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Design of Flat Slab with Resisting Earthquakes Technique

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***Abstract**: Flat slabs are highly versatile elements widely used in construction, providing minimum depth, fast construction and allowing flexible column grids. Common practice of design and construction is to support the slabs by beams and support the beams by columns. Here large Bending Moment & Shear Forces are developed close to the columns. These stresses bring about the cracks in concrete & may provoke the failure of slab, thus there is a need to provide a larger area at the top of column recognized as column head.Flat slab is a developing technology in India. This is built either by conventional RCC method or post tensioning method and it is a very costly in India. Usually flat slab method is used basically 10 m span. In post tensioning method conducts are given in which strength (wire ropes) after design interval of post tensioning in RCC method and steel is design two-way gain desire strength*

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I. Introduction

A flat slab consists of a reinforced concrete slab that is directly supported by concrete columns. C.A.P. Turner constructed flat slabs in U.S.A. in 1906 mainly by conceptual ideas, which was the origin of this type of construction. Later in 1914, Nicholas proposed a method of analysis of flat slabs based on simple statics. This method is used even today for the design of flat slabs and flat slabs and is known as the direct design method [1]. Structural engineers commonly use the equivalent frame method with equivalent beams such as the one proposed by Jacob S. Grossman in practical engineering for the analysis of flat slab structures. They are generally employed for architectural reasons for large rooms such as auditoriums, vestibules, theatre halls, show rooms of shops where column free space is often the main requirement. Flat slabs are used mainly in office buildings due to reduced formwork cost, fast excavation, and easy installation [2]. Many works and studies have been carried out on flat slabs and yet for Indian constructions the more refined works are needed by the researchers. Flat slabs are basically used for introducing more head rooms to the floors and to give better appearances for interiors. Major components of flat slab are capital/head, drop panel, columns strip and middle strips.

1.1 General

Reinforced concrete flat-slab structures have been and continue nowadays one of the cheapest and most popular ways to raise buildings. For relatively light loads, as experienced by apartment buildings, flat slabs are used. It is a simple conception structure based on a group of vertical elements supporting a slab of uniform thickness. This structure type is the most economical for spans from 4.5 m to6 m. (15 to 20 ft).

The first American flat slabbuildings were the C. A. Bovey Building in Minneapolis, Minnesota. It was built by C.A.P. Tuner in 1906. It was raised at the risk of its inventor, but performed well in the loading test. Between this structure and the paper on slabs by Westergaard and Slater in 1921, was plenty of room for argument. During that period some theories appeared from different authors trying to establish the amount of reinforcement to place in the flat slab. This amount was the point of discussion and had differences of 400% between different authors. During those years the use of the crossing beam analogy to design flat slabs, induced somehow that statics were not applied in slab construction [3]. In 1914 Nichols introduced statics to compute the moments in a flat slab. Nichols analysis was right but Turner design was not wrong, thus his work was generally refuted [4]. Although ACI did not introduce the analysis until 1971, Nichols's analysis forms the basis for the actual ACI's slab design(direct design). Nowadays the behavior of flat slabs under gravity loads is well-known. The ACI code describes clearly how to design such structures. Flat slabs subjected to gravity loads have a flexural behavior; here there are the three main points to describe the performance:

1. Before cracking the slab acts as an elastic slab.
2. between cracking and beginning of yielding the slab is no longer of constant stiffness due to the loss of inertia. Also, it cannotbe considered isotropic because the crack pattern may differ in both ways. However, these considerations, the slab can be assumed behaving elastically because it predicts the moments adequately.
3. Yielding of reinforcement starts in one or more regions of high moment. After these regions reach yielding moment redistribution occurs and the yielding spread through the slab. With further load the slab gets divided into different elastic slabs that can cause the collapse of the structure. The boundary load for that collapse can be computed with a yielding line analysis. Also, the vertical load can make the structure collapse under punching shear. This means that the slab is not able to resist the shear generated close to the supports or columns. Punching shear is also considered in the ACI code and can be avoided by simple geometrical restrictions and the correct design of the reinforcement.

Thus, the performance of this kind of buildings under vertical loads is well known, but the scope of this study is for laterally loaded flat slabs. The behaviorunder these conditions is totally different. Most of the structures are designed to resist lateral loads as wind, but this design in not enough when the structure is subjected toseismic forces. Along the history, flat slabs have had a spotty response againstearthquakes. In this case, the slab column connection becomes the critical element ofthe structure. The slab is a diaphragm with distributed strength and stiffness, and thecolumn is a rigid bar perturbing the slab. The connections affect the response of the entire structure and can cause collapse of the building even if the connections havenot reached failure. The entire structure is more vulnerable, and the response is not Easy to predict; many aspects of the behavior become uncertain.

