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Review on Reinforced Concrete Slabs behavior with Presence of Openings

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Abstract

Openings in slabs are an important issue that needs to be studied carefully because these openings have an important effect on load capacity and the general behavior of RC, reinforced concrete slabs. This research aimed to review the previous studies that highlighted the impact of presence of opening in RC one-way and two-way slabs in addition to a review of four important codes, ACI Code, British Standard, Canadian Standard, and European Standard, that focused on this topic. The review of previous studies is divided into two sections, the first is the effect of opening in one-way slabs and the second is the effect of opening in two-way slabs. These studies produced that the opening size and position significantly affect load capacity, flexural, shear resistance, and deflection of slabs. The opening in the slab reduces the load capacity and shear resistance by reducing the concrete mass of the section where the concrete is cut. The flexibility of that slab is reduced in the existence of the opening caused by reinforcement cutting. The effect of opening can be reduced by using additional reinforcements or by using CFRP, carbon fiber reinforced polymer-strengthening.

Keywords: *Review; RC; Opening; slabs*

1. Introduction

Due to a large number of service requirements for construction buildings, nowadays, openings are intensely needed in slabs and even in beams, such as openings for electrical cables, sewer, and cooling pipes or ducts or openings for stairs, elevators, or even for architectural purposes. Care shall be taken while incorporating these openings. Some are before construction which can be planned and some are after construction.

There are many different ways of restrengthening of opening in slab. These ways, are conducted internally before casting by adding additional reinforcements around the opening, externally by using carbon fiber reinforcement with casted and cut slabs, or by using both strengthening methods.

Several studies have been conducted on reinforced concrete slabs with openings to highlight the effect of opening on the shear, flexural, and general behavior of slabs in addition to the effect of size, shape, and position of opening on these slabs.

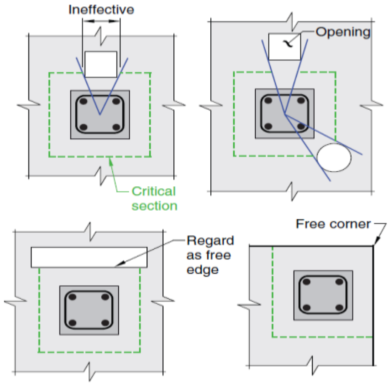
This research will review the limitations and conditions of ACI code, BS code, ES code, and CSA code in addition to many researches that studied the effects of openings in one-way and two-way slabs.

2. Opening in slabs according to different codes

2.1. Openings in slab systems according to ACI 318-19 [1]

ACI Code, (8.5.4.1) shows that the openings in slabs of any size are allowable if they satisfy the requirements of strength serviceability, and deflection. Alternatively, (8.5.4.2) shows that the opening is allowable in a slab system without beams if satisfied the following:

a- If the opening was in the area of middle strip intersections, the missing reinforcements should be compensated.
b- If the opening was in the area of the column strip intersection, the width of this opening shall not exceed (1/8) of the column strip in each span. In addition, the interrupted reinforcements should be compensated on the sides of the opening.
c- If the opening was in the intersection of the column strip and middle strip, the interrupted reinforcements shall not exceed (1/4) in either strip. In addition, the interrupted reinforcements should be compensated on the sides of the opening.
d- for slabs with shear heads, if the opening was in the column strip and close to the concentrated load or reaction area by less than (4h), a portion of bo enclosed by straight lines projecting from the centroid of the column, concentrated load or reaction area and tangent to the boundaries of the opening shall be considered ineffective. The locations of the effective portions of the critical section near typical openings and free edges are shown by the dashed lines in Figure (1).



Openings shown are located within 4h of the column periphery.

Fig. 1: Effect of openings and free edges (effective perimeter shown with dashed lines). [1]

2.2. Openings in slab systems according to British Standard 8110-1 [2]

According to British Standard (8110-1), (3.7.5), the opening should not override the column head and openings should formed with beams on all sides to transfer the loads to columns, otherwise should satisfy the following:

1- Opening in column strip: the greatest dimension of opening, in the direction than in line with the center-line of the slab, should not more than 0.4 of length, and the design moments distributed between the remaining structure.
2- Opening located in the intersection of column strips: the largest dimension of the opening should not exceed one-tenth of the column strip and the remaining section area is capable of carrying the design moments. In addition, the design shear should be reduced if appropriate.
3- Opening located in the intersection of column strip and middle strip: the largest dimension of the opening should not exceed one-quarter of the column strip and the remaining section area is capable of carrying the design moments.

In section (3.7.7.7), the effective perimeter is modified to allow for openings: If the location of the opening in the slab is at a distance less than six times the effective depth from the border of the concentrated-load, then that part that is enclosed by radial extensions from the center of the load is to the openings is considered not effective, as shown in figure (2).

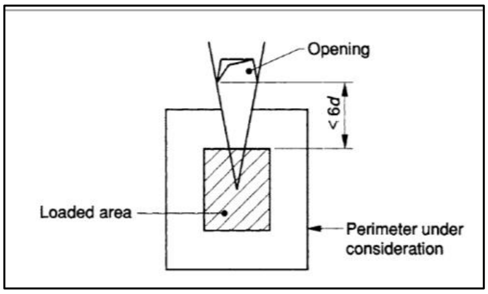


Fig. 2: Shear Perimeter of the slab with opening [2]

2.3. Openings in slab systems according to Canadian Standard A23.3 2019 [3]

In CSA (A23.3 2019), the opening in slabs had been considered according to the following:

1- In section (13.3.3.4) slab openings: If the distance between the opening and the concentrated load or load area is less than ten times the slab thickness or the location of the opening is in the column strip, then the area enclosed by the projections from the center of the load or load area and tangents to the boundaries of the opening considered as ineffective area.
2- In section (13.5.4): opening in slabs of any size is allowable if the slab system analysis shows that the factored resistance of the slab is at least equal to the factored loads in accordance with load compensations, load factors and factored resistance mentioned in (8.3), (8.4) and (13.3.3.4).
3- In two-way slabs without beams, openings could be done without the requirements given by (13.5.4) if met the following:
    a- If the opening was located at the intersection of middle strips, the reinforcement amount of the slab without opening should be maintained.
    b- If the opening was located in the intersection of column strips, then the interruption should be equal to or less than (1/8) of the column strip's width in either span and the reinforcement amount that was missed should be added adjacent to the opening sides.
    c- If the opening was located in the intersection of the column strip and middle strip, then the interrupted reinforcements should be equal to or less than (1/4) of reinforcements of either strip and the amount of the reinforcement that was missed should be added adjacent to the opening sides.
    d- The requirements of shear resistance, specified in (13.3.3.4), should be satisfied.

2.4. Openings in slab systems according to Europe Standard EN 1992-1-1 [4]

In section (6.4.2), Load distribution and basic control perimeter, the European Standard (1992-1-1_2004) mentioned the openings in (6.4.2) the load distribution and basic control parameter. If the distance between the opening and the load area does not exceed (6d), then the openings near the loaded areas, the area that is enclosed by the lines tangent to the opening and drawn from the center of the load area is considered ineffective.

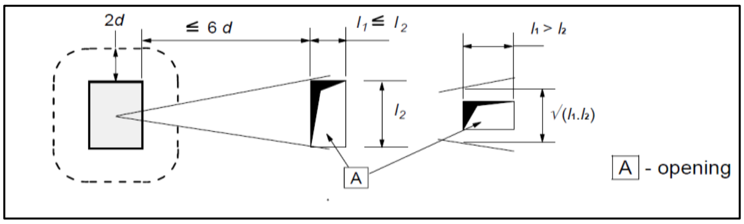


Fig. 3: Control perimeter near an opening according to ES (1992-1-1_2004) [4]

3. Previous researches that dealt with the issue of openings in slabs

There are a lot of researches that study the issue of the effect of openings in concrete slabs. These researches have dealt with the study of slabs on the basis of the two main types of slabs, which are one-way slabs and two-way slabs. These researches concentrated on the effect of opening size and location on the behavior of the slabs in terms of flexural, shear, and general behavior under concentrated or distributed loads. Table (2) illustrates the details of the slabs and openings of all studies with failure mode and ultimate load reduction caused by the presence of opening.

3.1. Effect of opening in one-way slabs

Hereunder a summary of studies that dealt with the behaviour of one-way slabs:

Paolo Casadei et al, 2005 [5]; produced a field test of strengthening cut-out opening in a one-way slab. What distinguishes this research is that the slabs that were tested are of a building that is scheduled for demolition. Openings were created in a one-way flat slab in the negative moment region and positive moment region. Then, these openings were strengthened using CFRP sheets with different schemes of strengthening. Six specimens were conducted as shown in Figure 4.

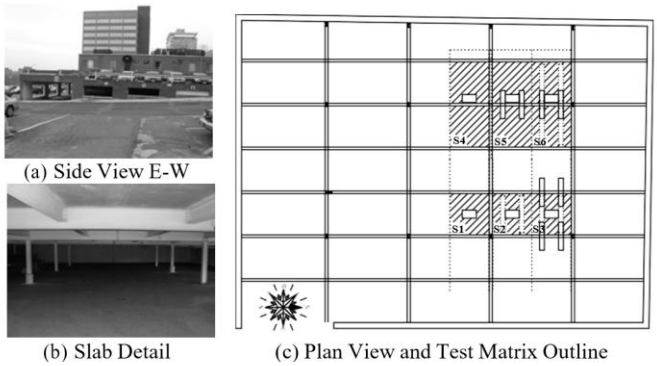


Fig. 4: Specimens of the building scheduled for demolition [5]

The details of opening and strengthening are shown in figure (5).

