Effect Of Openings On Post-Tensioned Flat Slab

M.Shallan, T. Sakr, R. Shaker, H. Abd-El- Mottaleb

Abstract: This paper investigates the effects of opening existence on the behavior of Post-tensioned flat slabs considering different opening locations and by using the finite element method. The design status, strip moments, Stress distribution around the opening and Long-term deflection are studied. Results indicated that, in most cases, significant decrease of bending moments in strips at which openings are located and this decrease is increased by increasing the opening size. Maximum stresses around the opening's perimeter and Maximum long-term deflection are increased by increasing the opening size. The existence of opening at column strip near the column has the worst effect on design status, on the other hand the opening at the center of the exterior panel has the least effect on the stresses around the perimeters of opening and the long-term deflection of the slab behavior. For this case, no spans produce excessive tensile stresses for spans up to 10m and opening size up to 0.25 of span length. The existence of opening at mid of interior or exterior span of column strip shows effects between the two previous openings concerning all parameters.

Index Terms: Post-tension, Deflections, Finite element, Floors, Stresses, Openings, Bending moments.

1 INTRODUCTION

POST- tensioned floors are now widely used all over the world and have too many applications due to their well-known advantages related to time, cost, and behavior [1]. Openings are indispensable element in slabs whether it used for architectural features, stairs, pipelines, elevator shafts, or utilities ducts [2]. Existence of opening and changing its size lead to decrease the stiffness of the floor and decrease the collapse carrying load, Choi [3] and Seliem [4]. Many researchers have studied the structural behavior of R.C slab with presence of opening. Floruţ et al. [5] show how creating openings affect the loading behavior of slabs. The openings nearby to a column are always used for plumbing and such a position of the openings increases shear stresses in the flat slab near the column [6]. Zhang et al. [7] performed a numerical study which showed that determination of the in-plane behavior is mainly affected by the opening presence. The failure mechanism of the slab with opening is different from the failure mechanism of the slab without the presence of opening, Khajehand and Panahshah [8]. Casadei et al. [9] concluded that the existence of opening in hogging area lead to increasing in the shear stress of the concrete slab, which lead to premature failure. Enochsson et al. [10] have concluded that large openings make the slab behave closer to a system of beams surrounding the four edge of the opening instead of a slab. Keyvani and Vaez [11] had proved that there is an obvious change in the slab behavior with opening and without opening. The over-simplification by ignoring the opening effect in analysis and design may lead to incorrect results. Yousef et al. [12] concluded that increasing the concrete strength for slab-column connection with or without opening led to a decrease in ductility factor. Ilbegyan et al. [13] studied the effect of opening existence in reinforced concrete flat slab with High and Normal-strength concrete. Elshafiey et al. [14] concluded that openings with size more than one-tenth of the span influence load -deflection curve of the slab. The curve inclination increased by 15% for the slab with opening at corner and by 20% for the slab with opening at column face. Clément et al [15], concluded that post-tensioning influences the behavior of (openings, cracks, rotations) and also the slab strength under concentrated load. Abdul-Razzaq et al [16] concluded that the failure load of the slab with tendons in both directions increased as compared with the failure load of the slab with tendons in one direction by about 89%. Abd-El-Mottaleb and Mohamed [17] studied the behavior of deflection due to creating 8- large openings with size equal 2m on post-tensioned flat slab by using two cases of concrete strength and different values of P/A.

The illustrated previous literature does not include thorough study for the effect of opening on the behavior of post-tensioned floors. This paper investigates the effect of existence of openings, its size and location on the behavior of post-tensioned floors. Openings with different sizes are applied at selected locations to floors with different spans and their effects are studied on the main design parameters such as moments, stresses, and deflections.

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2 NUMERICAL MODEL

In this work, the problem of Post-tensioned slab with opening is analyzed using The Finite Element Method and designed according to the ACI-318-11[18]. RAM Concept is selected as analysis and design software which applies the finite element method for elevated concrete floor systems. It uses plate bending element to represent the floor with versatile mesh generator as shown in Fig. 1 After performing the finite element analysis, design is based on strips such that each strip is checked/designed individually. Design is carried out using ACI-318-11 [18] as class U (un-cracked) section under service loads for which tensile stresses is limited as follows.

