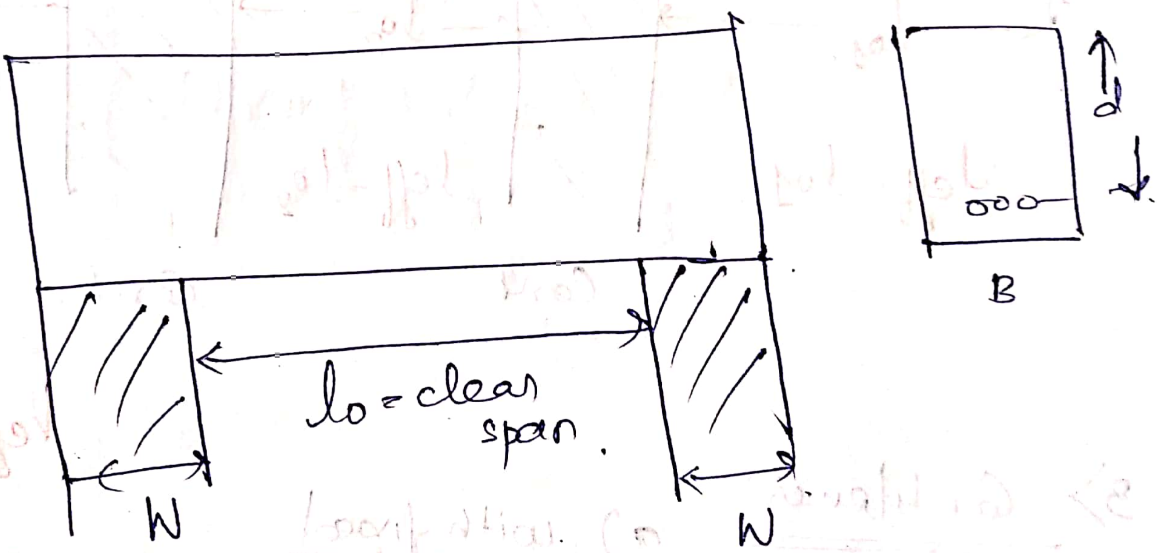
Design of slab (one way slab / Beams)

slabs are plate elements forming floors & roofs of building & carrying distributed loads primarily by flexure.

A) Effective span :

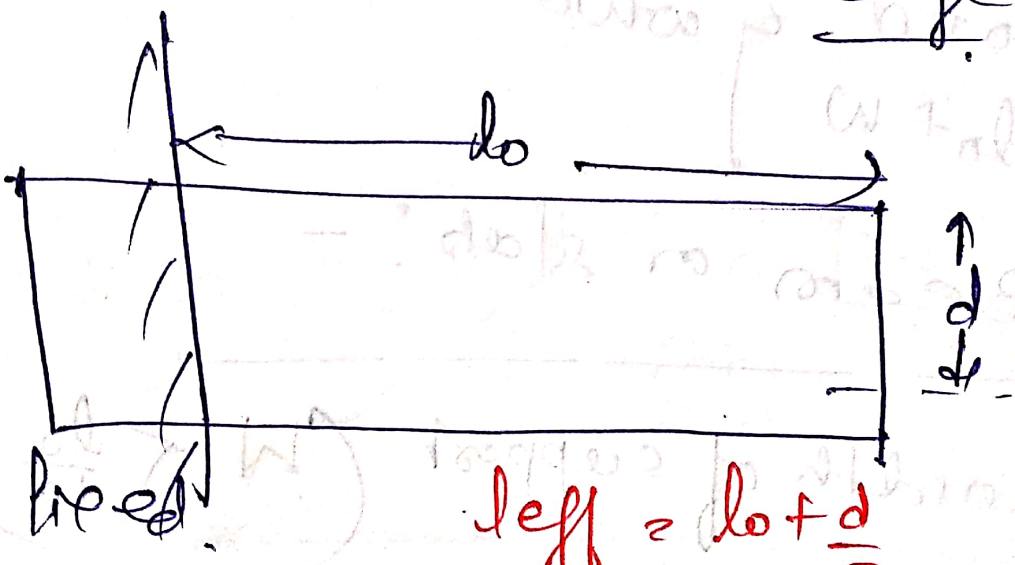
1) SSB / slab.



$l_{eff} = l_0 + d$
$= l_0 + W$ } whichever is less.

3) Cantilever;

a) with fixed Edge.



$l_{eff} = l_o + \frac{d}{2}$

Check for deflection (P-37, 23.2)

→ One of the most important check of limit state of serviceability condition

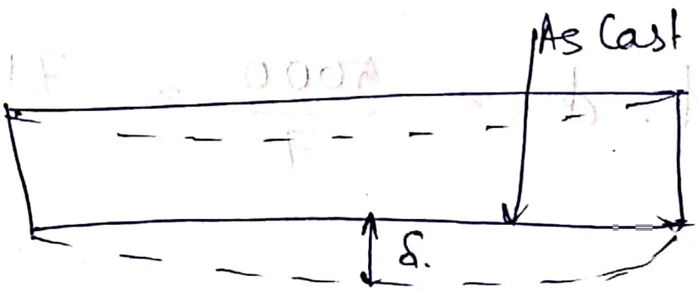
- The deflection of a structure shall be within some permissible limits so that it does not affect.
  1) Appearance
  2) finishing
  3) structure.

Limits of deflection :

1) The final deflection including the effect of temp, creep and shrinkage (due to all loads), measured from as cast level of support, ≯ $\frac{\text{span}}{250}$.

2) The deflection i/c the effect of temp, creep and shrinkage, occurring after erection of partition and application of finishes shall not be more than ≯ $\frac{\text{Span}}{350}$ or 20 mm } whichever is less.

(Here L.L is not provided, only D.L is there)



Check for deflection :

The deflection shall be generally with limits of

(1) Basic ratio of $\frac{\text{Span}}{\text{effective depth}}$ is not more than

(1) Cantilever = 7

(2) Simply supported = 20

(3) Cantilever = 26

$\Big\}$ (A) value.

$\therefore \dfrac{\text{span}}{\text{Eff. depth}} \leq \text{A value}$

$$\boxed{\therefore (\text{Eff. depth}) \geq \frac{\text{Span}}{\text{(A) value}}}$$

Q: Calculate Min^m effective depth required for a effective span of 5m for a Cantilever sp. slab.

Sol: $\text{eff. d} = \dfrac{5000}{7} = 714.28 \text{ mm}$

(Not good)

(2) If span > 10 m

The A value shall be multiplied by $\left(\dfrac{10}{\text{span in m}}\right)$ for simply supported and continuous Beam or slab.

(Not for Cantilever.)

So $$\boxed{\text{eff. depth (d)} = \frac{\text{span}}{\text{(A) value} \times \left(\frac{10}{\text{span in m}}\right)}}$$

Provision-3

Based on tension reinforcement provided, a modification factor (MF1) shall be used:

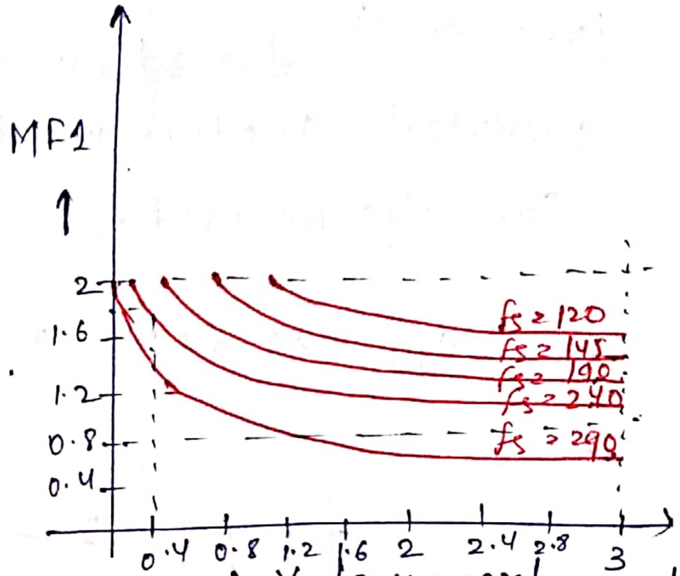
$\therefore$ Effective depth (d) = $\dfrac{\text{Span}}{\text{(A) Value} \times MF1}$

MF1 is read based on

(1) % tension reinforcement.

(2) Value of fs.

$f_s = 0.58 f_y \dfrac{\text{Area of steel required}}{\text{Area of steel provided}}$.



→ % tension reinforcement.

Continuing Eg (1) Span = 5m.
Cantilever beam.

option b

Suppose Fe 415 steel are used & we need 0.4% steel.

$\therefore$ p% = 0.4%.

