CHAPTER 11

Slab

CONTENTS

11. Slab

11.1 Introduction:

Slab is a structural member of which one dimension is very small as compared to other two dimensions and primarilly subjected to bending.

11.2 Classification of Slab:

A) Based on Shape:

1. Rectangular
2. Circular
3. Triangular
4. Any other shape.

B) Based on Bending behaviour.

1. One-way slab.
2. Two-way slab.

C) Based on Type of Construction:

1. Slab/Solid slab.
2. Flat slab.
3. Slab with opening.
4. Waffled Slab.

D) Based on Type of Loading:

1. Subjected to point load. (Bridge slab)
2. Subjected to UDL

In this chapter, analysis and design of solid rectangular, one-way and two way slab subjected to udl are going to be discussed.

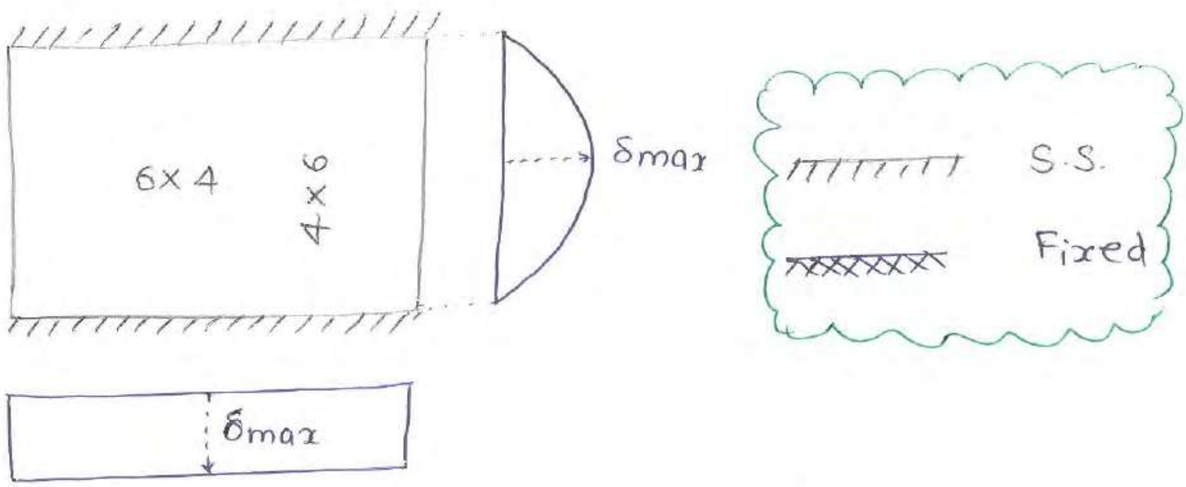
11.3 Bending Behaviour of Slab:

Based on dominating direction of bending, slabs are classified as one way or two-way.

11.3.1 One-way Slab:

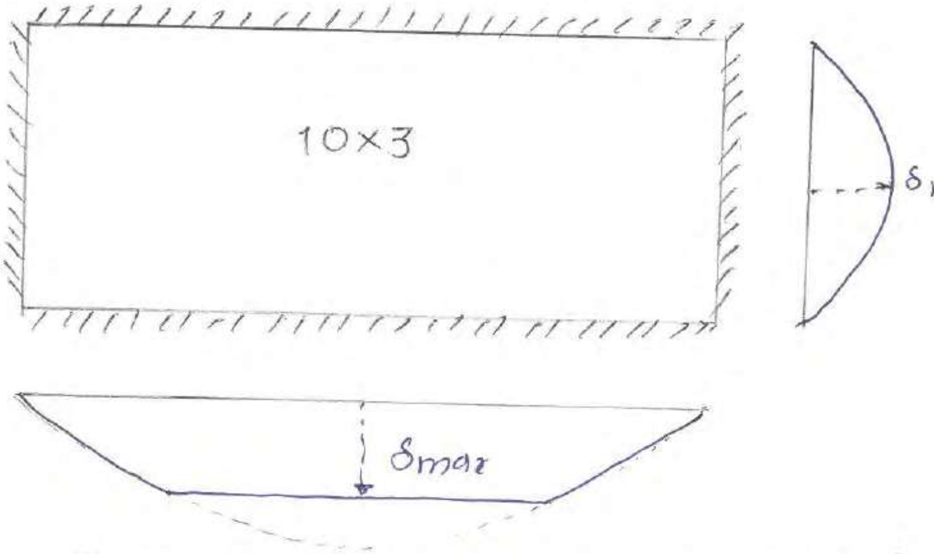
If bending in one-direction is very significant than other orthogonal direction then slab is classified as one-way.

A) Rectangular slab supported from opposite edges:



Rectangular slab supported from opposite edges is always one-way, irrespective of dimension.

B) Rectangular slab supported from all four edges.



Aspect ratio $= \frac{10}{3} = 3.33 > 2$

So, one way

A rectangular slab supported from all 4-sides is considered as one way if aspect ratio is more than 2.

$$\text{aspect ratio} = \frac{\text{Longer effective span}}{\text{Shorter effective span}}$$

$$= \frac{L_y}{L_x} > 2$$

* Note:-

Aspect ratio is valid only for rectangular slab supported from all four sides.

11.3.2 Two-way Slab:

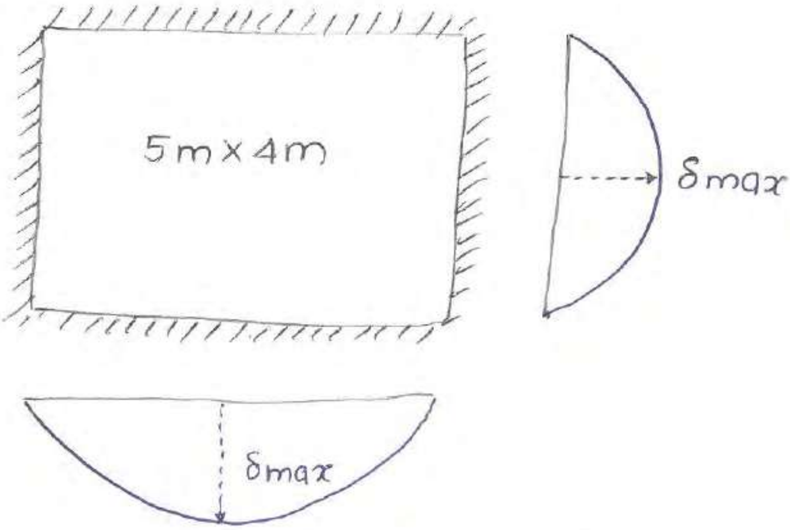
If bending is comparable in two-orthogonal directio then such slabs are called as two-way slabs.

A rectangular slab is classified as two-way based on following two-conditions.

1) Aspect Ratio:

2) Supporting condition.

If aspect ratio ≤ 2 and rectangular slab is supported from all 4-sides. then only rectangular slabs are classified as two-way.

