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" EXPERIMENTAL STUDY OF HIGH STRENGTH CONCRETE SLABS "

" دراسة معملية لسلوك البـــلاطات الخـــرسانية المسلحة عـــالية المقـــاومة "

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ملخص البحث :

تعتبر البلاطات الخرسانية المسلحة عالية المقاومة شائعة الاستخدام في عمل بلاطات الكـباري و المنشات ذات البحور الكبيرة و المنشات البحرية بالإضافة إلى المنشات المجاورة للشواطئ.

وقـد تم في هذا البحث تنفيذ برنامج عملي يشتمل علي ثلاث عشرة بلاطة خرسانية مسلحة عالية المقاومة. و قد تم تقسيمها إلى ثلاث مجموعات . المجموعة الأولى تحتوي علي أربــع بلاطات خرسانية مسلحة وتم استخدامها في دراسة تأثير زيادة مقاومة الخرسانة علي ســلوك البلاطات المسلحة. المجموعة الثانية تتكون من خمس بلاطات خرسانية مسلحة ذات نسـب مختلفة من حديد التسليح. المجموعة الثالثة تتكون من خمس بلاطات خرسانية مسلحة ذات فـتحات مركزية مربعة لها أبعاد مختلفة لدراسة تأثير أبعاد الفتحة علي سلوك البلاطات الخرسانية المسلحة عالية المقاومة.

وقد تم تحميل هذه البلاطات بأحمال مركزة متزايدة وتم تسجيل قيم الترخيم و الانفعال وحمـل الانهـيار وكذلك انتشار الشروخ من بداية التحميل وحتى الانهيار كما تم تصوير شكل توزيع الشروخ النهائي لكل بلاطة من البلاطات المختبرة .

وأخـيرا تـم وضع التوصيات الواجب توافرها و أخذها في الاعتبار و كذلك النتائج التـي تـم الحصول عليها من هذه الدراسة مع عرض المجالات المستقبلية المختلفة لاستكمال دراسة سلوك و تحليل البلاطات الخرسانية عالية المقاومة.

وقـد أظهرت نتائج الاختبارات أن البلاطات الخرسانية عالية المقاومة تظهر جساءة عالية و ترخيم اقل مقارنة بالبلاطات المماثلة من الخرسانة عادية المقاومة بالرغم من زيادة الشـروخ فـي البلاطات الخرسانية عالية المقاومة – كما أثبتت التجارب أن الفتحات المربعة ذات طول ضلع اقل من أو يساوى عشر طول ضلع البلاطة الخرسانية ليس لها تأثير يذكر على كفاءة البلاطة الخرسانية في مقاومة الأحمال.

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ABSTRACT

High strength reinforced concrete plates are commonly used for bridge decks, long span structures, marine platforms, and offshore structures .The reinforced concrete flat slabs are an economical and popular structural system, however the use of this system is limited due to its susceptibility to shear failure .One of the practical solutions used to increase the flat plate shear strength is to increase the concrete strength. In this research concrete characteristic strength up to 750 kg./cm^2.

In this investigation the focus will be on the effect of slab compressive strength (silica fume content), the effect of the reinforcement ratio and the effect of central square opening size on the behavior of the slabs. This goal is achieved through the studying the behavior of thirteen tested slabs.

The experimental program was carried out on thirteen reinforced concrete plate of (120 × 120 × 7) cm. resting on four supports and subjected to concentrated load. The load was applied gradually in increments to record the first crack load and the failure load, beside the deflections and the strains at each load increment.

Although it suffers more cracks than the normal strength concrete, high strength concrete has shown higher stiffness and less deflection . Square opening of side length up to 10% of the slab side did not affect the load of the slabs.

Keywords

High strength, Silica fume, Superplasticizer, Compressive strength, Flat slabs, Deflection, Reinforcement ratio, opening size.

Introduction

Flat plates are simple structure in concept and construction consisting of a slab of uniform thickness supported directly on columns. These slabs are mainly fail by shear, to overcome this defect the shear strength of these slabs are increased through the increase of the concrete compressive strength [1-4] . The effect of the compressive strength on the behavior of the flat slabs is focused on [5-7]. Steel reinforcement is considered the main item in the concrete cost. The effect of reinforcement ratio on the flat plates is researched. In many cases, openings are made in the flat slabs for mechanical and other purposes. The effect of the opening size on the behavior of the flat slabs is required to be found out [8]. To achieve these goals thirteen square flat plates (120 × 120 × 7) cm. are prepared, casted and tested. Four slabs have the same reinforcement ratio and different silica fume content, consequently different concrete compressive strength. The second five slabs have the same strength but different reinforcement ratio. The last five slabs have different central square side length starting from zero to 40 cm.

Experimental Program

The aim of the experimental work carried out in this study is to investigate the following items :

1 - The effect of silica fume content on the behavior of the high strength reinforced concrete flat slabs, For this purpose , five square slabs (120 × 120 × 7) cm with different silica fume content as follows :

a) The first slab (NSF0) is of normal strength concrete.

b) The second slab (HSF1) is of high strength concrete and the silica fume content is 10% by weight of the cement content .

c) The third slab (HSF2) is of high strength concrete and the silica fume content is 15% by weight of the cement content .

d) The fourth slab (HSF3) is of high strength concrete and the silica fume content is 20% by weight of the eement content .

All of these slabs have the same steel reinforeement ratio (μ =0.57%) .

2 - The effeet of steel reinforcement ratio on the behavior of the high strength reinforced concrete flat slabs. For this purpose , five high strength conerete square slabs models (120 × 120 × 7) cm. having different steel reinforcement ratio as follows :

a) The first slab (HSR1) has a steel reinforcement ratio of (μ = 0.43 %) .

b) The seeond slab (HSR2) has a steel reinforcement ratio of (μ = 0.57 %) .

c) The third slab (HSR3) has a steel reinforcement ratio of (μ = 0.72 %) .

d) The fourth slab (HSR4) has a steel reinforcement ratio of (μ = 0.87 %) .

e) The fifth slab (HSR5) has a steel reinforeement ratio of (μ = 1.08 %) .

