MENOUFIYA UNIVERSITY
FACULTY OF ENGINEERING
ENG. RESEARCH BULL.
Vol. 17 *part* 2, 1994

P.P. : 17 : 36
Received at :1/10/1992
Accepted at :24/2/1993

BEHAVIOUR OF REINFORCED CONCRETE FLAT SLABS WITH CENTRAL OPENINGS

M.H. soliman* and E.F. El-Salakawy**

* Professor of R.C. Structures, Civ. Eng. dept. Faculty of Engineering, Menoufiya University, Shebin El-Kom, EGYPT.
** Assist. Lecturer, Civ. Eng. Dept., Faculty of Engineering, Menoufiya University, Shebin El-Kom, EGYPT.

ABSTRACT:

The behaviour of reinforced concrete flat slabs with central openings of different size and shape were investigated under the application of uniformly distributed load. The aim of investigation is to predict deflections, maximum strains, initial cracking loads, cracks propagations and finally the failure loads. A finite element program based on nonlinear analysis has been developed to analyze reinforced concrete slabs to predict their behaviour . The predicted analytical results have been compared with those of the experimental.

INTRODUCTION:

Reinforced concrete slabs often contain openings of considerable sizes for ducts, pipes, and other services. The size and the shapes of those openings might greatly affect the behaviour of such slabs. This study has been made to investigate the effect of central opening of different sizes and shapes on the behaviour and strength of reinforced concrete flat slabs with different thickness under uniform load. Comparisons between the results of the experimental work and the finite element analysis are given.

SCHEME OF EXPERIMENTAL WORK:

Ten reinforced concrete slabs each of 150 cm side length with only bottom reinforcement of 8 bars 6 mm diameter of mild steel in both directions were tested.

The considered slabs can be classified into three groups:

Group 1: Two identical solid slabs 6 cm and 4 cm thickness without openings SOX6, SOX4 respectively.
Group 2: Six identical slabs 6 cm and 4 cm thickness, with central square openings of 20, 30 and 50 cm side length, C2-6, C3 6, C5 6, C2 4, C3 4 and C5 4 respectively.
Group 3: Two identical slabs 6 cm thickness having central circular openings of 50 cm diameter C5O6 and C5O4 respectively.

The dimensions and reinforcement arrangement are shown in Fig. (1).

The Models were casted in a smooth forms made of play-wood, and three cubes were casted also as a control specimens for each mix and stripped at the same day of its model.
The concrete mix used was made of ordinary portland cement, sand and gravel of 10 mm maximum nominal size. The mix proportions by weight were:

Cement	Sand	Gravel	W/C
1 :	2 :	4 :	0.5

The average compressive cube strength after 28 days was 220 kg/cm^2. The concrete was mixed mechanically and compacted manually.

TEST PROCEDURE:

Slabs were tested after 28 days from casting. Two days before testing, a brass demec points were fixed on the bottom surface of each slab in a position to allow for 15 cm gauge length and accuracy of 0.002 mm demec strain gauge to be used. Fig. (2) shows the demec points distribution on slabs and the special arrangement made to fix dial gauges of 0.01 mm accuracy and total travel of 20 mm in the desired position to ensure proper deflection readings.

The slab models were tested using the steel structure model shown in Fig. (3), supported on four corner supports, each was a steel plate 5*5*1 cm. A compressible material of 1 cm thickness was placed between the slab and the supports to ensure uniform reaction. The slabs were loaded up to failure in increments using partially filled sand sacks each of 30 kg. The load increment was 240 kg and 120 kg for 6 cm and 4 cm thickness models respectively. After application of each load increment the strains as well as the deflections were recorded, also cracks propagation marked, and finally the cracks patterns were photographed at failure.

RESULTS OF THE EXPERIMENTAL WORK:

Deflections:

Figures (4) and (5) show the maximum deflections recorded for the tested slabs. It is obvious that slabs without openings showed the minimum deflections while the one with the biggest opening size indicated the maximum deflections.

It is noted that maximum deflections recorded for slabs with circular openings compared with those having square openings of side length equal to the circular opening diameter indicate smaller deflections.

Figures (8) through (12) show maximum deflections of the different 6 cm thickness slabs and the corresponding 4 cm thickness slabs. It is obvious that the deflections of 6 cm thickness slabs at the initial cracking loads are smaller than those of 4 cm thickness slabs, while at the failure loads the opposite is noticed.

Tables (1) and (2) show the relation between maximum deflections for the tested slabs as percentages of that of solid slabs,

Tensile Strains:

Figures (6) and (7) show the load-maximum tensile strain relationships for the tested slab. It is clear that the maximum strains were recorded for the slabs with the biggest openings dimensions and the minimum for those solid slabs. It is noted also, that the maximum strains were recorded at the edge of the openings. The relations between the maximum tensile strains for the tested slabs are almost the same as the values given in tables (1) and (2).

Cracking and Failure Loads:

Figures (13) through (17) show the cracks propagation patterns at failure loads for the three tested groups. It is noted that the main cracks for all tested slabs of square opening are passing through the corner of the opening. The maximum carrying capacity represented in failure loads were recorded in solid slabs, while the minimum were recorded for slabs with the biggest opening size. Slabs with circular opening shows more carrying capacities and nearly axisymmetrical cracks pattern than these of square openings.

THE FINITE ELEMENT PROGRAM

A finite element program based on a non linear analysis of reinforced concrete using quadrilateral isoparametric plate bending elements (12 degrees of freedom). The nonlinear relationships of stress-strain for concrete in both compression and tension besides the effect of concrete tension stiffening are considered. To account for these nonlinearities ,an incremental loading procedure using tangent stiffness method was used.

Figures (8) through (12) show comparison between analytical and experimental results.

CONCLUSIONS:

This paper was done to study the behaviour and strength of the two way reinforced concrete flat slabs with central openings under uniformly distributed loads.
From the obtained results it could be concluded that:

(1) The dimensions of the opening considerably affect the behaviour of slabs with openings. The bigger the opening size the smaller the carry capacity accompanied with larger deflections strains and more cracks propagations.

(2) Circular openings shows more carrying capacities, more uniform cracks propagation and strains distributions and less deflections than those of a square opening having a side length equal to the circular opening diameter.

(3) The effects of openings stated in conclusions (1) and (2) have an inverse relation with slab thickness.

(4) comparison between the analytical and experimental results emphasizes good agreement. The deviation in some results are due to the small thickness and dimensions of the tested slabs which were chosen to be handled manually. These deviations are smaller for slabs with 6 cm thickness than those with 4 cm thickness.

Further research work on the location of the openings and the effect of cantilever besides the openings might be of importance and suggested as future works.

REFERENCES:

[1] E.F. El-Salakawy:
" Nonlinear analysis of flat slabs with openings ",
M.Sc. Thesis , civil Eng. dept., Faculty of Engineering, Menoufiya University, Shebin El-Kom, Egypt, 1992.

[2] M. H.Soliman
" Study of behaviour and cracks propagation of reinforced concrete flat slabs ",
Menoufiya University, Bulletin, October, 1991.