Assumed

$f_s = 0.58 \times 415 \times \dfrac{1}{1} = 240.7.$

Let us Read MF1 = 1.35

$\therefore$ depth required = $\dfrac{5000}{7 \times 1.35}$ = 529mm

option c

If double area of steel is used

$\therefore$ p% = 0.4×2 = 0.8%.

So $f_s = 0.58 \times 415 \times \frac{1}{2} = 120.35$.

Read from table $\therefore$ $MF = 1.75$

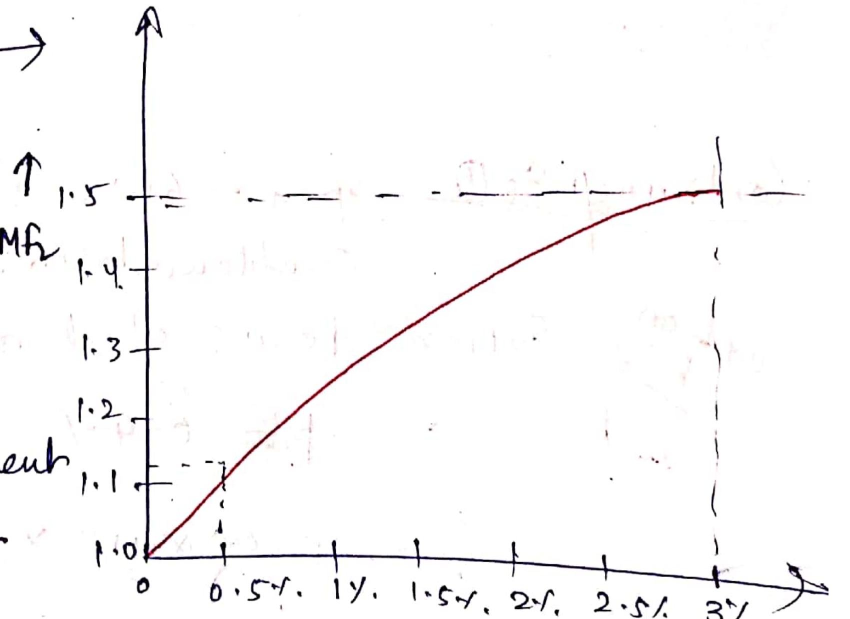
So, depth required $= \frac{Span}{A \times MF} = \frac{5000}{7 \times 1.75}$

$= 408$ mm

Provision (4) Based on compression reinforcement provided another modification factor (MF_2) can also be used.

effective depth $= \frac{Span}{A \times MF \times MF_2}$

fig. NO: 05 →



Eg (1) with option (C)

option D In addition to option C, if 0.5% compression reinforcement are also provided.

$MF_2 = 1.15$

$\therefore$ depth req $= \frac{Span}{A \times MF \times MF_2}$

$= \frac{5000}{7 \times 1.75 \times 1.15}$

=

Scanned with CamScanner

(E) For Beams:

(1) Min^m tensile reinforcement.

$$\frac{A_{st}}{Bd} \geq \frac{0.85}{f_y}$$

(2) Max^m tension reinforcement = 0.04 BD

(4% of total c/s area).

(3) Max^m Compression reinforcement = 4% of total c/s area.

= 0.04 BD.

(F) for slabs:

(1) Min^m Area of steel (tension).

a) 0.15% of total c/s area → Mild steel.

b) 0.12% " " " " → other type of reinforcement.

(2) $\boxed{\text{Max}^m \text{ dia of steel : } = \frac{1}{8} \text{ (thickness of slab)}}$

but generally

Eg: slab thickness = 125 mm.

Max^m dia of bar = $\frac{125}{8}$ = 15.625 mm

∴ Max^m dia = 12 mm ✓

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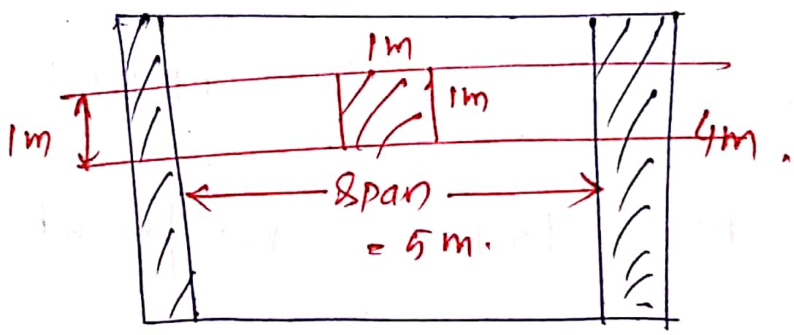
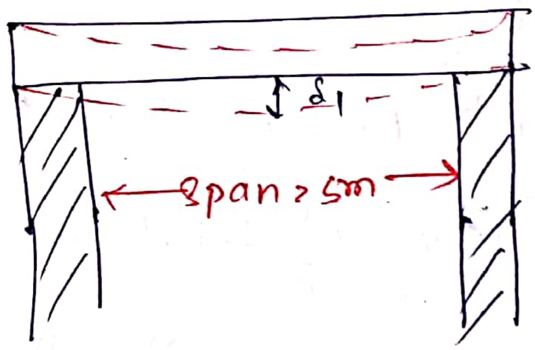
Design of one-way slab :

Condition for one-way slab :

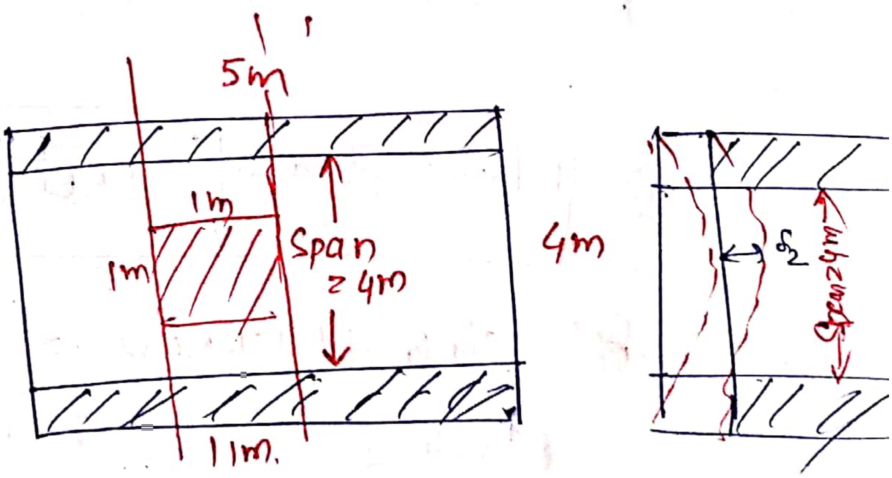
1) The slab is supported only on two opposite sides :-
Span of slab will be distance b/w the supports.
Eg:



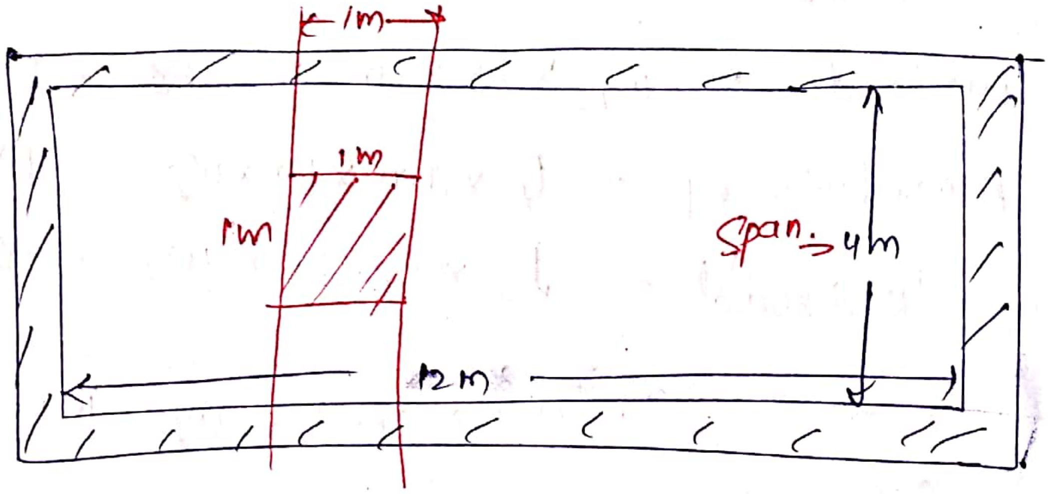
$\delta_1 > \delta_2$
as span is more.