All of these slabs have the same silica fume content (S.F. =15%) by weigh of the cement content .

3 – The effeet of central square open size on the behavior of the high strength reinforced conerete flat slabs.For this purpose , five high strength concrete square slabs models (120 × 120 × 7) cm. having different central opening size as follows :

a) The first slab (HSO1) has no central opening .

b) The seeond slab (HSO2) has a central square opening size of 10 cm.

c) The third slab (HSO3) has a central square opening size of 20 cm.

d) The forth slab (HSO4) has a central square opening size of 30 cm.

e) The fifth slab (HSO5) has a central square opening size of 40 cm.

All of these slabs have the same silica fume content (S.F. =15%) by weight of the cement content and steel reinforcement ratio (μ =0.57%) .

Table (1) Details Of The Test Specimens

Series no.	Slab no.	Compressive Strength. Kg./cm^2.	Slab thickness. cm.	Reinforcement ratio μ
I	NSF0	300	7	0.57 %
	HSF1	750	7	0.57 %
	HSF2	650	7	0.57 %
	HSF3	600	7	0.57 %
II	HSR1	650	7	0.43%
	HSR2	650	7	0.57 %
	HSR3	650	7	0.72 %
	HSR4	650	7	0.87 %
	HSR5	650	7	1.08 %
III	HSO1	650	7	0.57 %
	HSO2	650	7	0.57 %
	HSO3	650	7	0.57 %
	HSO4	650	7	0.57 %
	HSO5	650	7	0.57%

* NS - Normal Strength,* HS - High Strength,* S.F. - Silica Fume. * R - Reinforcement , *O - Opening

Material Used In Reinforced Concrete Slabs:

In designing and preparing the concrete mix, the material properties are as follows:

- A locally produced ordinary Portland cement (Suez Cement)
- Natural siliceous , well graded , clean , without any organic matters and any other impurities sand
- Crushed dolomite: one size of the stone were available size 1 with a nominal maximum size of 1/2 in. (12.5 mm)
- Clean potable water had been used for mixing and curing procedures .
- Silica Fume is a by-product resulting from the reduction of high-purity quartz with coal or coke and wood chips in electric arc furnaces during manufacturing of ferro-silicon alloys and silicon metal. It consists of extremely fine spherical particles with a surface area on the order of 20,000 m^2/kg, the average particle's diameter for silica fume is about 100 times smaller than the average diameter of cement particle.
- Chemical admixture ,One type of admixture was used in concrete mixes, with trade name Sikament- 163-M , which is classified as a High Range water reducer (HRWR) meeting the requirements of ASTM C 494(type- F).The admixture is a brown liquid with specific gravity of 1.2 kg./l . The dosage of the used superplasticizer will be between approximately 0.6 %- 2.5 % by weight of cement.

Table (2) Normal Strength Concrete Mix by weight

Mix proportions (Kg / m^3)						C.A./F.A.	W/(C+S)%	(S/C)%	A/(C+S)%	C_{28} Kg / cm^2
C	W	F.A.	C.A.	S.	A.					
350	179.6	619	1238	-	-	2	51.3	-	-	300

Table (3) High Strength Concrete Mix by Weight

Mix proportions (Kg / m^3)						C.A./F.A.	W/(C+S) %	(S/C)%	A/(C+S)%	C_{28} Kg / cm^2
C	W	F.A.	C.A.	S.	A.					
450	140	594	1188	45	12.9	2	28.3	10	2.61	750
450	139.7	587	1174	67.5	12.35	2	27	15	2.39	650
450	145.8	572	1146	90	13.7	2	27	20	2.54	600

C: Cement, W: water, F.A.: fine Aggregate, C.A.: Coarse aggregate, S: Silica Fume A: Admixture.

Concrete Mix Design

the absolute volume method was used to design the required trial mixes.

The following equation was applied:

$$\frac{C}{P_C} + \frac{F.A.}{P_{F.A}} + \frac{C.A.}{P_{C.A}} + \frac{W}{P_W} = 1\ m^3$$

Where (C , P_C) / (F.A ./ $P_{F.A.}$), (C.A , $P_{C.A.}$) and (W , P_W) are the weight and the specific gravity of cement , fine aggregate, coarse aggregate and water respectively. The absolute volumes of silica fume (S.F./$P_{S.F}$) and the added admixture (A / P_A) are the added in the L.H.S. of equation .

Testing Procedure

The plates were supported on four corner support . Each support was a cubic of reinforced concrete of (10 × 10 × 10) cm. with four longitudinal corner bar of mild steel (diameter = 8 mm.). Each plate model was loaded up to failure . Fig.(3) shows the loading system:

1- For the first and the second groups (the effect of silica fume content , the effect of reinforcement ratio) , we used one concentrated load at the center of the plate .
2- For the third group (the effect of the central square opening) we used a system consists of two intersecting steel I- beams (S. I. B. NO. 10) which were used for distributing the concentrated load applied at the intersection of the two beams to four equal concentrated load.

Measuring Devices

Mechanical Strain Gauge :

A mechanical strain gauge was used to determine the strains in the longitudinal direction. of the plate models. One small division of the dial gauge represents a displacement of 0.002.

Deflectometers :

Dial gauges of 0.01 mm accuracy and total capacity of 11mm., were used for deflection measurements at the bottom face of the slab.

Hydraulic Jack :

Hydraulic jack of maximum capacity 5 tons and the load is applied at the center of the plate.

Test Results

Test results of the three groups are discussed from the view point of : deflection, strain behavior, cracking behavior, and ultimate load. The values of deflection, cracking load and ultimate load for tested slabs are shown in table (2)

Load – Deflection Characteristics

The load – deflection curves were obtained using dial gauges of 10 mm. In all specimens the deflection values were recorded in three points laying along the center line of the plates. Figures (4) through (22) show the load - deflection relationship for all tested plates at different points for each incremental load, and it also include deflection comparison at different nodes for different plates of each groups.