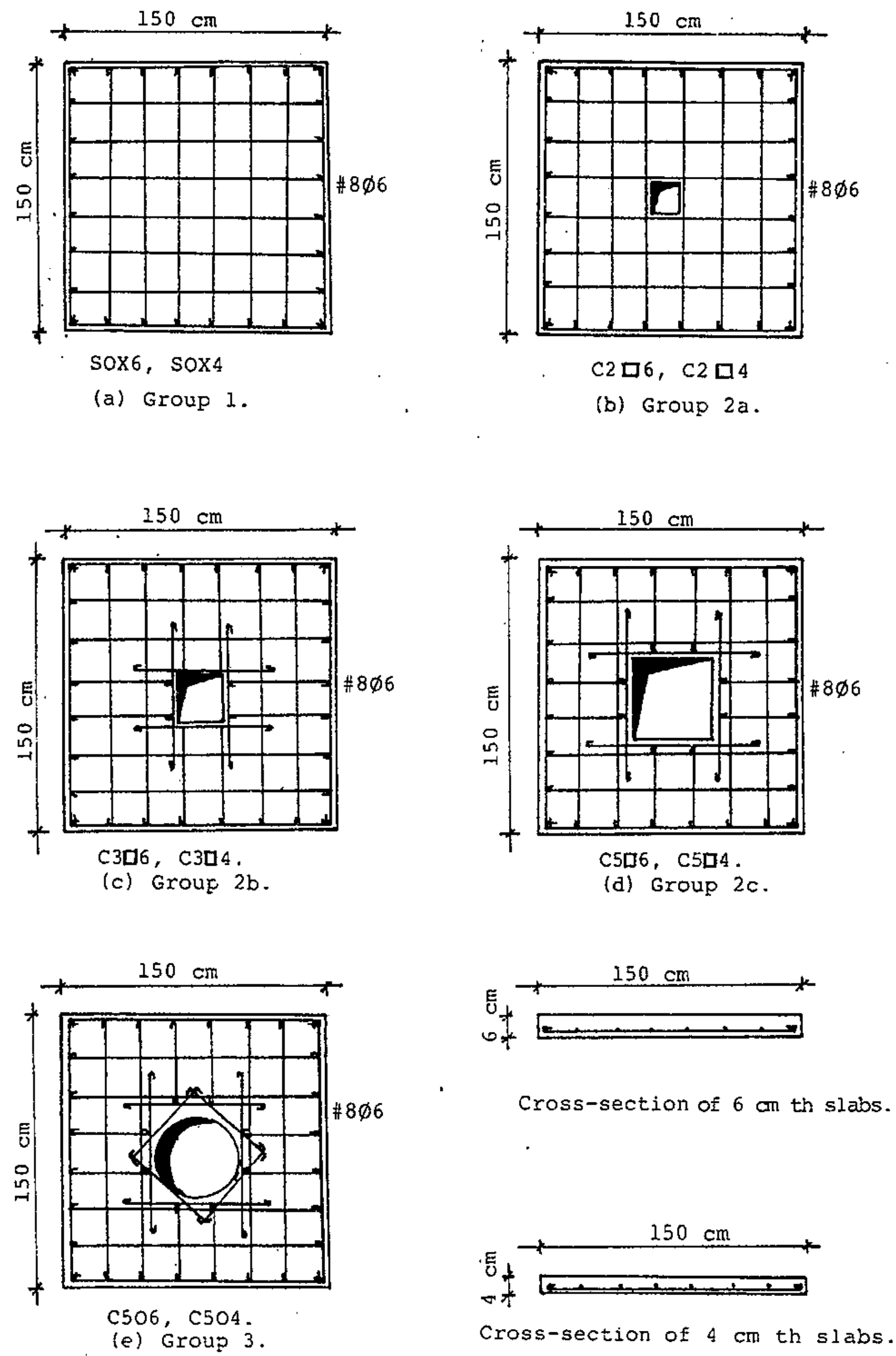
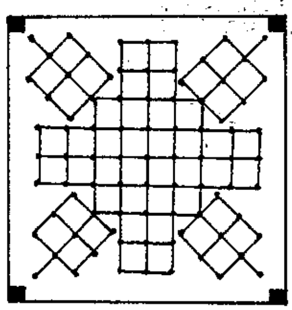
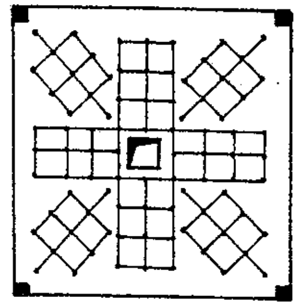


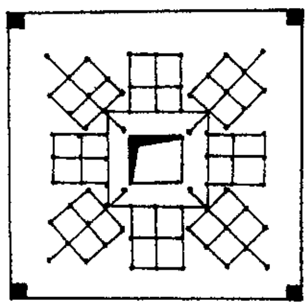
Figure (1): Dimensions and reinforcement arrangement for the tested slabs.



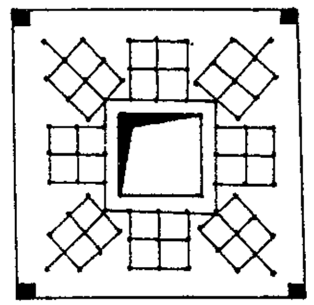
SOX6, SOX4
(a) Group 1.



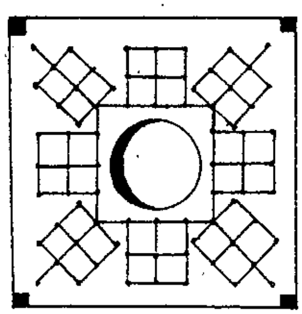
C2□6, C2□4
(b) Group 2a.



C3□6, C3□4.
(c) Group 2b.

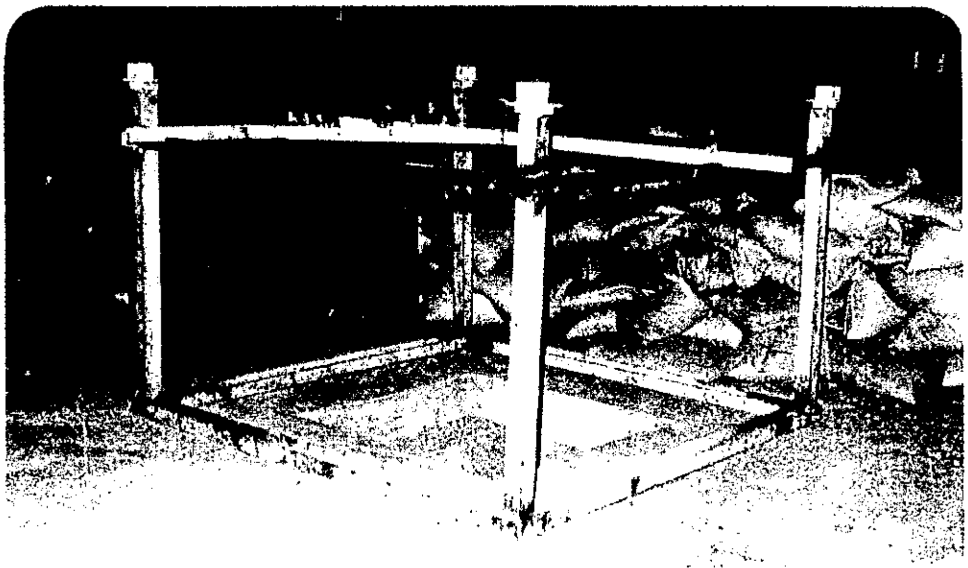


C5□6, C5□4.
(d) Group 2c.



C5O6, C5O4
(e) Group 3.

Figure (2): Demec points distribution on bottom surface of slab models.



(a) Steel structure.

(b) One of the tested slabs under loads.

Figure (3): Steel structure and dialgauge arrangement.