Stresses due to service loads ≤ $7.5\sqrt{f_c}$ (ACI-318-11 Clause 18.3.3) -eq. (a)

The section is then analyzed subjected to factored loads combinations as cracked section with stresses and strain distribution as shown in Fig. 2 and its capacity is calculates using the Equation.

$M_u \leq \emptyset M_n^0 = \emptyset A_{PS} f_{PS} (d_p - a/2)$ (ACI-318-11 Clause 18.12.2)

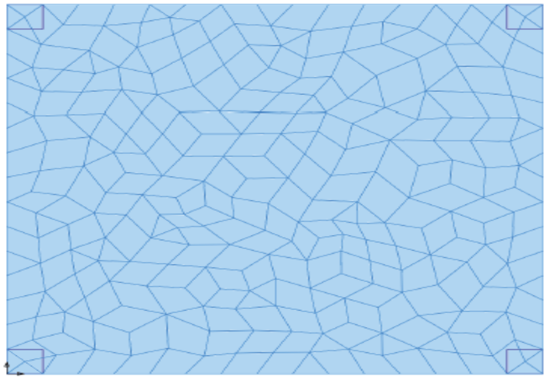


Fig. 1. *Mesh generation tool in RAM software*

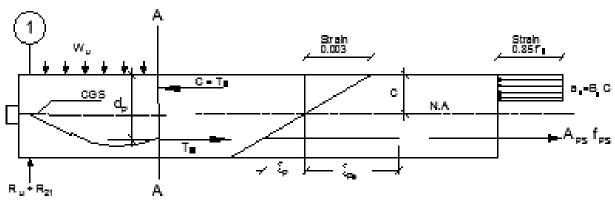


Fig. 2. *Stresses and strain distribution for Post-tensioned section*

3 VALIDATION THE NUMERICAL MODEL

Experimental work on bonded post tensioned concrete slab done by Bailey and Ellobody [19] was chosen to verify our numerical model. It was simply supported at its ends with Concrete and pre-stressing reinforcement properties as shown in table (1). BS8110-1 is used for designed. The loading and general layout of the slab is shown in figure (3). Mono-strands which made of seven high-strength steel wires was used. Three ducts were used in the slab as shown in figure (4). The load was applied progressively in equal increments of 5 kN. The average measured force in the three tendons was 169 kN.

TABLE 1

CONCRETE AND REINFORCEMENT PROPERTIES

concrete compressive strength	40 MPa
The tendons tensile strength	1,846 MPa
The tendons diameter	15.7 mm
The tendons area	150 mm2
The full applied design pre-stressing force	195 kN
short-term Losses	13%

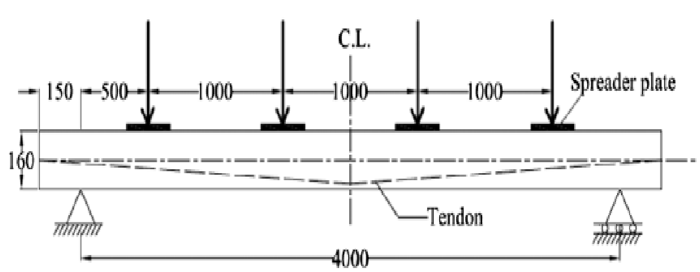


Fig. 3. *Loading and general layout of slab (model TB1) [19]*

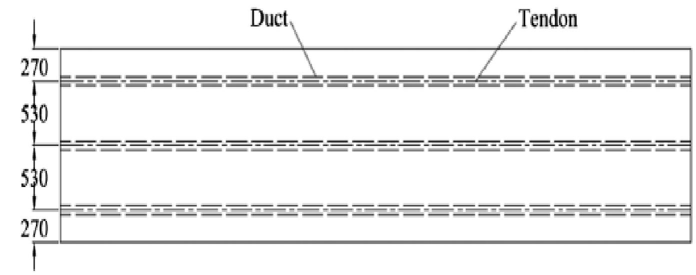


Fig. 4. *Plan view of slab (model TB1) [19]*

The load and central- deflection curve obtained from obtained by the finite element analysis and verified experimentally [19] is compared to the results of the results obtained by using our numerical model. As shown in figure 5, good agreement can be observed for the linear part of the curve which is accepted as our model as used in design is linear elastic. Up to the elastic limit almost identical results are observed.

