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# Behavior of Two-Way Post Tension Flat Slab

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**Abstract:** Post tension floors (PT) are one of the most widely used system which are very effective method regarding ultimate and serviceability limit states. A numerical model for discretized the two-way reinforced concrete flat slab with different system is investigated by using RAM software. The effects of different parameters are investigated in this study. Parameters investigated include concrete strength, thickness of the flat slab, different values of jacking (force (P) / area of strand (A)) and also, study the flat slab with opening by changing the values of P/A. Results indicated significant effect of PT system in the flat slab by decreasing the deflection. Also, the magnitude of the bending moment is reversed at one internal column by increasing the value of P/A for large thickness.

**Keywords:** Buildings, Structures & Design, Concrete Structures, Slabs, Stress Analysis, Post Tension, Finite Element Modeling, Ram Software

## 1. Introduction

A pre-stressed concrete structure has many advantages, such as decreasing cracks, saving materials, reducing deflection, and has been widely or increasingly used in long-span structures, shells, and nuclear containment vessels. PT floors are one of the most widely used systems for building construction all over the world. Such systems have too many behavior, construction and economic benefits over other systems used for floor construction. Openings in the concrete slabs may be large, such as those required for a new stairway, or small core penetrations, such as those required for plumbing risers. PT slabs have the added complexity in that PT strands may have to be cut. It is a common misconception that creating openings in existing PT slabs is difficult, expensive, and dangerous. This perception is perpetuated because the field procedures and hardware used to create these penetrations are not fully understood. This concern is sometimes given as a reason for avoiding PT construction in particular applications. The behavior of un-bonded post-tensioned one-way concrete slabs experimentally and numerically had investigated [3]. The pre-stress losses have been measured and compared with calculated design procedures. It has been shown that the codified design values overestimate the pre-stress losses. The analytical investigation of structures incorporating both post-tensioned tendons and post-compressed bars presented [1]. Mathematical expressions are derived for the analysis of such pre-stressed concrete structural beams for transfer and service conditions. An analytical example of a typical pre-stressed concrete beam is given and the structural behavior is properly assessed. The ultimate stress in un-bonded tendons from mechanical principles, instead of using experimental data fitting formula, an advanced nonlinear analysis method to calculate ultimate stress in un-bonded tendons developed [10]. An experimental studied on the effect of post-tensioned on the ultimate strength of hollow slabs with and without post-tension at varying post-stressing [2]. It is concluded that post-tension can be used to increase the bearing capacity of hollow slabs by up to 15% with the failure mode changes from flexural to shear as observed in laboratory experiments presented. Two-way slabs with bonded tendons outside the United States which based on the Australian Code, EC2, and the British Code, depending on location designed [6]. It seems rational that ACI 318 should require the same amount of bonded reinforcement in two-way slabs with bonded tendons as is required in slabs with unbonded tendons. It should be permitted to include the cross-sectional area of the bonded tendons in the total cross-sectional area of bonded reinforcement required. A flexural behavior model for continuous un-bonded PT (UPT) members has been proposed, which is a nonlinear analysis model that reflects the moment redistribution [7]. The studded showed that, the bending moment distribution and flexural stiffness ratio along the member were used to reflect the moment redistribution of continuous UPT members. Also, an experimental investigated in the behavior of PT fibrous concrete beams when tested under repeated load using the displacement control system up to failure [5]. The fibers contents ratios, type of fibers (steel and polypropylene) as well as the pre-stressing level (partially or fully) were the main parameters investigated. It can be concluded that steel fibers proved to have higher structural efficiency than polypropylene fibers, when used in the tested specimens. The results from a test study incorporating post-tensioning at the steel bar to determine the potential influence of pre-stress on the bond between the profiled steel sheets and concrete presented [9]. Also, a three dimensional nonlinear finite element model of post-tensioned push specimens is presented. The results indicated that incorporating the effects of pre-stress produces satisfactory results for the overall bond stress–slip behavior of post-tensioned push test specimens. The aspects of a square shaped waffle slab calculation, supported punctually and having a two-way post tensioning reinforcement disposed parabolically is presented [8]. The samples tested to failure in a simply-supported configuration presented [4]. A design model also presented for the evaluation of the ultimate moment capacity by extending the applicability of procedures currently available for composite and pre-stressed floor slabs.