OR



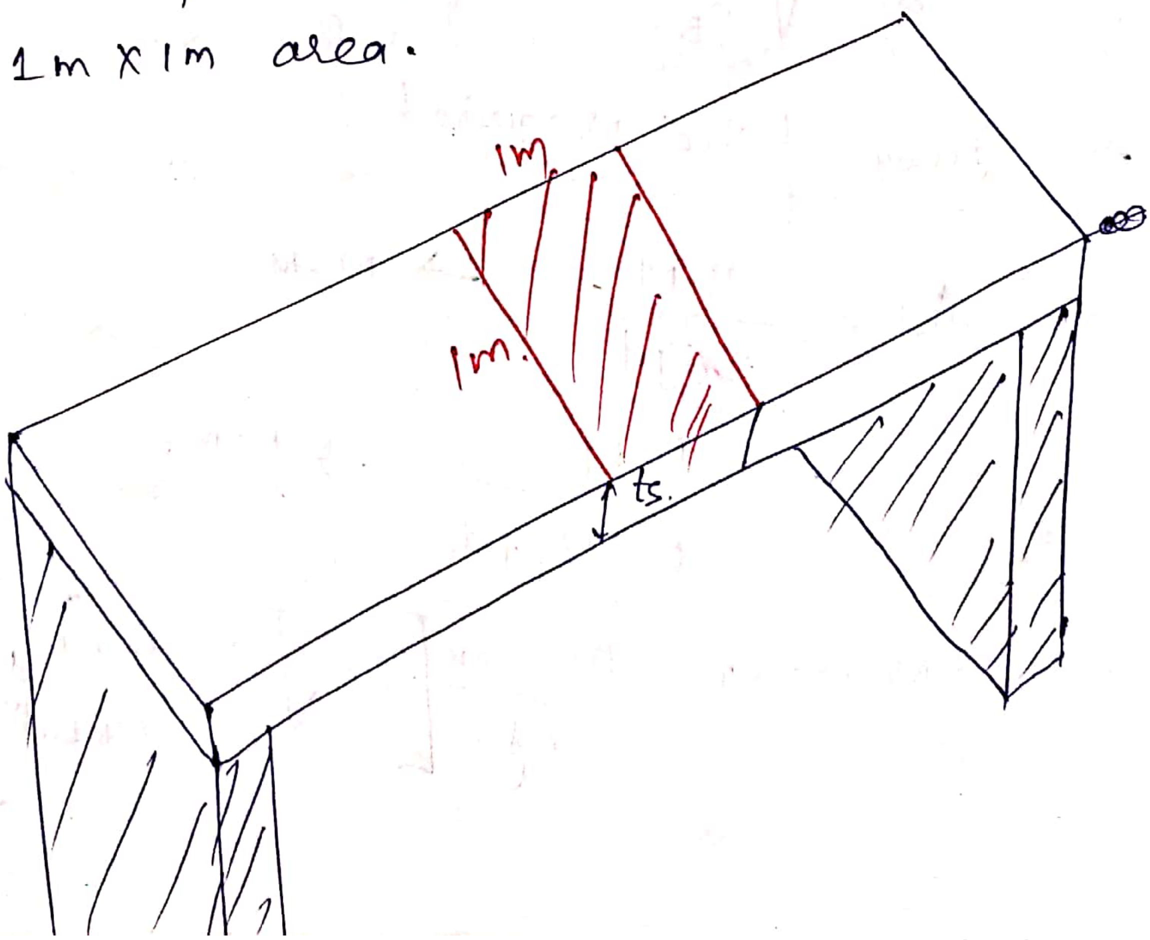
2) If the slab is supported on all its 4 side and span ratio, $\boxed{\frac{l_y}{l_x} > 2}$ Then also slab is said to be one-way slab.



In this case, The slab bend in the direction of shorter span. Span of slab is shorter span.

$\therefore$ span $= l_x = 4m$ (Eg:)

★ for any case: Consider 1m strip along the span for design and load is calculated for 1m × 1m area.



Load Calculation:

(1) Live Load $= w_L \times 1m \times 1m = w_1 \rightarrow L.L.$

(2) Floor finishing $= t_f \times 1m \times 1m \times w_f = w_2$

(3) Dead load $= t_s \times 1m \times 1m \times w_c = w_3$

$\left. \begin{matrix} w_2 \\ w_3 \end{matrix} \right\} D.L$

$\therefore$ Total load $= w = w_1 + w_2 + w_3.$

Design steps:

इसके पहले depth assume करना पड़ेगा, फिर l_{eff} निकालना पड़ेगा।

1) **Calculate Bending moment:**

Use a suitable formula $= BM$ or $= BM_u$.

[i.e. Use $\frac{wl^2}{8}$ or Moment coefficient].

2) **Calculate depth of slab required:**

$$d = \sqrt{\frac{BM}{QB}} \text{ or } \sqrt{\frac{BM_u}{QB}}$$

Max. of (+ve, −ve)

3) **Area of steel required:**

$$A_{st} = \frac{B.M}{\sigma_{st}\, j d} \rightarrow WSM$$

$$= \frac{B.M}{0.87 f_y\, j d} \rightarrow LSM.$$

URS ← or $\frac{0.5 f_{ck}}{f_y}\left[1 - \sqrt{1 - \frac{4.6 M_u}{f_{ck} B d^2}}\right] \times Bd$

4) ~~Cal~~ Check for shear force :

Calculate V or V_u.

$$\tau_v = \frac{V}{Bd} \text{ or } \frac{V_u}{Bd} < \tau_c \times K$$

A slab should never be designed for shear reinforcement.

The slab must be safe in shear.

Value of K : $(D \uparrow K \downarrow)$

D	≤150	175	200	225	250	275	≥300
K	1.30	1.25	1.20	1.15	1.10	1.05	1.00

5) Check for Development length :

(Compression rKn) → $L_d \leq 1.3 \frac{M_1}{V} + L_0$

(Normal Case) → or $\leq \frac{M_1}{V} + L_0$.

6) Check for Deflection.

ie $\left(\frac{l}{d}\right)_{max} > \left(\frac{l}{d}\right)_{Calculated}$

Ly Lx Ly/Lx

Design a simply supported roof slab for a room 8 m × 3.5 m clear in size if the superimposed load is 5 kN/m². Use M15 mix and Fe 415 grade steel.

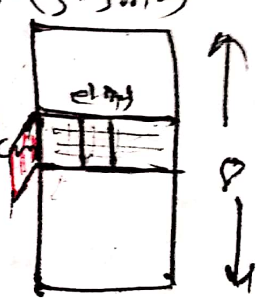
Solution

Since length of the slab is more than twice the width, it is a one-way slab. Load will be transferred to the supports along the shorter span. Consider a 100 cm wide strip of the slab parallel to its shorter span.

Minimum depth of slab $d = \dfrac{L}{\alpha\beta\gamma\delta\lambda}$ (Refer clause of IS456 23.2.1)

Let $\alpha = 20, \beta = 1, \gamma = 1, \delta = 1$ and $\lambda = 1$

1m = 100 cm



$\therefore\ d = \dfrac{3500}{20} = 175$ mm

Let us adopt overall depth $D = 190$ mm

Dead load of slab $= 0.19 \times 1.0 \times 25 = 4.75$ kN/m

Superimposed load $= 5 \times 1 = 5$ kN/m

Total load $= 9.75$ kN/m

Cover = 15 mm mild exposure

Factored load if the load factor is 1.5 = $1.5 \times 9.75 = 14.63$ kN/m

Maximum BM at centre of shorter span = $\frac{w_u l^2}{8}$

Assume steel consists of 10 mm bars with 15 mm clear cover.

Effective depth = $190 - 15 - 5 = 170$ mm

Effective span of slab = $3.5 + d = 3.5 + 0.17 = 3.67$ m

or wall
sgl not
given

$$\therefore \quad BM = 14.63 \times \frac{3.67^2}{8} = 24.63 \text{ kNm}$$

$$\text{Maximum shear force} = \frac{w_u l_c}{2} = 14.63 \times \frac{3.5}{2} = 25.60 \text{ kN}$$

Depth of the slab is given by $BM = 0.138\, \sigma_{ck}\, bd^2$

$$\text{or} \quad d = \sqrt{\frac{24.63 \times 10^6}{0.138 \times 15 \times 1000}} = 109 \text{ mm}$$

Adopt effective depth d = 150 mm and over all depth D = 170 mm

Area of tension steel is given by $M = 0.87\, \sigma_y A_t \left(d - \frac{\sigma_y A_t}{\sigma_{ck}\, b}\right)$

$$24.63 \times 10^6 = 0.87 \times 415\, A_t \left(150 - \frac{415 A_t}{15 \times 1000}\right)$$

