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PUNCHING SHEAR BEHAVIOR OF REACTIVE POWDER CONCRETE SLABS WITH DIFFERENT SHAPE

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ABSTRACT: This research presents an experimental study of punching shear strength of reactive powder concrete (RPC) square and trapezoidal flat slabs. Reactive powder concrete is an ultra-high strength and high ductility composite materials in form of a super plasticized cement mixture with silica fume and steel fibers.

Six reduced scale reinforced concrete slab specimens divided into two groups (square and trapezoidal slabs) were casted and tested in this study.

Each group consists of three specimens which are identical in size and shape but contains different percentages of steel fibers (0, 0.5 and 1) % of total volume.

Results indicated that, punching shear strength increases by about (62.5 and 100) % in square slabs and is about (8.3 and 41.7) % in trapezoidal slabs containing 0.5% and 1% of steel fibers respectively.

Keywords: Punching shear, steel fibers, regular and irregular shaped flat plates.

INTRODUCTION

Flat plates are common and competitive structural system for cast in place slabs in buildings since no beam is involved. The means that the formwork of these slabs is very simple and economic. Using this type of structure presents however a serious disadvantage because of the risk of a brittle punching failure at the connection between the slab and the column (1).

Large scientific efforts have been done in the past to predict the punching shear strength of the slab column connection. However, some punching failure that occurred during the past decades showed that it is necessary to improve design methods to avoid this type of failure (1).

Recently, new technique using steel fibers to improve the punching shear resistance and cracking control of slab-column connections has been proven to give good results (Alexander and Simmonds 1992 (2); The odorakopoulos and Swamy 1993 (3); Harajli et al. 1995(4); McHarg et al. 2000 (5), Naaman et al. 2007 (6); Cheng and Montesinos 2010a (7). Moreover, steel fibers also indicate high effectiveness in structures sustained lateral loads i.e. seismic loads because of their ability to absorb energy dissipation of the structures (Megally and Ghali 2000 (7);Cheng and Montesinos 2010b (7)).

Reactive Powder Concrete is a fiber-reinforced, superplasticized, silica fume – cement mixture with very low water –cement ratio (w/c) characterized by the presence of very fine quartz sand (150 – 400 μm) instead of ordinary aggregate .In fact, it is not a concrete because there is no coarse aggregate in the cement mixture. The absence of coarse aggregate was considered by the inventors to be a key aspect for the microstructure and the performance of the RPC in order to reduce the heterogeneity between the cement matrix and the aggregate. However, due to the use of very fine sand instead of ordinary aggregate, the cement factor of the RPC is as high as 900–1000 kg/m3 (8).

In the last few years, irregular shaped flat plat slabs are commonly used in high rise residential buildings. Architectural shape, interior layouts and requirements often dictate the use of irregular shaped flat slabs (9). However, the currently available building codes don't provide specific guidelines for designing irregular shaped flat slabs or building. Therefore, the design and testing of the specimens in this investigation were done experimentally.

This study is a part of series of experimental tests carried out on rectangular and non-rectangular shaped flat plat slabs made with steel fiber under the concentric load.

Experimental Program

Materials

Ordinary Portland cement (Type I) was used in all mixture. The cement is (Tasluoja). Silica fume with blain fineness of 20000 m2/kg was used. Table (1) and Table (2) show the chemical and Physical Properties of Cement. The chemical compositions of cement complied with the Iraqi standard specification I.Q.S. No.5 / 1984 requirements (10).

Natural siliceous sand of Al-ukhaider region with maximum size of 4.75mm and specific gravity and absorption of 2.7 and 1.5% respectively is used in this work. Table (3) show grading of the separated fine sand compared with the requirements of Iraqi specification No.45/1984 (11). Results indicate that the fine aggregate grading is within the requirements of the Iraqi specification No.45/1984 (11). For reactive powder concrete, very fine sand with maximum size 600μm is used. This sand is separated by sieving; its grading satisfies the fine grading in accordance with the Iraqi specification No.45/1984 (11).

The Superplasticizer based on polycarboxylic ether was used, it has the trade mark Glenium 51(G51) .Table (4) show the Typical Properties of Glenium 51. While tap water was used for casting and curing all the specimens.

The steel fibers used in this test program were straight steel fibers manufactured by Bekaert Corporation in China. The fibers have the properties described in Table (5).