In this paper, a numerical model for discretized the two-way reinforced concrete flat slab with different system (with and without PT-system is investigated). Opening in the slab is taken in the field strip position to demonstrate the effect of opening in the analysis of flat slab with and without PT system. Tendons are proposed based on the finite-element method, which can represent the interaction between the tendon and concrete. Results were thoroughly investigated and conclusions were driven concerning the enhancements resulting for the addition of PT system. Parameters investigated included P/A value, thickness of the flat slab, concrete strength and existence opening in the flat slab for different values of P/A as the main important design parameters affecting the system behavior.

## 2. Description of Analytical Model

The structural system consists of two-way concrete slabs (50×45m), supported by, columns and core system as shown in figure 1-a and finite element meshed as shown in figure 1-b. Also, the material properties are shown in table 1. The analysis uses the finite element method developed specifically for design of PT floor systems, namely RAM software. The structural model to be developed for each floor includes the entire concrete outline and its supports. The connections of the slab to the columns are to reflect the actual stiffness of the joints. The strain distribution across the depth of the member is linear, concrete is a homogeneous elastic material, and both concrete and steel behave elastically within the range of working stresses not-with-standing the small amount of creep which occurs in both materials under sustained loading.

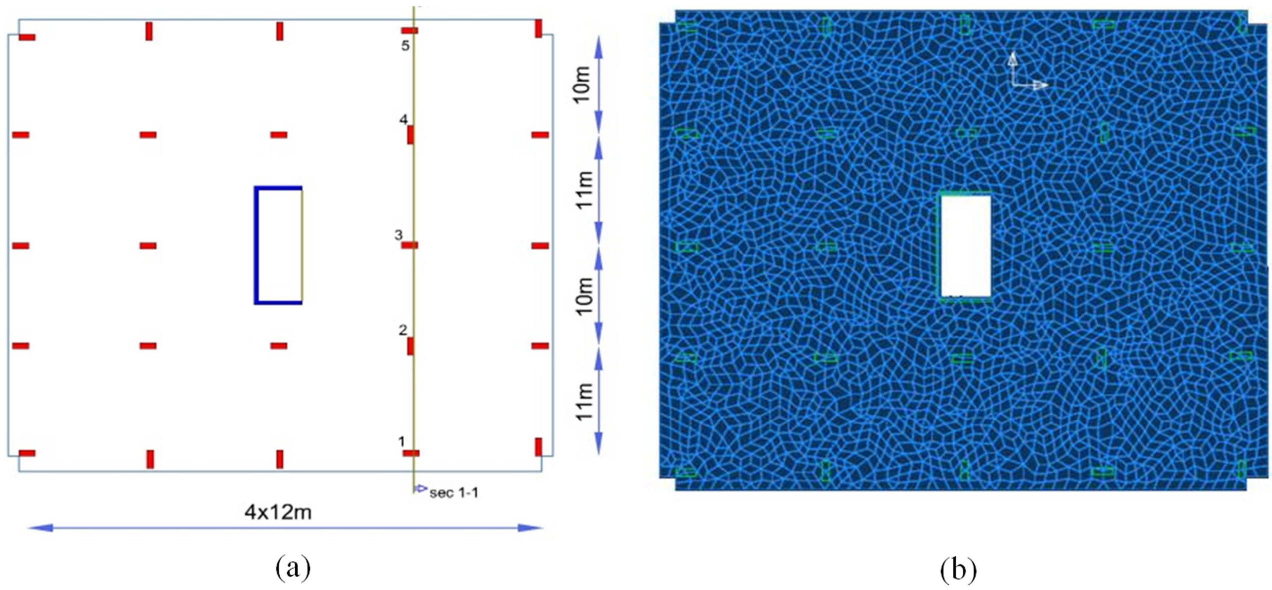



***Figure 1.*** *The Description of the flat slab a) statically system b) finite element generation element.*

## 3. Behavior of Flat Slab with and Without PT

This paper aims to compare between two systems for reinforced concrete flat slab (with and without PT) that allows solving the most common problems in flat slabs such as the deformation and cracks. This system is using anchorages by bonding between a high strength steel pre-stress tendon and the concrete, becoming a very effective method regarding ultimate and serviceability limit states. This method brings some advantages