UNIT-IV

SLABS

SLAB is a two dimensional element used as floors & roof coverings. It is a flexural member similar to beam but thickness is very small as compared to length & width.

Slabs are classified on the basis of longer span to shorter span ratio as

1) ONE WAY SLAB (2) TWO-WAY SLAB.

↓

$\frac{l_y}{l_x} \geq 2$ ..

one way slab is analysed similar to a beam, of 1m width.

2) Two way slab: (notes)

(i) If $\frac{l_y}{l_x} \geq 2$ the load carried by shorter span is 95% & that carried by longer span is only 5%. So such a slab can be designed as slab supported on two edges with bending in one-direction i.e shorter dir..

If the ratio $\frac{l_y}{l_x} < 2$, the load is shared by both the spans and bending in both directions

One way slab is subjected to larger BM than 2 way slab.

Depth of one way slab > depth of two way slab

Differences b/w One way & Two way slab

IS 456 recommendation for design of sl

devel: (1) Eff. span

(2) Deflection control (l/d)

= 37.6 (3) Reinforcement in slabs 31.7

(a) Min reinforcement 0.15% & 0.12%

(b) max. dia $\frac{1}{8}$th of total th.

st. (c) Distribution reinforcement.

(d) Spacing of Reinforcement

(i) Min. dist b/w bars (44)

ii) Max. dist " " 3d, or 300mm main
5d or 450mm dist

4) Cover – 20mm a codal 44

5) Bent up bars

(6) Curtailment of bars (7) Shear design.

LOADS ON SLAB : Loads coming on slab are

(i) Self wt (DL) of slab (ii) Live load (as per

iii) Floor finish from IS 875 (Part I)

UNIT-IV

TWO-WAY SLABS

ne Way Slab, bending takes place along span, and the BM carried along the longer usually very small compared to BM carried short span.

the slab is supported on all the four edges when the ratio of long span to short span ll (< 2), bending takes place along both the . Such a slab is known as two-way slab. ab spanning in two directions.

max-BM and deflection for a two way slab uch smaller than that of one-way slab hence a thinner slab is required.

nforcement is provided in both directions

Two way slab when loaded, the corners lifted up. If the corners are held down fixidity at the wall support etc, the BM further reduced, thus ...flections are ... In this case

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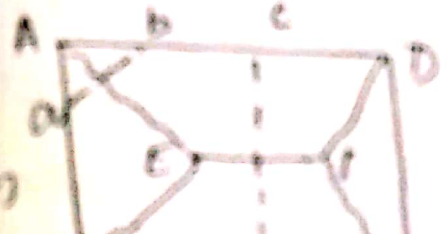
Types of Two Way Slabs

1. Slabs simply supported on the four edges, with corners not held down and carrying udl
2) " " " " " " with corners held down and carrying udl.
3 Slabs with edges fixed or continuous and carrying udl

I) Slabs SS on four edges with corners not held down and carrying udl

Such slabs are commonly used in single storey buildings where the supporting walls do not cause any fixidity. When such a slab is loaded to failure, a crack pattern at the bottom of slab (fig) is observed



Bending takes place in the direction 'cd' for portion EF of the slab

While near the corner (say A) bending take place along 'ab' ⊥r to crack direction 'AE' - Grashof-Rankine method is used for the analysis of such slab.

★ INDIAN STANDARD CODE METHOD (IS 456-2000)

IS 456-2000 lays down design rules for two cases of slabs spanning in two directions:
(a) Restrained slabs (b) Simply Supported Slabs

(A) RESTRAINED SLABS:

When corners of slab are held down/prevented from lifting, the max BM and max deflections are further reduced. However holding down of corners superimposes a twisting moment in the slab for which special reinforcement is needed at top and bottom face of the slab at each corner.

The two-way slabs may be designed as follows as per IS 456 2000

i) The max. BM per unit width in the slab are given by $M_x = \alpha_x w l_x^2$ & $M_y = \alpha_y w l_x^2$

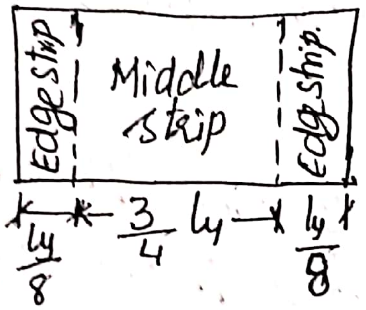
where α_x & α_y are coefficients given in table (26) of page 91