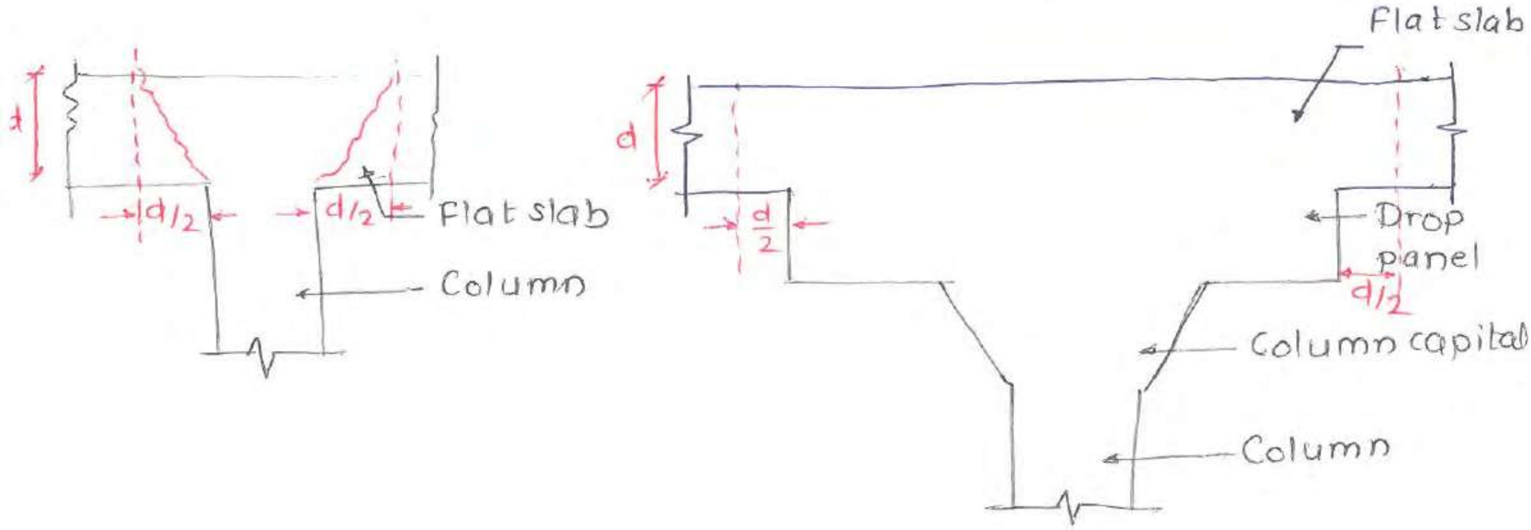


$$\text{Aspect ratio} = \frac{L_y}{L_x} = \frac{5}{4} = 1.25 < 2$$

So, Two-way

11.4 Flat slab:

It is a slab that directly rests on columns. Sometimes drop panel and or column capital are also used to prevent punching failure its behaviour is as two-way slab and thickness is invariably higher than thickness of slab in beam-slab system.



11.4.1 Reasons to Provide Flat Slab:

- For better asthetic.
- For better light dispersion.
- For ease in providing AC ducts, fire fighting ducts, electric ducts etc.
- For lesser story height

*** Note:**

Flat slabs are un-economical and can be provided for medium spans only because deflection exceeds in larger spans.

11.4.2 Codal Provisions:

- Minimum thickness 125mm
- Critical failure is punching shear failure/ two way shear failure.
- Critical section for punching shear is at a distance $\frac{d}{2}$ from face of column/drop panel / column capital.

11.5 Codal Provisions of Solid Slab:

11.5.1 Nominal Cover:

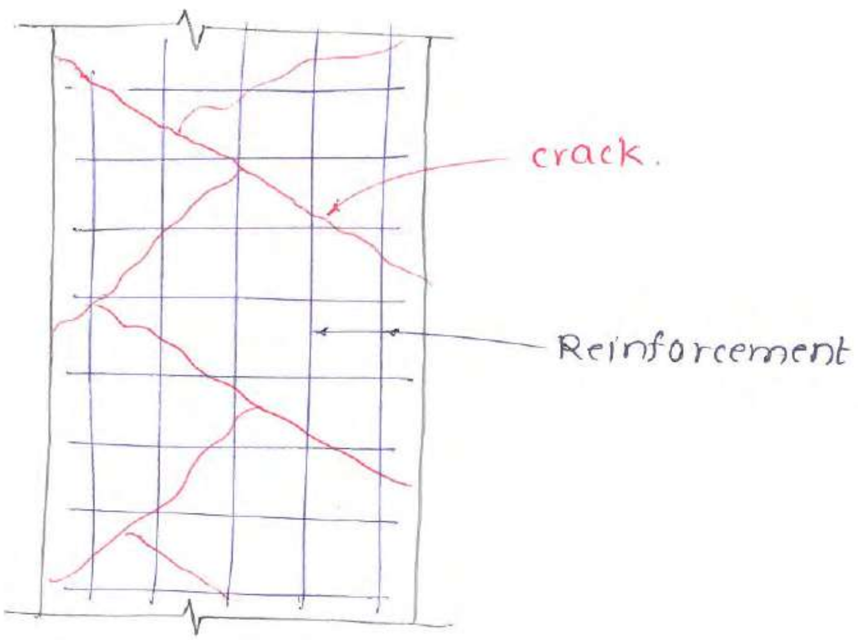
Minimum 20mm which can be reduced to 15mm for mild exposure and bar dia 12mm or less.

11.5.2 Reinforcement:

- Dia $\not> \frac{D}{8}$
- Minimum reinforcement
  - 0.15% of gross area for mild steel
  - 0.12% of gross area for HYSD.

*Note:-

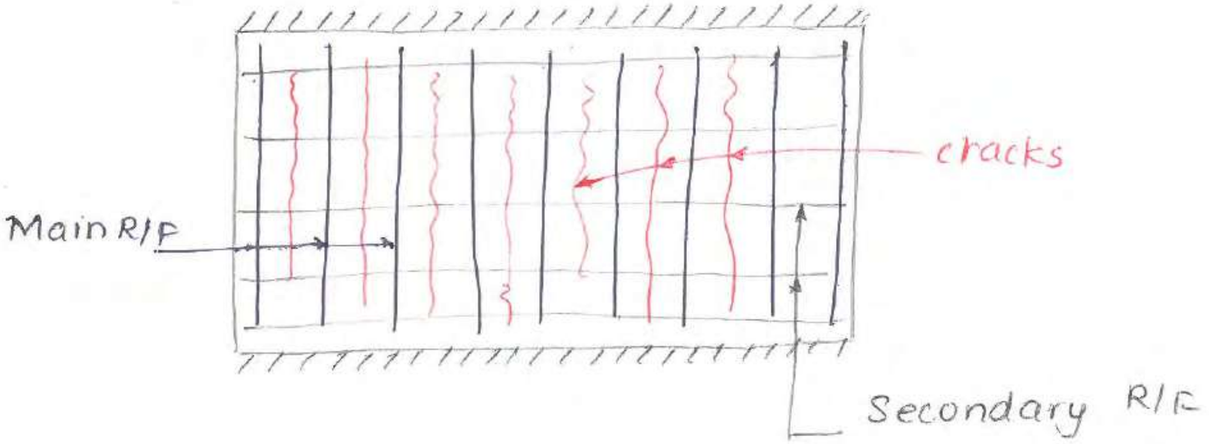
- This minimum value is for both orthogonal directions.
- This is provided to take care of shrinkage & temp. effect.



Pathway of concrete.

- Maximum spacing of main bars should not be more than 3d or 300mm whichever is less

- Maximum spacing of secondary/distribution reinforcement should not be more than 5d or 300mm whichever is less (before amrnendment 4, this value of 450mm)



- Main bars are always provided in bottommost layer

11.5.3 Deflection Control:

If rectangular two way slab is supported from all 4-sides with shorter span upto 3.5m and loading upto 3 kN/m² then $\frac{L_{eff}}{D}$ ratio should be less than values given below.

Supporting condition	Fe 250	Fe 415
• Simply supported	35	$0.8 \times 35 = 28$
• Continuous	40	$0.8 \times 40 = 32$

* Note:

• Fe 250

$\frac{L_{eff}}{D} < 35$

$\Rightarrow D > \frac{L_{eff}}{35}$

• Fe 415

$\frac{L_{eff}}{D} < 28$

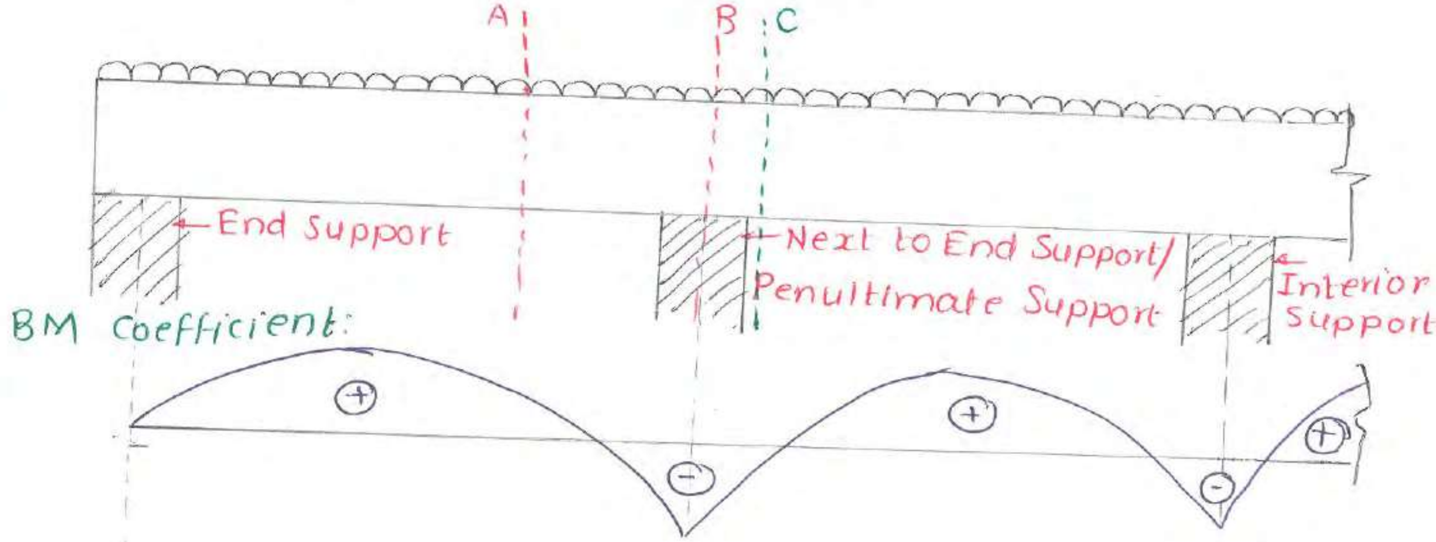
$\Rightarrow D > \frac{L_{eff}}{28}$

- From above calculation, it is clear that depth requirement to satisfy deflection criteria is more for HYSD ~~fe~~ than mild steel it means HYSD produces more deflection than mild steel.
- If rectangular slab is supported from all 4-sides then shorter span is always used in BM calculation and in above calculation.

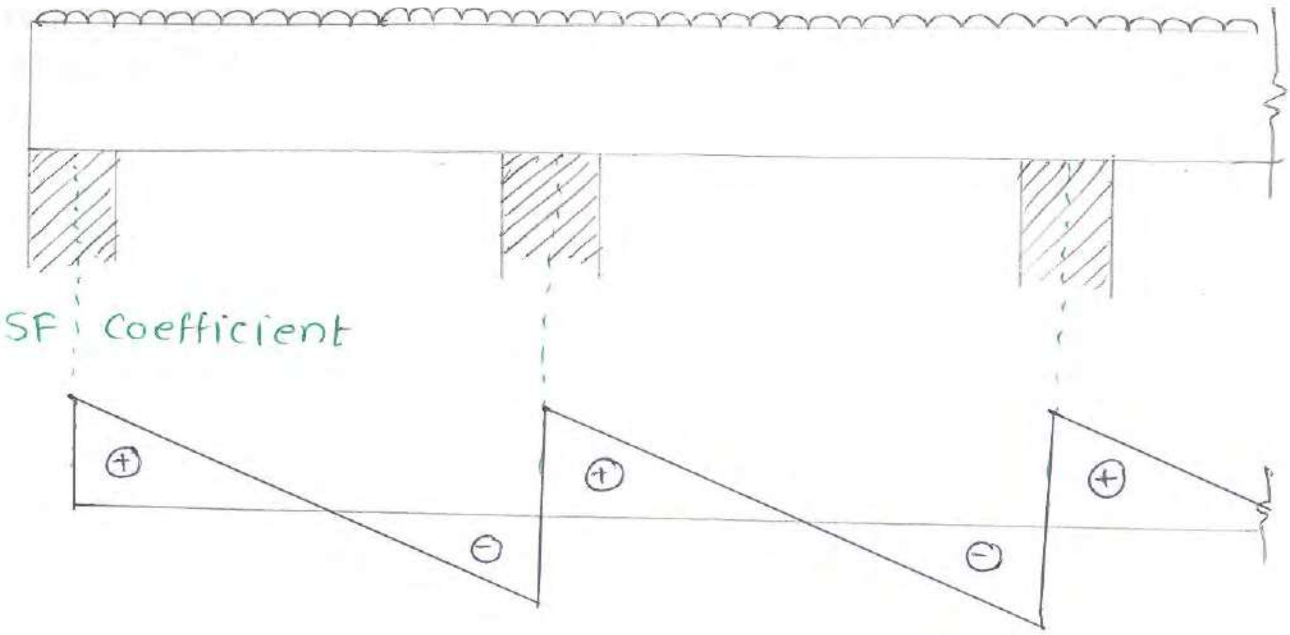
11.5.4 Bending Moment and Shear Force Coefficients:

Continuous beams and slabs are very common in a structure and lot of calculation is required to get positive and negative design BM. To simplify this, IS456 provides a table of BM and SF coefficients. These coefficients can be used if following conditions are satisfied.

1. Must be uniformly loaded.
2. Difference between longer and shorter span should not be more than 15% of longer span.
3. Spans should be 3 or more.



Fixed Load	$+1/12$	$-1/10$	$+1/16$	$-1/12$
Non Fixed Load	$+1/10$	$-1/9$	$+1/12$	$-1/9$



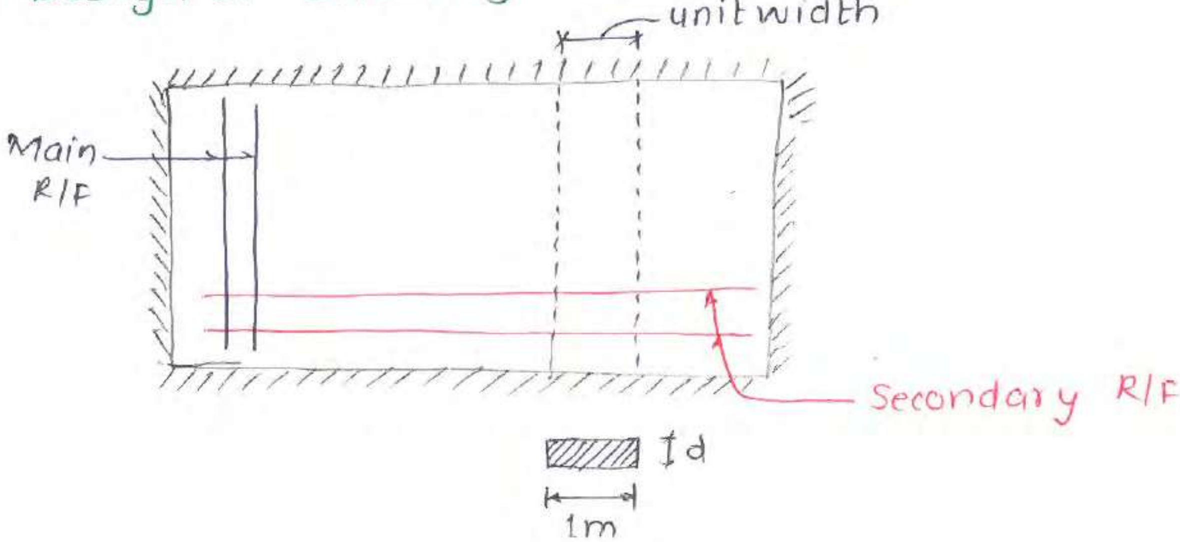
Fixed load	0.4	0.6	0.55	0.5	0.5
Non-fixed Load	0.45	0.6	0.6	0.6	0.6

$$BM_A = +\frac{1}{12} W_F L_{eff}^2 + \frac{1}{10} W_{NF} L_{eff}^2$$

$$BM_B = -\frac{1}{10} W_F L_{eff}^2 - \frac{1}{9} W_{NF} L_{eff}^2$$

$$SF_C = 0.55 W_F L_{clear} + 0.6 W_{NF} L_{clear}$$

11.6 Design of One-way Slab:



One way slab is designed by considering a strip of unit width.

Step 1: Assume suitable value of 'd' for preliminary design.

$$\frac{l_{eff}}{d} < k_1 k_2 k_3 k_4 \text{ (value)}$$

k_1 = depends on span

$k_2 = 1.25$ (corresponding to generally provided % of tension R/F)

$k_3 = 1$ (Singly R/F)

$k_4 = 1$ (Rectangular)

Calculate D by assuming suitable value of effective cover.

Step 2: Calculate Effective span.

