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Behavior of Post -Tensioned High Strength Concrete Slabs with Opening

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Abstract:

Design of slabs using the Post tension system, became now a very popular technique in design specially for large span slabs. the main advantage of using PT (Post-Tensioned) in design, is reducing the amount of used steel reinforcement, used in heavy loaded floors as it reduces the thickness of slab by about 20%, This leads to reduce the loads carried by columns and by turn reducing foundation dimensions; especially in high rise building. Recently, investigating the problem of using this type of slab with different opening dimensions and location are limited to a certain aspects.

Frequently, the presence of opening in slab is highly required for passing the different construction services like A.C Lines, electrical cables, pipes of gas & water, etc….

In this paper, the effect of openings in PT slabs has been investigated experimentally. An experimental program consisting of six square flat plate specimens, had been carried out. All specimens were made of high strength concrete with target strength fcu= 80 kN/mm² and had a variable opening ratios.

Keywords: HSC (High strength concrete), PT (Post-Tensioned Concrete), Finite element, Stresses, openings, Jacking force.

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Specifications of used materials:

To get the required concrete compressive strength the used concrete mix contents were: clean sand, Portland cement, coarse aggregate, clean drinking water and super plasticizer (Viscocrete-3425). Table (1) indicates the content of the used materials in HSC mix by weight per cubic meter.

Table 1. Concrete Mix proportion HSC (High Strength Concrete 80 MPa)

Cement, kg/m^3	Silica fume, kg/m^3	Water content, kg/m^3	Plasticizers (Viscocrete), kg/m^3	Sand, kg/m^3	Aggregate, kg/m^3	Sand-to-gravel ratio
500	75	175	20	447	1342	1-to-3

Table 2. Specifications of 1x7 Wire Structure Pre-stressed Concrete Strand:

Specifications	Tensile Strength (MPa)	Section Area (mm^2)	Grease Mass Per Meter (g/m)	Minimum Thickness of Coat (mm)	Friction Factor (u)	Effect Modulus (k)	Mass per Meter (kg/m)
1*7-Φ12.70	1720						
	1860	98.7	43	1.0	0.04 - 0.1	0.003-0.004	0.875
	1960						

Geometry and Dimension of tested specimens:

The tested specimens were square flat plate 1200 mm length and 200 mm thick with reinforcement 5Φ10 mm/m with different opening size. and 4 strands were distributed 2 strands at each direction and the jacking force for each strand = 12.5 ton. All tested slabs were with constant dimension and Reinforcements The obtained concrete compressive strength =79.5Mpa, details of tested specimens are shown in Table (3), showing the dimensions, distribution of reinforcement, openings and strand location for different tested specimens.