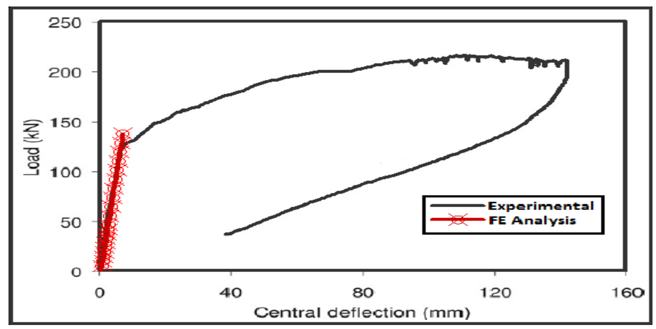


Fig. 5. *Load-central deflection relationship for experimental study and our numerical model [19]*

4 PARAMETRIC STUDY

An example with practical dimensions composed of post-tensioned floor of three equal spans in each direction having dimensions as shown in Table 2 is selected. Drop panels are used above columns to improve the resistance of the slab to punching shear. The concrete and the reinforcement (both pre-stressing and non-pre-stressing reinforcement) properties are shown in Tables 3-4.

TABLE 2

DIMENSIONS OF CASES STUDY

Span length (m)	Slab thickness (mm)	Internal drop panel thickness (mm)	external drop panel thickness (mm)	Length from the centerline of column to the edge of drop panel
Span 7	200	250	250	1400
Span 8	220	275	275	1600
Span 9	240	310	300	1800
Span10	280	360	350	2000

TABLE 3

CONCRETE PROPERTIES

Concrete properties	Value
Unit weight (γc)	24.5MPa
Cylindrical strength at 28 day (F`c)	35MPa
Cylindrical strength at transfer (F`ci)	20 MPa
Modulus of elasticity at 28 days (Ec)	27805 MPa
Modulus of elasticity at transfer (Eci)	21019 MPa

TABLE 4

REINFORCEMENT PROPERTIES

Non pre-stressing reinforcement		Pre-stressing reinforcement			
Modulus of elasticity for steel (Es)	Yield strength for steel (f_y)	Modulus of elasticity for steel (E_{Ps})	Ultimate strength for steel (f_{Pu})	Strand diameter	Post-tensioning system
200000 MPa	420MPa	195000 MPa	1860 MPa	12.7 mm	Low Relaxation,seven wire strand

Four positions had been chosen to create square openings as shown in Fig. 6 at which pronounced impact is expected to the floor behavior. Four different sizes are studied in each opening position which is proportional to the span length (0.125, 0.15, 0.2, and 0.25 of span). Tendon distribution in the slab is taken as banded /banded with minimum tendons in field strip. Fig. 7 shows the tendon distribution for x-direction for slab of 7m span. The distribution is kept the same as possible for all spans and opening sizes to enable studying the effect of opening Subjected to the same conditions.

