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Design of Post-tensioned Slab and Its Behavior with Opening

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Abstract

We live in a fast-paced world where every aspect of life has evolved. In this technological era, the need for change is constant. Many consumer goods have been adapted to fit the new circumstances. Post-tensioned slabs are the evolution in the field of design which got enhanced due to need of today's world and in this requirement of architects or customers are also increased by creating opening in slabs which has column to column support greater than 10 m. In this case we have to do post-tensioning with opening. Post-tension slab is more suitable for more than 10 m column supports, with less depth requirement and also with less percentage of steel requirement. Due to opening in slab, it is important to check the behavior of post-tensioned slab that the opening is favorable to it or not. This project involves the use of computer program to perform analysis of post-tensioned slab structure. ETABS 17.0.1 is used to perform analysis and design of post-tensioned slab. Slabs with no opening and with different opening were studied by using this software. In this project, mainly four models were modeled in which one model is of no-opening slab and remaining three are of different opening slabs using same materials and sections. Then comparison is done by using analysis and design results and then observing the displacement, story drift, stiffness, stresses, and reinforcement details.

Keywords: Post-tensioned slab, opening, story drift, story displacement, ETABS 17

INTRODUCTION

An increase in an urban population has led to an increase in demand for habitable space. This has inevitably created a demand for efficient floor systems. The post-tensioning method is increasingly popular today due to its broad range of applications. By employing post-tensioning, designers can create both economical and safe designs. The need for large, column-free areas has driven the use of post-tensioned (PT) slab systems, which are typically selected for their cost-effectiveness and ability to handle imposed loads while meeting serviceability limits [1–3].

PT concrete has been utilized for over 40 years in various construction projects, and it is now also used in India. Post-tensioning, which was originally utilized mainly in bridge construction, has expanded its application to include tanks, office buildings, hotels, parking structures, pavements, masonry, seismic walls, single-family homes, and more. This technique allows for the design of various structural forms, such as two-way spanning flat slabs, one-way spanning ribbed slabs, and banded beam and slab constructions. Flat slabs are supported by columns, with or without column heads, and can be solid or feature hollow forms in the soffit to create a series of ribs running in two directions (waffle or coffered slabs) [4–6].

The design principles for continuous flat slab floors are similar to those for two-way reinforced concrete slabs. A strip of the slab with unit width,

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continuous over supports, is analyzed as a continuous beam. Prestressing this continuous slab results in secondary moments. If cable profile is concordant, secondary moments can be eliminated [7].

Number of continuous flat slab have been built in which unbounded tendons are to be preferred both from the point of view of ultimate strength requirements and easy maintenance under adverse exposure conditions. The design of a continuous flat slab floors involves the computation of maximum and minimum moments for various load combinations and also the determination of suitable cable profiles so that the resulting stresses in the concrete are within the safe allowable limits as per codes [8, 9].

Shear stresses at the junction of column and slab should be carefully controlled by proper design and detailing of the critical shear zones. In India, the initial cost of the slab system in a typical conventional building is 25% of the total cost of building. This cost increases with span. Also, in terms of safety, the slab failure can create progressive collapse due to debris loading [10].

Therefore, it is essential to study slab systems for their relative safety and cost-effectiveness. PT slabs help reduce tensile stresses and cracks in the structure. They have proven to be more economical and effective compared to traditional reinforced cement concrete (RCC) beam-slab and RCC flat slab systems [11].

Post-tensioning involves applying tension to the reinforcement after the concrete has been poured and set. This method helps overcome the challenges of fixing the required tendon profiles in pre-tensioning. In post-tensioning, ducts are positioned according to the specified tendon profile and secured to the reinforcement framework. Highly workable concrete is then cast around the ducts. There are two methods for laying the tendons: They can be placed in the ducts before casting the concrete, or threaded through the ducts after the concrete has been cast. Typically, one end of the tendon is anchored in the concrete, while the other end is secured by an external anchorage system after stressing. Hydraulic jacks are used to apply stress once the concrete reaches its necessary strength. The prestressing force is then transferred to the concrete through the anchorage points [12–14].

Aim and Objectives

The specific objectives of the research are:

- To study the RCC and PT slab for different structural results.
- To determine the structural parameters for different opening PT slabs like displacement, drift, stiffness.
- To compare the reinforcement for different openings in given PT slabs (Figures 1 and 2) [15].