Step 3: Calculate DL and design BM. Use BM co-efficient for continuous slab.

Step 4: Calculate 'd' required for balanced section.

$BM_u = M_{u,lim}$

$\Rightarrow BM_u = Q b d^2$

$\Rightarrow d = ??$

where, b = 1000 mm

d calculated here should be less than 'd' assumed in Step 1. otherwise d suitably higher than calculated here and repeat Step 2 to Step 4.

Step 5: Since, 'd' provided is greater than d required in Step 4 so section is under reinforced.

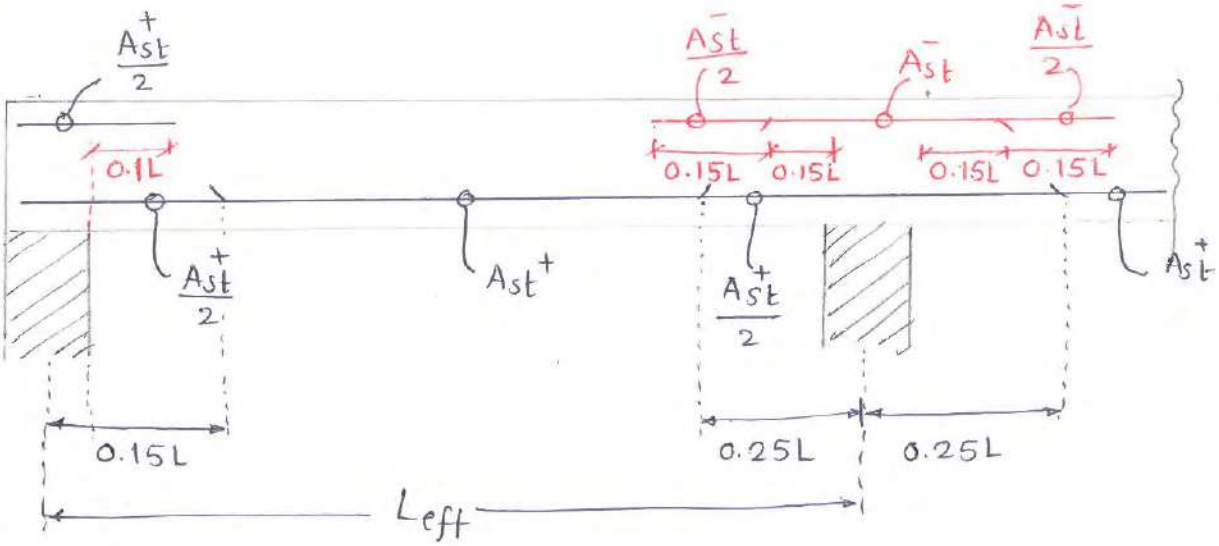
$$A_{st} = \frac{0.5 f_{ck} b d}{f_y}\left[1 - \sqrt{1 - \frac{4.6\, BM_u}{f_{ck} b d^2}}\right]$$

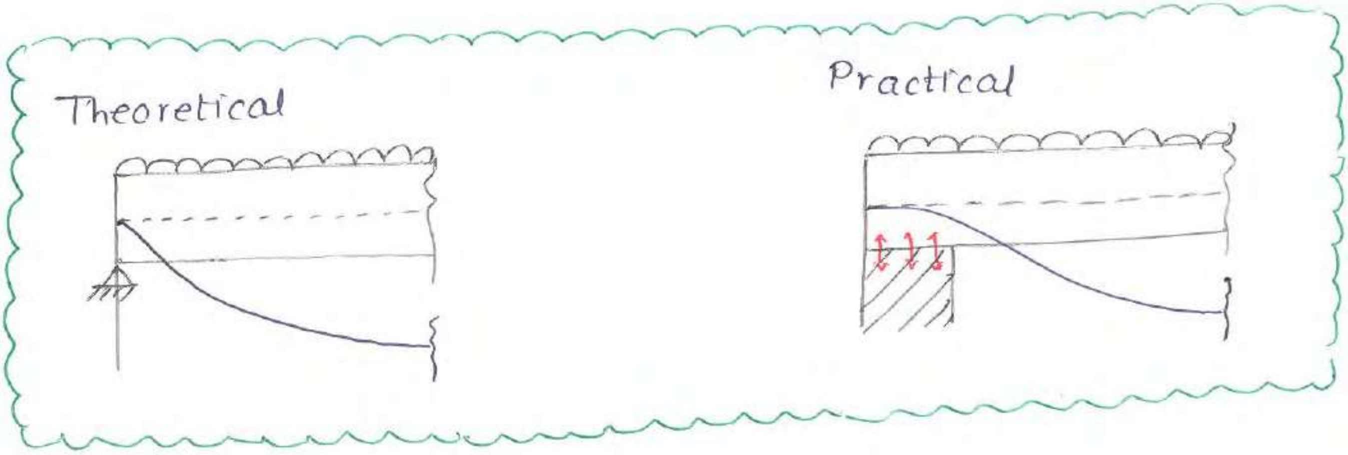
where, b = 1000 mm

Step 6: Ast calculated above should not be less than $A_{st,min}$

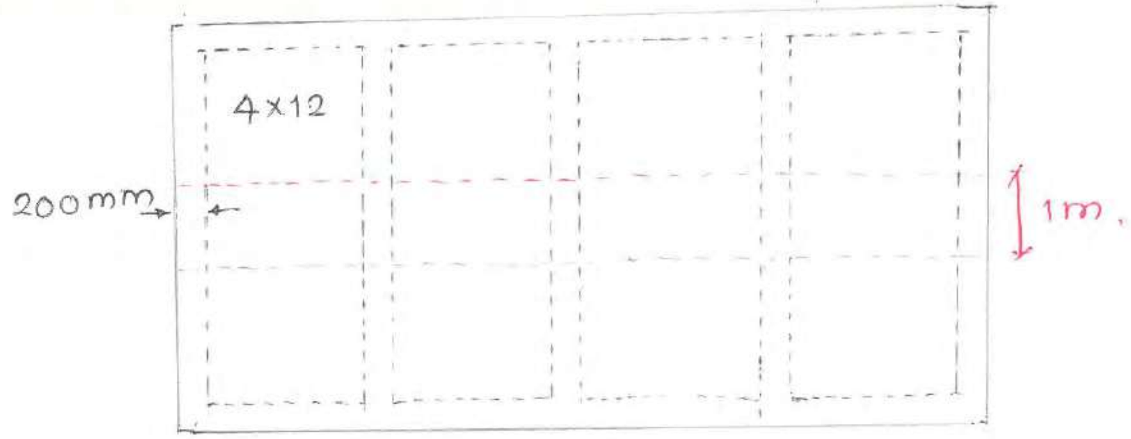
Step 7: Provide distribution reinforcement

Step 8: Reinforcement detailing.





Ex. Design the slab given below. LL is 6 kN/m², FF 65 mm thick, unit weight of floor F. (FF) 22 kN/m³, M20, Fe 415. mild exposure, slab is continuous over 4-equal spans.



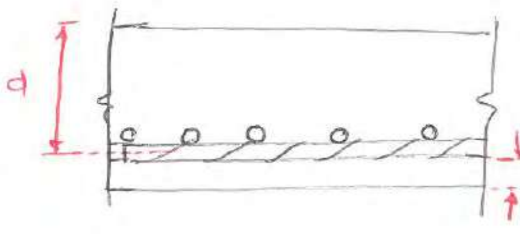
Step 1: Depth :

$$\frac{L_{eff}}{d} < K_1 K_2 K_3 K_4 \text{ (value)}$$

$$\frac{4.2\times10^3}{d} < (1)\ (1.25)(1)(1)\ \left(\frac{20+26}{2}\right)$$

$$d > 146.08\,mm$$

Assuming d = 150 mm



D = d + allowance for R/F + clear cover

= 150 + 10 (assumed) + 20 (mild exposure)

