Experimental work of effect of openings on the post-tensioned flat slab

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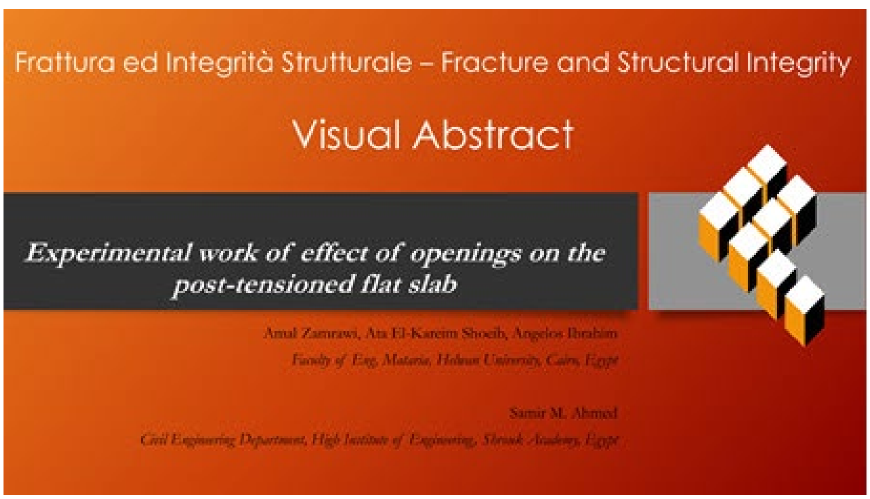

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INTRODUCTION

Flat slabs are considered one of the most important types widespread in building construction for many reasons, for example, ease of implementation, saving time and effort, and ease of architectural modification, if any. Therefore, many researchers have studied the post-tensioned flat slab technology due to its importance in recent decades. In some cases, openings may be made in concrete slabs for structural reasons, (see Fig. 1), such as passing feed lines for heating and ventilation. Or even for other architectural reasons [1,2].

A typical form of floor system that is extensively employed in contemporary structures is the reinforced concrete flat-slab. But the main issue with flat slabs is brittle punching shear failure brought on by concentrated heavy loads at the column-slab joints. Punching shear failures in this structural system are frequently brought on by poor building practices, a lack of shear reinforcement, and incorrect design decisions. Due to strong localized forces, punching shear failure is brittle and catastrophic. For that reason, in the past, many punching shear reinforcement techniques, including stirrups and studs, were created. Such systems' anchorage, bond, and detailing requirements are important development factors that have an impact on how effective they are. Recently, novel methods for preventing punching shear in flat slab floors have been presented, for Example, prestressing and FRP composite strengthening[1]. Since 1888, internal prestressing has been used to increase the slab section's resistance to punching shear. Subsequently, numerous studies have been done to determine the variables that influence punching shear capacity when utilizing internal prestressing. Numerous academics investigated the punching of post-tensioned slabs like [2 ,11].

Therefore, prestressing is a typical solution for flat slabs with wide spans and slab bridges, Additionally, it is a successful remedy for slabs that must withstand heavy concentrated loads like those seen in raft foundations. In these circumstances, prestressing is an appropriate procedure since it serves to reduce deflections at the serviceability limit state and to boost punching shear strength at the ultimate. Failures caused by punching in these members are particularly important because, in the absence of specific precautions (like integrity or shear reinforcement or relatively low ratios of flexural reinforcement), they are brittle and can spread to adjacent columns (overloaded after first punching a column), which will eventually cause the collapse of the entire structure [12].

Figure 1: This slab shows us the form of punshing failure and cracks if there are two holes next to the column.

According to [13], prior studies on the punching of flat slabs [14,20]have demonstrated that prestressing has a variety of potential positive consequences:

- Prestressing increased the in-plane compressive stresses in concrete, which increased the concrete's ability to withstand shear pressures.

- Tendon eccentricity, which typically results in bending moments that are the opposite of those caused by external movements. As a result, the failure region's crack apertures become smaller, increasing the concrete's ability to transfer shear stresses.

– The deviation forces that can be directly applied to the supported area are in equilibrium with the vertical components of the prestressing forces of inclined tendons intercepted by the punching failure surface. Thus, this element can be deducted from the shear load that concrete transfers.

The main objectives of this research are to clarify the effect of various factors on flat reinforced concrete slabs after tensioning, such as making openings before or after pouring and hardening the concrete, and thus the effect of the strand pieces after they have been subjected to the tensioning process, and also studying the effect of the difference in the number of strands and the difference in the force applied to them, (see Fig. 1):

The following points will also be discussed

- Defects in Concrete Structures – Types Causes, Prevention
- Causes for Defects in Concrete Structures
- Structural Defects due to Design and Detailing
- Structural Deficiency due to Construction Defects
- Other factors leading to poor design detailing
- Cracks
- Failure Mechanism due to Cracks Propagation Nature
- Design recommendations

EXPERIMENTAL PROGRAM

Description of specimens

The experimental work consisted of eight specimens of post-tensioned reinforced concrete flat slabs which classified into groups. All slabs had the same dimension and reinforcement. The slabs had dimensions with a 1750 mm length, 1750 mm width and 160 mm thick with concrete cover 25 mm. The main reinforcement was three bars of nominal diameter 10 mm in both directions. The opening size is 200 mm length and 200 mm width. The specimen details of the test setup of the eight specimens were shown in Fig. (2). Form work, Reinforcement, and strands of specimens are shown in Figs. (3 and 4) presented presence of openings and strain gauges.
The specimen's details were listed in Tab. (1) which indicates the description and behavior of a post-tensioned flat slab with openings under the concentrated load.
The Eight tested specimens were divided as following: 2 solid specimens (without any openings "control with 4 strands" and "control with 6 strands") as series S1 and S2 respectively; Flat slab with 2 openings (column corner) with 4 strands as a series S3; Flat slab with 2 opening (column sides) with 4 and 6 strands either before or after casting as series S4 and S7; Flat slab with 2 opening (column sides) with 6 strands one of them before and the other after casting as series S5 and S8. And the last with 2 opening after casting (column sides) with 6 strands which the strand was cuts series S6.

