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PUNCHING SHEAR AND FLEXURAL STRENGTHS OF SELF COMPACTED CONCRETE NON-RECTANGULAR SHAPED FLAT PLATE SLABS

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ABSTRACT :- This study is conducted to investigate experimentally the punching shear and flexural strengths of reinforced concrete flat plate slabs made with Non-Rectangular (triangular and trapezoidal) shaped. Four test self-compacting concrete slab groups were manufactured, each of which consisted of three slab specimens identical in size and shape but different in constituent's properties. All slabs are simply supported along the all edges and subjected to single point load applied at the center of gravity of each slab.

Experimental results shows that the use of self compacting concrete improves the punching shear resistance and allows higher forces to be transferred through the slab-column connection. For slabs which were designed to fail in punching shear, the ultimate capacity of the tested specimens increased by (7%) to (20%) when the shape of slab specimens changed from triangular to trapezoidal. In contrast of slabs which were designed to fail in flexure, the ultimate capacity of the tested specimens increased from (16%) to (58%) when the shape of slab specimens changed from triangular to trapezoidal.

The cracking load depends essentially on concrete strength and not on slab configuration, but, the ultimate capacity depends on both, concrete strength and shape of slab.

Keywords:- Punching Shear, Flexural, Self compacted, Slabs, Concrete, Non-Rectangular.

1-INTRODUCTION

Reinforced concrete slabs may be carried directly by the columns without using beams or girders. Such slabs are described as flat plates. Since the depth (thickness) of a typical slab is relatively small, its capacity to transfer load into the columns by shear is often low. As a result, most failure of flat plates is initiated by overstress in shear at the columns. These failures are termed Punching-Shear failures.

Punching shear failure of slabs is usually sudden and leads to progressive failure of flat plate structures; therefore, caution is needed in the design of slabs and attention should be given to avoid the sudden failure conditions.

Punching shear of rectangular (or square) shaped slabs were interested by several researches [1,2,3] and several experimental investigations were conducted to increase the punching shear strength of slabs by using steel fiber reinforced concrete or high strength concrete or concrete polymer composite[4]. Comprehensive studies on mechanical properties of self-compacting concrete were, also, interested by several researches [5].

Conventional shear reinforcement can be used to increase the punching shear strength of slabs, but, when the thin slabs are constructed, a very large of steel reinforcement are required to increase the load capacity. The newest construction material (technique) which can be used in such cases are moderate or high strength self compacted concrete rather than using conventional shear reinforcement to increase capacity of flat slab.

.Self-compacting concrete (SCC) was developed in Japan in the late 1980's and allows concrete to be placed fully compacted without segregation and with no additional energy (vibration)[6]. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.

Some times, and for architectural purposes, the flat slabs made with non uniform or irregular shaped, such as circular, triangular, trapezoidal,…ect.

The main objective of this study is to investigate experimentally punching shear and flexural strengths of self compacted concrete, triangular and trapezoidal shaped slabs.

2-EXPERIMENTAL WORK

2-1 Experimental Program

Four test slab groups were used, each of which consisted of three slab specimens identical in size but different in constituent's properties. Slabs which made with triangular shaped (first and second group), having a width of (450mm), hight of (600mm) and thickness of (50mm). While, the trapezoidal slabs were made with the same dimensions of first group but the upper side was made with (200mm) width, see Table (1) and Figure (1). Each slab was designated in a way to refer to a shape of slab (triangular or trapezoidal), concrete strength (S30, S50 and S70) and expected mode of failure (punching shear or flexural). Therefore, the slab (TS70P) is a triangular shaped slab made with (70MPa) concrete strength and the expected mode of failure is punching shear.

All slabs are simply supported along all edges and subjected to single point load applied at the center of gravity of each slab. The applied load is transformed from testing machine through a central column of dimensions (40x40mm). It may be noted that, each group is divided into three subgroup (slab specimens) based on expected mode of failure.

