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Behavior of RC Flat Slab with Opening Strengthened with Steel Reinforcement

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Abstract

This paper offering a wide-ranging study to investigate the punching shear behavior of reinforced concrete flat slab. The study involved of thirteen specimens tested under static load and divided into two groups; the study included one solid slab which considered the control slab. While the remaining slabs were parametric strengthened slabs with openings. The used variables were the opening size in addition to the strengthening of these openings by steel reinforcement. Six opening sizes (100x100, 150x150, 200x200, 250x250, 300x300, and 350x350) mm were constructed and tested under punching shear load. The results showed that the slabs behave linearly until it reaches about average value 23.5% of their ultimate strength for solid slab and by (17.2%) for the slabs with opening. The openings presence affected the load carrying capacity which decreased the cracking load by (45.8%) and ultimate load by (32.2%) when compared with the solid slab. Regarding the opening size, increase of the size led to decrease in the cracking and ultimate load of the flat slab which the opening with size of (350 x 350) mm caused maximum decrement which was by (60.75%) when compared with the solid slab. Reinforcing the opening with steel reinforcement could compensate the lost strength for small openings while the larger openings (greater than 150 x 150) compensated some strength due to the high condensation of shear stresses. The ductility of tested flat slabs was decreased with the existence of the opening and enhanced when the openings reinforced with steel reinforcement.

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

1. Introduction

Concrete flat slabs are a structural member supported by the column directly without of beams. It is used in a wide range around the world due to the simplicity of the structural system, implementation time and cost, in addition to the provide additional space to the building. 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 form depending on the shape of column which causes the column to penetrate the slab, causing partial or complete failure of the building **[1&2]**. The main disadvantages of this type of slabs are the large displacement, higher moment on the column connection, less stability because of the horizontal forces, and the failure by punching shear which is this phenomenon is the most critical case **[2]**. Punching shear failure can occur in the slabs with small thicknesses under high intensity concentrated load which lead to generate high shear stresses around the column **[3 & 4]**. Happening of the punching shear may lead to progressive collapse for the whole structure. The progressive collapse may occur when the structure doesn't have an enough load redistribution capacity **[5]**. Many parameters affect the punching shear behavior such as the strength of used concrete, slab's thickness, and steel reinforcement that used as mentioned by many researchers **[6,7]**. Reinforced concrete is the most affected the punching shear capacity of the slabs. The need to concrete with high strength against the punching shear became an urgent need because the concrete loses its ability to resist the applied loads due to the appearance of cracks which represent the starting point of the final failure. The presence of opening in the flat and solid slabs was necessary in order to passing some wires, pipes or electrical equipment, but the presence of the opening often has a negative impact on the resistance of the slab against punching forces, which requires strengthening these zones. To avoid this problem, it can resort to the use of steel reinforcement which these bars including properties that improve concrete properties. It was found that surrounding the opening by steel reinforcement inside concrete enhances tensile and shear strength, in addition to increasing energy absorption, and its ductility and durability **[8]**. Also, the presence of such type of strengthening does not mean an improvement in the behavior of flat slabs only, but also means that it is controls the direction and propagation of cracks **[9]**.

Also, punching shear behavior of flat slab with openings (within the international codes' recommended range) was characterized by many researchers **(Moe [10]; Hognestad et al. [11]; Fallsen et al. [12]; El-Salakawy et al. [13]; Essa, et al. [14]; Susanto, et al. [15]; Sherif, et al. [16]; Wensheng Bu and M. A. Polak, [17]; El-shafiey and Atta [18])**. However, their tests were essentially concentrated on slabs with openings with limited dimensions. Therefore, their results may not be suitable for directed extrapolation to cases involving large opening. Many researchers investigated the behavior of flat slabs which most of them were limited in use of parameters. EL-Shafiey and Atta [18] investigated the effect of the opening on the behavior of flat slabs. The main parameters in this study were the opening dimensions and position, and slab thickness. The results showed that the opening existence affected the strength of the RC flat slabs which reduced the ultimate load carrying capacity.

