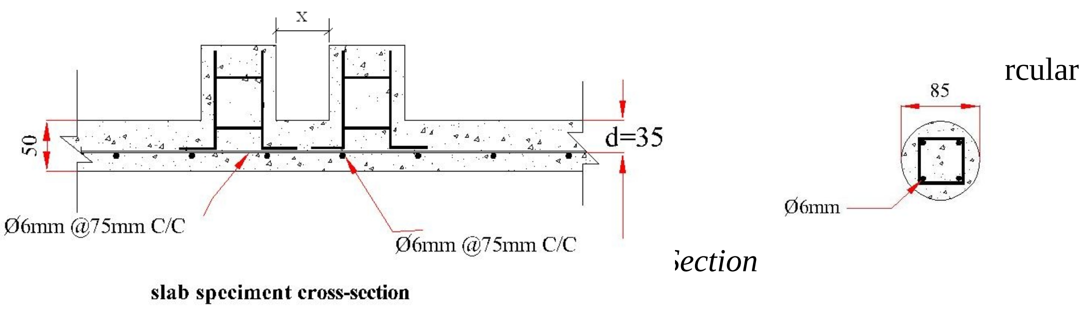

Fig. 2: Details of Specimens Cross-Section

Table 1: Dimension Details of Tested Slabs

Slab Designation	Column size (mm)	Cross-sectional area of column $(mm)^2$	Clear Distance between columns	
			X (mm)	X/d
S1			2	0.05
S2			18	0.5
S3			35	1
S4	Diameter=85	5674	53	1.5
S5	Height=75		105	3
S6			175	5
S7			245	7
S8			315	9

2-2 Materials

The properties and description of materials used in manufacturing the test specimens are reported and presented in Table 2; and the concrete mix proportions are reported and presented in Table 3.

Table 2: Description of Construction Materials

Material	Descriptions
Cement	Ordinary Portland Cement (Type I)
Sand	Natural sand from Al-Ukhaider region with maximum size of (4.75mm).
Gravel	Crushed gravel with maximum size of (10mm) from Al-Nibaee area.
Reinforcing Bars	Deformed welded wire fabric mesh (WWF) with (6mm) diameter and (75mm) c/c spacing each way are used as flexural reinforcement placed in tension faces. The average yield strength (f_y) is (438MPa) and the average ultimate strength (f_u) is (580MPa).
Water	Tap water.
Superplasticizer	Glenium 51

Table 3: Mix Proportions by Weight

Mix proportions	W/C ratio	Water (L/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	s.p% by weight of cement
1:1.5:2	0.31	155	500	750	1000	2

2-3 Test Measurement and Instrumentation

Hydraulic universal testing machine (MFL system) is used to test the specimens as well as control specimens. Central deflection has been measured by means of (0.01mm) accuracy dial gauge (ELE type) and (30mm) capacity. The dial gauges are placed underneath the bottom face of each span at midspan, see Fig. 3.

Fig. 3: Test Instrumentations

2-4 Mixing, Casting, Compacting and Curing Procedure

The mixing procedure is as follows:-

1. Before mixing, all quantities are weighed and packed in clean containers.
2. Saturated surface dry crushed gravel and dry sand are added to the rotary drum mixer of (0.18m^3) volume capacity and mixed for several minutes.
3. The cement is then added to the mixer, and 1/3 water is added gradually to the mix.2/3 of water is finally admixed with the superplasticizer and added to the mix. The total mixing time is (8-10 minutes).
4. The moulds are coated with oil before putting the reinforcing bar, or casting the control specimens.
5. Before placing the concrete in the mould, steel reinforcement is placed in the mould and the specimen is cast in two layers. Then, the column is cast continuously (monolithically) with the slab. Specimens are compacted by a table vibrator with a compaction time (2 minutes) for each layer. Some of these steps are explained in Fig. 4.

After casting, the slab specimens and control specimens are covered with polythene sheets and after (24 hours) they are stripped of the moulds and placed in water for other (27days) and then tested.

