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Strengthening of Flat Slab with Openings under Punching Shear Load

Hussein W. Shiyal[1], and David A.M. Jawad[2]
[1] Civil Engineering Dept, University of Basra, Basrah, Iraq.
[2] Civil Engineering Dept, University of Basra, Basrah, Iraq.

Abstract

This paper offerings a wide-ranging study to investigate the punching shear behavior of reinforced concrete flat slab with openings. The study involved of eighteen specimens tested under static load and divided into two series; the first group included flat slabs with openings while the second series were slabs with openings with varied compressive strength. The used variables were the opening location and number in addition to the compressive strength of slabs (40,50, 60, and 70 MPa). The results showed that the slabs behaves linearly until it reaches about average value 23.5% of their ultimate strength for solid slab and by (23%) for the slabs with opening. The openings presence affected the load carrying capacity which decreased the average cracking load by (31%) and ultimate load by (28%) when compared with the solid slab. Regarding the opening location, placing the opening near the central column led to decrease in the cracking and ultimate load of the flat slab with maximum decrement in the ultimate load was by (60.2%) when compared with the solid slab. increase of the compressive strength enhanced punching shear strength of the slabs with opening. The ductility and energy absorption of flat slabs were decreased with the existence of the opening and enhanced when the compressive strength increased.

Keywords: flat slab, punching shear, ductility, steel reinforcement and openings.

1. Introduction

Flat slabs are becoming more popular in many developing countries due to their ease of implementation and many other benefits. This type of slab is a structural element that carries the applied loads in a longitudinal and transverse direction, which requires the presence of reinforcing steel in both directions, but due to the low thickness of this element and the presence of the column on it directly and without the presence of a beam, it will be vulnerable to penetration failure as a result of the distribution of shear stress in a circular shape around the column which causes the column to penetrate the slab, causing partial or complete failure of the building **[1, 2]**. This phenomenon called as a punching shear failure which this mode of failure is a local mechanism failure and characterized by the formation of a cone-shaped element, as well as it is associated with brittle failure. Wood **[3]** stated that Due to both poor concrete quality and a lack of integrity reinforcement, flat slab failure mode might result in the gradual collapse of the entire structure. In order to provide enough room for mechanical, structural, and electrical purposes such passing pipes, light lumps wires, elevators equipment, openings are constructed in the flat slab. The punching shear stresses and significantly lower the punching shear capacity of RC flat slabs. Due to this, these gaps frequently increase the punching shear stresses and significantly lower the punching shear capacity of RC flat slabs. Because of this, it's crucial to calculate the punching shear stresses of flat slabs with openings that have different sizes and locations. In order to clarify the impact of openings on the punching shear behavior of RC slab-column connections under vertical loads with moment transfer, a strong finite element model is presented here. Openings of various sizes are placed parallel to the column at various distances to simulate the effect of openings. The proposed finite element model may be used to investigate the impacts of openings having various sizes and positions on the punching shear strength **[4,5]**. The punching resistance of these constructions cannot be accurately determined using the design codes. It is crucial to take extra shear stress and torsion into account when addressing unbalanced moment transmitted between columns and slabs because they make slab-column connections more susceptible to punching failure. The punching shear behavior of two-way RC slabs, however, may be significantly impacted by apertures, it is undoubtedly true. However, it is undoubtedly true that openings may significantly affect the punching shear behavior of two-way RC slabs. The same impacts would also be minimal in the space enclosed between two strips, or between the column and middle strips, if the opening size is less than 40% of the column strip width **[6]**. Additionally, the nonlinear analysis regarding the effect of the opening near the column region has a significant effect on the ultimate punching shear strength **[7]**.

In addition, investigations into the bending behavior of one-way slabs with opening showed that the size of the openings had an impact on how much load the slabs could support **[8]**. Furthermore, the largest improvement in bending strength was attained by one-way slabs with openings surrounded on all sides with steel bars on the tensile side and with an additional ECC layer of 20 mm on the compressive side, which was 23.0 % than that of slabs without openings **[9]**.

RC flat slabs' punching shear behavior is significantly influenced by the opening's sizes and positions, although some extensive investigations have been carried out to unearth new information **[10]**. Also, it was proved that the punching shear resistance decreases as a result of an increase in the opening size and decrease in the distance between opening and column, or both **[11]**. Additionally, it was discovered that the value of the punched shear strength is achieved as slabs without opening if openings are placed more than 4d from the column **[12]**. The stiffness of slabs without openings is higher than that of slabs with openings, and the energy dissipation capacity of slabs with openings diminishes as the opening size grows, according to study **[13]** and comparison with ACI 318-19 **[14]**. Since no sufficient study has been produced in the literature to correctly address these impacts, the current study is devised and implemented to evaluate the effects of openings, their distance from the column edge, number and reinforcing of these openings. The punching shear behavior of interior slab-column connections under vertical load is investigated using an improved finite element model given for this purpose. The approach taken in conducting this study may be summed up as follows. First, a demonstration of the finite element modeling process is shown. The finite element model is calibrated and verified by an existing experimental investigation, and it is then extended to conduct a parametric analysis on the interior slab-column connections where the slabs include opening that vary in size, position, and compressive strength.

2 Finite Element Modeling

Finite element method is considered one of the most developed techniques which is used in ANSYS software to simulate the behavior of the physical phenomena. Use of ANSYS software can define the behavior of the structural members such as beam, slabs, columns, etc. the first step in the modeling of the concrete flat slab in ANSYS requires section of the used elements which the selection must provide the same properties and behavior of the simulated material such as the concrete. The concrete simulated in ANSYS through the SOLID65 element which this element represents the concrete in term of the stresses, strains, and cracking capability. The steel reinforcement can be modelled by discrete method with use of LINK180 which this element consists of two nodes and six degrees of freedom divided on the nodes. Steel plates were modelled by use of three-dimensional element (SOLID185) which compatible with the behavior of steel material. defining the elements can be performed through the real constant option which allow to the modeler to define the element properties. Then, the behavior of each material is defined as follows; the concrete represented by multilinear stress strain curve which the highest point represents the crushing stress of the concrete. The steel reinforcement was defined as a bilinear relationship consists of two segments (the first segment represents the yielding stress while the second one represents the ultimate stress of steel rebar). Steel plate was modelled as a linear material to distribute the applied loads on an area in order to avoid the stress concentration on the stressed nodes. The nonlinear analysis was adopted in this study which involved testing of the material to the failure state. Numerical modeling of RC slabs calibrated by experimental results of other researchers is the main strategy of this study. To verify the model, six RC slabs are selected and simulated **[15, 16]**.