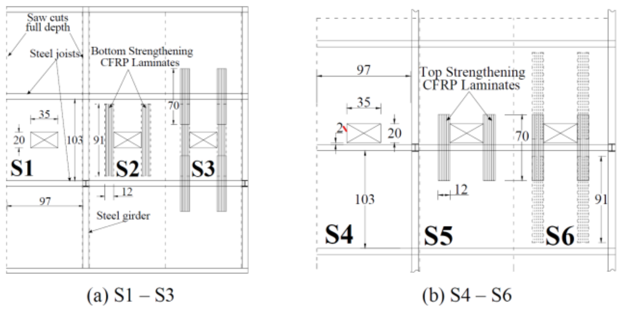


Fig. 5: Openings and strengthening schemes [5]

The tests explain that the strengthening using carbon fiber reinforcement polymer sheets significantly improved the load capacity related to slab with opening, which approximately reached 30%. On the contrary, a shear failure occurred when the opening was produced in the positive region and the strengthening with CFRP sheets is not effective in this region.
Koh Heng Boon et al, 2009 [6]; studied the behavior of a one-way slab with an opening. Five specimens were cast. One of these slabs was cast as a controller specimen. the other four slabs were cast with an opening in the mid-region of the span. One specimen had been casted with opening without any strengthening or additional reinforcements. One of the specimens was with additional reinforcements parallel to the length and width of the opening. One other specimen was strengthened by using additional diagonal reinforcement located at the edge of the opening. The last specimen was strengthened by using reinforcement bars around the opening in addition to reinforcement bars that located diagonally in the corners of the opening. Figure (6) shows the details of all specimens with opening and additional steel bars for strengthening.

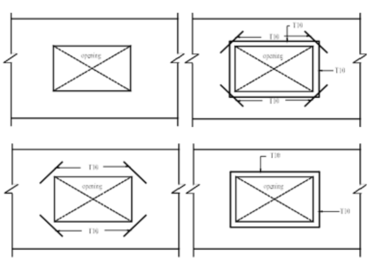


Fig. 6: Strengthening bars of opening [6]

The dimensions of all specimens were, 1100mm in length, 300mm in width, and 75mm in thickness, and the dimensions of opening were 300mm in length and 150mm in width.
The results explained that the ultimate-load of the slab was reduced by 36% in the existence of the opening. However, the best restrengthening way was by adding rebars surrounding the opening parallelly and diagonally, and adding only diagonal bars did not give a significant change.
H. M. Seliem et al 2011 [7] had produced a case study on the restoration of flexural capacity of continuous one-way RC slabs with cutouts. This research is distinguished by the fact that it was conducted on a real building that was scheduled for demolition. In which, a field test was applied to one-way slabs cut out in the positive moment region to make an opening with dimensions (610*610) mm2 which represents 18% of the clear span. Five different slabs were chosen to make five tests with the presence of three different strengthening ways. The three ways were, near surface mounted FRB, externally bonded FRB, and externally bonded with anchors FRB.
The results show that the flexural capacity of the slabs had been significantly affected by the presence of openings. However, the NSM CFRP was more efficient than EB CFRP plates without anchors. However, the slab resistance was not restored.
Kadhim et al, 2013 [8]; introduced a nonlinear finite element study of slabs with opening strengthening by either overlay concrete or carbon fiber reinforced polymer sheets surrounding the opening. The numerical analyses depended on a previous study of nine specimens. The dimensions of these slabs were 1200mmX250mmX100mm, one of them was cast with an unstrengthened opening, and eight others were cast with an opening then strengthened by overlay concrete and CFRP sheets surrounding the opening. The experimental study consisted of eleven slabs with dimensions of 3600mmX2400mmX150mm simply supported and tested with two-line loads. The opening is cut with dimensions of 1200mmX800mm and strengthened by overlying concrete or CFRP sheets.
The results of this study concluded that the ultimate-load capacity was increased by 10% to 60% when CFRP sheets were used. In addition, the use of CFRP sheets gives better efficiency than overlay concrete.
Ali M. Al-hafiz et al, 2013 [9]; in their paper, Flexural Strength of Reinforced Concrete One-Way Opened Slabs with and without Strengthening, investigates a new strengthening technique to enhance the behavior of one-way slabs with openings. Fifteen RC slabs were investigated in this paper. The opening was made in the middle of the span with dimensions of 75mm for each side. A steel plate with steel connectors was used in all sides of the opening for strengthening. The variables were the slab thickness and steel thickness. Were the slab thickness used were, 40mm, 60mm, and 80mm. The steel thicknesses used were 2mm, 4mm, and 6mm. All sabs had the dimensions of 1100mm length and 400mm width. The steel plate used for reinforcing the opening is shown in Figure (7).

Fig. 7: Specimens and steel plate used for strengthening [9]

Test results show that the ultimate loads with an opening without strengthening had been reduced by 23% to 27% if they compared with slabs that have no opening. While the ultimate loads with strengthened openings had been reduced by 3.5% to 23% in comparison with slabs without openings.
Qusay W. Ahmed 2018 [10], in his paper, worked on the behavior of reinforced concrete one-way slabs with openings. One specimen was cast as a controlled specimen without any opening. Three specimens were implemented to have a square opening in middle of the span with dimensions of 150mm, 200mm, and 250mm sides. Two specimens with rectangular and circular openings. Two specimens were cast with additional strengthening bars surrounding the opening and diagonally at the corners of the opening respectively. The last specimen was cast with double reinforcement surrounding the opening.
The results showed that an opening of 200mm*200mm reduced the load capacity by about 50%. The slab with strengthening rectangular and diagonal bars showed a significant enhancement in load capacity and the additional diagonal bars showed no significant effect.
Salman et al, 2018 [11] in their experimental work they studied the behaviour of slabs that have an opening. Six specimens were prepared with dimensions of 1.5m length, 0.5m width, and 10cm thickness. One specimen was cast without an opening and five specimens were cast with a (20cm*20cm) opening located at the center of the slab. CFRP is used for strengthening the opening edges. The main parameters were the area, width, and length, of the CFRP and the presence of the opening. Figure (8) explains the details of specimens.

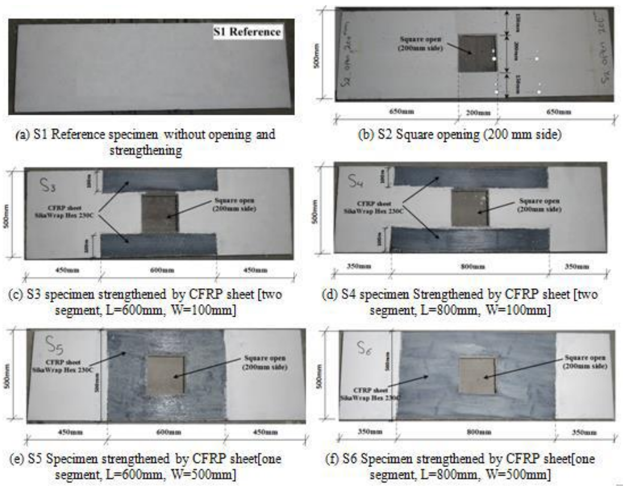


Fig. 8: Opening in slabs with different sizes. [11]

The results displayed that the load capacity was influenced by a 50% decrease in the presence of an opening in comparison to the controlled specimen. The specimens that were strengthened by CFRP sheets recorded an increase of about (24-92) %. The deflection at the mid zone was also reduced by about (40-62) % in the presence of CRFP. Finally, noticed a cracking width reduction by about (44-95) %.

Abd-Elhakim A. Khalil et al, 2019 [12]; in their research studied the behavior of a cantilever slab with an opening. Seven specimens were cast in the dimensions shown in the Fig (9).

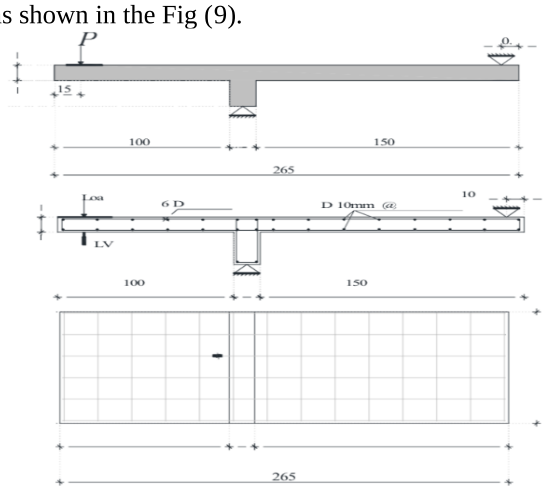


Fig. 9: Control specimen details [12]

One of these specimens casted without opening as shown in Figure 9. While the other specimens were cast with different locations and dimensions of the opening. Table (1) shows the details of openings and reinforcements.