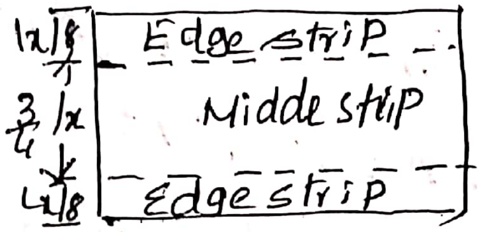
where w = total load per unit area

M_x & M_y are moments on strips of unit width spanning l_x & l_y respectively.

l_x & l_y = lengths of short span & long span respectively

ii) slab are considered as divided in each direction into middle strips and edge strips





(iii) The max moment as calculated in step (i) apply on to the middle strips

iv) Tension Reinforcement provided at mid span in the middle strip shall extend in the lower part of slab to with in 0.25l of a continuous edge or 0.15l of a discontinuous edge.

v) Reinforcement in edge strip shall be 0.15% for mild steel and 0.12% for HYSD bars (+ vi)

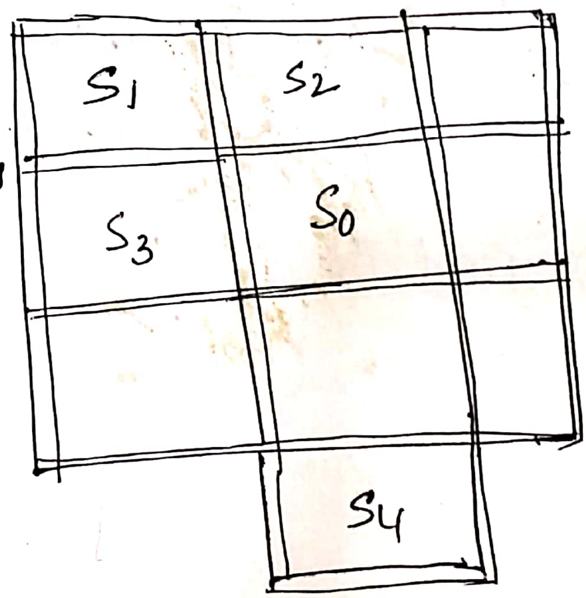
vi) Torsion Reinforcement shall be provide at any corners when the slab is simply supported (free to lift) on both the edges meet at that corner. It shall consist of top and bottom reinforcement each with layers of bars placed parallel to the sides of the slab.

~~#2~~ Slab Simply Supported ~~Slab~~ on the four Edges with corners held down and carrying U.D.L (RESTRAINED SLABS)

When corners held down, the Max. B.M and max. deflection are further reduced. However holding down of corners super imposes a twisting moment in the slab for which special reinforcement is needed at top and bottom faces of the slab at Each Corner.

→ Aspect Ratio = $\frac{l_y}{l_x} \leq 2$ → TWO Way Slab.

→ End conditions of slabs



S_0 → Interior panel

S_1 – Two adjacent Edges discontinuous.

S_2 = ~~Three~~ one long Edge discontinuous.

S_3 – one short Edge discontinuous

S_4 – Three Edges discontinuous.

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Design Steps for 2-way slabs

1) Given :- Live load, l_x & l_y.

2) find depth from Stiffness (deflection) Consideration

$D = \frac{Span}{35}$ (S.S Slab)

$D = \frac{Span}{40}$ (continuous slab).

③ Find total loads acting on the slab.

④ Find the BM coefficients α_x & α_y depending upon l_y/l_x and the End condition of slab.

⑤ Find BM in Short & longer direction

⑥ Calculate Effective depth.

⑦ Find Ast & chk IS456 requirement.

#2 Design a RCC slab for a room of size 5.5m x 4.0m clear in size, if the S.I load is 5 kN/m². Use M_{20} grade concrete and Fe415 grade steel. The Edges are simply supported and edges are held down (restrained).

Design:

Step 1: Given : L.L = 5 kN/m²

l_x = l x b = 5.5 x 4.0 m.

→ depth from stiffness consideration (IS 456 P.(39))

$$D = \frac{span}{35 \times 0.8} = 0.14m = 140mm$$

⇒ provide an Eff cover d' = 30mm

∴ d = 140 - 30 = 110mm

→ Eff. spans

$l_x = 4 + 0.11 = 4.11m$; $l_y = 5.5 + 0.11 = 5.61 m$

→ Aspect ratio $\frac{l_y}{l_x} = \frac{5.61}{4.11} = 1.36 < 2$ ∴ ~~Two way slab~~.

∴ Design as two-way slab

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#2 Design a RCC slab for a room of size 5.5m x 4.0m clear in size, if the S.I load is 5 kN/m². Use M20 grade concrete and Fe415 grade steel. The Edges are simply supported and Edges are held down (restrained).