in relation to the traditional strengthening with pre-stress that are discussed in the following section. The flat slab with 320mm thickness and $f_{cu}$40MPa is studied in case of with and without PT system to clarify the effect of PT system. Figure 2 shows the distribution of the moment at the selected columns for sec 1-1 as shown in figure 1-a. The figure illustrates the benefits of the PT especially in the value of the bending moment along the flat slab which the PT system gives less value of moment along the sec1-1. The average decrease in the moment is about 57.5%. Also, the vertical deflection decreased in case of PT. The vertical deflection change from (137.8 to 30.16mm) in case of without and with PT respectively which average decreased by 78%. This can be simply attributed to the effect of PT system.

***Table 1.*** *Properties of flat slab model.*

| Material Properties | Value |
|---|---|
| Concrete strength($f_{cu}$) | 25&40MPa |
| Modulus of Elasticity for concrete($E_c$) | $4400\sqrt{f_{cu}}$ |
| Yield strength for steel ($f_y$) | 400MPa |
| Modulus of Elasticity for steel($E_s$) | 200000MPa |
| Strand diameter | 12.7mm |
| Modulus of Elasticity for PT($E_{PS}$) | 195000MPa |
| Yield strength of PT($f_{py}$) | 1674MPa |
| Post tension system | bonded |

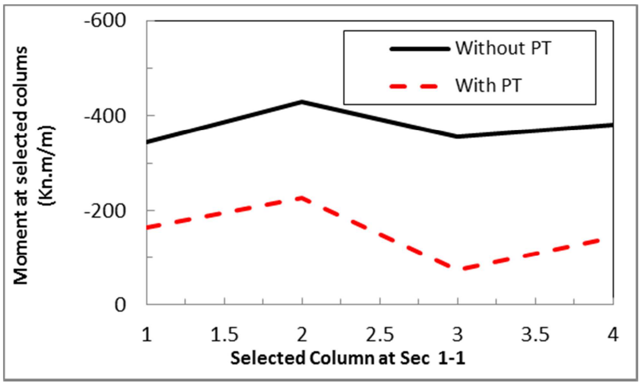



***Figure 2.*** *The Distribution of the Moment at the selected columns at sec1-1.*

## 4. Effect of Slab Stiffness

Thus, in this part, the effect of the slab stiffness is investigated by analyzing flat slab without PT and with PT which $f_{cu}$40MPa and P/A is equal to 1.5 Kn/m$^2$ for different thickness of flat slab 240, 260, 280 and 320 mm. Figure 3 demonstrated the effect of PT in the maximum vertical deflection for different slab thickness. In case of PT for all different thickness, the maximum vertical deflection decreased. For example in case of 240 and 320mm, the reduction in the vertical deflection is about 45% and 78% respectively. On the other hand (for both cases of with and without PT) by observing in this figure demonstrated that, the rate of decreasing vertical deflection is higher in case of small thickness (240 &260mm). But by increasing the thickness (280 &320mm), this rate is decreased which the figure show small effective of PT in these cases.