It is understood then that the behavior is difficult to predict, nevertheless there are some ways to model the structure into a system easier to understand? A structureresponds to an earthquake excitation with a vibration that absorbs the energytransmitted by the earthquake. The amplitude of this response depends on thecharacteristics of the building, foundations and the non-structural items inside. It hasobvious complications to model the structure as a system with all that elements. Thus,the usual methods for seismic analysis of structures try to simplify the structure into asimple degree of freedom. This is a concentrated mass, a spring and a damper. Theexcitation the mass will oscillate and absorb the energy. In general, thestructures cannot be represented by single degrees of freedom because they are morecomplicated. Then they can be modeled as a series of mass connected between themby different springs. This configuration still admits an easy dynamic analysis butintroducing more details of the properties of the system. While modeling the structureinto a system for its further dynamic analysis, it is important to well determine thestiffness of each floor as well as the connections.Lately the main concern at seismic zones has been to differentiate betweenflat-slabs safe enough and the ones that are not safe to resist seismic motions. A wideresearch has been developed around this topic trying to study the parameters thatgovern the lateral behavior of flat-slab structure. In this hunt some analytical researchhas been developed and also a wide variety of scale models have been essayed atdifferent laboratories in order to get experimental data [5].

1.2 Objectives

To model the structure in the best way to represent its behavior and in a manner that fits the requirements for LARZ, the program that will be Used. To perform a static analysis with LARZ. To complete a dynamic Analysis with LARZ subjecting the structure to different earthquakes Motions.

- To determine the limits of the structure resisting earthquakes. To

decide whether the flat slab is safe or not.

- To suggest the behavior that will occur during the test and propose, ifnecessary, improvements in the structure or the test configuration.

II. Literature Review

Mostly among all available literature and experimental work is based on analytical part of the flat slab floors. A lot of research work has taken place in this field addressing all the relevant issues pertaining to the modelling,analysis and construction of flat slab structure structures.

Park *et al*. (2009): - found that Equivalent Frame method is not appropriate in accurately predicting the response of two-way slab systems under lateral loads. Currently design [6].

Subramanian (2005) found that to increase the punching shear strength of flat slab, the shear reinforcement is found to provide economical solution. They not only enhance the shear capacity but also result in flexural failure of the slab and thus increasing the ductility of flat slab, which is very important in earthquake prone zone [7].

Meghally and Ghali(2005): - have proposed the value of the unbalanced moment to be used in punching shear design [8].

Kim and Lee (2005)proposed an improved analytical method that can consider the stiffness degradation effects in the slab depending on the lateral drifts using super element for the efficient and accurate analysis of flat slab structure. The major observations and findings could be summarized as follows [9].
Structural analysis of the flat slab structure having irregular plan or slab with openings can be performed and stress distribution of floor slab can be easily represented by finite element method if the stiffness degradation could be considered properly

Corley and Jirsa(1970): - first developed "Equivalent Frame Method (EFM)" for design of all types of slab system in 1970. This method had no limitation like direct design method. They compared the moment calculated by EFM with those measured in test slab and the moment shown the satisfactory agreement. They provided the list of constants for calculating stiffness, fixed end moments and carry over factor for beam element [10].

Dovich and Wight (2005): - developed an effective slab width model to describe the lateral behavior of the reinforced concrete flat slab frame with in a two-dimensional nonlinear frame analysis [11].

Hwang and Moehle(1993): - carried out an experimental study on nine panel model having a slab supported without beams, drop panels, slab shear reinforcement. A part of the slab was designed for gravity and wind load in accordance with ACI 318-83 [12].

Erberik, and Elnashai(2004) study focuses on the derivation of such fragility curves using medium-rise flat-slab buildings with masonry infill walls. The study employed a set of earthquake records compatible with the design spectrum selected to represent the variability in ground motion. Inelastic response-history analysis was used to analyze the random sample of structures subjected to the suite of records scaled in terms of displacement spectral ordinates, whilst monitoring four performance limit states. The fragility curves developed from this study were compared with the fragility curves derived for moment-resisting RC frames. The study concluded that earthquake losses for flat-slab structures are in the same range as for moment-resisting frames. Differences, however, exist. The study also showed that the differences were justifiable in terms of structural response characteristics of the two structural forms [13].