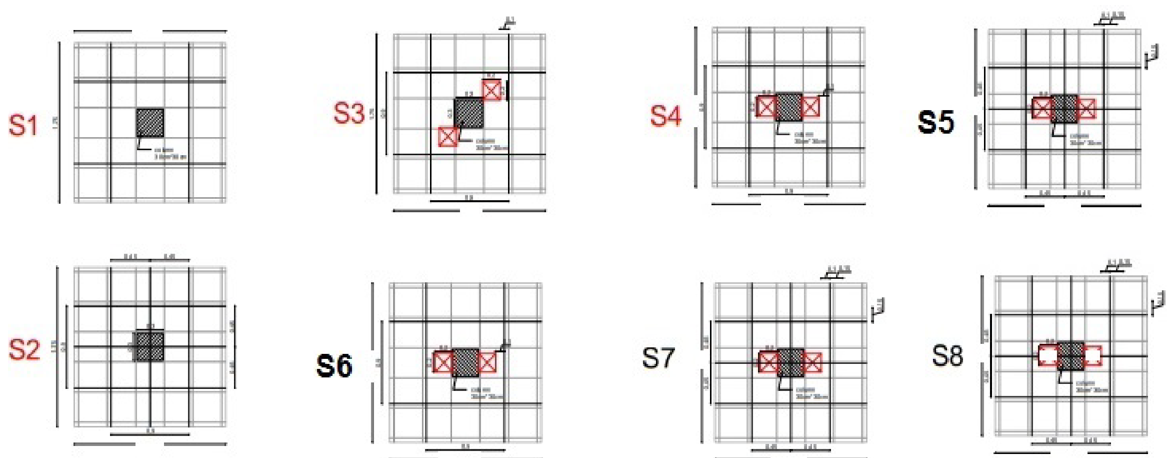

Figure 2: An illustration for all slabs to show the number of the strands and the different locations of the holes.

Parameters / Variables

Parametric studies are the factors that study the effect of the following variables on the Post Tension Flat slab, to understand its behavior with the presence of openings in different places of the column;
- Different locations of the holes in relation to the column, whether they are adjacent to the column or if they are at the corner of the column.
- The different effect of the openings that were made before pouring the concrete and those that were made after pouring.
- Different number of strands.
- Changing the forces with which the strands are tightened.
- Studying the effect of cutting the strand after tension.

Model	Openings existence	Casting	Prestressing System		Pu	Δ
			No. of strands	Force/cable (kN)	kN	mm
S1	Control "solid"	--------------	4	80	300.81	11.5
S2	Control "solid"	--------------	6	53.33	345.932	9.7
S3	2 opening (column corner)	Opening before casting	4	80	245.190	18.860
S4	2 opening (column sides)	Opening before casting	4	80	258.095	13.48
S5	2 opening (column sides)	Opening before casting	6	53.33	286.485	11.8
S6	2 opening (column sides)	Opening after casting	4	80	230.489	18.1
S7	2 opening (column sides)	Opening after casting	6	53.33	284.421	16.2
S8	2 opening (column sides)	Opening after casting and cutting the strand	6	53.33	265.933	17.496

Table 1: Description of openings, strands, and the tension forces applied to them, for eight specimens of flat post-tensioned reinforced concrete slabs.

Materials

The experimental test specimens were made of concrete that was cast in Egypt using local components. Ordinary Portland cement was used for the cement, and siliceous sand and nice, clean, well-graded dolomite made up the fine and coarse aggregates. As the primary reinforcement steel, 10 mm diameter high tensile steel bars were used. Three randomly chosen samples of bars from each batch were used to test the qualities of reinforcing steel bars based on the findings of the tension tests. All specimens' primary steel was subjected to strain measurements using internal electrical strain gauges (Type KFG-10-120-C1-11), the gauge length was 10 mm, the resistance was 119.8 0.2 ohms, the gauge factor was 2.11 1%, and the transverse sensitivity was 0.2%, as shown in the Fig. (3).

Concrete mix and curing

In order to mix, a concrete drum mixer was used. Sand, aggregate, and cement were first carefully mixed without the addition of water until they had reached a uniform color. After adding the water, the mixing process went on for another three minutes or so until a consistent tint was achieved. The specimens were covered with wet burlap sheets to cure the concrete after it had been poured in the molds and fully compacted using a vibrating table. For each slab specimen, two standard cubes (150 x 150 x 150 mm) were cast and tested to establish their compressive strength. To ensure complete curing, all specimens were immersed in a basin of water, (see Fig. 4), for seven days after being remolded after 24 hours together with the sides of steel shutters. The average compressive strength for cubes was 34.5 MPA for the mix, as shown in the Fig. (4 and 5).

Figure 3: Details of reinforcement steel.

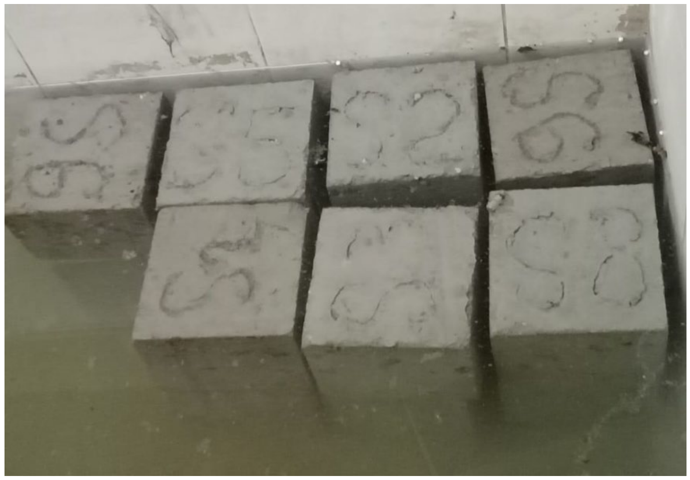

Figure 4: Standard cubes (150 x 150 x 150 mm), while immersed in water.

Figure 5: The shape of the cracks in the test cubes on the crushing machine.

PRESTRESSING PROCESS AND STEPS OF TESTING

All test specimens were cast on the same day and all slabs underwent water curing after 24 hours.
- The wooden form work was prepared according to the dimensions of the slab
- Then prepare the rebar, consisting of two upper and lower 3 Ø 10 nets and chairs.
- Reinforcing steel of the column and connecting it to the reinforcement of the slab. Slots were made in the wooden frame for the cables according to their number in the tiles.
- The anchors were installed, and the cables were passed through them and then through the spiral brackets and installed.
- A wooden box was made with the size of the hole and placed in the hole location for the slabs that had holes before pouring in the slabs (S3, S4 and S5), but for the slabs (S6, S7, and S8), the holes were made after the concrete was poured and hardened, as shown in the figure.
- We prepared the concrete pour and pouring was completed.
- Standard cubes were cast.
- Samples and test cubes were treated with water.

- After 28 days, the cubes were tested.
- Grout injection after 29 days through Grout vent.
- After 32 days, the Strands were injected.
-Then the Strands were tightened.
- Making openings in slabs, and Strands Cutting (S6, S7 and S8), as shown in Fig. (6 and 7).
- Samples were prepared for testing.

Figure 6: (S 8) After making the two holes and cutting the strand.

Figure 7: A picture to illustrate the shape of the opening after casting, as well as the cut strand after tension.