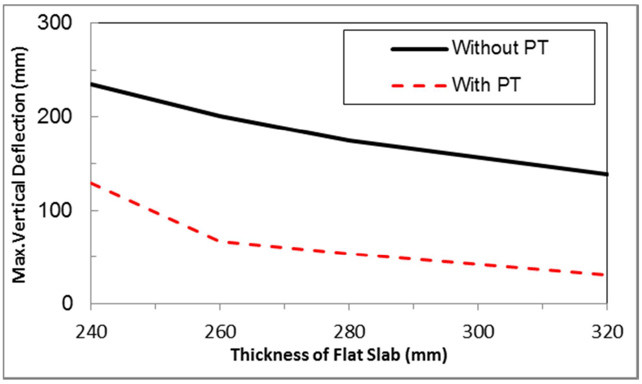



***Figure 3.*** *The Relation between the maximum vertical deflections against the flat slab thickness.*

## 5. Effect of Concrete Strength

One of the important parameters that are willing to affect the flat slab system behavior is to change the grade of concrete. Two values of compressive strength of concrete (25 and 40MPa) are considered to investigate their effect for two system of flat slab with and without PT which P/A take as 1.5 Kn/m$^2$. The relationship between maximum vertical deflections with different value of P/A ratio for two cases of concrete strengths is shown in figure 4.

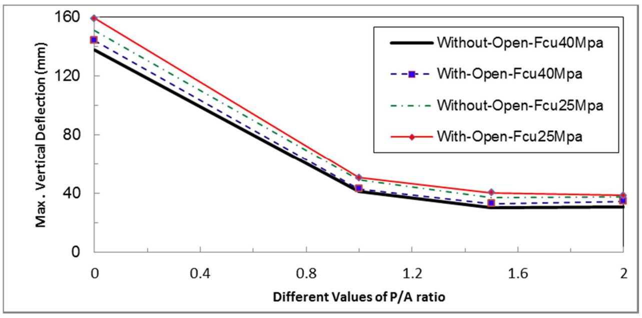



***Figure 4.*** *The relation between maximum vertical deflection with different value of P/A ratio .*

The results demonstrated that by increasing the value of the compressive strength of concrete, the overall stiffness of the slab increases which means more decrease in the vertical deflection in the slab. This is mainly due to the higher tensile strength and better PT behavior of flat slab. Also, this figure illustrated the effect of PT and change in the concrete strength is observed clearly in case of small thickness 240mm. On the other hand, the deflection can be attributed to the slight decrease in the amount of deflection in case of 320mm and PT slab when change the value of concrete strength from 25 to 40MPa due to stiffness of the slab is large enough.

## 6. Effect of PT Stiffness

In this section studied the stiffness of the PT by change the value of P/A. Three common values of the P/A (1, 1.5 and 2 Kn/m$^2$) are considered. Figure 5 shows more vertical deflection contours occurs in case of without PT system when compared with P/A equal to 2Kn/m$^2$. The same indication is shown in figure6 which illustrated this reduction in the deflection by using different value of P/A in case $f_{cu}$ 40MPa. For example, the reduction in the deflection from P/A equal 1 to 1.5Kn/m2 in case of thickness 260 mm are about 29.3%. The previous generally shows the higher efficiency of PT system in decreasing the deflections in the flat slab.

On the other hand, by observing the figure 6 it can be noted that the vertical deflection of slab in case of 320 mm thickness when increase the P/A from 1.5 to 2Kn/m$^2$ was nearly equal value. But it has led to an adverse effect as the arrangement in the moment at the selected columns which adverse the moment at column-3 in sec 1-1which located of this point represent in figure 1-a from negative value to positive value as shown in table2, where other point decreased the moment in it by increasing the value of P/A. Also, the change in the vertical deflection contour of flat slab by change the value of P/A in case of $f_{cu}$ 25MPa is shown in table3. These figures are shown in the table3 demonstrated the sec of the maximum vertical deflection contour which located at (16,-33) and (22,-33) from the center line of the slab as shown in figure 7-a . By observing in these figures demonstrated that by increasing the P/A in case of slab with 320 mm thickness, the deflection distribution is changed due to more stresses is occurred.