Clark et al. [19] investigated the punching shear strength of concrete slabs with low-weight aggregate. Light weight aggregates of Pellite, Liapor, Fibo, Lytag, and Leca were used in this investigation. The light weight aggregate was compared with the normal weight aggregates. The experimental investigation found that the design densities of the materials studied ranged from 85% to 65% of that of standard weight concrete. The low weight aggregate was up to 30% stronger in shear than the reference aggregate concretes when compared to their densities. The punching shear strength of reinforced concrete slabs with varied span-depth ratios was examined by John et al. [20]. Ten slabs were evaluated for the experimental investigation. Five of the ten had flexural reinforcement, while five had both flexural and shear reinforcement. The authors found from their experimental analysis that for reinforced concrete slabs of constant thickness, punched shear strength rises when the span to depth ratio falls below six. Finite element analysis methods must be confirmed and validated before being used in a practical setting by comparing the findings to genuine experiment data. Based on earlier experimental findings, a numerical simulation of reinforced concrete slab experimental punching shear behaviors has been constructed in this study. Prior to actual implementation, it is crucial to validate and verify finite element analysis methods by comparing the findings to authentic experiment data. This work builds on earlier experimental investigations to construct a numerical simulation for experimental punching shear behaviors of reinforced concrete slabs. The main objective of this work is to assess the possibility to upgrade the capacity of the punching shear of flat slabs although of opening's existence. Based on the previous studies, steel reinforcement used to strengthen ten flat slabs. The results were in term of load-displacement curves, ductility, energy absorption, stiffness, and crack pattern.

1.2 Punching Phenomenon

The punching shear case is shown in Fig. 1. It should be noted that there are two ways that the punching shear may occur; the first case when the concrete crushes at control perimeter of RC column uσ. the second case is tension failure of concrete. The critical perimeter around the column is assumed at distance 2d from the column face where d is an effective depth of the slab **[21]**.

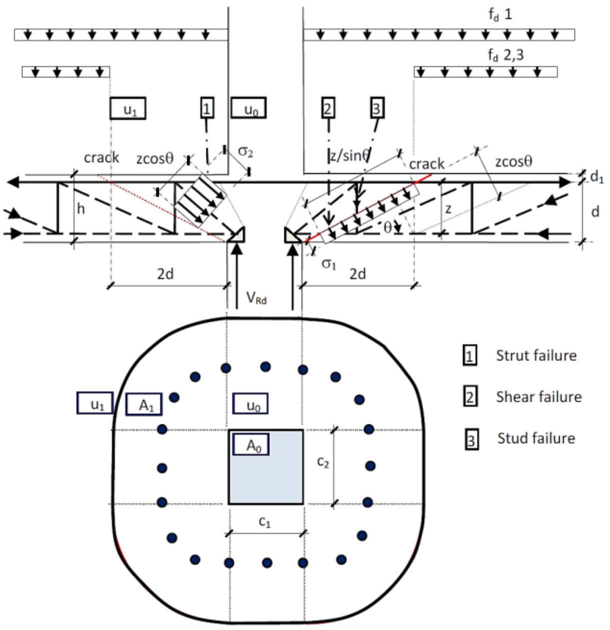


Fig.1 Analysis of Punching Shear Mechanism [21].

1.3 Punching Shear Analysis

Crushing of the strut at column perimeter is controlled by reduced compressive strength of concrete, see formula (1);

$$v_{\mathrm{Rd,c}} = \frac{0{,}18}{\gamma_{\mathrm{C}}} k\left(100 \rho_l f_{\mathrm{ck}}\right)^{1/3} \geq 0.035 k^{3/2} f_{\mathrm{ck}}^{1/2} \qquad \text{…. (1)}$$

punching strength was limited according to these equations as revealed in VRd,c of formula (**1**). According to the equation 2, kmax and V_{Rdc} must be more than the punching strength of such slabs, revealed in formula (**3**).

$$v_{\mathrm{Ed,max}} = \frac{\beta V_{\mathrm{Ed}}}{u_0 d} \leq v_{\mathrm{Rd,max}} = 0{,}4 \nu f_{\mathrm{cd}} \qquad \text{…. (2)}$$

…. (3)

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

$$v_{\mathrm{Rd,cs}} = 0{,}75 v_{\mathrm{Rd,c}} + 1{,}5\left(\frac{d}{s_r}\right) A_{\mathrm{sw}} f_{\mathrm{ywd,ef}}\left(\frac{1}{u_1 d}\right) \leq k_{\max} v_{\mathrm{Rd,c}}$$

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 strength while the second one represents the ultimate strength 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 **[22-24]**.