~~No of bars = 6.498~~

or $A_t = 510$ mm²

$$\frac{(1000)\frac{\pi}{4}\times(10)^2}{510} \text{ mm}$$

Use 10 mm bars @ 150 mm c/c giving total area

$\frac{1000}{150} \times 78.5 = 523.3 = 523$

= 523 mm² > 510 mm² OK

Bend alternate bars at L/7 from the face of support where moment reduces to less than half of its maximum value. Temperature reinforcement equal to 0.15 % of the gross concrete area will be provided in the longitudinal direction.

$$= 0.0015 \times 1000 \times 170 = 255 \text{ mm}^2$$

Use 6 mm MS bars @ 100 mm c/c giving total area

$$= 28 \times \frac{1000}{100} = 280 \text{ mm}^2 > 255 \text{ mm}^2 \quad \text{OK}$$

Check for shear

$$\text{Percent tension steel} = \frac{100 A_t}{bd} = \frac{100 \times (78.5 \times 1000/300)}{1000 \times 150}$$

$$= 0.17\%$$

Shear strength of concrete for 0.17% steel $\tau_c = 0.35$ N/mm²

For 170 mm thick slab, $k = 1.25$

$$\therefore \tau_c' = k\,\tau_c = 1.25 \times 0.35 = 0.44 \text{ N/mm}^2$$

$$\text{Nominal shear stress } \tau_v = \frac{V_u}{bd} = \frac{25600}{1000 \times 150}$$

$$= 0.17 \text{ N/mm}^2 < \tau_c' \qquad \text{OK}$$

The slab is safe in shear. , $\tau_{c\,max}$

Check for development length

Moment of resistance offered by 10 mm bars @ 300 mm c/c

$$M_1 = 0.87\,\sigma_y A_t \left(d - \frac{\sigma_y A_t}{\sigma_{ck}\, b} \right)$$

$$= 0.87 \times 415 \times 78.5 \times \frac{1000}{300} \left(150 - \frac{415 \times 78.5 \times 1000/300}{15 \times 1000} \right)$$

$$\approx 13.48 \times 10^6 \text{ Nmm} = 13.47 \text{ kN-m}$$

Shear force will remain constant

$$V = 25600 \text{ N}$$

inclined bar will resist shear

$$\text{Let us assume anchorage length } L_o = 0$$

$$L_d \le 1.3 \frac{M_1}{V}$$

$$56\,\phi \le \frac{1.3 \times 13.48 \times 10^6}{25600}$$

$$\text{or,} \quad \phi < 12 \text{ mm} \qquad \text{OK}$$

$\phi = 10$ mm

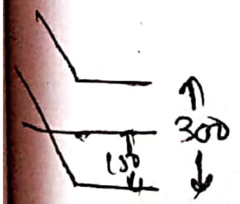
The Code requires that bars must be carried into the supports by at least $L_d/3 = 190$ mm.

Check for deflection

$$p_t = \frac{100 \times (78.5 \times 1000/150)}{1000 \times 150} = 0.34\ \%$$

Table 10.1 gives $\gamma = 1.40$ at a service stress of 240 MPa in Fe 415 grade steel.

$$\beta = 1, \delta = 1 \text{ and } \lambda = 1$$



$$\text{Allowable} \quad \frac{L}{d} = 20 \times 1.40 = 28$$

$f_s = 0.58 f_y \frac{(A_{st})_{req}}{(A_{st})_{prov}}$

$= 0.58 \times 415 \times 510/523$

$= 234.72$

$$\text{Actual} \quad \frac{L}{d} = \frac{3670}{150} = 24.5 < 28 \qquad \text{OK}$$

80 from graph. modification factor $= 1.4$

The details of reinforcement are shown in Fig. 14.3.

BM = M_1

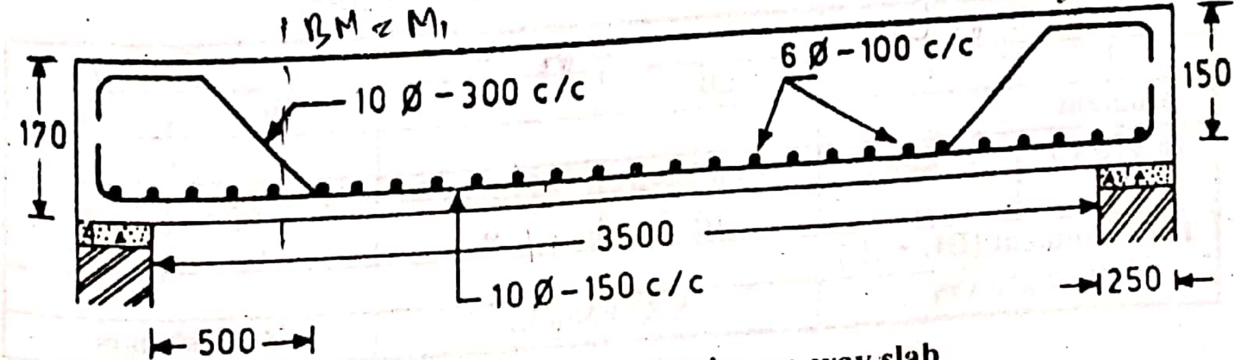


Fig. 14.3 Reinforcement in one-way slab

Design of Two-way slab:

A slab is said to be two way slab when:

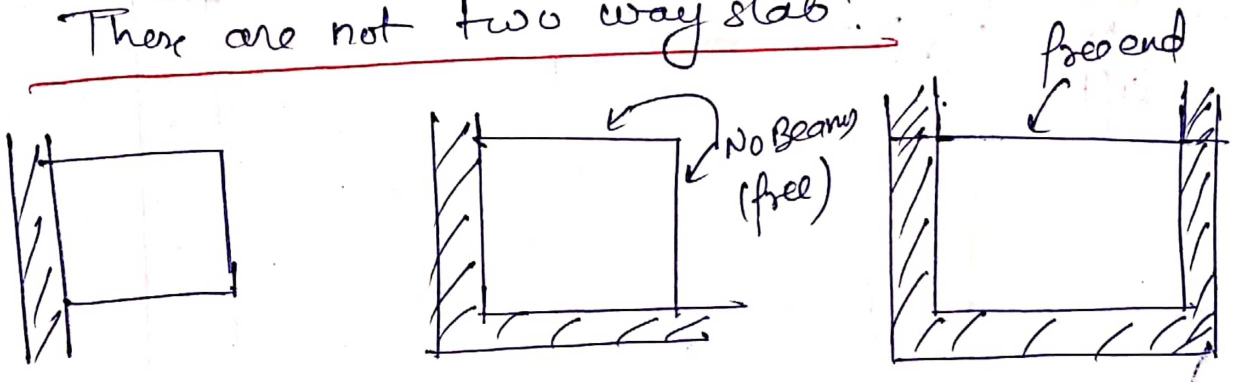
1) The slab must be supported on all four sides.

2) The slab has span ratio $\boxed{\frac{l_y}{l_x} \leq 2}$.

l_y = longer span

l_x = shorter span.

There are not two way slab:

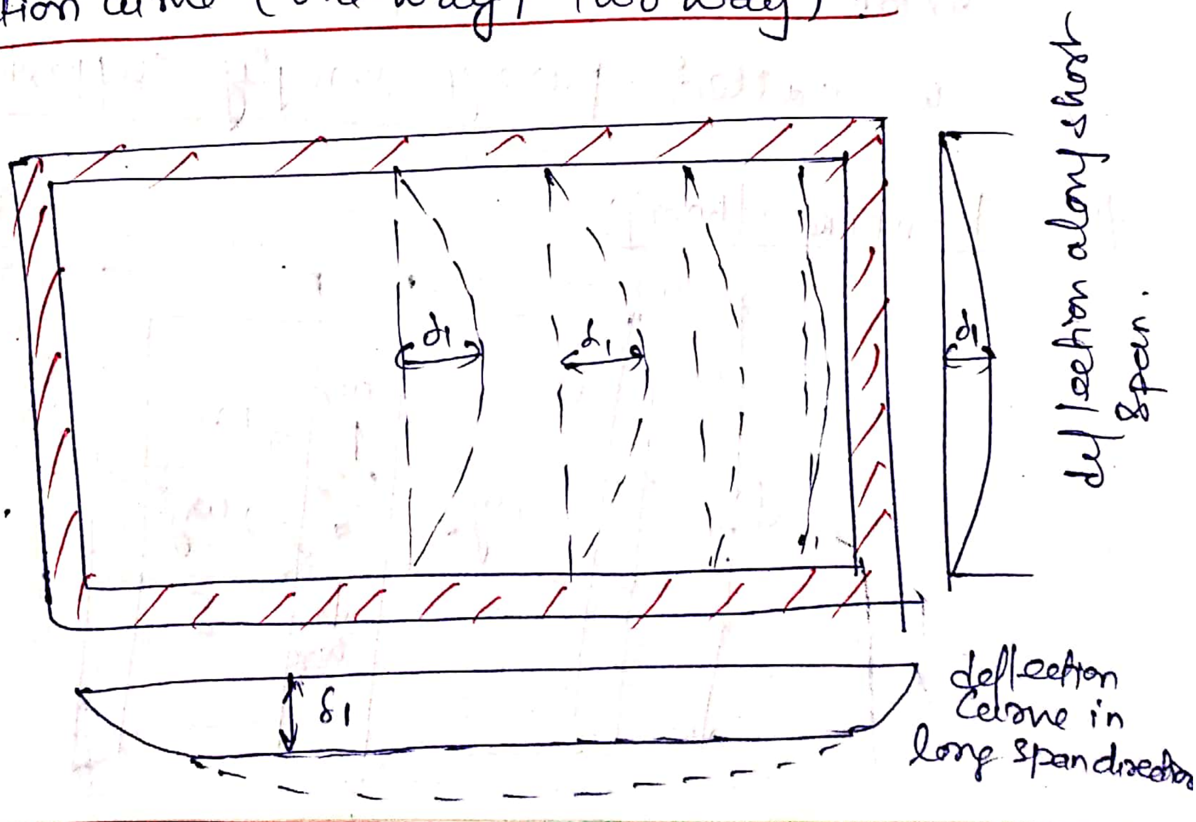


Cantilever. Two side supported slab. Three side supported slab.