Jofriet and McNeice (1971) studied experimentally and numerically a slab where the comers were prevented from lifting and subjected to a point load at the centre. They used plate element for their numerical analysis. This slab was subsequently analyzed by many other investigators. The main emphasis was on predicting behavior in flexure [14].

Vidosa, Kotsovos, & Pavlovic(1988) used 8 node ax symmetric elements with smeared crack model to investigate reinforced concrete slabs under symmetric punching loads. They analysed two series of slabs. The first series comprised of four circular slabs tested by Kinnimen et al (1978); the second series consists of five squareslabs tested by Elstner and Hognestad (1956) [15].

III. Result and Discussion

3.1Design Of Two-Way Slab: -
Problem Based On Design of Two-Ways Lab: -
Design: - Design a slab over a room 6m×6m as per I.S. code the live lode on the slab is 4000N/m^2. The floor finish weight is 1000N/m^2. Use M-20 concrete and Fe-415 steel.
Solution: -
Given: -Room size 6m×6m, live load 4000 N/ m^2, floor finish 1000 N/ m^2, Fy-415(steel), M-20 Grade (concrete), bearing of supporting wall=150mm (assume)
Span between center of bearing along the length = 6.15
Span between center of bearing along the width =6.15
Assuming 0.3% steel. Modification Factor =1.43
(NOTE: - The M.F depends on the % of tensile steel which may be initially assuming 0.3% to 0.4%)
(Table 21.6 M.F.(α_1) corresponding to the% of tensile steel)
Effective depth required = $\frac{Lspan}{20(modification factor)} = \frac{6150}{20\times1.43}$ = 215.03mm$\cong$ 220
(Providing 8 mm Ø bar if Fe-415 and 10mm Ø bar if Fe-250 Steel in used)
2. Providing 8mm diameter bar at clear cover of 15mm than

Over all depth = 220+15+4
= 240
Actual effective depth along the length
= 240-15-4
=221 mm
Actual effective depth along the width
= 240-15-8-4
= 215 mm
Clear span + Effective depth (along the length) L_Y = 6 + 0.221 =6.221 m
Clear span + Effective depth (along the length)L_X = 6 +0.213 =6.213 m
Span ratio = $\frac{lx}{ly} = \frac{6.221}{6.231}$ = 1.0023
Referring to IS Table (page no. 91)
r =1.0012, $\alpha_{x} =$0.0623, α_y =0.0619
Load calculation: -
Dl of Slab = 25 x 240 = 6000 N/ m^2
Floor finishing = 1000N/m^2
Live load = 4000 N/ m^2
Total load = 11000 N / m^2
Factor load = Wu =1.5 x11000 =16500 N / m^2
Max. Span B.M. per meter width along the width
$M_{ux} = \propto_x w_u l_x^2 = 0.0623\times16500\times6.213^2$
= 39680.28 Nm
Max. Span B.M. per meter width along the width
$M_{uy} = \propto_y w_u l_x^2 = 0.0619\times16500\times6.213^2$
=39425.508Nm
(NOTE: -Equating the limiting moment of resistance to the factored moment and find the effective depth required from flexural strength consideration)

When Fe-415 steel is used
$M_{u(lim)} = 0.138\ f_{ck}\ bd^2$
When Fe-250 steel is used
$M_{u(lim)} = 0.149\ f_{ck}\ bd^2$
Equating $M_{u(lim)}$ to M_{ux}
0.138 f_{ck} bd^2 = 39680.28x1000 Where :-(b=1000) & (f_{ck}=20)
d = 119.90 ≅ 120mm
Effective depth provided (d)= 221mm
Find the area of steel required per meter width of the slab % of steel required

$P_t = 50x\ [\frac{1-\sqrt{1-\frac{4.60}{fck}\times\frac{mu}{bd^2}}}{\frac{fy}{fck}}]$ where: - {b=1000}

4. $Pt = 50\ x\ [\frac{1-\sqrt{1-\frac{460\ x39680.28\ x1000}{20\ x\ 1000\ x221}}}{\frac{415}{20}}]$