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step 2 **Loads acting on slab:**

i) S.I. load .... 5 kN/m

ii) Dead load (0.14×1×25) ... 3.5 kN/m.

iii) Floor finish ...... 1.0. kN/m.

Total load 9.5 kN/m

$\Rightarrow$ $W_u = 1.5 \times 9.5 = 14.25$ kN/m

step 3 **BMs:**

→ Bm coefficients α_x & α_y : Table 26 pg (91)

For $\frac{l_y}{l_x} = 1.36 \Rightarrow$ $\alpha_x = 0.082$, $\alpha_y = 0.056$

→ BM is shorter direction, $M_{ux} = \alpha_x \cdot W_u \cdot l_x^2$

$M_{ux} = 0.082 \times 14.25 \times 4.11^2 = 19.74$ kN-m

→ BM in longer direction, $M_{uy} = \alpha_y \cdot W_u \cdot l_x^2$

$M_{uy} = 0.056 \times 14.25 \times 4.11^2$

$M_{uy} = 13.48$ kN-m

Step 2 **Loads acting on slab:**

i) S.I. load .... 5 kN/m

ii) Dead load (0.14×1×25) — 3.5 kN/m.

iii) Floor finish ..... 1.0. kN/m.

Total load 9.5 kN/m

⇒ $W_u = 1.5 \times 9.5 = 14.25$ kN/m

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$M_{uy} = 0.056 \times 14.25 \times 4.11^2$

$M_{uy} = 13.48$ kN-m

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Step 3: Depth of Slab:(d)

$M_0 = 2.76\, bd^2$

$\Rightarrow d = \sqrt{\dfrac{19.76 \times 10^6}{2.76 \times 1000}}$

$\Rightarrow \boxed{d = 85mm} < 110mm.$

∴ Provide d = 110mm from stiffness consideration.

Step 4 Area of Steel in x-dir:

$A_{stx} = \dfrac{M_{ux}}{0.87 f_y(d - 0.42 x_{umax})} = \dfrac{19.74 \times 10^6}{0.87 \times 415(110 - 0.42 \times 0.48 \times 110)}$

$\Rightarrow \boxed{A_{st} = 623 mm^2}$

∴ Provide 10mmϕ bars @ Spacing $= \dfrac{623}{\frac{\pi(10)^2}{4}} \times 1000$

$= 125$ mm c/c.

Area of Steel in y-direction

$A_{sty} = \dfrac{M_{uy}}{0.87 f_y(d - 0.42 x_{umax})} = \dfrac{13.48 \times 10^6}{0.87 \times 415(110 - 0.42 \times 0.48 \times 110)}$

$\boxed{A_{sty} = 426mm^2}$

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Provide 8mm ϕ bars @ $\frac{426}{\frac{\pi (8)^2}{4}} \times 1000 = 117$ mm c/c.

Step 5: Check for shear:

$V_{ux} = \frac{W_u l_x}{2} = \frac{14.25 \times 4.11}{2} =$

$\tau_{vu} = \frac{V_u}{bd} = \frac{\quad}{1000 \times 110} =$

τ_c for M_{20} concrete & $p_t = \frac{623}{1000 \times 110} \times 100 =$ %

is ....

$\tau_v < \tau_c$ ∴ safe in shear.