Table 1: Openings and reinforcements details [12]

Group	Slab	Fcu (MPa)	Opening Shape	Internal reinforcement (mm^2)
G1	SC	25		D10@160mm
G2	SB-400-200	25		D10@160mm
G2	SB-200-400	25		D10@160mm
G2	SB*-400-200	25		D10@160mm
G3	SM-400-200	25		D10@160mm
G3	SM-400-400	25		D10@160mm
G3	SM-200-400	25		D10@160mm

Results show that the opening in the cantilever slab causes a significant reduction of the flexural and stiffness of these slabs. The slab that has an opening closer to the support was the most affected slab.

Aman et al, 2020 [13], studied the performance of RC slabs with opening strengthened by CFRP sheets. In this research, ten slabs with dimensions of 1000mmX530mmX25mm were cast. One controlled slab without opening and nine other slabs were cast with the opening of area equal to 5%, 10%, and 20% of slab area. The strengthening applied was one ply, two ply, and three plies of CFRP sheets around the opening as shown in Figure (10).

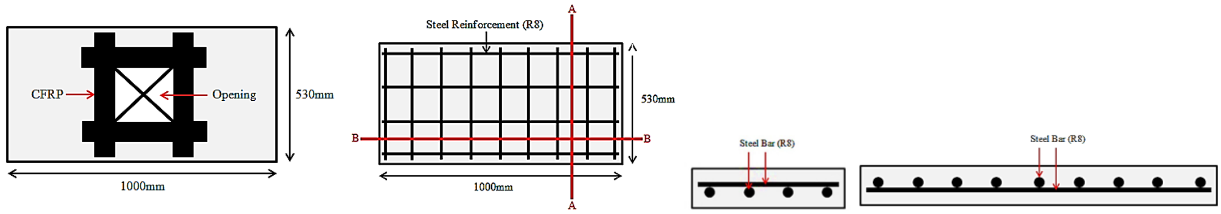


Fig. 10: Specimens and strengthening modeling [13]

The results indicated that the opening strengthened by three layers gives a highest resistance to the load. In addition, the deflection is reduced by increasing the CFRP ply.

Nalan Kaya and Ozgür Anil, 2021 [14], tested seven specimens to predict the load capacity of one-way steel reinforced concrete slabs. A comparison between experimental and theoretical, finite element analysis, study also had been done. The specimen's dimensions and the openings dimensions are explained in Figure (11).

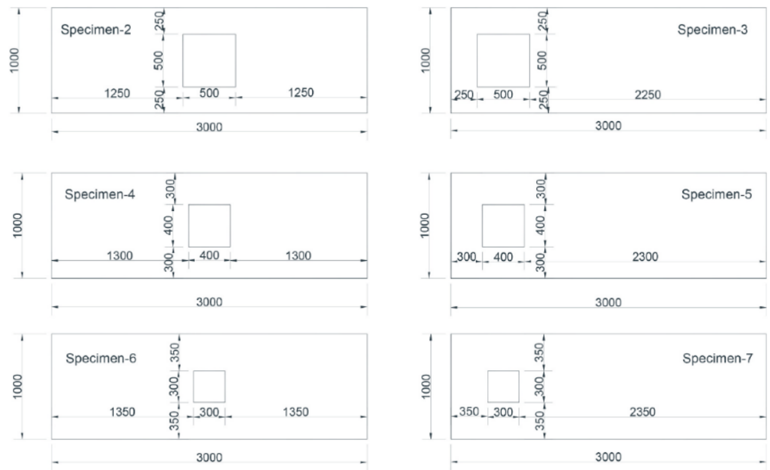


Fig. 11: opening dimensions and locations.[14]

In addition to the specimens shown in Figure 11, one specimen without an opening had been cast for comparison. The experimental results closely matched the theoretical ones in terms of displacement, ultimate-load, the stiffness, and the mode of fail. The results showed a large amount of reduction of the ultimate load capacity in the specimen when the opening is located in the region that has a high moment in comparison to slabs when the opening is located in its high shear area. The ductility and energy dissipation showed a higher reduction. The opening which in the high shear area led to a brittle-failure because of cracks occurring. The final results of this research indicated that the openings in the one-way slabs significantly reduced the load capacity of that slabs.

Moataz Gamal et al, 2021 [15], performed a study of strengthening of continuous RC slab with opening using near-surface mounting strengthening. Seven slabs with openings were cast with dimensions of 2400 mmX500 mm and thickness of 100mm. One of these slabs were used for comparison in which it has no any opening and the other slabs were casted with different situations of openings and strengthening methods. Two points load centered at each span which length of 1100mm. Ultimate load, crack width and mode, failure mode, and deflection were discussed in this research. A significant enhancement of ultimate load was done by using near surface mounted steel bars ranging between 156% to 225%. Steel bars were more effective in comparison with CFRP bars for strengthening the region of negative moments.

Abas Golham et al, 2023 [16], studied the flexural behavior of a one-way slab reinforced by glass fiber-reinforced polymer GFRP bars with an opening strengthened by carbon fiber-reinforced polymer CFRP sheets. Five slabs were constructed for an experimental flexural test. The dimensions of all slabs were: 750mm width, 2650mm length, and 150mm thickness. One of these slabs was cast without any opening as a reference one. Four slabs were cast with square and rectangular openings with dimensions of 250mm*250mm and 250mm*500mm respectively. These openings were reinforced by CFRP sheets as in Figure (12).

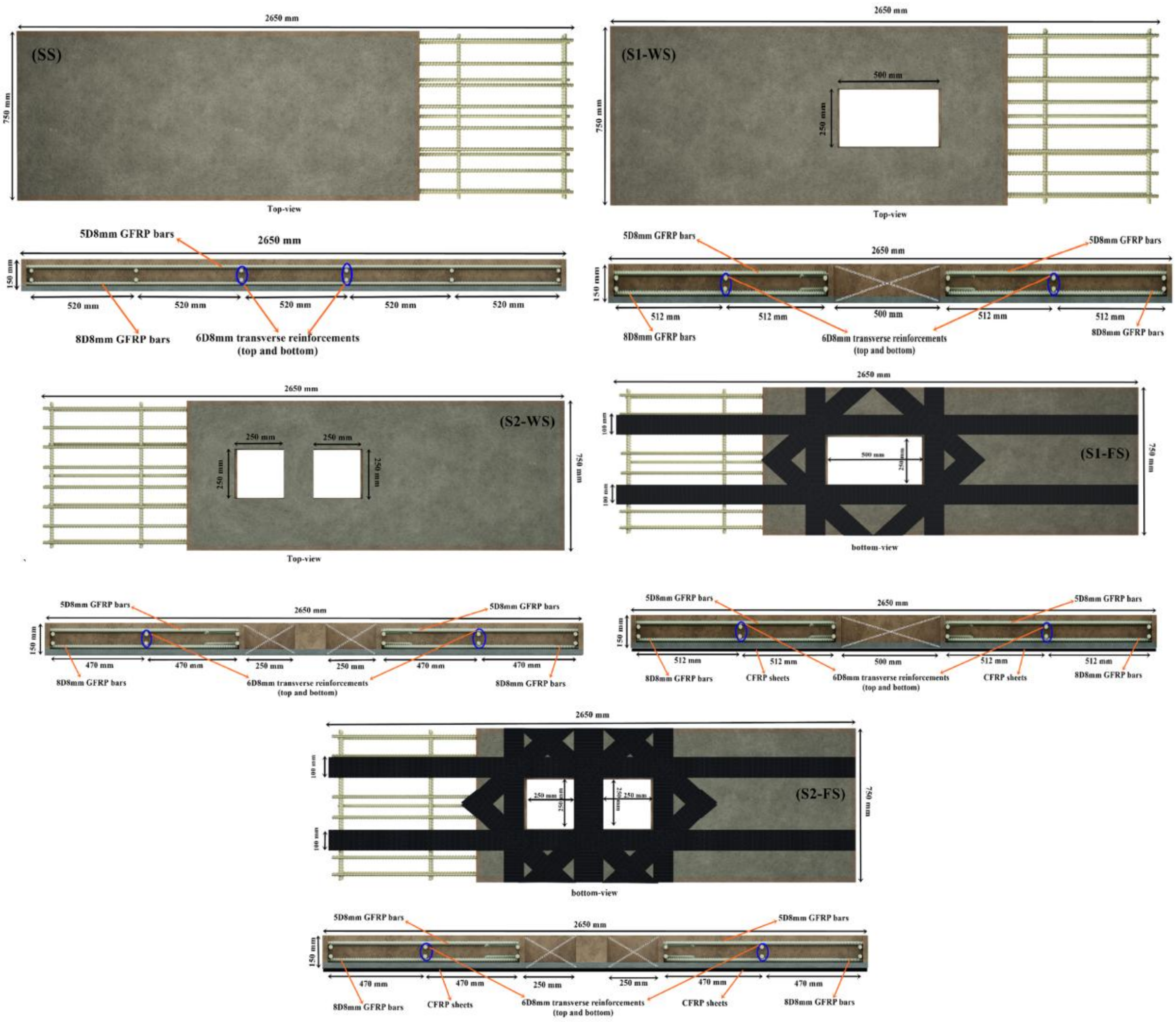


Fig. 12: Specimens Details [16]

The presence of an opening in the mid-span of the slabs reduced the failure load by about 41% for rectangular openings and about 43% for two square openings in comparison to the slab without opening. The existence of CFRP sheets around the opening has improved the slab's capacity by about 44% to 52% in terms of flexural load and stiffness by about 95% to 101% and decreased the deflection by about 45% to 56%.

