Non-linear Finite Element Analysis for the Behavior of Punching Shear in Flat Slabs with Openings

Fatma Sheta [1], Ezz El-Din Mostafa [2], Ayman Khalil [3]

Abstract— This study presents a theoretical investigation aiming at studying the effect of different opening size and location, and different column aspect ratio on the punching shear behavior of flat slabs with openings. A detailed parametric study is conducted on ten full scale reinforced concrete flat slab modeled using ANSYS 19. The investigated specimens are of dimensions 3000x3000x200 mm and flexural top reinforcement over column with constant ratio equal to 0.80%. It has been observed that the punching shear strength is inversely proportional to the opening size. The punching shear strength decreased by 10% when the size of the opening increased. However, the punching shear strength is directly proportional to the distance from the opening to the column's face regardless the size of the opening. On the other hand, the punching shear strength increased by 8.7% when the opening size is 600x600 mm and located away from the column's face by distance (d) compared to specimen of opening size 400x400 mm and located adjacent to column's face, it was noted that the punching shear strength is inversely proportional to the column aspect ratio.

Index Terms— Flat slabs, Punching shear, Opening size, Opening location, Aspect ratio, Nonlinear finite element analysis, ANSYS.

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1 Introduction

The flat slab system is a beamless reinforced concrete slab. In this system, the loads are directly transferred to columns through the concrete slab thickness. This type of two-way reinforced concrete slabs is widely used in construction; some of the advantages of this system are the simplicity of the formwork, the minimum time of construction, as well as the larger clear floor height. These advantages made the flat slab system a good choice for construction.

Due to the transmission of vertical loads directly to the column by the small thickness of the reinforced concrete slab, the punching shear force increases and might lead to failure. This type of failure is one of the most critical disadvantages of flat slab system, as it is a brittle sudden failure.

The presence of openings due to mechanical/electrical needs increase the risk of this brittle failure as the openings discontinuous the load path of the concrete structure. For this reason, the accurate estimation of punching shear strength of flat slabs with openings is considered as a major issue.

This research deals with flat slab specimens with openings using non-linear finite element program ANSYS19. Researchers studied the behavior of flat slabs with and without openings under the effect of various parameters such as the presence of shear reinforcement, flexural reinforcement ratio, opening size and location, and the eccentricity of the applied load.

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Rasha Mabrouk et al. (2017) [1] investigated the effect of horizontal and vertical shear reinforcement on the punching shear behavior of flat slabs without openings. They concluded that the flexural reinforcement ratio of the flat slabs has a significant on the punching shear strength. As the flexural reinforcement ratio increased from 1% to 2.45%, and the horizontal mesh spaced at 100 mm (0.5 d), the punching shear capacity of the slab increased by 18%. As the flexural reinforcement ratio increased from 0.67% to 1.64%, and the horizontal mesh spaced at 150 mm (0.7 d), the punching shear capacity of the slab increased by 35.2%. Also, for adding the vertical shear reinforcement, the punching shear strength of the flat slab increased by 10% when the used rebar diameter was bigger, and the spacing between stirrups was smaller.

Georgios P. Balomens et al. (2018) [2] studied the effect of openings size and location on the behavior of punching shear strength of flat slab. They concluded that the presence of openings reduced the punching shear capacity of the slab, and the numerical results show that the punching shear capacity of the slab for any opening placed at a distance of 4d from the face of the column regardless the size of the opening remains almost the same compared to the specimen without openings.

Nazzar et al. (2014) [3] tested the effect of opening size and location according to column's face and size on the behavior of punching shear capacity of flat slab. They concluded that the existence of openings decreased the punching shear strength, and the opening size was inversely proportional to punching shear strength, as the punching shear resistance decreased by 29.25% for larger openings, and decreased by 12.42% for smaller openings compared to the control specimen with openings. While the location of openings is directly proportional to punching shear resistance, as the punching shear strength decreased by 19.65% for opening nearest to column's face, and decreased by 13.47% for opening at distance 70 mm.

Liana L.J Borges et al. (2013) [4] tested the effect of shear reinforcement, as well as location and size of opening on the punching shear behavior of flat slabs with openings. They noted that the presence of openings increases the values of deflection. On the other hand, the presence of shear reinforcement reduces the deflection values. Also, using shear reinforcement adjacent to radial sides of openings is effective.

The analytical finite element analysis work presented in this research forms a part of a major analytical study to investigate the punching shear behavior of internal slab-column connection near openings. The objective of this paper is to study the effect of the opening size and location, as well as different column aspect ratios on the punching shear behavior of reinforced concrete flat slabs with openings at internal columns.

2 METHODOLOGY

The finite element analysis program ANSYS 19 was used. This study was conducted in two phases. The purpose of the first phase is to verify ANSYS capability of estimation of punching failure loads. This was done by simulating the experimental work conducted by Ozgur Anil et al. [5]. A comparison between the finite element results and experimental results is shown for validation.