MODELING METHODOLOGY

Modeling Data

Model with no Openings PT Slab

Section Properties

Column-1000 × 1000 mm slab – 350 mm

Drop Panel Length = 5.8 m

Depth = 450 mm

Tendon (Standard as per IS06934-1991) 12.7 mm (diameter)

Strand Area = 99 mm^2

Tensile Strength = 1860 N/mm^2

Material Properties

Grade of concrete-M35

Grade of reinforcement-Fe 500 MPa, Fe 415 MPa

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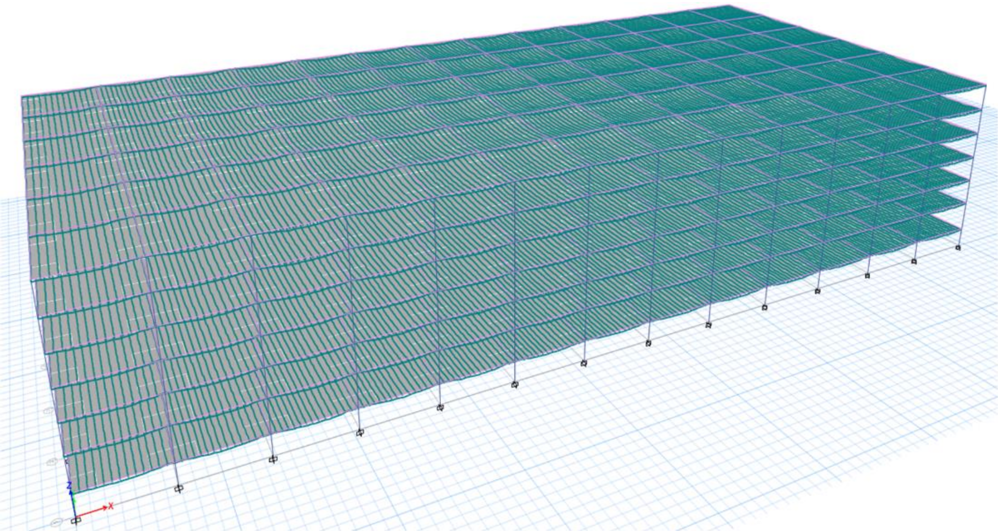

Figure 1. Three-dimensional (3D) model of post-tensioned slab (PT) with no opening.

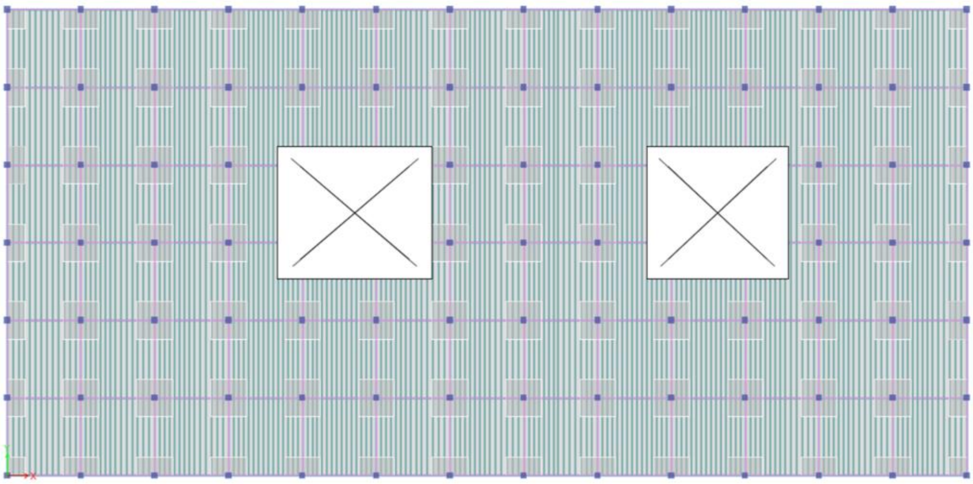

Figure 2. Model plan of post-tensioned (PT) slab with 9.18% openings.

Model with 9.18% Opening PT Slab Section Properties

Section Properties

Beam 300 × 500 mm; Column 1000 × 1000 mm; Slab 350 mm

Opening size – 9.18% (2 numbers of 25.15 × 20.5 m).