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 compression 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 **Fig**.**2**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 **[25]**. 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 **[25]**. The constitutive stress-strain curve of the concrete model presented by the experimental study was defined in the concrete depending on the Kachlakev **[25]** and ACI 318M-19 **[26]**. 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 **[27]**. All used properties of the concrete and the other concrete slabs

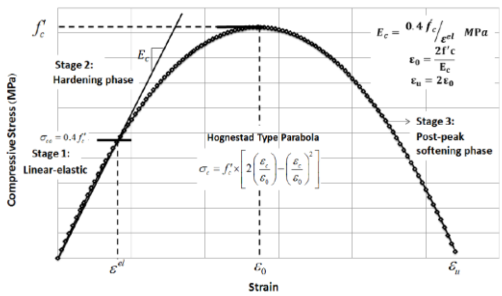


Fig.2 Stress-strain relationship of the concrete.

Table.1 Properties of concrete.

Material	Yield strength [MPa]	Used element	Poisson ratio	Adopted stress-strain curve
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

4. Verification

Six models presented by an experimental study by Oukaili and Salman **[27]** 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 **[27]**. 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 %

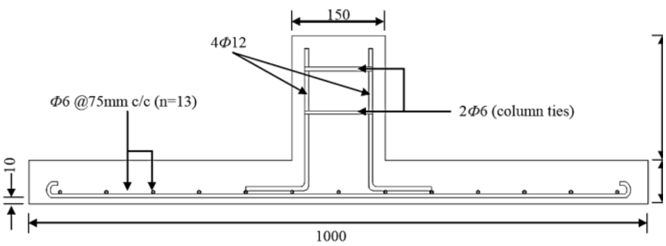
CC0	86.0	90.76	94.76%	9.87	13.98	70.60 %
CF1	88.6	88.95	99.61%	11.29	13.33	84.70 %

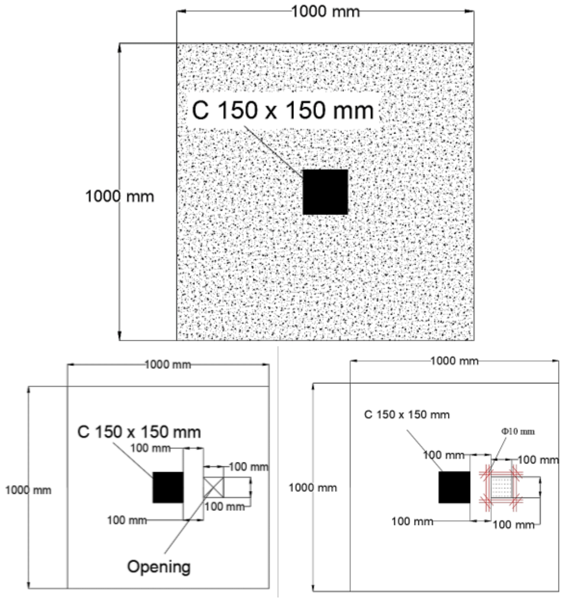
5. Parametric Study

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 Fig. 3 and Table 3 which is the similar specimens presented by Oukaili and Salman **[27]**. The reference slab details are presented in Fig. 2 which is the similar specimens presented by Oukaili and Salman **[23]**. The slab dimensions were (1000 x 1000 x 70) mm reinforced with Φ6@ 75 mm as main reinforcement and 4 Φ12 and 4 Φ6 mm as main and transverse reinforcement of the column. The series consists of 12 slabs with multi opening sizes and reinforcement. All openings in the specimens were square with the sides. Six sizes of openings were used: (100×100mm), (150×150mm), (200×200mm), (250×250mm), (300×300mm) and (350×350) as revealed in Fig. 3. Regarding the opening, as required by code design criteria, reinforcement was employed to surround the apertures. Reinforcing the opening by steel reinforcement was modelled in form of surrounded reinforcement which the strengthening bars was fully connected to the shared nodes, which provides a full bond with the concrete. The presence of strengthening bars in this way will provide greater cohesion between the concrete elements, which prevents the generation of initial cracks as a result of stress concentration at the first loading conditions.