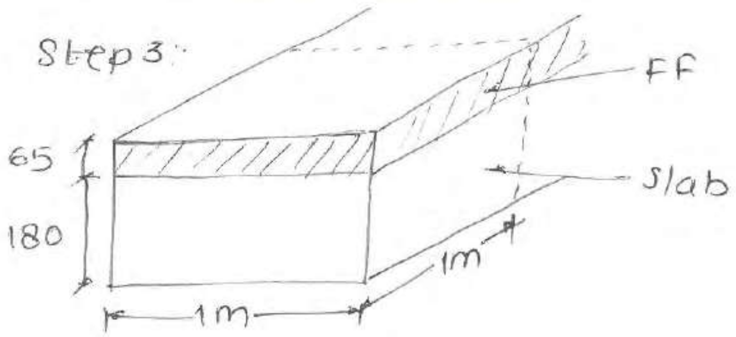
D = 180mm

Step 2: IS 456 doesn't provide L_{eff} for all types of supporting conditions. Considering simply supported as a ~~nearest~~ similar supporting condition for the present case

$$L_{eff} = \text{Minimum} \begin{cases} \bullet\ L_c + d = 4 + 0.15 = 4.15\,m \\ \bullet\ \frac{b_1}{2} + L_c + \frac{b_2}{2} = \frac{0.2}{2} + 4 + \frac{0.2}{2} = 4.2\,m \end{cases}$$

$$L_{eff} = 4.15\,m$$

Step 3:



Self weight = 0.18 × 1 × 1 × 25

= 4.5 kN/m²

FF. = 0.065 × 22 = 1.93 kN/m²

Fixed Load = 5.93 kN/m²

LL = 6 kN/m²

Factored fixed load = $1.5 \times (4 + 1.93) = 8.89\ kN/m^2$

Factored Non-fixed load = $1.5 \times 6 = 9\ kN/m^2$

$$BM_u^+ = +\frac{1}{12} W_F L_{eff}^2 + \frac{1}{10} W_{NF} L_{eff}^2$$

$$= \frac{1}{12} \times 8.89 \times (4.15)^2 + \frac{1}{10} \times 9 \times (4.15)^2$$

$BM_u^+ = 28.26\ kNm$ (Sagging)

$$BM_u^- = -\frac{1}{10} W_F L_{eff}^2 - \frac{1}{9} W_{NF} L_{eff}^2$$

$$= -\frac{1}{10} \times 8.89 \times (4.15)^2 - \frac{1}{9} \times 9 \times (4.15)^2$$

$= -32.53\ kNm$

$BM_u^- = 32.53\ kNm$ (Hogging)

Step 4: 'd' required for balanced section.

$$BM_u^- = M_{u,lim}$$

$$BM_u^- = 0.138 f_{ck} b d^2$$

$$32.53 \times 10^6 = 0.138 \times 20 \times 1000 \times d^2$$

$$d = 108.56\ mm < 150\ mm\ (Ok)$$

Step 5: Ast required

$$A_{st}^+ = \frac{0.5 f_{ck} b d}{f_y}\left[1 - \sqrt{1 - \frac{4.6\ BM_u^+}{f_{ck} b d^2}}\right]$$

$$= \frac{0.5 \times 20 \times 1000 \times 150}{415}\left[1 - \sqrt{1 - \frac{4.6 \times 28.26 \times 10^6}{20 \times 1000 \times 150^2}}\right]$$

$A_{st}^+ = 566.46\ mm^2$

Similarly

$A_{st}^- = 661.48\ mm^2$

Step 6: $A_{st,min} = 0.12\% bD$

$$= 0.12 \times \frac{1}{100} \times 1000 \times 180$$

$A_{st,min} = 216 mm^2$

Difference between A_{st}^{+} and A_{st}^{-} is not very significant so providing A_{st}^{-} for both.

$A_{st}^{-} = 661.48 mm^2$

Assuming $\phi = 10mm$

$$\text{Spacing} = \frac{1000}{\text{No. of bar}}$$

$$= \frac{1000}{A_{st}^{-} / \frac{\pi}{4}\phi^2}$$

$$= \frac{1000}{661.48 / \frac{\pi}{4} \times 10^2} = 118.73 mm$$

Providing 10ϕ @ 100

Step 7: Distribution Steel

$A_{st,min} = 0.12\% bD = 216 mm^2$

Assuming $\phi = 8mm$

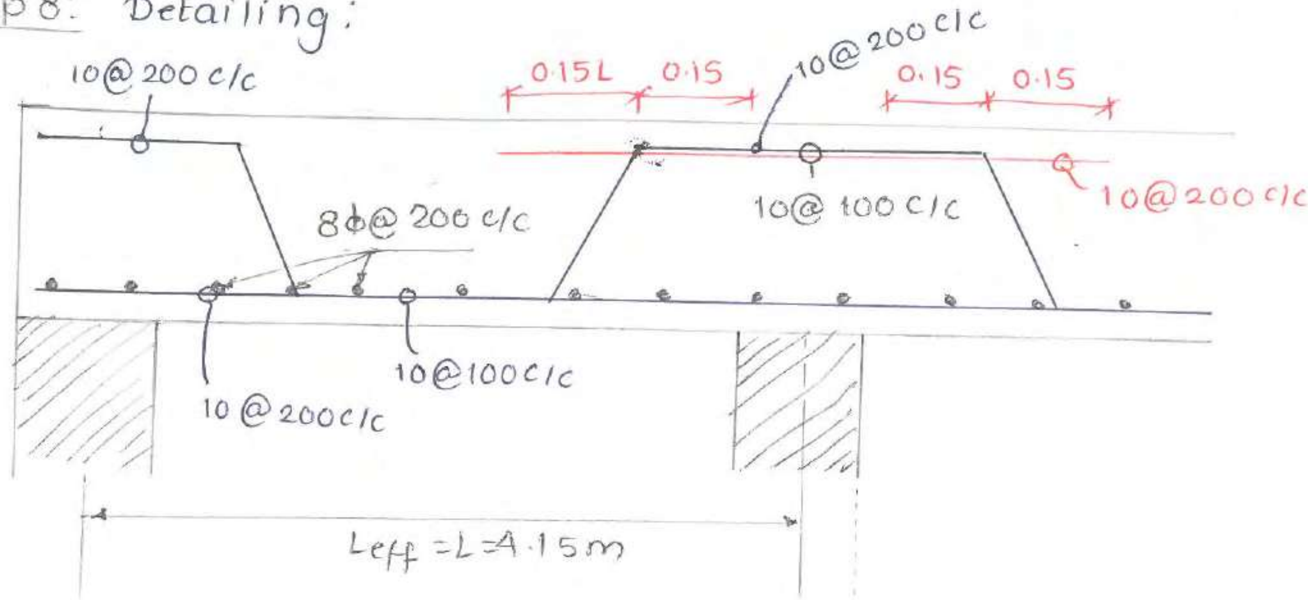
$$\text{Spacing} = \frac{1000}{\text{No. of bar}}$$

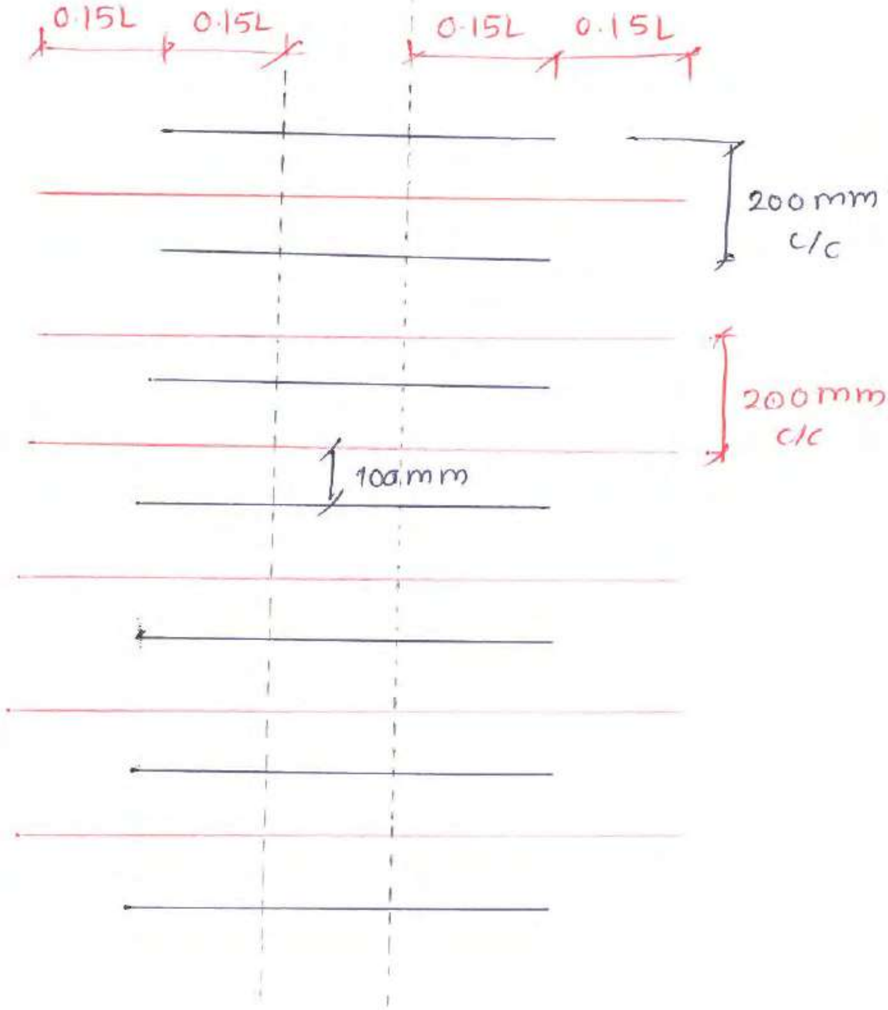
$$= \frac{1000}{A_{st,min} / \frac{\pi}{4}\phi^2}$$