Al Kallas et al, 2023 [17], conducted an experimental program to evaluate the effect of opening in a one-way ribbed slab. Four specimens were made of three ribs divided into one ribbed slab without an opening, one ribbed slab with an opening without strengthening, and two ribbed slabs with opening an and strengthened by using carbon fiber reinforced polymer sheets. The dimensions of all slabs were 2600mm in length, 825mm in width, and 175mm in depth. The opening was in the flexural region of the slab with a side length of 400mm. The middle rib was cut included by the hole. Figure (13) explain the details of the specimens with opening and strengthening.

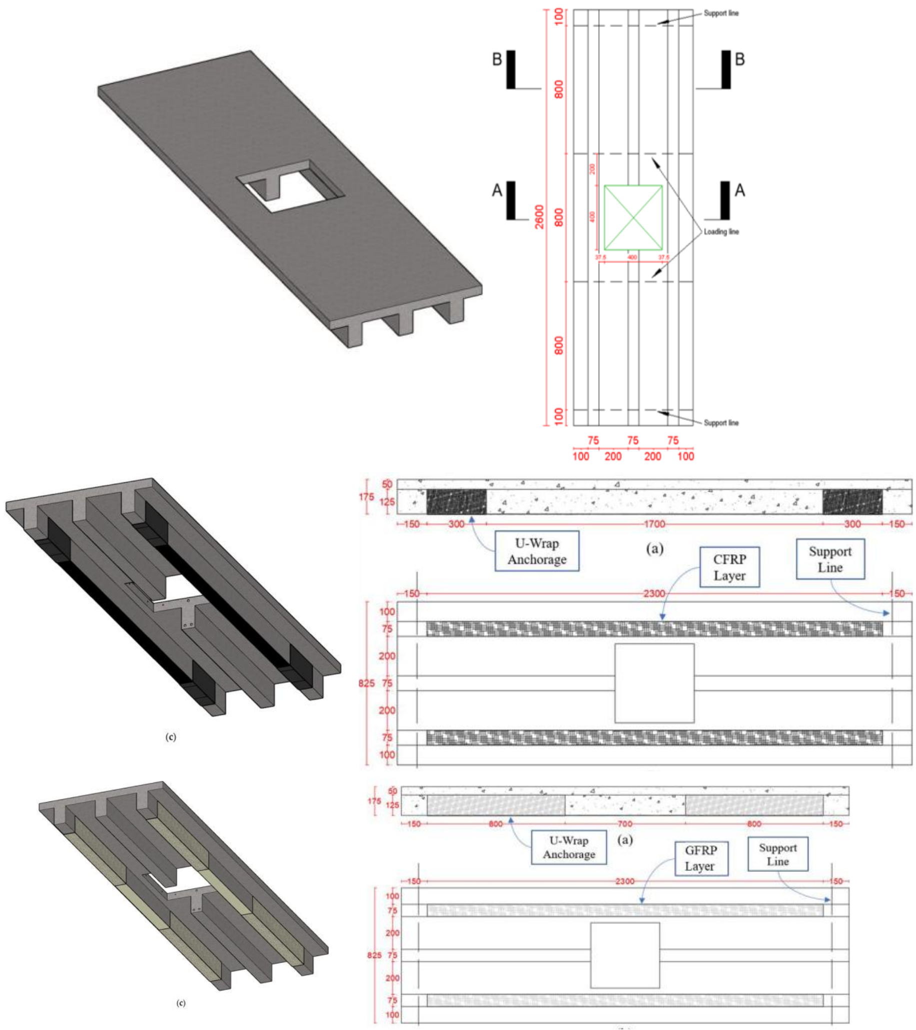


Fig. 13: Ribbed slab specimen with opening and strengthening details. [17]

After analyzing the four specimens to conduct the peak load for these slabs, the test concluded the following:

- The failure was a flexural zone failure for control and for the slab that has an opening without CFRP-strengthening. The failure of strengthening slabs was due to the rupture of FRP sheets combined with the concrete cover.
- The slab with opening capacity was reduced by about (38%) compared with the control slab without an opening because that opening was in the flexural zone and one rib was cut by this opening. In other words, only two ribs still working.
- The strengthening by CFRP and GFRP sheets restored the slab's load capacity. In addition, this strengthening enhanced that capacity by about 2% to 8% in comparison with the control specimen without opening.

The stiffness of strengthened slabs with an opening enhanced by about 35% to 48% in comparison with unstrengthened slabs with an opening. Also, energy dissipation reduced by about 11% to 19%.

3.2. Effect of opening in two-way slabs

Piotr Rusinowski, 2005 [18], in his thesis, discussed the behavior of two-way slabs with an opening under a distributed load. The slabs were divided into two groups. The first group had been cast with openings and reinforced by steel bars. The second group had been cast without opening and then the openings were sawed up and strengthened with Carbon Fiber Reinforced Polymers (CFRP). All slabs are square with dimensions (2.6*2.6*0.1) m^3. Uplift in the corners is allowed in boundary conditions and because of that, the slab reinforced only in the bottom. There are two types of openings which named "small hole" with dimensions (0.85*0.85) m^2 and "large hole" with dimensions (1.2*1.2) m^2 as shown in Fig (14). The opening location was in the center of the slab.

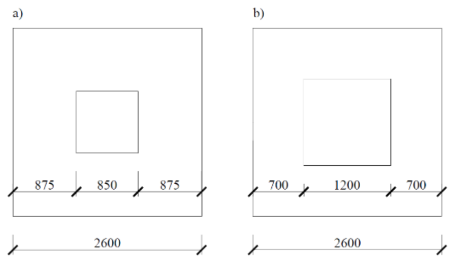


Fig. 14: Rusinowski specimens details. [18]

The results of the experiment show that the opening made in an existing slab could be strengthened by carbon fiber reinforced bands which is adequate and applicable. Whereas, the additional reinforcements in the corners of the opening, in the case of a slab cast with an opening, didn't obtain enough results and cannot be recommended in a actual structure.
Chee Khoon Ng. et al, 2008 [19], studied the effect of opening in in a square slab. The yield line analysis method is used to estimate the ultimate limit state.

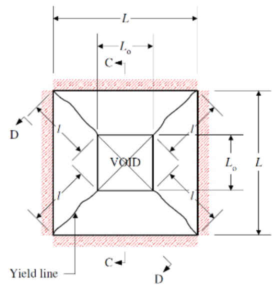


Fig. 15: Square slab with a central-opening. [19]

Results show that the ultimate load capacity decreased by increasing the area of the opening. Also, the small openings, less than 30% of the slab area, have an insignificant influence on the load-capacity. In addition, the very significant effect of the opening in the slab occurs when the size of the opening is equal to or more than 50% of the slab dimensions.
Luaai Muhammed Abbas [20], 2011 delt with the problem of an opening in two-way RC slabs. In which, CFP, carbon-fiber-polymer, is used instead of normal steel reinforcement. Eleven specimens of simply supported square slaps had been used with openings in the center of these slabs. The controlled specimens are two slabs with openings reinforced by steel bars and the remaining slabs reinforced with carbon fiber-reinforced polymer bars. The details of slabs and openings are shown in Fig (16). The results show that the opening significantly affects the behavior of slabs in general and the slabs reinforced with FRP bars deflected more than slabs reinforced with steel bars by a percentage of (21% - 29%).

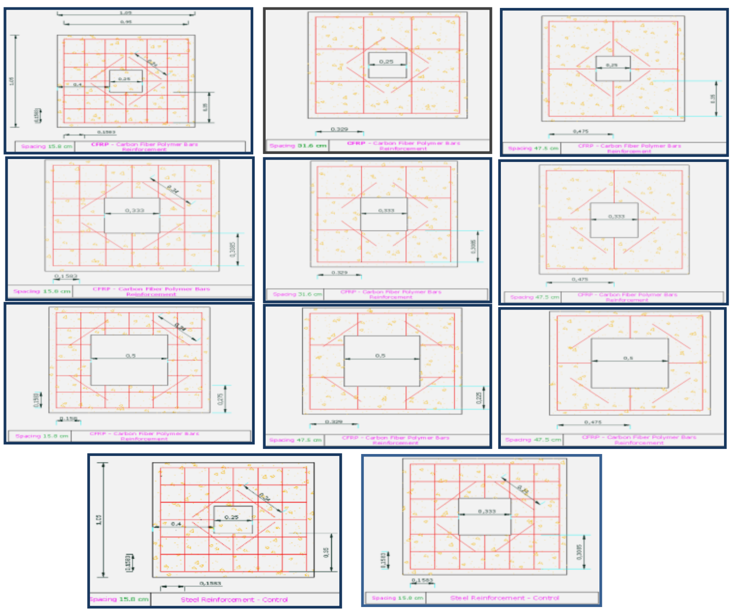


Fig. 16: Experimental work specimens details. [20]

EL-Shafiey et al in 2012 [21], studied the Behavior of Flat Slabs with Openings Adjacent to Columns. This study investigates the punching capacity of a flat slab that has an opening adjacent to a column experimentally and theoretically. Seven specimens of flat slab prepared with dimensions (1,700 x 1,700 x 150 mm) and loaded up to failure. One specimen was constructed without opening as a controlled specimen and the remaining six specimens were divided into two groups. The first group of three specimens with opening in front of the column face. The second group of three specimens was constructed with an opening at the column's corner. Column dimensions, slab thickness, and steel reinforcements remained constant in all specimens, and opening size and position worked as the main parameters. Figure (17) shows the specimens and openings location and dimensions.