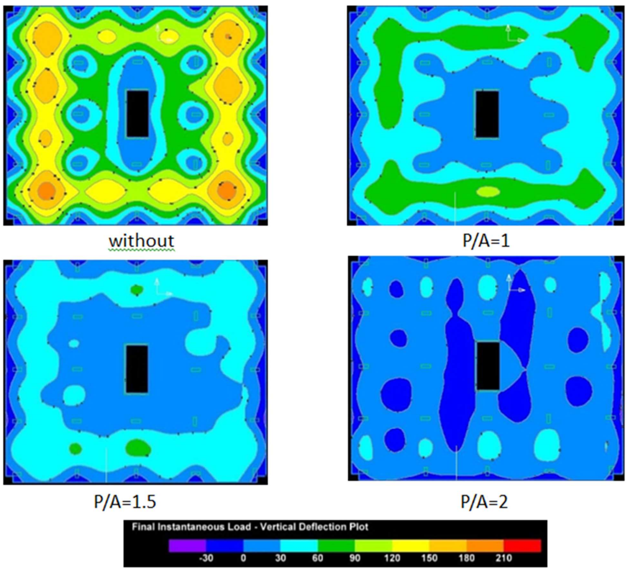



***Figure 5.*** *Vertical deflection contours with different value of P/A for thickness280mm and $f_{cu}$ 25MPa.*

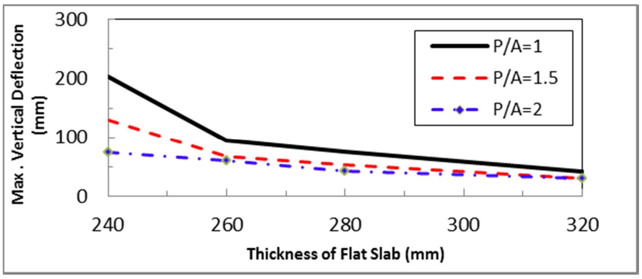



***Figure 6.*** *The Relation between the maximum vertical deflections against the flat slab thickness with different value of P / A for $f_{cu}$ 40 MPa.*

# 7. Flat Slab with and Without Opening

There are two types of openings that are commonly cut into existing slabs; small penetrations and large openings. Small penetrations are those that can be cut into a slab without affecting any of the existing PT tendons; conversely, large openings are those that require the cutting of existing tendons. In this study 8-large openings are taken in the flat slab in the field strip with dimension 2×2m as shown in figure 7 for different concrete stiffness. The figure 7 shows the location of theses opening and figure 7-a and figure 7-b show the location of latitude PT. Figure 8 shows the relation between the maximum vertical deflection in the flat slab with and without opening and different values of P/A in two cases of concrete strength ($f_{cu}$ 25 and 40 MPa) for thickness 320mm. This figure demonstrated that, in case of without PT, the maximum vertical deflection increases by decreasing the stiffness of the slab especially in case of $f_{cu}$ 25MPa with opening. Also, the best value of P/A is equal to 1.5 in the most cases of studied which decreased the vertical deflection in the flat by compared to another ratio of P/A.