Table.3 Details of specimens

ID	Opening size, mm	Reinforce-ment	f′c (MPa)	Distance of opening from column, mm
XXX	N/A	N/A	30	N/A
S100	100 X 100	N/A	30	100 mm
S100-R	100 X 100	@10 mm	30	100 mm
S150	150 X 150	N/A	30	100 mm
S150-R	150 X 150	@10 mm	30	100 mm
S200	200 X 200	N/A	30	100 mm
S200-R	200 X 200	@10 mm	30	100 mm
S250	250 X 250	N/A	30	100 mm
S250-R	250 X 250	@10 mm	30	100 mm
S300	300 X 300	N/A	30	75 mm
S300-R	300 X 300	@10 mm	30	75 mm
S350	350 X 350	N/A	30	50 mm
S350-R	350 X 350	@10 mm	30	50 mm





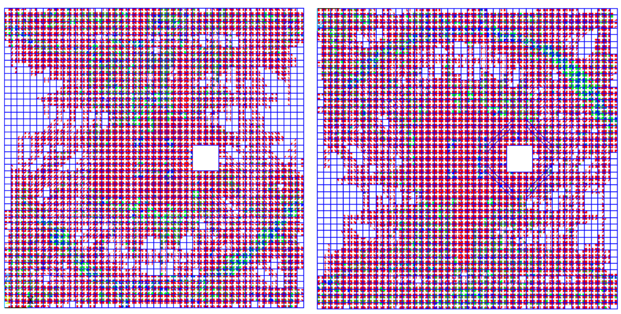
S100 **S100-R**

Fig.3 Reference and parametric slabs details.

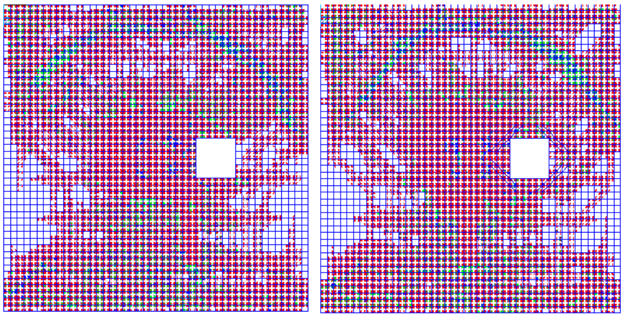
6. Test Results

6.1 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 (17.2%) 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. Cracks began in the column region, then spread and extended in an inclined direction, eventually crushing the concrete and occupying the majority of the punched slabs at the final stage of the loading. When the slab was reinforced with steel reinforcement, the cracks propagation showed a greater spread, as seen in **Fig.4** The stress distribution was affected by strengthening which redistributed the stresses around the opening and cause a propagation in the shear stresses along the slab.



(a) S100. **(b)** S100-R.



(c) S150. **(c)** S150-R.

Fig.4 Crack pattern for reference and strengthened slabs.

6.2 Load-Displacement Relationship

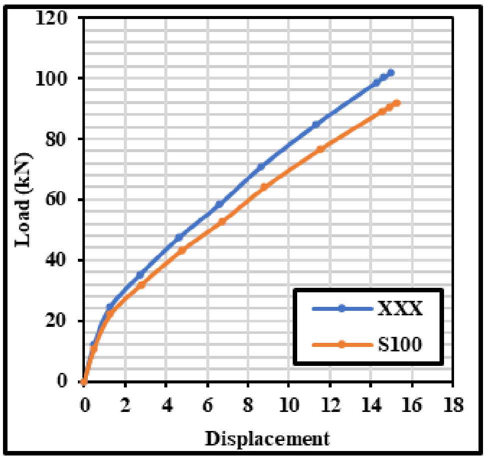
The obtained results of the tested slabs are presented in the Table 4. Thes slabs included testing of thirteen slab specimens under static loads which showed an ultimate load carrying capacity of (100.5) kN for the reference slab while the parametric slabs exposed an ultimate load ranged between (39.45 – 101.25) kN with maximum displacement ranged between (6.22 – 17.95) mm as demonstrated in Table 6. The ultimate load carrying has been affected due to several parameters such as opening size in addition to the strengthening by steel reinforcement. Expressing the obtained results with other calculation such as ductility to provide full understand to the behavior of flat slabs with opening. 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 (17.2%) for the slabs with opening.

Table.4 Obtained results of the tested slab.