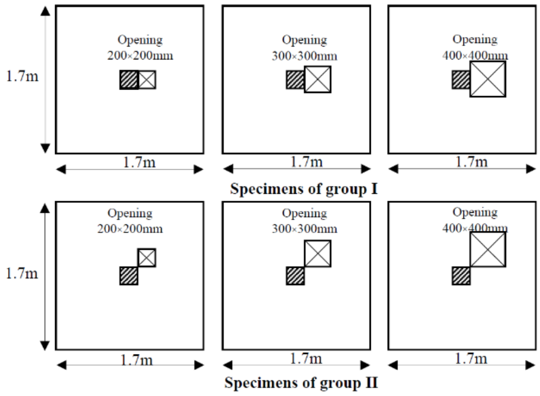


Fig. 17: Specimens details of EL-Shafiey et al. [21]

The results show that the opening located at the column face reduced punching capacity by about 26%, 48%, and 51%, while the opening located at the corner of the column reduced punching capacity by about 21%, 30%, and 39%. in addition, the distance away from the column by 1.5 times of slab thickness has an insignificant effect on the slab punching strength.

Anil et al in 2014 [22], investigated the effects of opening size and location on the punching shear behavior of two-way reinforced concrete slabs. Eight specimens had been constructed with different variable locations of openings in addition to one specimen without an opening for comparison. The dimensions of the slabs were (2m*2m*0.12m). A square column with dimensions of (0.2m*0.2m) is located at the center of the slabs to apply load on it. The locations and sizes of openings are detailed in Figure (18).

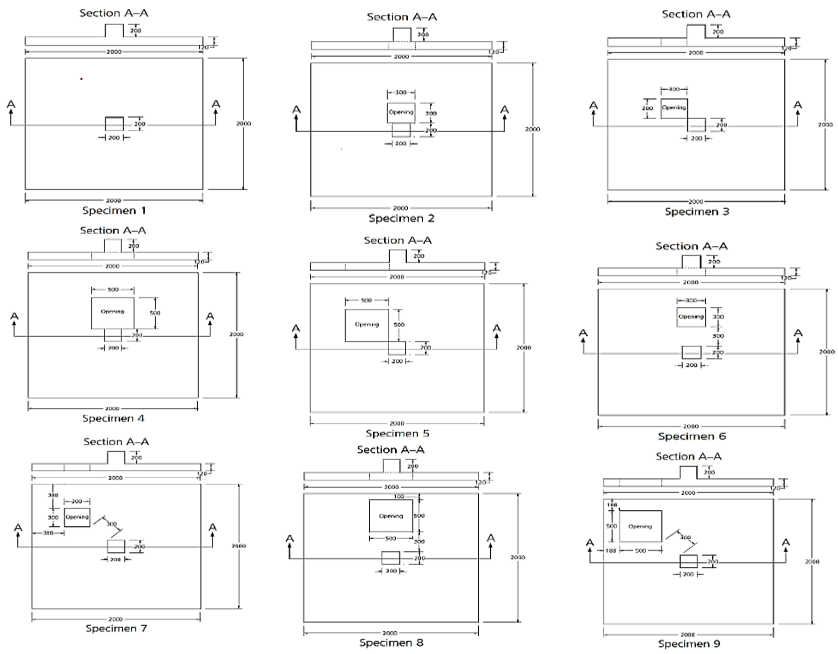


Fig. 18: Specimens details of Anil et al. [22]

The results proved that there is an inverse relationship between the resistance of the slab to shear stresses and the dimensions of the opening. Increasing the dimensions of the opening reduces the slab's shear capacity. In addition, the further the hole is from the column, the greater the shear capacity of the slab.

Oukaili et al in 2014 [23], in their research The Punching Shear Strength of Reinforced Concrete Flat Plates with Openings studied the behavior of slabs with openings in terms of punching shear of simply supported slaps. The size and place of openings were the test parameters. The dimensions of the slabs were 70mm in depth with 1000mm for both directions. The cross-section of the column was 150*150 mm2, 200mm in height as shown in Fig (19).

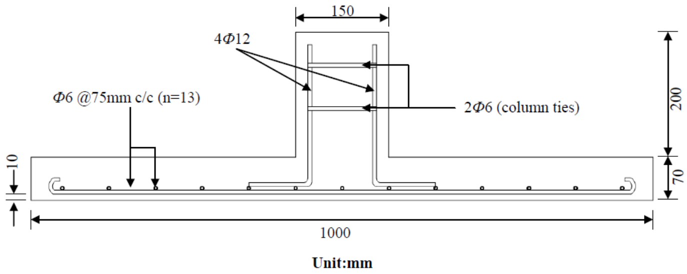


Fig. 19: Reinforcement's details of slab. [23]

Six specimens (XXX, SF0, CF0, LF0, CC0, and CF1) had been tested. The opening sizes and locations are explained in Figure (20).

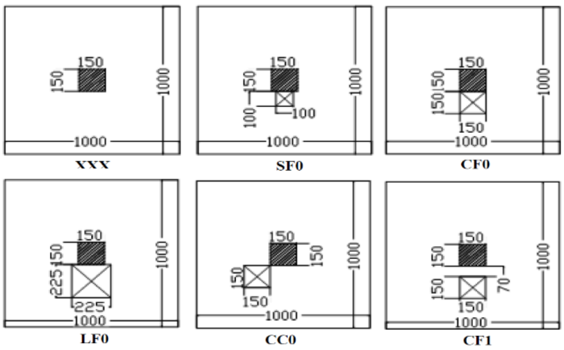


Fig. 20: Specimens details of Oukaili et al. [23]

The effect of openings was decreasing in shear capacity between 11.43% and 29.25% in comparison with the controlled specimen and decreasing of stiffness between 0.31% and 83.00% depending on the dimensions and position of these openings with respect to the column.

Taehun Ha et al in 2015, [24] studied The Effects of Openings on The Punching Shear Strength of RC Flat-Plate Slabs Without Shear Reinforcement. The aim of this study is to investigate the effect of opening in the punching shear of a flat plate slab without shear reinforcements. The parameters of this study are the position and number of openings. Eight slabs were tested depending on punching shear resistance. The shear resistance of all specimens compared with the prediction of several codes. ACI, CEB, and FIB codes were adopted. The results show that the reduction of the critical section due to the existence of openings causes a reduction of punching shear. The most influencing shape, in shear resistance, is the L shape. Figure (21) shows the details of specimens and their openings.

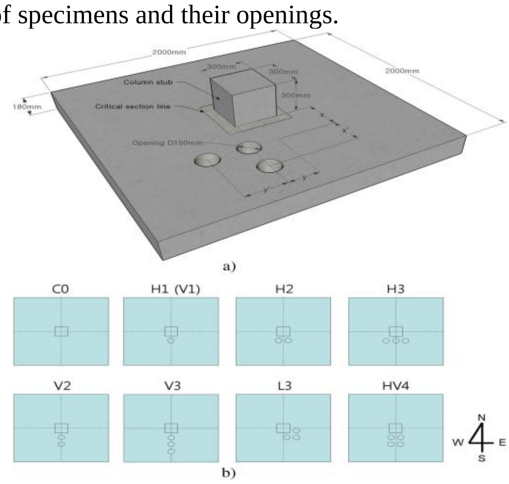


Fig. 21: Specimens details of Taehun Ha et al. [24]

Chkheiwer et al, 2017 [25] in their paper, studied the ability to use the wire mesh as a strengthening of two-way slabs after making an opening in different shapes. Fifteen slabs were constructed with the dimensions of 0.8m*0.8 m and 95mm thickness and high strength concrete was used. The specimens were divided into two groups depending on the opening shape. The first group had a square opening and the second one had a rectangular opening. The opening of the first group strengthened by using wire-mesh with different situations. The opening of the second group strengthened by using steel-fibers with multiple ratios. Figure (22) shows the specimens' details.

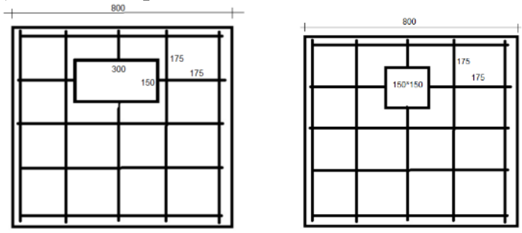


Fig. 22: Specimens details of Chkheiwer et al. [25]

The test results show that the two strengthening methods increased the load capacity of the tested slabs. Also, the two ways of strengthening show a reduction in cracks in the inside face of openings. In general, the wire mesh technique was more effective than the other technique.
Hassan et al, 2017, [26] introduced a study of introducing an opening in two-way loaded slabs. The slabs were rectangular with dimensions of 1.65mX1.65mX0.08m and the surrounding beam with dimensions of 250mmX100mm as shown in the Figure (23).