Test setup and procedure

The head bearing plates on the jack heads were modified to prevent any eccentricity from incorrect positioning or column head leveling, ensuring that the load eccentricity was maintained throughout the loading process. The hydraulic jack, coupled to a manual pump to supply oil pressure, and the system of plates and rollers that allowed rotations at the top end of the column were the components of the column axial loading system, as illustrated in Fig. (8, 9 and 10).

Using a fully computerized system, the tested slab-column connections were loaded up to 25% of the ultimate load after failure. Data recorded for each of the tested slab-column connections included the cracking loads, ultimate loads, deflections, and strains in the steel reinforcing mesh in two directions.

In order to guarantee uniform load distribution, the specimens were positioned between the jack heads and the steel frames using a quasi-static displacement control approach that was centered on its axis using two bearing plates. The data gathering system that was coupled to the computer was then connected to the strain gauges.

Steel strain and vertical displacements of the concrete were measured and confirmed prior to loading. The data acquisition system's testing software was used to reset the electrical instrumentation measurements to zero. Throughout the test, the load was delivered progressively at a steady rate of loading. The concentrated load that was applied increased monotonically from zero to failure load. At various loading levels, the strain in the main reinforcement was measured.

The electrical load cell, electrical pressure sensor, and LVDTs, as illustrated in Fig. (11), that measure slab deflections were all continuously read by the data acquisition system. Electrical strain gags measurements were recorded at the displacement maxima, and the system paused for 10 seconds to allow crack monitoring. Readings after failure loads (the unloading zone) of up to 25% of the maximum loads were obtained for some specimens. This procedure was carried out manually utilizing variable load increment because the machine lacked displacement control capabilities.

A metal plate must be placed between the jack of the loading machine and the concrete column to distribute the machine load on the column and then on the slab.

Figure 8: Test Setup for the loading machine on the slab.

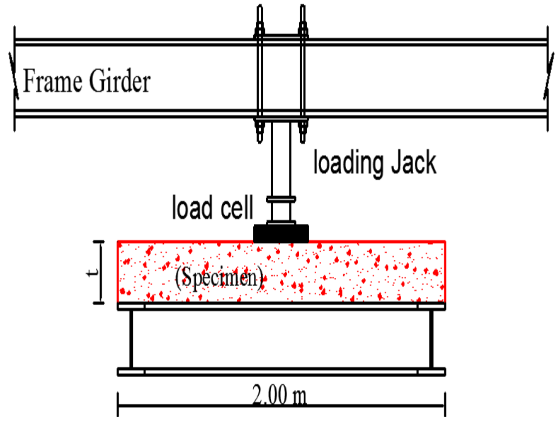

Figure 9: Illustration for the loading machine

Figure 10: A metal plate between the jack of the loading machine and the concrete.

Figure 11: LVDT to measure slab deflections.

Failure load and mid-span deflection

Some tables, curves and graphs of the values of failure loads and deflection at mid-span for the eight test slabs will be reviewed, in order to make comparisons of the different values of the eight slabs for a better understanding of the behavior of slabs with openings in different places and with different numbers of strands.

Model	Pre-stressing System	Pmax	Δmax
	No. of strands	kN	mm
S1	4	300.81	11.5
S3	4	245.190	18.86
S4	4	258.095	13.48
S6	4	230.489	18.1

Table 2: Failure load and mid-span deflection comparisons between solid specimens (S1), and other specimens with openings subjected to 4 strands.

Model	Pre-stressing System No. of strands	Pmax kN	Δmax mm
S2	6	345.932	9.7
S5	6	286.485	11.8
S7	6	284.421	16.2
S8	6	265.933	17.496

Table 3: Failure load and mid-span deflection comparisons between solid specimens (S2), and other specimens with openings subjected to 6 strands.

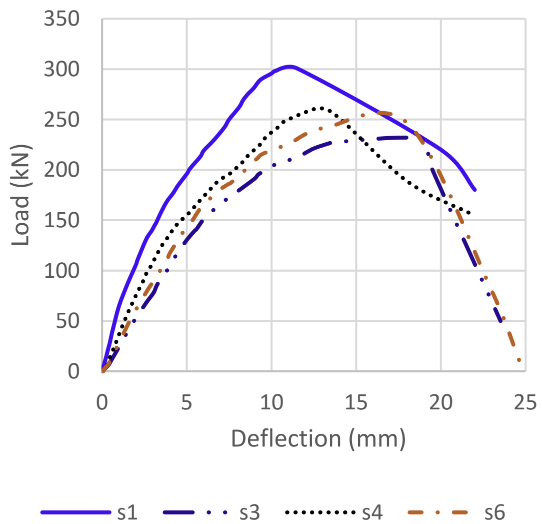

Figure 12: Load versus mid-span deflection for flat slab subjected to 4 strands, for control specimen (S1) and specimens with openings.

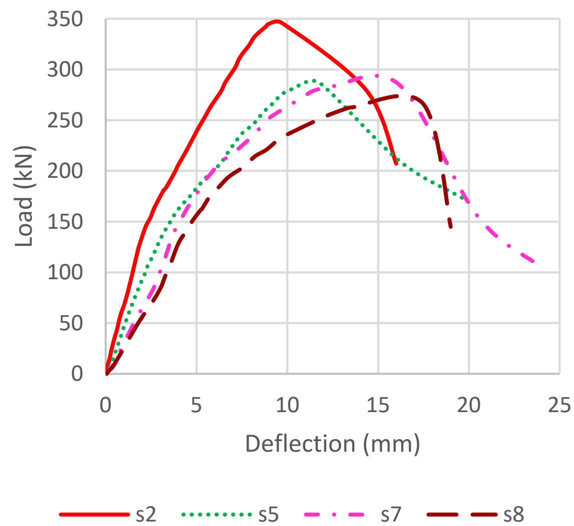

Figure 13: Load versus mid-span deflection for flat slab subjected to 6 strands, for control Specimen and specimens with openings.

