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THE EFFECT OF POST-TENSIONED FLAT PLATES ON SEISMIC BEHAVIOR OF CONCRETE STRUCTURES

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ABSTRACT

Due to rapid population growth and limited construction space, high-rise buildings have been commonly used to overcome this problem. Post-tensioned flat slabs are widely utilised in this type of structures majorly, because of their light weight and low floor height. These buildings must effectively resist lateral loads which are more critical in this case. Therefore, this paper aims to analyse and compare the seismic behavior of post-tensioned flat plate buildings with that of conventional flat plate buildings. Time period, story drifts, and frames' moments and forces are studied and their results are compared. Response spectrum method is employed in the analysis. The results indicated that the post-tensioning system is more effective than the conventional concrete system.

KEYWORDs: Flat plate; Post tension; Time period; Story drift; Response spectrum.

1. INTRODUCTION

Traditionally, structures were built using ordinary reinforced concrete. However, in recent decades, numerous high-rise buildings were done by post-tensioning. Post-tensioned flat slabs provide beneficial advantages over reinforced concrete slabs in terms of their ability to reduce cracks, deflection, and construction time, as well as decrease the overall weight of the structure. "Although prestressed concrete has many benefits, it requires more attention to specific design considerations that are not usually considered in construction of ordinary reinforced concrete" (Ghoneim, M. and El Mihilmy, M., 2008) [5]. Therefore, knowing and analysing their performance under lateral forces is a matter of concern.

In a recent study by Satwika, V. and Jaiswal, M. (2022) [14], the effect of drop panels, prestressed system, and tendons layout (banded and distributed) on the behavior of flat slabs was investigated. ETABS software was used to compare RCC flat slab and post-tensioned flat slab. The results indicate that "depth can be safely reduced by the provision of drops" and " banded tendons are more effective in improving punching shear capacity of flat slab". In terms of supports reactions, punching shear, and deflection, the overall study shows that "post-tensioned flat slab may be a better option than flat slab".

Rath, S. R., Sethy, S. K. and Dubey, M. K. (2019) [13] did a comparison between post-tensioned flat slab and conventional slab using SAFE software. The results were obtained from the analysis included different parameters such as slab forces, slab displacements, and reinforcement quantity. The study showed that post-tensioned flat slab exposed lesser forces than the normal conventional slab. Also, normal flat slab displacements were larger than that ones in post-tensioned flat slab. "It was clearly

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concluded that post-tensioned flat slab is better than conventional for many reasons".

In a research submitted by Vijaykumar, D. S. and Jawalkar, G. C. (2019) [15], a comparison between RC flat slabs and post-tensioned flat slabs was carried out. This study considered different parameters including slab displacement, strip bending moments, and shear forces. The results showed that "maximum bending moment values decrease for Post-tensioned flat slab. As well as, maximum shear forces and displacement values are considerably less in PT flat slab as compared to RC flat slab".

Abd-El-Mottaleb, H. E. and Mohamed, H. A. (2019) [1] conducted analytical research on the behavior of post-tensioned flat slabs considering different thicknesses, different values of concrete compressive strength, and slab stiffness. They observed that increasing the compressive strength of concrete enhances the overall stiffness, which leads to a decrease in the vertical deflection of the slab. Moreover, "the rate of decreasing vertical deflection is higher in case of small thickness".

Kumar, A. and Dr. Borghate, S. B. (2018) [9] presented several seismic models to evaluate story shear and story drift in different types of slabs. Their study included an uncracked flat plate, a cracked flat plate, an uncracked flat slab with drops, and a cracked flat slab with drops. The research revealed that story shear in prestressed flat slab buildings is greater than that in prestressed flat plat buildings. As well, uncracked sections exhibited higher story shear compared to cracked sections. Moreover, cracked sections displayed more story drifts than uncracked sections.

An attempt was made by Koti, A. I. and Vanakudre, S. B. (2018) [8] to study "parameters such as moments, stresses, and time period of post-tensioned flat slab with drop under seismic for Equivalent Frame method and strip base method". The research exhibited that "post-tensioned slab with drop helps to reduce the stress in the slab and the moment calculated for post-tensioned flat plate is less when compare to moment calculated for RC flat plate".

Jnanesh Reddy, R. K. and Pradeep, A. R. (2017) [7] conducted an analytical study to compare the cost of a normal flat slab system with the cost of a post-tensioned flat slab system. The study showed that the needed concrete and steel are lesser in case of the post-tensioned flat slab system. Therefore "it is more economical to construct with PT slab than with the RCC flat slab".