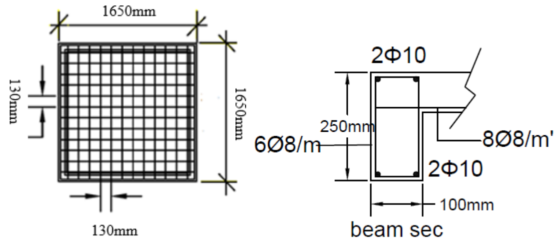


Fig. 23: Control slab details of Hassan et al. [26]

Seven specimens were cast, one was without an opening, three were cast with an opening and three were cast without an opening then an opening was cut during loaded with 30% of the total load. The openings of the last three slabs were supplied by a plate frame welded to reinforcement bars after removing the concrete cover then the concrete and reinforcements were cut. The shapes of the openings were square, rhombus, and circular.
The results show that the slabs supplied with steel frames behave like the slabs that are cast with openings. In addition, the deflection of them was larger. However, the ultimate load of the slabs with existing square rhombic and circular openings was reduced by 60% 64%, and 55% respectively in comparison with the control slab, and the ultimate load of the slabs with produced square rhombic and circular openings was reduced by 67% 78% and 80% respectively in compare with the control slab.
Esraa Jasim et al in 2018 [27] tested ten specimens with an opening in addition to a controlled specimen without an opening in this thesis. the dimensions of all specimens were (800mm*800mm) with a thickness of 70mm. The openings used were (100mm*100mm), (150mm*150mm), (200mm*200mm) and finally (250mm*250mm). One of these specimens had been cast without opening as a controlled specimen. The reinforcement used was steel bars of 8mm diameter. Figure (24) shows the specimens' details with their openings.

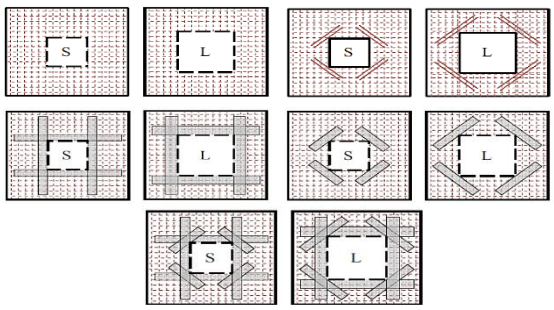


Fig. 24: Specimens details of Esraa Jasim et al. [27]

Results were evaluated under uniformly distributed load and all slabs were simply supported at their four edges. Each model containing an opening was examined once without strengthening and once with strengthening by CFRP sheets. All specimens were designed to fail in flexural. A decrease in ultimate load was observed in the slabs that have strengthened openings in

comparison with the controlled slab especially slabs with an opening that has dimensions of (150mm*150mm) that has (100mm*100mm) away from the corner edge. The results showed that the cracking load was enhanced by the use of CFRP sheets by about (6.0%-77%), and (2.0%-40.8%) of the maximum load comparing with the specimens without openings.
Rasoul et al in 2018 [28], studied the punching shear of self-compacting slabs with opening. The constants of this experiment were slab dimensions, concrete of self-compacting, and steel reinforcement ratio while the variables were the shape and location of openings. The dimensions of all specimens were 450mmX450mmX40mm as shown Figure (25).

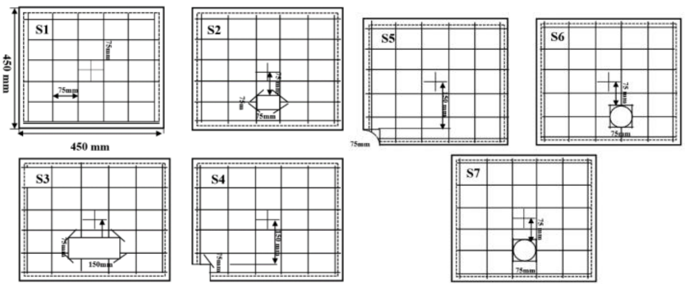


Fig. 25: Specimens details of Rassul et al. [28]

Three shapes of openings, square, rectangular, and circular were used and the location of these openings varied as shown in Figure (25). The designing of these specimens took in consider to fail by punching.
The results show that the ultimate punching shear of the slab decreased by increasing the opening size and the corner square opening introduced the larger ultimate punch-shear. Regarding circle opening, the ultimate punching of slab corner opening is the largest and the lowest one is the opening in front of the load location.
Mahlis et al in 2018 [29], studies how the opening effect on the behaviour of a two-way slab. The total number of specimens was ten. These specimens were divided into two groups. The first group consists of five slabs. One of them was cast with an opening in the mid-span as a controlled slab without strengthening, three slabs with openings strengthened internally with additional reinforcements surrounding the opening in multiple lengths and one slab with opening strengthened by CFRP at the tensile side. The second group consists of five slabs containing one slab tested to estimate the load-capacity as a controlled one. The other four slabs were loaded reaching the occurring of the initial-cracks. After that, they were strengthened with CFRP ply and near surface mounting steel-bars, and then openings were cut out at the center of the span then the load was applied till complete failure occurred.
The results showed that the presence of an opening affected the load capacity of slabs by about 18.2% and the additional reinforcements enhanced the load capacity by about 15% to 51% and finally the strengthening by CFRP and near-surface mountain steel bars also enhanced the load capacity but using longer anchorage at the opening sides is more recommended.
Mohamed, et al in 2019 [30] report in their paper the results of the evaluation of the effect of strengthening a slab that has an opening using carbon FRB composite sheets. The investigation was conducted numerically for ten specimens. One of these specimens was established with an opening without any strengthening. Nine slabs were conducted with an opening in the tension side and strengthened by CFRP laminates. The variables were the CFRP laminate thickness and width. The dimensions of the control slab are shown in Figure (26).

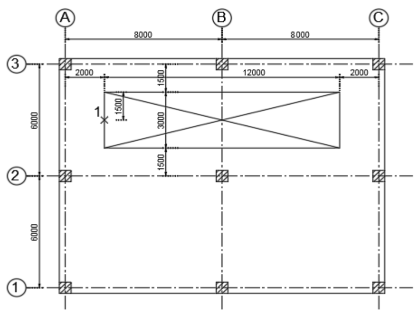


Fig. 26: Control specimen details. [30]

Finite-element analysis was used to examine the ten specimens and concluded that load carrying capacity of slabs with large openings increased by increasing the amount of CFRP sheets for strengthening and also the ductility index increased by decreasing the amount of CFRP sheets.
Sheta et al in 2020 [31] conducted a parametric study of ten RC flat slabs with different opening sizes and locations using ANSYS19. The slab dimensions were 3000mmX3000mmX200mm with a load column in the center of the slab with dimensions of 200mmX200mm. A control slab was without an opening, as shown in the Figure (27), and nine other slabs with different sizes and locations of openings.

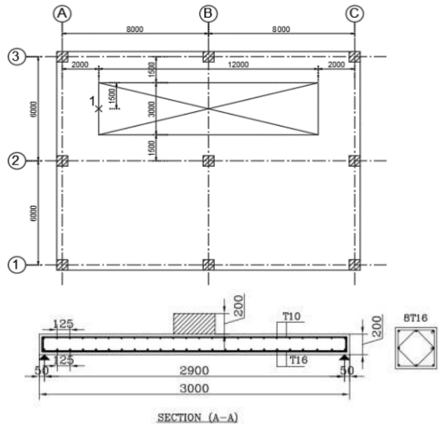


Fig. 27: Control specimen details. [31]

The slab punch-shear force decreased by 10% when the opening changed from 400mm to 600mm and the punch shear capacity is in direct-proportion to the load column face distance regardless of the dimensions of the opening. In addition, the punching shear strength of the slab with an opening of 600mm*600mm increased by about 8.7% in comparison with the opening of 400mm*400mm placed away from column-face by distance [d].

Yooprasertchai et al in 2021 [32] investigated the capacity of punch-shear for flat-plate slabs which has an opening. This study consists of 2-groups. The first group has seven specimens, each specimen has two openings unless one with no opening for comparison. The opening shapes were square, circular, and rectangular in different locations. The second group consists of one slab with no opening, to be a control one, and six slabs with four openings for each slab. The opening shapes were also square, circular, and rectangular in different locations. The dimensions of the slab and locations of openings can be noticed in Figure (28).

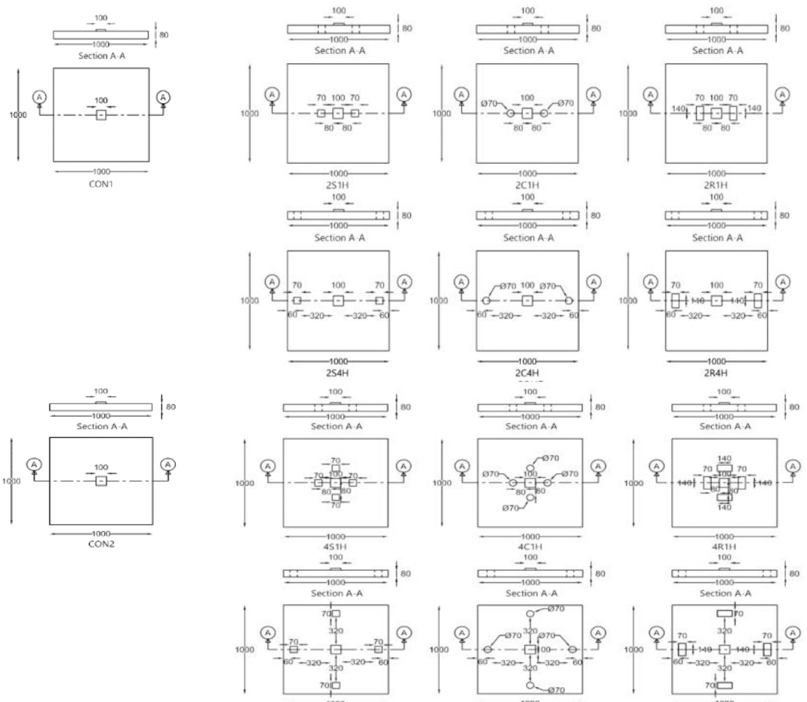


Fig. 28: Specimens of Yooprasertchai et al. [32]

It was found that the minimum effect of opening on shear capacity was the circle opening and the largest effect was by rectangular one. Furthermore, to get less impact of shear force, the opening should be at a distance of four times the thickness of the slab away from the column location. Finally, the increase in opening numbers causes a decrease in the shear capacity of the slab.