It is clear from figures (18) and (19) that the deflection of the tested slabs are inversely proportional to the characteristic strength of concrete where the slab HSF1 which has a characteristic strength of 750 kg./cm^2 has recorded minimum deflection at all load stages while slabs NSF0, HSF2, and HSF3 have showed larger deflections as shown in figure.

Figures (20), and (21) show the deflections of the slabs reinforced with different reinforcement ratios. The deflection proportion inversely with reinforcement ratio. Slab HSR1 which have minimum reinforcement ratio has registered maximum deflection while slab HSR5 with maximum reinforcement ratio has registered minimum deflection. On the other hand the normal strength concrete slab deflects more than high strength concrete slab although they have the same reinforcement ratio.

For slabs with opening side length increase, the overall stiffness of the slab decrease, consequently the deflection increase. This is clear in figure (22).

Strain Behavior

For all the tested slabs , measurements are made to determine the distribution of concrete strain. The maximum concrete strain measured for high strength concrete slabs, and normal strength concrete slab was 0.0029 and 0.0024 respectively and thus The concrete strains never reached the crushing strain stated in the codes . Figures from (23) to (25) show the load - max strain relationship for each group.

Cracking behavior

First cracking load and Ultimate loads for all tested slabs are shown in figures (26) ,(27) and (28). For group(I) high strength concrete has shown better behavior than normal strength concrete. The cracking load for the slabs casted with high strength concrete is always bigger than the cracking load of normal strength concrete.

For group(II) -slabs with different reinforcement ratio- the cracking load is not consistent with the reinforcement ratio. In case of HSR5 the cracking load was bigger than all the previous cases. It was expected that the cracking load is proportional to the reinforcement ratio.

Crack patterns

The figures from (28) to (33) show the crack patterns recorded while load is applied to the tested plates. It is noted that the high strength reinforced concrete plates recorded higher cracks number than normal strength reinforced concrete plate as shown in this figures.

Ultimate Load

The values of ultimate load compared to the cracking load for all tested slabs are shown in figures (26) and (27) .

Group (I) of slabs (different silica fume content) , the second and third slabs gave highest values of ultimate load. These specimens have the highest characteristic strength and then the ultimate load capacity of slabs is proportional to the characteristic strength of concrete.

For group(II) , The increase in reinforcement ratio is accompanied by increase in the ultimate load capacity as expected.

Slabs with opening (group III), In general the results were consistent. as the opening side length increase, the ultimate load decrease.

Conclusions

- High strength concrete is more sensitive than normal strength concrete in designing the mix, mixing procedure, casting, and curing.
- Shrinkage - reducing admixtures are recommended to reduce drying shrinkage.
- Superplasticizing admixtures are capable of considerably improving the workability and thus we can get better compaction and higher density.
- The optimum silica fume content in high - strength concrete slabs as an replacement of the ordinary cement content (450 kg / cm^2) was approximately between 10 % and 15 % .
- The high strength concrete slabs showed higher stiffness and consequently smaller deflection values than normal strength concrete slabs and then the deflection of the tested slabs are inversely proportional to the characteristic strength of concrete.

- The cracking load for the slabs casted with high strength concrete is always bigger than the cracking load of normal strength concrete.
- High strength concrete slabs suffer more cracks than normal strength concrete slabs.
- Concrete strains in the tangential direction never attained limiting strain value of 0.0035.
- Experimental results showed that The deflection proportion inversely with reinforcement ratio.
- It was expected that the cracking load is proportional to the reinforcement ratio.
- For slabs with opening side length increase, the overall stiffness of the slab decrease, consequently the deflection increase.
- The carrying capacities (ultimate load) of high strength concrete slabs did not change with the presence of square central opening with the side length equal 10 % Of the slab side length.
- The carrying capacity decreased approximately by 5% for opening with the side length equal 20 % Of the slab side length.
- The carrying capacity decreased by about 17% for opening with the side length equal 33 %of the slab side length.