Pt. = 0.236 %
Area of steel required per meter width = Ast = $\frac{Pt\ \ (b\times d)}{100}$
Ast =$\frac{0.236\times1000\times221}{100}$ = 521.56 mm^2
The percentage of steel provided should be grater then 0.12% when Fe 415 steel is provided
And greater then when Fe 250 steel is provided.
Provided 8 mm bar of the Fe 415 or 10mm bar to 12 mm bar of Fe 250.
Spacing of bar = $\frac{areaofonebar\ \ \times1000}{Ast}$
= $\frac{0.785\times8\times8\times1000}{512.56}$
Not: - 1. Min. spacing of bar =75 mm
2. Preferably the spacing of the bar may be between 100 mm top 150 mm
Actual area of steel is provided =A_{st} = $\frac{0.785\times8\times8\times1000}{120}$ = 416.7 mm^2
Actual percentage of steel provided = 0.18 %

Percentage of steel originally assumed = 0.3%

∴The design is safe from serviceability condition.

Steel for long span

$\frac{Muy}{bd^2} = \frac{39425.50 \ x \ 1000}{1000 \ x213^2}$ = 0.868

Percentage of steel required: -

P_t = 50x $[\frac{1-\sqrt{1-\frac{4.60}{20}\times 0.868}}{\frac{415}{20}}]$ where: - {b=1000}

∴A_{st}= $\frac{0.253}{100} \times 1000 \times 213$ = 538.89 mm^2

Spacing of 8mm Ø bar = $\frac{50 \ X \ 1000}{538.89}$ = 92.78 ≅ 120mm

Provide 8mm Ø bar @ 120mm c/c

Check for shear for short span strip

S.F. at the end $V_u = w_u \times \frac{Lx}{2}$

$= \frac{16500 \ X \ 6.213}{2}$

= 51257.25 N

Nominal shear stress $(\tau_v) = \frac{\text{Vu}}{bd} = \frac{51257.25}{1000 \ X \ 221}$

= 0.23 N/mm^2

Actual area of bottom steel available near support

$= \frac{416.7}{2}$ = 208.35 mm^2

Percentage of bottom bar steel near Support

$=\frac{208.35}{100\times 221} \times 100 = 0.94\%$

Corresponding design shear strength =0.46 N/ mm^2

For the slab thickness of 221 mm = 1.16 (page no.84)

Table 26.3 Design shear strength $t_c$of concrete (N / mm^2)

τ_c= 0.608

$\tau_v = \tau_c$ (the slab is safe in shear)

Cheek for development length: -M_1 =0.87 x f_y x A_{st}xd$[1-\frac{Ast.\times fy}{b\times d\times fck}]$= 0.87x415x208x221x$[1-\frac{208.35\times 415}{1000\times 221\times 20}]$

= 16.29 x10^6 N/mm

V_u =51257.25 N

Lo = $\frac{150}{2} - 15$ =60 mm

L_d= $\frac{0.87\times fy\times \emptyset}{4\times 1.92}$ =$\frac{0.87\times 415\times 8}{4\times 1.92}$ =376 mm

(τbd) design bond stress for high grade f_e 415 bars = 1.92 N/mm^2

We Find L_d<1.3$\frac{m1}{vu}$+l

∴The design is safe in anchorage.

Quantity and Cost Estimate on of Two-Way Slab

Consider first 10 cu.m unit =1 cu.

Consider M-20 grade of concrete (1:1.5:3)

Total dry weight of concrete material = 10 X 1.5

=15 cu.m

Calculation of material = X+ 1.5X+3X = 15 cu.m

= 5. 5X=15cu.m

Quantity of cement = 2.727 cu.m =18bag

Quantity of sand =4.0905 cu.m

Quantity of aggregate =8.81 cu.m

[NOTE: - For eliminating of bulking quantity of sand should be consider extra of 0.33 cu.m per cu.m]

∴ Total quantity of sand = (4.0905+0.33 X 4.0905) = 5.453 m^3

Total length of bar = L+2hook+one depth

=L+16D+R

Total length = 6.22+16×0.01+$\frac{2.546}{10}$ - $\frac{1.8}{10}$

=6.4546
No. of bar = 52 nos
Total length of bar =52×6.4546=335.639 m
Both Side = 335.639×2= 671.278 m
Weight = 0.62×671.278 =416.192kg
[NOTE: -Provided 10mm bar@ 120mm c/c]
Length of bar = L+ 16D
=6.22+16+0.008
=6.348m
No. of bar = 12 nos
Total length of bar = 6.348 X 12 =76.176 m
For both side = 76.176 X 2 = 152.352 X 0.395= 60.179 kg
Total weight of steel (main bar + distribution bar)
= 416.192+60.179 = 476.371 kg
Total volume of concrete = L×B×H
= 6.30×6.30×0.221 =8.77 cu.m
Steel in 10 cu.m of concrete = $\frac{10}{8.77}$×476.372
= 543.10 kg