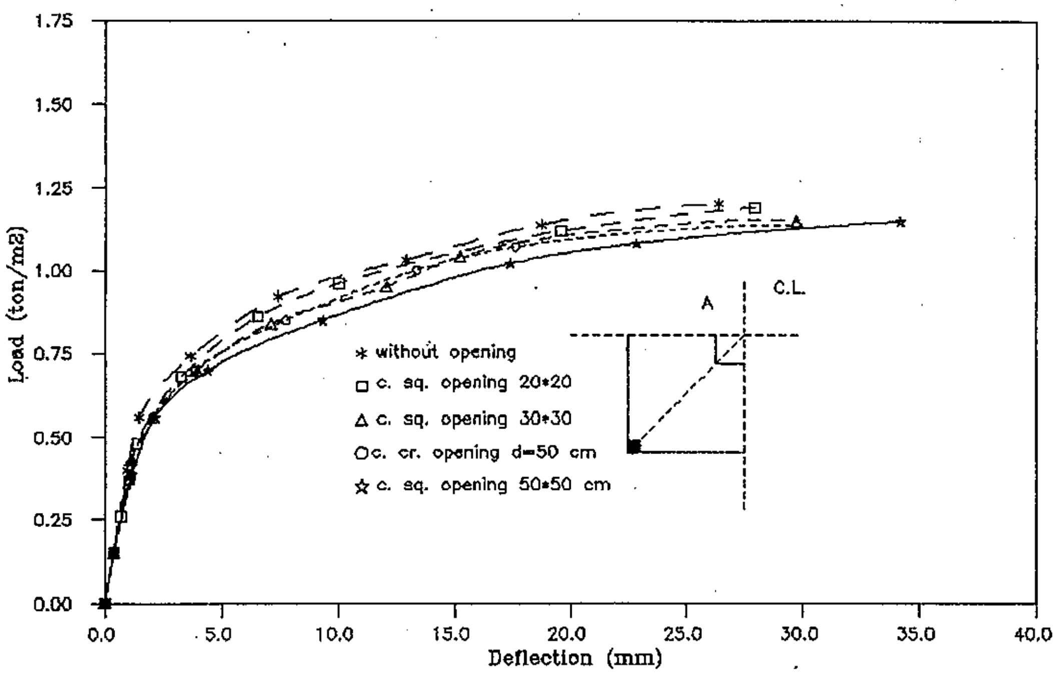


Figure (4) LOAD DEFLECTION RELATIONSHIP FOR 6cm THICKNESS PLATE WITH DIFFERENT CENTRAL OPENING SIZE (point A)

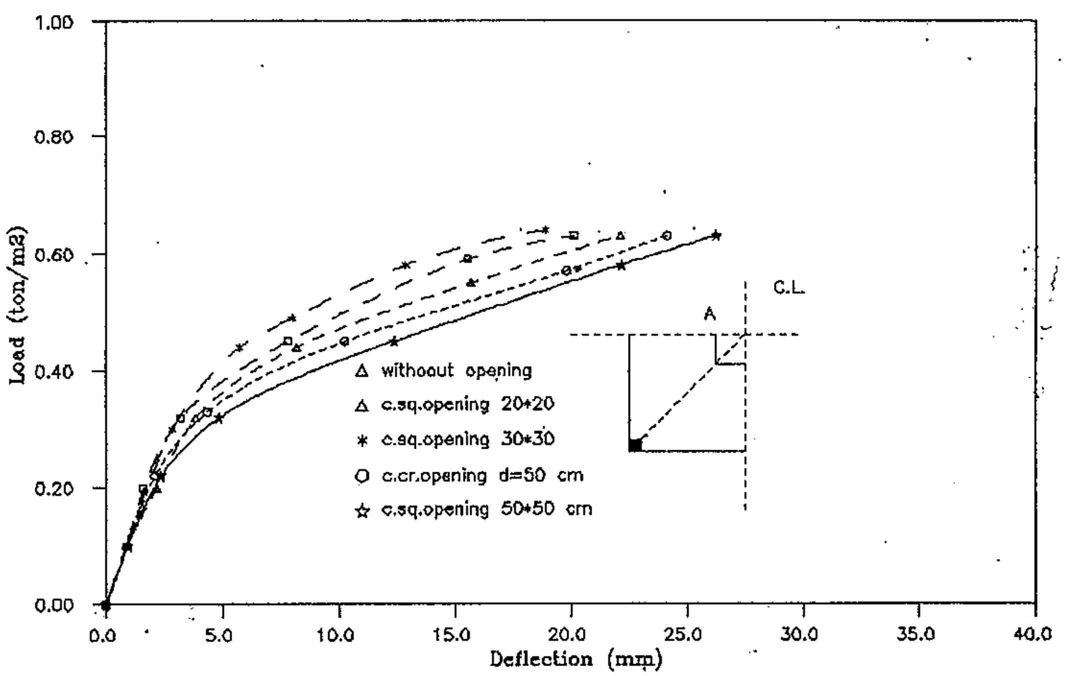


Figure (5) LOAD DEFLECTION RELATIONSHIP FOR 4cm THICKNESS PLATE WITH DIFFERENT CENTRAL OPENING SIZE(point A)

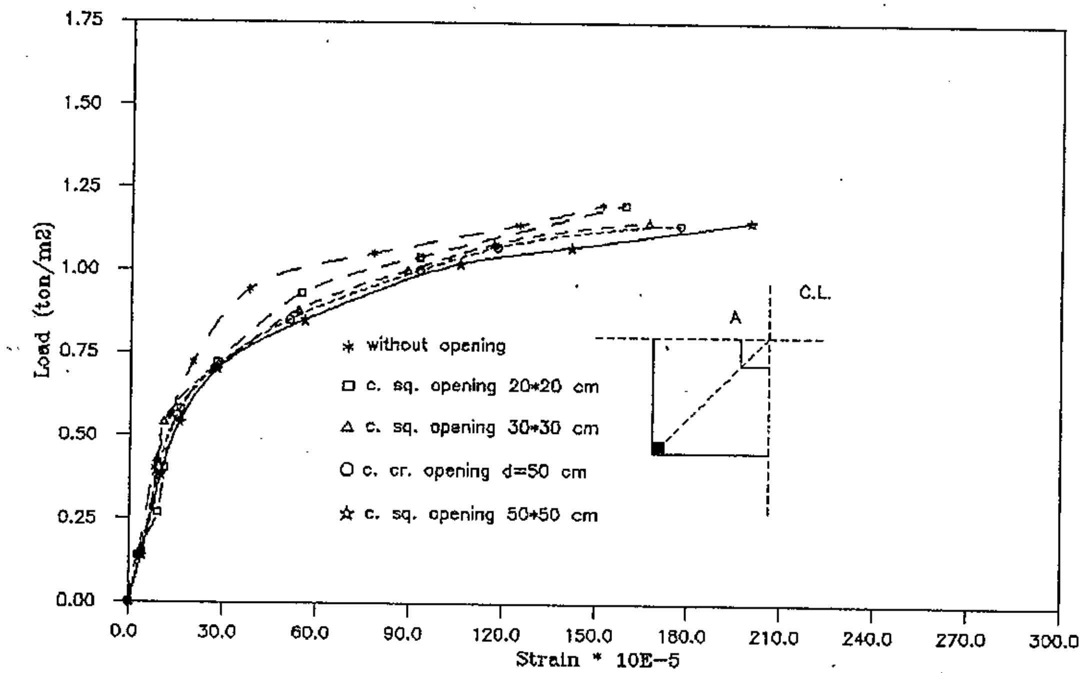


Figure (6) LOAD-MAXIMUM STRAIN RELATIONSHIP FOR 6cm THICKNESS PLATE WITH DIFFERENT CENTRAL OPENINGS (point A)