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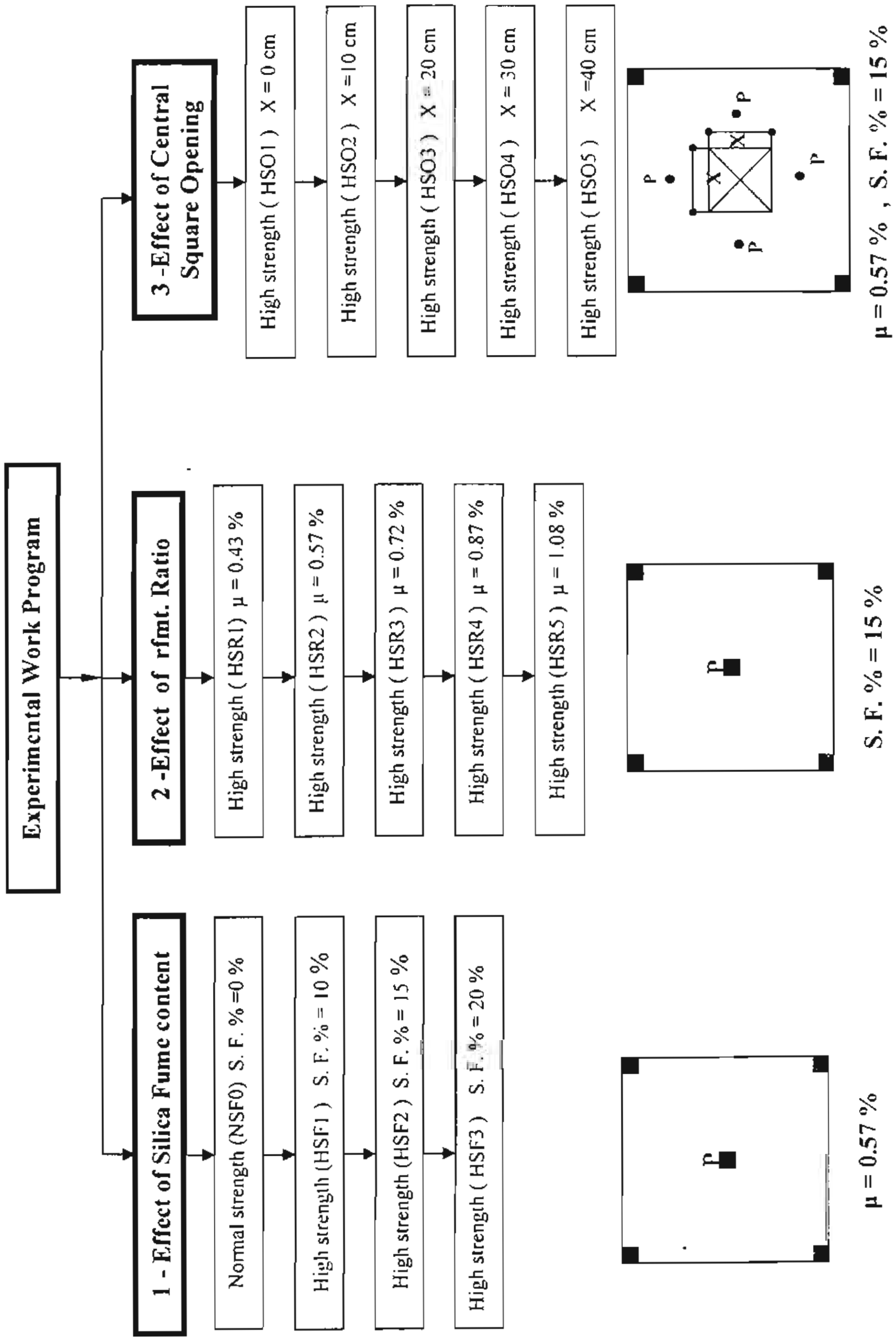
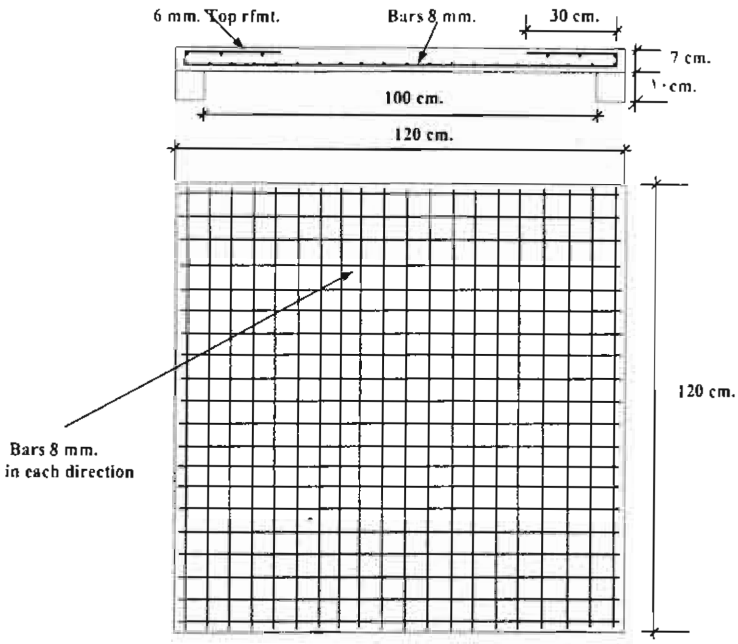
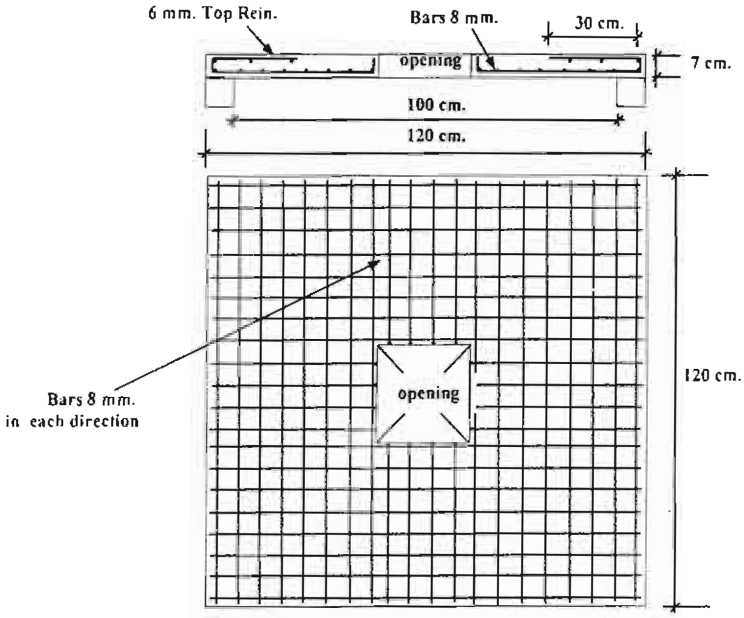

Experimental Work Program
1 - Effect of Silica Fume content
Normal strength (NSF0) S. F. % =0 %
High strength (HSF1) S. F. % = 10 %
High strength (HSF2) S. F. % = 15 %
High strength (HSF3) S. F. % = 20 %
μ = 0.57 %
2 -Effect of rfmt. Ratio
High strength (HSR1) μ = 0.43 %
High strength (HSR2) μ = 0.57 %
High strength (HSR3) μ = 0.72 %
High strength (HSR4) μ = 0.87 %
High strength (HSR5) μ = 1.08 %
S. F. % = 15 %
3 -Effect of Central Square Opening
High strength (HSO1) X = 0 cm
High strength (HSO2) X = 10 cm
High strength (HSO3) X = 20 cm
High strength (HSO4) X = 30 cm
High strength (HSO5) X =40 cm
μ = 0.57 % , S. F. % = 15 %