In a study submitted by Imran, M., Visweswara, M. and Ashok, J. (2017) [6], a comparison between normal flat slab and post-tensioned flat slab was accomplished. This research used "various types of buildings with G+9, G+11, G+14, G+19, and G+24 stories". Authors evaluated bending moments of the slabs, lateral displacements, maximum displacements of shear walls, and story drifts of the studied buildings. In general, they found that "post-tensioned flat slab is more effective under seismic loading compared to flat slab".

In summary, these studies provided valuable insights into the advantages of post-tensioned flat slabs, emphasising their superior performance in punching shear and deflection reduction. However, the researches did not give any idea about the effect of tendons on lateral forces and moments that transmitted to the columns. Thus, this paper shows a comparative study of post-tensioned flat plate buildings and conventional flat plate buildings under seismic forces. Parameters investigated included time period, story drifts, and frames' moments and forces. The outcomes of this study will contribute to comprehend the seismic performance of post-tensioning system.

2. MATERIAL AND METHODS

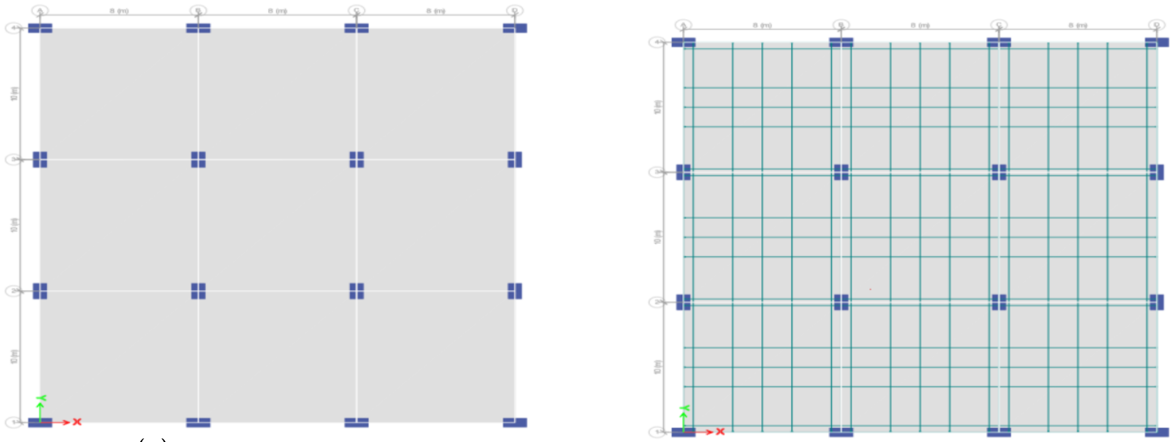
In this section, a brief description of the samples is presented. The study includes six different models:

1- Five-story flat plate building.
2- Eight-story flat plate building.
3- Twelve-story flat plate building.
4- Five-story post-tensioned flat plate building.
5- Eight-story post-tensioned flat plate building.
6- Twelve-story post-tensioned flat plate building.

All the previous buildings have a typical story with a symmetrical plan as shown in Figure 1.

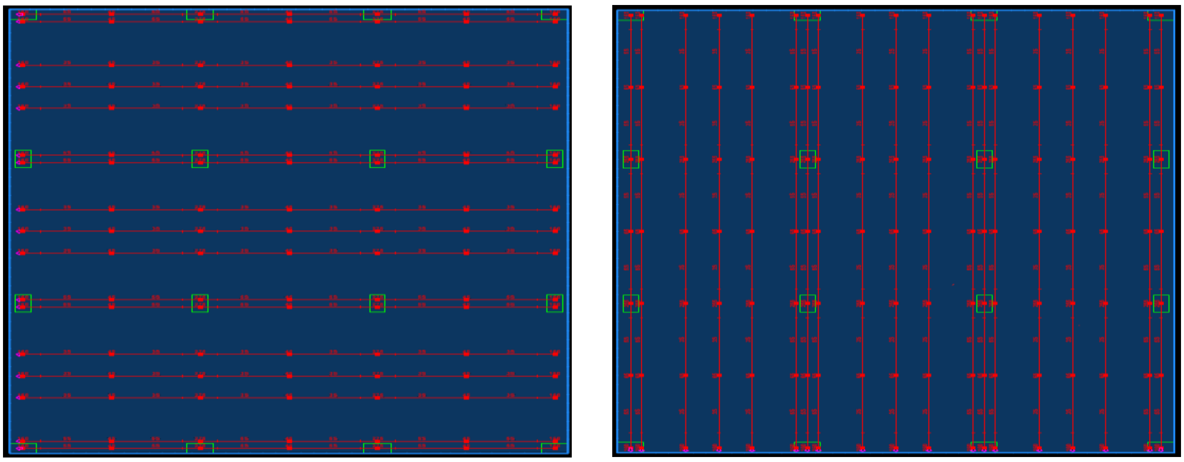
Post-tensioned flat plates were designed by RAM CONCEPT software using bonded tendons for strengthening in both directions (X&Y) (Figure 2). Banded arrangement was adopted for tendons in column strips, while distributed arrangement was used for tendons in field strips. Furthermore, every tendon in column strips consisted of five strands, while in field strips consisted of three strands.