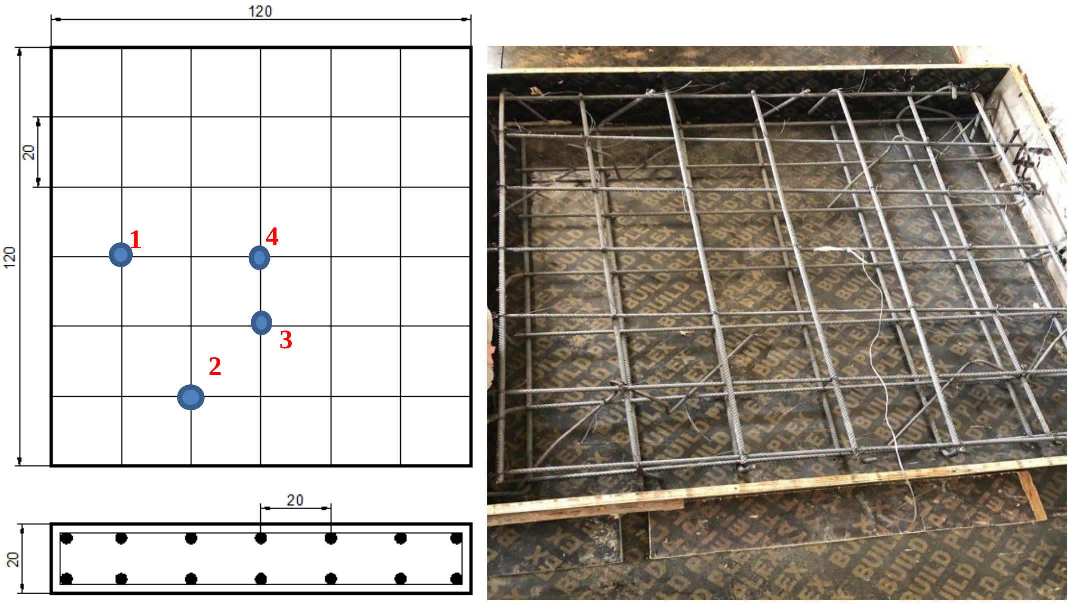


Fig. 1. Typical Steel arrangement details of slab No (S1) without opening. (Reference specimen)

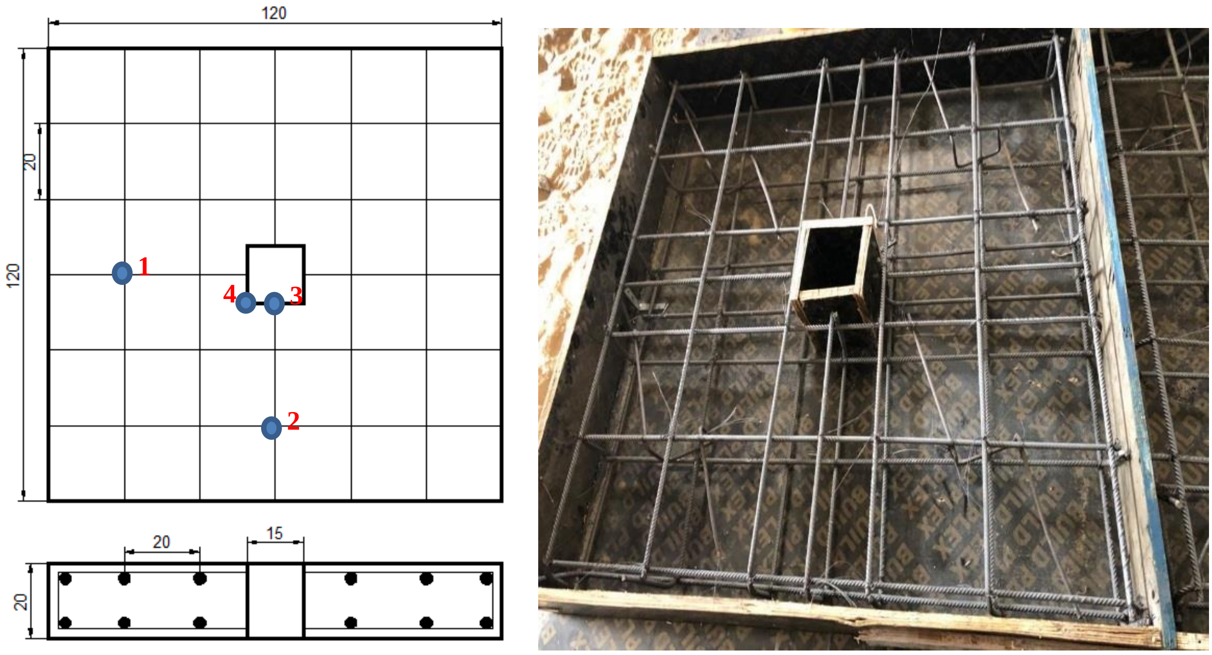


Fig. 2. Typical Steel arrangement &a details of Flat slab No (S2) with opening.