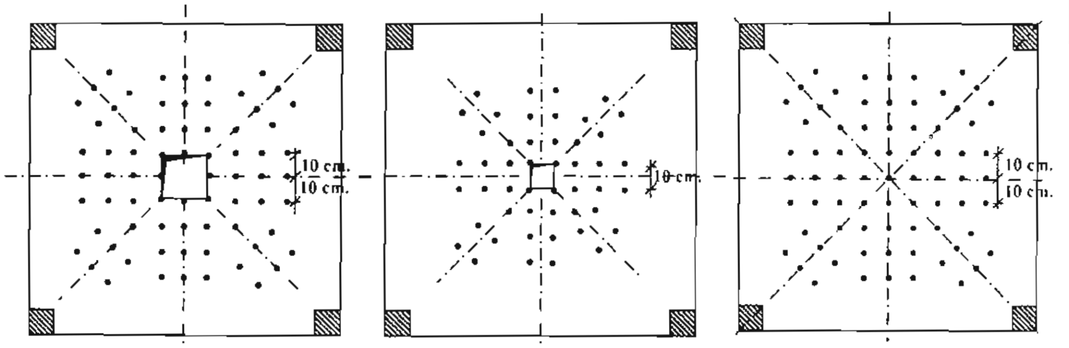


Dimensions of the typical tested slabs without opening and reinforcement details.



Dimensions of the typical tested slabs with opening and reinforcement details.

Fig. (1) Details Of Different Slab Groups

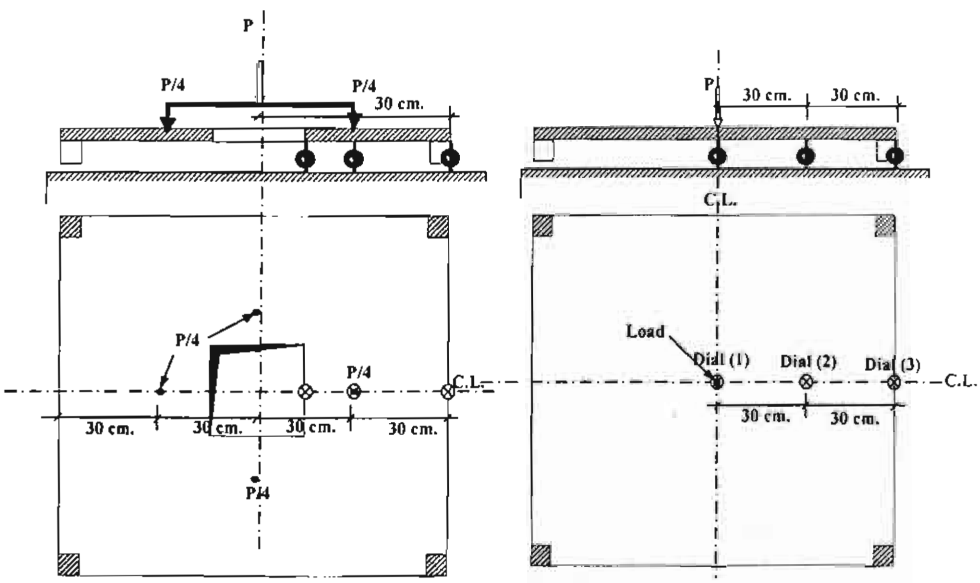


(c) Arrangement of Demec Points in Plate Modelwith Opening (20×20) , (30×30) , (40×40) Cm.

(b) Arrangement of Demec Points in Plates Model With Opening (10×10) Cm.

(a) Arrangement of Demec Points in PlatesModels without Opening

Fig. (2) Arrangement of Demec Points for Strain Measurement



Arrangement of Dial Gauges and Load Application for Slabs with Opening

Arrangement of Dial Gauges and Load Application for Plates without Opening

Fig. (3) Arrangement of Dials for Different Tested Plates

Table (4) Experimental Test Results.

Group No.	Slab	Concrete strength kg. / cm^2	Rfmt. μ, percent	First crack load (kg.)	Deflection at First crack, (mm.)		Ultimate load P_u (kg.)	deflection at Ultimate load (mm.)	
					At point (1)	At point (2)		At point (1)	At point (2)
Group (I)	NSF0	300	0.57	1400	2.21	1.94	2800	8.15	6.32
	HSF1	750	0.57	1400	1.09	0.88	3200	6.38	4.57
	HSF2	650	0.57	1600	1.67	1.2	3200	7.12	4.82
	HSF3	600	0.57	1400	1.6	0.99	3000	6.09	4.17
Group (II)	HSR1	650	0.43	1400	1.6	1.02	2800	6.1	4.57
	HSR2	650	0.57	1600	1.67	1.2	3200	7.12	4.82
	HSR3	650	0.72	1600	1.24	0.99	3200	5.54	4.2
	HSR4	650	0.87	1600	1.18	0.85	3400	6.33	4.7
	HSR5	650	1.08	2000	1.88	1.3	3400	5.02	4.21
Group (III)	HSO1	650	0.57	2200	1.84	1.61	4200	7.76	5.1
	HSO2	650	0.57	2200	1.79	1.67	4200	7.21	5.21
	HSO3	650	0.57	2800	3.55	2.81	4000	8.67	5.71
	HSO4	650	0.57	2800	4.32	3.88	4000	8.33	6.98
	HSO5	650	0.57	2400	3.89	3.46	3600	7.86	6.84