2.1 Concrete, Steel Reinforcement, and steel plate

Concrete is considered a semi-brittle material and has a different compressive behavior than its tensile behavior. Concrete usually exhibits linear elastic behavior for about 30-35% of the maximum strength of concrete under compressive load (σcu). Following the yielding point, the tension progressively increases until it reaches maximum stress. The gradual increase in the load cause increase in the curve reaching the ultimate compressive strength, then the curve will begin to drop and reach the point of failure in which the crushing of the concrete occurs at the highest value of strain (0.0035) as revealed in **Figure.1** The tension case included an increase of the curve to the ultimate value of the tensile strength (which is equal to 10% of the compressive strength) which after this point, the concrete loses its stiffness and begins to crack **[17, 18].** To define the concrete material in ANSYS, there are essential values that must be input in the software such as Young modulus, Poisson ratio, stress-strain curve, compressive and tensile strength values, besides the open and closed shear cracks coefficient **[17]**. The constitutive stress-strain curve of the concrete model presented by the experimental study was defined in the concrete depending on the Kachlakev **[17]** and ACI 318M-19 **[14]**. To imitate concrete behavior, plasticity-based damage is employed. Regarding the modeling of the concrete slabs in ANSYS, elements of SOLID65, LINK180, and SOLID185 were used to simulate the concrete, steel rebar, and steel plate. SOLID65 is the solid element with 8 nodes that has three degrees of freedom in each node and can crack, crushing as the concrete does. Steel reinforcement are represented by LINK180 with two nodes and three degrees of freedom at each node. The steel reinforcement is defined in ANSYS as a bilinear relationship. The SOLID185 (steel plate) has the same nodes number and element faces of the concrete element (SOLID65) but with different behavior. The elastic linear behavior was utilized to define the steel plate element. Concerning the adopted behavior of the concrete slabs, the data concrete compressive strength, yield stress of the steel reinforcement, and steel plate were quoted from the experimental research of Oukaili and Salman **[19]**. All used properties of the concrete and the other concrete slabs

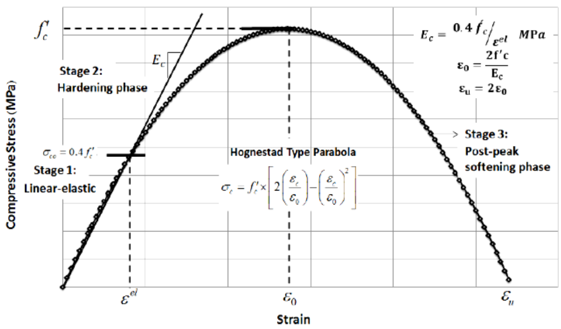


Fig.1 Stress-strain relationship of the concrete.

Table.1 Properties of concrete.

Material	strength [MPa]	element	PRXY	Behavior
Concrete	25	SOLID65	0.2	Multilinear isotropic
Steel bar	450	LINK180	0.3	Bilinear isotropic
Bearing plate	E= 2 x 10^5	SOLID185	0.3	Linear isotropic

3. Verification

Six models presented by an experimental study by Oukaili and Salman **[19]** selected for the validation process. The modelled slabs have the same geometry, boundary conditions, and material properties that used in the experimental study presented by Oukaili and Salman **[19]**. When comparing the validation outcomes with the experimental study, the comparison was conducted in terms of the load-displacement relationship, as demonstrated in **Table.2** The average percentage difference in ultimate load values was around (98.3%), and the maximum displacement values were around (83.7%), which was regarded an acceptable result.

Table.2 Results of the validation between the experimental and numerical study.

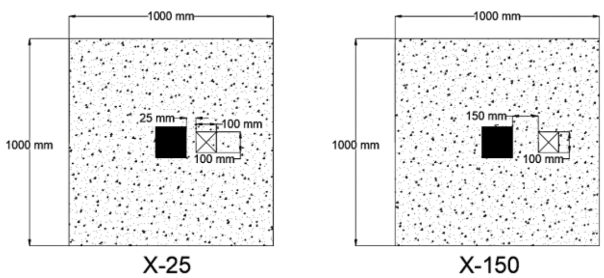
ID	$V_{Ansys(KN)}$	$V_{Exp.(KN)}$	$V_{Ansys}/V_{Exp.}$	$\Delta_{Ansys(mm)}$	$\Delta_{Exp.(mm)}$	$\Delta_{ans.}/\Delta_{exp.}$
XXX	100.5	101.65	98.87%	14.93	15.91	93.84%
SF0	88.47	89.02	99.38%	12.73	14.46	88.04%
CF0	83.2	81.68	101.86%	11.12	13.81	80.52%
LF0	68.7	71.92	95.52%	10.34	12.24	84.48%
CC0	86.0	90.76	94.76%	9.87	13.98	70.60%
CF1	88.6	88.95	99.61%	11.29	13.33	84.70%

4. Parametric Study

After obtaining good results from the process of validation between theoretical and experimental results. It is possible to start studying the variables to find out their effect on the behavior of the concrete slab. The reference slab details are presented in **Figure.2** and **Table.3** which is the similar specimens presented by Oukaili and Salman **[19]**. A total of eighteen slabs are investigated into two series. The first series included fabrication of flat slabs with multi opening form. Regarding the opening location, the specimens (X-25, X-150, and X-300) involved of fabrication of openings (100 x 100) mm located at (25, 150, and 300 mm) from the edge of the central column. The second group (XD-35, XD-250, XD-460) involved of fabrication of openings located at (35, 250, and 460 mm) from the diagonal corner of the central column. While the third group, included three specimens with many opening number (X-150-2O, X-25-2O, and X-150-4O) which involved of two and four openings as revealed in **Figure.1** All openings in the specimens were square with the sides with size of (100×100mm), as revealed in **Figure.1** The second series included fabrication of eight flat slabs with the same properties geometry of the model (XD-35 and X-150-4O) which these models were slab with critical opening case. The variable in this series is the compressive strength which were (40, 50, 60, and 70 MPa) to investigate the possibility of the compressive strength to condensate the effect of the opening.