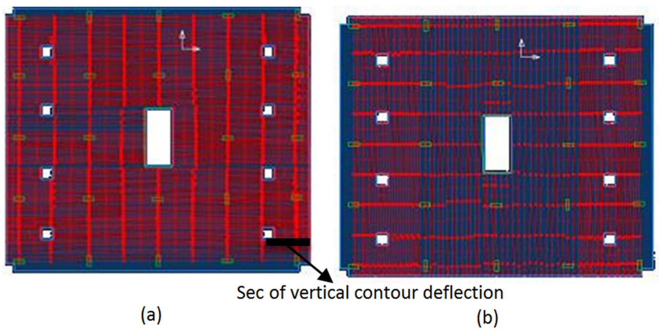


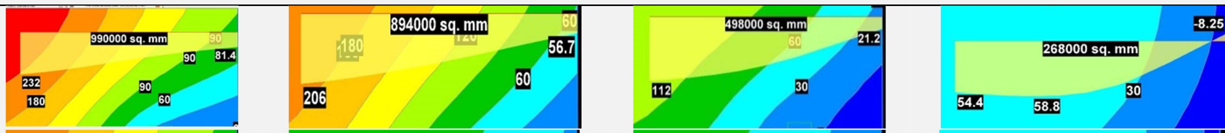
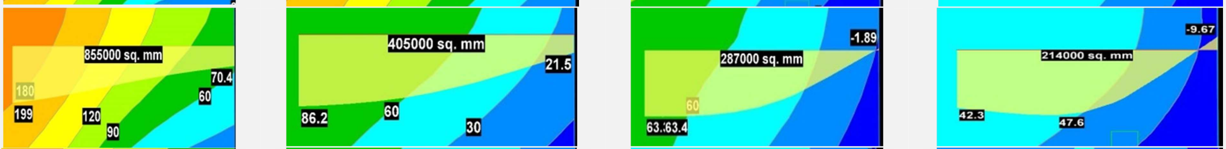
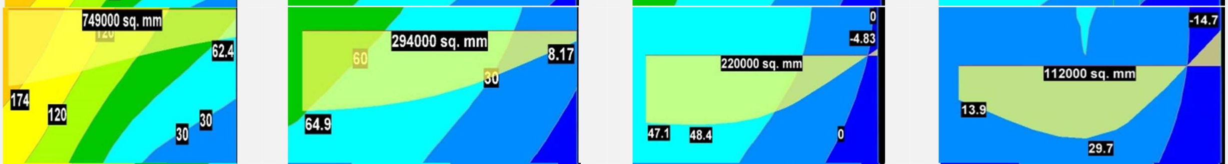
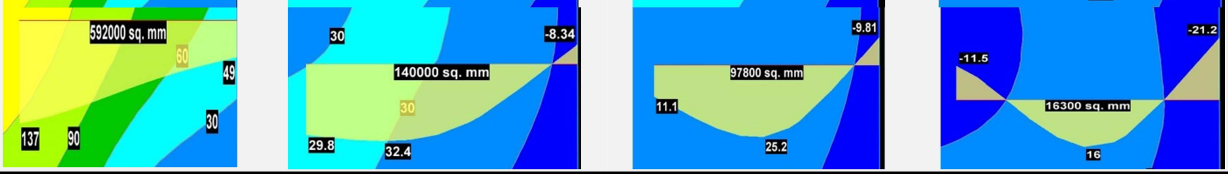

***Figure 7.*** *Location of latitude PT in X and Y-direction.*

***Table 2.*** *Value of Moment (KN.m/m) at sec1-1 for $f_{cu}$ 40MPa with different slab thicknesses.*

| Case | Column | $t_s$=240mm | $t_s$ =260mm | $t_s$=280mm | $t_s$=320mm |
|---|---|---|---|---|---|
| Without PT | 1 | -300 | -311 | -322 | -344 |
| | 2 | -371 | -385 | -400 | -430 |
| | 3 | -304 | -317 | -330 | -356 |
| | 4 | -328 | -341 | -353 | -382 |
| | 5 | -307 | -318 | -329 | -350 |
| P/A=1 | 1 | -273 | -249 | -246 | -206 |
| | 2 | -314 | -289 | -296 | -267 |
| | 3 | -202 | -170 | -169 | -120 |
| | 4 | -256 | -227 | -229 | -188 |
| | 5 | -331 | -301 | -289 | -236 |