The structures were modeled by ETABS (2020) software and designed as per ACI 318-19 [2]. They utilise two-way moment frames as a lateral resisting system, which are connected by a rigid diaphragm. Theses frames were studied and designed using ultimate and service load combinations as per ASCE 7-16 [3]. To compare seismic behavior of flat plate buildings and post-tensioned flat plate buildings, linear dynamic analysis was conducted. The seismic analysis was carried out by the response spectrum method. More details of the buildings are given in Table 1.



(a) (b)

Fig. (1):- Buildings plan (a) flat plate plan; (b) post-tensioned flat plate plan



(a) (b)

Fig.(2):- Tendons plan (a) X direction plan; (b) Y direction plan

Table(1):- Properties of the buildings selected for the study

Structural Details	
Span in X direction (m)	8
Span in Y direction (m)	10
Story height (m)	3
Live load (kN/m^2)	3
Super imposed dead load (kN/m^2)	2
Slab thickness (cm)	32
Concrete Compressive strength (f`c) (MPa)	40
Rebar yield strength (fy) (MPa)	400
Tendon tensile strength (fpu) (MPa)	1860
Strand diameter (mm)	12.7
Importance factor (I)	1
Seismic design category (SDC)	D

3. RESULTS

1- Time period:

Time periods for the models are shown below:

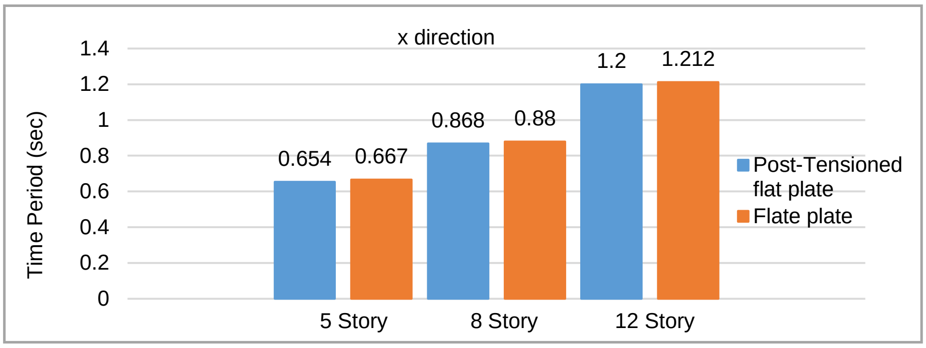


Fig. (3):- Time period in x direction

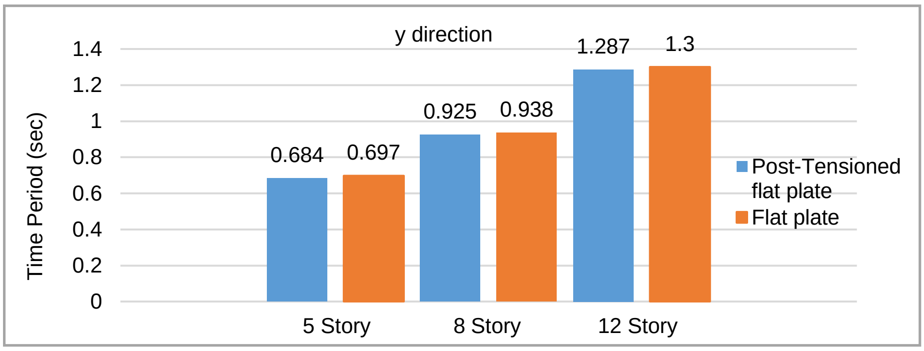


Fig. (4):- Time period in y direction

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2- Story drift:

Story drifts for the studied buildings are given below:

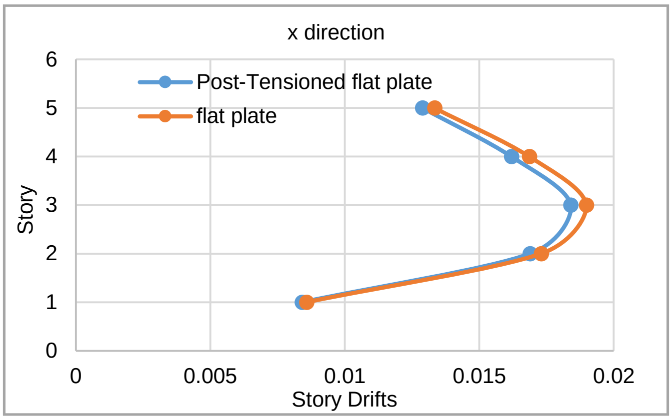

Fig.(5):- Story drifts in the five-story building (x direction)

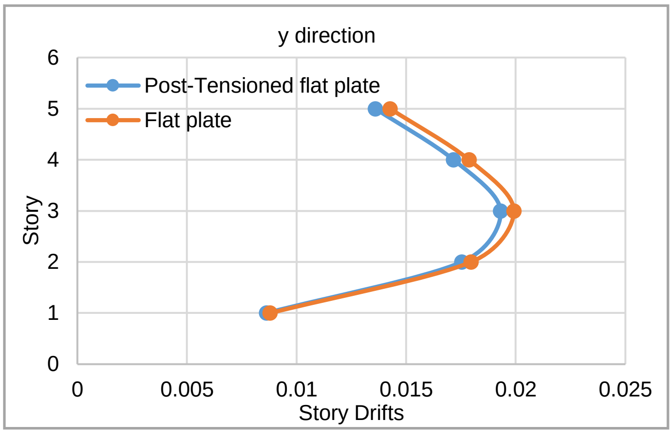

Fig.(6):- Story drifts in the five-story building (y direction)

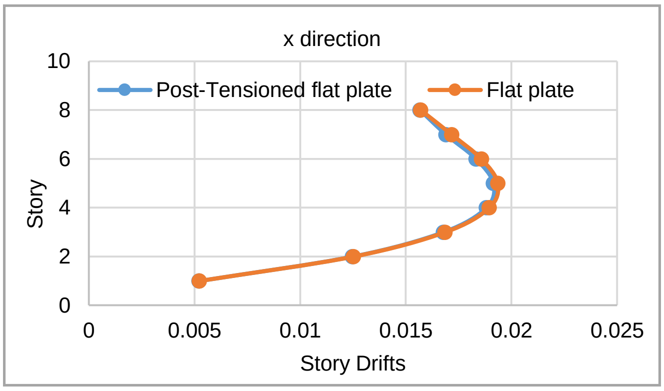

Fig.(7):- Story drifts in the eight-story building (x direction)

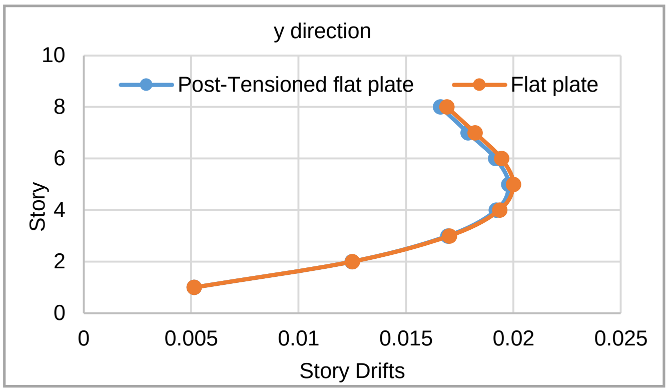

Fig.(8):- Story drifts in the eight-story building (y direction)