Table.3 Details of specimens

ID	Opening size, mm	*f'c* **MPa**	Opening Direction	Distance to column
XXX	N/A	35.7	-	N/A
X-25	100 X 100	35.7	Horizontal	100 mm
X-150	100 X 100	35.7	Horizontal	100 mm
X-300	100 X 100	35.7	Horizontal	100 mm
XD-35	100 X 100	35.7	Diagonal	100 mm
XD-250	100 X 100	35.7	Diagonal	100 mm
XD-460	100 X 100	35.7	Diagonal	100 mm
X-150-2O	100 X 100	35.7	Horizontal	100 mm
XD-35-2O	100 X 100	35.7	Diagonal	100 mm
X-150-4O	100 X 100	35.7	Horizontal	75 mm
XD-35-1	100 X 100	40	Diagonal	100 mm
XD-35-2	100 X 100	50	Diagonal	100 mm
XD-35-3	100 X 100	60	Diagonal	100 mm
XD-35-4	100 X 100	70	Diagonal	100 mm
X-150-4O-1	100 X 100	40	Horizontal	75 mm
X-150-4O-2	100 X 100	50	Horizontal	75 mm
X-150-4O-3	100 X 100	60	Horizontal	75 mm
X-150-4O-4	100 X 100	70	Horizontal	75 mm



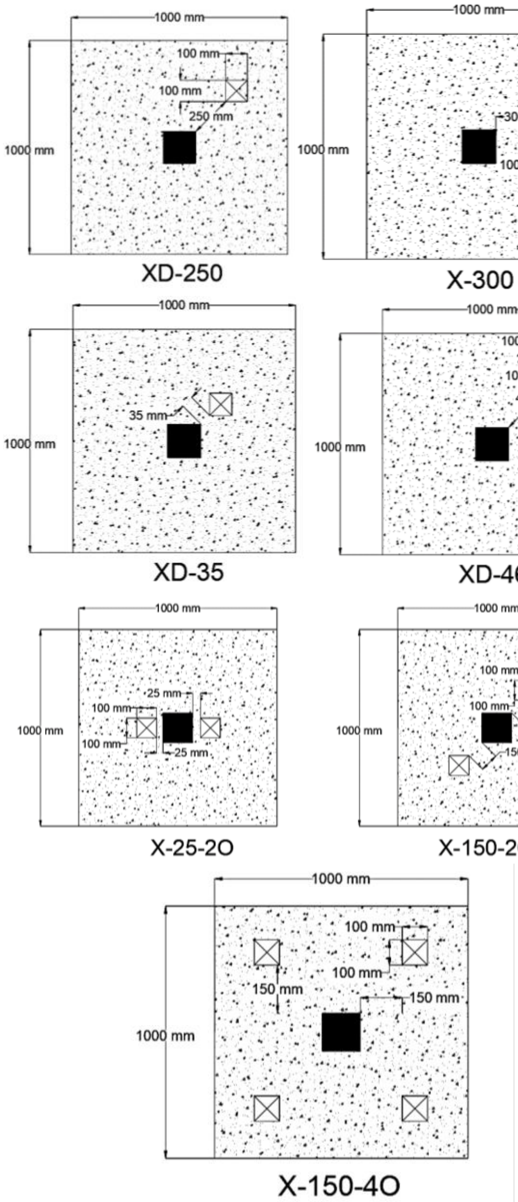
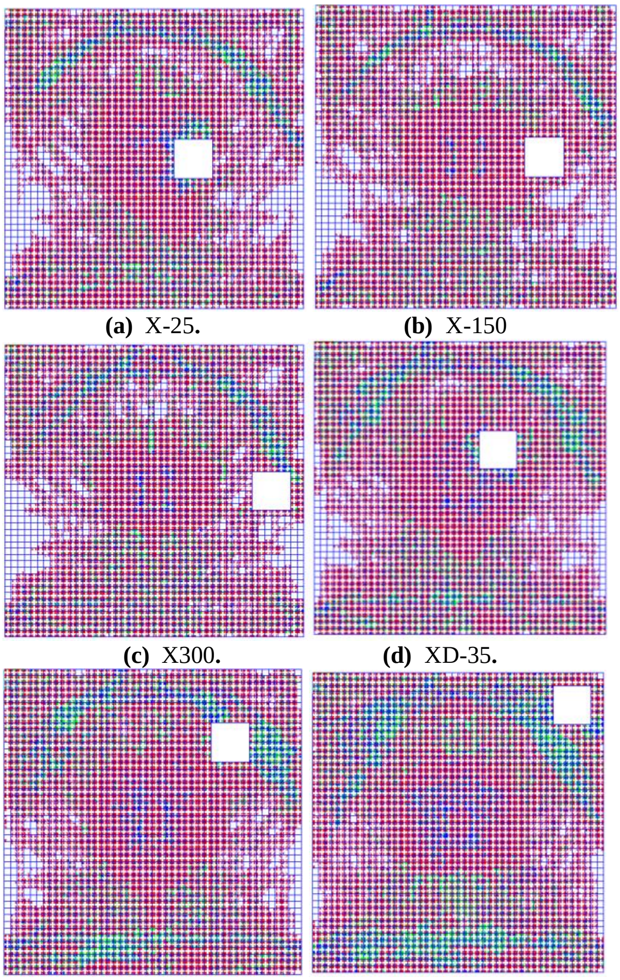


Figure.2 Reference and parametric slabs details.

5. Test Results

5.1 Failure and Cracking Mode

The cracking mode showed approximately similar cracking mode for most of the tested slabs as follows; the cracking phase appeared the first crack at (23.5%) for the control slabs and an average of (23%) for the slabs with opening which the first cracking was affected by the opening existence. The cracking phase was affected by the strengthening by steel reinforcement. The cracks appeared in the majority of the reinforced slabs at a lower phase than the reference slab. The cracks initiated horizontally form a circle of cracks around the column. These cracks extended and widened until reaching the ultimate shear strength capacity. Regarding the deformed area, the existence of openings increased the area of deformation and cracks amount. Larger amount that obtained was for the model with openings which showed increase in the deformed area in comparison with the control solid slab. Constructing of more openings increased the deformed area as revealed in **Figure.3** The crack pattern for the flat slabs with higher compressive strength didn't affect by the variation of the compressive strength.