Abstract Of Estimated Cost Of Two-Way Slab: -

S.NO	PARTICULARS OF ITEMS	QUANTITY	RATE(Rs.)	AMOUNT(Rs.)
[A]	MATERIAL: -			
	1: -R.C.C. work (1:1.5:3) excluding steel and it's bending but shuttering & bending of steel			
	* cement			
	*sand	2.727 cu.m	260/0.034 cu.m	21060.00
	*aggregate	4.0905 cu.m	500/cu.m	2045.25
	2: - steel bars in including bending inR.C.C. work	81.81 cu.m	1300/cu.m	10635.30
		543.10 kg	40/kg	21724.00
			Total =	**55464.55/-**
[B]	LABOUR: -			
	* Head Mason	1	400.00	400. 00
	*Mason	2		700.00
	*Mazdoor		350.00	
	Male mazdoor	20		4000.00
	Female Mazdoor	15		2700.00
	*Bhisthi	03	200.00	450.00
	* Car painter	10	180.00	3500.00
	* Bar bender with Black smith	10		3000.00
			150.00	**14750.00**
			350.00	
			300.00	
			Total =	
[C}	Cantering & shuttering (Timber slab& bally 5% of A)	_	_	2773.22
[D]	Tools & planks [1.5% of A+B]	_	_	1053.21
[E]	Water charge [1.5% of A+B+C]	_	_	1094.81
[F]	Contingencies charge [5% of A]	_	_	2773.22
[G]	Contractor charge [10% of Total]	_	_	7790.90

GRAND TOTAL: -Rs. 85699.91 /-
Total cost for 10 cum of R.C.C. slab = **85700.00Rs**
∴ Cost for 877 cum R.C.C. slab = $\frac{8.77}{10}$×85700.00 = **75159.00 Rs.**
DESIGN OF FLAT SLAB

Flat slab Terminology & Important Point: -
Drop: - sometimes the thickness of the slab is increased by 25% to 50% over the column head.

This part of the slab of greater thickness is called the Drop.
Column Head: - The Upper supporting part of a column is enlarged to form the column head.
The diameter of the column head is made 0.20 to 0.25 of the span lengths.
*When column heads are provided, that portion of the column head which lies within the largest right circular cone or pyramid that has a vertex angle of 90^0 and can included entirely within the outline of the column and column heads, shall be considered for design purpose.
Column strip: -
*Negative moments at interior supports
= 75% of the total (-ve) moment in the panel at that support
*Negative moment at an interior support
=Total (-ve) moment in the panel at the supports

*Positive moment for each span: -
For each span, the column strip shall be designed to resist 60% of the total (+ve) moment in the Panel.
Middle strip: -
* Each middle strip shall be proportioned to resist the sum of moment assigned to its two-half middle strip.
*That portion of the design moment not resisted by the column strip shall be assigned to the adjacent middle strip.

Shear in flat slab: -
The critical section for shear shall be at a distance $\frac{d}{2}$ from the periphery of the column or drop panel. Perpendicular to the plane of the slab where, d is the effective depth of the section.

Problem based on design of flat slab: -
Problem: - Design an interior panel of a flat slab for a live load of 400 N/m^2 the slab is provided with a floor finish weighing 1000 N/m^2 the panel are 6m x 6m. Drop shall be provided use M-20 concrete and Fe-415 for steel.
Solution: -
Step-1 Thickness of the slab
As per IS Code 456-2000: - Through the interior panel is to be design. Will choose the thickness required for an end panel and provide the same thickness for interior panel.
Consider modification factor = 1.50
As par IS Code (13.2.1)
Effective depth required =$\frac{span}{\left(\frac{20+26}{2}\right)xModificationfactor}$

$= \frac{6000}{23\times1.5}$= 174 mm
Let provide 10 mm ϕ bar at a clear cover of 15 mm.
Effective cover to the center of upper layer of bar = 15+10+5 = 30 mm
Overall depth required = 174+30 = 204 mm.
Provide a thickness of 200 mm.