Have, other design formulas. Refer Books.

* Deflection curve (One way / Two way)

Above slab is supported on all four sides.



(B) IS Code Method   Pg IS-456 : 2000 (90-91) (Annex-D)

IS code method provide soln for simply supported slab as well as restrained slab of all kind.

(A) Simply supported slab (No-no moment at ends)

Moment formulae : (ie corners free to lift)

$M_x = \alpha_x \, w \, l_x^2$

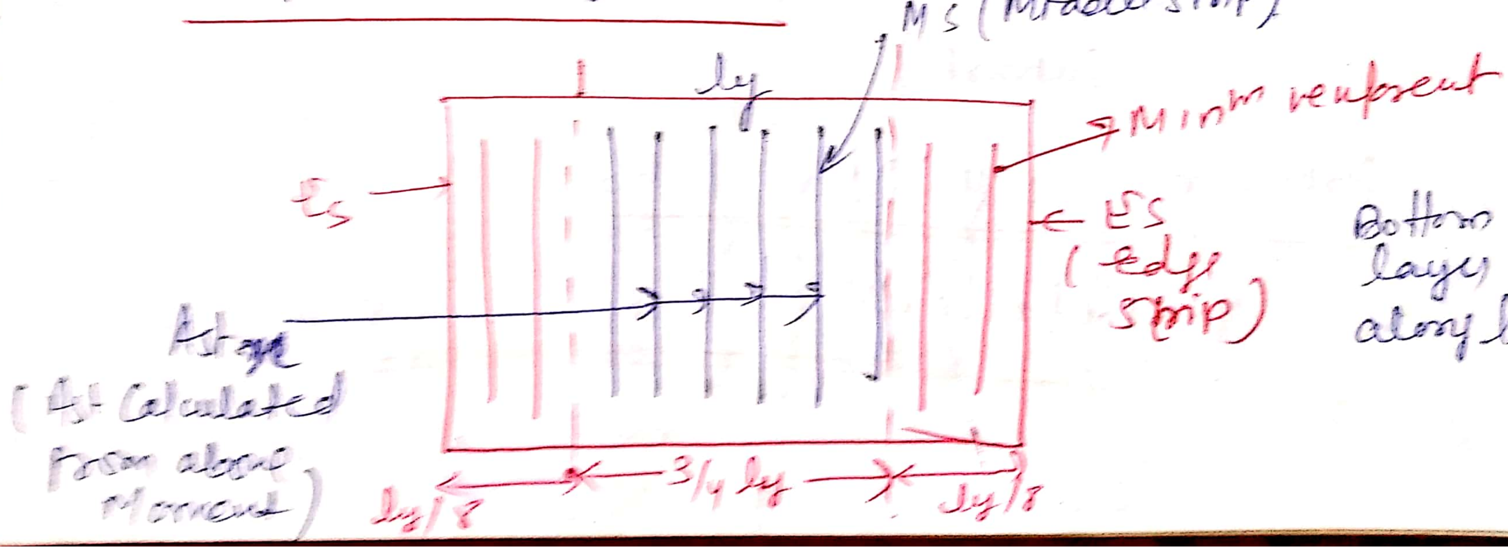
$M_y = \alpha_y \, w \, l_x^2$

α_x & α_y are to read from table 27 / pg 91.

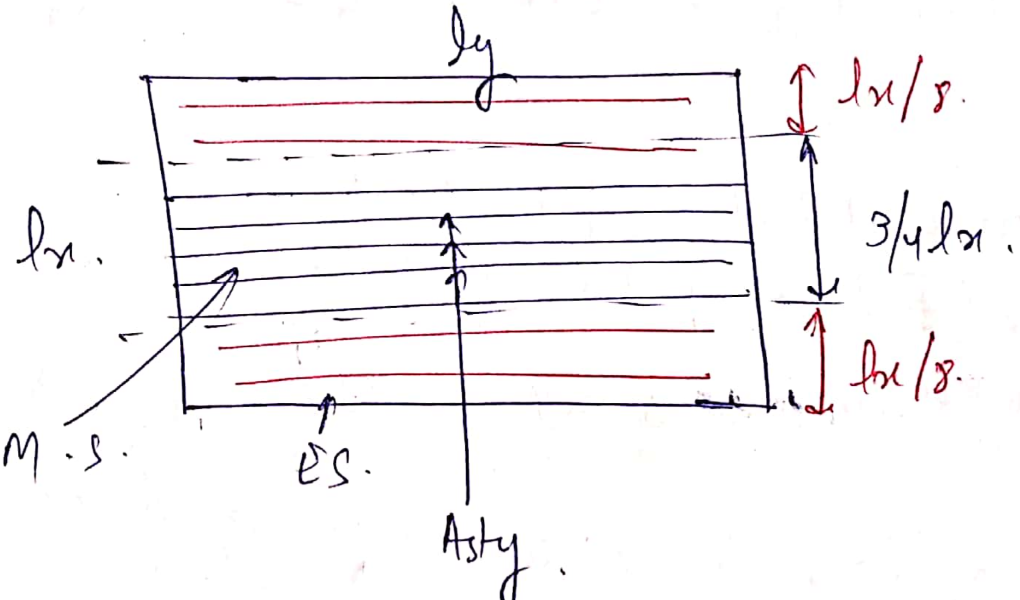
	1.0	1.1	1.2	1.3	1.4
α_x	0.062	0.074	0.081	0.093	0.099
α_y	0.062	0.061	0.0059	0.057	0.057

Provision D1.2 D1.3 D1.7.

D1.2 The slab steel can be divided into middle strip and edge strip



Bottom layer along lx.



(Bottom layer reinf for +ve B.M)

D.1.3 The moment values as calculated above are applicable for middle strip only not for edge strip