One percentage of silica fume was used (25%) by mass of cementitious material. The chemical composition and properties of silica fume are given in Table (6). The silica fume used in this work conforms to the chemical and physical requirements of ASTM C1240-03 (12) as shown in Tables (7) and (8) respectively.

The steel reinforcement deformed bar mesh of (6mm) was used as bottom mesh reinforcement with 10mm concrete cover. Yield strength of the wires is (360 MPa). The spacing in each direction for square and trapezoidal slabs is (75 mm) c/c. It may be noted that, for both square and trapezoidal shaped slabs, the steel reinforcement were designed to fail in punching shear.

Details of Test Specimens

Two test slab series were casted and tested, each of which consisted of three slab specimens identical in size but different in constituent's properties. all slabs Specimens were made with Square shaped and having a dimension of (450*450)mm, and thickness of (50mm), see Table (9) and Figure (1).While, the trapezoidal slabs were made with dimensions (450mm) width (lower side), (620mm) length, (50mm) thickness and the upper side was made with (200mm) width.

Each group consists of three specimens containing three percentages of steel fiber (0, 0.5 and 1)% of total volume.

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 (40*40mm).

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. Figure (2) show MFL Testing Machine.

Mix Design

Several mixtures were tested in order to find the desired strength. Then three percentage were used (0, 0.5and 1)% with cube compressive strength of (85, 101 and 115)MPa. The composition of mixture used in this investigation is shown in Table (10).

Preparation of Specimens

The procedure followed in preparing RPC mixes was as follows: the desired quantity of silica fume was mixed in dry state with the required quantity of cement. This operation was continued to 5 minutes to ensure that silica fume powder was thoroughly dispersed between cement particles. Then, fine sand was put in the mixer and mixed for 10 minutes. Then, the superplasticizer was dissolved in water and the solution of water and superplasticizer was added to the rotary mixer and the whole mix ingredients were mixed for a sufficient time. The mixer was stopped and mixing was continued manually especially for the portions not reached by the blades of the mixer. The mixer then was operated for 5 minutes to attain reasonable fluidity. Fibers were uniformly distributed into the mix slowly in 5 minutes during mixing process, and then the mixing process continued for additional 2-3 minutes. In total, the mixing of one batch requires approximately 25- 30 minutes.

Several effects were noticed when adding the fibers to the concrete matrix, the most striking of which is the great reduction in workability, which is reduced as the fiber content is increased.

After that, the concrete was poured in the molds. For testing compressive strength 3 cubs of size (50*50) mm for each mixture were cast. For testing punching shear resistance, three regular shaped (square) slabs and three irregular shape (trapezoidal) slabs were cast for each mixture. Then, all the specimens were covered with polythene sheet for 24 hours. After that, the specimens were demolded and were put in water for 28 days for curing. After the period of curing, the specimens (cubs and slabs) were tested.

RESULTS AND DISCUSSION

Results of Compressive Strength

From Table (11), it can be seen an increase in compressive strength (19 and 35) % as compared to the nonfibrous RPC slab by The addition of steel fibers (0.5 and 1)% respectively. This is due to the fact that increase may be associated with crack arrest property of the fibers which accounts for the increase in compressive strength and may be attributed to the high tensile strength of steel fiber.

Results of Punching Shear

Punching test was carried out on two series of slabs as follows:

Series 1:

This series consists of 3 regular shaped (Square) slabs with dimensions (450*450*50)mm.

Series 2:

This series consists of 3 irregular shaped (trapezoidal) slabs with dimensions (450*620*200)mm.

All the slabs were supported along their perimeter and tested by pushing down square steel column of dimensions (40*40)mm on the center of gravity of each slab. While the deflection was measured using the dial gage of 0.01 mm sensitivity. Figure (3) shows the loading test system. Table (11) and (12) show the result of; First crack load, Ultimate load, Deflection at first crack, Deflection at ultimate load, Ductility ratio, Failure Perimeter and Maximum Diameter for slabs in Series 1 and Series 2, respectively. While Figure (4) shows the failure pattern and Figure (5) show the load deflection curve for slabs in series 1 and 2 respectively. From Tables (11), Tables (12) and Figures (4 and 5), the following observations are noticed:

First crack loads are approximately equal for all slabs. While the deflection at first crack is different from one slab to another, this may be attributed to the stiffness of the concrete.

