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Comparative Analysis of Flat Slab and Post-Tensioned Flat Slab Using SAFE

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Abstract: Looking at the modern trend of construction, post-tensioned flat slab are widely adopted in commercial and residential sectors. A study on analysis and behavior of Post-tensioned flat slab is been done in this thesis. Modeling and analysis of flat slab and PT flat slab is done using SAFE. For post-tensioning 12.7 dia and 9.5 dia 7 ply high tensile steel strands are used in analyzing the PT slab. Slab panel of 8m by 12m is modeled for different cases and respective properties are assigned. Slab is divided into column strip and middle strips. Drops are provided along column strip in flat slab and PT flat slab. Results are compared with flat slab and PT flat slab with respect to deflection, punching, moment and stresses. The quantities of reinforcing steel, post-tensioning steel, concrete required for the slab is calculated for the same and cost per square meter are presented in graphical form. Overall study on PT flat slab proves that PT flat slab could be a better option compared to flat slab, in respect of cost of project.

Key words: Flat slab, Post-Tensioned flat slab, SAFE, Tendons.

I. INTRODUCTION

In modern construction high tensile steel reinforcement known as tendons are widely adopted in post-tensioned flat slabs. Post-tensioned slab helps in reducing tensile stresses and cracks of the member. Post-tensioned slabs have proved to be economical and effective compared to normal RCC beam-slab and RCC flat slab. A study on analysis and behavior of Post-tensioned flat slab is done for three different configurations of columns.

Post-tensioning

The process of tensioning done after casting of concrete is known as Post-tensioning. Post-tensioning helps in overcoming the difficulty of fixing required profile of tendons in pre-tensioning. Ducts are placed with the required tendon profile by fixing them to the reinforcement cage. Concrete is cast around the duct.

There are two possibilities of laying tendons. First, the tendons can be kept in the duct before casting and then concrete is poured. Second, tendons are threaded through the ducts after casting of concrete.

Usually one end is anchored in concrete and the other end is anchored by external anchorage system after stressing. Stressing is done by hydraulic jacks after concrete attains its required strength. Prestressing force from tendons is transferred to concrete at anchorage ends. Post-tensioning is of two types [9].

A. Bonded Post-tensioned Member

After anchoring the tendons, ducts are filled with cement grouting. It helps in bonding the tendon with concrete and prevents corrosion of tendon. Such type of post-tensioned members is known as bonded post-tensioned member [9].

B. Unbonded Post-tensioned Member

In this type the tendons are connected only at the ends where it has anchored. There is no bond between tendon and concrete. In few cases ducts are not filled with grouting due to some practical difficulties. This type of members is known as unbonded post-tensioned member [9].

Application of Post-tensioning

- Construction of slabs or beams, where large column free space are required.
- Used extensively for construction of slabs on ground on expansive soils.
- For construction of long span beams and bridges.
- To construct crack-free tennis courts.
- Construction of post-tension slabs in commercial or residential building for economy, durability and esthetic look.
- Strengthening of existing structures by external post-tensioning.
- Concrete water tanks are often post-tensioned to depreciate crack width and leakages.

II. MODELLING AND ANALYSIS

SAFE 2D Post-tensioned flat slab models under consideration are shown in Fig.1.

Case I, II, and III refer to the disposition of the columns and sub case A, B, and C refer to the orientation of the column drop. Sub case A represents column drop provided along Y direction whereas sub case B represents column drop provided in X direction.

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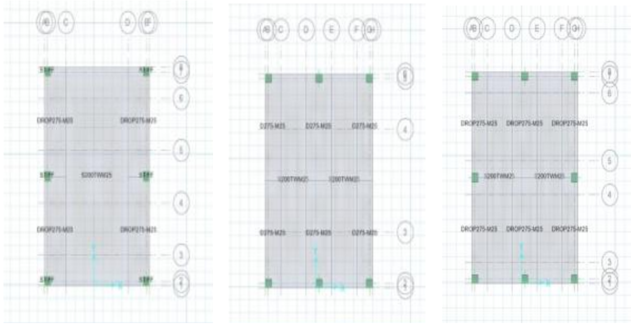


CI-A CII-A CIII-A

Fig.1. PT flat slab 2D model for Class I, II, & III - A configuration

Sub case C refers to the column drops provided both along X and Y directions.