Step-2: - Load calculation: -
Dead load of the slab = 25X200 = 5000 N/m^2
Floor finish = 1000 N/m^2
Live load = 4000 N/m^2
Total load = 10000 N/m^2

Factored load (W_u) =1.5X10000 = 15000 N/m^2
Diameter of the column head (D) $= \frac{L}{4} = \frac{6}{4} = 1.5$ N/m^2
Size of the drop $=\frac{L}{2} x \frac{L}{2} \quad = 3mX\ 3m$

Step-3: -Bending Moment calculation: -
Total design moment in one principle direction
$M_0 = \frac{WL}{8}$
Where, W = design load on the area L x L
= 15000 X 6 X 6 = 450,000 N

M_0 = $540{,}000\ X\ \frac{6}{8}$= 405000 N-m
Distribution of moments: -
As par IS Code 456-2000 (31.4.3.2)
Total negative moment = $0.65M_0$ = 0.35 X 405000
= 263250 N-m

Bending Moment for column strip: -
Negative moment at support = 0.75 X 263250
= 197437.5 n-m
Positive design moment = 0.6 X 141750
= 85050 N-m

Bending Moment for middle strip
Negative moment = 0.6 X 263250
= 65812.5 N-m
Positive moment = 0.4 X 141715
= 56700 N-m

Step-4 Depth Calculation: -
The depth of the slab checked for a bending moment of 85050 N-m
$M_{u.\ limit} = M_u$
$0.138F_{ck}bd^2$ =0.138 X 20 X 3000d^2 = 85050 X 1000
d = 101.3 mm
Effective depth provided = 200 – (15+12) = 174 mm

Depth of Drop
The design moment for the drop is –ve moment in the column in the strip (197437.5)
$0.138F_{ck}bd^2$ = 0.138 X 20 X 3000d^2 = 197437.5 X 1000
d = 155 mm

As per IS Code – The thickness of the drop may be made 50% more than the thickness of the slab.
Thickness of drop (d') = 200+0.5 X 200 = 300 mm
Actual effective depth (d) = 300 – 30 = 270 mm

Step-5 Reinforcement Calculation
Reinforcement for the drop
$M_u/(bd^2) = \frac{197437.5\ X\ 1000}{3000\ X\ 270\ X\ 270}$
$p_t = 50[\frac{\left\{1-\left(1-\frac{4.6}{20}X\ 0.903\right)\right\}}{\frac{450}{20}}]$ = 0.265%
$A_{st} = \frac{0.265}{100}X(3000X270)$ = 2146.5 mm^2
This is the steel required in a width of 3m.
Steel required per meter width $=\frac{2146.5}{3}$
= 715.5 mm^2
Spacing of 10 mm ϕ bars $\frac{79X1000}{715.5}$ = 110.4 mm
Provide 10 mm ϕ bar @ 110 mm c/c.

Steel for positive moment of 85080 N-m in the column strip.
Effective depth of slab (d) = 200 - 30 = 170 mm
$M_u/(bd^2) = \frac{85050X1000}{3000X170X170}$ = 0.981
$p_t = 50[\frac{\left\{1-\left(1-\frac{4.6}{20}X\ 0.981\right)\right\}}{\frac{450}{20}}]$ = 0.289%
$A_{st} = \frac{0.289}{100}X(3000X270)$ = 1473.9 mm^2
(Per 3m width)
Steel required per meter width $=\frac{79X170}{3}$ = 491.3 mm^2

Spacing of 10 mm ϕ bars = $\frac{79X1000}{491.3}$ = 161 mm
Provide 10 mm ϕ bars @ 160 mm c/c
Reinforcement for middle strip: -
Steel for negative moment of 65812.5 N-m
$\frac{M_u}{bd^2} = \frac{65812.5 \times 1000}{3000 \times 170^2} = 0.759$
$\therefore P_t = 50[\frac{1-\sqrt{1-\frac{4.6}{20}\times 0.759}}{\frac{415}{20}}] = 0.22\%$
$\therefore A_{st} = \frac{0.22}{100} \times (3000 \times 170) = 1122\ m^2$ (per 3m width)
∴ Steel required per meter width $= \frac{1122}{3} = 374\ mm^2$
Spacing of 10mm Ø bars $= \frac{79 \times 1000}{374} = 211 mm$
Provide 10 mm Ø @ 210mm $^c/_c$
Steel for positive moment of 56700 N-m.
$\frac{M_u}{bd^2} = \frac{56700}{3000 \times 170^2} = 0.654\%$
$\therefore P_t = 50[\frac{1-\sqrt{1-\frac{4.6}{20}\times 0.654}}{\frac{415}{20}}] = 0.189\%$
$\therefore A_{st} = \frac{0.189}{100}(3000 \times 170) = 963.9$ (per 3m width)
∴ Steel required per meter width $= \frac{963.9}{3} = 321.3\ mm^2$
Spacing of 10 mm Ø bars $= \frac{79 \times 1000}{321.3} = 246\ mm.$
Provide 10 mm Ø @ 240 mm $^c/_c$