This increasing result is due to the existence of fibers across the diagonal crack, which restricts the crack propagation through the shear span and tends to tie up the crack opposite sides towards each other compared with the control nonfibrous RPC slab

The ultimate load increases with the increase of concrete strength. This increment is about (62.5 and 100) % in square slabs and is about (8.3 and 41.7) % in trapezoidal slabs. This is mainly due to the presence of steel fibers which greatly increases the overall rigidity of the slab and allows RPC slabs to behave plastically at the onset of shear failure with steel fibers pull out of the cement matrix rather than snap.

It is observed that the ultimate load for square slabs is higher than for trapezoidal slabs. This may be because the area subjected to the loads is regular.

It is clear from the Tables that the ductility ratio also increased by the presence of steel fibers. The ductility ratio increased from 4.5% to 5.5% for Square slabs, and increased from 5.35% to 7.37% for trapezoidal slabs , when the percentage of steel fiber increase from (0.5 to1)% respectively, compared with the nonfibrous RPC slabs. This is expected since the presence of fibers causes a reduction in the deflection at cracking load and increases the deflection at ultimate load.

When the load was applied to the slab specimens, the first crack was formed at about (32, 27, and 25) % of the ultimate load for slab (S0, S0.5, and S1) respectively. As the load was increased, radial cracks started to appear and extended from the center towards the slab edges in both the tension and compression faces of the slab resulting in rupture of the slab specimen into separated segments.

CONCLUSIONS

For all slabs first crack loads are approximately equal. While the deflection is different from one slab to another at first crack, this may be attributed to the stiffness of the concrete.

This increasing result is due to the existence of fibers across the diagonal crack, which restricts the crack propagation through the shear span and tends to tie up the crack opposite sides towards each other compared with the control nonfibrous RPC slab.

When increase in concrete strength the ultimate load increases. This increment is about (8.3 and 41.7) % in trapezoidal slabs and is about (62.5 and 100) % in square slabs. This is mainly due to the presence of steel fibers which greatly increases the overall rigidity of the slab and allows RPC slabs to behave plastically at the onset of shear failure with steel fibers pull out of the cement matrix rather than snap.

Because the area subjected to the loads is regular, the ultimate load for square slabs is higher than for trapezoidal slab.

By the presence of steel fibers the ductility ratio was increased. The ductility ratio increased from 4.5% to 5.5% for Square slabs, and increased from 5.35% to 7.37% for trapezoidal slabs , when the percentage of steel fiber increase from (0.5 to1)%respectively, compared with the nonfibrous RPC slabs. This is expected since the presence of fibers causes a reduction in the deflection at cracking load and increases the deflection at ultimate load.

The first crack was formed when the load was applied to the slab specimens at about (32, 27, and 25) % of the ultimate load for slab (S0, S0.5, and S1) respectively. As the load was increased, radial cracks started to appear and extended from the center towards the slab edges in both the tension and compression faces of the slab resulting in rupture of the slab specimen into separated segments.

Table (1): Chemical Composition and Main Compounds of Cement*

Oxides Composition	Content%	Limits of Iraqi Specification No.5/1984 [10]
CaO	62.96	---
SiO_2	21.04	----
Al_2O_3	5.20	----
Fe_2O_3	2.68	----
MgO	1.77	< 5.00
SO_3	2.40	< 2.80
L.O.I.	3.32	< 4.00
Insoluble residue (I.R)	1.32	< 1.50
Lime saturation factor (L.S.F)	0.93	0.66-1.02
Main compounds (bougue's equations)		
C_3S	57.04	
C_2S	14.83	---
C_3A	9.25	---
C_4AF	10.95	---

*** Chemical analysis was conducted by National Center for Construction Laboratories and Researches.**

Table (2): Physical Properties of Cement*

Physical Properties	Test Results	Limits of Iraqi Specification No.5/1984
Specific Surface Area (Blaine Method), cm^2/g	2985	Not less than 230
Setting Time (VicatApparatatus), Initial Setting, (min) final setting, (min)	 166 255	 Not less than 45 Not greater than 10 hr
Compressive strength, MPa at 3 days Compressive strength, MPa at 7 days	18.76 26.81	≥ 15.00 ≥ 21.00
Soundness (Autoclave Method) %	0.35	≤ 0.8

*** Chemical analysis was conducted by National Center for Construction Laboratories and Researches.**

Table (3): Grading of the Separated Fine Aggregate

Sieve size (mm)	Cumulative Passing %	Limits of Iraqi specification No.45/1984 [11]
4.75	100	100
2.36	100	100
1.18	100	100
0.600	100	100
0.300	45	15 – 50
0.150	11	0 – 15

Table (4): Typical Properties of Glenium 51*

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

* Supplied by the manufacturer.

