

Analysis on Design of Flat SLAB Structure

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ABSTRACT: This work includes the design and estimate for flat slabs of various spans, ranging from 6.0 m to 12.0 m, by reinforced concrete cement and prestressed concrete techniques. For smaller spans, associated with normal building works, prestressed concrete construction becomes too cumbersome, irrespective of the economics involved. Intensity of assumed loading is kept sufficient enough, so that the factored bending moment will be comparable to that developing in cases of commercial buildings. Post-tensioning is preferred as it is in vogue, in construction of large span slabs.

All structural costs, floor framing is usually the largest component. Likewise, the majority of a structure's formwork cost is usually associated with the horizontal elements. Consequently, the first priority in designing for economy is selecting the structural system that offers lowest overall cost while meeting load requirements. Post tensioning is the key to cost-effective multifamily construction. In addition, post-tensioned structures can be designed to have minimal deflection and cracking, even under full load. Thinner floors provide lower building weight, which creates a corresponding reduction in other structural elements. There are also some associated labour and time savings

I. INTRODUCTION

A flat slab is a two-way reinforced concrete slab that usually does not have beams and girders, and the loads are transferred directly to the supporting concrete columns. They are subjected to both vertical and lateral loads. Lateral loads due to wind and earthquake governs the design rather than the vertical loads. The buildings designed for vertical load may not have the capacity to resist the lateral loads. The lateral loads are the premier ones because in contrast to vertical load that may be assumed to increase linearly with height; lateral loads are quite variable and increase rapidly with height. Under a uniform wind and earthquake loads the overturning moment at the base is very large and varies in proportion to the square of the height of the building. The lateral loads are considerably higher in the top storey rather than the bottom storey due to which building tends to act as cantilever. These lateral forces tend to sway the frame. In many of the seismic prone areas there are several instances of failure of buildings which have not been designed for earthquake loads. All these reaction makes the study of the effect of lateral loads very important.

In general normal frame construction utilizes columns, slabs & beams. However it may be possible to undertake construction without providing beams, in such a case the frame system would consist of slab and column without beams. These types of slabs are called flat slab, since their behavior resembles the bending of flat plates.

Pure rigid frame system or frame action obtained by the interaction of slabs, beam and column is not adequate. The frame alone fails to provide the required lateral stiffness for buildings taller than 15 to 20 (50m to 60m) stories. It is because of the shear taking component of deflection. Produced by the bending of columns and slab causes the building to deflect excessively. There are two ways to satisfy these requirements. First is to increase the size of members beyond and above the strength requirements and second is to change the form of structure into more rigid and stable to confine deformation. First approach has its own limits, whereas second one is more elegant which increases rigidity and stability of the structure and also confine the deformation requirement. In earthquake engineering, the structure is designed for critical force condition among the load combination. In the present study the response of multi-storey commercial reinforced concrete. Frame and r c flat slab to the lateral and vertical loads have been done.

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II. LITERATURE REVIEW

Mostly among all available literature and experimental work is based on the analytical parts of flat slab floors .seismic response of flat slab building has been a subject of discussion since many decades. A lot of research work has taken place in this field addressing all relevant issues pertaining to the modeling, analysis and construction of flat slab structures.

Park et al. (2008) found that equivalent frame method is not appropriate in accurately predicting the response of two-way

slab systems under lateral loads. Currently design .code, aci 318-05[2.1] permit the efm for the analysis of two-way slab system under gravity loads and lateral loads such as seismic loads.

Subramanian et al (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.

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. 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 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 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.

Dovich and wight et al (2005) developed an effective slab width model to describe the lateral behavior of the reinforced concrete flat slab frame with in a two dimensional non linear frame analysis.

III. STRUCTURAL DESIGN

The objectives of the design are,

- Slab Design.
- Beam Design.
- Column Design.
- Footing Design.