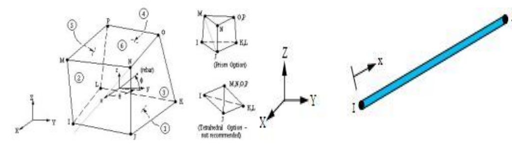
The purpose of the second phase is to perform a detailed parametric study to investigate the punching shear behavior of slab-column connections near openings.

2.1 Element types

Concrete was modeled using SOLID65 element which has eight nodes, each node has three degrees of freedom in the form of translations in X, Y, and Z directions. This element is capable of plastic deformations, cracking in tension, and crushing in compression. The geometry of SOLID65 element is shown in Figure 1 (a).

Subsequently, LINK180 element was used to model reinforcing steel rebar, this element is a 2-node element, each node has three degrees of freedom in the form of translations in X, Y, and Z directions. this element is a uniaxial tension compression element; the geometry of LINK180 element is shown in Figure 1 (b).

For loading steel plate, SOLID45 element was used for the simulation, it has eight nodes with three degrees of freedom at each node, and its translations are in X, Y, and Z directions. the geometry of SOLID45 element is shown in Figure 1 (a).



(a) SOLID65 for concrete
SOLID45 for steel plate

(b) Link180 for steel

Figure 1. Elements used for modeling concrete and steel

2.2 Material properties

- **Phase 1**

This phase simulates the work done by Ozgur Anil et al. [5]. Concrete material properties are defined as poisons ratio 0.2, and modulus of elasticity 22000 MPa in the finite element program ANSYS 19. The shear transfer coefficients for open and closed cracks were set to 0.5, and 0.7, respectively for the control specimen. As well as, for the slab with opening specimen, the shear transfer coefficients for open and closed cracks were set to 0.2, and 0.8, respectively. The uniaxial cracking stress was set to 3 MPa for both specimens. The stress-strain curve for used concrete material is shown in Figure 2, and the properties of concrete material for both specimens are summarized in Table 1.

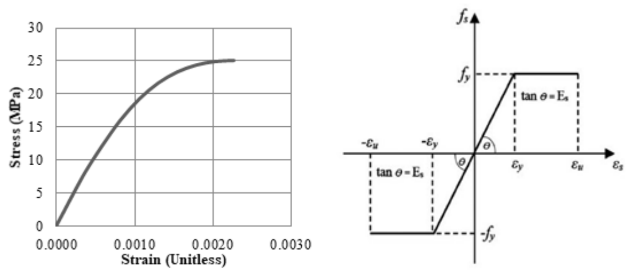
TABLE 1: MECHANICAL PROPERTIES FOR CONCRETE MODEL

Reinforced Concrete			
Linear Isotopic	Modulus of elasticity =22000 MPa		
	Poisson's ratio =0.2		
Concrete	Property	Control specimen	Slab with opening specimen
	Open shear transfer coefficient (βo)	0.5	0.2
	Closed shear transfer coefficient (βc)	0.7	0.8
	Uniaxial cracking stress	3	3
	Uniaxial crushing stress	25	25
	Tensile crack factor	0.6	0.6

The material definition for steel reinforcement rebar was assumed elastic perfect plastic with Poisson's ratio of 0.3, and modulus of elasticity 200000 MPa. The properties of material for both steel reinforcement and steel plate elements are summarized in Table 2, and the idealized stress-strain curve for steel material is shown in Figure 2.

TABLE 2: MATERIAL PROPERTIES FOR STEEL REINFORCEMENT AND STEEL PLATES

Steel Reinforcement Rebar	
Linear Isotropic	Modulus of elasticity =200000 MPa
	Poisson's ratio =0.3
Bilinear Isotropic	Yield stress =480 MPa
	Tang. Model =480
Steel Plate	
Linear Isotropic	Modulus of elasticity =200000 MPa
	Poisson's ratio =0.3



Concrete stress strain curve

Idealized stress strain curve for steel

Figure 2. Stress-strain curves for concrete and steel

- **Phase 2**

This phase represents the theoretical parametric study. Concrete material properties are defined as Poisson's ratio 0.2, and modulus of elasticity 24100 MPa in the finite element program ANSYS 19. The shear transfer coefficients for open and closed cracks were set to 0.5, and 0.7, respectively for the control specimens. As well as, for the slab with opening specimens, the shear transfer coefficients for open and closed cracks were set to 0.2, and 0.8, respectively. The modulus of rupture was calculated by the following equation of ECP 203-2018 [6], and set to 3.28 MPa for all specimens

$$f_{ctr} = 0.6\sqrt{fcu}$$

The stress-strain curve for used concrete material is shown in Figure 3 and the properties of concrete material for all specimens are summarized in Table 3.