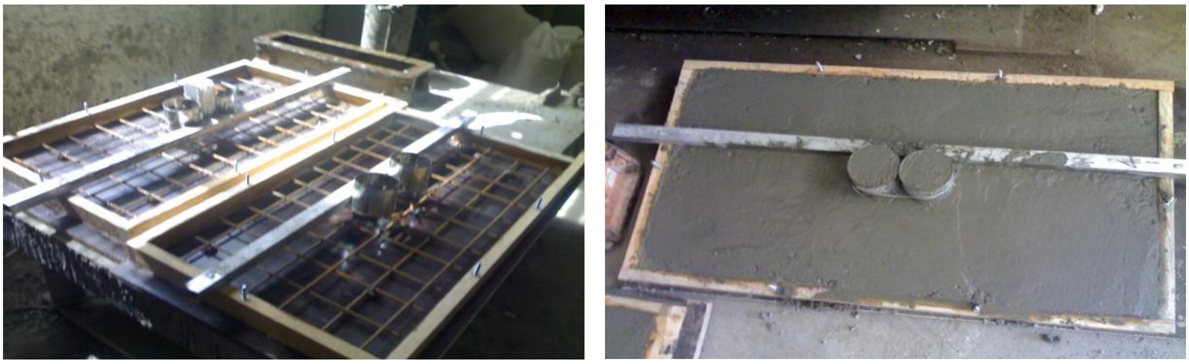

Fig.4: Casting Procedure

3- Results and Discussion

3-1 General

In this study, (8) slab specimens are tested. These slabs are identical in size and ratio of steel reinforcement, but different in the clear distance between columns in the slab specimen. According to this variable, ultimate loads, crack patterns as well as shapes of failure are different from each other.

3-2 Crack Pattern

The test results of cracking and ultimate loads are reported and presented in Table 4. When the load is applied to these slab specimens, the first crack is formed at about (8.18-12.3) % of the ultimate load for the slab specimens. At ultimate load, punching shear failure occurs suddenly for all specimens

The first crack appears around the sides of the column on the tension face of the slab and other cracks form at the central region of the slab. By increasing the load, these cracks widen and increase in number. At ultimate load, punching shear failure occurs suddenly for all slabs. Fig. 5 illustrates crack patterns and failure modes of specimens.

Also, it is observed that, the flexural cracks do not appear in the tensile face of these slabs. This may be due to the effect of the high effective depth, high strength concrete and the steel reinforcement in improving ductility, flexural strength and punching shear resistance of concrete slabs. This may be attributed to the fact that, for high reinforcement ratios, a brittle punching failure can occur, and yield lines can form, but these do not necessarily occur, Park and Gamble(4).

From Fig. 5 it is evident that the capillary cracks appear in the tensile face of the slabs when the moment generated from the applied load reaches to the crack moment

Table 4: First Crack and Ultimate Loads of Slabs

Slab	Clear distance between columns		f'_c (MPa)	First crack load (P_{cr}) (kN)	Ultimate Load (P_u) (kN)	$\frac{Pcr}{Pu}$ (%)
	(X) mm	X/d				
S1	2	0.05	53.5	7.5	61	12.30
S2	18	0.5	53.5	6	67	8.96
S3	35	1	53.5	8	70	11.43
S4	53	1.5	53.5	7	71	9.86
S5	105	3	54.2	7.5	79	9.49
S6	175	5	54.2	8.5	83	10.24
S7	245	7	54.2	8.5	91	9.34
S8	315	9	54.2	9	110	8.18