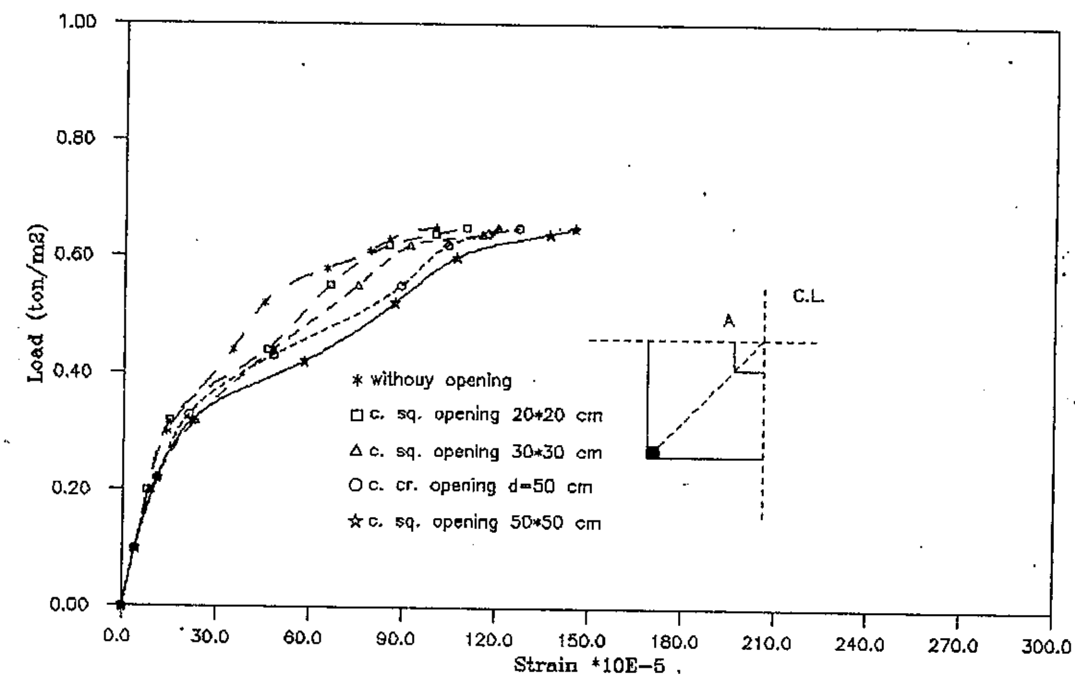


Figure (7) LOAD MAXIMUM-STRAIN RELATIONSHIPS FOR 4cm THICKNESS PLATE WITH DIFFERENT CENTRAL OPENINGS (point A)

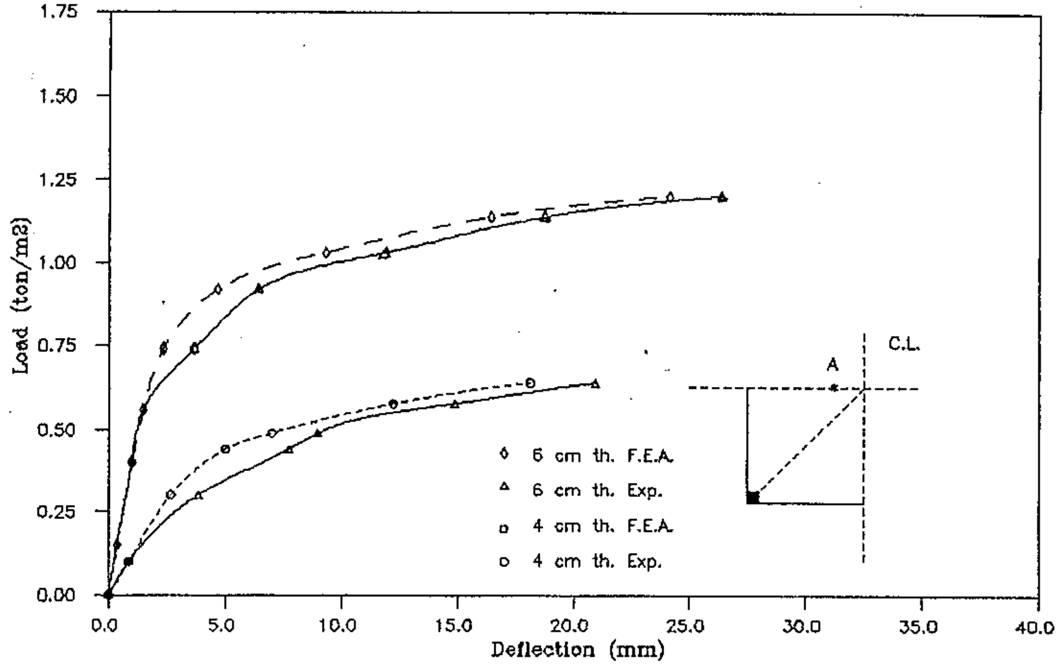


Figure (8) LOAD DEFLECTION RELATIONSHIP FOR GROUP 1 WITHOUT OPENING(point A)

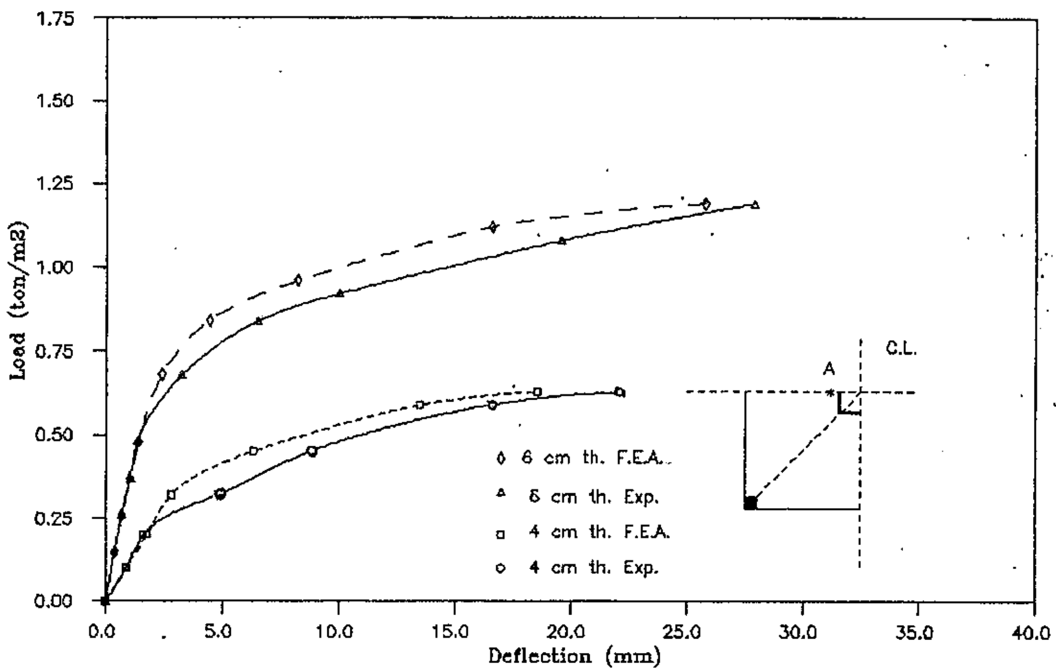


Figure (9) LOAD DEFLECTION RELATIONSHIP FOR GROUP 2a WITH SQUARE OPENING 20*20 cm(point A)