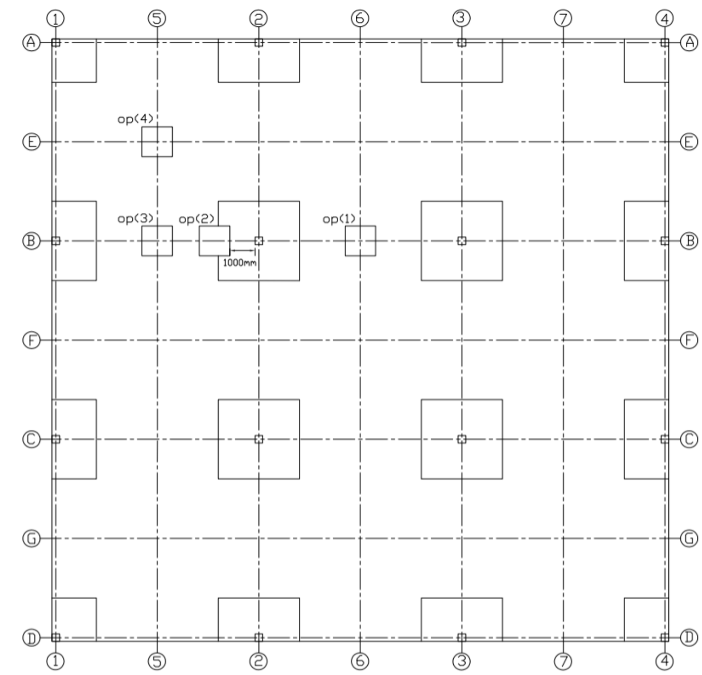


***Fig.** 6. Position of openings.*

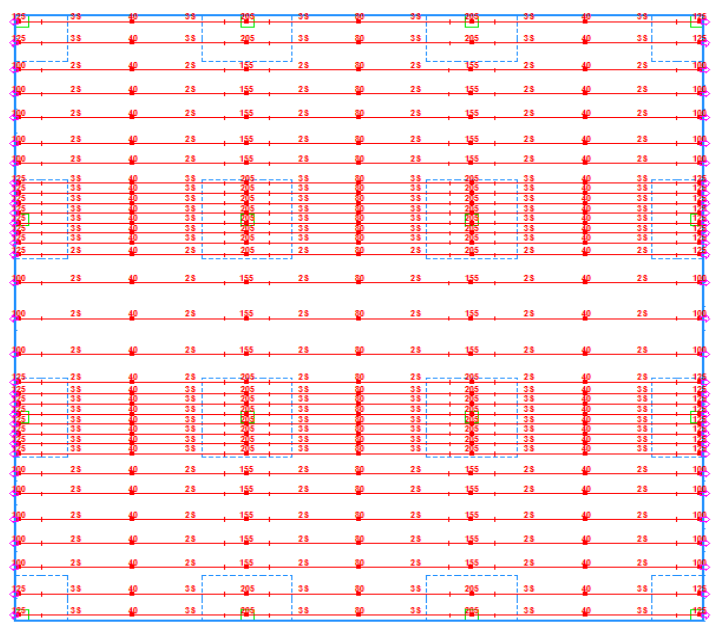


***Fig. 7**. Tendons layout (x-direction).*

5 RESULTS AND DISCUSSION

Several parameters are considered to investigate the effects of opening existence and its size on the behavior of Post-tensioned slabs. Moments, stresses, deformations are of most importance as main design parameters. In the original problem, the slab is designed such that tensile stresses are within the code limits for all spans. As openings are applied to the slab, some spans may fail depending on opening size, location, and the span length. The effect of opening existence with different size and location on design status is discussed in Figs. (8-11) which show the total number of failed spans against span length and opening sizes. For opening at location 1, as shown in Fig. 8, the existence of opening with all studied sizes does not affect the status of design spans for the cases of 7, 8, and 9m spans. In the 10m span, design status changes as openings are applied such that tensile stresses exceed allowable for limited spans. As shown in Fig. 9, the existence of openings at location 2 affects the status of spans for all span lengths and opening sizes with more affected spans for longer span lengths. On the other hand, only the status of the 9 and 10m spans are affected by openings in position 3 as shown in Fig. 10 while spans 7, and 8m still not affected. The existence of opening in position 4 does not affect the status of any spans for all studied cases as shown in Fig. 11. The above discussions indicate the high sensitivity of slabs to opening at column strip near the column for all spans, the relative sensitivity to openings at column strip mid-span for relatively long span slabs and the low sensitivity to openings at field strip mid-span for all spans and opening sizes.