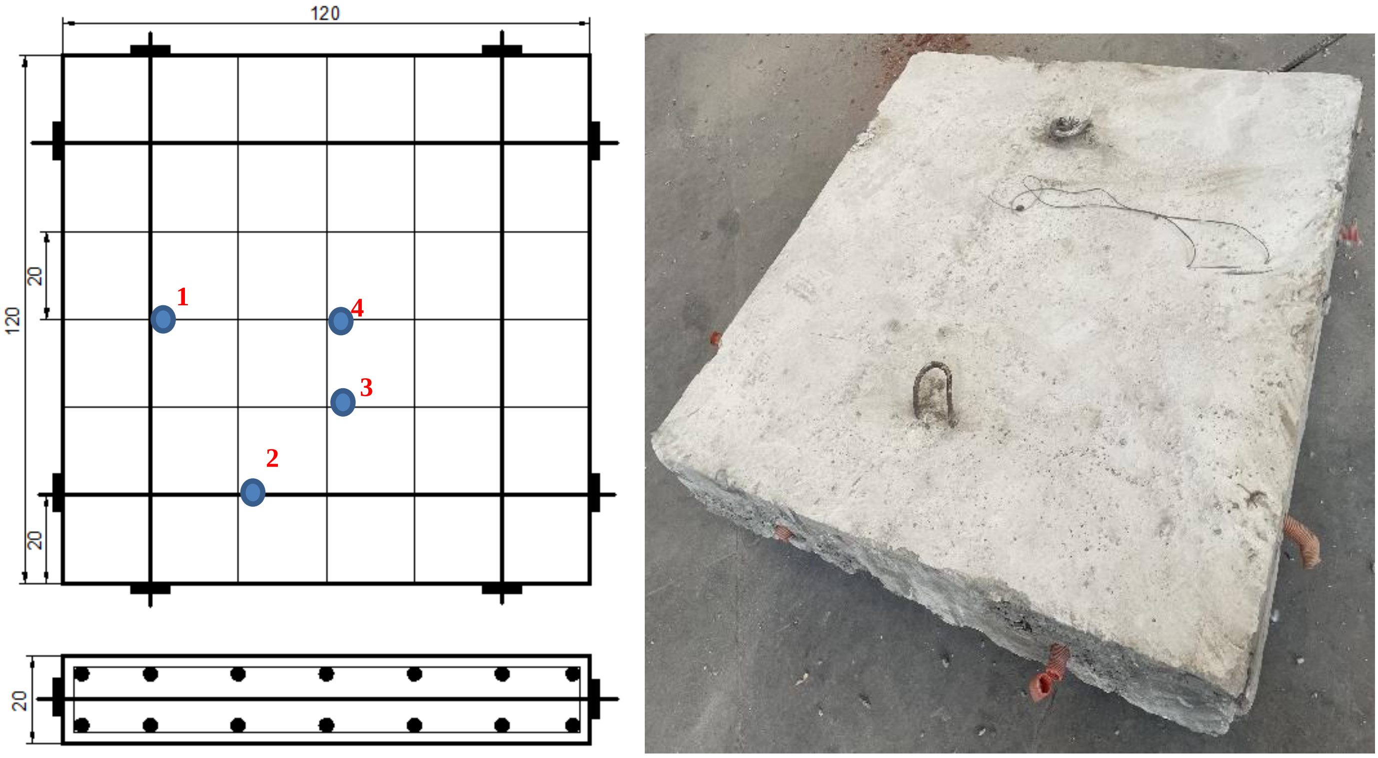
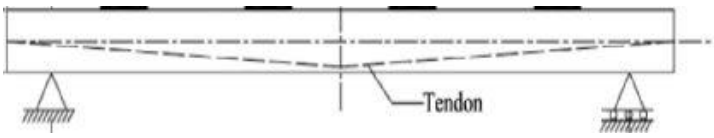


Fig. 3. Typical Steel arrangement details of PT slab No (S3) and strands distribution.