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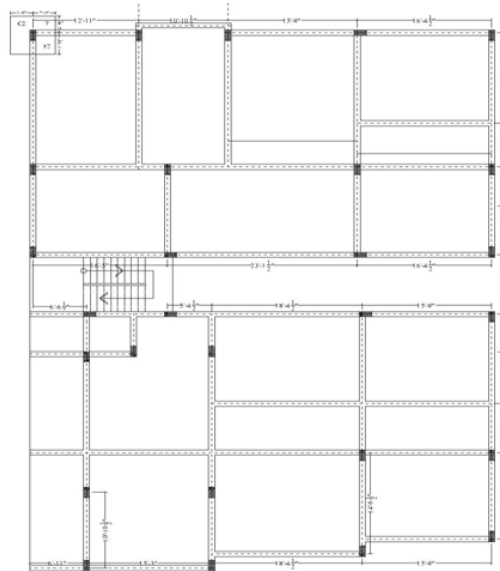


Fig 1 view of building plan

A. DESIGN OF SLAB

i) Data:-

Clear span = 4.83 m

Wall thickness = 0.23 m

Live load = 2 kn/m²

Floor finish = 1 kn/m²

F_{ck} = 20 kn/m²

F_y = 415 kn/m²

dx = 4.83 m, dy = 6.02 m

dy/dx = 6.02/4.83 = 1.246 < 2

hence the slab is to be designed as a two way slab.

ii) Thickness of slab :-

Assume effective depth = span/28

$$= 4830/28$$

$$d = 172.5 \text{ say } 175 \text{ mm}$$

Adopting clear cover 20 mm & using 10 mm bars

Overall depth ; D = 175 + 20 + 10/2

$$D = 200 \text{ mm}$$

iii) Effective span:-

Least of the following,

$$L_x = 4.83 + 0.175 = 5.005 \text{ m}$$

$$L_y = 6.02 + 0.175 = 6.195 \text{ m}$$

$$L_y/L_x = 6.195/5.005 = 1.238$$

iv) Loads :-

$$\text{Self wt of slab} = 0.200 \times 1 \times 25$$

$$= 5 \text{ kn/m}^2$$

$$\text{Live load} = 2 \text{ kn/m}^2$$

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Floor finish = 1 kn/m²
Total load = 8 kn/m²
Factored load (Wu) = 1.5 × 8 = 12 kn/m²

v) Design moments & shear forces :-

The slab is simply supported on all the four sides. The corners are not held down. Hence moment coefficients are obtained from table 27 of IS 456.

$\alpha_x = 0.074$
 $\alpha_y = 0.056$
 $M_{ux} = \alpha_x \omega l_x^2$
 $= 0.074 \times 12 \times 5.005^2$
 $= 22.24 \text{ kn-m}$

$M_{uy} = \alpha_y \omega l_y^2$
 $= 0.056 \times 12 \times 5.005^2$
 $= 16.83 \text{ kn-m}$

Factored shear force (Vu) = Wu.l/2
 $= 12 \times 5.005 / 2$
 $= 30.03 \text{ KN}$

vi) Min depth required :-

The minimum depth required to resist the bending moment

$M_u = 0.138 f_{ck} b d^2$
 $22.24 \times 10^6 = 0.138 \times 20 \times 1000 \times d^2$
 $d = \sqrt{(22.24 \times 10^6 / 0.138 \times 20 \times 1000)}$
 $d = 89.76 \text{ mm} < 175 \text{ mm}$

vii) Reinforcement :-

Along x- direction

$M_{ux} = 0.87 f_y A_{st} d (1 - f_y A_{st} / f_{ck} b d)$
 $22.24 \times 10^6 = 0.87 \times 415 \times A_{st} \times 175 (1 - 415 \times A_{st} / 20 \times 1000 \times 175)$
 $A_{st} = 368.05 \text{ mm}^2$

Using 8 mm dia bars , spacing of bars

$S = a_{st} / A_{st} \times 1000$
 $= (\pi / 4 \times 8^2) / 368.05 \times 1000$
 $= 136.57 \text{ mm say } 130 \text{ mm}$

Maximum spacing is (1) $3d = 3 \times 175 = 525 \text{ mm}$

(2) 300 mm whichever is less

Hence, provide 8 mm bars at 130 mm c/c

Along y-direction

These bars will be placed above the bars in x-direction

Hence, $d = 175 - 8 = 167 \text{ mm}$

$M_{uy} = 0.87 f_y A_{st} d (1 - f_y A_{st} / f_{ck} b d)$
 $16.83 \times 10^6 = 0.87 \times 415 \times A_{st} \times 167 (1 - 415 A_{st} / 20 \times 1000 \times 167)$
 $A_{st} = 289.54 \text{ mm}^2$