2-2 Materials

In manufacturing test specimens, the following materials are used: ordinary Portland cement (Type I); crushed gravel with maximum size of (10mm); natural sand from Al-Ukhaider region with maximum size of (4.75mm) and fineness modulus (3.18); Lime stone powder (L. S. P.) with fineness (3100 cm^2/gm), high water reducer super plasticizer; clean tap water was used for both, mixing and curing. The concrete mix proportions are reported and presented in Table (2).

The steel reinforcement mesh consist of welded wire fabric (WWF); each wire have yield strength (f_y) of (310 MPa) and (5mm) in diameter at (75 mm) and (150mm) c/c spacing in each way for triangular group and trapezoidal group respectively. A clear cover of (5mm) was provided below the mesh. It may be noted that, for both triangular and trapezoidal shaped slabs, the steel reinforcement were designed to ensure the tested specimens to fail either by punching shear or flexural.

2-3 Test Measurements and Instrumentation

Hydraulic universal testing machine (MFL system) was used to test the slabs 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 were placed underneath the bottom face at the center.

2-4 Test Results of Specimens

Properties of the SCC in the fresh state were measured and presented in Table (3). Also, test results of mechanical properties of hardened concrete specimens are summarized in Table (4). Compressive strength was carried out on (100x100x100mm) cubes and tensile strength in flexural (modulus of rupture) were carried out in accordance with ASTM-C78[7].

2-5 Test Procedure

Setup of tested specimens is shown in Figure (2). All slab specimens were tested using universal testing machine (MFL system) with monotonic loading to ultimate states. The tested slabs were simply supported and loaded with a single-point load. The slabs have been tested at ages of (28) days. The slab specimens were placed on the testing machine and adjusted so that the centerline, supports, point load and dial gauge were in their correct or best locations.

Loading was applied slowly in successive increments; the applied load is transformed from testing machine through a central column of dimensions (40x40mm). At the end of each load increment, observations and measurements were recorded for the mid-span deflection and crack development and propagation on the slab surface. When the slab reached advanced stage of loading, smaller increments were applied until failure, where the load indicator stopped recording any more and the deflections increased very fast without any increase in applied load.

The developments of cracks (crack pattern) were marked with a pencil at each load increment.

3-RESULTS AND DISCUSSION

3-1 General Behavior

Photographs of the tested slabs are shown in Figure (3) and test results are given in Table (5). The first and third group of tested slabs was designed to fail in punching shear, while the second and fourth group was designed to fail in flexure with tensile mode, which was characterized by the formation of cracks in the tensile stress zone (bottom face), then yielding of steel bars. Generally, as the load was increased, radial cracks started to appear and extended from that perimeter toward the slab edges. At the same time, the cracks increased in number at the center regain of the slab. A complete failure occurred by increasing the load.

3-2 Failure Mode

All the tested specimens of first and third group (TS30P, TS50P, TS70P, TRS30P, TRS50P and TRS70P) were failed in punching shear, the punching shear failure occurred by developing of cracks and this cracks progressed rapidly and announced an imminent failure and as a result crushing of the concrete, Figure (3).

Failure by flexure takes place for all the tested specimens of second and fourth group (TS30F, TS50F, TS70F, TRS30F and TRS50F) except of slab (TRS70F), which failed in punching shear, refer to Table(5). Failure by flexure occurred by yielding of the steel reinforcement, followed by crushing of the concrete in the compression zone at very large deformations.

3-3 Ultimate Loads

Ultimate load capacity of tested specimens are reported and presented in Table (5). Generally, the experimental results show that the ultimate capacity increased with increasing of concrete strength. The ultimate load increased (9% to 26%), (8% to 58%), (5% to 12%), (5% to 16%) when the concrete compressive strength changed from (30MPa) to (50MPa) and (70MPa) for first, second, third and fourth group respectively. The use of self compacting concrete (SCC) improves the punching shear resistance and allowing higher forces to be transferred through the slab-column connection. As a result, the ultimate capacity depends on both, concrete strength and shape of slab.

3-4 Cracking Loads

Results presented in Table (5) show that the cracking loading decreased with increasing the strength of concrete. For slab specimens (TS30P, TS50P and TS70P), cracking occurred at a shear force of approximately (20%), (18%) and (16%) of ultimate load respectively. Specimen (TS30F, TS50F and TS70F), cracking occurred at a shear force of (31%), (27%) and (20%) of ultimate load respectively.