Model Description
Flat slab and PT flat slab both are modelled in SAFE Ver. 12.2.0. Slab of size 8m x 12m centre to centre is modeled with 250mm offset on each side of slab. Model is analyzed for uniform live load of 4 kN/m^2. Detailed descriptions of flat slab and PT flat slab for different cases have been enumerated in Table 1 and Table 2.

III. RESULTS AND ANALYSIS

The flat slab and PT flat slab are analyzed for Case I, II, and III (A, B, and C) configurations. The details of flat slab and PT flat slab results are enumerated in Table 3 and Table 4.

From the results the following observations are made:

1. Based on the results obtained for deflection, punching shear, moments in both column strip and middle strip and stresses at top and bottom of slab for flat slab, Case I – C gives better results compared to other two cases. Similarly in PT flat Slab it is noted that Case I – A gives better results compared to other two cases in all configuration.

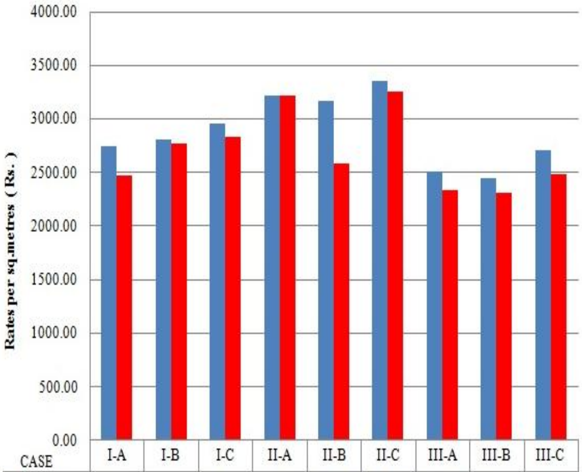
2. Based on the results obtained for deflection, punching shear, moments in both column strip and middle strip and stresses at top and bottom of slab for flat slab, Case II – C gives better results compared to other two cases in all configuration. Similarly in PT flat Slab Case II – B gives better results compared to other two cases. The results obtained from Case II – B are considerably less (about 35% to 45%) of Case II – A and Case II – C.

3. Based on the results obtained for deflection, punching shear, moments in both column strip and middle strip and stresses at top and bottom of slab for flat slab, Case III – A gives better results compared to other two cases in all format. Similarly in PT flat Slab Case III – B gives better results compared to other two cases.

IV. COST COMPARISON

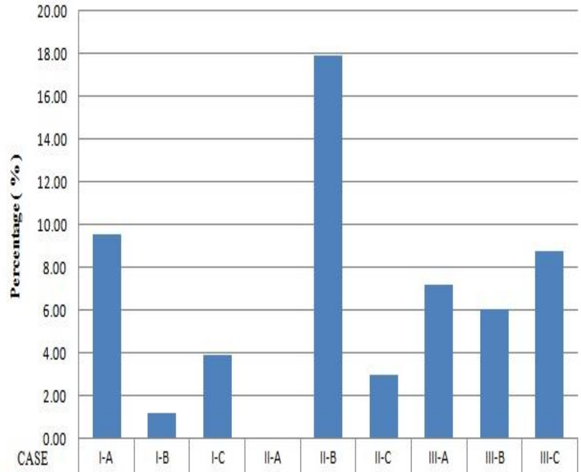
Concrete quantity and steel quantity based on moments in column strip and middle strip along X and Y directions were worked out for flat slab. Similarly tendon, concrete and steel quantities were also worked out for PT flat slab. For different grade of concrete, steel and strands prorate rates are adopted to arrive at the cost of slab. Actual cost per sqm for flat slab and PT flat slab is shown in Fig. 2. Based on the differences in cost for flat slab and PT slab percentage of saving in cost is arrived at and is shown in Fig 3.

From Fig. 3 it is observed that average percentage cost saving for PT flab slab is about 5-7 percent of flat slab. Case III gives better results in all three configurations. Compared to case I and II about 6% to 8.5% is saved in case III. Case II – B gives higher percentage of cost saving (about 18%) than other two cases.