$$= \frac{1000}{216 / \frac{\pi}{4} \times 8^2} = 232.71 mm$$

Providing 8ϕ @ 200 mm c/c

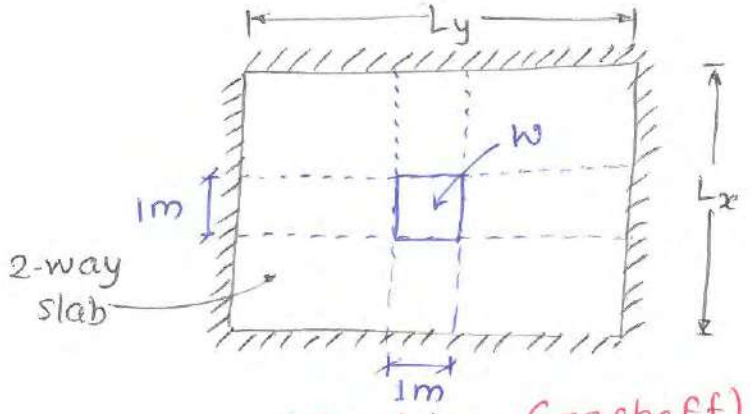
Step 8: Detailing:





11.7 Two-way Slab:

11.7.1 Analysis:



(Rankine - Grashoff)

$$w_x + w_y = w \quad \cdots\cdots (i)$$

For equal deflection of both strips

$$\frac{5}{384}\frac{w_x L_x^4}{EI} = \frac{5}{384}\frac{w_y L_y^4}{EI}$$

$$w_x L_x^4 = w_y L_y^4 \quad \cdots\cdots (ii)$$

from (i) and (ii)

$$w_x + \frac{w_x L_x^4}{EI} = w$$

$$w_x = \frac{w L_y^4}{L_x^4 + L_y^4}$$

$$\Rightarrow \quad w_x = \frac{w r^4}{1+r^4} \qquad \left(\because r = \frac{L_y}{L_x}\right)$$

Similarly,

$$\Rightarrow \quad w_y = \frac{w}{1+r^4}$$

For shorter Span

$$M_x = \frac{w_x L_x^2}{8} = \left(\frac{wr^4}{1+r^4}\right)\frac{L_x^2}{8}$$

$$= \left(\frac{1}{8}\frac{r^4}{1+r^4}\right) w L_x^2$$

$$M_x = \alpha_x w L_x^2$$

For Longer span

$$M_y = \frac{w_y L_y^2}{8}$$

$$= \left(\frac{w}{1+r^4}\right) \frac{1}{8} \frac{L_y^2}{L_x^2} L_x^2$$

$$= \left(\frac{1}{8} \cdot \frac{r^4}{1+r^4}\right) w L_x^2$$

$$M_y = \alpha_y w L_x^2$$

* Note:-

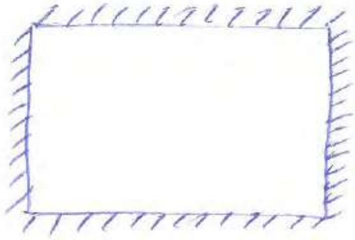
- For aspect ratio 2, M_x is 4 times higher than M_y so slab is considered as one-way for $r > 2$.
- α_x is always higher than α_y so reinforcement corresponding to M_x is provided in bottom most layer
- Value of α_x and α_y for rectangular slab simply supported ~~slab~~ from all 4-sides with corners allowed to lift, are given in Table 27 of IS 456 (Page 91)
- For restrained slab (corners are not allowed to lift), α_x and α_y were modified by Marcus. and these values were given in Table 26 of IS 456 (1978). Corrections were applied for prevension of lifting of corners and torsional effect. However α_x and α_y given in Table 26 of IS 456 (2000) are based on Yield line theory (Not on Marcus correction)

11.7.2 Types of Two-way Slab

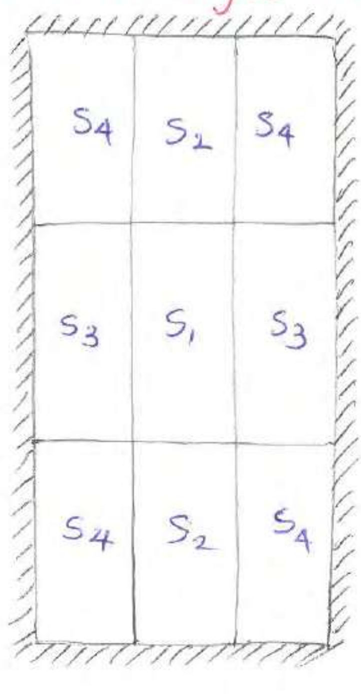
Rectangular 2-way slab
supported from all sides

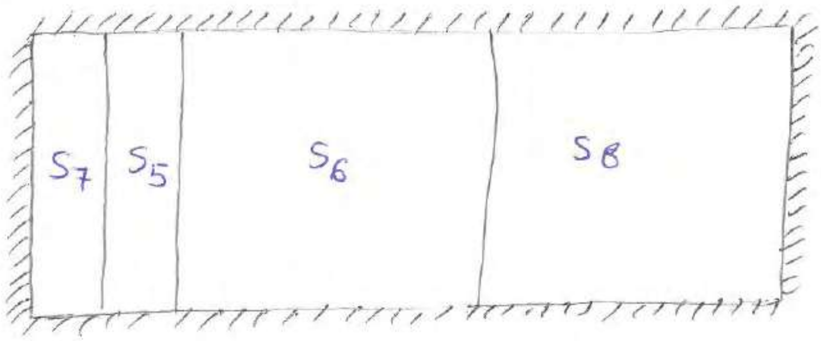
Restrained
(Corners are not allowed to lift)
9-types

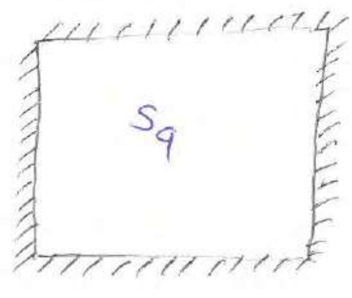
Not-Restrained.
(Corners are allowed to lift)