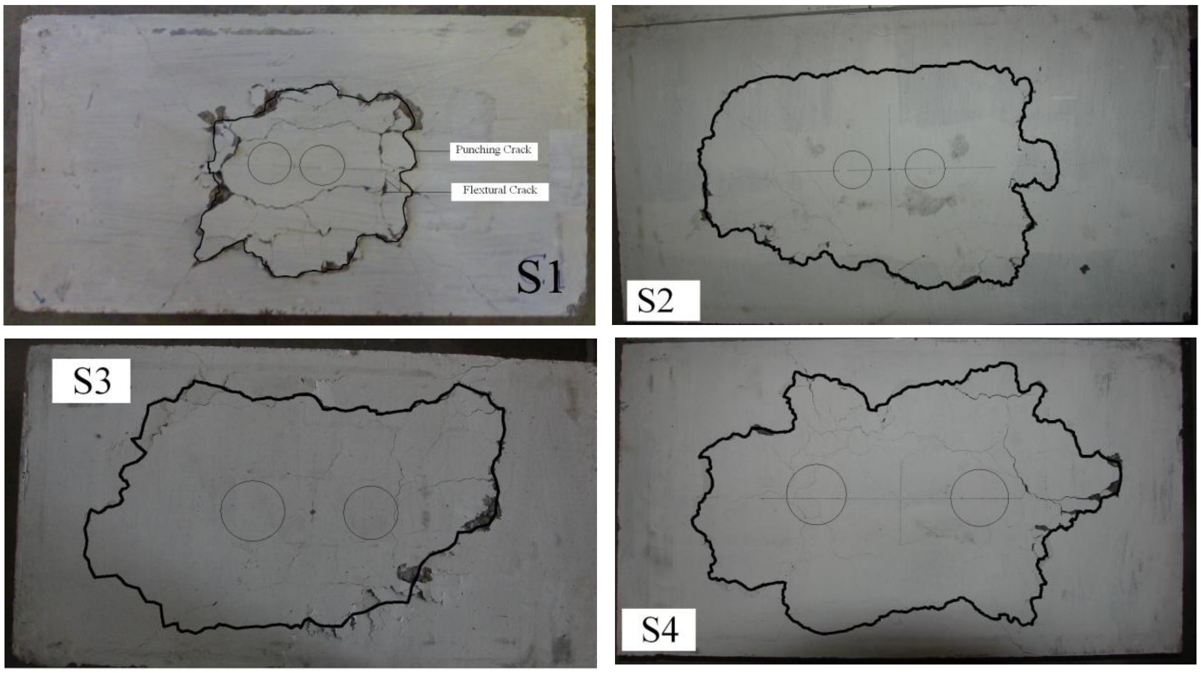

Fig. 5: Crack Patterns at a Bottom Face of Slabs at failure stage.

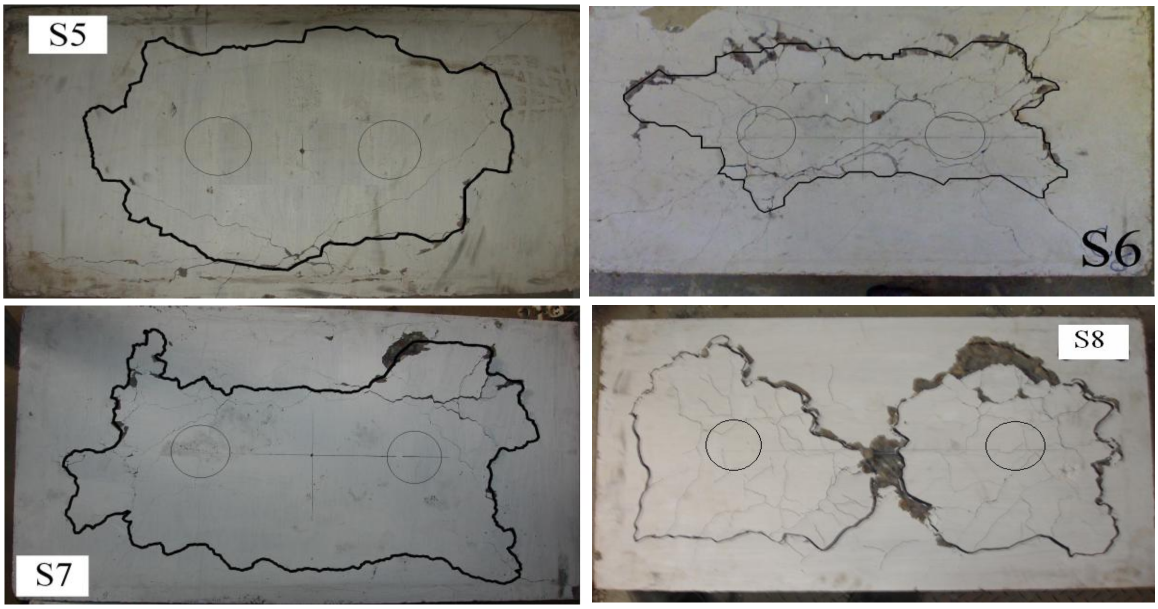

Fig. 5: Continued

3-3 Load-Deflection Behavior

The deflection results of all specimens are illustrated in Table 5. The test results show that, the maximum deflection at ultimate load occurs when the clear distance between columns is equal to (9d)(slab S8), and the deflection at the ultimate load decreases when the distance between columns is decreased. This is due to the fact that the maximum (failure or ultimate) load increases as the distance between columns is increased. Fig. 6 and Fig.7 show the load-deflection relationships of the slabs.

Table 5: Load and Deflection Characteristics at First Crack and at Ultimate Loads

Slab	Deflection at first crack (mm)		Deflection at ultimate load (mm)	
	Under right column	Under left column	Under right column	Under left column
S1	0.94	0.95	12.20	12.15
S2	1.85	1.92	17.00	16.15
S3	1.39	1.31	13.50	12.70
S4	0.64	0.60	14.10	14.00
S5	1.05	1.18	19.10	19.00
S6	1.22	1.40	22.30	22.60
S7	2.30	2.07	23.00	22.90
S8	2.20	1.80	25.90	25.84