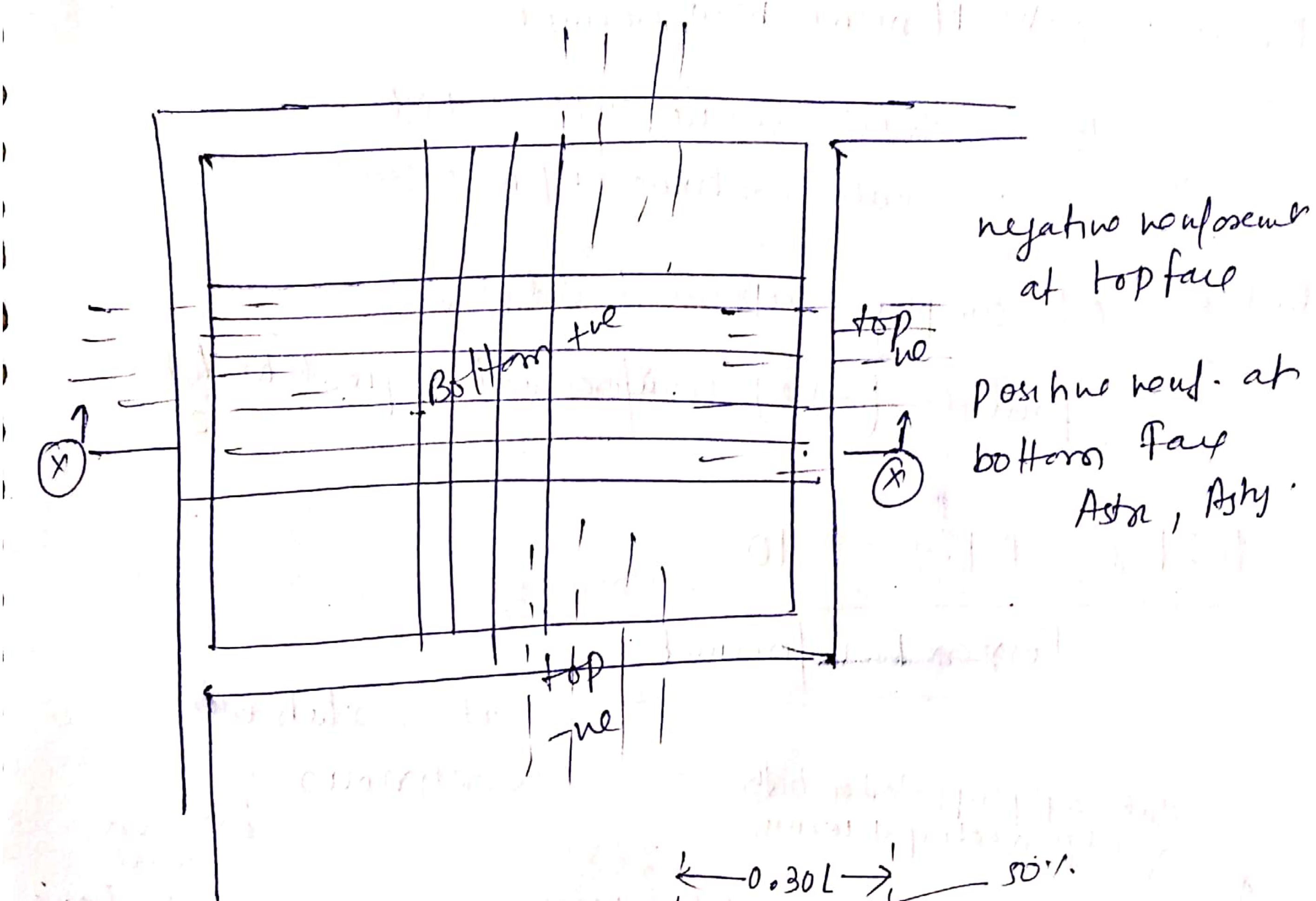
D.1.7 In edge strip

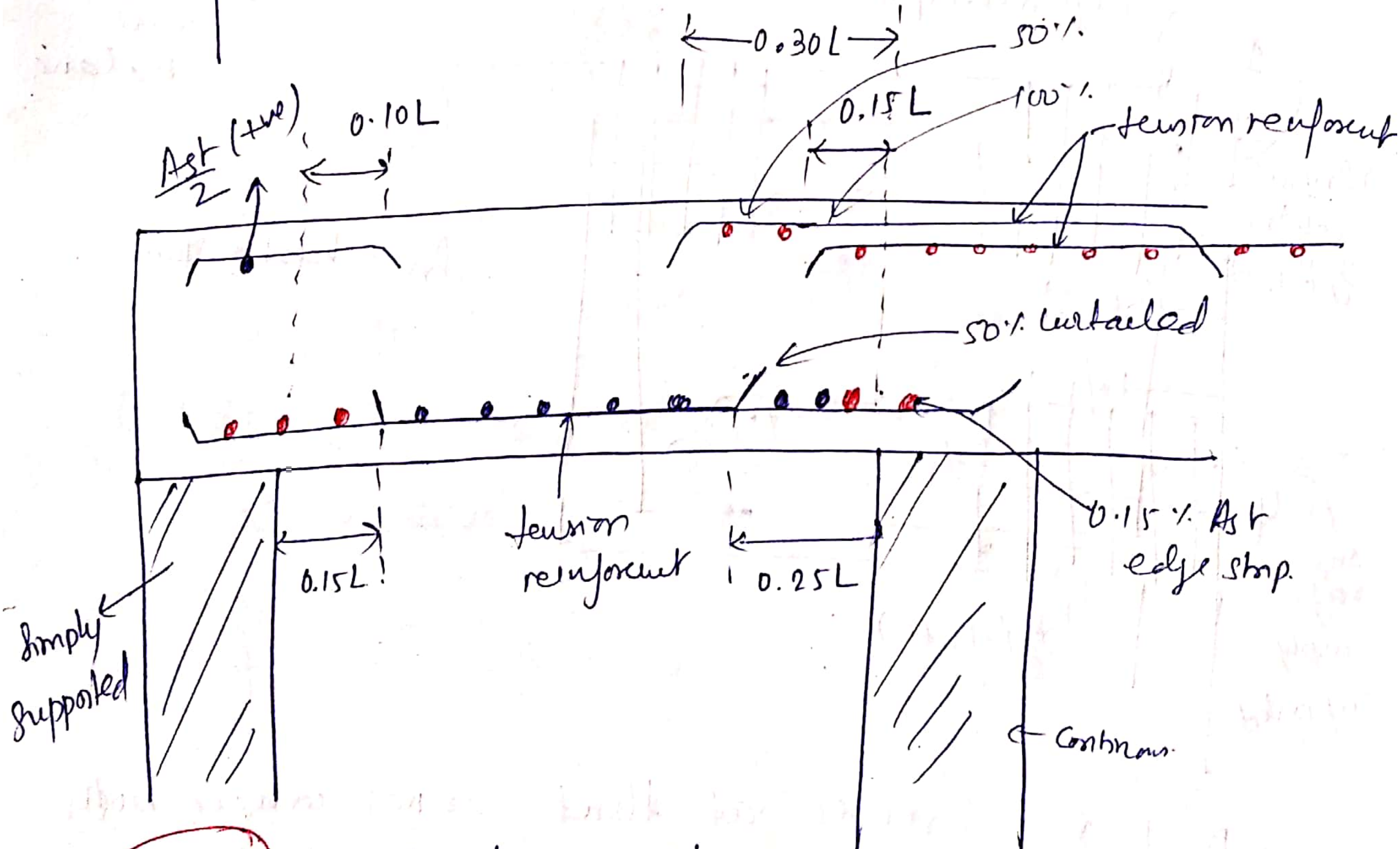
→ Provide Min^m reinforcement (distribution bars)
= 0.12% or 0.15% of total c/s area.

('as in ends moments are very less
(because +ve moment decrease, only when -ve moment that comes to continuous support).

Provision D1.4 D1.5 D1.6

Detailing of Reinforcement





D.1.4 → about +ve Moment steel.

100% upto 0.15L from support.
50% may be curtailed.
50% must extend upto support.

D.1.5.4 -ve Moment reinforcement

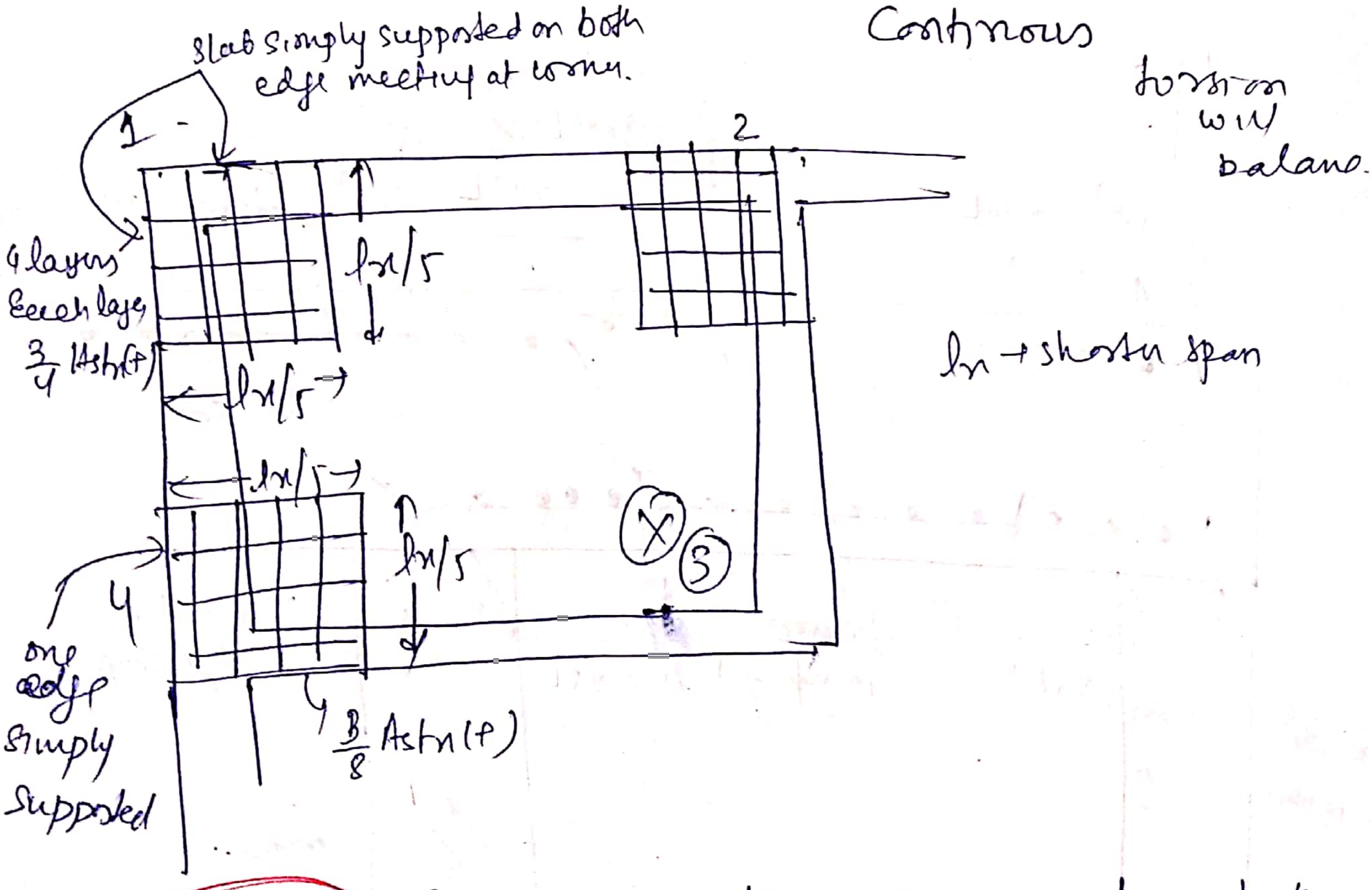
100% shall continue upto 0.15 l.
50% shall continue upto 0.30 l.