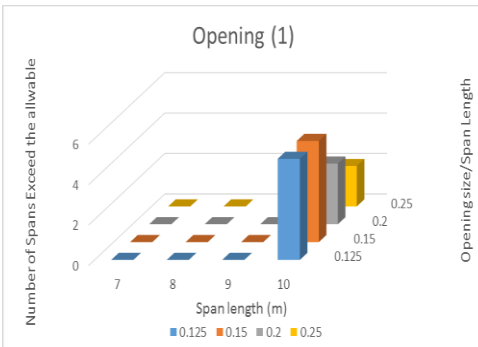


***Fig. 8**. Number of spans exceeding the allowable tensile stresses for opening position 1.*

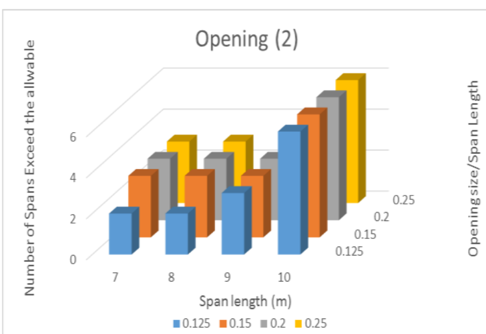


***Fig. 9. Number of spans exceeding the allowable tensile stresses for opening position** 2.*

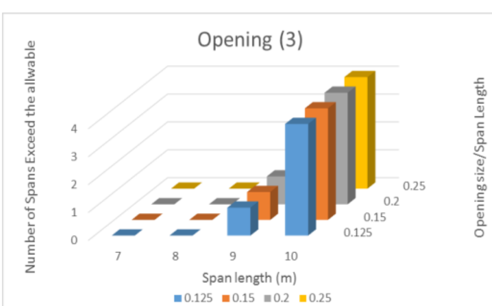


Fig. 10. Number of spans exceeding the allowable tensile stresses for opening position 3.

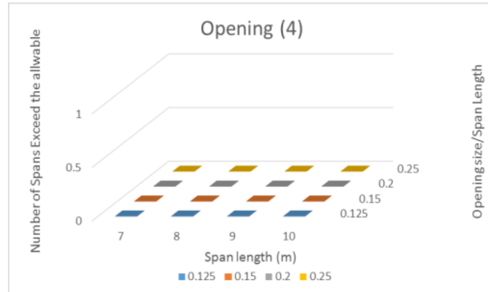
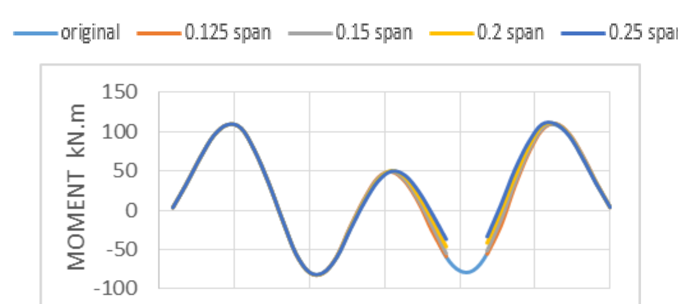
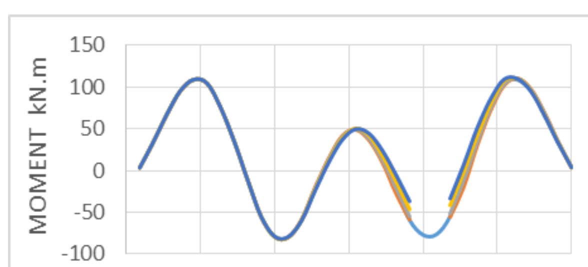


Fig. 11. Number of spans exceeding the allowable tensile stresses for opening position 4.