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Using 8 mm dia bars, spacing of bars

$$S = a_{st}/A_{st} \times 1000$$

$$= (\pi/4 \times 8^2) / 289.54 \times 1000$$

$$= 173.6 \text{ mm say } 170 \text{ mm}$$

Max. spacing is (1) $3d = 3 \times 167 = 501 \text{ mm}$

(2) 300 mm whichever is less

Hence, provide 8 mm bars at 170 mm c/c

viii) Reinforcement in Edge strip :-

$A_{st} = 0.12\%$ of gross area

$$= 0.12/100 \times 1000 \times 200$$

$$A_{st} = 240 \text{ mm}^2$$

Using 8 mm dia bars, spacing of bars

$$S = a_{st}/A_{st} \times 1000$$

$$= (\pi/4 \times 8^2) / 240 \times 1000$$

$$= 209.44 \text{ mm say } 200 \text{ mm}$$

Max. Spacing is (1) $5d = 5 \times 175 = 875 \text{ mm}$

(2) 450 mm whichever is less

Hence provide 8 mm bars at 200 mm c/c in edge strips in both directions

ix) Torsion Reinforcement :-

Area of reinforcement in each layer

$$A_t = \frac{3}{4} A_{stx} = \frac{3}{4} \times 368.05 = 276.04 \text{ mm}^2$$

Distance over which Torsion reinforcement is to be provided = $1/5$ short span

$$= 1/5 l_x$$

$$= 5005/5$$

$$= 1001 \text{ mm}$$

Using 6 mm bars, spacing

$$S = a_{st}/A_{st} \times 1000$$

$$= (\pi/4 \times 6^2) / 276.04 \times 1000$$

$$= 102.43 \text{ mm say } 100 \text{ mm}$$

Hence provide 6 mm bars at 100mm c/c at all the four corners in four layers

x) Check for deflection :-

For simply supported slabs basic value of l/d ratio = 20

Modification factor tension steel F_l

% of steel,

$$= A_{st}/bd \times 100$$

$$= (368.05/1000 \times 175) \times 100$$

$$= 0.21 \%$$

$$F_s = 0.58 \times f_y = 0.58 \times 415 = 240 \text{ N/mm}^2$$

From fig 4 of IS 456, modification factor = 1.5

Maximum permitted l/d ratio = $1.5 \times 20 = 30$

$$L/d \text{ provided} = 5005/175 = 28.6 < 30$$

Hence deflection control is safe

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B. DESIGN OF BEAMS

1) Data:

$f_{ck} = 20\text{N/mm}^2$
 $f_y = 415\text{N/mm}^2$
 $l = 6.02\text{N/mm}^2$

2) Depth of beam :

Selecting the depth in range of $l/12$ to $l/15$ based on stiffness

$$d = 6020/15 \\ = 401.33\text{mm}$$

Adopt $d = 410\text{mm}$

$$D = 450\text{ mm}$$

3) Effective span:

C/c distance between the supports = $6.02 + 0.23$
 $= 6.25\text{m}$

Clear span + $d = 6.02 + 0.41$
 $= 6.43\text{m}$

Hence effective span = 6.25m

4) loads :-

Self weight of the beam = $0.23 \times 0.45 \times 1 \times 25$
 $= 2.58\text{kn/m}^2$

Load from slab = 8kn/m^2

Total load = 10.58kn/m^2

Factored load = $1.5 \times 10.58 = 15.87\text{kn/m}$

5) factored B.M (Mu) & S.F:-

$$\text{Factored B.M (Mu)} = Wl^2/8 \\ = 15.62 \times 6.25^2 \\ = 77.548\text{kn-m}$$

$$\text{Factored s.f (Vu)} = Wl/2 \\ = 15.882 \times 6.25 \\ = 49.63\text{kn}$$

6) Depth required:-

The min depth req to resist b.m

$$Mu = 0.138F_{ck}bd^2$$

$$77.548 \times 10^6 = 0.138 \times 20 \times 250 \times d^2$$

$$D = 349.5 < 410\text{mm}$$

Hence ok

7) Tension reinforcement:-

$$Mu = 0.87 F_y A_{st} d (1 - F_y A_{st})$$

$F_{ck}bd$

$$A_{st} = 0.87 \times 415 \times A_{st} \times 410 (1 - 415 \times A_{st}) \\ 20 \times 230 \times 410$$

$$A_{st} = 604.19\text{mm}^2$$

Provide 4 bars of 16ϕ bars

$$A_{st} \text{ provided} = 804.248\text{mm}^2$$

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8) design shear stress :-

$$\begin{aligned}\text{Nominal shear stress (T}_v\text{)} &= V_u/bd \\ &= 49.63 \times 10^3 / 230 \times 410\end{aligned}$$