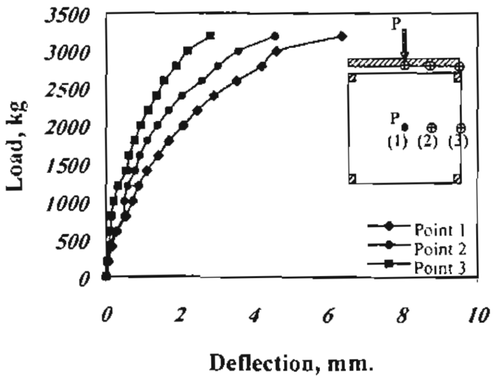


Fig. (5) Experimental Load - Deflection Relationship of Plate HSF1

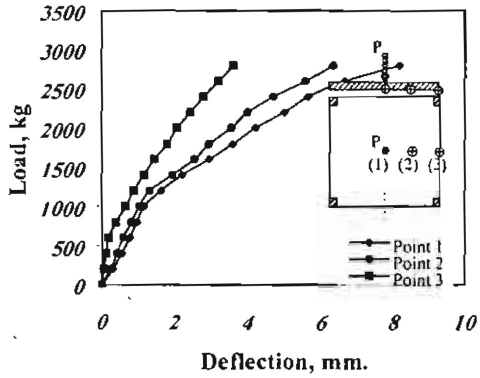


Fig. (4) Experimental Load - Deflection Relationship of Plate NSF0

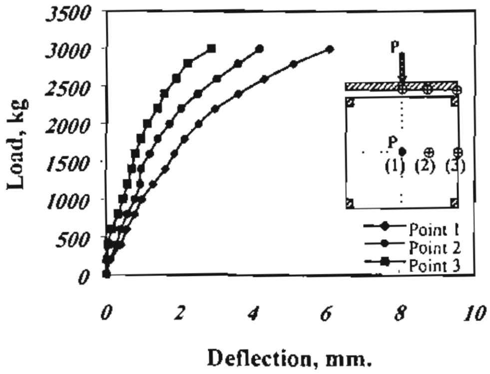


Fig. (7) Experimental Load - Deflection Relationship of Plate HSF3

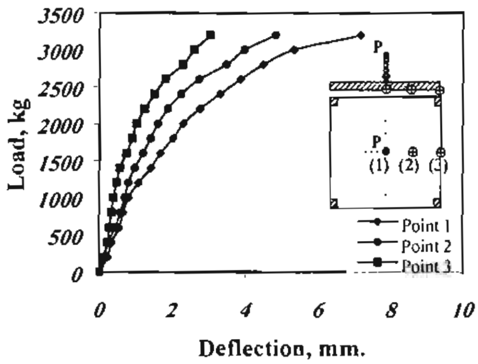


Fig. (6) Experimental Load - Deflection Relationship of Plate HSF2

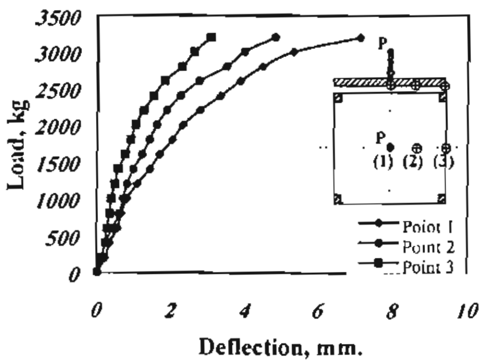


Fig. (9) Experimental Load - Deflection Relationship of Plate HSR2

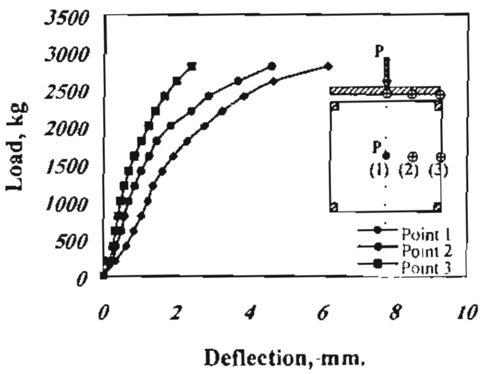


Fig. (8) Experimental Load - Deflection Relationship of Plate HSR1

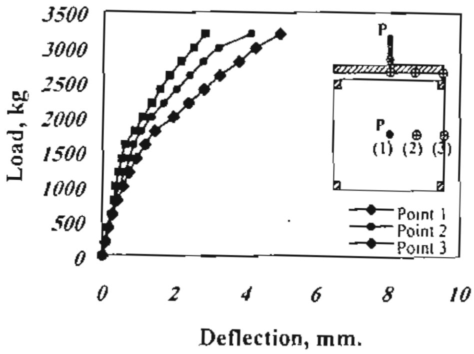


Fig. (11) Experimental Load - Deflection Relationship of Plate HSR4

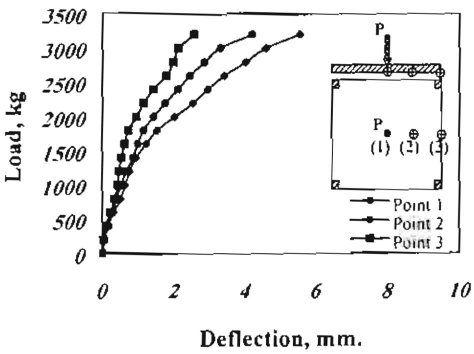


Fig. (10) Experimental Load - Deflection Relationship of Plate HSR3

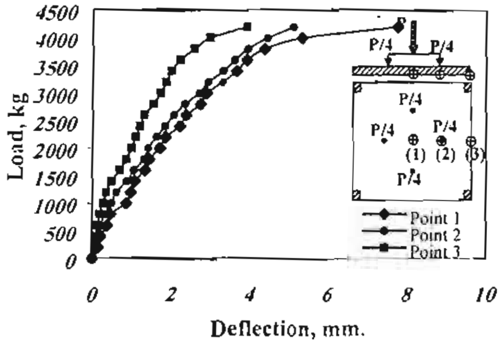


Fig. (13) Experimental Load - Deflection Relationship of Plate HSO1