(a) X-25. **(b)** X-150 **(c)** X300. **(d)** XD-35. **(e)** XD-250. **(f)** XD-460.

Figure.3 Crack pattern for reference and flat slabs.

5.2 Load-Displacement Relationship

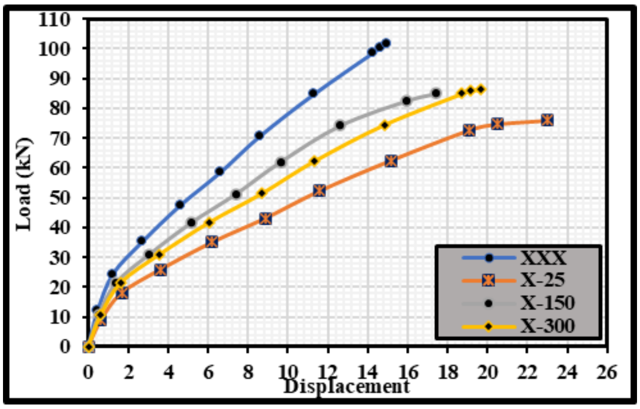
The obtained results of the tested slabs are presented in the **Table.4** These slabs included testing of eighteen slab specimens under static loads which showed an ultimate load carrying capacity of (100.5) kN for the reference slab while the parametric slabs exposed an ultimate load ranged between (40 – 138.25) kN with maximum displacement ranged between (8-23.3) mm as demonstrated in Table 4. The ultimate load carrying has affected due to several parameters such as opening location and number in addition to the compressive strength. Expressing the obtained results with other calculation such as ductility and energy absorption to provide fully understand to the behavior of flat slabs with opening.

Table 4. obtained results of the flexural slab.

ID	Pcr (kN)	Pu (kN)	Δ (mm)	Pcr Inc.	Δ%	DI	Tn
XXX	٢٣,٦٢	١٠٠,٥	١٤,٩٣١	-	-	٥,٥٠	١٠٨٠
X-25	١٤,٨	٧١,٤	١٥,٨٤	٦٢,٦٦%	١٠٦.1%	٤,٨٢	1136
X-150	١٦,٨٣	٧٧	١٦,٦٦	٧١,٢٥%	١١١,٦%	٤,٥٨	٩٥٣,٤
X-300	٢٠,٣٨	٨٦,٤	١٩,٦٨	٨٦,٢٨%	١٣١,٨%	٤,٢٤	١٠٧٠
XD-35	١٥,٣٢	٧٤,٢٥	١٦,٢٨	٦٤,٨٦%	%١٠٩	٤,٨٥	٧٣٠,٩
XD-250	١٨,٥٨	٨٩,٦	١٦,١٢٩	٧٨,٦٦%	%١٠٨	٤,٨٣	٨٧٤,٦
XD-460	١٨,٤٦	٩٣,٣٣	١٥,٥٣	٧٨,١٥%	%١٠٤	٥,٠٦	٨٧٦,٧
X-150	١٤,٦	٦٣,٥	٢٣,٢٩٨	٦١,٨١%	%١٥٦	٤,٣٥	٩٦٥,١
XD-35	١١,٥٥	٤٠	٨,٠٣١	٤٨,٩٠%	٥٣,8%	٣,٤٦	٢٠٧
X-150	١٦,٢٣	٥٧,٦٧	٢٠,٤٢٥	٦٨,٧١%	١٣٦,٨%	٣,٥٥	٧١٤,٨
XD-35	١٦,٤	٨٣,٢١	١٣,٢٢	٦٩,٤٣%	٨٨,٥٤%	٥,٠٧	٨٠٥,٨
XD-35	١٩,٧٣	٩٨,٦٣	١٢,٣	٨٣,٥٣%	٨٢,٣٨%	٥,٠٠	٩٣٨,٥
XD-35	٢١,٣١	١١٦,٥٨	١٠,٨٤	٩٠,٢٢%	٧٢,٦٠%	٥,٤٧	١٠١٦
XD-35	٢٥,٤٥	١٣٤,٢٥	٨,٦٤	١٠٧,٧%٥	٥٧,٨٧%	٥,٢٨	.١٢١٥
X-150	١٦,٢٣	٥٧,٦٧	٢٠,٤٣	٦٨,٧١%	١٣٦,٨%٠	٣,٥٥	٧١٤,٨
X-150	١٩,٨	٧٠,٣٦	١٩,٥	٨٣,٨٣%	١٣٠,٦%٠	٣,٥٥	٧٨٣,٩
X-150	٢٣,٦١	٨٨,٢٣	١٧,٣٢	٩٩,٩٦%	١١٦,٠%٠	٣,٧٤	٨٧٦,٥
X-150	٣٤,٣	١٢٢,٦٧	١٣,٧٧	١٤٥,٢%٢	٩٢,٢٢%	٣,٥٨	944.5
X-150	٤٠,٦	١٣٨,٢٥	٩,٢٢	١٧١,٨%٩	٦١,٧٥%	٣,٤١	1077

A. Effect of the Opening Location and Number

Regarding the location variable, modeling of slab with variable location. The first group (X-25, X-150, and X-300) which involved three openings located at (25, 150, and 300 mm) included reduction in the ultimate shear load capacity and increase in the deflection of these slabs. The slab with opening of (100 x 100) at (25 mm) from the column edge caused a decrement in the load carrying capacity by (29%) and increment in the deflection by (6.1%) as revealed in **Figure.4a** Placing the opening at 150 and 300 m from the central column edge reduced the shear strength by (23.4% and 14.1%) and increase in the deflection by (9%, 8%, and 4%) when compared with the control slab (XXX) as revealed in **Figure.4a** Concerning the second group (XD-35, XD-250, XD-460) which involved of fabrication of openings located at (35, 250, and 460 mm) from the diagonal corner of the central column. The opening presence in the diagonal direction caused a reduction in the slab strength against punching shear but with less percentage than those of horizontal direction openings. The reduction in the slab with one diagonal opening (XD-35) was by 26.1% and increase in the defection by 9%. While the diagonal openings in specimens (XD-250 and XD-460) reduced the ultimate shear strength by 10.8% and 7.1% and increased the deflection by (8% and 4%) respectively as demonstrated in **Figure.4c** While the third group, included three specimens with many opening number (X-150-2O, XD-35-2O, and X-150-4O) which involved of two and four openings. Creating of the two horizontal openings at opposite directions (X-150-2O) reduced the ultimate strength of the RC slab by (36.75%) and increased the deflection by (56%) as exhibited in **Figure.4** Increase of openings number to four at the slab corners caused more decrement in the shear strength which was by (42.6%) and increased deflection by (36.8%) as shown in **Figure.4** Modelling of two diagonal openings near the column (@35 mm) in the RC slab reduced the ultimate shear strength by (60.2%) and decreased the deflection by (46.6%) as revealed in **Figure.4d**