Hussain et al, 2022 [33] studied the effect of opening in a two-way slab. Four types of fibers were used to investigate how the fiber of concrete affects the flexural behavior of these slabs. The aim of the study is to indicate the properties of hardened concrete and the flexural behavior of two-way slabs. Two slabs, one with an opening and the other without, had been cast as a controlled specimen. Eight slabs had been cast with different types of fibers. All slabs had a dimension of (800mm*800mm*100mm) and were reinforced with 12mm diameter steel bars. Figure (29) explains the details of specimens.

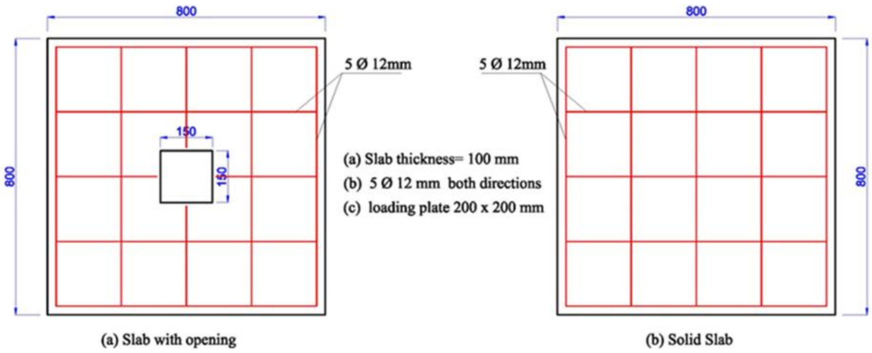


Fig. 29: Specimens details of Hussain et al. [33]

Loads were applied at the center of the slabs on a steel-plate with dimensions of 200mm*200mm.
Results showed that the hooked fibers improve the cracking load and the flexural ductility of slabs generally enhanced in the presence of fiber.

Zuhair et al in 2022 [34] studied the effect of circular opening on flat plate slab. The two-way slab was cast with dimensions of 750mm for both sides without opening and three other slabs were cast with different diameters of openings. The openings were 60mm, 75mm, and 90mm. The results of the test show that the load-carrying capacity of the slabs decreased by increasing the size of the opening. Where the load capacity of the slab that had a 60mm opening was reduced by 15.4%, the load capacity of the slab that had a 75mm opening was reduced by 20%, and finally, the load capacity of the slab that had a 90mm opening reduced by 23%.
Shiyal et al in 2022 [35] studied the punching shear of thirteen slabs with the presence of openings in different sizes. One of these slabs was without an opening, for comparison, and six slabs have openings of the following sizes: (100*100, 150*150, 200*200, 250*250, 300*300, and 350*350) mm^2. The dimensions of the slabs and the punching column details are in Fig (30).

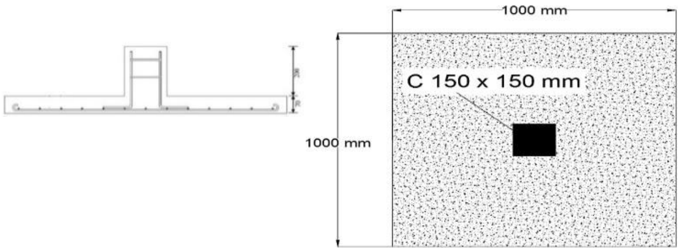


Fig. 30: Specimens details of Shiyal et al. [35]

The variables of these tests were the opening size and steel reinforcement of these openings. The results of this study show that the carrying capacity, cracking load, and strain of concrete are significantly affected by the existence of an opening despite the reinforcement surrounding the opening which redistributes the shear stresses and makes more propagation in the slab section.
Abd-EL-Mottaleb et al in 2022 [36] studied the effect of opening on a multi-panel flat slab with CFRP bars. This paper has an experimental study and theoretical study using ANSYS 19. The experimental study consists of a two-way slab, 1100mm length, and 1100mm width, with an opening of 250X250mm. The numerical study consists of six square slabs. The slab dimensions are 12000X12000mm and a thickness of 150mm with marginal beams of depth 500mm and width of 250mm. Columns distributed at 4000mm clear span. The slabs are divided as follows: one flat slab without an opening, three slabs with an opening of 1000X1000mm varied in location, one slab opening of 2000X2000 mm, and one slab with an opening of dimensions 800X800mm.
Results show that the load capacity and stiffness reduced in the presence of an opening and increasing the opening dimensions reduced the efficiency of the slab. The largest effect of opening is when the opening is in the corner of the panel.
Shoukry et al in 2023 [37] worked at the experimental study on continuous RC flat slabs with openings strengthened with CFRP. Five continuous slabs with openings were cast in addition to one controlled slab without opening. The details of specimens shown in Figure (31).

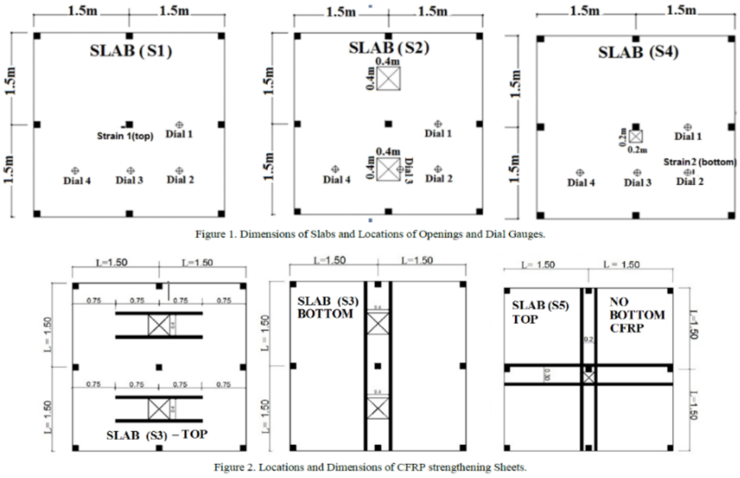


Fig. 31: Specimens details of Shoukry et al. [37]

Three of these specimens that have different sizes and locations of opening had been strengthened by sheets of CFRP. The results show that the ductility, toughness, and failure modes have been affected by the existence of openings. The slabs strengthened by (CFRP) show enhanced failure load and failure modes.

Milligan et al in 2023 [38] studied the influence of opening in punching shear of RC slabs with L-shape column. The finite-element method was used to analyze the slabs using ANSYS19. Slab details are in Figure (32).

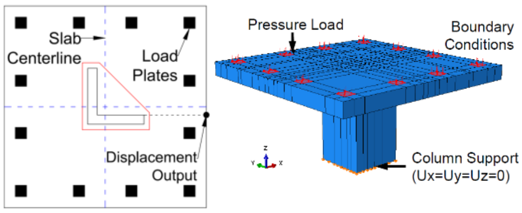


Fig. 32: Slab details of Milligan et al. [38]

Figure (33) shows the opening situations.

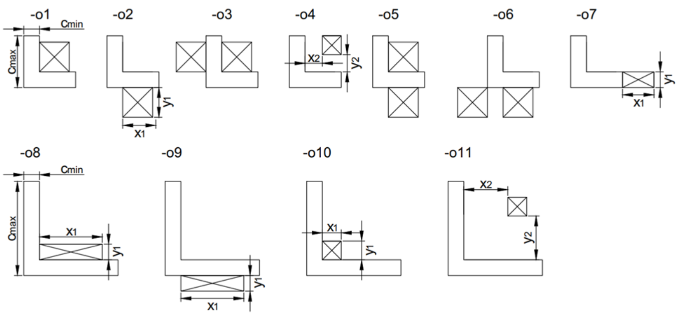


Fig. 33: Opening locations. [38]

The results of the test illustrate the following:

- Stiffness and connection capacity reduced by the existence of an opening.
- Openings between column flanges of L-shaped slab column connections have a minor impact on concentric behavior.
- Forces transferred along the outer edge of L-shaped slab column connections.
- Load transferred through one-way shear in that area.
- Region between column flange is relatively ineffective for L-shaped slab column connections.
- ACI318-19 for L-shaped slab column connections is inaccurate.
- ACI 421.1R-20 could be used for the estimation of punching shear capacity of L-shaped slab column connections.