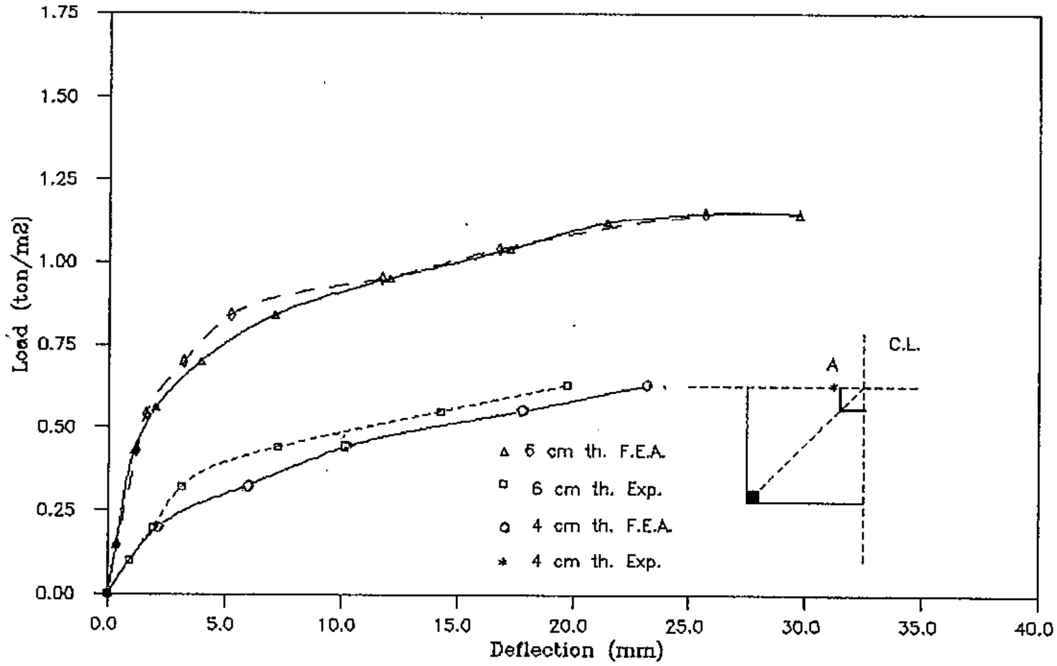


Figure (10) LOAD DEFLECTION RELATIONSHIP FOR GROUP 2b WITH SQUARE OPENING 30*30 cm(point A)

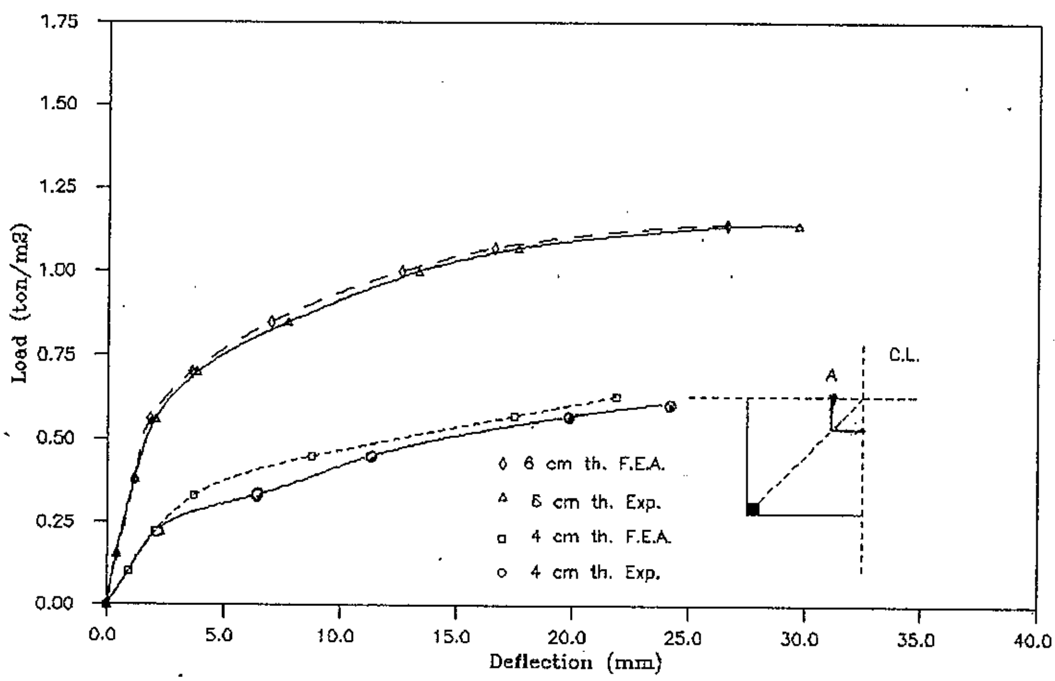


Figure (11) LOAD DEFLECTION RELATIONSHIP FOR GROUP 2c WITH SQUARE OPENING 50*50 cm(point A)

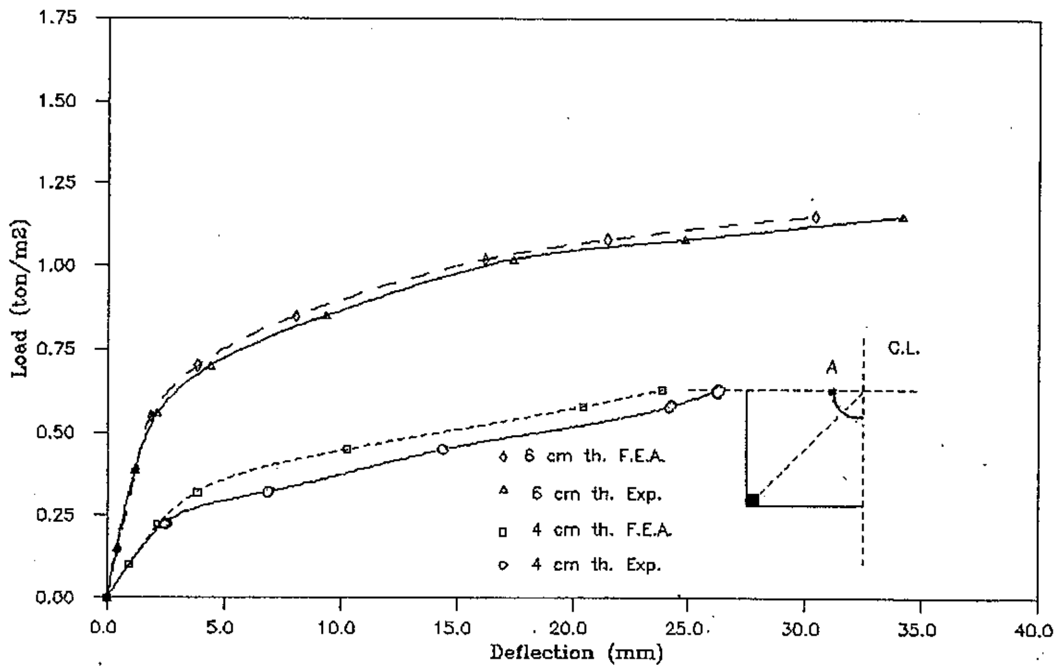


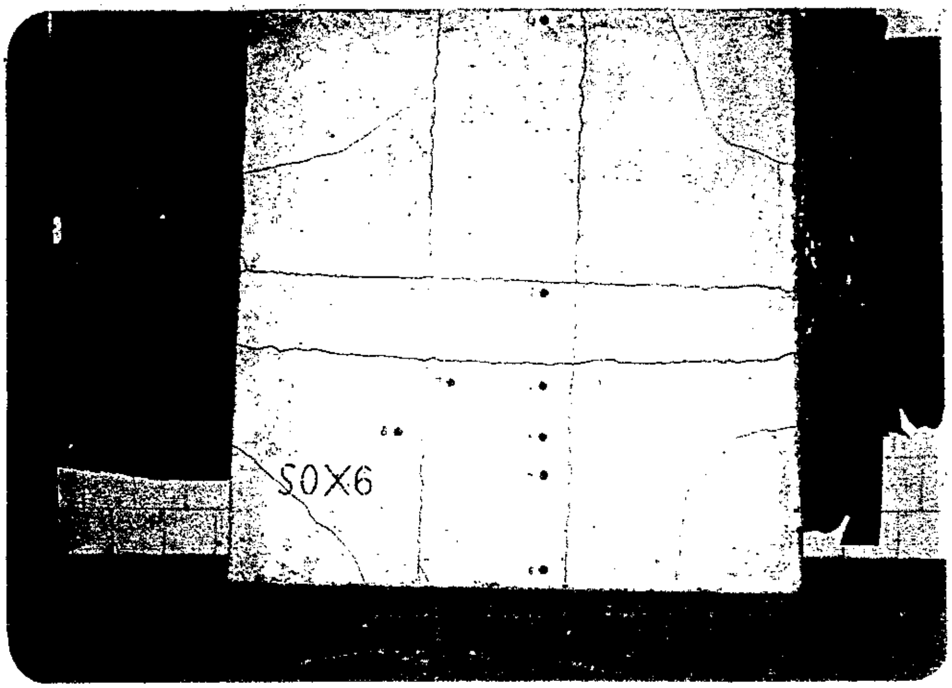
Figure (12) LOAD DEFLECTION RELATIONSHIP FOR GROUP 3 WITH CIRCULAR OPENING d=50 cm(point A)

Table (1): Relation between maximum deflections of the tested slabs.