Drop Panel Length = 5.8 m

Depth = 450 mm

Tendon (Standard as per IS06934-1991) 12.7 mm (diameter)

Strand Area = 99 mm^2

Tensile Strength = 1860 N/mm^2

Material Properties

Grade of concrete M35

Grade of reinforcement Fe 500 MPa, Fe 415 MPa

RESULTS AND DISSCUSSION

Displacement

The displacement (Δ) at the story level can be understood as the movement of a particular point in applied ground motion direction from its center of gravity.

For non-opening PT slab, details are shown in Table 1.

Table 1. Maximum story displacement for non-opening post-tensioned (PT) slab.

Story	Load Case	Maximum	Minimum	Ratio
		mm	mm	
Story5	Dead	0.321	0.000212	1514.774
Story4	Dead	0.53	0.0001809	2929.257
Story3	Dead	0.487	0.0001439	3385.613
Story2	Dead	0.484	0.0001075	4507.372
Story1	Dead	0.488	0.00007199	6781.476
Plaza	Dead	0.493	0.00003913	12606.379
Basement	Dead	0.305	0.000007829	38915.269
Story5	Live	0.169	0.0001311	1286.909
Story4	Live	0.262	0.0001117	2349.308
Story3	Live	0.243	0.00008883	2735.557
Story2	Live	0.242	0.00006632	3646.988
Story1	Live	0.244	0.00004442	5489.546
Plaza	Live	0.246	0.00002415	10185.831
Basement	Live	0.153	0.000004825	31676.341
Story5	PT-FINAL	12.965	7.757	1.671
Story4	PT-FINAL	11.657	6.302	1.85
Story3	PT-FINAL	10.231	4.899	2.088
Story2	PT-FINAL	8.858	3.517	2.518
Story1	PT-FINAL	7.599	2.193	3.465
Plaza	PT-FINAL	6.376	1.019	6.258
Basement	PT-FINAL	3.364	0.152	22.171
Story5	PT-TRANSFER	13.962	8.354	1.671
Story4	PT-TRANSFER	12.553	6.786	1.85
Story3	PT-TRANSFER	11.018	5.276	2.088
Story2	PT-TRANSFER	9.539	3.788	2.518
Story1	PT-TRANSFER	8.183	2.362	3.465
Plaza	PT-TRANSFER	6.866	1.097	6.258
Basement	PT-TRANSFER	3.623	0.163	22.171
Story5	EQ x	24.937	24.909	1.001
Story4	EQ x	22.585	22.577	1
Story3	EQ x	19.325	19.316	1
Story2	EQ x	15.247	15.233	1.001
Story1	EQ x	10.658	10.646	1.001
Plaza	EQ x	5.973	5.962	1.002
Basement	EQ x	1.216	1.21	1.005
Story5	EQ y	24.925	24.882	1.002
Story4	EQ y	22.557	22.548	1
Story3	EQ y	19.299	19.289	1.001
Story2	EQ y	15.223	15.211	1.001
Story1	EQ y	10.645	10.629	1.001
Plaza	EQ y	5.98	5.953	1.004

Story	Load Case	Maximum	Minimum	Ratio
Basement	EQ y	1.221	1.209	1.01
Story5	Wind x	3.231	3.147	1.027
Story4	Wind x	3.06	2.97	1.03
Story3	Wind x	2.762	2.676	1.032
Story2	Wind x	2.312	2.237	1.034
Story1	Wind x	1.725	1.663	1.038
Plaza	Wind x	1.034	0.987	1.048
Basement	Wind x	0.23	0.214	1.072
Story5	Wind y	3.231	3.147	1.027
Story4	Wind y	3.06	2.97	1.03
Story3	Wind y	2.762	2.676	1.032
Story2	Wind y	2.312	2.237	1.034
Story1	Wind y	1.725	1.663	1.038
Plaza	Wind y	1.034	0.987	1.048
Basement	Wind y	0.23	0.214	1.072

For 9.18% opening PT slab, details are shown in Table 2.

Table 2. Maximum story displacement for 9.18% opening post-tensioned (PT) slab.