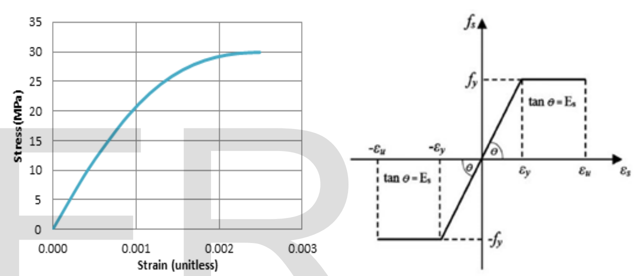
TABLE 3: MECHANICAL PROPERTIES FOR CONCRETE MODEL

Reinforced Concrete			
Linear Isotopic	Modulus of elasticity =24100 MPa		
	Poisson's ratio =0.2		
Concrete	Property	Control specimen	Slab with shear rft and/or opening specimen
	Open shear transfer coefficient (βo)	0.5	0.2
	Closed shear transfer coefficient (βc)	0.7	0.8
	Uniaxial cracking stress	3.28	3.28
	Uniaxial crushing stress	30	30
	Tensile crack factor	0.6	0.6

The material definition for steel reinforcement rebar was assumed linearly as poisons ratio of 0.3, and modulus of elasticity 200000 MPa. The properties of material for steel reinforcement and steel plate element are summarized in Table 4, and the idealized stress-strain curve for steel material is shown in Figure 3.

TABLE 4: MATERIAL PROPERTIES FOR STEEL REINFORCEMENT AND STEEL PLATES

Steel Reinforcement Rebar	
Linear Isotropic	Modulus of elasticity =200000 MPa
	Poisson's ratio =0.3
Bilinear Isotropic	Yield stress =400 MPa (for flexural and comp. RFT)
	Yield stress =350 MPa (for stirrups)
	Tang. Model =400
Area of used link section	T10=78.5 mm²
	T12=113 mm²
	T16=201 mm²
	T18=254.5 mm²
	T22=380 mm²
Steel Plate	
Linear Isotropic	Modulus of elasticity =200000 MPa
	Poisson's ratio =0.3



Concrete stress strain curve

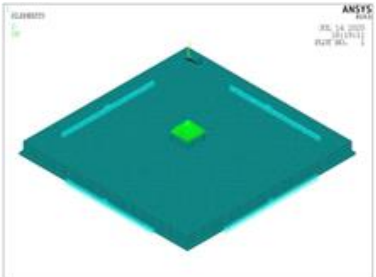
Idealized stress strain curve for steel

Figure 3. Stress-strain curves for concrete and steel

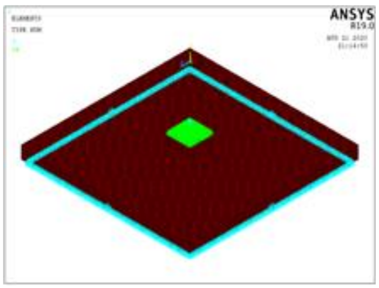
2.3 Loads and boundary conditions

In order to ensure that the finite element model get a unique solution for all specimens modeled in both verification and parametric study, four lines of nodes were given constrain in the vertical direction (Y-direction) only. for the horizontal movement, there were four quadrant nodes constrained in the two main directions (X, and Z) directions.

The displacement Δ is concentrated in the master node of the column as a displacement control choice, the loads and boundary conditions for both verification and parametric study are shown in Figure 4.



a) Verification models

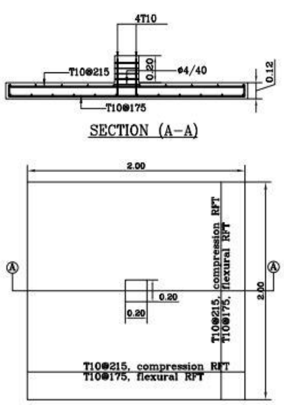


b) Parametric models

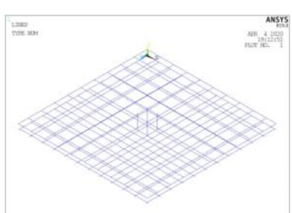
Figure 4. Boundary conditions and applied loads for modeled

2.4 Phase one

Two slab specimens with dimensions of (2000x2000x120) mm were modelled. The first specimen was a control specimen without openings, and reinforced by steel rebar of diameter 10 mm spaced 175 mm center to center for compression reinforcement mesh, and 215 mm center to center for flexural reinforcement mesh as shown in Figure 5.



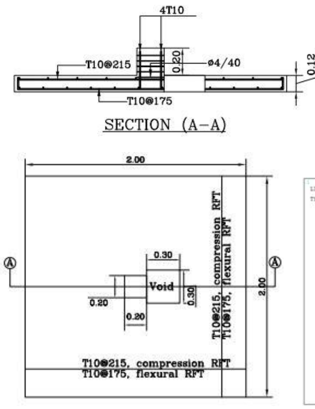
a) Specimen geometry



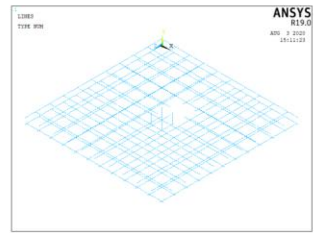
b) Mesh reinforcement

Figure 5. Details of control specimen

The second specimen was a slab with opening of size (300x300) mm, and reinforced by steel rebar of diameter 10 mm spaced 175 mm center to center for compression reinforcement mesh, and 215 mm center to center for flexural reinforcement mesh as shown in Figure 6.



a) Specimen geometry



b) Mesh reinforcement

Figure 6. Details of slab with opening specimen

Table 5 summarize the comparison of the ultimate punching load and the corresponding ultimate deflection of the experimental results recorded by Ozgur Anil el al. [5], and the results obtained from the finite element model.