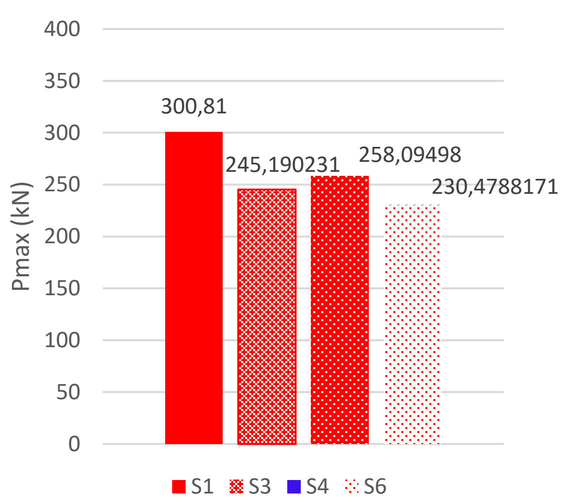

Figure 14: Load comparisons between control Specimen(S1) and specimens with openings subjected to 4 strands

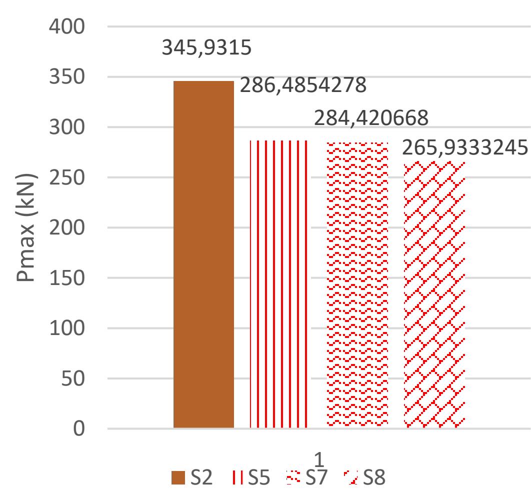

Figure 15: Load comparisons between control specimen(S2) and specimens with openings subjected to 6 strands.

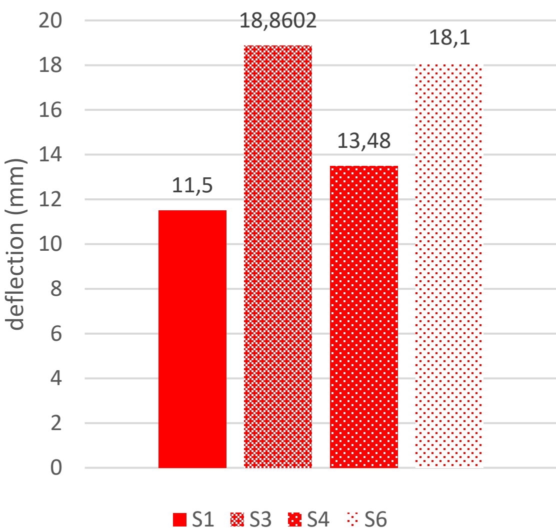

Figure 16: Mid-span deflection comparisons between control specimen(S1) and specimens with openings subjected to 4 strands.

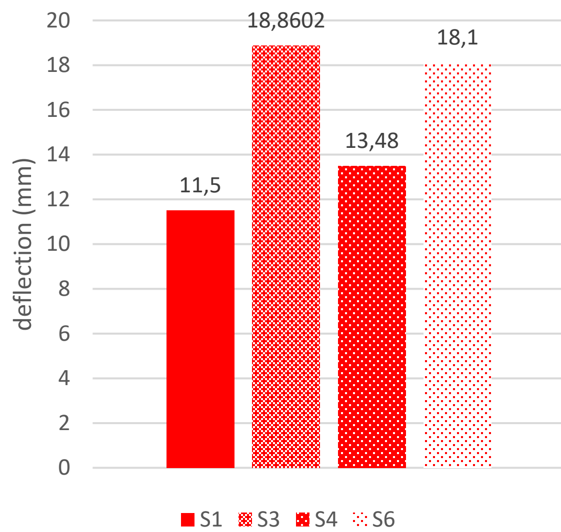

Figure 17: Mid-span deflection comparisons between control specimen(S2) and specimens with openings subjected to 6 strands.

As observed from Figs. 12 to 17 and Tabs. 2 and 3; it was noticed that the number of strands has an obvious effect on the value of load capacity and deflection. There was a significant reduction in load capacity in the case of using 4 strands at specimens S3, S4 and S6 (range from 14% to 23%) and for 6 strands at specimens S5, S7 and S8 (range from 15% to 25%). Also, the reduction in deflection in the case of specimens with 4 strands (about 15% ~ 40%) while for specimens with 4 strands S5, S7 and S8 was about (20% ~ 45%) and S8 is the weakest specimen when compared with control case S1 and S2. This loss in load capacity of the specimens is due to the reduction in the section capacity due to the loss in the cross-sectional area necessary to bending moment resisting, beside the reduction in the moment of inertia at the section that leads to decrease the stiffness of the slab against resisting the flexural stresses.

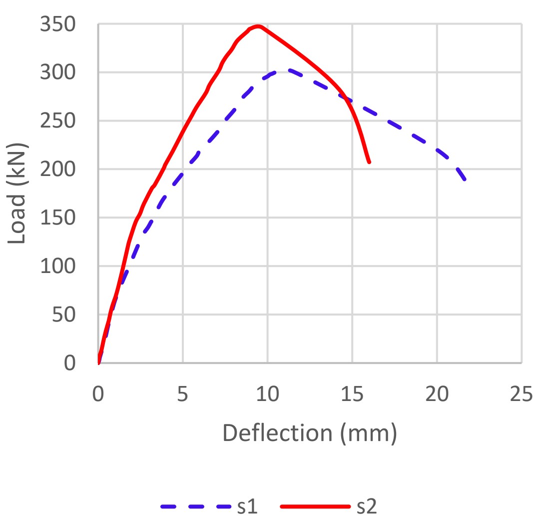

Figure 18: Load versus mid-span deflection for flat slab subjected to 4 and 6 strands for "control specimens", which without any openings, (S1 and S2).

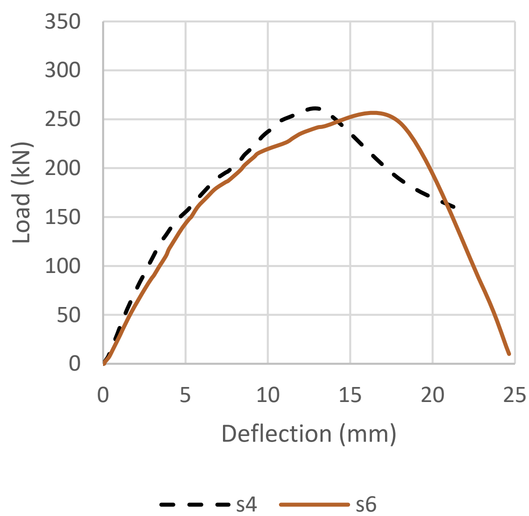

Figure 19: Load versus mid-span deflection for flat slab subjected to 4 strands specimens "specimens with openings either before or after Casting" (S4 and S6).

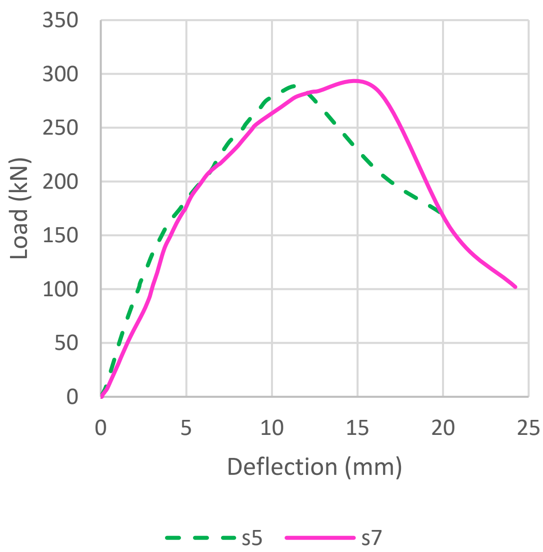

Figure 20: Load versus mid-span deflection for flat slab subjected to 6 strands specimens "specimens with openings either before or after Casting" (S5 and S7).