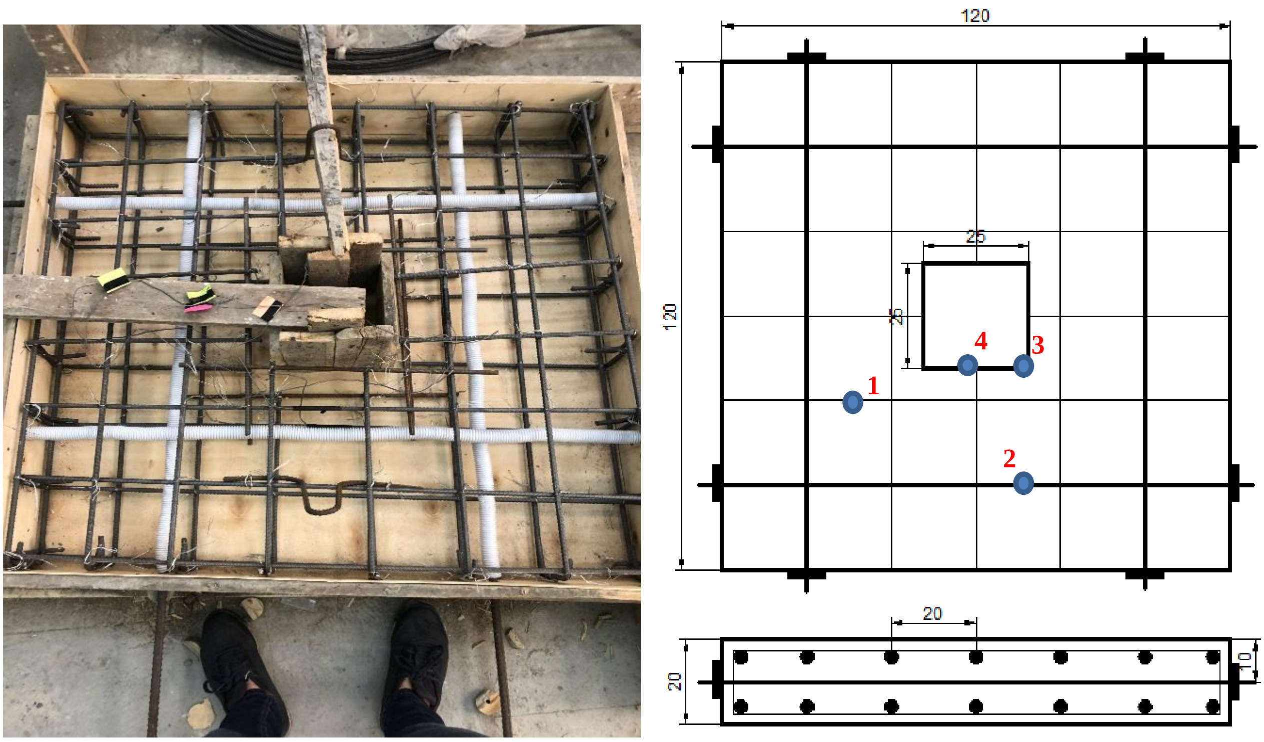


Fig. 4. Typical Steel arrangement details of PT slab S6 and strands distribution, with opening 25*25 cm.

Test Parameters

The six specimens were made of high strength concrete with target compressive strength f_{cu} =79.5Mpa. For the strands, all specimens had constant jacking force = 12.5 ton, elongation equal 2 to 2.5 cm for all strands and tensioned from one side.

Table 3. Details of the tested specimens

Specimen	f_{cu} (MPa)	d_s (mm)	Type	S_n	P_j (ton)	A_s
S1	79.5		Solid slab			5Φ10/m
S2	79.5		Flat slab with opening			5Φ10/m
S3	79.5	12.7	Un-bonded	4	12.5	5Φ10/m
S4	79.5	12.7	Un-bonded	4	12.5	5Φ10/m
S5	79.5	12.7	Un-bonded	4	12.5	5Φ10/m
S6	79.5	12.7	Un-bonded	4	12.5	5Φ10/m

Where:
f_{cu} is the strength of concrete standard cube 150mm. d_s is the diameter of the pre-stressed strands. S_n is the number of pre-stressed strands in specimens. P_j is the jacking force. As is the steel reinforcement in each side.

Preparation of Specimens for Testing :

Using the same mix proportions, a total number of six slabs were formed and cast post-tensioned HSC square slabs with central openings including one solid flat slab and one solid post-tensioned slab were cast, All the slabs had the same dimensions and concrete compressive strength of 79.5MPa. The slabs were reinforced using the same reinforcement ratio (p) of 0.013. An internal pre-stressing technique was considered by compressing the side surface of each slab directly by horizontal force of 12.5ton. The slabs were loaded uniformly to failure using a hydraulic jack with a capacity greater than 130 ton. Tables (4) shown all details of the slabs, openings, dimensions and pre-stressing force. The mechanical operation for post tensioning is shown in Figure (5):

Fig. 5. The mechanical operation for pre-stressing specimens.