TABLE 5: COMPARISON OF EXPERIMENTAL AND NUMERICAL ANALYSES RESULTS

Spec.	Maximum load (kN)			Corrsponding max. deflection (mm)		Deflection at service load (mm)		
	$V_{Exp.}$	$V_{Num.}$	Diff. (%)	$\delta_{Exp.}$	$\delta_{Num.}$	$\delta_{Exp.}$	$\delta_{Num.}$	Diff. (%)
Control	194	175	9.77	37.6	37.2	11	8	-18
With opening	99	108	9.10	18.1	15.5	5.3	3.8	-28

Figure 7 shows the load-deflection curves for both analytical and experimental results for control specimen, and the slab with opening specimens. both the experimental and analytical specimens failed in a brittle mode showing typical punching shear behavior. it has been noted that the difference between ultimate punching load obtained from the finite element model and experimental results didn't exceed ±9.77, and ± 9.1 % for control specimen and slab with an opening specimen, respectively. as well as, the difference between the corresponding ultimate deflection recorded during the experimental work and deflection obtained from the finite element model didn't exceed ±18, and ±28 % for control specimen and the slab with an opening specimen, respectively. The experimental and analytical results showed that the presence of an opening adjacent to column's face reduced the ultimate punching load by 48%, and 38%, respectively when compared to the control specimen without openings.

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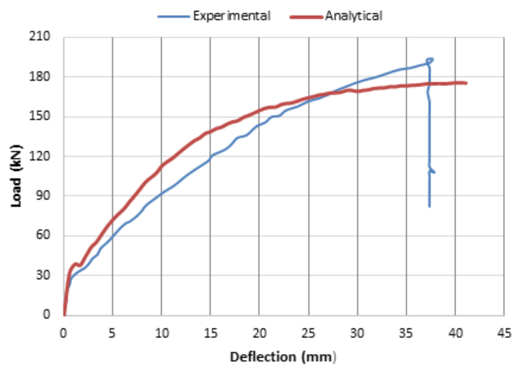
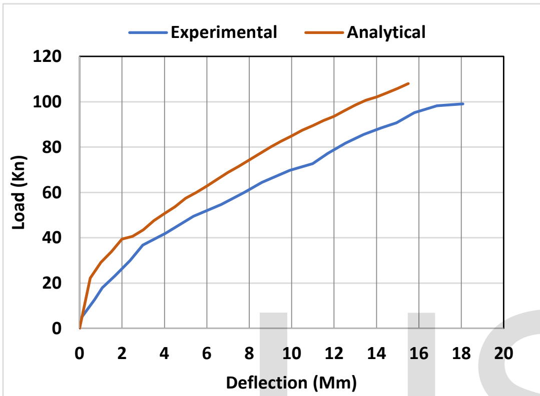


a) Control specimen



b) Slab with opening specimen

Figure 7. Comparative load-deflection

Generally, from the previous results it can be concluded that the analytical results are in a good agreement with the recorded experimental results, and the analytical work done by using ANSYS19 is very satisfactory and reliable in the study of other various parameters in the next step, namely, the effect of opening size and location, as well as, the column aspect ratios on the punching shear behavior of reinforced concrete flat slab with openings at internal columns.

2.5 Phase two

For an adequate simulation, ten full scale specimens were investigated. All the investigated specimens were of slab dimensions (3000x3000x200) mm, and with column of size (400x400) mm with three different aspect ratios (1:1, 3:2, 2:1). The investigated slabs were reinforced with flexural reinforcement ratio of 0.80% as steel rebar of diameter 16 mm spaced 125 mm center to center in both directions, and for the compression steel reinforcement rebar of diameter 10 mm was used and spaced 125 mm center to center in both directions. Table 6, Figure 8, and Figure 9 show the details of the ten investigated specimens.

Specimen S was the control slab specimen without openings, specimens S01, S02, and S03 were with column of size (400x400) mm(control columns) with column aspect ratio (1:1) and openings of sizes (400x400) mm adjacent to column's face, (600x600) mm adjacent to column's face, and (600x600) mm at distance d from the column's face were added to S01, S02, and S03, respectively. Specimens S04, S05, and S06 were with column of size (320x480) mm with column aspect ratio (3:2) and openings of sizes (400x400) mm adjacent to column's face, (600x600) mm adjacent to column's face, and (600x600) mm at distance d from the column's face were added to S04, S05, and S06, respectively. And specimens S07, S08, and S09 were with column of size (270x540) mm with column aspect ratio (2:1) and openings of sizes (400x400) mm adjacent to column's face, (600x600) mm adjacent to column's face, and (600x600) mm at distance d from the column's face were added to S07, S08, and S09, respectively in order to investigate these two parameters on the behavior of the slab.