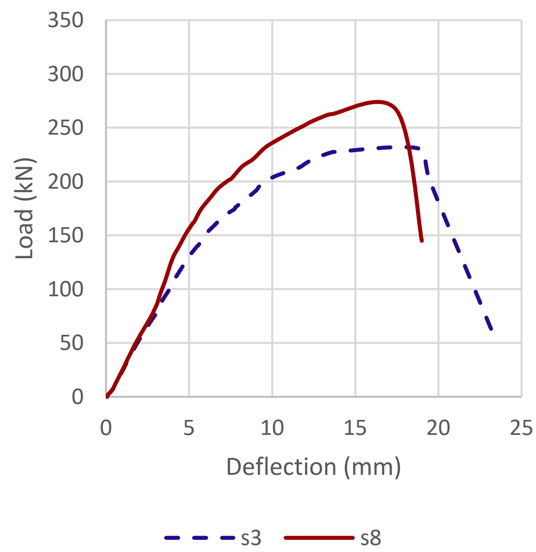

Figure 21: Load versus mid-span deflection for flat slab specimens with openings subjected to 4 strands, either before or after Cutting the Strands, (S3 and S8).

As observed from Figs. 18 to 21; it was noticed that, while increasing the no. of strands and rearranging the force subjected to each strand, the amount of force on each of the specimens are the same. Rearranging the force subjected on strands has an obvious effect on the value of load capacity and deflection. Also, the status of making openings has an obvious effect on the value of load capacity and deflection. The values of load capacity in case of using 6 strands are slight difference more than using 4 strands (about 10%) for control specimens S1&S2. Also, the status of making openings has an obvious effect on the value of load capacity and deflection as making openings before casting is more than what done after casting as indicated in Tabs. 2 and 3 and Fig. 12 to 17.

Ductility

Ductility is the measure of a materials' ability to plastically deform without fracturing when placed under a tensile stress that exceeds its yield strength. Ductility (μ) released from the formula "the ratio between maximum deflection (Δmax) at the ultimate load and the deflection at yielding point= Δmax/Δy", as shown in the Fig. (22). The Ductility values for the eight Slabs are also explained in Tabs. (4 and 5).

Model	Pre-stressing System	Py	Δy	μ
	No. of strands	kN	mm	
S1	4	249.7	7.48	1.54
S3	4	191.2	9	2.10
S4	4	207.825	8.3	1.62
S6	4	197.434	8.3	2.18

Table 4: Ductility for solid specimens (control/S1), and other specimens with openings of flat slab subjected to 4 strands.

model	Pre-stressing System	Py	Δy	μ
	No. of strands	kN	mm	
S2	6	287.155	6.582	1.47
S5	6	236.2	7.47	1.58
S7	6	231.2	7.9	2.05
S8	6	214.1	8.2	2.13

Table 5: Ductility for solid specimens (control/S2) and other specimens with openings of flat slab subjected to 6 strands.

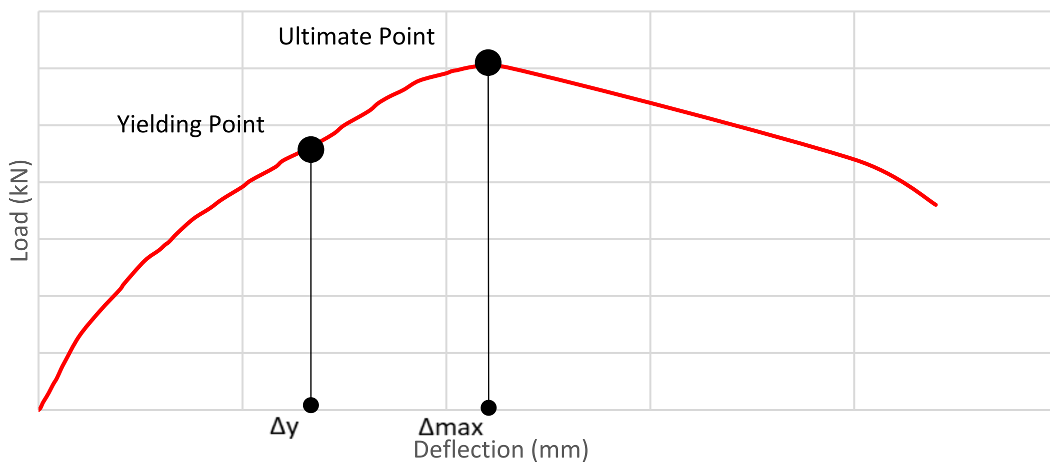

Figure 22: Indication for deducing Yielding point and Ultimate point from Load mid-span deflection curve.

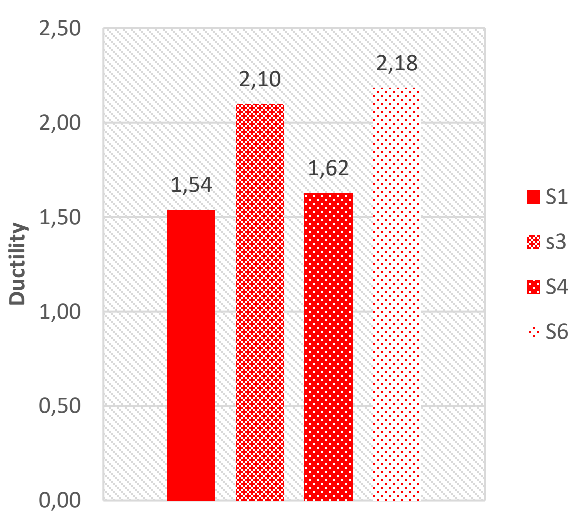

Figure 23: Ductility induced from 4 strands post-tensioned flat slab.