C. DESIGN OF COLUMN

$$\text{Load from beam} = 76.765 \text{ KN}$$

$$\text{Self wt of column} = 0.23 \times 1 \times 25 = 5.75 \text{ Kn/m}$$

$$\text{Total load} = 82.515 \text{ Kn/m}$$

$$\text{Factored load (w}_u\text{)} = 1.5 \times 82.515 = 123.77 \text{ Kn/m}$$

$$\text{Length of column} = 3.0 \text{ m}$$

$$\text{Left} = 0.65 \text{ l}$$

$$= 0.65 \times 3000$$

$$= 1950 \text{ mm}$$

Check type of the column,

$$1950/230 = 8.478 < 12$$

Hence designed as a short column.

$$\text{Side of the column on one side} = 230 \text{ mm}$$

Net gross area of column is — A_g

Assuming 1% of steel,

$$A_{sc} = 1\% A_g = 0.01 A_g$$

$$\text{Area of concrete, } A_c = A_g - A_{sc} = A_g - 0.01 A_g = 0.99 A_g$$

For axially loaded short columns,

$$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$$

$$123.77 \times 10^3 = 0.4 \times 20 \times 0.99 A_g + 0.67 \times 415 \times 0.01 A_g$$

$$A_g = 115667.5 \text{ mm}^2$$

Since the column is rectangular & one side of the column is 230 mm, dimension of the other side

$$A_g/230 = 115667.5/230 = 502.9 \text{ mm say } 500 \text{ mm}$$

Adopt 230 mm × 500 mm rectangular column,

$$A_{sc} = 0.01 A_g = 0.01 \times 115667.5$$

$$= 1156.675 \text{ mm}^2$$

Provide 6 mm bars of 16 mm diameter,

$$A_{sc} \text{ provided} = 1206.4 \text{ mm}^2$$

Lateral ties :-

$$\text{a) } \phi/4 = \frac{1}{4} \times 16 = 4 \text{ mm}$$

$$\text{b) } 6 \text{ mm}$$

Hence, adopt 6 mm diameter bars

Pitch of the ties shall be minimum of

$$\text{a) least lateral dimension of column} = 230 \text{ mm}$$

$$\text{b) } 16 \text{ times of the dia of longitudinal bar} = 16 \times 16 \\ = 256 \text{ mm}$$

$$\text{c) } 300 \text{ mm}$$

D. DESIGN OF FOOTING

a) Data :-

$$\text{Axial load} = 307.068 \text{ KN}$$

$$\text{Size of the column} = 280 \times 500 \text{ mm}$$

$$\text{S.B.C of soil} = 200 \text{ kn/m}^2$$

$$F_{ck} = 20 \text{ kn/m}^2$$

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$F_y = 415\text{kn}$

1) Size of footing:

Load from the column = 307.068kn

Self wt from of footing = 10% of column load = 307.068/10

Total load on the soil = 337.775kn

Area of footing = $337.775/200 = 1.689\text{m}^2$

Provide 1.2×1.5m footing so that the cantilever projection of the footing from the column face is same equal to

$$\left(\frac{1.2-0.23}{2}\right) = \left(\frac{1.5-0.5}{2}\right) = 0.5\text{mm}$$

Area of footing provided = 1.2×1.5mm

2) Upward soil pressure:

Factored load $P_u = 1.5 \times 307.068$

= 460.602kn

Soil pressure at ultimate load =

$Q_u = P_u/\text{area of footing}$

$Q_u = P_u / \text{area of footing}$

$Q_u = 460.602 / 1.2 \times 1.5$

= 255.89kn/m²

= 0.26n/mm

3) Depth of footing from B.M consideration:

The c critical section for B.M will be at the face of the column as shown $M_u = qul (B-b/8)^2$