TABLE 6 DESCRIPTION AND DETAILS OF ALL SPECIMENS

Sub-set ID	Spec. ID	Column		Opening dims. (XxY) mm		Distance (L)
		Dims. (axb) mm	Aspect ratio	X	Y	
Control	S	400x400	1:1	No openings		No openings
I	S01	400x400	1:1	400	400	------
	S02			600	600	------
	S03			600	600	d
II	S04	320x480	3:2	400	400	------
	S05			600	600	------
	S06			600	600	d
III	S07	270x540	2:1	400	400	------
	S08			600	600	------
	S09			600	600	d

* a: is the smallest column's dimension.
* b: is the largest column's dimension.
* X, Y: are the dimensions of opening.
* L: is the distance from the edge of column to the edge of opening.

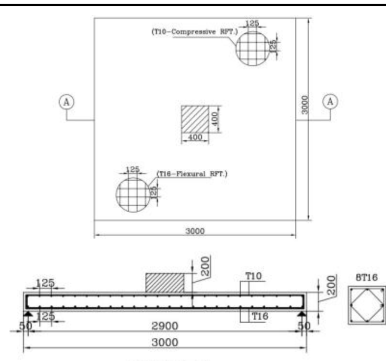


Figure 8. Geometry and reinforcement of specimen "S"

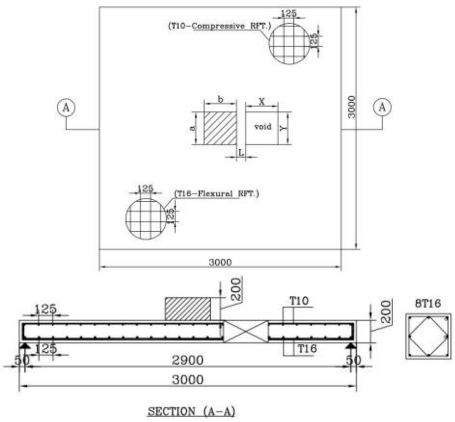


Figure 9. Geometry and reinforcement of specimens "from S01 to S09"

3 Results and Discussion

The investigated ten full scale specimens of group A were divided into three sub-sets, each one focusing on one parameter under study. All the results of the investigated specimens are discussed in this section.

3.1 Effect of opening size and location

The presence of opening reduced the punching shear capacity by 27.3, 34.7, and 21%, of specimens S01, S02, and S03, respectively, when compared to the control specimen S. but, the deflection increased by 30, 45, 25%, of specimens S01, S02, and S03, respectively, when compared to the control specimen S. It is obvious that the punching shear resistance is inversely proportional to the opening size as the opening size increased from (400x400) mm to (600x600) mm, the punching shear strength reduced by 10%. On the other hand, the deflection increased by 11%.

The punching shear resistance is directly proportional to the distance from edge of column to edge of opening, as the punching shear strength increased by 21% for specimen S03 with opening located at distance d from the column's face when compared to specimen S02 with opening of the same size but located adjacent to column's face.

As well as, the punching shear strength increased by 8.7% for specimen S03 with opening located at distance d from the column's face when compared to specimen S01 with opening of smaller size, and located adjacent to column's face. On the other hand, the deflection decreased by 14% for specimen S03 with opening located at distance d from the column's face when compared to specimen S02 with opening of the same size but located adjacent to column's face, and slightly decreased by 4.8% for specimen S03 with opening located at distance d from the column's face when compared to specimen S01 with opening of smaller size, and located adjacent to column's face.

The obtained results from ANSYS 19 of sub-set I are summarized in Table 7.

TABLE 7: ANALYTICAL RESULTS OF THE OPENING SIZE AND LOCATION EFFECT

Sub-set ID	Spec. ID	Opening dims. (XxY) mm		Distance (L)	ANSYS results			Difference	
		X	Y		Vu (kN)	δ_{ult} (mm)	$\delta_{serv.}$ (mm)	V_u/V_c	$\delta_{serv.}/\delta_c$
Control	S	Control			772	26	6.4	V_c	δ_c
I	S01	400	400	----	561	18	8.4	0.73	1.30
	S02	600	600	----	504	16.4	9.3	0.65	1.45
	S03	600	600	d	610	20	8	0.79	1.25

*d: the effective depth of the slab.
*Vc: comparable failure load value.
* δc: comparable deflection value.
* L: is the distance from the edge of column to the edge of opening.

Figure 10 shows the load deflection curves of sub-set I compared to the control specimen SP.00 to investigate the effect of opening size and location on the punching shear behavior of flat slab with openings.