Specimens (TRS30P, TRS50P and TRS70P), cracking occurred at a shear force of (17%), (16%) and (15%) of ultimate load respectively. In specimens (TRS30F, TRS50F and TRS70F), cracking occurred at a shear force of (21%), (18%) and (16%) of ultimate load respectively.

For slabs failed in punching shear and constructed with same concrete strength and reinforcement (first and third group), the cracking load decreased from (3%) to (1%) when the shape of slab specimens changed from triangular to trapezoidal. In contrast of slabs failed in flexure and constructed with same concrete strength and reinforcement (second and fourth group), the cracking load decreased from (10%) to (4%) when the shape of slab specimens changed from triangular to trapezoidal. This means the cracking load depends essentially on concrete strength and not on slab configuration.

3-5 Crack Pattern

The cracking pattern depends on the longitudinal and transverse steel spacing. Slabs which made with triangular or trapezoidal shape and designed to fail in punching shear shows the crushed zone around the center line passing through the loaded cross sectional area, Figure (3).

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. Figure (3) illustrate crack patterns and failure modes of triangular and trapezoidal shaped slabs.

The second and fourth group, were failed in flexure with tensile mode, which was characterized by the formation of cracks in the tensile stress zone (bottom face) and in different directions.

3-6 Area of the Failure Zone

The failure perimeters and corresponding maximum diameter of the punching failure zones are measured and presented in Table (6). For triangular shaped slabs, with increasing the strength of concrete, the failure perimeter increased significantly.

The crack angle of punching shear was found to be approximately between (22) to (36) degrees. It may be noted that, for specimens which made with high strength concrete, the crack angle was relatively less inclined (crack angle of approximately 22 degrees). Generally, the trapezoidal shaped specimens show high failure perimeter than triangular specimens. As a result, the failure cracks extend more in trapezoidal slabs than in the triangular specimens.

3-7 Load – Deflection Behavior

Load-Deflection curves under the center of loaded area for tested specimens were constructed and presented in Figure (4) and Figure (5). Load-Deflection curves between triangular shaped slabs (group-1 and group-2) are shown together in Figure (4). While, Load-Deflection curves between trapezoidal shaped slabs (group-3 and group-4) are shown together in Figure (5).

3-8 Effect of Slab Configure (shape) in Ultimate Capacity

As shown in Table (5), for slabs failed in punching shear and constructed with same concrete strength and reinforcement (first and third group), the ultimate capacity of tested specimens increased by (7%) for S70P slab and (20%) for S30P slab when the shape of the slab changed from triangular to trapezoidal . In contrast of slabs failed in flexure and constructed with same concrete strength and reinforcement (second and fourth group), the ultimate capacity of tested specimens increased from (16%) to (58%) when the shape of slab specimens changed from triangular to trapezoidal. This means, the ultimate capacity influenced by the shape of slab. The shape of slab represents the main parameter to specify the crushed zone around the column (failure perimeter)

4-CONCLUSIONS

1. The use of self compacting concrete (SCC) improves the punching shear resistance and allowing higher forces to be transferred through the slab-column connection. The cracking load depends essentially on concrete strength and not on slab configuration, but, the ultimate capacity depends on both, concrete strength and shape of slab.
2. For triangular shaped slabs, the failure perimeter increased significantly with increasing the strength of concrete, while, for the trapezoidal shaped slabs, the failure perimeters were increased marginally. This means, the shape of slab represents the main parameter to specify the crushed zone around the column (failure perimeter).
3. For slabs designed to fail in punching shear, the ultimate capacity of tested specimens increased by (7%) to (20%) when the shape of slab specimens changed from triangular to trapezoidal. In contrast to slabs designed to fail in flexure, the ultimate capacity of tested specimens increased by (16%) to (58%) when the shape of slab specimens changed from triangular to trapezoidal, i.e. ultimate capacity is influenced by the shape of slab.
4. The trapezoidal shaped specimens show high failure perimeter than triangular specimens. As a result, the failure cracks extend more in trapezoidal slabs than in the triangular specimens and with extended failure perimeter, more reinforcement will resist the punching shear stresses. The resistant of triangular shaped slabs is less in comparison with trapezoidal shaped slabs.
5. When the strength of concrete was increased, the tested specimens show brittle behavior which was characterized by high load resistance (sharp ascending part of load-deflection curve) with small area under the curve and as a result, brittle failure occurred. This type of failure is not recommended in design.
6. For the same shape and concrete strength of slab, increasing the reinforcement alters the mode of failure from flexural to punching shear mode.