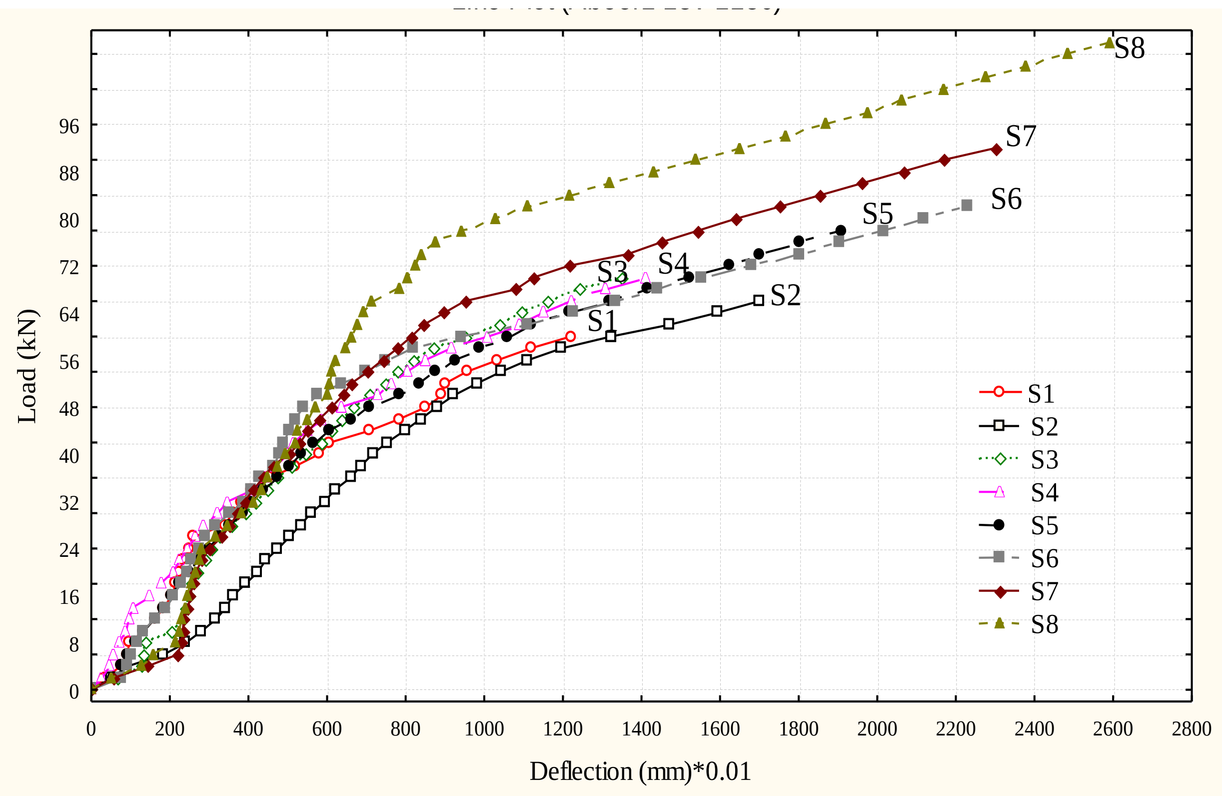

Fig. 6-a: Load-Deflection Relationships for all slabs (right columns).