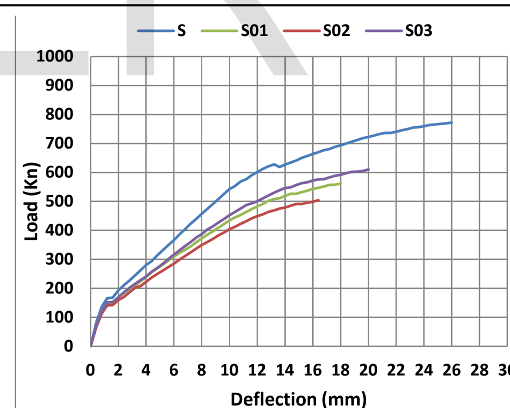


Figure 10. Load-Deflection curves of group A, Sub-set I

3.2 Effect of column aspect ratio

It has been noted that the column aspect ratio has a significant effect on the punching shear capacity of the slab as the punching shear resistance of specimen S04 was approximately the same as S01 when the aspect ratio increased from 1 to 1.5, but when the aspect ratio increased from 1 to 2, the punching shear resistance of specimen S07 reduced by 3% when compared to S01, and the deflection for S04 was the same as S01 when the aspect ratio increased from 1 to 1.5, and slightly increased by 2% for S07 when compared to S01 as the aspect ratio increased from 1 to 2 for slabs with opening size (400x400) mm, and located adjacent to column's face.

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For specimens with opening of size (600x600) mm and located adjacent to column's face, it has been noted that the punching shear resistance decreased by 5% for S05 when compared to S02 as the aspect ratio increased from 1 to 1.5, and decreased by 10% for S08 when compared to S02 as the aspect ratio increased from 1 to 2. On the other hand, the deflection slightly increased by 2% for S05 as the aspect ratio increased from 1 to 1.5 when compared to S02, and increased by 10.4% for S08 when compared to S02 as the aspect ratio increased from 1 to 2.

For specimens with opening of size (600x600) mm and located at distance "d" from the column's face, it has been noted that the punching shear resistance decreased by 6.7% for S06 when compared to S03 as the aspect ratio increased from 1 to 1.5, and decreased by 4% for S09 when compared to S03 as the aspect ratio increased from 1 to 2. On the other hand, the deflection slightly increased by 5.3% for S06 as the aspect ratio increased from 1 to 1.5 when compared to S03, and slightly increased by 5.3% for S09 when compared to S03 as the aspect ratio increased from 1 to 2. The obtained results from ANSYS 19 of sub-set I, II, and III are summarized in Table 8.

TABLE 8: ANALYTICAL RESULTS OF THE EFFECT OF COLUMN ASPECT RATIO

Spec. ID	Col. dims. (mm)	Opening dims. (XxY) mm		Distance (L)	ANSYS results			Difference	
		X	Y		Vu (kN)	δ_{ult} (mm)	$\delta_{serv.}$ (mm)	V_u/V_c	$\delta_{serv.}/\delta_c$
S01	400x400	400	400	--	561	18	5.2	V_c	δ_c
S02		600	600	--	504	16.4	4.8	V_c	δ_c
S03		600	600	d	610	20	5.7	V_c	δ_c
S04	320x480	400	400	--	563	17.2	5.2	1.00	1.00
S05		600	600	--	477	15.6	4.9	0.95	1.02
S06		600	600	d	569	17.6	6	0.93	1.05
S07	270x540	400	400	--	544	17.6	5.3	0.91	1.02
S08		600	600	--	452	15.6	5.3	0.90	1.10
S09		600	600	d	585	19.2	6	0.96	1.05

*d: the effective depth of the slab.
*Vc: comparable failure load value.
* δc: comparable deflection value.
* L: is the distance from the edge of column to the edge of opening.

Figure 11, Figure 12, and Figure 13 show the load deflection curves of sub-set II, and III when compared to specimen of sub-set I to investigate the effect of different column aspect ratios on the punching shear behavior of flat slab with opening.