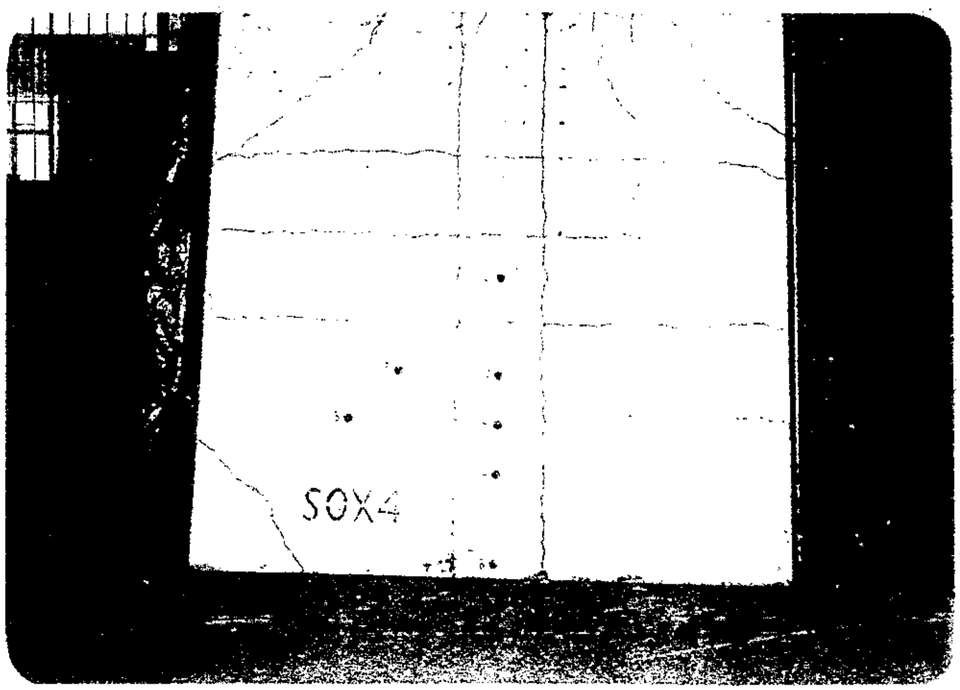
Slab \ Percentage	Max. deflections as % of Those of Solid slabs.	
	At cracking loads	At failure loads
C2□6	112	106
C2□4	113	106
C3□6	121	112
C3□4	136	117
C5□6	158	129
C5□4	170	134
C5 O 6	133	117
C5 O 4	153	127

Table (2): Comparison between maxi deflections of 6 Cm th and 4 Cm th slabs.

Slab with \ Percentage	% of max. deflection for 6 Cm th./ 4 Cm th slabs.	
	At cracking loads	At failure loads
No. Opening	59	144
Sq. opening 20 * 20	58	138
Sq. Opening 30 * 30	55	134
Sq. opening 50 * 50 .	51	130
Cr. opening d = 50 Cm	53	131

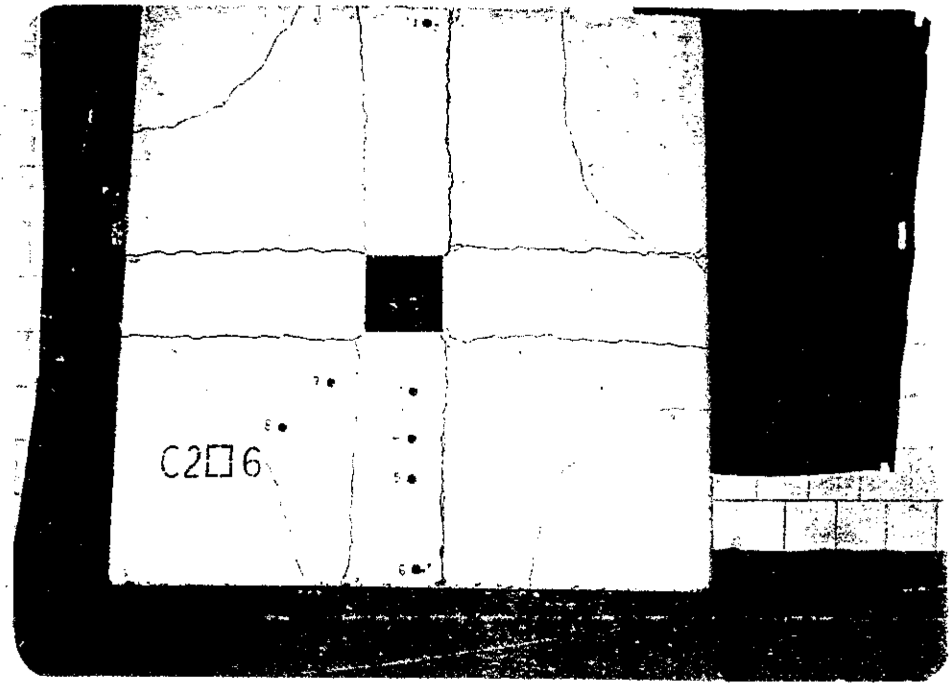


(a) SOX6.

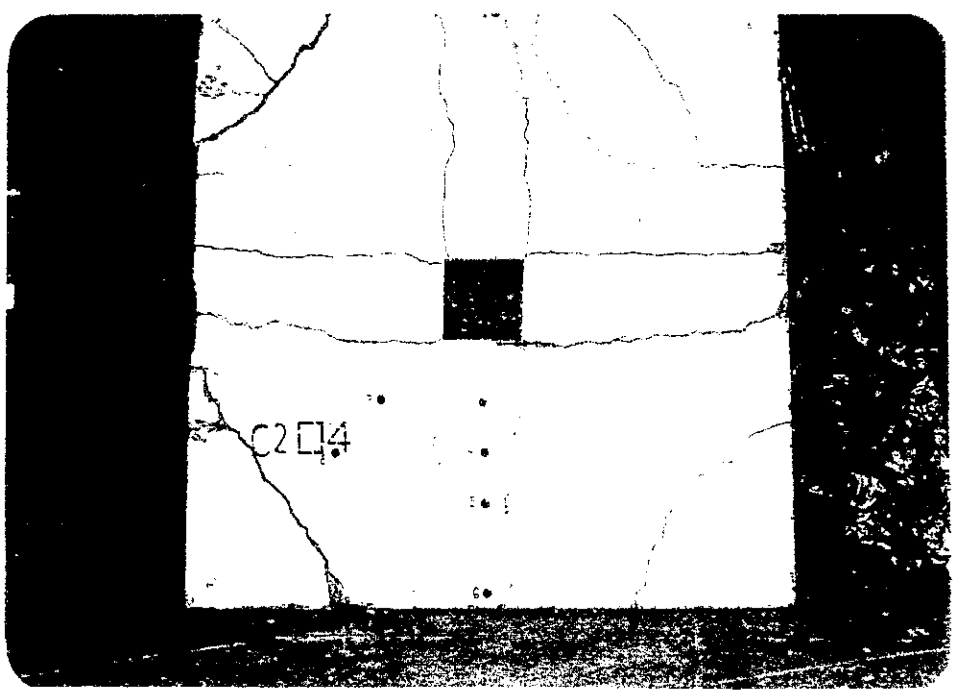


(b) SOX4.