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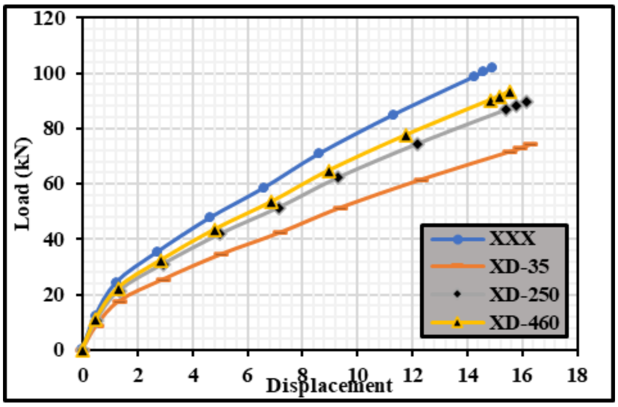

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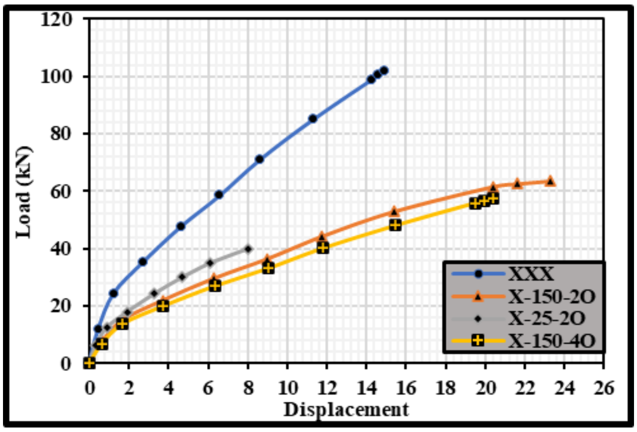

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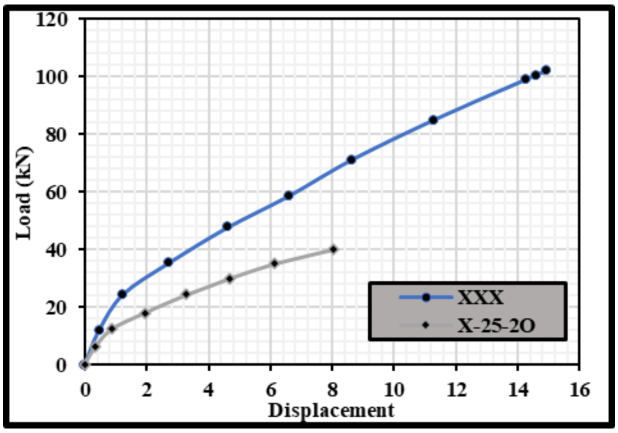
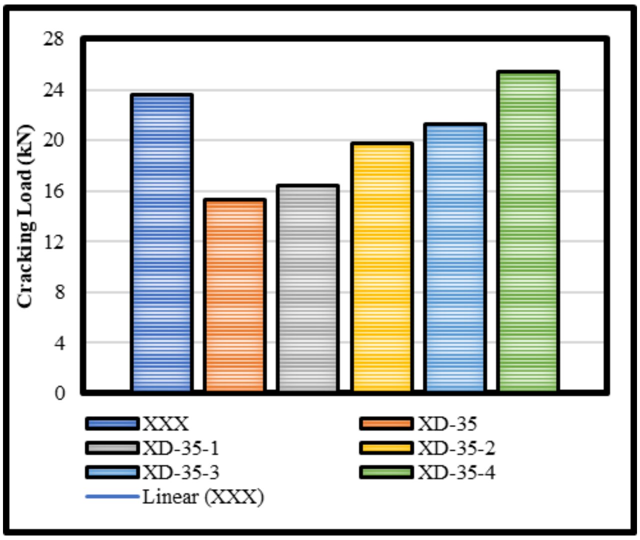


(b)

Figure.4 Load displacement relationship curve of flat slabs.

B. Effect of Compressive strength

The test results showed that the increase of the compressive strength could compensate the occurred loss due to the opening existence with gaining an additional strength. Regarding the model with two diagonal opening (XD-35), increase of the compressive strength (40, 50, 60, and 70 MPa) increased the cracking and ultimate shear strength. The increment in the cracking load increased from (15.32) kN to (16.4, 19.73, 21.31, and 25.45) kN which equal to (7%, 28.8%, 39.1%, and 66.1%) respectively as shown in **Figure.5a** in comparison with the control slab (XXX), the increase in the compressive strength equal and greater than (60) MPa. Regarding the ultimate punching shear strength, the increment in the ultimate load increased from (74.25) kN to (83.2, 98.63, 116.58, and 134.25) kN which equal to (12%, 32.8%, 57%, and 80.8%) respectively as shown in **Figure.5b** In comparison with the control slab (XXX), the increase in the compressive strength equal and greater than (60) MPa. While the deflection, the increase of the compressive strength decreased the deflection by (18.2%, 24.5%, 33.4%, and 47%) when the compressive strength increased to (40, 50, 60, and 70 MPa) respectively as revealed in **Figure.5c** Concerning the model with four corner opening (X-150-4O), increase of the compressive strength (40, 50, 60, and 70 MPa) enhanced the cracking and punching shear strength. The improvement in the cracking load increased from (16.23) kN to (19.8, 23.6, 34.3, and 40.6) kN which equal to (22%, 45.5%, 111%, and 150%) respectively as shown in **Figure.5d** In comparison with the control slab (XXX), the increase in the compressive strength equal and greater than (50) MPa. Regarding the ultimate punching shear strength, the increment in the ultimate load increased from (57.67) kN to (70.36, 88.23, 122.67, and 138.25) kN which equal to (22.6%, 53.8%, 113%, and 141%) respectively as shown in **Figure.5e** In comparison with the control slab (XXX), the increase in the compressive strength equal and greater than (60) MPa. While the deflection, the increase of the compressive strength decreased the deflection by (4.5%, 15.2%, 23.6%, and 55%) when the compressive strength increased to (40, 50, 60, and 70 MPa) respectively as revealed in **Figure.5 f**