Story	Load Case	Maximum	Minimum	Ratio
		mm	mm	
Story5	Dead	0.317	0.12	2.644
Story4	Dead	0.452	0.107	4.216
Story3	Dead	0.379	0.089	4.256
Story2	Dead	0.354	0.069	5.133
Story1	Dead	0.335	0.053	6.342
Plaza	Dead	0.324	0.034	9.652
Basement	Dead	0.222	0.007	30.866
Story5	Live	0.164	0.061	2.668
Story4	Live	0.224	0.055	4.049
Story3	Live	0.19	0.046	4.128
Story2	Live	0.177	0.036	4.993
Story1	Live	0.166	0.026	6.279
Plaza	Live	0.159	0.016	9.986
Basement	Live	0.111	0.004	30.164
Story5	PT-FINAL	6.114	1.007	6.071
Story4	PT-FINAL	6.024	0.961	6.267
Story3	PT-FINAL	5.966	0.907	6.579
Story2	PT-FINAL	5.927	0.839	7.061
Story1	PT-FINAL	5.859	0.746	7.852
Plaza	PT-FINAL	5.492	0.584	9.402
Basement	PT-FINAL	3.234	0.17	18.987
Story5	PT-TRANSFER	6.585	1.085	6.071
Story4	PT-TRANSFER	6.487	1.035	6.267
Story3	PT-TRANSFER	6.425	0.977	6.579
Story2	PT- TRANSFER	6.383	0.904	7.061
Story1	PT-TRANSFER	6.31	0.804	7.852
Plaza	PT-TRANSFER	5.915	0.629	9.402

Basement	PT-TRANSFER	3.483	0.183	18.987
Story5	EQ x	30.779	30.722	1.002
Story4	EQ x	22.419	22.372	1.002
Story3	EQ x	19.162	19.122	1.002
Story2	EQ x	15.1	15.061	1.003
Story1	EQ x	10.538	10.505	1.003
Plaza	EQ x	5.892	5.865	1.005
Basement	EQ x	1.197	1.187	1.008
Story5	EQ y	30.843	30.753	1.004
Story4	EQ y	22.457	22.384	1.003
Story3	EQ y	19.191	19.125	1.003
Story2	EQ y	15.121	15.06	1.004
Story1	EQ y	10.546	10.498	1.005
Plaza	EQ y	5.893	5.856	1.006
Basement	EQ y	1.199	1.185	1.011
Story5	Wind x	4.243	4.073	1.057
Story4	Wind x	3.947	3.737	1.173
Story3	Wind x	3.337	3.014	1.023
Story2	Wind x	2.518	2.410	1.001
Story1	Wind x	1.837	1.764	1.032
Plaza	Wind x	1.377	1.076	1.016
Basement	Wind x	0.618	0.572	1.073
Story5	Wind y	4.391	4.243	1.057
Story4	Wind y	4.274	4.097	1.075
Story3	Wind y	3.934	3.734	1.037
Story2	Wind y	3.527	3.482	1.037
Story1	Wind y	2.834	2.538	1.042
Plaza	Wind y	1.825	1.637	1.058
Basement	Wind y	0.92	0.792	1.043

Non-opening PT slab shows less displacement as compared to slab with opening (Figure 3).

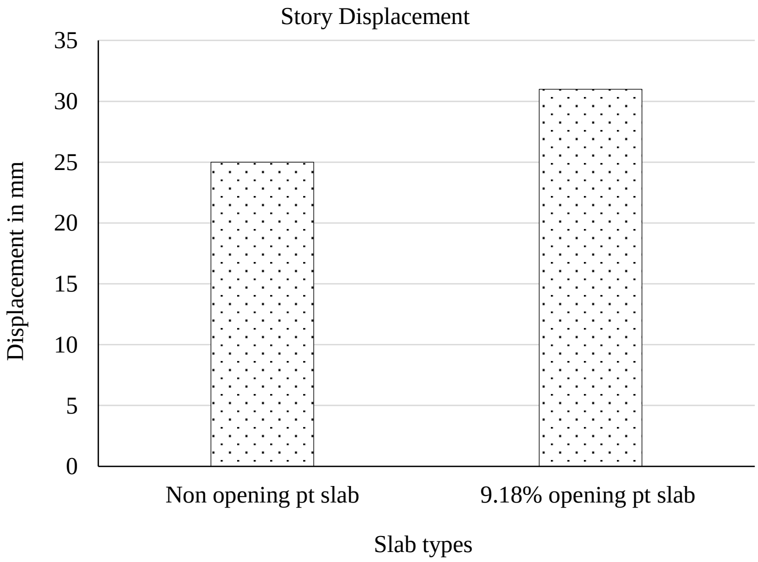

Figure 3. Maximum displacement versus different opening slab types.