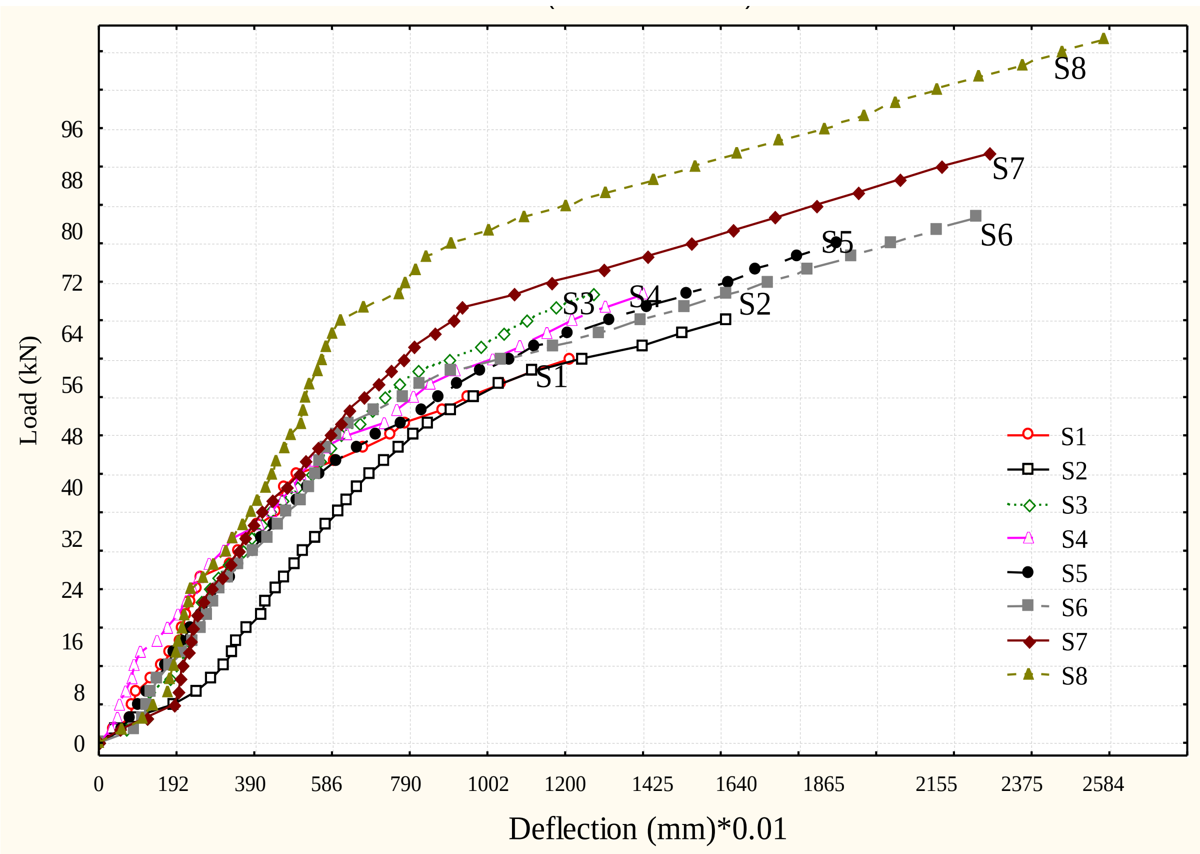

Fig. 6-b: Load-Deflection Relationships for all slabs (left columns).