5-NOTATION

t = Slab thickness;

$w1$= Top width;

$w2$ = Bottom width;

l = Slab length (height);

f_{cu} = Ultimate cube compressive strength;

f_r = Modulus of rupture;

P_u= Ultimate load;

P_{cr}= Cracking load;

P_{ui}= Ultimate load of considered slab;

P_{ur}=Ultimate load of reference slab;

f_y = Yield tensile strength;

ϕ = Diameter of reinforced bars.

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Table (1): Properties and Description of Tested Slabs.

Slab Shape	Group	Slab Designation	*t* *(mm)*	*w1* *(mm)*	*w2* *(mm)*	*l* *(mm)*	Reinforcement
Triangular	Group-1	TS30P	50	0	450	600	ф 5mm@ 75 c/c
		TS50P	50	0	450	600	
		TS70P	50	0	450	600	
	Group-2	TS30F	50	0	450	600	ф 5mm@150 c/c
		TS50F	50	0	450	600	
		TS70F	50	0	450	600	
Trapezoidal	Group-3	TRS30P	50	200	450	600	ф 5mm@75 c/c
		TRS50P	50	200	450	600	
		TRS70P	50	200	450	600	
	Group-4	TRS30F	50	200	450	600	ф 5mm@150 c/c
		TRS50F	50	200	450	600	
		TRS70F	50	200	450	600	

Table (2): Concrete Mixes.

Material	Mix Designation		
	S30	S50	S70
Cement (kg/m^3)	367	474	540
Limestone Powder (kg/m^3)	195	105.3	64
Sand (kg/m^3)	841	807.4	880
Gravel (kg/m^3)	791	784	780
Water (L/m^3)	183	180	155
Super plasticizer (L/m^3)	4	8.1	18

Table (3): Properties of the SCC in the Fresh State.

Mix Designation	Slump Flow (mm/sec)	L-Box	T20 (Sec.)	T40 (Sec.)	T50 (Sec.)
S30	770	1.0	1.5	2.2	3.5
S50	720	0.93	2.2	3.5	4.1
S70	658	0.82	5.5	6.3	8.1

Table (4): Mechanical Properties of Concrete After (28) day of Curing.

Property (MPa)	Mix Designation		
	S30	S50	S70
Cube Compressive strength (f_{cu})*	32.5	48.8	68.5
Modulus of rupture (f_r)**	4.5	7	9.5

*Average of three samples (per mix) by using (100x100x100mm) cubes.
** Average of two samples (per mix) by using (100x100x500mm) prisms.

Table (5): Ultimate, Cracked load and type of Failure of Tested Slabs.

Slab Shape	Group	Slab Designation	P_u (kN)	P_{ui}/P_{ur}	P_{cr} (kN)	P_{cr}/P_u	Failure Mode
Triangular	Group-1	TS30P*	35	1.00	7	0.20	Punching Shear
		TS50P	38	1.09	7	0.18	Punching Shear
		TS70P	44	1.26	7	0.16	Punching Shear
	Group-2	TS30F*	24	1.00	7.5	0.31	Flexure
		TS50F	26	1.08	7	0.27	Flexure
		TS70F	38	1.58	7.5	0.20	Flexure
Trapezoidal	Group-3	TRS30P*	42	1.00	7	0.17	Punching Shear
		TRS50P	44	1.05	7	0.16	Punching Shear
		TRS70P	47	1.12	7	0.15	Punching Shear
	Group-4	TRS30F*	38	1.00	8	0.21	Flexure
		TRS50F	40	1.05	7	0.18	Flexure
		TRS70F	44	1.16	7	0.16	Punching Shear

* Reference Slabs

Table (6): Failure Characteristics of Tested Slabs.