Step-6: - Check for shear stresses
It is necessary to check for shear stress at the following critical sections.
Critical section in the drop: -
(This critical section is taken at a distance of half effective depth of the slab from the column head)
Effective depth of the drop = 300-30 = 270 mm.
Dia. of the column head = 1.50 m.
Dia. Of the critical circle = 1.50+0.27 = 1.77 m.

Load on the one column.
Load from the slab: 10000×6× 6 = 360000 N
Additional load due to 100 mm additional thickness
$= 25 \times 100 \times 3 \times 3$
= 22500 N
Total = 382500 N
Total shear force on the critical section
= Total load transferred to one column – Total load acting within the critical section
$= 382500 - \frac{\pi}{4} \times 1.77^2[25 \times 300 + 25 \times 200]$
= 351742.83 N

Factored shear $V_u = 1.5 \times 351742.83 = 527614.25$ N
$\therefore \tau_u$ = Nominal shear stress $= \frac{v_u}{bd}$
(IS code clause 40.1)

Where, V_u = Factored shear force
b = Perimeter of the critical circle
$= \pi \times 1.77 \times 1000 = 5560.6\ mm$
d = Effective depth of the drop = 270 mm
$\therefore \tau_v = \frac{527614.25}{5560.6 \times 270} = 0.35\ ^N/_{mm^2}$
Ultimate shear strength of concrete
$= 0.25\sqrt{f_{ck}} = 0.25\sqrt{20} = 1.12\ ^N/_{mm^2}$

$k_s = 1$ Since the column head is circular

$\therefore k_s \tau_c = 1 \times 1.12 = 1.12 N/mm^2$

$\therefore \tau_v < k_s \tau_c$ $\therefore$ The design is safe in shear.

Critical section for the slab: -

This critical section is taken at a distance of one half of the effective depth of the slab from the edge of the drop.

Total length of the critical section = 4(3+0.17)
= 12680 mm

Total shear force at the critical section = load acting on the area $(6^2 - 3.17^2)$
ie. load acting on 25.951 m^2

$\therefore$ = 10000 $\times$ 25.951 = 259510 N

Factored shear v_u = 1.5 $\times$ 259510 N = 389265 N

Nominal shear strain $\tau_v = \frac{v_u}{bd}$

$= \frac{389265}{12680 \times 170}$

$= 0.18 N/mm^2$

This is less than $1.12 N/mm^2$

Hence, the design is safe.

Quantity Estimation of Flat slab

Consider first 10 cum unit = 1 cum

Consider M-20 grade of concrete (1:1.5:3)

Total dry weight of concrete material = 10 + $[\frac{50}{100} \times 10]$
= 15cum

Calculation of material = x+1.5x+3x = 15 cum

5.5x = 15 cum

x = 2.727 cum

Quantity of cement (x) = 2.727 cum = 81 bag

Quantity of sand (1.5x) = 2.727 $\times$ 1.5 cum = 4.0905 cum

Quantity of aggregate (3x) = 2.727 $\times$ 3 = 8.181 cum

For eliminating of bulking total quantity of sand
= $(4.0905+0.33\times 4.0905) = 5.453$ cum

Reinforcement calculation

1.) Main bar of slab (L) = $9+16\times 0.010 - 0.008$
= 9.08 m (vertical)

Weight = $38\times 9.08 \times 0.62$
= 213.92 Kg

2.) Main bar of slab (L) = $9.08\times 57 \times 0.62$
= 320.89 Kg (Horizontal)

3.) Distribution bar = $60 \times 9.08 \times 0.62$ = 333.78 Kg

Abstract of Cost Estimation of Flat Slab: -

S.NO.	PARTICULARS OF ITEM	QUANTITY	RATE (Rs.)	AMOUNT (Rs.)
[A]	Material			
	*Cement	2.727 cum = 81 bags	260/bag	21060.00
	*sand	4.0905 cum	500/cum	2045.25
	*Aggregate	8.181 cum	1300/cum	10635.30
	Reinforcement			
	*Main bar	330.13 kg	40/kg	13205.20
	*Distribution bar	206.03 kg	40/kg	8241.20