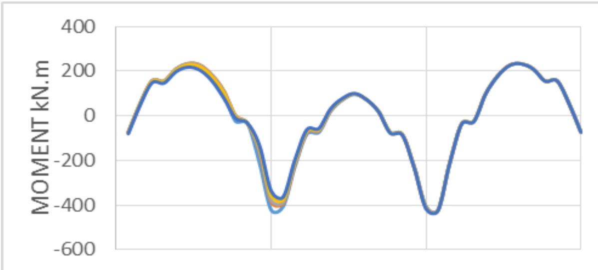
The moment behavior is then investigated in Fig. 12 which shows the bending moment diagrams for the case of 7 meters span. For opening 1, change in results is observed at horizontal strips B, E, and F and vertical strips 6 with strips B and 6 more affected. In both strips, as openings are located through these strips, bending moment is decreased due to opening existence or the increase of opening size. The maximum decrease of moments related to the original bending moment without opening reaches 23.1%, 31.2%, 45.7%, 58.9% at strip B and 27.2%, 32.7%, 45.5%, 56.1% at strip 6 for opening size 0.125, 0.15, 0.2, 0.25 of the span length, respectively. For opening 2, the maximum decrease reaches 8.3%, 10.4%, 15.6%, and 20.1% at strip B, while for strip 5 the bending moment increased by 8.5% for opening size 0.125 then decreased by 3.5%, 31.1%, and 49.8% for opening size 0.15, 0.2, 0.25. For opening 3, the maximum decrease reaches 18.9%, 27.9%, 38.7%, 50.3% at strip B and 26.1%, 29.3%, 51.5%, 69.5% at strip 5 for opening size 0.125, 0.15, 0.2, 0.25, respectively. For opening 4, the maximum decrease reaches 13.0%, 15.8%, 22.8%, and 40.2% at strip E and 12.7%, 16.2%, 22.9%, 39.5% at strip 5 for opening size 0.125, 0.15, 0.2, 0.25, respectively. Other strips show no or little changes in bending moment due to the existence of openings or the change of their size for all studied span length.



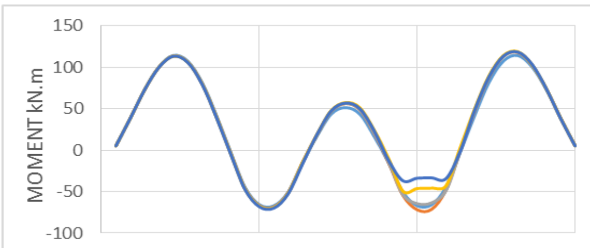
a. Strip B - Opening 1



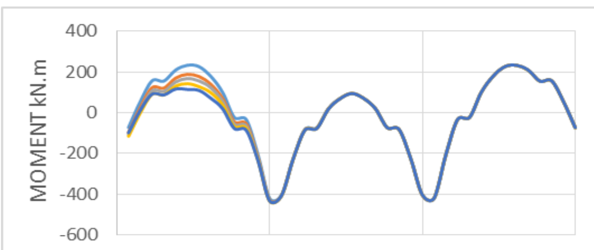
b. Strip 6 - Opening 1



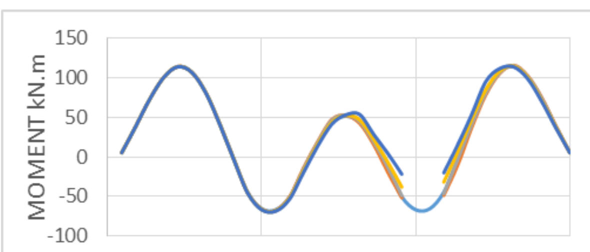
c. Strip B - Opening 2



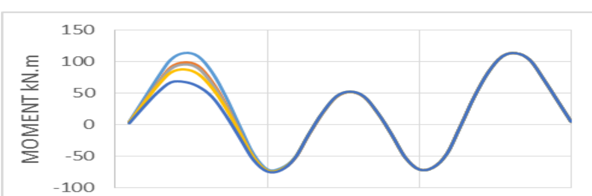
d. Strip 5 - Opening 2



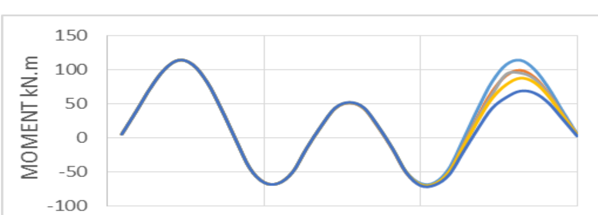
e. Strip B - Opening 3



f. Strip 5 - Opening 3



g. Strip E - Opening 4



h. Strip 5 - Opening 4

Fig. 12. *(a- h)The bending moment diagrams for the most affected strips (7 m span)*