Slab Shape	Group	Slab Designation	Failure Perimeter (mm)	Maximum Diameter (mm)
Triangular	Group-1	TS30P	750	200
		TS50P	890	300
		TS70P	1040	360
Trapezoidal	Group-3	TRS30P	1050	300
		TRS50P	1010	290
		TRS70P	1080	330
	Group-4	TRS70F	1210	400

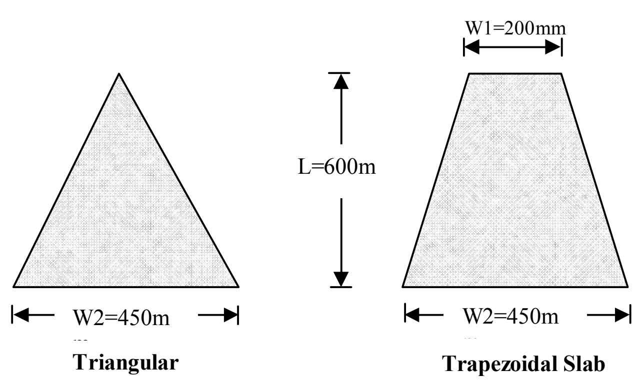

Fig.(1): Dimensions of Tested Slabs.

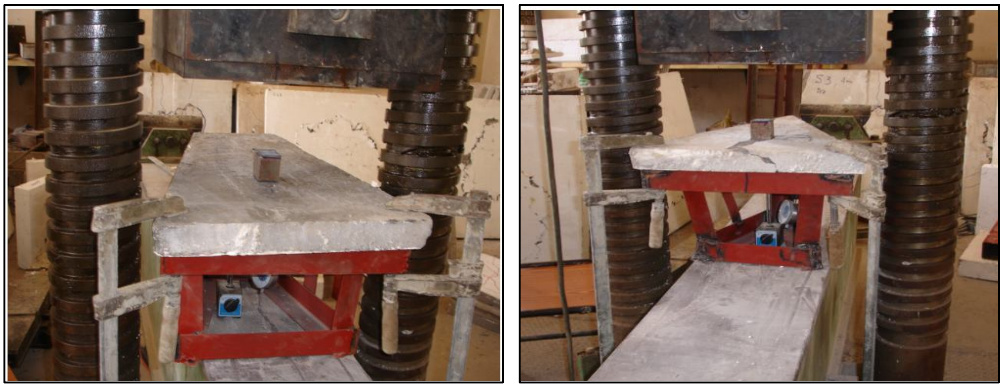

Fig.(2): Setup of Tested Specimens.