= $0.16 \times 1500(1200-230/8)^2$

= $5.733 \times 10^6 \text{N-mm}$

4) Reinforcement:

$M_u = 0.87 F_y \times 415 \times A_{st} \times 450 (1 - 415 A_{st} / 20 \times 1500 \times 250)$

$A_{st} = 557.25\text{mm}^2$

Using 16mm diameter bars, spacing of bars

$S = a_{st} \times B / A_{st}$

= 304.42mm

Hence provide 12mm bars at 300mm/c

5) Check for one way shear:

The critical section for one way shear is at a dist d from the face of the column as shown in the fig ;

Fact S.F = $V_u = \text{soil pressure from the shaded area.}$

D. COMPONENTS OF DROP DESIGN

1) column strip : column strip means a design strip having a width of 0.25 l_1 , but not greater than 0.25 l_1 , on each side of the column centre-line, where l_1 is the span in the direction moments are being determined, measured centre to centre of supports and l_2 is the -span transverse to l_1 , measured centre to centre of supports.

2) middle strip : middle strip means a design strip bounded on each of its opposite sides by the column strip.

3) panel: panel means that part of a slab bounded on each of its four sides by the centre -line of a column or centre-lines of adjacent-spans.

Divisions into column and middle strip along:

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Longer span	Shorter span
$L_1=22.8\text{ m}, L_2=17.4\text{ m}$	$L_1=17.4\text{ m}, L_2=22.8\text{ m}$
i. Column strip $=0.25L_2=4.4\text{ m}$	i. Column strip $=0.25L_2=5.7\text{ m}$
But not greater than $0.25 L_1=5.7\text{ m}$	But not greater than $0.25 L_1=4.4\text{ m}$
ii. Middle strip $=17.4-(5.7+5.7)=6\text{ m}$	ii. Middle strip $=22.8-(4.4+4.4)=14\text{ m}$

the drops when provided shall be rectangular in plan, and have a length in each direction not less than one- third of the panel length in that direction. For exterior panels, the width of drops at right angles to the non- continuous edge and measured from the centre -line of the columns shall be equal to one –half the width of drop for interior panels. Since the span is large it is desirable to provide drop.

Drop dimensions along:

Longer span	Shorter span
$L_1=22.8\text{ m}, L_2=17.4\text{ m}$	$L_1=17.4\text{ m}, L_2=22.8\text{ m}$
Not less than $L_1/3 = 7.6\text{ m}$	Not less than $L_1/3 = 5.8\text{ m}$

Hence provide a drop of size 7.6 X 7.6 m i.e. in column strip width.

4) column head :

Where column heads are provided, that portion of a column head which lies within the largest right circular cone or pyramid that has a vertex angle of 90° and can be included entirely within the outlines of the column and the column head, shall be considered for design purposes

Column head dimension along:

Longer span	Shorter span
$L_1=22.8\text{ m}, L_2=17.4\text{ m}$	$L_1=17.4\text{ m}, L_2=22.8\text{ m}$
Not less than $L_1/4 = 5.7\text{ m}$	Not less than $L_1/4 = 4.35\text{ m}$

Adopting the diameter of column head = 1.30 m =1300 mm

5) Drops :

The drops when provided shall be rectangular in plan, and have a length in each direction not less than one third of

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the panel in that direction. For exterior panels, the width of drops at right angles to the non continuous edge and measured from the centre-line of the columns shall be equal to one half of the width of drop for interior panels.

6) Depth of flat slab:

The thickness of the flat slab up to spans of 10 m shall be generally controlled by considerations of span (l) to effective depth (d) ratios given as below:

- Cantilever 7;
- Simply supported 20;
- Continuous 26

For slabs with drops, span to effective depth ratios given above shall be applied directly; otherwise the span to effective depth ratios in accordance with above shall be multiplied by 0.9. For this purpose, the longer span of the panel shall be considered. The minimum thickness of slab shall be 125 mm.