Table 4. Tested Slabs Geometry:

Slabs	Length*Width (mm)	Thickness(mm)	Openings dimensions (mm)	Concrete Compressive Strength (MPa)	Pre-stressing force (kN)	Failure Force (kN)
S1	1200*1200	200	Solid Flat	79.5	-	735
S2	1200*1200	200	150*150	79.5	-	555
S3	1200*1200	200	150*150	79.5	125	1200
S4	1200*1200	200	200*200	79.5	125	1225
S5	1200*1200	200	250*250	79.5	125	1140
S6	1200*1200	200	Solid P.T	79.5	125	1300

FABRICATION of tested specimens:

The concrete mix was conducted on a stiff wooden formwork consisting of thick wood sheets. Firstly, the formwork was watered and then, all reinforcement of the tested slabs was placed inside from work. Three electrical resistance strain gauges for each slab were pasted to the steel reinforcement cage to measure strains in steel rods. The strain gauges was located at the edge span of slab, to the mid span of slab and at edge of opening to record the maximum occurred strains in steel. After that, concrete was placed on the wooden formworks and the specimens were moisture cured for seven days.

TEST INSTRUMENTATIONS AND MACHINES:

Strain meters was used to measure accurately strains in the steel bars. Dial gauge was used to measure mid-span deflections for each slab drying testing operation. Pre-stressing force was applied using a hydraulic jack connected to a 250kN load cell and an electrical pump. The slabs were uniformly loaded to failure by a hydraulic jack with a capacity greater than 1500 kN, Fig. (6).

Details of TEST-SETUP:

After curing time, all the slabs were ready for the experimental test. Test-set up can be summarized in the following points:

1- A strain meter was connected to the three strain gauges for each slab.
2- All the slabs were painted with a white color for photographing.
3- Dial gauges were placed at the bottom surface of each tested slab to measure the mid-span deflection
4- A very small glassy square plate were pasted& placed between gauges and the bottom surface of each slab to ensure accurate deflection measurements (LVDT).
5- Pre-stressing system consisted of four long strands (12.7 mm dia.).
6- The end of each bar was welded to a square steel plate. A square rigid steel plate was placed between the pulling hydraulic jack and the side surface of each tested slab to transfer the horizontal external pre-stressing force to slab.
7- To perform the uniformly distributed load as shown in figure (6) a very rigid steel beam on two steel hinge were used to transfer vertical load from a hydraulic jack to the top surface of each tested slab through sixteen-point loads.
8- Each slab was loaded incrementally to failure with a giant hydraulic jack with a capacity greater than 1500kN, and meanwhile all readings were recorded and cracks were marked on bottom surface of specimens & followed.
9- Test-setup and the used instrumentations are shown in Fig. (6) to Fig. (8).

Fig. 6. Uniform load distribution point.

Fig. 7. Adjusting the dial gauges at bottom surface of specimen for measuring deflection (LVDT).

Fig. 8. General testing setup.

Test Results and Observations

The applied load was increased incrementally with increment of 50.0 kN until the failure of slab. The data were recorded manually for each load application and cracks were marked.

Crack pattern Observation

Cracks for all tested specimens were critically observed after each loading cycle at the bottom surface of specimen. The propagation of cracks was traced and marked with the application of load up to failure. The development of cracks in all specimens followed almost a similar pattern. For slab (S1) (Reference slab) the diagonal cracks spread at a load of about 111 kN, After that, tangential cracks started to grow up to failure stage at load of 757 kN, For slabs S2, S3, S4, S5 & S6 the diagonal cracks appeared at a load of about 94 kN, 450 kN, 420 kN, 550 kN and 448 kN respectively.

Slabs S1, 3, 4, 5 and S6 it behaves the same cracking propagation and the recoded failure loads were 612 kN, 1210 kN, 1230 kN, 1270 kN and 1204 kN respectively.