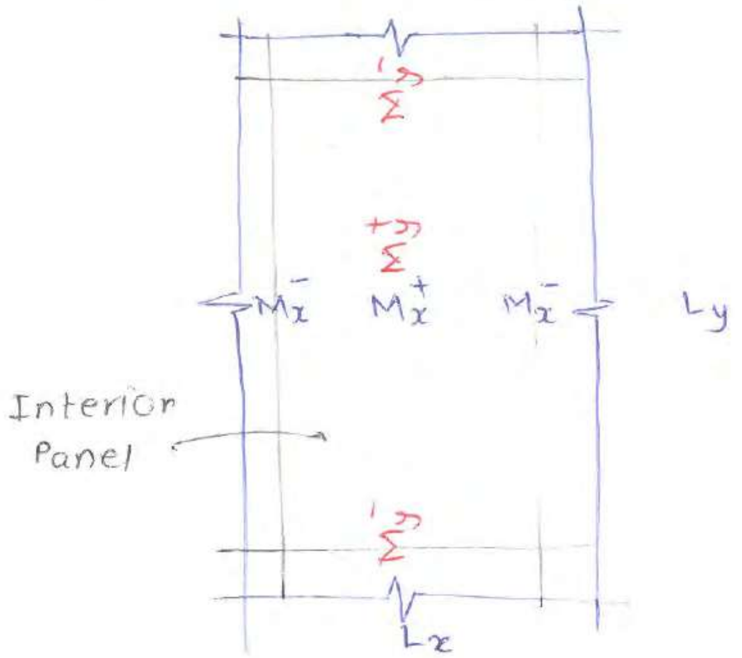
* Restrained Slab:
  1. Interior Panel
  2. One short edge discontinuous
  3. One long edge discontinuous
  4. Two adjucent edges discontinuous
  5. Two-short edges discontinuous
  6. Two-long edges discontinuous
  7. Three edges discontinuous (One long edge continuous)
  8. Three edges discontinuous (one short edge continuous)
  9. All 4-edges discontinuous