Table (5): Properties of Steel Fibers*.

Length (mm)	**Diameter (mm)**	**Density (kg/m^3)**	**Tensile Strength f_u (MPa)**	**Aspect ratio**
13	0.2	7800	2600	65

***Manufacturer Properties**

Table (6): Composition and Properties of Silica Fume*

Composition (%) – Property	**Silica fume**
SiO_2	98.87
Al_2O_3	0.01
Fe_2O_3	0.01
CaO	0.23
MgO	0.01
K_2O	0.08
Na_2O	0.00
Blaine fineness (m^2/kg)	20000

***Manufacturer Properties**

Table (7): Chemical Requirements of Silica Fume (SF)

Oxide Composition	**S.F.**	**Limit of Specification Requirement ASTM C 1240**
SiO_2, min. Percent	90.0	> 85.0
Moisture Content, Max. Percent	0.68	< 3.0
Loss on Ignition, Max. Percent	2.86	< 6.0

Table (8): Physical Requirements of Silica Fume

Physical Properties	**S.F.**	**Limit of Specification Requirement ASTM C 1240**
Percent Retained on 45-µm (No.325) Sieve, Max.	7	< 10
Accelerated Pozzolanic Strength Activity Index with Portland Cement at 7 days, Min. Percent of Control	128.6	> 105
Specific Surface, Min, m^2/g	21	> 15

Table (9): Properties and Description of Tested Slabs.

Slab Shape	Slab Designation	Thickness (mm)	Width (mm)	Length (mm)	Reinforcement
Square	S0	50	450	450	ϕ 6mm@ 75 c/c
	S0.5	50	450	450	
	S1.0	50	450	450	
Trapezoidal	T0	50	200*450	620	
	T0.5	50	200*450	620	
	T1.0	50	200*450	620	

Table (10): Concrete Mixes

Mix Type	Cement kg/m^3	Sand kg/m^3	Silica Fume %	Silica Fume kg/m^3	w/c	Super plasticizer L/m^3	Steel Fiber Content %	Steel Fiber Content kg/m^3
S*0.0,T*0.0	1000	1000	25	250	0.2	3.0	0	0
S0.5,T0.5	1000	1000	25	250	0.2	3.0	0.5	39
S1.0 ,T1.0	1000	1000	25	250	0.2	3.0	1	78

***Where: S/ Square Slab, T/ Trapezoidal Slab**

Table (11): Test Results for Series 1(Square Specimens)

Slab Designation	f_{cu} (MPa)	Loading (kN)		(F.C.L)/ (U.L) (%)	Deflection (mm) at		Ductility ratio*(Ψ)	Failure Perimeter (mm)	Maximum Diameter (mm)	Failure Mode
		First Crack (F.C.L)	Ultimate (U.L)		First Crack	Ultimate Load				
S0.0	85	16	50	32	77	170	2.2	126.5	26	Punching Shear
S0.5	101	18	66	27	31	155	5.0	137	28	
S1.0	115	22	83	25	26	143	5.5	148.5	32.5	

Table (12): Test Results for Series 2 (Trapezoidal Specimens)

Slab Designation	f_{cu} (MPa)	Loading (kN)		(F.C.L)/ (U.L) (%)	Deflection (mm) at		Ductility ratio*(Ψ)	Failure Perimeter (mm)	Maximum Diameter (mm)	Failure Mode
		First Crack (F.C.L)	Ultimate (U.L)		First Crack	Ultimate Load				
T0.0	85	15	60	25.0	80	143	1.79	119	27	Punching Shear
T0.5	101	17	65	26.2	26	139	5.35	129	31	
T1.0	115	22.5	87.5	25.7	21	155	7.38	154	37	