All diagonal cracks grew wider & extending to the edge of the specimens until radial cracks had been developed. The crack pattern of each specimen is shown in Fig. 9 to Fig. 14.

Fig. 9. Crack pattern of slab (S1) (Reference slab).

Fig. 10. Crack pattern of slab (S2).

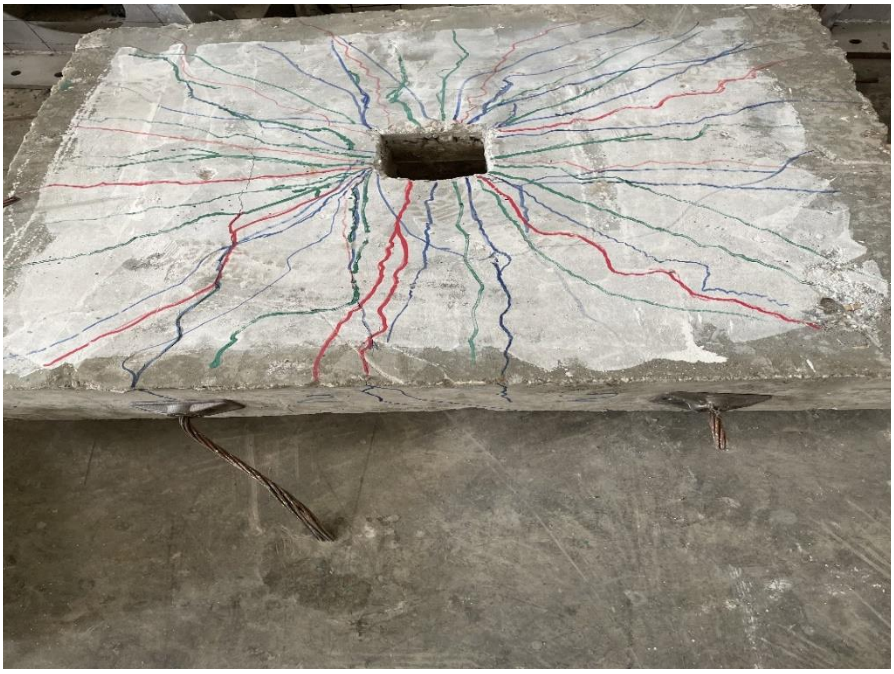


Fig. 11. Crack behavior of slab (S3).

Fig. 12. Crack pattern of slab (S4).

Fig. 13. Crack pattern of slab (S5).

Figure. 14. Crack behavior of slab (S6).

Deflection Characteristics

The load-deflection relationships of the tested slabs are shown in Fig.15-a to Fig.15-c. From these relationships, it could be observed that the rate of deflection was linear up to the cracking load. Beyond that with increasing the applied load cracks' propagation increased and became wider and the rate of deflection increased rapidly up to failure. After investigating the deflection of the tested slabs was compared with their reference slab. Table (5) Failure loads & deflection of tested slabs.

Table5. Test Results

Specimen	Cracking load (kN)	Failure load (kN)	Max deflection (mm)
S1	111	757	13.7
S2	94	612	15.4
S3	450	1110	16.5
S4	420	1130	17.1
S5	550	1170	18.4
S6	448	1204	18.9