ID	Pcr (kN)	Pu (kN)	Δ (mm)	Pcr Inc.	Reinf. Inc.	Open Dec.	Δ Var.	Ductility Index
XXX	23.62	100.5	14.931	-	-	-	-	5.495
S100	20.71	92.05	15.246	87.69%	-	90.37%	90.37%	5.123
S100-R	22.28	101.25	16.465	94.31%	109.99%	99.40%	99.40%	6.432
S150	17.97	89.42	15.557	76.09%	-	87.79%	87.79%	4.97
S150-R	20.63	100.15	17.26	87.35%	112.00%	98.32%	98.32%	5.94
S200	13.31	72.32	16.179	56.34%	-	71.00%	71.00%	4.22
S200-R	15.39	81	17.95	65.16%	112.00%	79.52%	79.52%	4.64
S250	11.24	63.12	10.89	47.57%	-	61.97%	61.97%	4.04
S250-R	11.93	66.276	11.434	50.51%	105.00%	65.07%	65.07%	4.53
S300	8.78	52.6	9.334	37.19%	-	51.64%	51.64%	3.85
S300-R	9.11	55.23	9.811	38.58%	105.00%	54.22%	54.22%	4.05
S350	6.23	39.45	6.222	26.39%	-	38.73%	38.73%	3.2
S350-R	6.64	41.42	6.534	28.09%	104.99%	40.66%	40.66%	3.5

6.3 Effect of Opening Size

Fig.5 expose the results of the tested slabs load deflection curve. The control solid slab demonstrated an ultimate load carrying capacity with (100.5) kN and (14.93) mm displacement. The parametric slabs created with opening near middle column. The parametric models are twelve slabs created with one opening with different sizes. The influence of the opening's, size was clear on the reinforced slab behavior. Is should be noted that all slabs of this series faced a punching shear failure even the steel reinforcement were placed around the opening. Concerning the slab with openings (S100) which have an opening with dimensions (100 x 100) mm near the column, the opening presence affected the ultimate load carrying load capacity and displacement in addition to the remaining calculations. The opening existence redistribute the stresses which showed concentration in the corners of the opening and around the middle column. The opening existence affected the cracking load which decreased by (12.7%) which the cracks appeared at (23.5%) in the control solid slab when it decreased to (22.5%) after creating the opening near the column. This phenomenon occurred because the openings decrease the ability of the slab to resist the loads. The failure by punching shear occurred at (92.05) kN which is smaller than the solid slab (XXX) by (9.4%) as revealed in **Fig.5a** The displacement is the most affected properties by the openings presence which the displacement increased by (2%) in comparison with solid slab. Regarding the other slabs were fabricated with larger openings, the increase of opening size to (150 x 150) as occurred in model (S150) which the cracking load decreased by (24%) when compared with the control slab (XXX). While the ultimate load carrying capacity and maximum displacement, the opening presence caused a decrease in the ultimate load by (12.2%) and increase in the ultimate displacement by (8.4%) as revealed in **Fig.5b** Regarding the remaining slabs with larger openings (200, 250, 300, and 350 mm), starting from the opening (200 x 200) the cracking load decrease by large percentage which was by (43.6%) when compared with reference slab the ultimate load decreased by (38%) and the displacement reduced by (27%) as revealed in **Fig.5c** The slabs with openings (250, 300, and 350 mm), the decrease in the cracking load reached to its peak value which were by (52.5%, 62.8%, and 73.6%) respectively. Regarding the ultimate load and maximum displacement, the reduction in the values were (27%, 37.5%, and 58.5%) and (39%, 48.5%, and 61.3%) respectively as revealed in **Fig.5 d, e,** and **f**.



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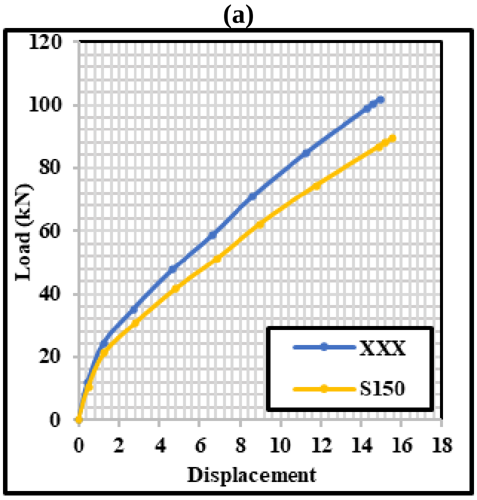

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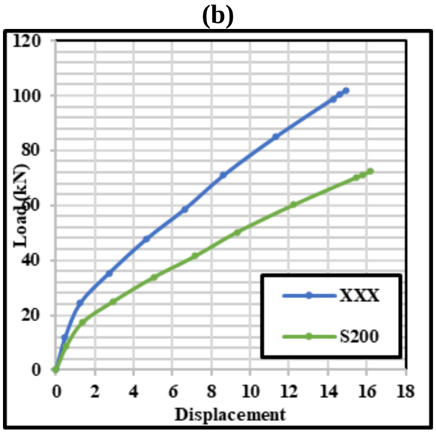