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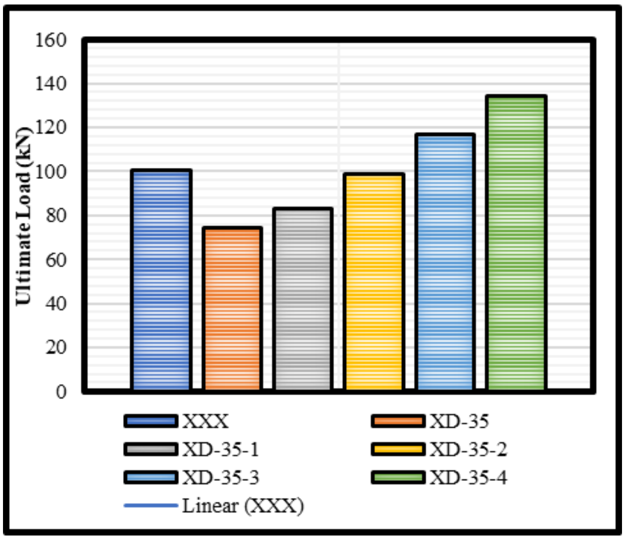

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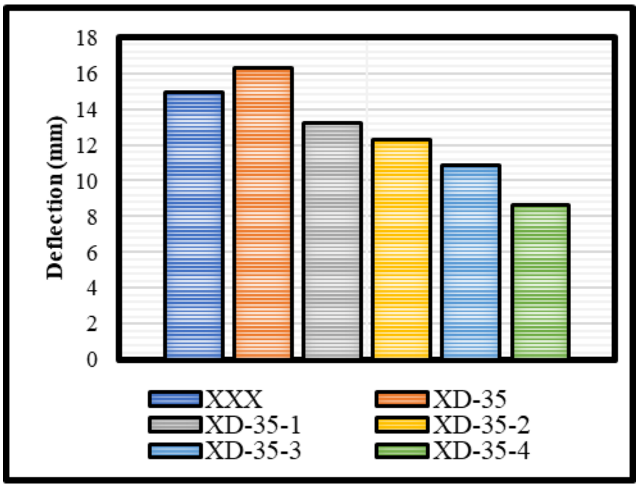

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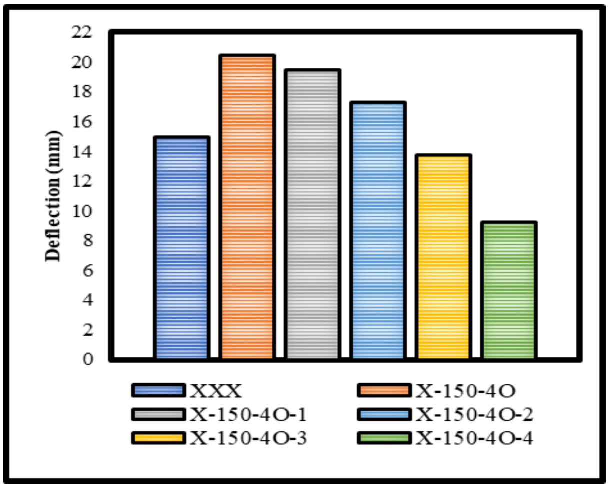

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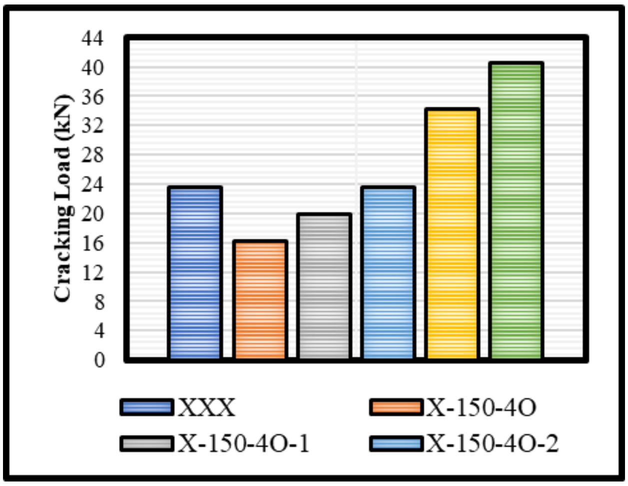

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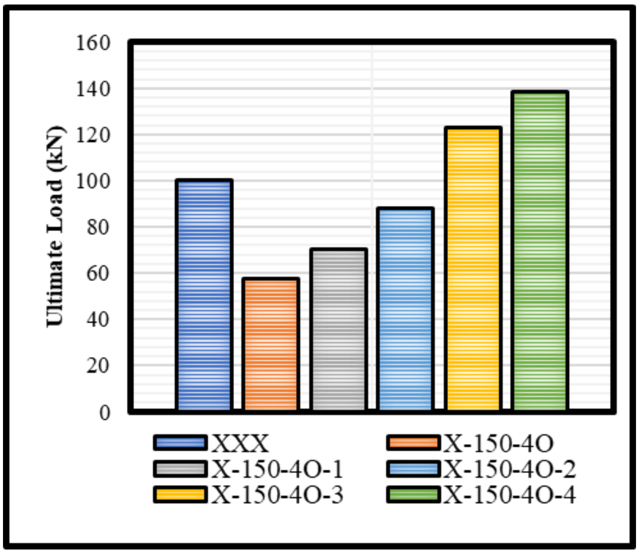
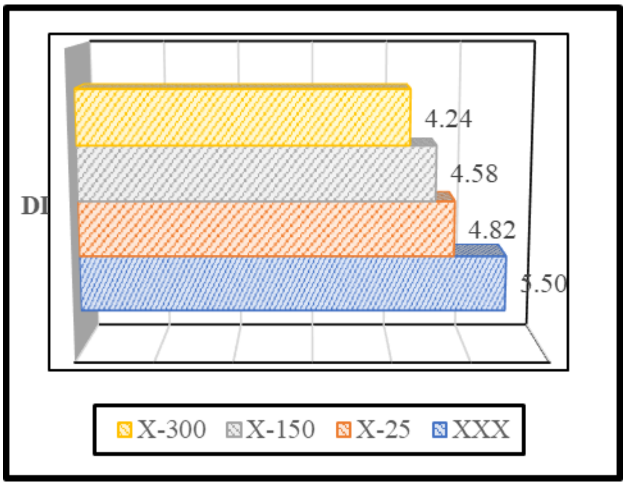