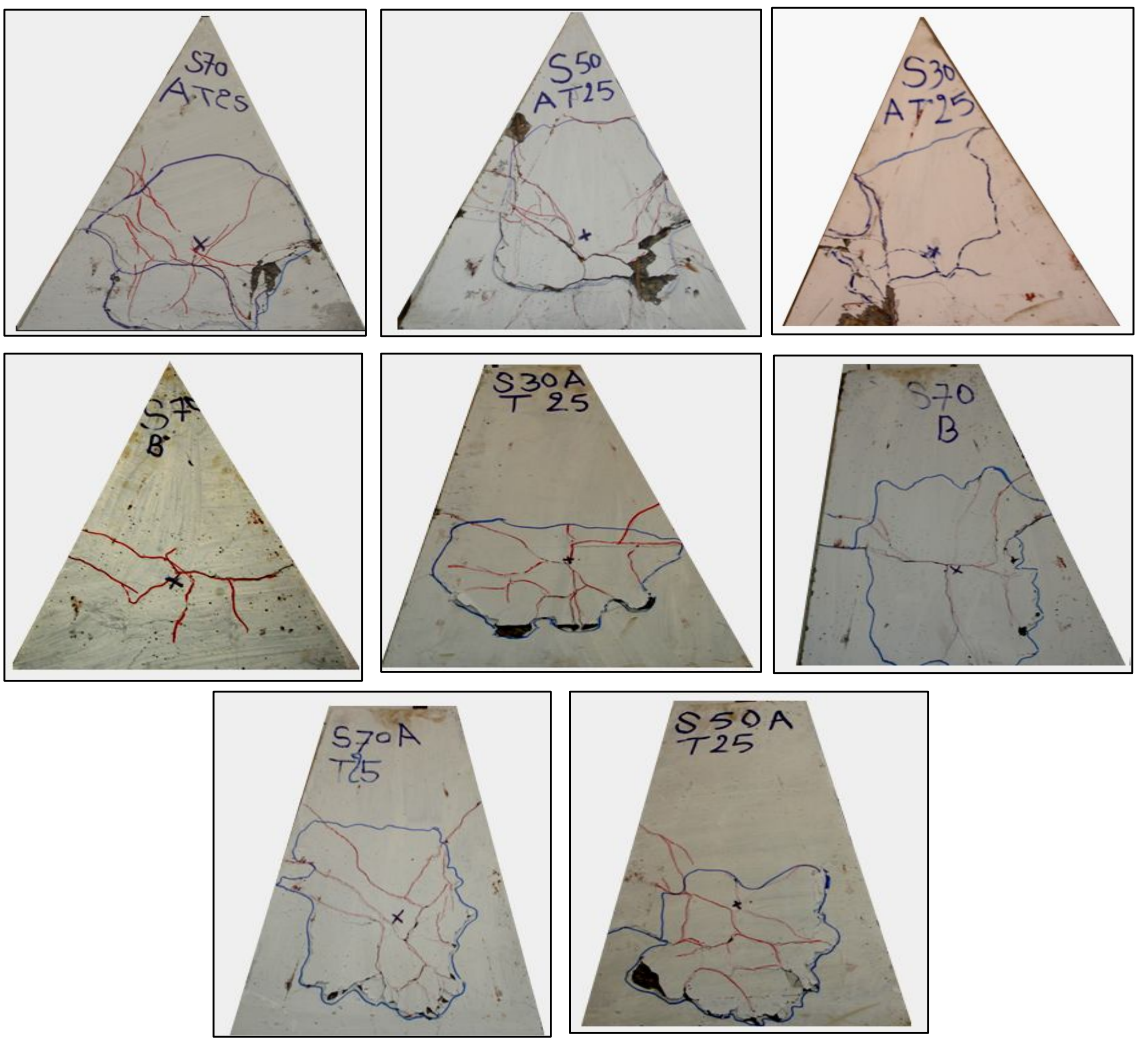

Fig. (3): Crack Pattern of Specimens at Failure; Punching Shear and F.

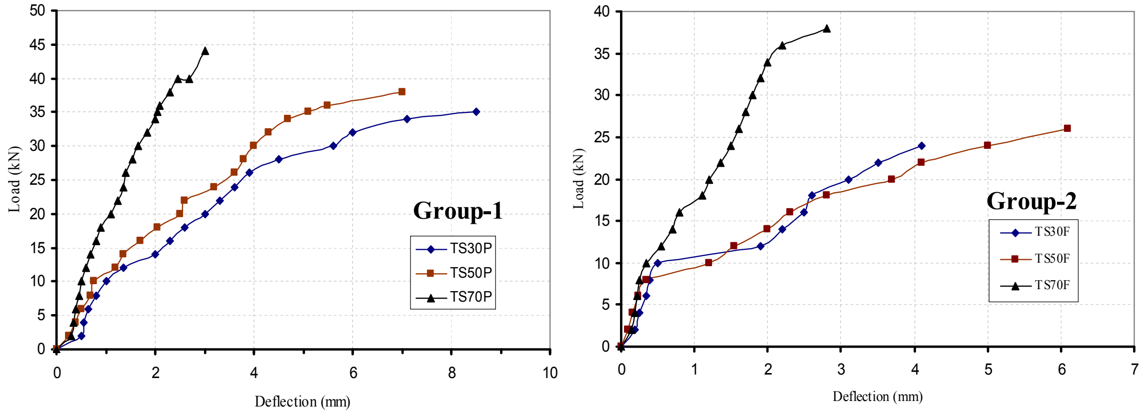

Fig. (4): Load-Deflection Curves of Triangular Shaped Specimens.