Figure (13): Crack propagation patterns for solid slabs, Group 1.

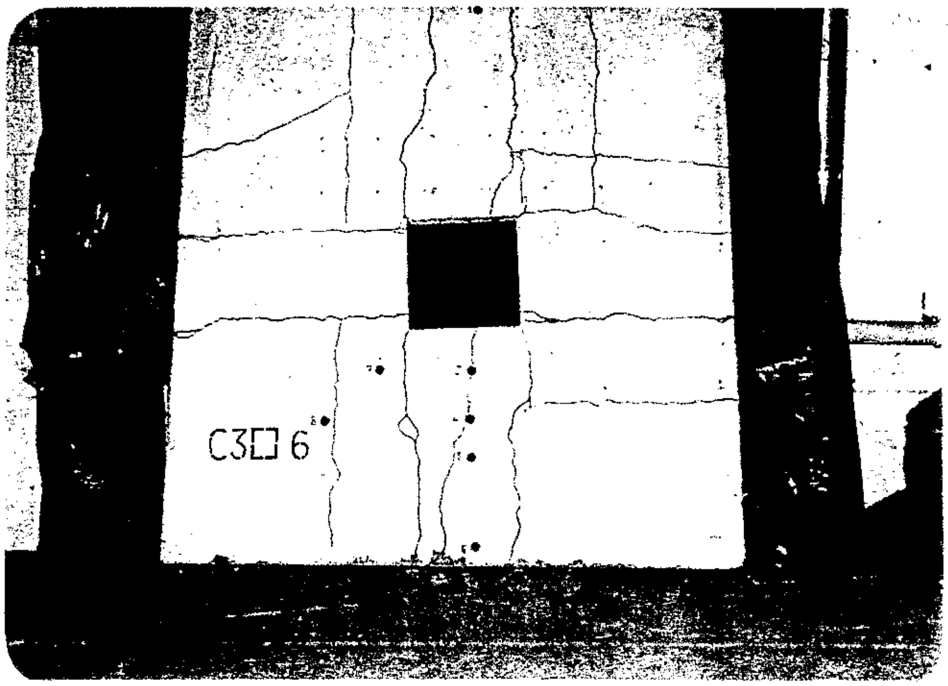


(a) 6 Cm thickness slab. C2□6.

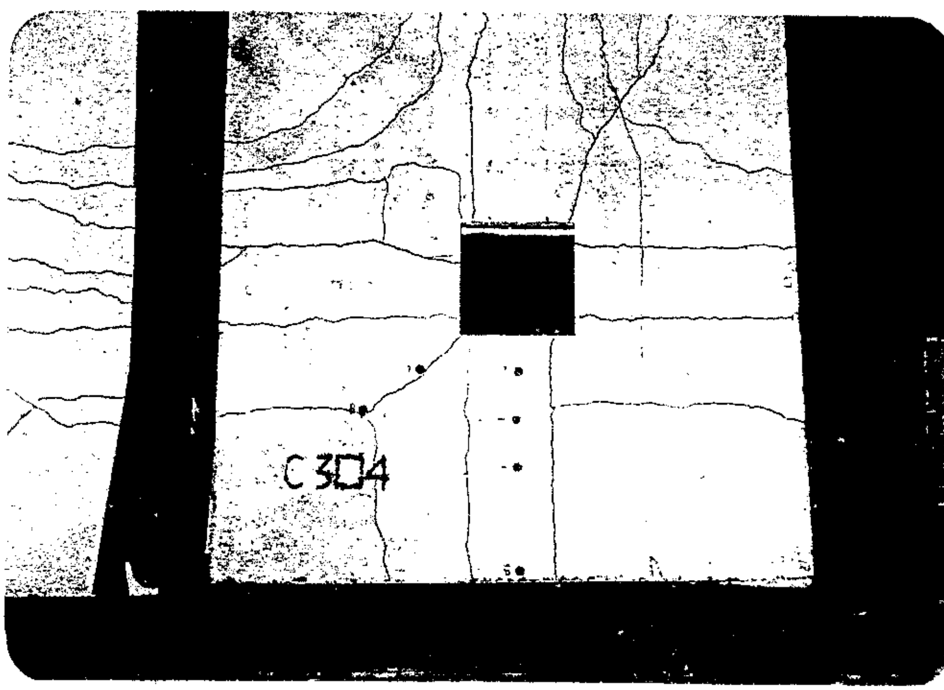


(b) 4 Cm thickness slab. C2□4.

Figure (14): Cracks propagation patterns for slabs with square openings 20x20 Cm, Group 2a.

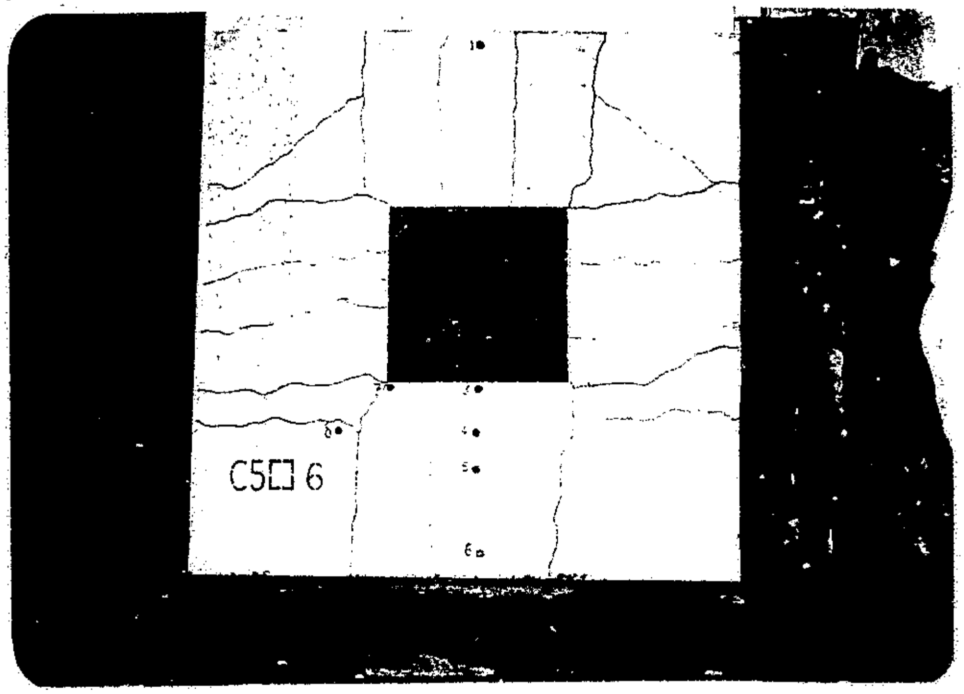


(a) 6 Cm thickness slab C3□6.