STORY DRIFT

The relative displacement between the story and the story adjacent to it in considered earthquake shaking direction is presented in Tables 3 and 4 and Figure 4.

Table 3. Story Drift for non-opening post-tensioned (PT) slab.

Story	**Load Case**	**Drift**
		mm
Story5	EQ x	0.000564
Story4	EQ x	0.00078
Story3	EQ x	0.000973
Story2	EQ x	0.001093
Story1	EQ x	0.001212
Plaza	EQ x	0.000951
Basement	EQ x	0.00038
Story5	EQ y	0.000568
Story4	EQ y	0.000779
Story3	EQ y	0.000972
Story2	EQ y	0.001093
Story1	EQ y	0.001221
Plaza	EQ y	0.000952
Basement	EQ y	0.000382

Table 4. Story drift for 9.18% opening post-tensioned (PT) slab.

Story	**Load Case**	**Drift**
		mm
Story5	EQ x	0.000567
Story4	EQ x	0.000778
Story3	EQ x	0.000969
Story2	EQ x	0.001086
Story1	EQ x	0.001828
Plaza	EQ x	0.000939
Basement	EQ x	0.000374
Story5	EQ y	0.000571
Story4	EQ y	0.00078
Story3	EQ y	0.000971
Story2	EQ y	0.001089
Story1	EQ y	0.001836
Plaza	EQ y	0.000939
Basement	EQ y	0.000375

Non-opening PT slab shows less drift as compared to other opening slabs.

CONCLUSIONS

1. The lowest displacement value is 24.909 mm of non-opening slab and largest displacement value is 30.779 mm with openings of 9.18%.
2. From story displacement data, it is observed that as we increase the opening size of slab the displacement is also increased.

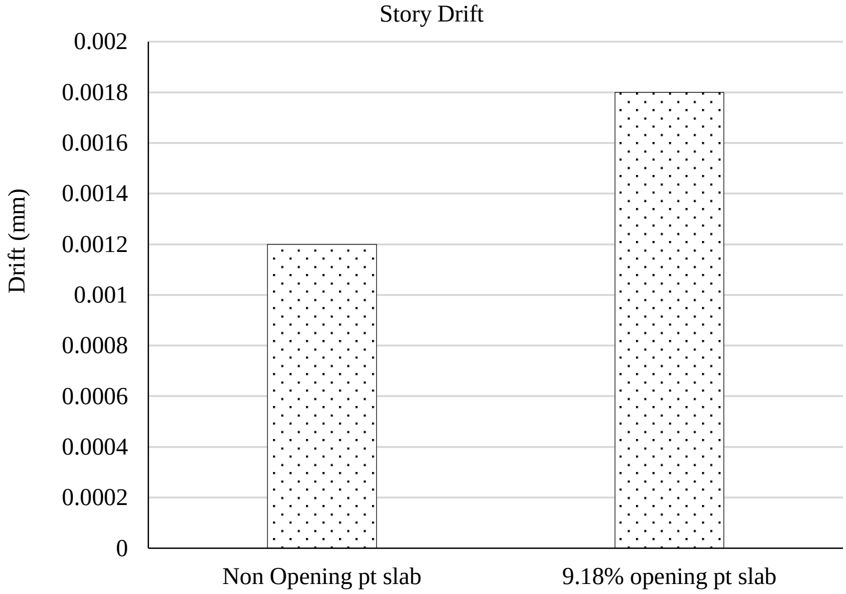

Figure 4. Maximum displacement versus different openings slab types of drift.

3. The value of story drift for non-opening PT slab is 0.001221 mm and for 9.18% opening PT slab is 0.001836. There is not much change seen in drift due to different opening of slab.
4. The major effect of opening in slab is in story stiffness; 9.18% opening slab story stiffness is decreased by 53.06% than the non-opening slab.
5. As we increase the opening size, required reinforcement for that slab is also increased. For non-opening slab maximum top flexural reinforcement is 165 mm^2/m and it increases with size of opening. For maximum 9.18% opening PT slab, it is 603.12 mm^2/m.

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