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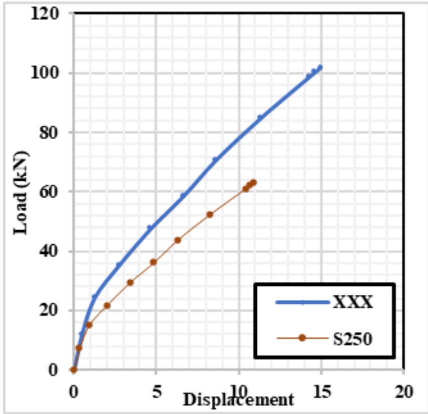

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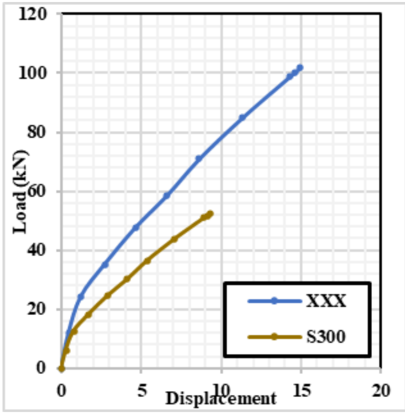

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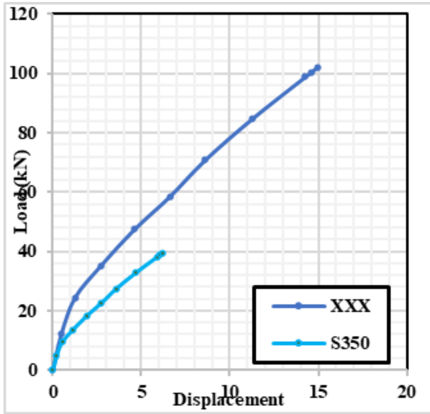
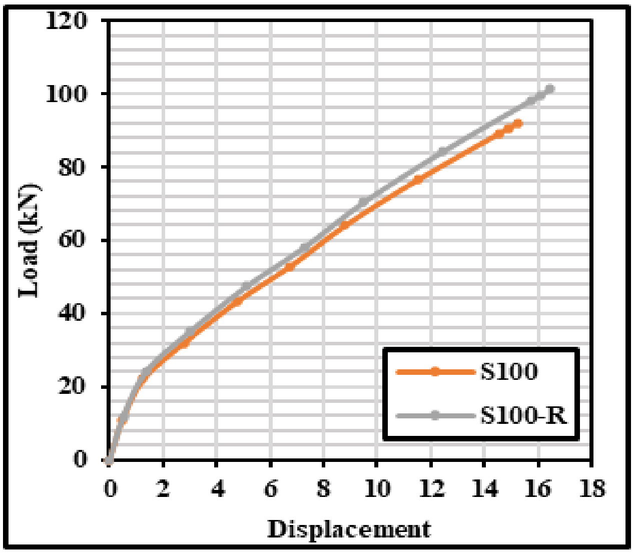


(f)

Fig.5 Load-displacement relationship of solid slab and slab with opening.

6.4 Effect of Opening Reinforcement

Reinforcing the opening exhibited an acceptable result to some extent which reinforcing the openings with sized less than 250 mm revealed a good enhancement in comparison with the larger openings which the enhancements were insignificant. the energy absorption, and ductility index revealed a good enhancement when the openings reinforced with steel reinforcement. Concerning the slab with openings (S100) which have an opening with dimensions (100x100) mm near the column, the reinforcement restored the lost strength due to the opening's existence which gaining an additional slight increment. The cracking load increased by (7.55%). The reduction in the ultimate load carrying capacity from (12.3%) to (0%) with gaining an additional strength by (1%). While the displacement increased by (8%) when the opening reinforced with steel reinforcement as revealed in **Fig.6a** Concerning the slab with opening of (150 x 150) (S150), the reinforcement restored the full loss in strength approximately with increase in the displacement from (17.26 to 15.58 mm) which equal to (11%) as revealed in Fig. 6 b. The cracking load of such slab also increased which was by (14.8%). Maximum upgrade in the ultimate load was by (19.8% and 19%) for the slabs with openings (150 and 200 mm) as occurred in models (S150-R and S200-R). Regarding the remaining slabs with openings of (250, 300, and 350), the behavior of these slabs was differed in comparison with smaller openings which the reinforcing the opening by steel reinforcement provided little enhancement and less than the slabs with smaller openings which the enhancement in the ultimate load carrying capacity was by (5%, 4.75%, and 4.18%) respectively as revealed in **Fig.6 c, d, e,** and **f**. The cracking load of such slabs showed less enhancements which the upgrade didn't exceed the 6%. The displacement also didn't get a significant improvement which showed maximum value of 5%.