CASE	I-A	I-B	I-C	II-A	II-B	II-C	III-A	III-B	III-C
Flat Slab	2741.6	2802.1	2954.3	3211.2	3168.3	3351.5	2506.2	2451.6	2707.9
PT Flat Slab	2471.6	2771.7	2837.3	3219.1	2587.8	3251.1	2335.4	2312.3	2479.3

Fig. 2. Cost comparison for flat slab and PT flat slab



CASE	I-A	I-B	I-C	II-A	II-B	II-C	III-A	III-B	III-C
% of saving	9.52	1.19	3.92	0.03	17.94	2.96	7.18	6.02	8.75

Fig. 3. Percentage of cost savings in PT flat slab

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TABLE I DESCRIPTION OF FLAT SLAB MODELS

CASE	Grade (MPa)	Slab thickness (mm)	Drop thickness (mm)	Long span (m)			Short span (m)		
				MCS	ECS	MS	MCS	ECS	MS
I A	M25	200	275	-	1.5	5	3	1.5	3
I B	M25	200	275	-	1.5	5	3	1.5	3
I C	M25	200	275	-	1.5	5	3	1.5	3
II A	M25	200	275	2	1	2	-	2	8
II B	M25	200	275	2	1	2	-	2	8
II C	M25	200	275	2	1	2	-	2	8
III A	M25	200	275	2	1	2	2	1	4
III B	M25	200	275	2	1	2	2	1	4
III C	M25	200	275	2	1	2	2	1	4

TABLE II DESCRIPTION OF POST-TENSIONED FLAT SLAB MODELS

CASE	Grade (MPa)	Slab thickness (mm)	Drop thickness (mm)	Long span (m)					Short span (m)				
				MCS	ECS	MS	Strands (Nos)	Dia (mm)	MCS	ECS	MS	Strands (Nos)	Dia (mm)
I A	M35	200	275	-	1.5	5	3	9.5	3	1.5	3	3	9.5
I B	M35	200	275	-	1.5	5	5	9.5	3	1.5	3	5	9.5
I C	M35	200	275	-	1.5	5	5	9.5	3	1.5	3	5	9.5
II A	M40	200	275	2	1	2	7	12.7	-	2	8	3	9.5
II B	M35	200	275	2	1	2	5	9.5	-	2	8	3	9.5
II C	M35	200	275	2	1	2	5	12.7	-	2	8	3	9.5
III A	M35	175	225	2	1	2	5	9.5	2	1	4	3	9.5
III B	M35	175	225	2	1	2	3	9.5	2	1	4	3	9.5
III C	M35	175	225	2	1	2	3	9.5	2	1	4	3	9.5

TABLE III ANALYSIS RESULTS OF FLAT SLAB MODELS

		CASE								
		I A	I B	I C	II A	II B	II C	III A	III B	III C
Deflection (mm)		10.25	8.90	8.75	30.26	30.26	15.25	6.00	6.40	5.85
Punching										
At Exterior column		2.10	1.86	1.82	3.73	3.73	3.36	0.85	0.84	0.81
At interior column		1.20	1.14	1.13	2.07	2.07	1.77	0.65	0.66	0.65
Column Strip Moment (kN-m for strip)										
At Mid	+ve M_{ux}	95.90	182.20	181.25	0.00	0.00	0.00	65.50	96.70	91.50
	-ve M_{ux}	228.50	210.00	205.00	0.00	0.00	0.00	155.00	155.70	145.00
	+ve M_{uy}	0.00	0.00	0.00	205.40	102.80	201.00	54.50	30.50	55.50
	-ve M_{uy}	0.00	0.00	0.00	315.00	330.00	311.00	119.00	115.00	113.00
At End	+ve M_{ux}	53.20	93.00	95.50	15.10	33.00	32.00	12.00	19.50	21.75
	-ve M_{ux}	126.50	110.00	108.50	98.00	101.00	96.00	50.00	47.00	48.00
	+ve M_{uy}	53.00	29.00	51.85	131.00	67.00	129.00	35.75	18.75	36.50
	-ve M_{uy}	123.50	122.50	118.50	209.00	213.00	206.00	99.50	84.50	85.00
Middle Strip Moment (kN-m for strip)										
+ve M_{ux}		87.50	69.80	69.85	93.50	60.30	79.00	56.50	41.50	57.00
-ve M_{ux}		10.50	5.00	5.00	0.00	0.00	0.00	5.50	0.00	3.50

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+ve M_{uy}		63.90	68.80	68.80	83.20	103.50	81.50	24.00	28.30	24.30
-ve M_{uy}		12.40	42.70	42.75	45.70	102.00	87.00	3.62	20.00	15.50
Stresses (MPa)										
Top	σ_x	-2.40	-2.55	-2.45	-8.50	-8.50	-8.50	-2.30	-2.30	-2.30
	σ_y	-4.95	-4.85	-4.85	-2.15	-1.70	-2.00	-4.40	-4.00	-3.35
Bottom	σ_x	2.35	2.45	2.40	8.50	8.00	8.10	2.20	2.20	2.20
	σ_y	4.95	4.85	4.85	2.10	1.60	1.90	4.00	4.00	3.35