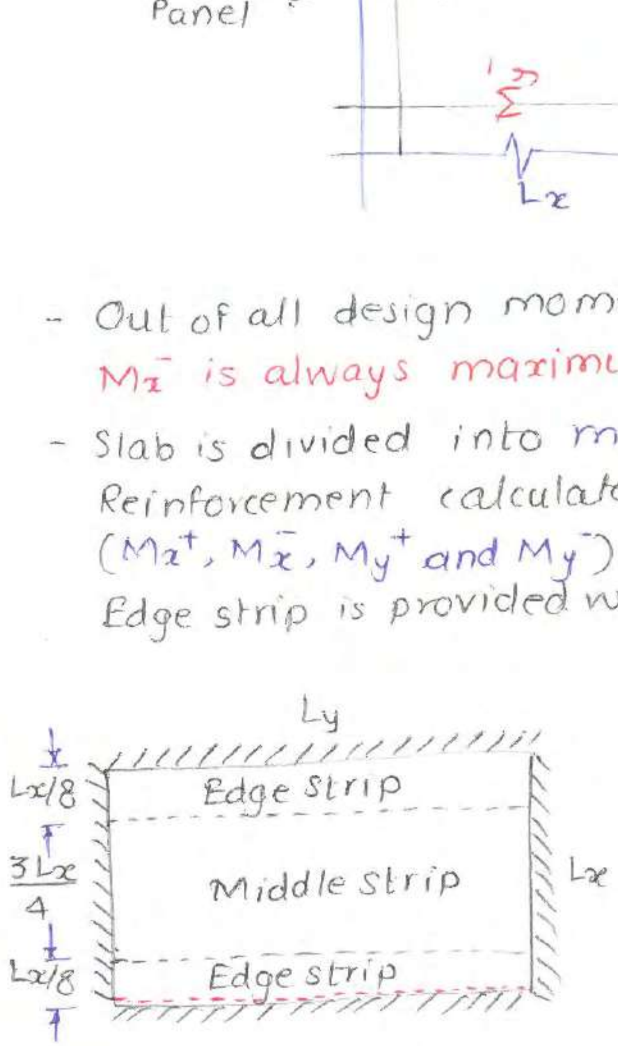


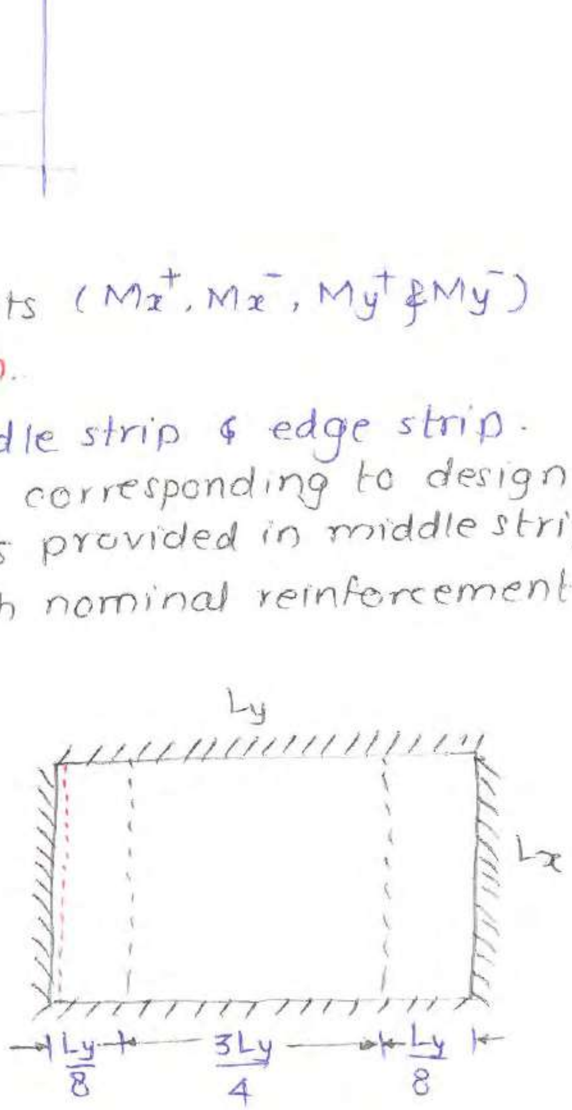


11.7.3 Reinforcement Detailing:

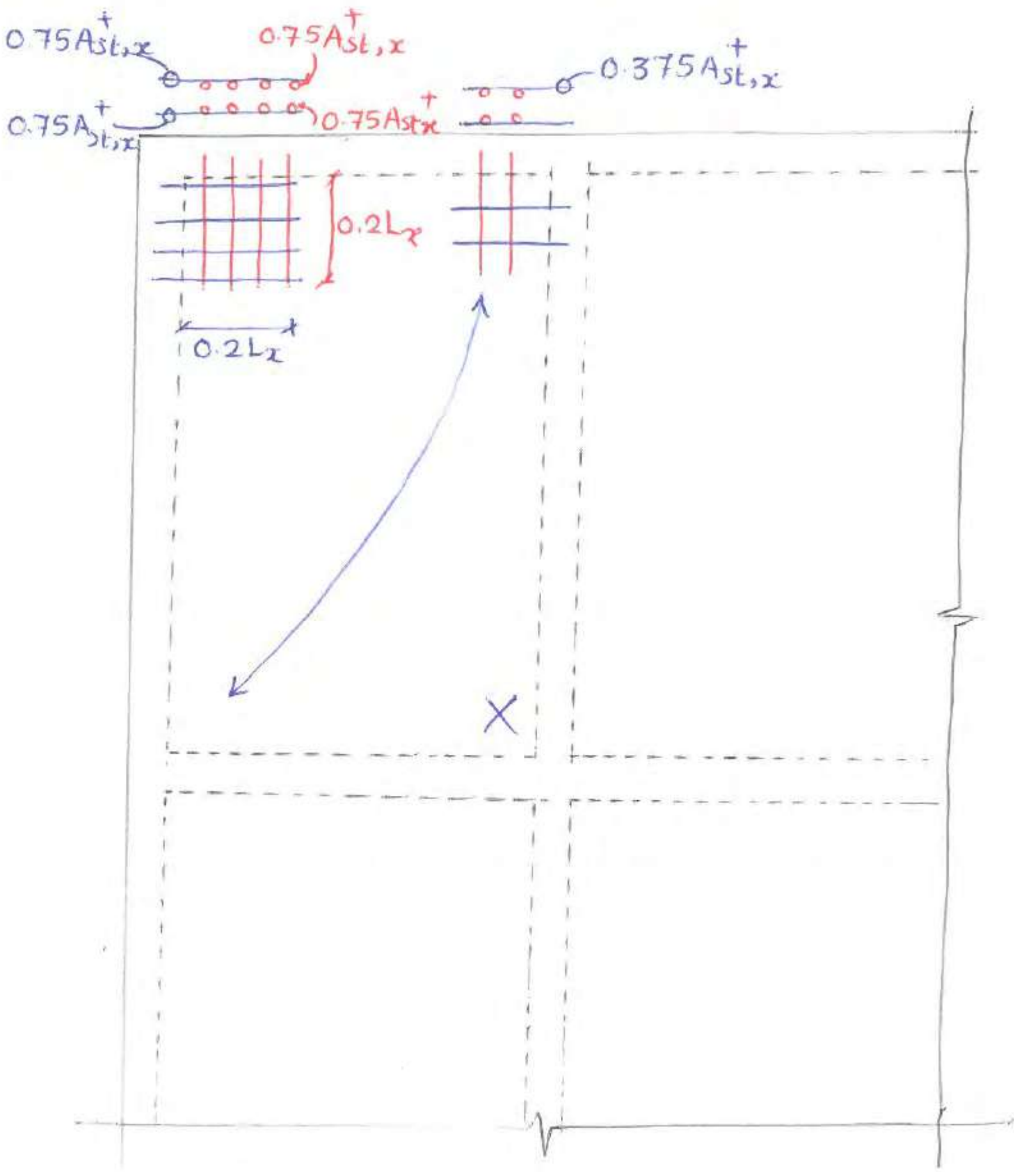


- Out of all design moments (M_x^+, M_x^-, M_y^+ & M_y^-) M_x^- is always maximum.
- Slab is divided into middle strip & edge strip. Reinforcement calculated corresponding to design BM (M_x^+, M_x^-, M_y^+ and M_y^-) is provided in middle strip only. Edge strip is provided with nominal reinforcement.

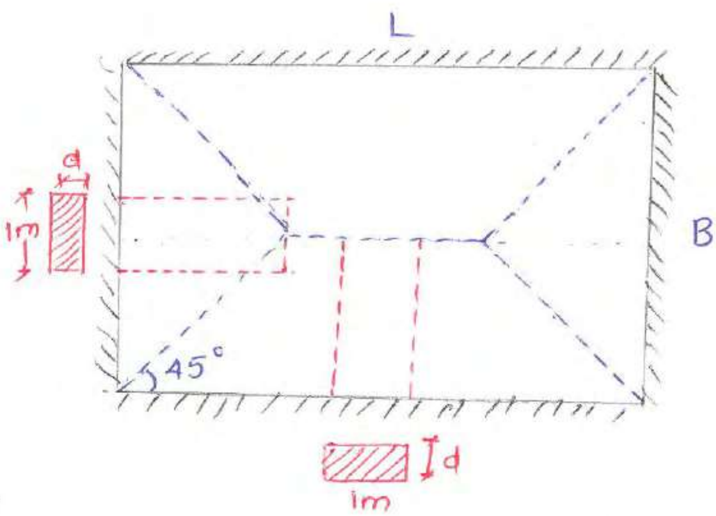




- If slab is restrained from lifting at corners then torsion reinforcement is provided to prevent cracking due to high value of torsion at discontinuous edges.
  a) At two adjacent discontinuous edges, 75% of max^m positive reinforcement ($0.75\,A_{st,x}^+$) is provided in two layers for a distance $0.2\,L_x$ in both directions.
  b) At one discontinuous edge, 50% of above value. ($0.375\,A_{st,x}^+$)



11.8 Shear Stress in Slab:



Maximum shear stress along longer side

$$= \frac{\text{Load on strip}}{\text{Resisting area}}$$

$$= \frac{W_u\left(\frac{B}{2}\times 1\right)}{1\times d}$$

$$= \frac{W_u B}{2d}$$

Maximum shear stress along shorter side $= \frac{\text{Load on strip}}{\text{Resisting area}}$

$$= \frac{w_u \times \left[\frac{B}{2} \times 1\right]}{1 \times d}$$

$$= \frac{w_u B}{2d}$$

B.C. Punmia

Avg. shear stress along shorterside $= \frac{\text{Load on triangular portion}}{\text{Total resisting area along shorter side}}$

$$= \frac{w_u \left[\frac{1}{2} \times B \times \frac{B}{2}\right]}{B \times d}$$

$$= \frac{w_u B}{4d}$$

Maximum shear stress is always higher than avg. shear stress. since, slab is designed for maximum shear stress so considering $\frac{w_u B}{3d}$ (greater than avg. shear stress $\frac{w_u B}{4d}$) as design shear stress for slab.

*Note :-

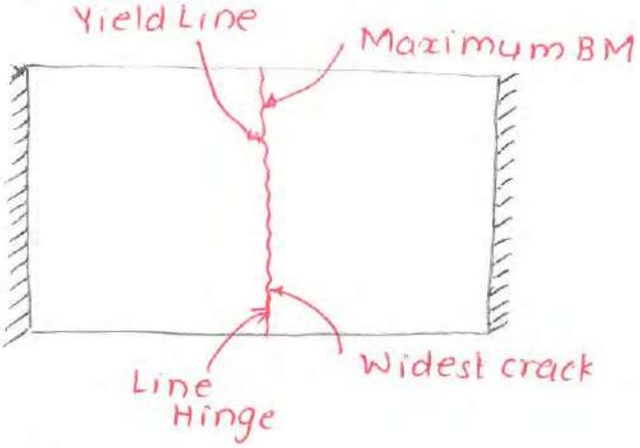
Critical section for shear in slab is at a distance 'd' from face of support if support provides comp. to the end of slab.

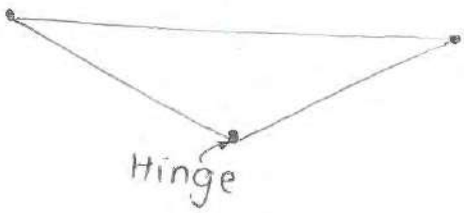
11.9 Yield Line Theory:

It is an enelastic method of analysis by which ultimate load carrying capacity of slab is calculated.

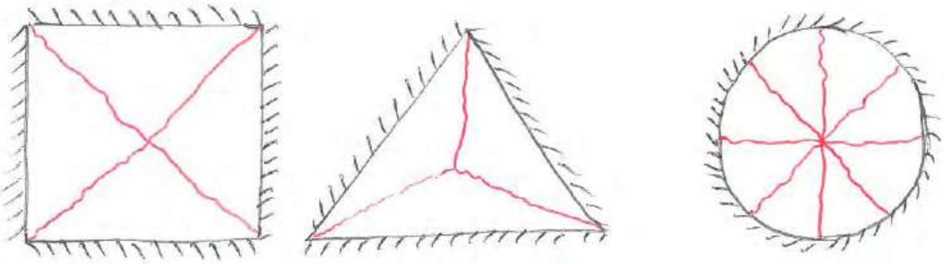
- **Formation of Plastic Hinge in Concrete Slab:**

Plastic hinge in the slab is in the form of line hinge corresponding to widest crack pattern. This is also termed as Yield Line.

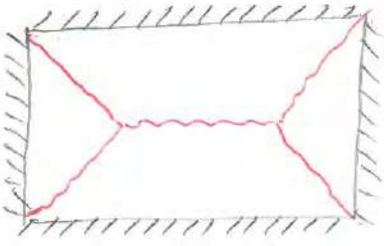




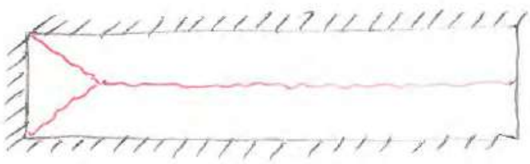
- **Guidelines to Draw Yield Line:**
  - It must be straight line.
  - It terminates at slab boundaries or intersects other yield lines
  - Yield line acts as axis of rotation.
  - Each segment of slab should act as rigid body after formation of yield line.



(a) (b) (c)

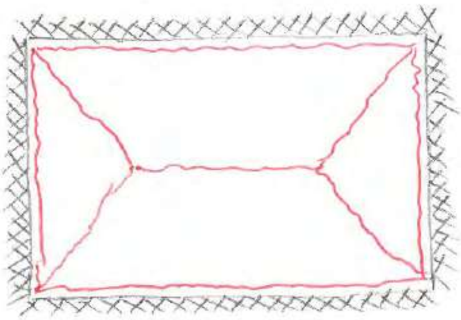


(d)



(e)

(f)



(g)

....Chaple 11 Ends Here....