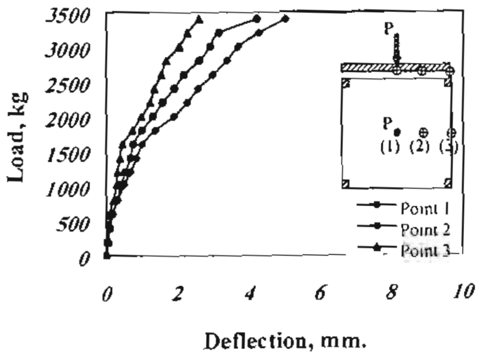


Fig. (12) Experimental Load - Deflection Relationship of Plate HSR5

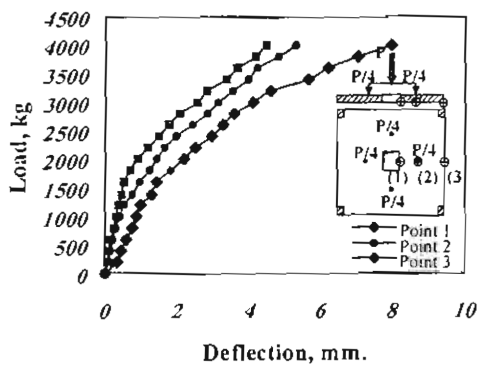


Fig. (15) Experimental Load - Deflection Relationship of Plate HSO3

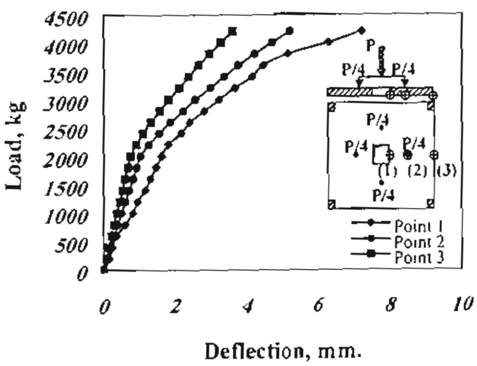


Fig. (14) Experimental Load - Deflection Relationship of Plate HSO2

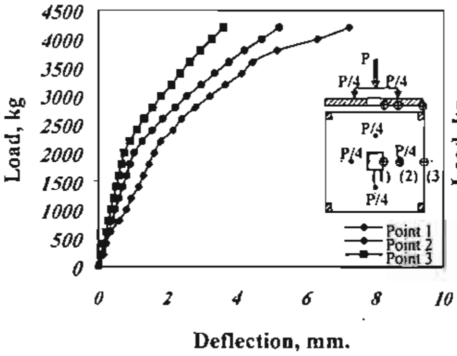


Fig. (17) Experimental Load - Deflection Relationship of Plate HSO5

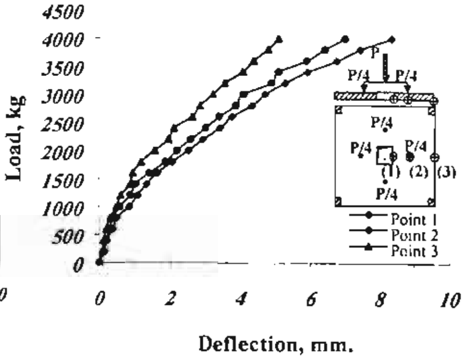


Fig. (16) Experimental Load - Deflection Relationship of Plate HSO4

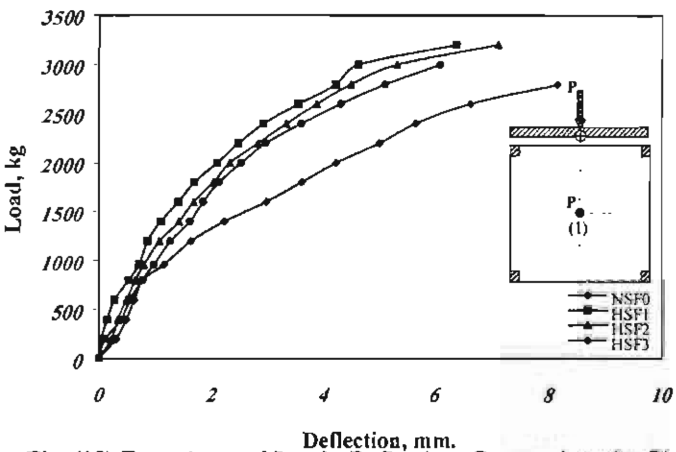


Fig. (18) Experimental Load - Deflection Comparison for Plates of Group (I) at Point (1)

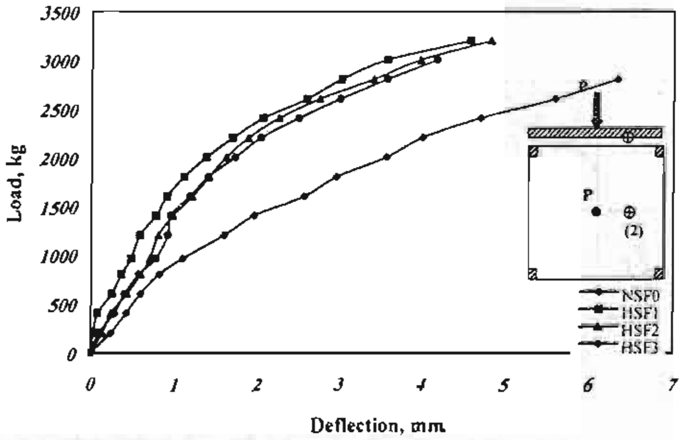


Fig. (19) Experimental Load - Deflection Comparison for Plates of Group (I) at Point (2)

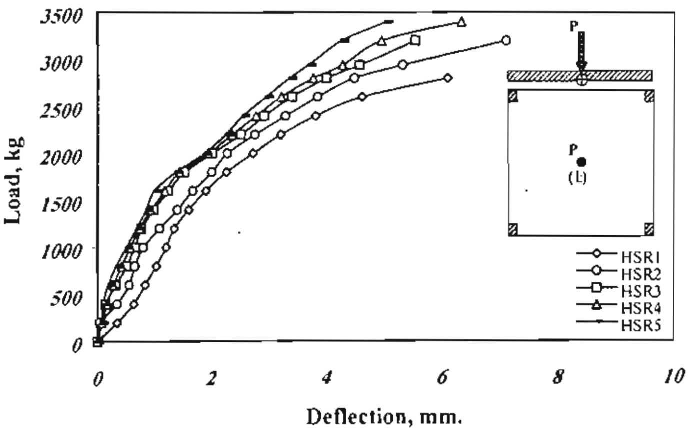


Fig. (20) Experimental Load - Deflection Comparison for plates Of Group (II) At Point (1)