Considering the effect of opening existence on moment values at specific points is discussed in this section for only opening at location (2) as it shows the most critical behavior in design status. Figures 13 and 14 show the effect of opening size on strip moments at different points at the affected strips for opening location (2), Fig. 13 shows the effect of opening size on moment for the point at strip B through grid 2 for spans 7, 8, 9, and 10m. The bending moment ratio shown in the vertical axis is defined as the moment at the specified section divided by the moment at the same section for the case of the original slab (without opening) for the same span length. The horizontal axis represents the ratio between the opening size and the span length. The figure shows that the bending moment ratio is decreased by increasing the opening size for all spans. It also shows that the values of bending moment ratio are less than (1.00) which means that the existence of opening causes a decrease in bending moment for all cases of opening size compared to the case of no opening. The decrease is approximately uniform for all spans such that the relationship is almost linear. Increasing of opening size from 0.125 span length to 0.25 span length leads to a decrease in bending moment from 0.965 to 0.798 which mean that, the ratio of decrease is about 3.5% to 20.2%, which is considered a large decrease. The figure also shows a similar behavior for all spans with remarkably similar moment ratios which means that the existence of opening with specified size (percent of span) decreases the moment with the same ratio (percent of original moment). The above-mentioned observation does not mean that the value of moment decrease is the same for all spans. The same relationship is shown in Fig. 14 for the point at strip 5 through grid B for the same opening location 2 from which the same behavior is observed concerning the opening size. The main difference is that the creation of the first opening with size 0.125 span length leads to an increase of bending moment with a ratio equal 1.10% related to the bending moment at the same section for the case of the original slab (without opening) then the bending moment return to decrease by increasing the opening size . This can be attributed to that opening 2 is located near the column strip at axis 2 than the column strip at axis 1 which makes the first opening (0.125 span length) change the original path of loading to the column strip at axis 1 instead of going to the column strip at axis 2.

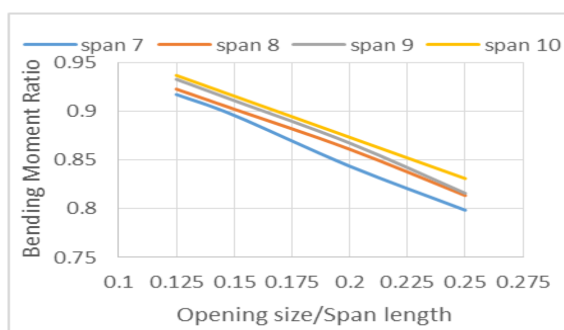


Fig. 13*. Relation between the moment ratio for the point at strip B through grid 2 and the opening size for different span lengths for opening location 2*

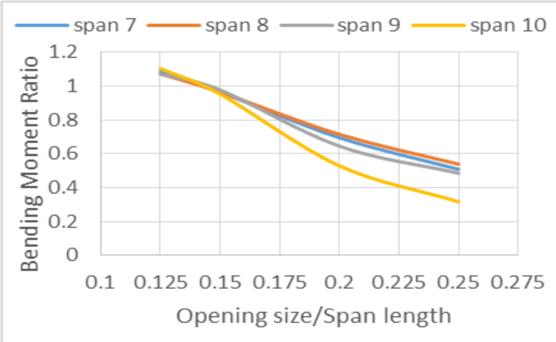


Fig. 14. *Relation between the moment ratio for the point at strip 5 through grid B and the opening size for different span lengths for opening location 2.*