			Total =	55186.95/-
(b)	Labour *Head Mason *Mason Majdoor * Male Majdoor * Female Majdoor * Bhisthi * Car Painter * Bar Bender * Black Smith	 01 02 20 15 03 10 04 04	 400.00 350.00 200.00 180.00 150.00 350.00 350.00 250.00 Total =	 400.00 700.00 4000.00 2700.00 450.00 3500.00 1400.00 1000.00 14150.00/-
(c)	Centering and Shuttering (Timber slab& Bally) [5% of A]			2759.00
(d)	Tools & Plans [1.5 % of A+B]			1040.05
(e)	Water charge [1.5% of A+B+C]			1081.43
(f)	Contingencies charge [5% of A] Contractor Profit [10 % of total]		 Grand Total=	2759.00 6424.14 83400.57/-

Total cost for R.C.C slab = Rs. 83400.57 /-

∴ Cost for (6m × 6m × .2m) R.C.C slab = $\frac{7.2}{10} \times 83400.57$

= Rs. 60048.41/-

Quantity and Cost Estimation for Drop Panel

Consider first 1 drop pane of M-20 grade of concrete

Total quantity of concrete = 3X3X0.3 = 2.7 cu.m

Total dry weight of concrete = 2.7+0.52X2.7 = 4.104 cu.m

<u>Material calculation</u>

X + 1.5x 3x = 4.104

X = 0.746 cu.m

Cement = 0.746 cu.m = 23 bag

Sand = 1.19 cu.m

Aggregate = 2.238 cu.m

Steel = 3.152 X 28 X 2 X 0.62

69.72 Kg

Abstract of Estimated Cost

S.NO.	PARTICULAR	QUATITY	NO.	RATE(Rs.)	AMOUNUNT(Rs.)
A.	Material				
1.	Cement	23 bags	4	260/bag	23920.00
2.	Sand	1.9 cu.m	4	500.00/cu.m	2380.00
3.	Aggregate	2.238 cu.m	4	1300.00/cu.m	11637.6.00
4.	Steel	69.72 Kg	4	40.00/Kg	11155.20
				TOTAL =	49092.80/-
B.	Labour				
1.	Head mason	½		400/day	200.00

2.	Mason	2		350/day	700.00
3.	Mazdoor				
	Male mazdoor	10		200/day	2000.00
	Female mazdoor	15		180/day	2700.00
4.	Bhisti	3		150/day	450.00
5.	Carpenter	8		350/day	2800.00
6	Bar binder	3		350/day	1050.00
7..	Black smith	3		250/day	750.00
.				TOTAL =	10650.00/-
C.	Centering and shuttering (4% of A)				1963.71
D.	Tools and plans (1.5% of A+B)				896.14
E.	Water charges (1.5% of A+B+C)				925.60
F.	Contingencies (5% of A)				2454.62
G.	Contactor profit (10%of total)				6568.28
				GRAND TOTAL=	65982.00/-

Total cost of drop panel = Rs.65982.00/-MKO.

IV. Result

Construction Cost of Two-Way Slab: -
GRAND TOTAL: -Rs. 85699.91 /-
Total cost for 10 cum of R.C.C. slab = 85700.00Rs
∴ Cost for 8.77 cum R.C.C. slab = $\frac{8.77}{10}$×85700.00 = 75159.00 Rs
Shear stress - positive
Shear strain - positive
Construction Cost of Flat Slab: -
Total cost for R.C.C slab = Rs. 83400.57 /-
∴ Cost for (6m × 6m × .2m) R.C.C slab = $\frac{7.2}{10} \times 83400.57$
= Rs. 60048.41/-
Shear stress - positive
Shear strain - positive

V. Conclusion

Flat slab construction is a developing technology in India. Flat slab can be designed and built either by conventional RCC or post tensioning. However due to issue mentioned above with Post Tensioning construction in India and its higher cost, conventional RCC should be preferred choice for span up to 10m design of conventional RCC flat slab in India, Utilizing Indian code, has may short coming, which have to be addressed and revised soon.

For the larger area flat slab is more effective in term of weight, aesthetic, cost, if the application of live load is less. But in case of shear area two-way slabs is more effective.

The problem which we had considered is mentioned to design a flat slab by considering drop panel but without drop panel we can also design the flat slab by increasing the dimension of the column.

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