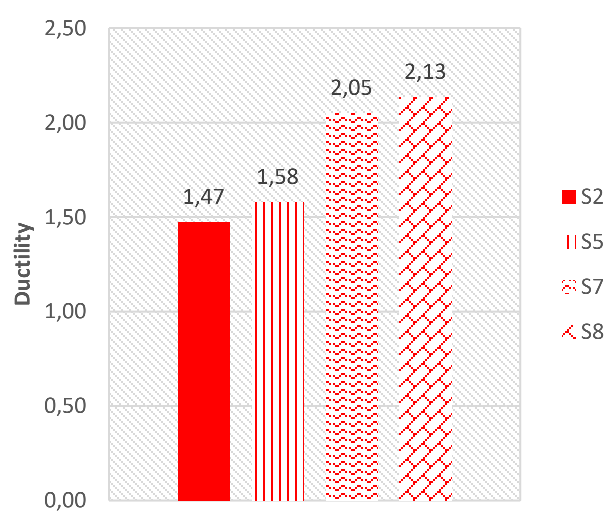

Figure 24: Ductility induced from 6 strands post-tensioned flat slab.

This bar chart indicates the effect of number of strands and openings case on post-tensioned flat slab. The specimens cracked at the yielding point that indicated at Tab. (5 and 6) and ultimate load at the ultimate point that indicated at Tab. 2 and 3. The ductility Ratio, as indicated in Fig. (23 and 24) and Tab. (4 and 5).

STIFFNESS

Stiffness is an indicator of the tendency for an element to return to its original form after being subjected to a force, it depends on the slope of P-Δ curve. There are 3 tangents deduced from the P-Δ curve (**Kin** till cracking point, **K1** till yielding point, **K2** till the ultimate point). Stiffness is the **Kavg** = (**K1 + K2) / 2**, as shown in Fig. (25).

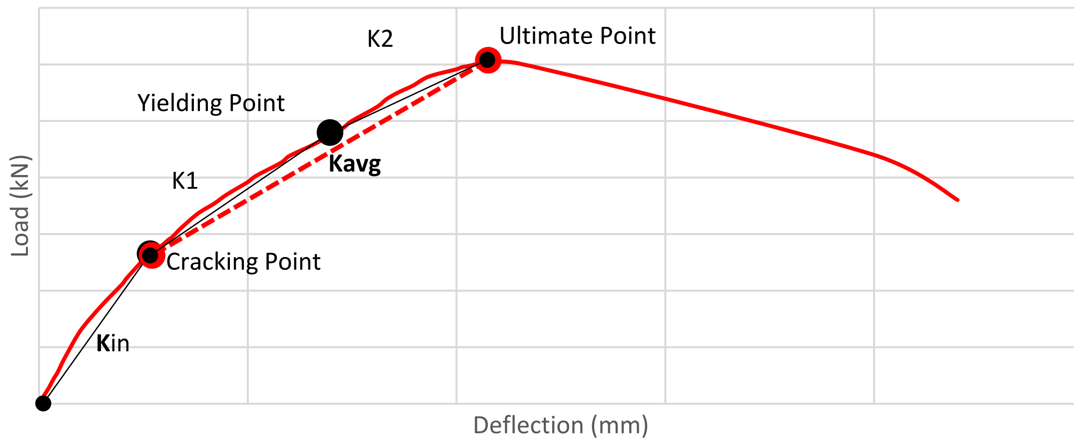

Figure 25: Indication for Stiffness of flat slab subjected to post-tensioned strands.

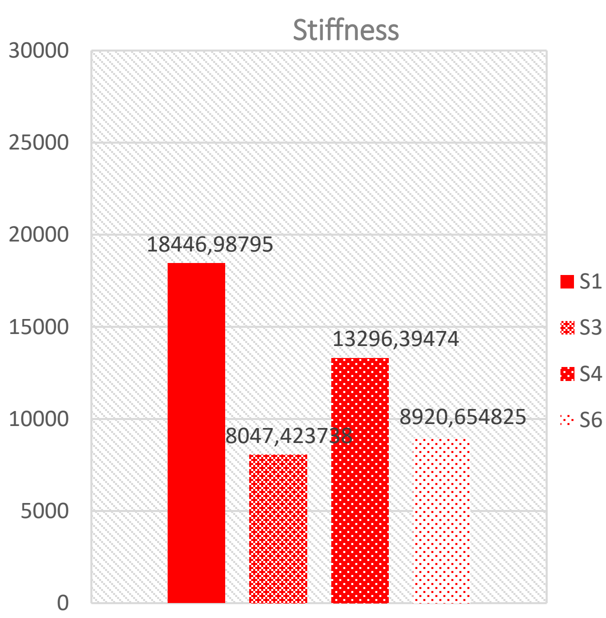

Figure 26: Stiffness induced from 4 strands post-tensioned flat slab.

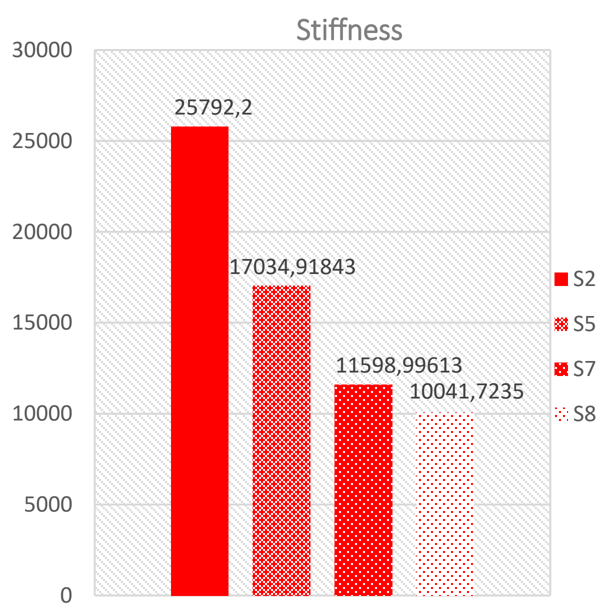

Figure 27: Stiffness induced from 6 strands post-tensioned flat slab.

Post-tensioned flat slabs subjected to 4 and 6 strands at the different places and cases of openings either before or after casting, and the Stiffness value as shown in Fig. (26 and 27). S1 and S2 were the highest values, Because there are no openings in the slab, while S8 was the lowest values of 4 and 6 strands, this is due to the presence of two holes next to the column and also due to cutting two strands before loading the slab for testing.

Energy Absorbed

Energy Absorbed indicated from Area under load mid-span deflection curve according to this formula AEI = A total "A1+A2" / A1 where A1 Area under curve at elastic zone till cracking point and A2 Area undercover from cracking point till ultimate point, as shown in the Fig. (28).

Model	Pre-stressing System No. of strands	Pcr kN	Δcr mm	AEI
S1	4	147.7	3.2	13.02
S3	4	113.167	3.24	9.35
S4	4	126.727	3.6	9.73
S6	4	120.39	4.11	8.36

Table 6: Energy Absorbed for solid flat slab and other specimens with openings subjected to 4 strands.

Model	Pre-stressing System No. of strands	Pcr kN	Δcr mm	AEI
S2	6	168.378	2.816	13.91
S5	6	140.667	3.24	11.99
S7	6	140.375	3.781	9.33
S8	6	131.251	4.084	8.18

Table 7: Energy Absorbed for solid flat slab and other specimens with openings subjected to 6 strands.