Hadi et al in 2020 [39] studied the effect of opening on square-slab and rectangular-slab. The shape of the slab and the shape of the opening are the two factors of this study. The theoretical method used to analyze the specimens was the yield line method. The results of this study can be concluding the following:

- The decreasing of the opening decreases the area load capacity.
- The rectangular opening has a larger effect than the square opening.
- The area load capacity of the rectangular slab is larger than that square slab by about 2.5 percent.
- A significant reduction in slab strength caused by reducing an opening in an existing slab.

3.3. A brief result for one-way and two-way studies

Comparisons can be drawn between all previous studies in Table (2) to get a general idea of the effect of openings in concrete slabs.

Table 2: Comparison between the previous researches:

Reference	Slab Type	Slab Dimensions in (mm) L*W*t	Opening Size in (mm) L*W	Opening Zone	Strengthening Type	Failure type	ultimate load reduction with opening presence (%)
Paolo Casadei et al, 2005[5]	One-way	1030*970*200	350*200	Middle strip and column strip	CFRP	Flexural and shear	21
Koh Heng Boon et al, 2009 [6]	One-way	1100*300*75	300*150	Centre of the slab	Steel bars around and diagonally on the corners of the opening	Flexural	36
H. M. Seliem et al, 2011[7]	One-way	15748*3358*200	610*610	Middle strip	CFRP	Flexural	18
Majid Mohammed et al, 2013 [8]	One-way	1200*250*100 3600*2400*150	800*1200	Centre of the slab	CFRP	Flexural	35
Ali M. Al-hafiz et al, 2013 [9]	One-way	1100*400*40 1100*400*60 1100*400*80	75*75	Centre of the slab	No Strengthening	Flexural	27
Qusay W. Ahmed 2018 [10]	One-way	1400*450*90	150*150 200*200 250*250	Centre of the slab	Steel bars diagonally at the corners of the opening and additional reinforcement around the opening	Flexural	50
Wissam et al, 2018 [11]	One-way	1500*500*100	200*200	Centre of the slab	CFRP	Flexural	50
Khalil et al [12]	Cantilever slab	2550*830*120	200*400 400*400	Close to support	No Strengthening	Flexural	51
Aman et al, 2020 [13]	One-way	1000*530*25	160*160 230*230 320*320	Centre of the slab	CFRP	Flexural	8
Kaya et al, 2021[14]	One-way	3000*1000*150	300*300 400*400 500*500	High moment area and high shear area	No Strengthening	Flexural	44
Moataz Gamal et al, 2021[15]	Continuous One-way	2400*500*100	Not mentioned	Not mentioned	Near-surface mounting strengthening	Flexural	-
Golham et al, 2023 [16]	One-way	2650*750*150	250*250 250*500	Centre of the slab	CFRP	Flexural	43
Al Kallas et al, 2023 [17]	One-way ribbed slab	2600*825*175	400*400	Centre of the slab	CFRP	Flexural	38
Rusinowski, 2005 [18]	Two-way	2600*2600*100	850*850 1200*1200	Centre of the slab	CFRP	Flexural	25
Ng. et al, 2008 [19]	Two-way	5000*5000*D 4000*4000*D 3000*3000*D	From 0 to 0.9 of slab length	Centre of the slab	No Strengthening	Flexural	32
Luaai Muhammed Abbas, 2011 [20]	Two-way	1050*1050*75	250*250 330*330	Centre of the slab	No Strengthening	Flexural	52
EL-Shafiey et al in 2012 [21]	Two-way	1700*1700*150	200*200 300*300 400*400	Close to center-load column	No Strengthening	Punching shear	44

Table 2 (continued)

Anil et al, 2014 [22]	Two-way	2000*2000*120	300*300 500*500	Away from or close to center-load column	No Strengthening	Punching shear	60
Oukaili et al, 2014 [23]	Two-way	1000*1000*70	150*150 225*225	Away from or close to center-load column	No Strengthening	Punching shear	29
Taehun Ha et al in 2015 [24]	Two-way	2000*2000*180	Circle of 150mm diameter	Away from or close to center-load column	No Strengthening	Flexural	29
Chkheiwer et al in 2017 [25]	Two-way	800*800*95	300*150150*150	25mm from the edge of the slab	Wire mesh And steel fiber	Flexural	29
Hassan et al, 2017 [26]	Beam edge two-way slab	1650*1650*80	300*300 and circle of 300mm diameter	Centre of the slab	Steel frame at the circumference of the opening	Flexural	35
Esraa Jasim et al, 2018 [27]	Two-way	800*800*70	100*100 150*150 200*200 250*250	Centre of the slab	Steel bars at the corner of the opening and CFRP	Flexural	36
Rasoul et al, 2018 [28]	Two-way	450*450*40	75*75 75*150 And circle of 75mm diameter	Close to the edge of the slab and in the corner of the slab	No Strengthening	Punching shear	44
Mahlis et al, 2018 [29]	Beam edge two-way slab	1650*1650*100	300*300	Centre of the slab	Steel bars surrounding the opening and CFRP	Shear	18
Mohamed et al, 2019 [30]	Two-wat continuous flat slab	16000*12000*300	12000*3000	Middle strip	CFRP	Flexural	-
Sheta et al, 2020 [31]	Two-way	3000*3000*200	400*400 600*600	Close to the center-load column	No Strengthening	Punching shear	35
Yooprasertchai et al, 2021 [32]	Two-way	1000*1000*80	70*70 70*140 Circle of 70mm diameter	Away from or close to center-load column	No Strengthening	Punching shear	45
Hussain et al, 2022 [33]	Two-way	800*800*100	150*150	Centre of the slab	Steel fiber	Flexural	-

Table 2 (continued)

Zuhair et al, 2022 [34]	Two-way	750*750*75	Circle of 60mm, 75mm, and 90mm diameter	Close to center-load column	No Strengthening	Flexural	23
Shiyal et al, 2022 [35]	Two-way	1000*1000*70	100*100 150*150 200*200 250*250 300*300 350*350	100mm from the central load column	Steel bars around and at the corners of the opening	Punching shear	32
Abd-EL-Mottaleb et al, 2022 [36]	Two-way	1100*1100*D 12000*12000*150	250*250 800*800 1000*1000 2000*2000	Middle strip And column strip	No Strengthening	Flexural	33
Shoukry et al, 2023 [37]	Two-way	3000*3000*60	200*200 400*400	Column strip	CFRP	Punching shear	25
Milligan et al, 2023 [38]	Two-way	2160*2160*152	X*Y	Close to punching column	No Strengthening	Punching shear	14
Hadi et al, 2020 [39]	Two-way	(3-5)*(3-5)*t	From 0 to 0.9 of slab area	Centre of the slab	No Strengthening	Flexural	56

It is obvious that there are many researches that published in the literature that discussed the effect of opening on the performance of slabs as well as the strengthening technique to compensate the reduction in slabs load carrying capacity. Most of the studies have focused on either one-way single span slabs or two-way single span slabs. However, very few studies have considered multiple span slabs or continuous slabs in which the redistribution of loads and the effect of openings on the adjacent slabs were ignored. Also, studies are required to understand the effect of openings on beam-slab systems where the openings are inserted at the face of beams. In addition, more studies are required to optimize the location of openings in slabs with minimum effect on the performance.

4. Conclusion:

Based on the previous researches, reviewed previously, it can be concluded that openings in concrete slabs can affect the overall behavior of these slabs significantly despite the methods used to restrengthen these slabs, as follows:

1- ACI 318-19 Code and the other codes recommended that the opening of any size is allowable if it satisfy the strength and deflection requirements, unless there is a limitation should be followed. These limitations depend on the which strip of slab that the opening located in. In all cases, a compensation of reinforcement should be provided around the opening.
2- British standards recommended providing a beam on all sides of opening to transfer the loads to the column.
3- According to ACI code, the area that enclosed by straight lines projecting from the centroid of the column, concentrated load or reaction area and tangent to the boundaries of the opening shall be considered ineffective if the opening is at a distance less than 4h from that concentrated load or column. While the British Standard consider that distance as 6d. Canadian standard considered that distance as 10h and European Code considered it as 6h. where h is the slab thickness and d is the effective depth of the slab.
4- According to previous studies, the presence of openings in RC slabs has negative effect on the flexural, shear resistance, and load-capacity of slabs. This effect is inversely proportional to the dimensions of the opening in the slab. In which, the larger the opening, the more negatively it affects the slab performance.
5- Opening size has a direct proportion with the deflection, concrete strain, and crack width of concrete slabs.
6- In slabs that had a concentrated load or column, the load resistance of this slab is inversely proportional to the closeness of this opening with that load or column. In which, all codes put a limit to the distance between the opening and the load or column.
7- In the slab that has a beam in all directions, the effect of this opening will be larger if that opening is placed in the middle of the slab.

8- Generally, the resistance of the slab with opening could be enhanced by adding an additional reinforcement or by using carbon fiber reinforced polymers (CFRP) or both methods can be used to return the slab to its design strength.
9- Almost all published in the literature have focused on either one-way single span slabs or two-way single span slabs.
10- Very few studies have considered multiple span slabs or continuous slabs in which the redistribution of loads and the effect of openings on the adjacent slabs were ignored.
11- Up to the knowledge of the authors there are no studies that considered the effect of openings on beam-slab systems where the openings are inserted at the face of beams.

For future studies, it is recommended to optimize the location of openings in slabs with minimum effect on the performance where several options are available.

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