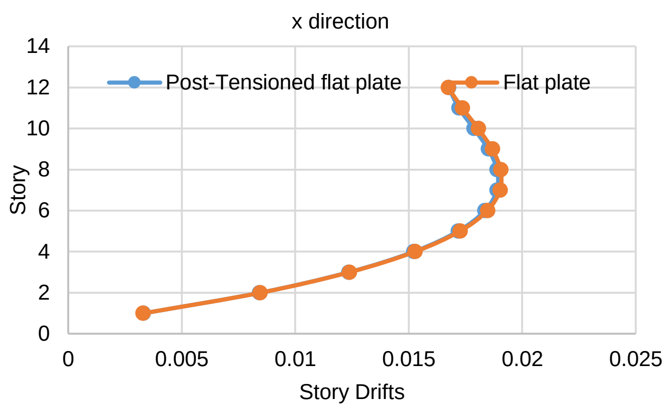

Fig.(9):- Story drifts in the twelve-story building (x direction)

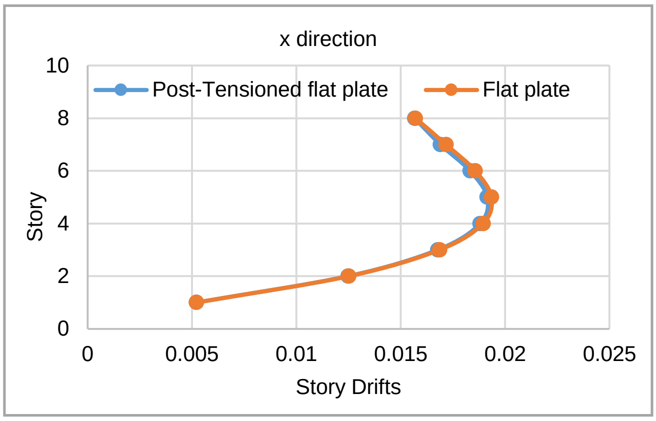

Fig. (10):- Story drifts in the twelve-story building (y direction)

3- Frames' moments and forces:

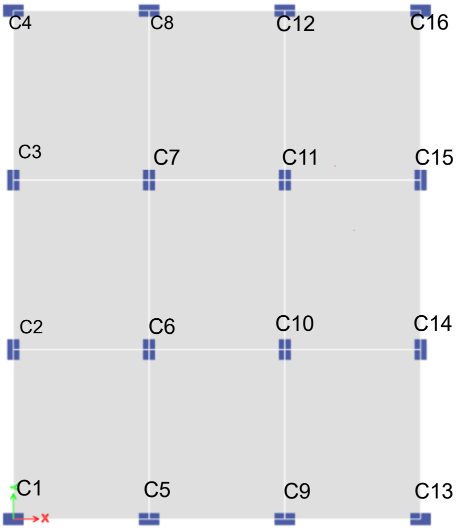

Fig. (11):- Columns labels

Table (2):- Forces and moments of ground columns resulting from the load case (PT-FINAL) in the five-story building

Column	Output Case	P	V2	V3	M2	M3
		kN	kN	kN	kN-m	kN-m
C1	PT-FINAL	104.9662	171.094	121.7888	201.7968	302.5578
C2	PT-FINAL	8.759	70.4791	73.4319	132.7597	102.2338
C3	PT-FINAL	12.4392	70.6697	-76.8455	-139.398	102.666
C4	PT-FINAL	103.5813	172.5073	-118.109	-196.164	305.5567
C5	PT-FINAL	6.6259	44.9159	138.1371	219.3041	80.085
C6	PT-FINAL	-126.389	17.4643	84.8938	151.0458	27.3791
C7	PT-FINAL	-120.609	17.5604	-88.849	-158.348	27.5411
C8	PT-FINAL	4.6425	45.4562	-134.447	-214.179	81.1304
C9	PT-FINAL	11.7908	-49.7778	138.1487	219.3733	-91.0122
C10	PT-FINAL	-121.67	-19.9796	84.9221	151.0857	-32.0545
C11	PT-FINAL	-115.888	-20.0751	-88.8776	-158.386	-32.2175
C12	PT-FINAL	9.8037	-50.3181	-134.459	-214.247	-92.0677
C13	PT-FINAL	102.5184	-165.366	122.7064	203.5807	-295.233
C14	PT-FINAL	7.3028	-68.8289	73.9676	133.8361	-101.204
C15	PT-FINAL	10.9841	-69.0204	-77.3894	-140.472	-101.638
C16	PT-FINAL	101.1424	-166.781	-119.019	-197.942	-298.238

Table (3):- Forces and moments of ground columns resulting from the load combination (0.9D + 1E) in the five-story post-tensioned flat plate building