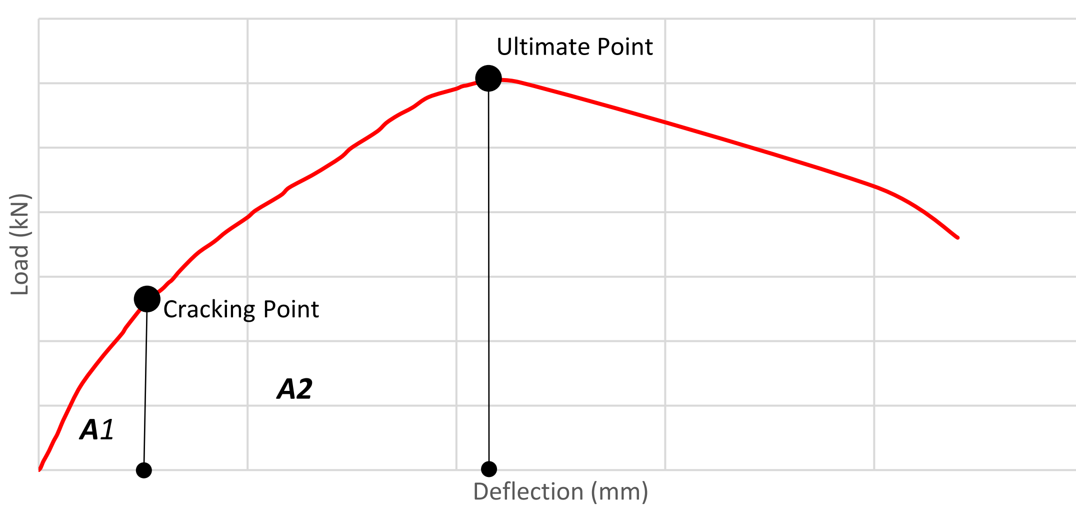

Figure 28: Indication for Calculating the Energy absorbed from Area under curve

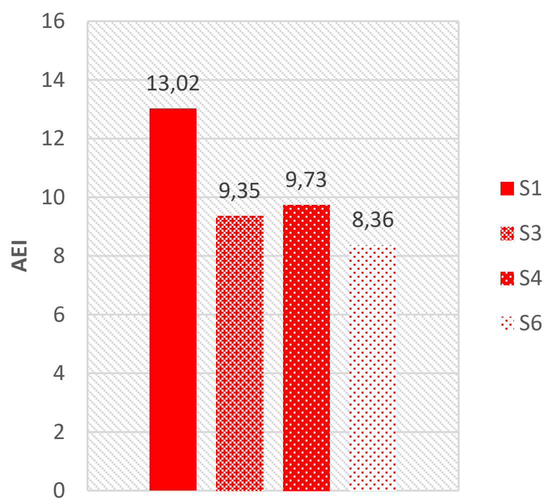

Figure 29: Energy Absorbed induced from 4 strands post-tensioned flat slab.

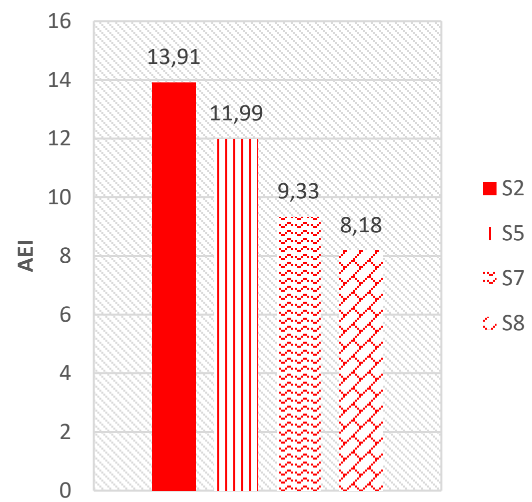

Figure 30: Energy Absorbed induced from 6 strands post-tensioned flat slab.

According to the values at Tabs. 6 and 7, it's obvious that the value of S2 is the control specimen in the case of 6 Strands and, which having the highest value of energy absorbed as it is the specimen with whole capacity as it is the solid specimen without any openings. For S3 with holes in the corner, the energy absorption value is lower than the sample with T holes in the side of the column with four branches like S4, due to the stress concentration in the column corners.
When comparing through Bar Chart, two slabs with 4 strands and two openings next to the column, but one of them has two openings before Casting S4 and the other after Casting S6, we find that the value of the Energy absorbed for slab S4 is higher than that of slab S6. To clarify better, compare the strongest sample S2, with 6 strands and no openings, with the weakest sample, S8, with two holes after casting, in which 2 strands were cut after the tensioning process and before testing the slab. We note that there is a difference of approximately 59%.
After these comparisons, we find that the energy value increases as the number of strands increases and the number of openings in the slab decreases. We also understand that the location of the openings affects the Energy absorbed value, as shown in the Fig. (29 and 30).

Strain

Strain is the deformation of a material from stress. It is simply a ratio of the change in length to the original length. Deformations that are applied perpendicular to the cross-section are normal strains, while deformations applied parallel to the cross-section are shear strains, as shown in Figs. (31).

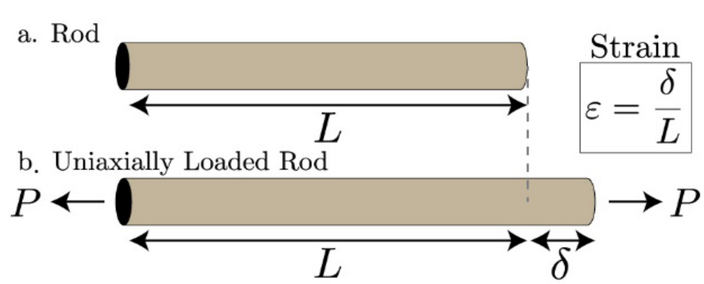

Figure 31: Strain mechanism.

Model	Pre-stressing System	Py	Δy	Strain
	No. of strands	ton	mm	με
S1	4	24.97	7.48	207.2
S3	4	19.743	7.47	144.8
S4	4	20.783	8.3	185.1
S6	4	19.743	8.3	181.5

Table 8: Strain for solid flat slab and other specimens with openings subjected to 4 Strands.

Model	Pre-stressing System	Py	Δy	Strain
	No. of strands	ton	mm	με
S2	6	28.716	6.582	218.3
S5	6	23.62	7.47	211.6
S7	6	23.12	20.186	215.9
S8	6	21.41	16.308	175.7

Table 9: Strain for solid flat slab and other specimens with openings subjected to 6 Strands.

It is clear to us from Tabs. 8 and 9 that the greater the number of strands, the greater the strain value. Also, the strain values are higher in slabs with openings before pouring.