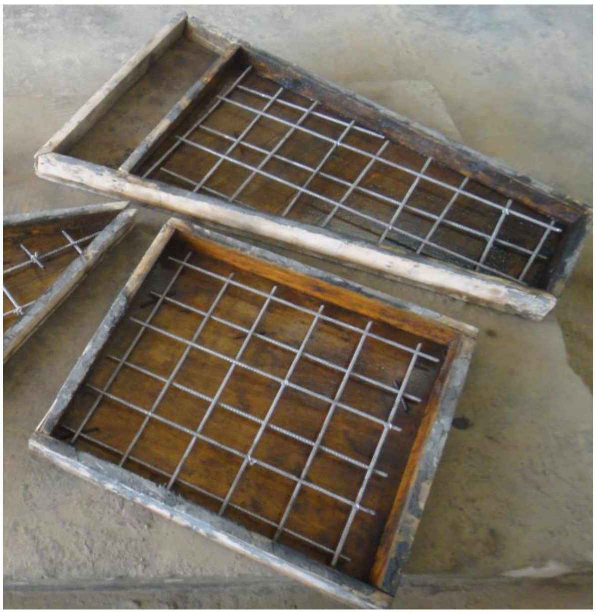

Figure (1): The Square and Trapezoidal Specimens

Figure (2): MFL Testing Machine

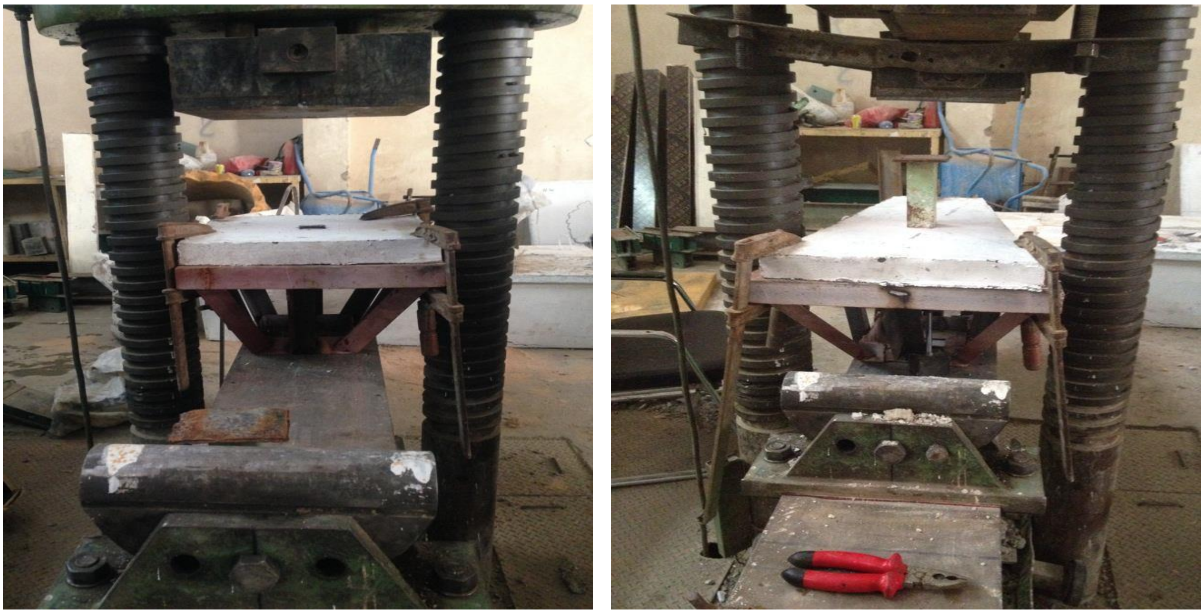

Figure (3): Shows the Loading Test System

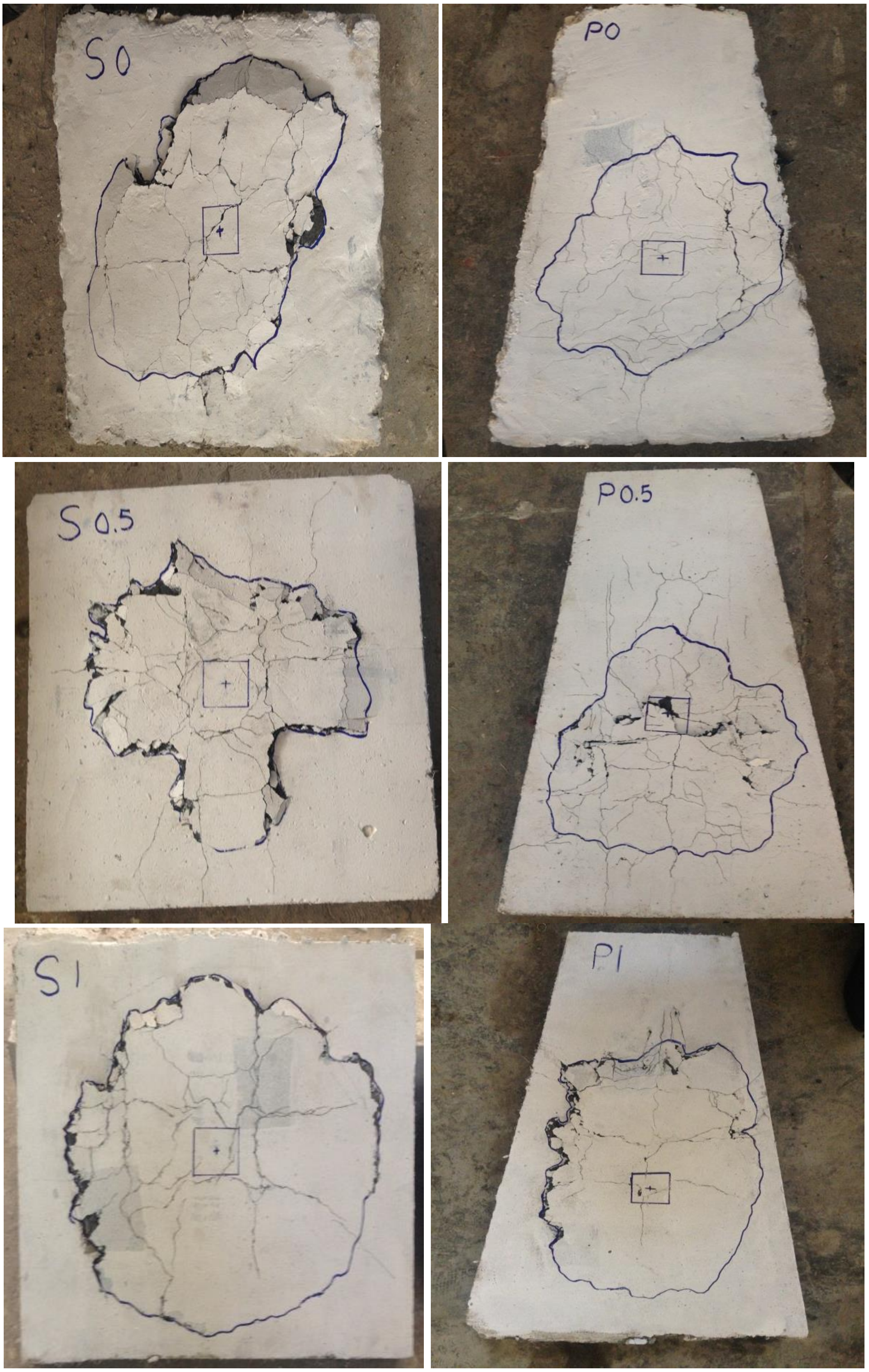

Figure (4): Failure Pattern

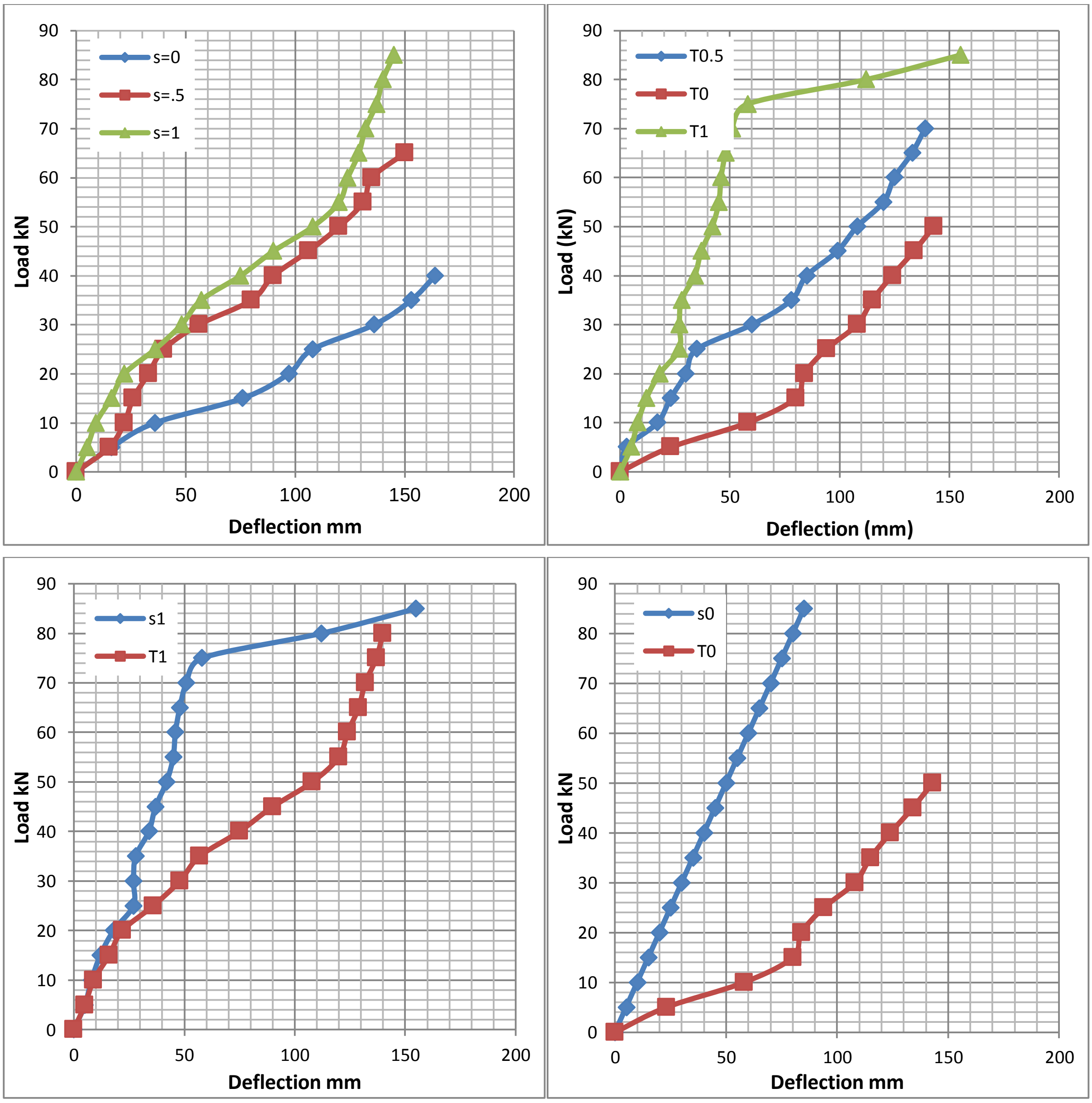

Figure (5): show the load deflection curve for slabs in series 1 and 2.

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مقاومة القص الثاقب للبلاطات ذات الاشكال المختلفة المكونة من خرسانة المسحوق الفعال المسلحة

الخلاصة:

يتناول هذا البحث عرض دراسة عملية لتاثير الالياف الحديدية على مقاومة القص الثاقب للبلاطات المكونة من خرسانة المسحوق الفعال المسلحة بالالياف الحديدية والمختلفة في الشكل (مربع وشبه منحرف).

تم اجراء البحث العملي على ست بلاطات خرسانية مسلحة، تم تقسيم البلاطات الى مجموعتين، كل مجموعة متالفة من ثلاث بلاطات متشابهة في الشكل ولكن تحتوي على ثلاث نسب من الالياف (0، 0.5 و 1)% من الحجم الكلي للخليط.

اظهرت النتائج العملية بان مقاومة القص الثاقب ازدادت بتاثير الالياف الحديدية بنسبة (62.5 و 100)% في البلاطات المربعة وبنسبة (8.3 و 41.7)% في البلاطات ذات الشكل الشبه منحرف عندما كانت نسبة الالياف 0.5% و 1% على التوالي.