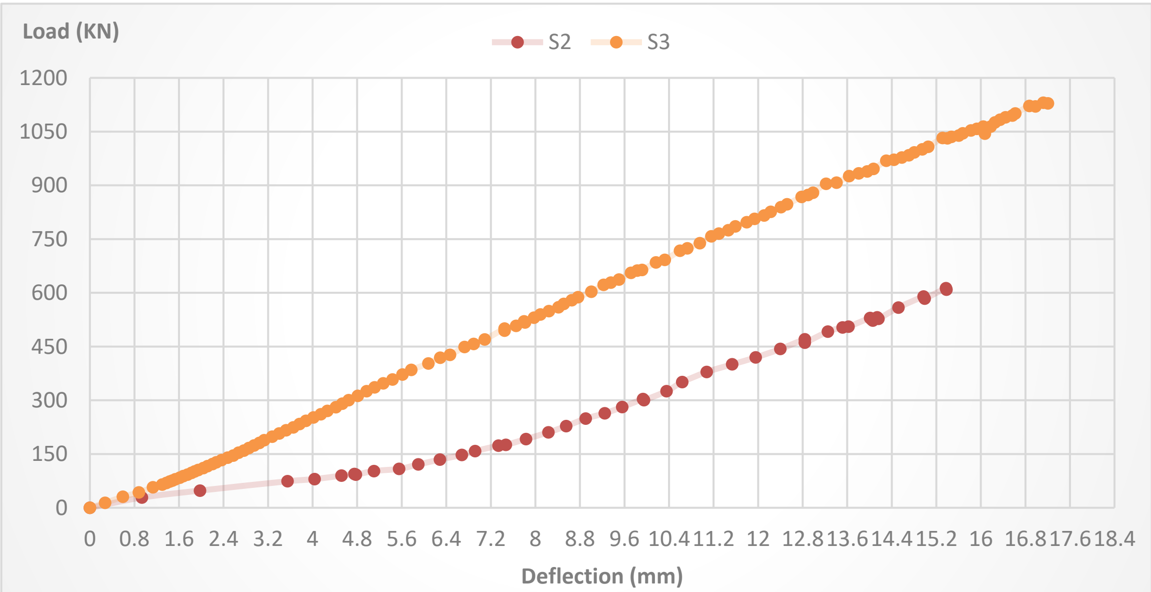


Fig. (15-a) Load - deflection relationship for specimen S2 and S3.

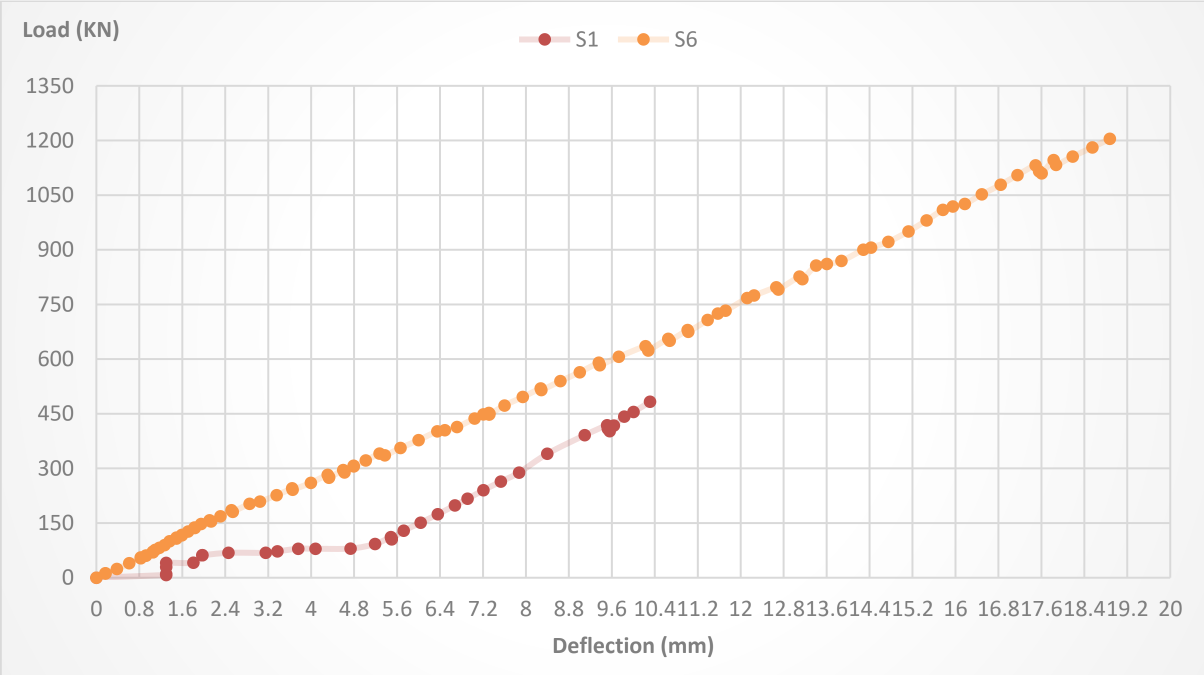


Fig. (15-b) Load-deflection relationship for specimens S1 and S6.