Considering the flat slab as a continuous slab over a span not exceeding 10 m

$$\frac{L}{d} = 26 \rightarrow d = \frac{L}{26}$$

Depth considering along:

Longer span	Shorter span
$L_1=22.8\text{m}, L_2=17.4\text{m}$ $d = \frac{L}{26} = \frac{2280}{26} = 256.7 \text{ mm}$	$L_1=17.4\text{m}, L_2=22.8\text{m}$ $d = \frac{L}{26} = \frac{1740}{26} = 215.4 \text{ mm}$
Say 260 mm	Say 220 mm

Taking effective depth of 25mm

- Overall depth $d = 260 + 25 = 285 \text{ mm}$
- 125 mm (minimum slab thickness as per is: 456)
- It is safe to provide depth of 285 mm.

7) Effective depth of the slab

Thickness of the slab, from consideration of maximum positive moment anywhere in the slab.

Maximum +ve BM occurs in the column strip (long span) = 90.91 KNm

∴ factored moment = $1.50 \times 90.91 = 136.36 \text{ KNm}$

$$M_o = 0.138 f_{ck} b d^2 \quad (b = 2800 \text{ mm})$$

$$d = \sqrt{\frac{136.36 \times 10^6}{0.138 \times 20 \times 2800}}$$

$$d = 132.83 = 140 \text{ mm}$$

Using 12 mm ϕ (diameter) main bars.

$$\text{Overall thickness of slab} = 140 + 15 + \frac{12}{2} = 161 \phi 170 \text{ mm}$$

$$\therefore \text{Depth (a long longitudinal direction)} = 175 - 15 - \frac{12}{2} = 150 \text{ mm}$$

$$\therefore \text{Depth (a long longitudinal direction)} = 150 - 12 = 130 \text{ mm}$$

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8) Thickness of drop

Thickness of drop from maximum –ve moment consideration Thickness of drop from consideration of maximum –ve moment anywhere in the panel. Max –ve BM occurs in the column strip = 1622.8 KNm

$$M_u = 0.138 f_{ck} b d^2 \quad (b = 2800 \text{ mm})$$

$$1.5 \times 1622.8 \times 10^6 = 0.138 \times 20 \times 1400 \times d^2$$

$$d = 254.3 \text{ mm}$$

Say 260 mm. Use 12 mm \emptyset bars

$$\text{Over all thickness of flat slab : } D = 260 + \frac{12}{2} = 281 \text{ mm}$$

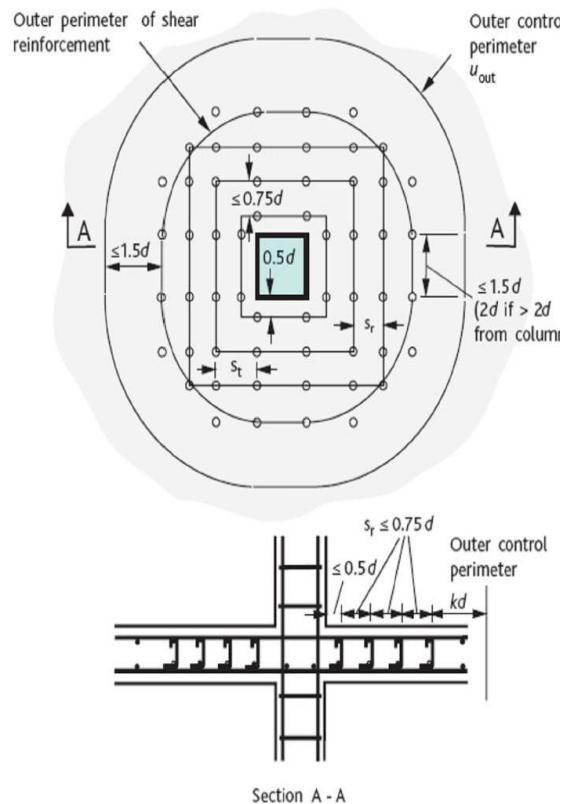


Figure 2 Drop reinforcement details

IV. CONCLUSION

- Flat plate/slab construction is a developing technology in India flat slabs has many advantages over conventional slabs and hence it can be a very good option for modern constructions demanding structural stability and state of art aesthetic aspects and prospects.
- Flat plate/slab can be designed and built either by conventional reinforced concrete. or post-tensioning. However, due to issues mentioned above with post-tensioning construction in India and its higher cost, conventional reinforced concrete design should be the preferred choice for spans up to 10 meters.
- Design of conventional reinforced concrete. flat plate/slab in India, utilizing Indian codes, has many shortcomings, which have to be addressed and revised soon.

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