(e)

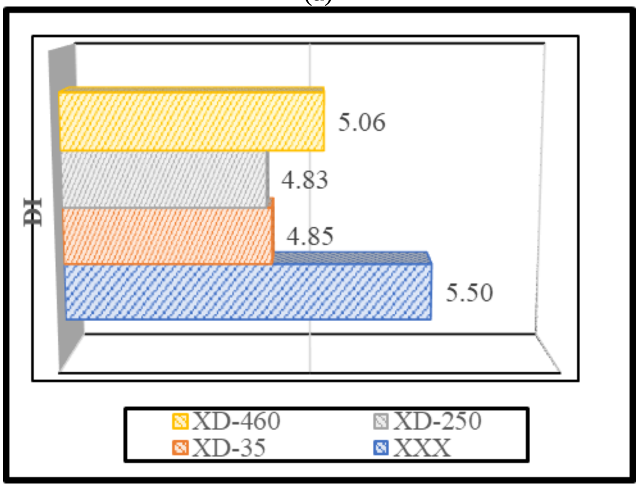
Figure 5. Load displacement relationship curve of flat slabs.

6. Ductility of the Tested Slabs

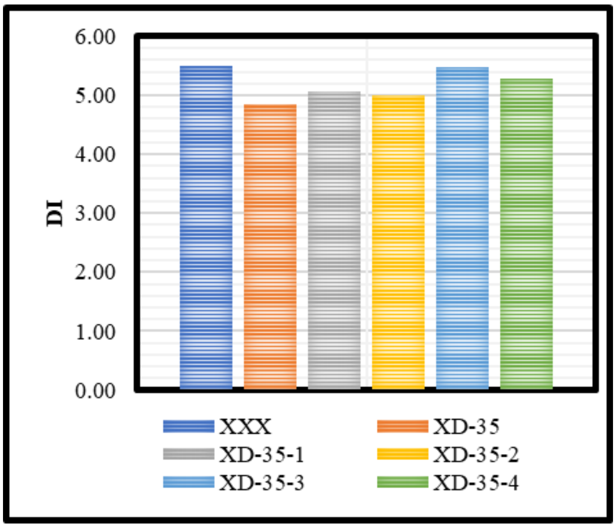
Marzouk and Hussein **[20]** stated that the ductility can be calculated by dividing the displacement at ultimate load to the one of the yielding value which agreed by Priestley and Park **[21]** and recommended by Robertson and Durrani (1991) **[22]**. Opening's effect and as expected has a significant effect on the ductility of the concrete slabs but increase of the compressive strength could gain an additional enhancement beside the compensation of the ductility loss to some extent especially for small openings sizes. It is important to point out an important point, which is that despite the presence of openings, the performance of the reinforced slabs has improved greatly when the compressive strength increased, which gave high efficiency to withstand the slab to resist the punching shear loads and was able to recover the loss in the ductility of the concrete slab in addition to obtaining additional improvements developed the performance of the structural member. This is an excellent indicator of the possibility of making openings of various shapes even if they are in critical regions. Opening's location and number have an effect on the ductility of the concrete slabs. Creating of openings in multi-location reduced the ductility which the first group (X-25, X-150, and X-300) included reduction by (12.3%, 16.8%, and 23%) respectively as revealed in **Figure.6a** The maximum effect on the ductility occurred when the opening location been near the slab edge. While the second group with opening in diagonal direction (XD-35, XD-250, XD-460) included reduction by (12%, 12.25%, and 8.1%) respectively as revealed in **Figure.6b** Regarding the openings number, the most affected variable on the ductility was the opening number which creating two opening in horizontal direction (X-25-2O) reduced the ductility index by (37%). While increase of the opening number two four reduced the ductility to (36%). Opening's existence has an effect on the ductility of the concrete slabs. But increase the compressive strength enhanced the ductility. Increase the compressive strength of the model with two diagonal opening (X-35) from (35.7 MPa) to (40, 50, 60, and 70 MPa) enhanced the ductility by (4.7%, 3%, 12.8%, and 8.8%) respectively when compared with the model (XD-35-1) with compressive strength of 35.7 MPa as revealed in **Figure.6 c** Concerning the model with four openings (X-150-4O), the increase the compressive strength to (50 MPa) enhanced the ductility by (5.3%) only when compared with the model (X-150-4O) with compressive strength of 35.7 MPa as revealed in **Figure.6 d** The compressive strength of (40 and 60 MPa) didn't offered any enhancement in the ductility. While the model with highest strength of (70 MPa) (X-150-4O-4), the ductility decreased by 5%. Comparing the ductility of model with higher compressive strength with the reference solid slab (XXX) showed less ductility even the compressive strength as increased.