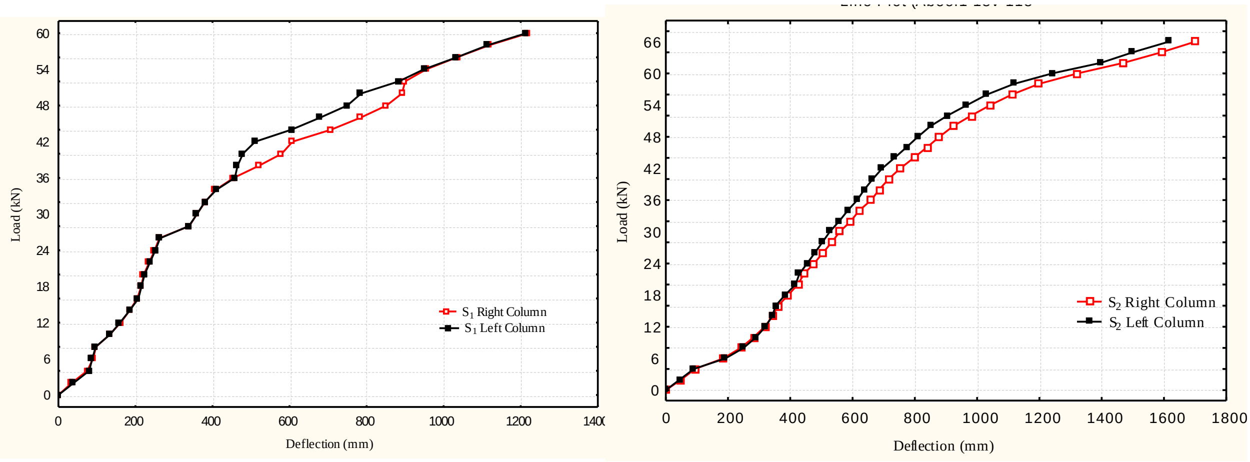

Fig.6: Load-Deflection Relationships for each slab. Deflection (mm)*0.01

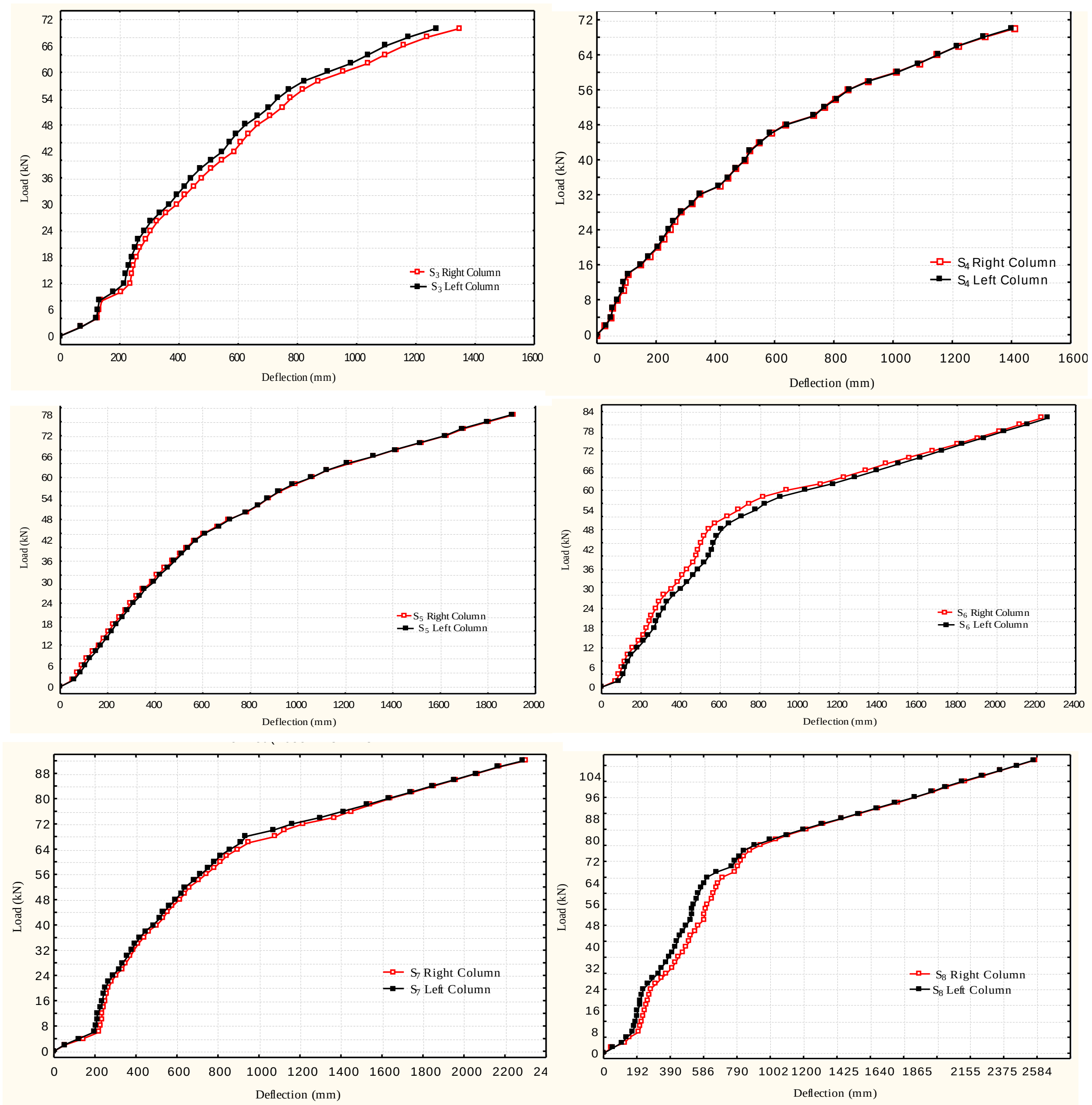

Fig.6: Continued. Deflection (mm)*0.01

3-4 Ultimate Loads

Ultimate load capacity for punching failure is illustrated in Table 4.The test results show that:-

1. The ultimate load of the maximum value occurs when the distance between columns is equal to (9d).
2. The maximum ultimate load is reached when separation of failure zone occurs.
3. The ultimate load of slabs decreases by about (17.3 to 44.5) % of the maximum ultimate load when the clear distance between columns varies between 7d and 0.05d as shown in Fig.7.

If a comparison is made between these test results and Al-Hafiz [(3)] test results of specimens with normal strength concrete ($f`_c$ =24 MPa),it is concluded that ;when the concrete compressive strength factor ($\sqrt{f`_c}$) (ACI-318 Code 2008)[(5)] is increased by about 50% ($f`_c$ is increased from 24 to 55MPa),the ultimate loads increase by (16,17.5,20.7,21.4,31.67,31.74 and 32.84) % for the specimens from 0.05d to 9d respectively, Fig. 7 explained this comparison