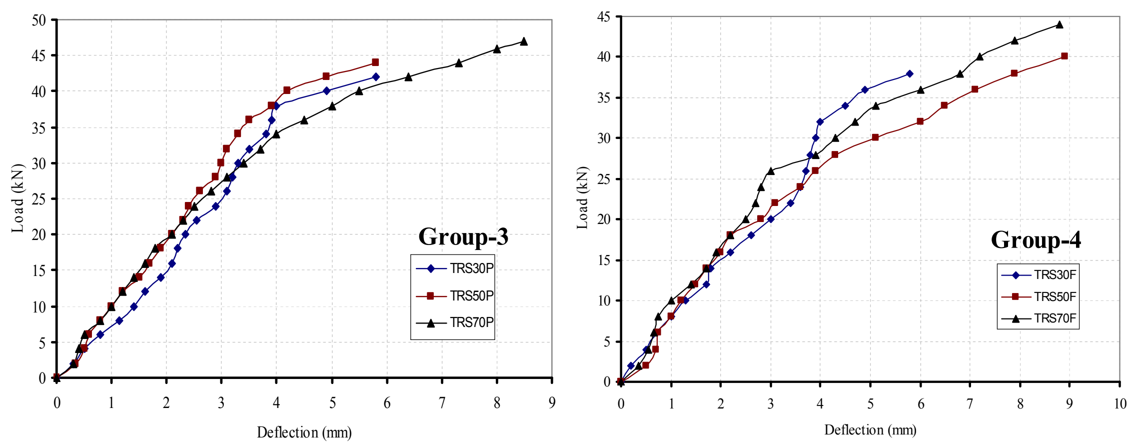

Fig. (5): Load-Deflection Curves of Trapezoidal shaped Specimens.

تحليل مقاومة القص الثاقب ومقاومة الانثناء للبلاطات الصفائحية الخرسانية ذاتية الرص ذات الاشكال غير المستطيلة

علي حميد عزيز — **لمى فاضل حسين**

مدرس — **مدرس المساعد**

قسم هندسة الطرق والنقل– كلية الهندسة– الجامعة المستنصرية

الخلاصة

يتناول هذا البحث دراسة عملية لتقييم مقاومة القص الثاقب ومقاومة الانثناء للبلاطات الخرسانية ذاتية الرص ذات الشكل المثلثي والشكل شبة المنحرفة ،تم فحص اربعة مجاميع من البلاطات (اعتمادا على الشكل) كل مجموعة تضم ثلاثة بلاطات متشابهه في الشكل ومختلفة في التسليح و مقاومة انضغاط الخرسانة. اسندت البلاطات المفحوصة اسنادا بسيطا من جميع الاتجاهات وتم تسليط الاحمال بواسطة حمل مركز في مركز ثقل كل بلاطة.

اظهرت الدراسة ان استخدام الخرسانة ذاتية الرص قد حسن من مقاومة البلاطات المفحوصة وسمح بانتقال احمال عالية من خلال المفصل الرابط بين البلاطة و العمود الخرساني. بالنسبة للبلاطات المصممة للفشل بالقص الثاقب، ازدادت مقاومة المقطع حوالي (7%) الى (20%) عندما تغير شكل البلاطة من الشكل المثلثي الى شبه المنحرف، بينما ازدادت مقاومة المقطع بمقدار (16%) الى (58%) عندما تغير شكل البلاطة من الشكل المثلثي الى شبه منحرف بالنسبة للبلاطات المصممة للفشل بالانثناء.

اظهرت النتائج، كذلك، ان حمل التشقق يعتمد بصورة رئيسية على مقاومة الخرسانة المستخدمة ، بينما يعتمد الحمل الاقصى على مقاومة الخرسانة المستخدمة وشكل البلاطة.