Elastic Stresses around openings are also studied as a main parameter affected by the existence of openings. Top and bottom stresses in both direction of the slab is investigated for eight points (four points at corners and four points at mid of each edge). Figure 15 Shows the maximum stresses (maximum from both top and bottom stresses in both direction x, y for all points) for different opening size at different opening location (for 7.00 m span). The figure shows compressive stresses at the location of opening (4) while tensile stresses are shown for other opening locations. The maximum tensile stresses are shown at the location of opening (2) and the minimum tensile stresses are shown at the location of opening (1) .Tensile stresses values at the location of opening (3) is located between the stresses values of opening (1) and (2). The same behavior is shown for all openings size. The figure also shows that cutting opening with any size will lead to increase of tensile stress or decrease of compression stress or change the stress gradually from compression to tension. So our main observation is that the existence of opening near column at the column strip has the worst effect on the stresses around opening while opening at mid span of field strip has the lowest effect which is consistent with design status results.

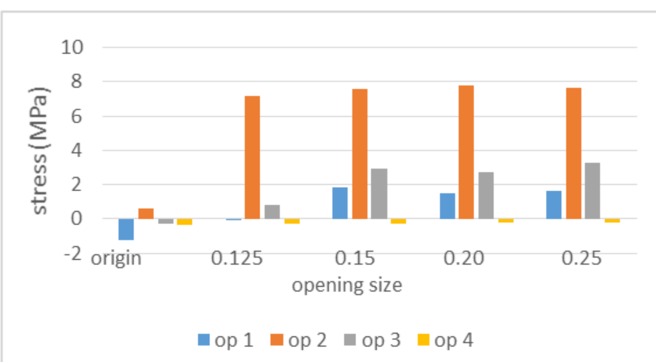


Fig. 15. *Maximum tensile stress around openings*

Long-term deflection is also studied as shown in Fig. 16 which illustrates the maximum long-term deflection for different opening positions and sizes (in case of 7.00 m span). The figure shows that the maximum deflection is increased by increasing the opening size for openings located at column strip B "opening (1), (2), (3)". Increasing in maximum deflection is considered small at opening location (1), in contrast opening location (2) which shows a large increase in maximum deflection which reaches 33.5% from the original case (without openings) due to increasing the opening size. Opening (3) show a behavior between opening (1) and opening (2). For opening (4), the existence of opening increases the values of the maximum long-term deflection with small values decreased by increasing the opening size.

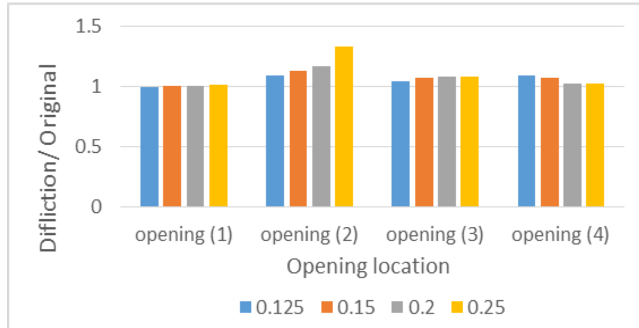


Fig. 16. *Maximum deflection due for different opening size at different location*

6 CONCLUSION

Regarding the parameter's studied about the effect of openings on the behavior of PT flat slabs, it can be concluded that

1. The existence of opening at column strip near the column has the worst effect on the slab behavior. It causes tensile stresses to exceed the allowable values at number of spans, increases significant the tensile stresses around the opening and the long-term deflection of the slab which increases by increasing the opening size.
2. Creating opening at the center of the exterior panel has the least effect on the stresses around the opening and the long-term deflection of the slab behavior. In addition, no spans produce excessive tensile stresses for spans up to 10m and opening size up to 0.25 of span length.
3. The openings located at mid interior span and mid exterior have no effect on the status of design for relatively short spans (7, 8 and 9m) for the interior opening and (7 and 8m) for the exterior one while for longer spans, it is related to the opening size. Both stress around the opening and long-term deflection are increased due to the opening existence
4. Bending moments Values of at the strips through openings are reduced for all studied spans and opening sizes with more than 65% of the original moment without openings.

DECLARATION OF CONFLICT OF INTERESTS

The authors have declared no conflict of interests.

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