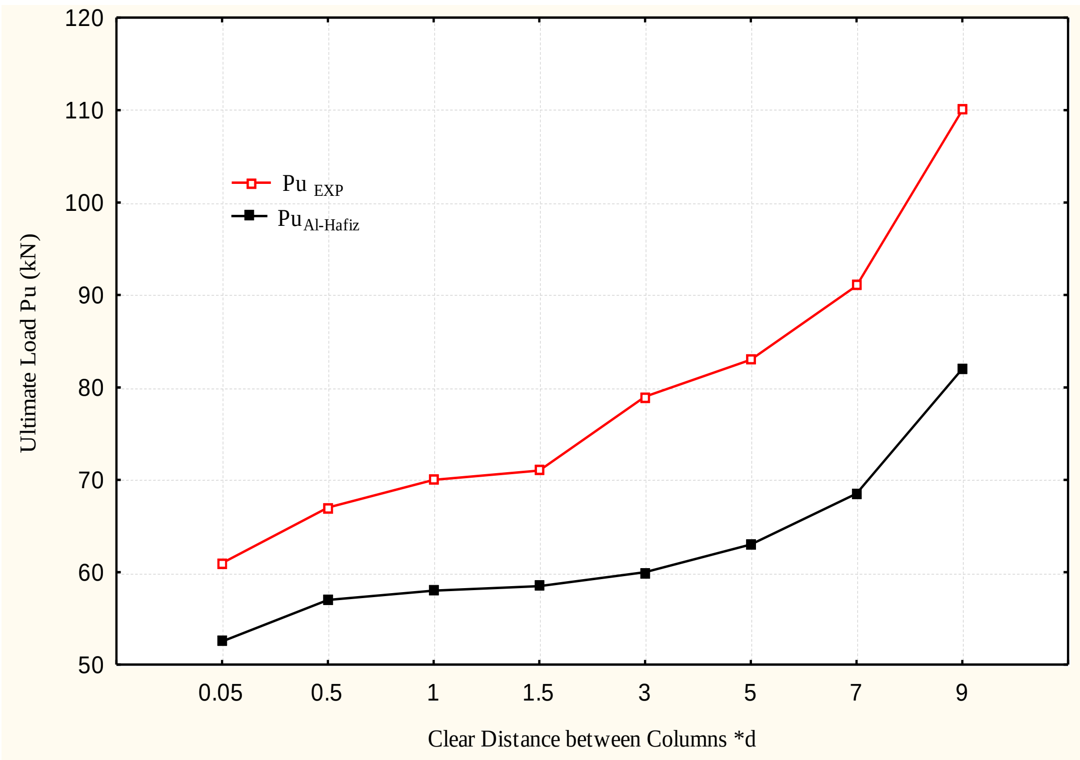

Fig.7: Ultimate Load-Clear Distance between Columns Relationship

3-5 Area of Failure Zone

The areas and perimeters of the punching failure zones are measured and their values are illustrated in Table (6). The failure zone separates into two zones under columns when the clear distance between columns equals to (9d), i.e. at slab (S8).

Also Table 6 gives comparisons between the present results and Al-Hafiz [3] results. From this comparison, it is concluded that; when the compressive strength factor ($\sqrt{f`_c}$) is increased by about 50%, the areas of punching failure zone decrease by about (45, 48, 38, 38, 46, 45, 45 and 19) % respectively.

Table 6: Area and Perimeter of the Failure Zone

Present results			Al-Hafiz results		
Slab	Measured area (mm^2)	Measured perimeter (mm)	Slab	Measured area (mm^2)	Measured perimeter (mm)
S1	72063	1258	S1	130889	1596
S2	96065	1403	S2	185876	2047
S3	120265	1309	S3	195294	1911
S4	123073	1635	S4	199163	2131
S5	128125	1316	S5	237136	2316
S6	129709	1934	S6	249495	2391
S7	140168	2085	S7	255220	2412
S8	81441	1368	S8	105494	1484
	76574	1455		89525	1283

3-6 Comparison between Experimental Results and the ACI-318M Code (2008) [5]

Many codes and researchers have presented different formulae for predicting punching shear strength of slabs based on their understanding of punching behavior, the ACI-318M Code (2008) is considered in this study and compared with its results. Punching strength is predicted by considering the nominal shear stress, the control perimeter (b_o) and the effective depth (d) but the clear distance between columns is neglected; see table 7 and Fig. 8.

Table 7: Punching Shear strength of Slabs

slab	$(P_u)_{EXP}$ (kN)	$f`_c$ (MPa)	$b_\circ$ (mm)	v_u (kN) using ACI Code $v_u=\frac{1}{3}\sqrt{f`_c}\,b_\circ\,d$
S1	61	53.5	891	76
S2	67	53.5	923	78.8
S3	70	53.5	957	81.6
S4	71	53.5	993	84.7
S5	79	54.2	1097	94.2
S6	83	54.2	1237	106.2
S7	91	54.2	1377	118.3
S8	110	54.2	754	129.6