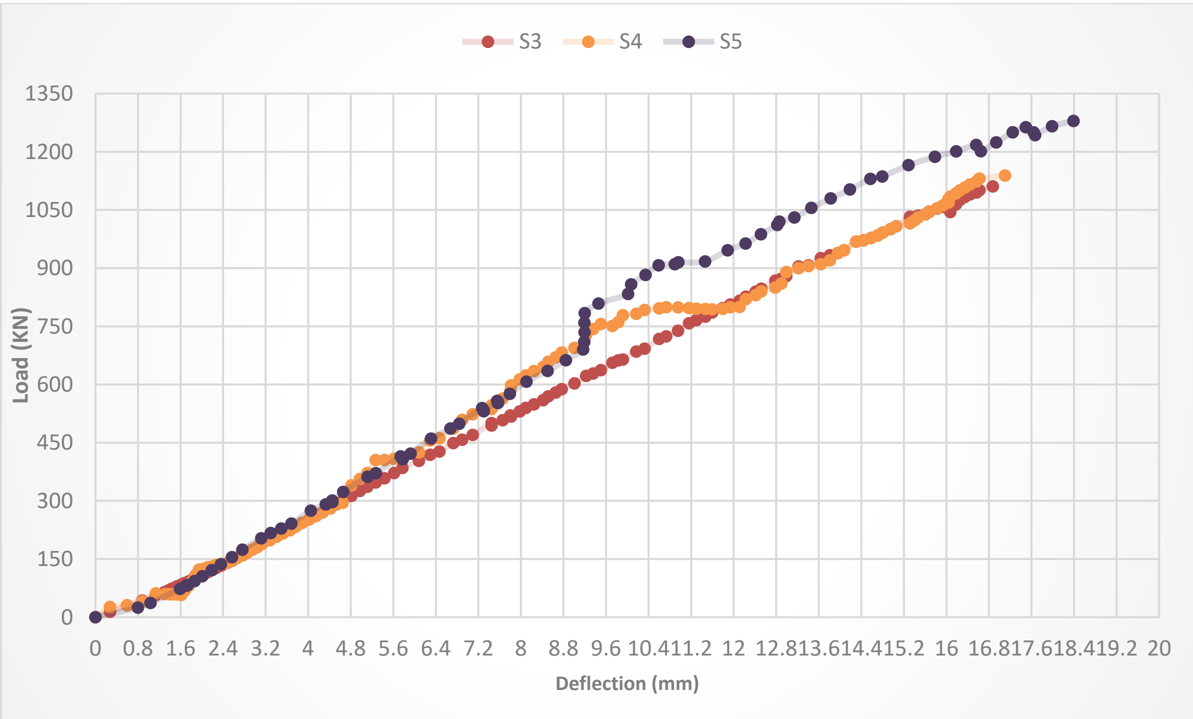


Fig. (15-c) Load-deflection relationship for specimens S3, S4 and S5.

the maximum deflection for different opening positions and sizes, the maximum deflection is increased by increasing the opening size the maximum deflection was at (LVDT) point 4 in corner of opening size 250×250mm², opening which shows a large increase in maximum deflection which reaches 33.5% from the original case (without openings) due to increasing the opening size.

1- Location of LVDT center line. 3- Location of LVDT edge of opening.

2- Location of LVDT center line. 4- Location of LVDT corner of opening.

Conclusions

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. Both stress around the opening and long-term deflection are increased due to the opening existence, 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.
4. Openings with dimension span /10 and more than column dimensions affected the inclination of load - deflection curve of the slab. The inclination of the curve is increased by about 15 % and 20% for slabs with opening at column corner and at column face respectively.
5. 5. If two openings are required adjacent to the supporting column, it is recommended to arrange them at two opposite faces or at two neighboring corners. This arrangement gives the minimum decreasing of the ultimate punching load.
6. 6. For slabs with opening dimension up to span/10; although these openings size is twice the codes limits, both British BS 8110 and ECP 203-2007 show good prediction.

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