D.1.6 At simply supported edge.

Provide (-ve) reinforcement equal to $\frac{A_{st}}{2}$.

D.1.8 D.1.9 D.10

Torsion Reinforcement



D.1.8 Provide at that corner where both edges are simply supported.

1. provide in 4 layers.
2. size of mesh = $\frac{l_x}{5}$
3. Area of steel in each layer = $\frac{3}{4} A_{st_x}(+)$

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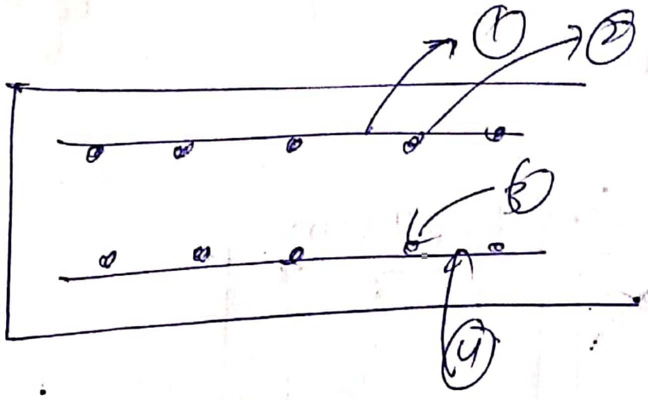


1, 2, 3, 4
Main reinf will also serve purpose of torsion if Ast in each layer is $\frac{3}{4}$ Astx (+) there is no need of extra reinforcement.

D.1.9 Also provide at corner where at least one edge is simply supported.

1. provide in 4 layers.
2. size of mesh $\frac{lx}{5}$.
3. Area of steel in each layer

$= \frac{1}{2} \times \frac{3}{4}$ Astx (+)

$= \frac{3}{8}$ Astx (+)

D.1.10 when both edges are continuous.
No need to check for torsion (But reinforcement in there)

D.1.11 if $\frac{ly}{lx} > 2$ design one way

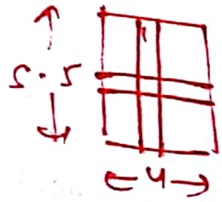
Design a two-way slab for a room 5.5 m × 4.0 m clear in size if the superimposed load is 5 kN/m^2. Use M15 mix and Fe 415 grade steel.

(a) edges simply supported – corners not held down.

Ly   Lx

$\frac{L_y}{L_x} = \frac{5.5}{4} < 2.$

Solution



(a) Edges simply supported—corners not held down

Assume over all thickness of slab as 140 mm and effective depth as 120 mm.

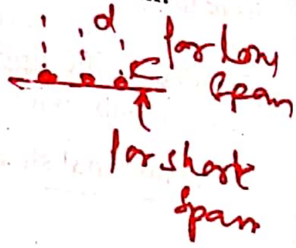
D

Effective spans will be

$$l_x = 4 + 0.12 = 4.12 \text{ m}$$

$$l_y = 5.5 + 0.12 = 5.62 \text{ m}$$

$$\frac{l_y}{l_x} = 1.36 < 2$$



Moments along short span M_x and along long span M_y are given by

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

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

For $\frac{l_y}{l_x} = 1.36$, $\alpha_x = 0.096$ and $\alpha_y = 0.053$ (Table 14.3)

Dead load of slab $= 0.14 \times 25 = 3.5 \text{ kN/m}^2$

Superimposed load $= 5 \text{ kN/m}^2$

Total load $= 8.5 \text{ kN/m}^2$

With a load factor of 1.5, factored load $= 12.75 \text{ kN/m}^2$

$$M_x = 0.096 \times 12.75 \times 4.12^2 = 20.80 \text{ kNm/m}$$ Max^m

$$M_y = 0.053 \times 12.75 \times 4.12^2 = 11.50 \text{ kNm/m}$$

The effective depth d of the slab is given by

$$BM = 0.138\, \sigma_{ck}\, bd^2$$

b = 1 m
= 1000 mm

or,

$120 - 15 - \phi/2$

$$d = \sqrt{\frac{20.8 \times 10^6}{0.138 \times 15 \times 1000}} = 100 \text{ mm}$$

Adopt effective depth as 100 mm and over all depth as 120 mm.

Area of steel A_{tx} along short span $= \frac{0.36\sigma_{ck}\, bx_m}{0.87\sigma_y} = \frac{0.36 \times 15 \times 1000 \times 0.48 \times 100}{0.87 \times 415}$

$$= 718 \text{ mm}^2 \rightarrow \text{Calculated}$$

Use 10 mm bars @ 100 mm c/c, total area $= 785 \text{ mm}^2$

$\frac{1000}{100} \times 78.5$

Spacing $= \frac{1000 \times 78.5}{718}$

$> 718 \text{ mm}^2$ OK

Provided

Area of tension steel A_{ty} along long span

Spacing

$$BM = \text{force of tension} \times \text{lever arm}$$

$$11.50 \times 10^6 = 0.87\, \sigma_y A_{ty} \left(d' - \frac{\sigma_y A_{ty}}{\sigma_{ck}\, b}\right)$$

where,

$$d' = d - \text{dia of bar} = 100 - 10 = 90 \text{ mm}$$

$$11.50 \times 10^6 = 0.87 \times 415 \times A_{ty}\left(90 - \frac{415 A_{ty}}{15 \times 1000}\right)$$

or $$A_{ty} = 409 \text{ mm}^2$$ → provided

Use 8 mm bars @ 100 mm c/c, total area = 500 mm^2 > 409 mm^2 OK

The Code requires that the minimum area of steel should be 0.12 %.

$$= 0.0012 \times 120 \times 1000 = 144 \text{ mm}^2$$

$$< A_{ty} \quad \text{OK}$$

$$< A_{tx} \quad \text{OK}$$

Curtail alternate bars at 1/10th of effective span in each direction in accordance with clause D-2.1.1 of the Code. Provide 50 % of the maximum positive steel at top near the supports to resist bending moment due to partial fixity. This steel is provided in 0.1 *l* length from the face of supports.

Check for shear force at short edges

Maximum shear force intensity in either direction can be taken as 1/2 w L_x where L_x is clear short span.

$$\text{Maximum SF} = \frac{1}{2} w L_x = \frac{1}{2} \times 12.75 \times 4.0 = 25.5 \text{ kN/m}$$

$$\text{Nominal shear stress} \quad \tau_v = \frac{25.5 \times 1000}{1000 \times 90} = 0.28 \text{ N/mm}^2$$

$\frac{N}{mm} \times \frac{mm}{mm \times mm}$

90 → d'

$$\text{Percent tension steel} = \frac{100 A_s}{bd} = \frac{100 \times (50 \times 5)}{1000 \times 90} = 0.28 \%$$

→ at support so curtailed area

Shear strength of M 15 concrete for 0.28 % steel $\tau_c = 0.37$ N/mm^2

$$\text{Shear strength in slabs} = \tau_c' = k\,\tau_c$$

$$k = 1.3 \text{ for } D = 120 \text{ mm}$$

$$\therefore \tau_c' = 1.3 \times 0.37 = 0.48 \text{ N/mm}^2$$

$$> \tau_v \quad \text{OK}$$

The slab is safe in shear.