| Case | Column | $t_s$=240mm | $t_s$ =260mm | $t_s$=280mm | $t_s$=320mm |
|---|---|---|---|---|---|
| P/A=1.5 | 1 | -245 | -219 | -211 | -165 |
| | 2 | -284 | -256 | -260 | -226 |
| | 3 | -173 | -137 | -132 | -72.2 |
| | 4 | -225 | -192 | -191 | -142 |
| | 5 | -296 | -266 | -249 | -190 |
| P/A=2 | 1 | -189 | -189 | -142 | -83.7 |
| | 2 | -224 | -224 | -189 | -143 |
| | 3 | -120 | -105 | -58.3 | 21.2 |
| | 4 | -164 | -157 | -114 | -49.8 |
| | 5 | -227 | -230 | -168 | -98 |

***Table 3.*** *Vertical deflection contour at chosen section with different value of P/A.*

| $t_s$mm | Without PT | P/A=1Kn/m$^2$ | P/A=1.5Kn/m$^2$ | P/A=2Kn/m$^2$ |
|---|---|---|---|---|
| 240 |  | | | |
| 260 |  | | | |
| 280 |  | | | |
| 320 |  | | | |

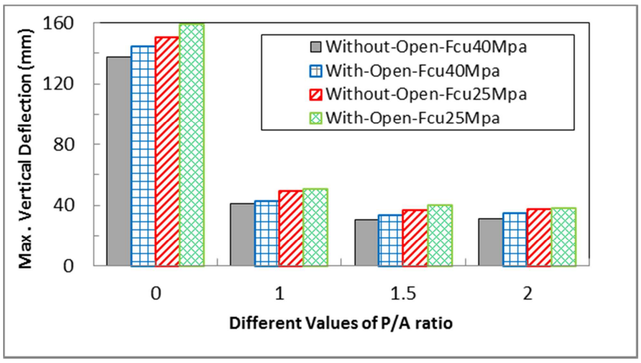



***Figure 8.*** *The Relation between the maximum vertical deflection for with and without opening against the different values of P/A in case of $f_{cu}$40 and 25MPa.*

# 8. Summary and Conclusions

The use of post tension in the flat slab for improving the role of the flat slab is increased nowadays due to the large spans are used in the flat slab which need much steel reinforced to save the deflection in the slab. The present study investigated the effects of important design parameters on the behavior of flat slab. The analysis uses the finite element method developed specifically for design of post-tensioned floor systems, namely RAM software. The main findings of the study are as follows:

1. PT system decreased the maximum vertical deflection such that for case of 240 and 320mm, the reduction is about 45% and 78% respectively.
2. Also, the rate of decreasing vertical deflection is higher in case of small thickness (240 &260mm). But by increasing the thickness (280 &320mm), this rate is decreased which show small effective of PT in these cases.
3. In case of PT system, for the thickness 320mm, no change observed by increasing the compressive strength of concrete from 25MPa to 40 MPa.
4. By increasing the P/A in case of slab with 320 mm thickness, the deflection distribution is changed due to more stresses is occurred.
5. P/A ratio has more effective in case of small thickness. The reduction in the deflection is about 29.3% when change the ratio of P/A from 1 to 1.5 kn/m$^2$ in case of thickness 260mm.
6. For the slab thickness with 320mm no change in the vertical deflection can be observed when increase the P/A from 1.5 to 2kn/m$^2$.
7. On the other hand, it has led to an adverse effect as the arrangement in the moment at the selected columns which adverse the moment at column 3 in sec 1-1 from

negative value to positive value, where other point decreased the moment in it by increasing the value of P/A.

8. It is often necessary to create openings in existing concrete slabs. The stiffness of the flat slab decreases with opening especially in case of $f_{cu}$25MPa. So, PT in case of opening slab is good method to solve the deflection in it. And the best value of P/A in this study is equal to 1.5 $Kn/m^2$, in case of $f_{cu}$40 MPa, by compared to another cases.

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