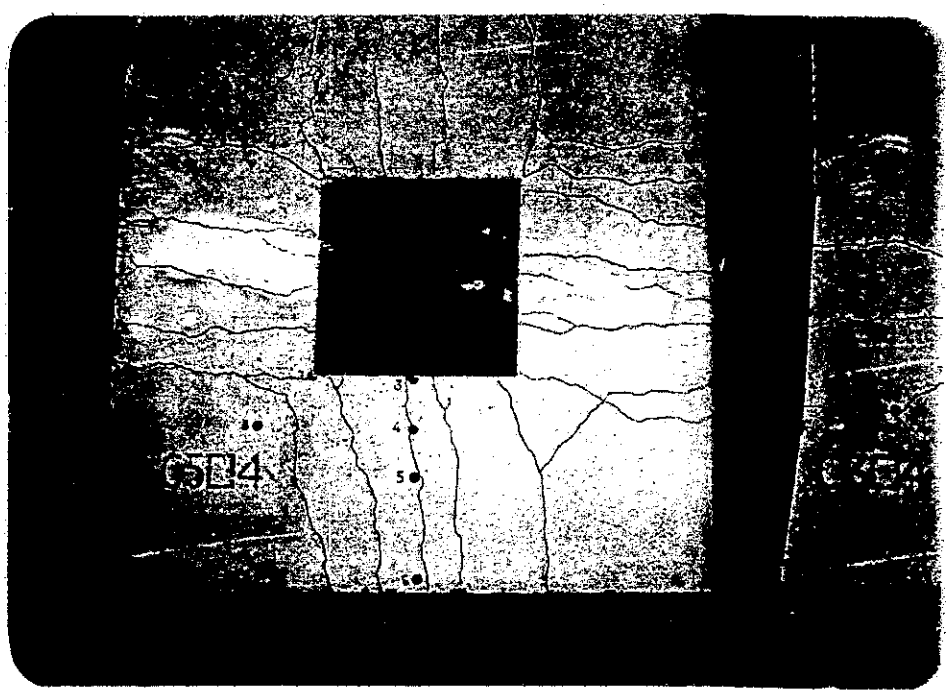


(b) 4 Cm thickness slab. C3□4.

Figure (15): Cracks propagation patterns for slabs with square openings 30x30 Cm, Group 2b.

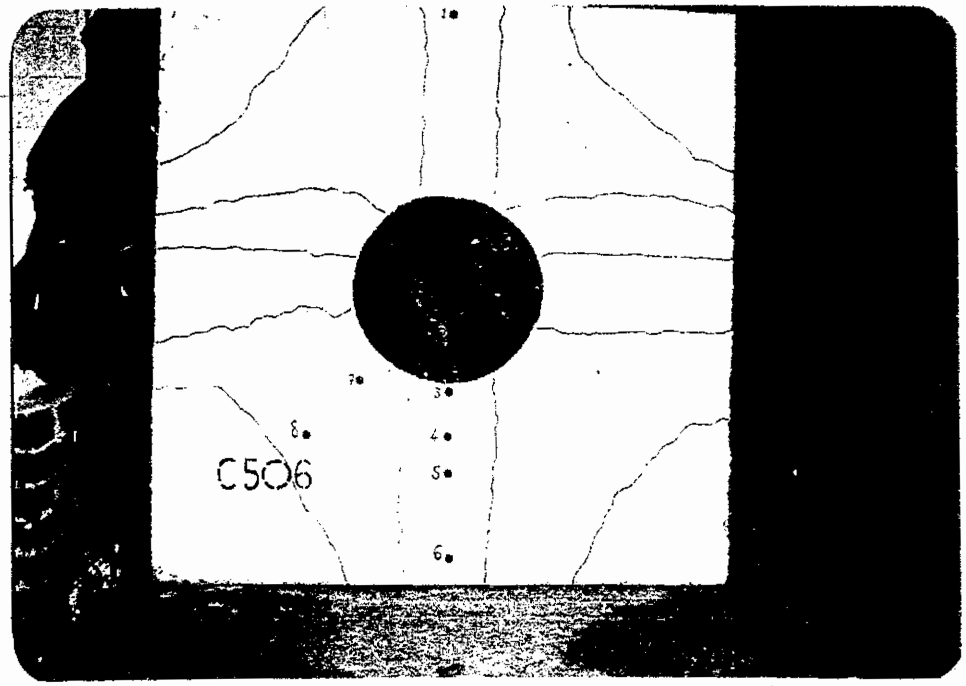


(a) 6 Cm thickness slab. C5☐6.

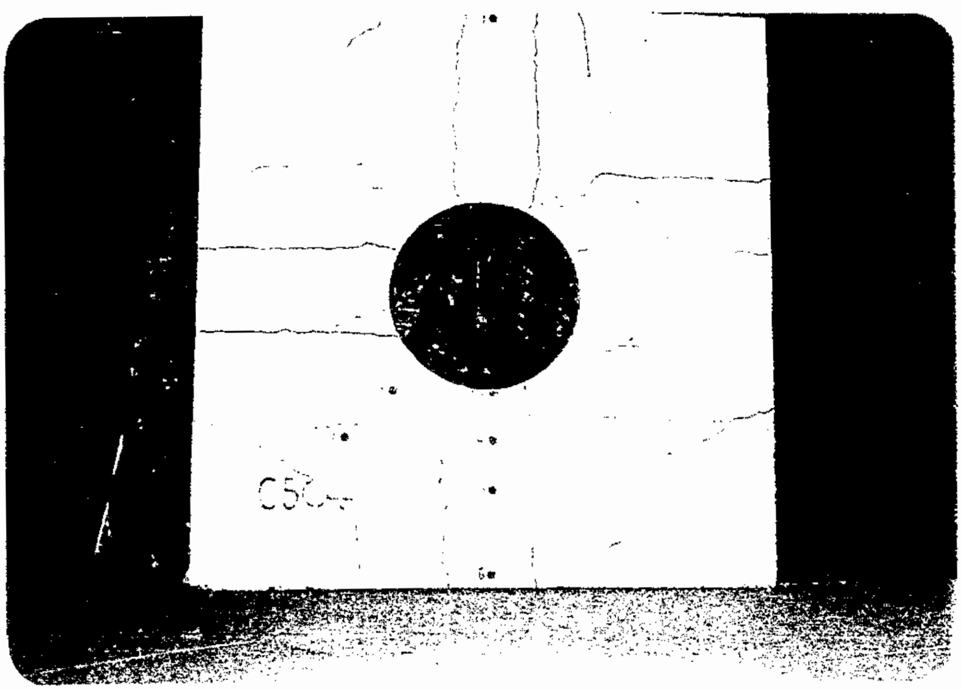


(b) 4 Cm thickness slab. C5☐4.

Figure (16): Cracks propagation patterns for slabs with square openings 50x50 Cm, Group 2c.



(a) 6 Cm thickness slab. C5O6.



(b) 4 Cm thickness slab. C5O4.

Figure (17): Cracks propagation patterns for slabs with circular openings d = 50 Cm, Group 3.

"سلوك البلاطات المستوية ذات الفتحات المركزية"

أ٠د/"منير حسين سليمان و م/"إيهاب فتحى السلكاوى"
قسم الهندسة المدنية ـ كلية الهندسة بشبين الكوم ـ جامعة المنوفية

الملخص العربى :ـ

تم اجراء تجارب معمليه على عشرة بلاطات مستويه ذات فتحات مركزية مختلفة الشكل والمقاس لدراسه سلوكها تحت تأثير الأحمال المنتظمة وإستنتاج حمل التشريخ الابتدائى وحمل الانهيار والترخيم والانفعال الأقصى وكذلك مدى إنتشار وتوزيع الشروخ ٠

إستعملت فى هذه الدراسة طريقة العناصر المحدده الغير خطية لدراسة سلوك عشرة بلاطات تماثل نظيرتها المدروسة عمليا وبمقارنة النتائج وجد أن هناك توافق كبير بينهما ٠