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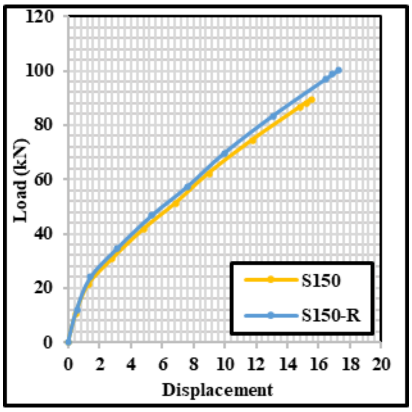

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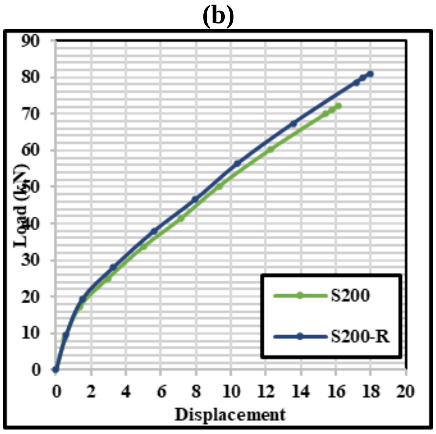

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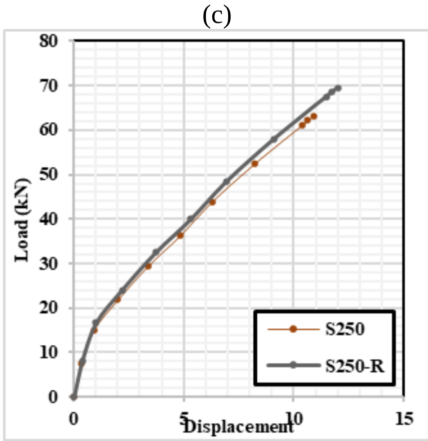

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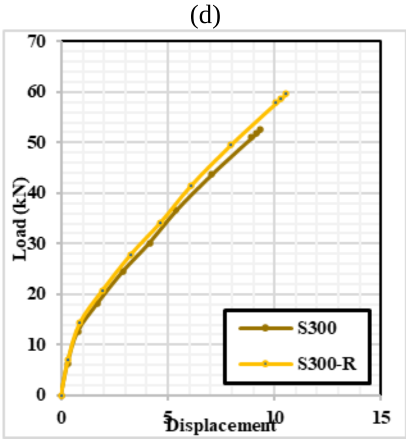

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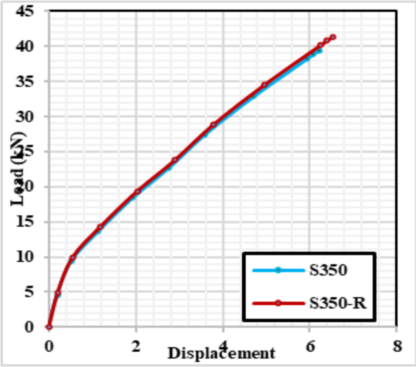
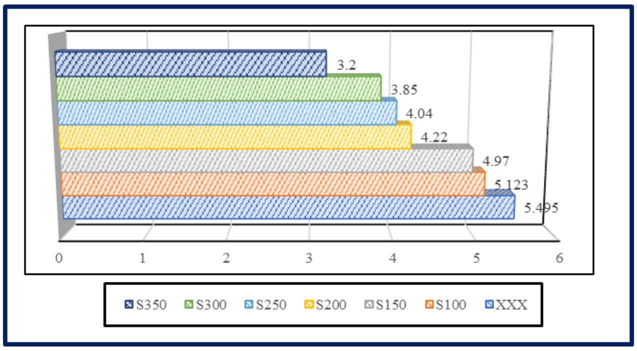


(f)

Fig.6 Response of punched shear slabs.