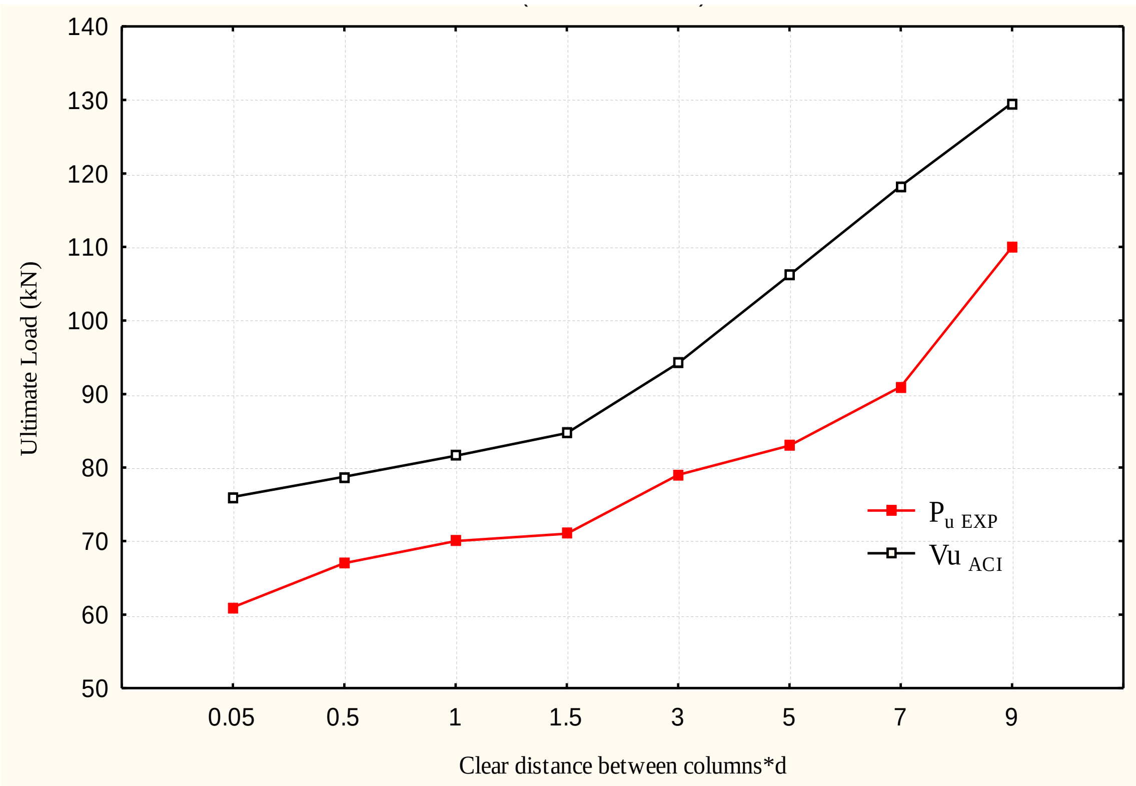

Fig. 8: Ultimate Load-Clear Distance between Columns Relationship

From Fig. (8) It is evident that the punching shear strengths computed by ACI-318M Code (2008) [(5)] are greater than experimental results because the code does not consider the effect of double columns in its equation.

4-Conclusions

Depending on the test results of this study, the following conclusions are obtained:-

1. The first crack is formed at about (8.18-12.3) % of the ultimate load for the slab specimens. At ultimate load, punching shear failure occurs suddenly for all specimens.
2. The ultimate load varies linearly with the distance between columns, and has maximum values at the distance equal to (9d).
3. The maximum ultimate load is reached when separation of failure zone occurs.
4. The ultimate load decreases by about (17.3 to 44.5) % of the maximum ultimate load when the clear distance between columns decreases from 7d to 0.05d.
5. The failure zone separates into two zones under columns when the clear distance between columns is equal to (9d).
6. The increase in concrete compressive strength factor ($\sqrt{f`_c}$) by about 50% causes increase in the ultimate loads by (16, 17.5, 20.7, 21.4, 31.67, 31.74 and 32.84) % for varying distance between columns from 0.05d to 9d respectively.
7. The increase in concrete compressive strength factor ($\sqrt{f`_c}$) by about 50% causes decrease in the area of failure zone by about (45, 48, 38, 38, 46, 45, 45 and 19) % for varying distance between columns from 0.05d to 9d respectively.

6-References

1. Husain, L.F.,” Punching Shear and Flexural Strengths of Fibrous Modified Reactive Powder Concrete Flat Plates “M.Sc. Thesis, Civil Engineering Department, Al-Mustansiriya University, January-2008.

2. Nobari, H., and Ejlaly, R., "Punching Shear Resistance of High Strength Concrete Slabs ", Asian Journal of Civil Engineering (Building and Housing), V.4, No.1, 2003.

3. Al-Hafiz,A.M., " Experimental Study of Punching Shear for Reinforce Concrete Flat Plates With Coupled Columns" M.Sc. Thesis, Civil Engineering Department, Al-Mustansiriya University, January-2009.

4. Park, R. and Gamble, W.L.,"Reinforced Concrete Slabs", John Wiley and Sons, Inc, 1980.

5. ACI Code (318M-08), "Building Code Requirements for Structural Concrete", ACI, Detroit, March, 2008.