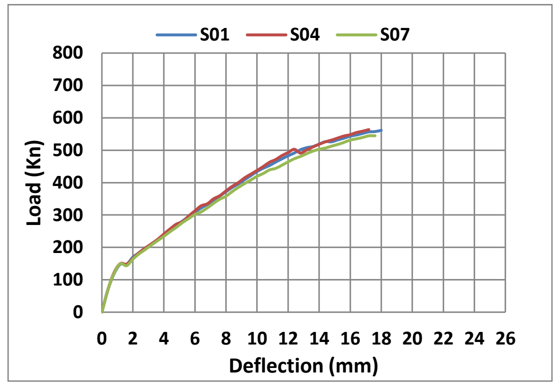


Figure 11. Load-Deflection curves of group A, opening size (400x400) mm

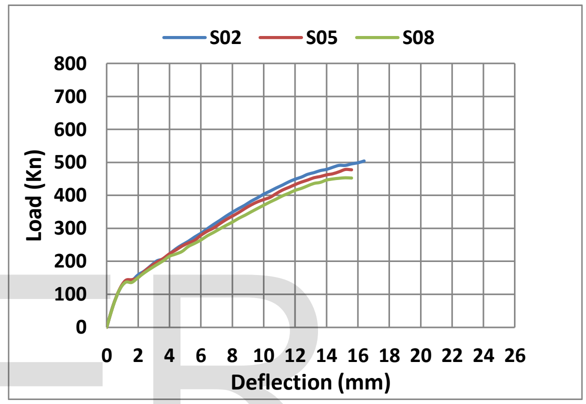


Figure 12. Load-Deflection curves of group A, opening size (600x600) mm

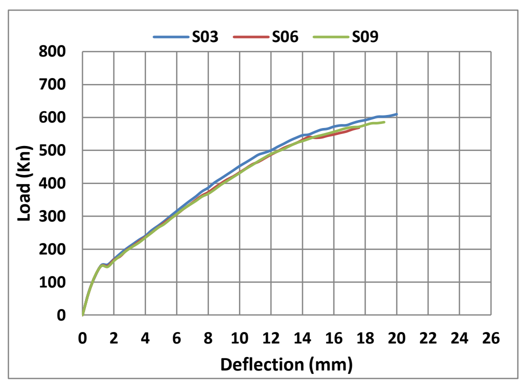
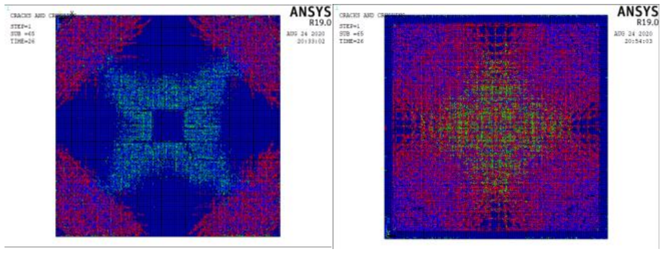


Figure 13. Load-Deflection curves of group A, opening size (600x600) mm at d

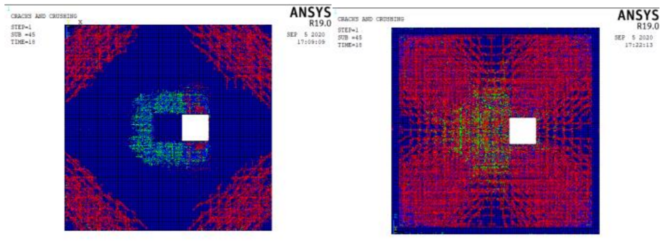
3.3 Crack patterns

The crack pattern is shown at top and bottom of the investigated flat slab specimens in the finite element model. For all investigated specimens the behavior changes after the first flexural crack appeared, as the load increase the cracks extended and widened toward the support of the slab with different speeds. Generally, the mode of failure of all investigated specimens is a brittle failure as shown in figures from Figure 14 to Figure 23.