TABLE IV ANALYSIS RESULTS OF POST-TENSIONED FLAT SLAB MODELS

		CASE								
		I A	**I B**	**I C**	**II A**	**II B**	**II C**	**III A**	**III B**	**III C**
Deflection (mm)		0.55	1.30	1.00	9.30	6.75	11.65	2.77	3.00	2.62
Punching										
At Exterior column		0.82	1.40	1.35	3.48	2.12	3.60	0.97	1.00	0.96
At interior column		0.47	0.86	0.87	1.79	1.10	1.77	0.70	0.72	0.70
Column Strip Moment (kN-m for strip)										
At Mid	+ve M_{ux}	2.85	5.50	23.10	0.00	0.00	0.00	20.85	29.00	26.80
	-ve M_{ux}	27.00	66.00	63.00	0.00	0.00	0.00	54.00	53.00	52.70
	+ve M_{uy}	0.00	0.00	0.00	87.20	22.00	112.62	19.35	17.40	23.50
	-ve M_{uy}	0.00	0.00	0.00	107.00	46.00	145.00	36.00	32.00	39.00
At End	+ve M_{ux}	3.50	4.50	16.70	16.00	5.50	3.50	4.50	4.50	3.20
	-ve M_{ux}	11.50	21.00	28.70	10.00	10.00	21.00	10.00	10.00	5.70
	+ve M_{uy}	13.50	39.10	19.60	57.25	17.00	73.17	15.00	10.00	20.76
	-ve M_{uy}	31.00	69.00	44.50	77.00	54.00	104.00	45.00	44.00	55.80
Middle Strip Moment (kN-m for strip)										
+ve M_{ux}		2.50	7.30	7.30	83.85	5.15	77.60	23.30	12.00	22.00
-ve M_{ux}		4.40	8.00	8.00	0.00	10.75	0.00	9.00	6.00	6.30
+ve M_{uy}		5.50	31.00	31.00	26.36	26.15	43.75	9.76	10.30	12.30
-ve M_{uy}		7.70	13.65	13.65	15.95	13.15	40.90	3.60	0.00	17.00
Stresses (MPa)										
Top	σ_x	-1.65	-1.75	-1.20	-8.47	-4.15	-7.30	-2.85	-3.00	-3.10
	σ_y	-0.30	-0.55	-0.50	-1.65	-0.75	-1.50	-1.30	-0.50	-0.60
Bottom	σ_x	-1.10	-1.75	-1.50	-1.57	-0.55	1.60	-2.25	0.50	0.30
	σ_y	0.17	0.15	0.85	-0.15	-0.80	0.19	1.85	3.35	2.30

V. CONCLUSIONS

The following conclusions are drawn from the present case study.

1. Deflection for PT flat slab is about 80% to 90% in Case I, 65% to 75% in Case II and 55% to 65% in Case III.
2. The punching shear capacity ratio is within permissible limits for Case I and Case III, whereas it higher than permissible limits for Case II.
3. Positive and negative moments in case of PT flat slab are less, ie. About 75% to 85% in Case I, 60% to 70% in Case II and 50% to 60% in Case III.
4. Stresses in case of PT flat slab are within the permissible values as per guidelines provided by IS: 1343-1980.
5. In case of PT flat slab Case I –A, Case II – B and Case II –C have given better results with respect to deflection, punching, moment and stresses compared to flat slab.
6. In all the Cases, PT flat slabs are economical and cost effective than flat slab. In Case II –A there was no much difference in cost.
7. Case II -B proves to be more economical than other cases.
8. About 7% to 8.5 % of cost saving could be observed for PT flat slab in Case III by reducing thickness of slab and drop.
9. Overall study on PT flat slab proves that PT flat slab could be a better option compared to flat slab, in respect of cost of project, stability and durability.

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NOTATIONS

PT = Post-Tensioned slab
MCS = Width of Mid Column strip
ECS = Width of End Column Strip
MS = With of Middle Strip
σ_x = Stress in X direction
σ_y = Stress in Y direction
+ve M_{ux} = Ultimate positive moment in X direction
-ve M_{ux} = Ultimate negative moment in X direction
+ve M_{uy} = Ultimate positive moment in Y direction
-ve M_{uy} = Ultimate negative moment in Y direction

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BIOGRAPHIES

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