Column	P	V2	V3	M2	M3
	kN	kN	kN	kN-m	kN-m
C1	-43.4606	1323.777	118.7334	216.2747	5510.418
C2	-394.266	686.325	97.2255	168.9117	2171.698
C5	-1830.35	1366.892	64.6867	157.0505	5453.942
C6	-3757.9	867.4822	92.1814	157.6642	2305.794

Table (4):- Forces and moments of ground columns resulting from the load combination (0.9D + 1E) in the five-story flat plate building

Column	P	V2	V3	M2	M3
	kN	kN	kN	kN-m	kN-m
C1	-175.572	1183.532	-27.7107	-25.5355	5337.571
C2	-416.974	583.8635	5.5263	4.3409	2044.842
C5	-1874.52	1324.914	-77.1931	-71.1328	5447.159
C6	-3711.45	844.2428	9.2436	7.2594	2285.415

Table (5):- Forces and moments of ground columns resulting from the load combination (0.9D + 1E) in the eight-story post-tensioned flat plate building

Column	P	V2	V3	M2	M3
	kN	kN	kN	kN-m	kN-m
C1	-304.872	2582.689	325.4968	671.8747	19005.16
C2	-416.306	1038.749	244.8685	541.5334	5442.734
C5	-3503.61	2429.969	278.795	609.1446	18520.12
C6	-6751.52	1156.457	247.8712	524.9941	5451.214

Table (6):- Forces and moments of ground columns resulting from the load combination (0.9D + 1E) in the eight-story flat plate building

Column	P	V2	V3	M2	M3
	kN	kN	kN	kN-m	kN-m
C1	-566.199	2187.048	-31.7676	-21.7676	18176.78
C2	-528.458	804.3386	23.655	34.7906	5018.101
C5	-3580.77	2290.657	-77.5526	-58.6444	18214.79
C6	-6659.11	1041.365	27.028	36.007	5218.998

4. DISCUSSION

The observations made from the above results are as follows:

In figures (3-4) it is observed that time periods; in both directions; in post-tensioned flat plate buildings are about 1% to 2% shorter than flat plate buildings. The reduction in time period attributes to the high stiffness of post-tensioned flat plates, noting that this reduction is constant regardless of stories number.

Based on figures (5-6-7-8-9-10), flat plate buildings exhibit greater story drifts than post-tensioned flat plate buildings. In case of five-story building, the story drifts in post-tensioned flat plate buildings are 2% to 5% lower than flat plate ones. While in eight-story building the reduction is less than 2%. However, this ratio becomes less than 1.3% in case of twelve-story building. It is evident that as the number of stories increases, the reduction in story drifts decreases.

When utilising post-tensioning system in slabs, these slabs will be subjected to axial compressive forces, which will be transmitted to columns in form of axial forces, shear forces, and flexural moments, as shown in the table 2. Post-tensioning forces generate axial tensile forces in peripheral columns, while inner columns experience axial compressive forces. Furthermore, post-tensioning forces cause additional moments on the columns in both directions (x & y).

Referring to tables (3-4-5-6), it can be observed that shear forces and flexural moments in columns of post-tensioned flat plate buildings exceed those in conventional flat plate buildings. Moreover, as the number of stories increases, the impact of the post-tensioning system on columns becomes more pronounced. It is obtained that the post-tensioning system significantly affects the design of columns.

5. CONCLUSIONS

The use of post-tensioning system in flat slabs is increasing nowadays. Consequently, analysing their behavior during an earthquake is crucial. This study aimed to seismically compare the behavior of flat plate buildings and the behavior of post-tensioned flat plate buildings. Different parameters investigated such as time period, story drifts, and frames' moments and forces.

The main findings of the study are as follows:

- Post-tensioning system reduces time period.
- Flat plate buildings exhibit greater story drifts compared to post-tensioned flat plate buildings.
- When increasing the number of stories, the reduction in story drifts becomes less pronounced.
- Post-tensioning forces cause axial tensile forces in peripheral columns.
- Inner columns experience axial compressive forces due to post-tensioning forces.
- Post-tensioning forces cause additional moments on columns in both directions (x & y).
- Shear forces and flexural moments in columns of post-tensioned flat plate buildings surpass those in conventional flat plate buildings.
- The impact of the post-tensioning system on columns becomes more significant as the number of stories increases.

In conclusion, post-tensioning system increases the stiffness of the structure which improves its the seismic behavior.

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