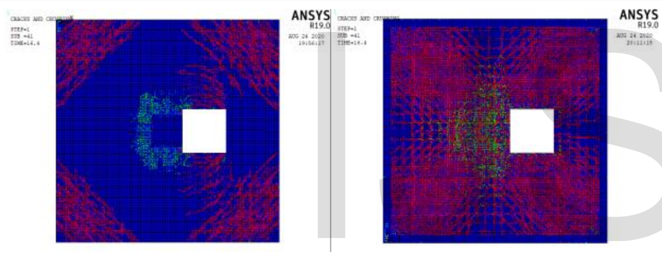
Top View Bottom View

Figure 14. Cracking pattern at top and bottom for S



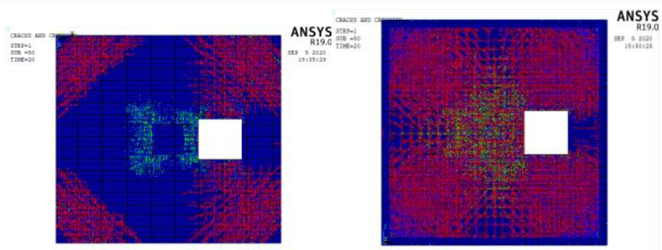
Top View Bottom View

Figure 15. Cracking pattern at top and bottom for S01



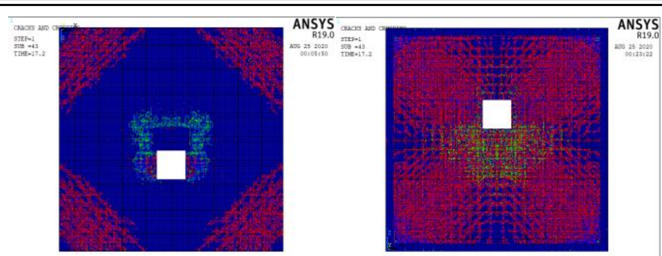
Top View Bottom View

Figure 16 Cracking pattern at top and bottom for S02



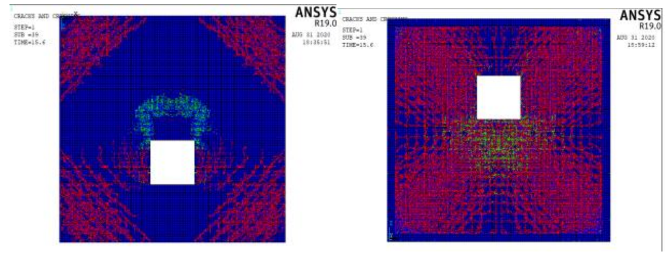
Top View Bottom View

Figure 17 Cracking pattern at top and bottom for S03



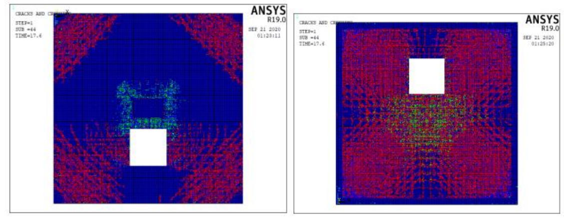
Top View Bottom View

Figure 18. Cracking pattern at top and bottom for S04



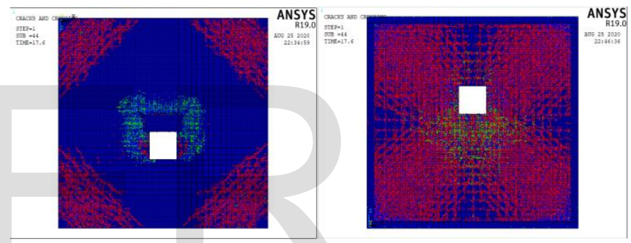
Top View Bottom View

Figure 19. Cracking pattern at top and bottom for S05



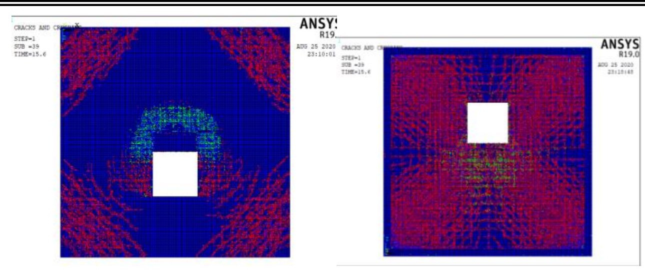
Top View Bottom View

Figure 20. Cracking pattern at top and bottom for S06



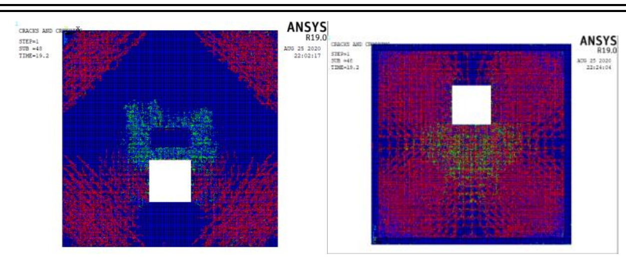
Top View Bottom View

Figure 21. Cracking pattern at top and bottom for S07



Top View Bottom View

Figure 22. Cracking pattern at top and bottom for S08



Top View Bottom View

Figure 23. Cracking pattern at top and bottom for S09

4 Conclusion

Based on the results of the current study conducted on ten full scale flat slab specimens, the following main conclusions may be deduced:

a. The results show that the non-linear finite element analysis program ANSYS 19 is an efficient and powerful tool, which can be used to simulate the true punching shear behavior of flat slabs with reasonable accuracy.

b. Flat slab specimens with openings of different size and locations revealed that the opening presence decreases the punching shear strength of flat slabs when compared to the control specimen without openings.

c. Studying specimens with different opening size revealed that increasing the opening size from (400x400) mm to (600x600) mm caused a punching shear strength reduction of 10%. On the other hand , the deflection increased by 11%.

d. Studying specimens with different opening locations revealed that the punching shear strength is directly proportional to the distance from column edge to opening edge regardless the opening size. Specimen with opening size (600x600) mm located at distance “d” from the column’s face increased by 21% when compared to a specimen with opening of the same size but located adjacent to column’s face. On the other hand the deflection for the same specimen decreased by 14%. The punching shear strength increased by 8.7% for specimen with opening of size (600x600) mm located at “d” from the column’s face when compared to a specimen with opening of smaller size and located adjacent to column’s face, and the deflection for the same specimen slightly decreased by 4.8%.

e. Flat specimens with square column of aspect ratio (1:1) give a slightly higher results when compared to specimens connected to a rectangle column with aspect ratio (3:2), and (2:1).

f. The punching shear strength for specimens with opening size (400x400) mm, and located adjacent to column’s face was almost the same as the specimen of column aspect ratio 1 when the column aspect ratio increased from 1 to 1.5, and slightly decreased by 3% when the column aspect ratio increased from 1 to 2.

g. The punching shear strength for specimens with opening size (600x600) mm, and located adjacent to column’s face slightly decreased by 5% when compared to the specimen of column aspect ratio 1 as the column aspect ratio increased from 1 to 1.5, and decreased by 10% when the column aspect ratio increased from 1 to 2.

h. The punching shear strength for specimens with opening size (600x600) mm, and located at distance “d” from column’s face slightly decreased by 6.7% when compared to the specimen of column aspect ratio 1 as the column aspect ratio increased from 1 to 1.5, and slightly decreased by 4% when the column aspect ratio increased from 1 to 2.

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