Check for development length at short edge

Moment of resistance offered by 8 mm bars @ 200 mm c/c.

$$M_1 = 0.87\,\sigma_y A_t \left(d - \frac{\sigma_y A_t}{\sigma_{ck}\, b}\right)$$

$$(d' = 100 - 10/2 - 8/2 = 91 \text{ mm})$$

50 r.

$$M_1 = 0.87 \times 415 \times (50 \times 5) \times \left(91 - \frac{415 \times 50 \times 5}{15 \times 1000}\right)$$

$$= 7.5 \times 10^6 \text{ Nmm}$$

$$V = 25.5 \text{ kN}$$

Anchorage value of bars bent at 90° including 60 mm straight length

$$L_o = 60 + 8\phi = 124 \text{ mm}$$

$$\text{Development length } L_d = 56\,\phi$$

$$L_d \leq 1.3\, M_1/V + L_o$$

M₁ r

$$56\,\phi \leq \frac{1.3 \times 7.5 \times 10^6}{25500} + 124$$

Code?

$$\text{or, } \phi < 9.1 \text{ mm}$$

Diameter of bar used is 8 mm which is less than 9.1 mm OK

Similar check can be made at long edges. The slab should be checked in deflection and modifications be made, if necessary. The details of reinforcement are shown in Fig. 14. 14a, 14.14b and 14.14c.

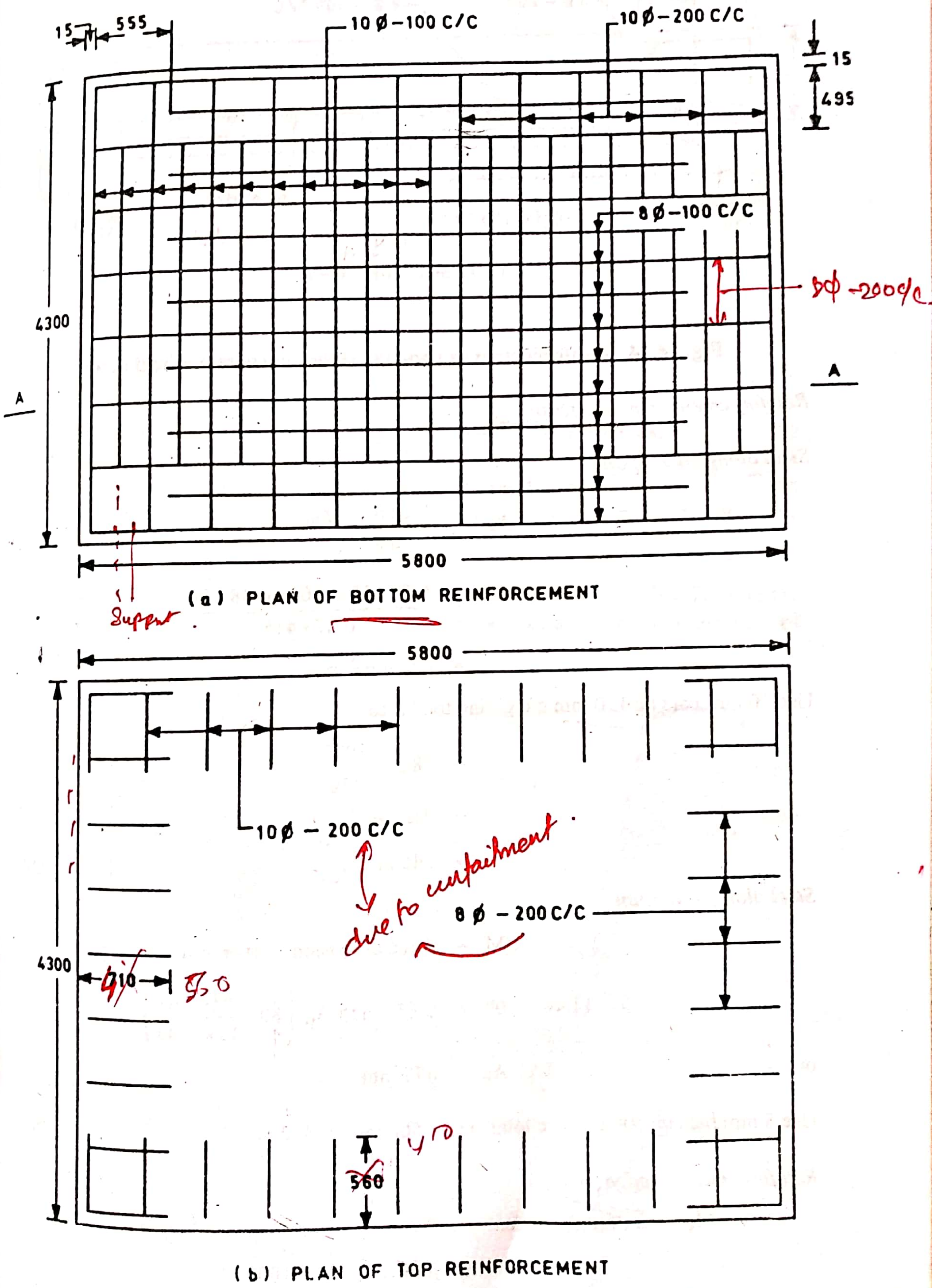


Fig. 14.14 Reinforcement in two-way slabs - corners not held down (contd.)

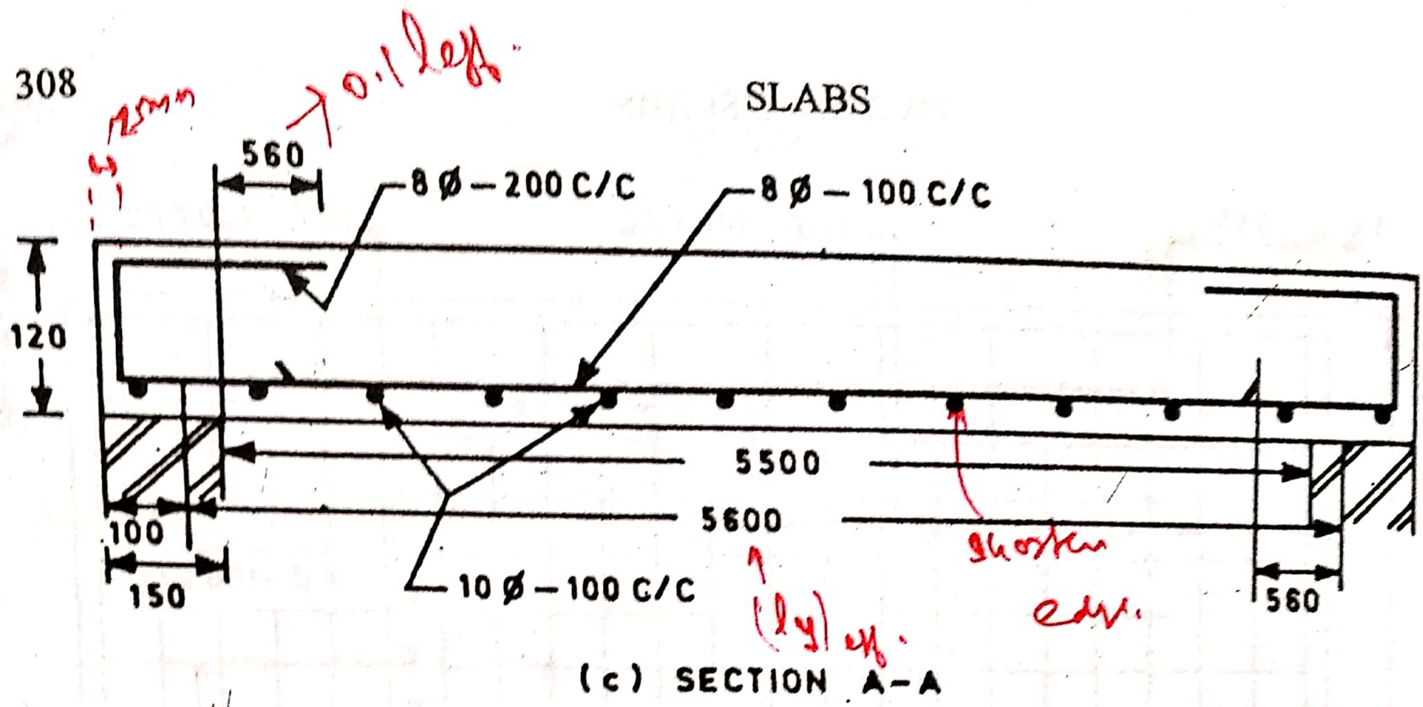


Fig. 14.14 Reinforcement in two-way slabs - corners not held down