Stress values were obtained by installing a Strain Gauges, on the bottom reinforcement mesh of the slab while it was in a position with the column from above; Strain Gauges is the red cable is next to the column, As shown in the Fig. (32 and 33), and the strain values are also shown in Tabs. (8 and 9)which were read using Strain Gauges.

Figure 32: Strain Gauges it was installed on a slab reinforcement.

Figure 33: The Strain Gauge "red cable" is connected to the white cable of the Device for reading Strain results.

Defects in concrete structures – Types causes, prevention

There are numerous sorts of flaws in concrete structures, including scaling, spilling, dusting, curling, crazing, blistering, delamination, and cracking. These flaws may result from a number of causes or reasons.

Causes for defects in concrete structures

The following general categories can be used to classify the causes of defects in concrete structures: 1. Structural deficiencies brought on by incorrect design decisions, loading criteria, unanticipated overloading, etc.
2. A structural flaw brought on by poor construction.
3. Damage from cyclones, earthquakes, fires, and other disasters.
4. Damage from a chemical assault.
5. Environmental harm caused by the sea.
6. Damage from granular materials being abraded.
7. Concrete can move because of its physical qualities.

Structural defects due to design and detailing

In this case, the design needs to be carefully scrutinized, and the design team needs to come up with remedial measures. When this is finished, the steps for implementing the corrective actions will be similar to those brought on by previous issues.

Structural deficiency due to construction defects

The main cause of trouble for the post tensioned flat slab is poor construction practices. These flaws can be split into three categories:
1. Defects resulting from poor raw materials.
2. Failure to use the intended concrete mix.
3. The production, transportation, and placement of the concrete were all done using subpar construction equipment.
4. Poor craftsmanship.
5. Poor-quality detailing..

Other factors leading to poor design detailing.

1. Re-entrant corners, first.
2. Sudden modifications to the part.
3. Substandard joint details.
4. Limits on deflection.
5. Drips and scuppers with poor detail.
6. Poor or insufficient drainage.
7. Poor expansion joint details.

Cracks
One of the many sorts of flaws that can be seen in a hardened concrete surface are cracks, which raise concerns since they have an impact on the strength and longevity of a concrete slab. The bond between the steel and concrete can be broken by cracks that enter an area where pre-stressing strand is present, see Fig. (34 and 35) lengthening development and transfer lengths and reducing moment and shear capacity. Additionally, cracks allow for an increase in corrosives such as chlorides, exposing steel reinforcing strands.
There are several reasons why concrete can crack, but when they are sufficiently deep, it becomes unsafe to use the concrete structure. Cracking can be caused by a number of factors, including the use of concrete mixes with an excessively high slump, inadequate curing, the omission of expansion and contraction joints, the wrong sub-grade, and poor mix design. To stop cracking, steer clear of calcium chloride-containing admixtures, use cement that has a low water-to-cement ratio, and add more coarse aggregate to the mix. Surfaces need to be guarded against rapid moisture evaporation. Loads shouldn't be applied until the concrete surface has attained its maximum strength.

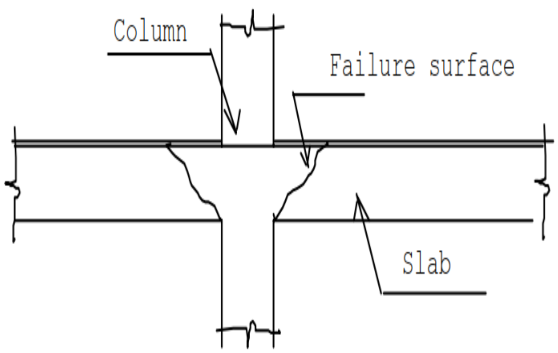

Figure 34: An illustration for Punching failure surfaces of tensioned flat slab.

Figure 35: Punching failure surfaces of post tensioned flat slab Openings, (S3).

Failure Mechanism due to Cracks Propagation Nature
The post-tensioned flat slab specimens were tested till failure, and the tests were stopped when the punching cone surface was clearly formed at the bottom surface of the slab. The failure was initiated with longitudinal hairy cracks that started from the column faces to the slab edges. Then gradually the punching cone surface was formed around the column edges, while increasing the load the major crack of punching cone width was increased till the crushing of concrete around the punching cone surface. Fig. 23 shows clearly that the specimen exhibited a brittle punching shear failure. The crack pattern is marked in black during the loading of the slab. The appearance of cracks during increased load on the slab was numbered.

Design recommendations:
It is clear to us from Fig. (2) and Tab. (1) that the total tension force on all slabs is equal, and its total amounts to 320 kN on the strands located in any eight slabs. The tension force on One strand in the slabs (S1, S3, S4 and S6) is 80, while it is 53.33 kN on the One strand in the slabs (S2, S5, S7 and S8).
By comparing the results together, it becomes clear that Pmax is higher in slabs with openings before pouring, and it is also higher in slabs with a higher number of strands, so the following is recommended:
- Holes are made before pouring
- If it is necessary to make holes, it is preferable for them to be next to the column and not in the corners of the column.
- Increase the number of strands as much as possible.

Figure 30: Failure Mechanism of the Post-tensioned Flat Slab during experimental tests.The appearance of cracks during increased load on the slab was numbered.

CONCLUSION

1. The reduction in load capacity of specimens having openings compared to control specimen, which subjected to 4 strands were less about 15~25% while for specimen which subjected to 6 strands were about 15%.
2. For specimen S8 is the weakest specimen as after casting the strands were cut, the difference in load capacity was about 23% when compared to the control Specimen S2.
3. Ductility of control specimens (S1 and S2) were the lowest values according to having the lowest maximum deflection with reset to yielding deflection values and also specimens having 6 strands have lower values than others with 4 strands. For specimens having openings subjected to 4 strands and 6 before casting (S3, S4 and S5), were fewer values of ductility than others with openings made after casting (S6, S7 and S8), with ratio (25% for S4 and S6) and (5% for S5 and S7) respectively. For control specimens (S1 and S2), their values were near together but (S2) has a lower ratio, less than 5%.
4. Stiffness of control specimens (S1 and S2) were the largest values compared to other specimens that having openings, and also specimens having 6 strands were more values than others with 4 strands.
   Stiffness for specimens having openings and subjected to 4 strands were ranged (25% -48%), but for specimens having openings and subjected to 6 strands were ranged (38%-44%) when compared to solid (control) specimens.
5. Energy absorbed for solid specimens were the largest values compared to other specimens that having openings, and also specimens having 6 strands were more values than others with 4 strands.
   Energy absorbed for specimens having openings and subjected to 4 strands were ranged (29% - 35%) for specimens having openings and subjected to 6 strands were ranged (25%-45%) when compared to solid (control) specimens.

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