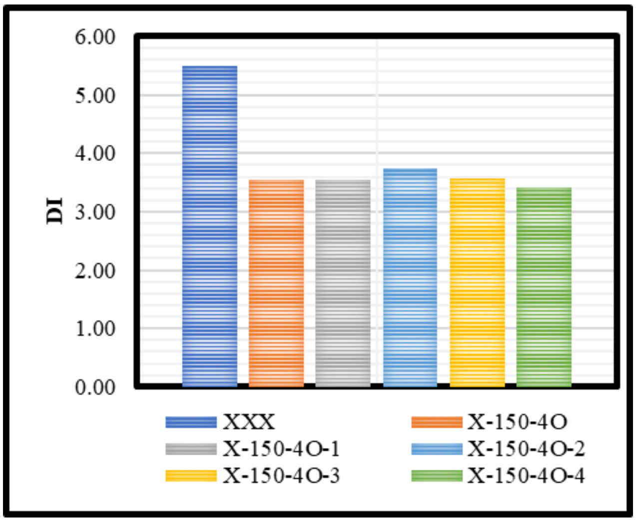
(a)



(b)



(c)



(d)

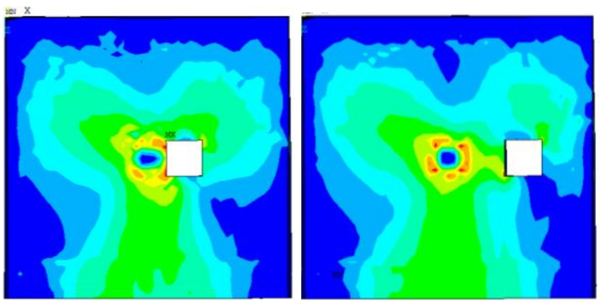
Figure.6 Ductility index of reinforced concrete flat slabs.

7. Energy Absorption

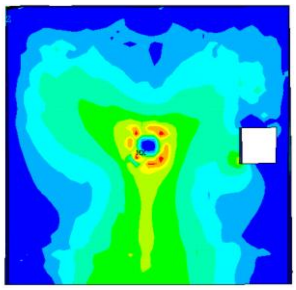
Opening's location and number have an effect on the energy absorption of the concrete slabs. Creating of openings in multi-location reduced the ductility which the first group (X-25, X-150, and X-300) included reduction by (4.1%, 11.8%, and 1%) respectively as revealed in Table 4. While the second group with opening in diagonal direction (XD-35, XD-250, XD-460) included reduction by (33%, 19%, and 18.9%) respectively as revealed in Table 4. The maximum effect on the energy absorption occurred when the opening location been near the column. Regarding the openings number, the most affected variable on the ductility was the opening number which creating two opening in horizontal direction (X-25-2O) reduced the ductility index by (81%). While increase of the opening number two four reduced the ductility to (34%) as revealed in Table 4. Opening's existence has an effect on the energy absorption of the concrete slabs. But increase the compressive strength enhanced the energy absorption. Increase the compressive strength of the model with two diagonal opening (X-35) from (35.7 MPa) to (40, 50, 60, and 70 MPa) enhanced the energy absorption by (10.3%, 16.5%, 8.3%, and 19.6%) respectively when compared with the model (XD-35-1) with compressive strength of 35.7 MPa as revealed in Table 4. Concerning the model with four openings (X-150-4O), the increase the compressive strength to (40, 50, 60, and 70 MPa) enhanced the energy absorption by (9.7%, 11.8%, 7.7%, and 14%) only when compared with the model (X-150-4O) with compressive strength of 35.7 MPa as revealed in Table 4. The average enhancement in the energy absorption for the model with two openings was higher than those of four openings which was by (14%) while for slab with four openings was (10.8%).

8. Stress Distribution

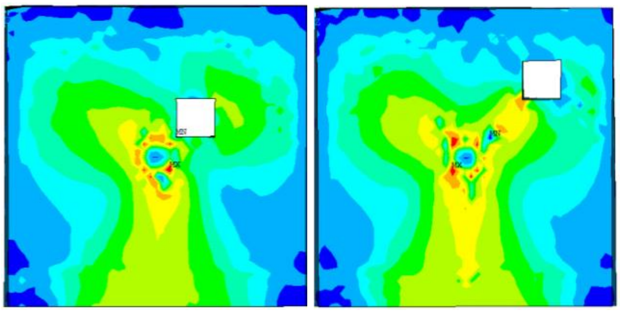
Shear stress distribution in all slabs is presented in **Fig.7** The shear stresses showed more concentration around the column in high concentration in case of the solid slab. While the slabs with openings, the concentration of stresses showed more condensation at the opening corners which the stresses concentrate with more area when the openings located at the critical region as occurred in model (X-25) and the stresses concentration tend to decrease when the opening moved away from the critical zone as occurred in models (X-150 and X-300) when the opening moved by (150 and 300) mm from the column edge. Regarding the RC slab with diagonal opening, the most critical case occurred when the opening located @35 mm diagonal distance from the column corner and the stresses concentration tend to decrease when the opening moved away from the critical zone as occurred in models (XD-250 and XD-460) when the opening moved by (250 and 460) mm from the column corner. Regarding the opening number, creation of two opening in horizontal and diagonal directions increased the stresses in the critical zone in comparison with the RC slab with one opening. Increase of opening number to four enhanced the propagation of stresses along the flat slab.



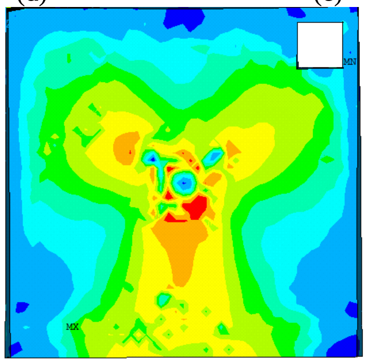
(a) (b)



(C)



(d) (e)



(f)

Figure.7 Shear stresses distribution of tested models.

9. Conclusions

In this manuscript, the results of 18 RC slab which discussed and revealed. Based on these numerical studies, the following conclusions are drawn:

1- All specimens were failed in punching shear mode.
2- The opening existence affected the load carrying capacity of the flat slabs. Existence of opening decreased the cracking load of the flat slab due to the developing of shear stresses around the central column and at the corner of opening.
3- The most affected variable is the opening location which decrease distance between the opening and the central column caused higher decrement in the cracking and ultimate load capacity. placing the opening near the central column led to decrease in the cracking and ultimate load of the flat slab with maximum decrement in the ultimate load was by (60.2%) when compared with the solid slab
4- Increase of the compressive strength enhanced punching shear strength of the slabs with opening.

5- The ductility and energy absorption of flat slabs were decreased with the existence of the opening and enhanced when the compressive strength increased

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