7. Ductility of the Tested Slabs

Marzouk and Hussein **[28]** defined the term of ductility which is agreed by the approach that established by Priestley and Park **[29]** and recommended by Robertson and Durrani (1991) **[30].** Opening's effect and as expected has a significant effect on the ductility of the concrete slabs but with reinforcing the opening with steel reinforcement 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 size of the openings, the performance of the reinforced slabs has improved greatly when the opening was reinforced, and this is due to the presence of steel reinforcement, 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.



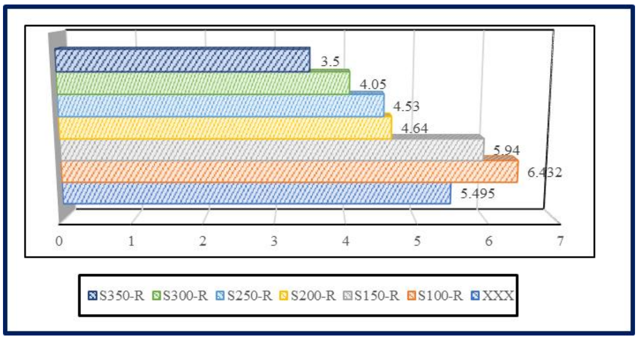
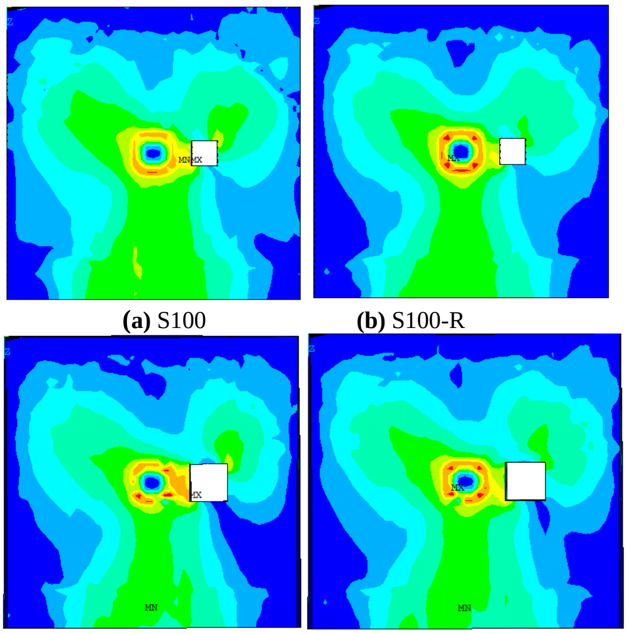


Fig.7 Ductility index of reinforced concrete flat slabs.

8. Stress Distribution

Shear stress distribution in all slabs is presented in **Fig.8** 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 on the larger openings. Regarding the stresses propagation at the slabs with reinforced openings which the reinforcement increases spread area of stresses. Comparing the results between the slab with small openings (100x100 and 150x150), the stresses in the un reinforced openings showed concentration and stress propagation at the opening corners while in case of the reinforced opening, the stress concentration reduced at the opening corners and propagated with larger areas with reduction in the intensity of shear stresses. Level of intensity ranged from colors (blue-green- yellow-brown-red) respectively in concentration, the minimum intensity is blue while maximum intensity referred in red color. In regard to the series one, the distribution of the stresses affected by all used parameters as shown below in **Fig.8** It must be noticed that these figures explained the path of stresses and the zones of its concentration.



(a) S100 **(b)** S100-R

(a) S150 (b) S150-R

Fig.8 Shear stresses distribution of tested models.

9. Conclusions

In this manuscript, the results of 13 RC strengthened 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 and the most affected variable is the opening size which increase the opening size caused higher decrement in the cracking and ultimate load capacity. Maximum decrement occurred in the ultimate punching shear strength in the model with largest opening size (350 x 350) which the shear stresses crushed the concrete around the central column.

3- Existence of opening even in case of reinforced 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.

4- Reinforcing the opening compensated the lost strength with gaining an additional slight strength to some extent especially for small openings (100x 100 and 150 x 150). Which the larger opening caused high condensation of shear stresses around the opening and central column lead to punching shear failure.

5- Surrounding the opening with steel reinforcement redistributed the shear stresses and caused more propagation in the slab section.

6- The existence of openings increases the strains in concrete on the compression face of the slabs.

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