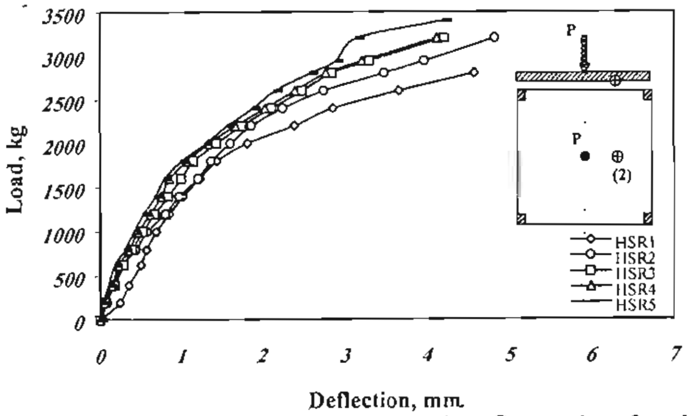


Fig. (21) Experimental Load - Deflection Comparison for plates Of Group (II) At Point (2)

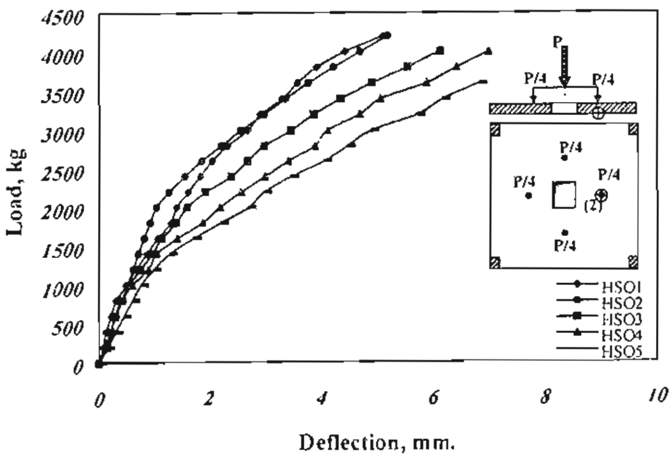


Fig. (22) Experimental Load - Deflection Comparison for plates Of Group (III) At Point (2)

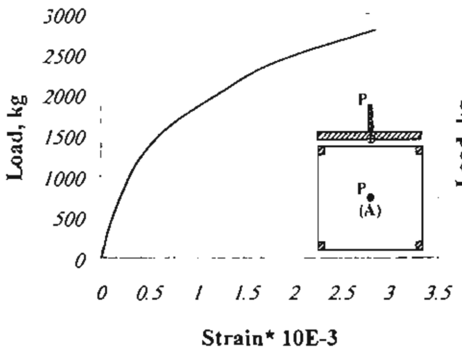


Fig.(24) Experimental Load - Max. Strain for Plate HSR1

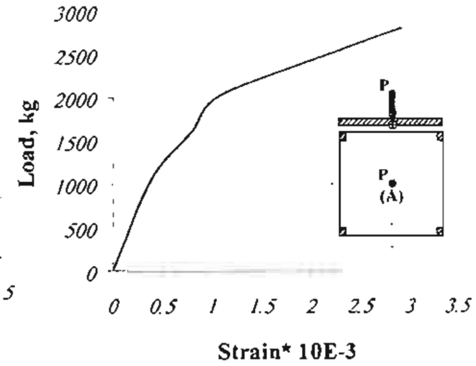


Fig. (23) Experimental Load - Max. Strain for Plate HSF3

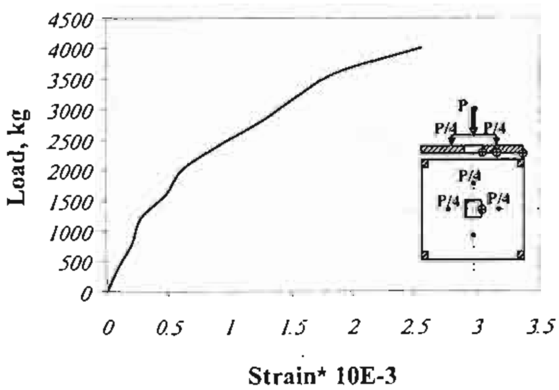


Fig.(25) Experimental Load - Max. Strain for plate HSO3

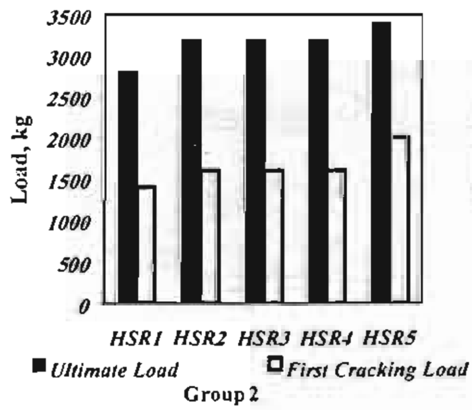


Fig. (27) Ultimate Loads And First Cracking Load For Plates Of Group (2)

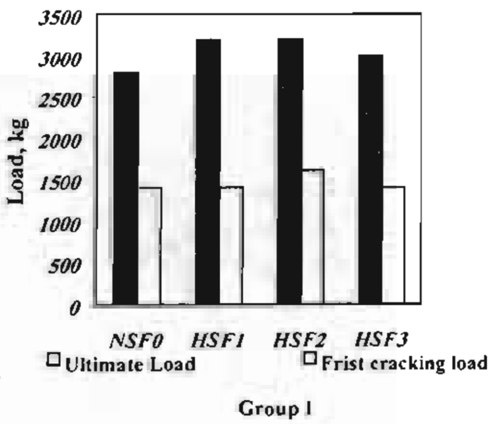


Fig. (26) Ultimate Loads and First Cracking Load For Plates Of Group (1)