Step 6: Check for L_d ; mix 30mm

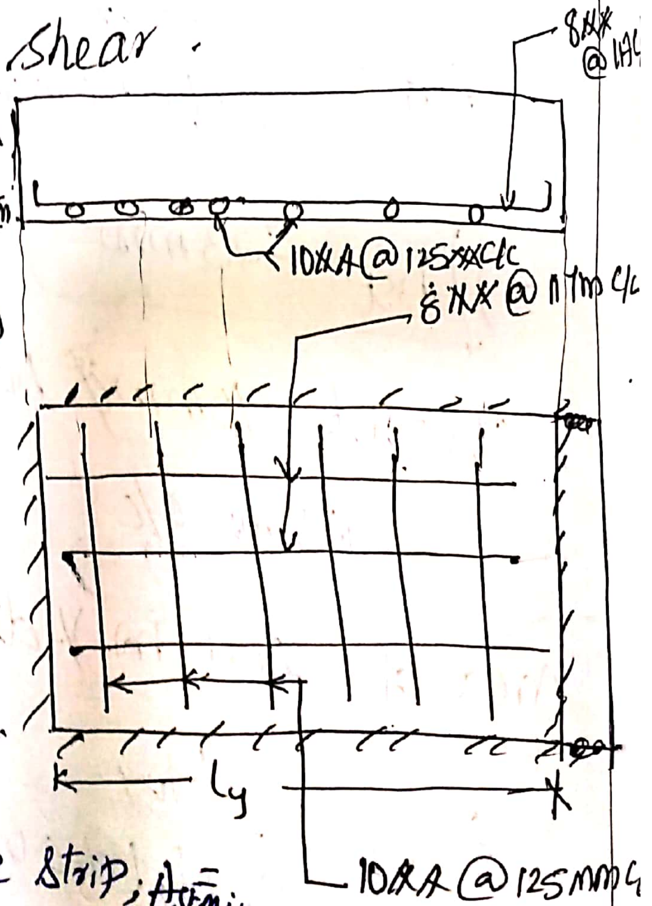
$L_d = 47\phi = 47 \times 10 = 470$ mm

$1.3 \frac{M_u}{V_u} + L_0 > L_d$

$L_0 = \frac{l_s}{2} - d' = \frac{300}{2} - 30$

~~$= \frac{300}{2} - 30$~~ $= 120$mm or 12ϕ

$1.3 \times \frac{19.74}{\quad} + 0.12 > 470$mm.



Also Reinforcement in Edge strip; $A_{st} = A_{st\,min}$

using 8mm ϕ

spacing $= \frac{a_{st}}{A_{st}} \times 1000 \nless 5d$ or 450mm

#3 A RC slab is to be provided for a room measuring 5.8m × 5.0m size. The width of supporting beam is 250mm. The slab carries a L.L of 4kN/m² and floor finish of 1kN/m². Use M_{20} concrete and Fe 415 grade steel. Design the slab for the corners free to lift conditions. Draw reinforcement details.

Sol Design

→ $l_y = 5.8 + 0.25 = 6.05m$; $l_x = 5 + 0.25 = 5.25m$

$$\frac{l_y}{l_x} = \frac{6.05}{5.25} = 1.15 < 2$$

∴ Design as a two way slab

step2 Depth from deflection consideration,

$$D = \frac{l_x}{35 \times 0.8} = \frac{5.25}{35 \times 0.8} = 0.19m \simeq 190mm$$

→ Provide an eff. cover of 30mm

$$\therefore d = 190 - 30 = 160mm$$

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step 3 **Loadings:**

i) Live load ----- 4 kN/m²

ii) Dead load
(0.19×25) ----- 4.75 kN/m²

iii) Floor Finish ------ 1.00 kN/m²

Total load = 9.75 kN/m²

factored load, $w_u = 1.5 \times 9.75 = 14.62$ kN/m² × 1

≃ 14.62 kN/m.

step 4 **BMs:**

BM coeff. α_x & α_y from Table 27

→ $\frac{l_y}{l_x} = 1.15$ & ~~all Edges are discontinuous~~

⇒ $\alpha_x = 0.079$ & α_y & 0.06

∴ $M_{ox} = 0.079 \times 14.62 \times 5.25^2 =$

$M_{ox} = 31.83$ kN-m

$M_{oy} = 0.06 \times 14.62 \times 5.25^2$

$M_{oy} = 24.18$ kN-m

⇒ depth of slab from bending consideration:

$$d = \sqrt{\frac{M_{ux}}{2.76 \times b}} = \sqrt{\frac{31.83 \times 10^6}{2.76 \times 1000}}$$

$\therefore d = 108 mm$ < 160mm

∴ provide depth = 160mm as calculated by deflection limits.

step 5 Area of Tension Steel

$$A_{stx} = \frac{M_{ux}}{0.87 f_y (d - 0.42 x_{umax})} = \frac{31.83 \times 10^6}{0.87 \times 415 (160 - 0.42 \times 0.48 \times 160)}$$

$\therefore A_{stx} = 1022 mm^2$ 690mm²

∴ provide 10mm ϕ bars @ $\frac{\pi (10)^2/4}{~~1022~~ \; 690} \times 1000$ = ~~76mm~~ 113mm c/c

$$A_{sty} = \frac{24.18 \times 10^6}{0.87 \times 415 (160 - 0.42 \times 0.48 \times 160)}$$

A_{sty} = ~~777 mm²~~ 524 mm²

provide 10mm ϕ @ $\frac{\pi (10)^2/4}{~~777~~ \; 524} \times 1000$ = 150mm c/c

Step 6: corners are free to lift, therefore TORSIONAL STEEL is to be provided.

⇒ Area of Torsteel,

$$A_{st\,x\,Tor} = \frac{3}{4} A_{st\,x}$$

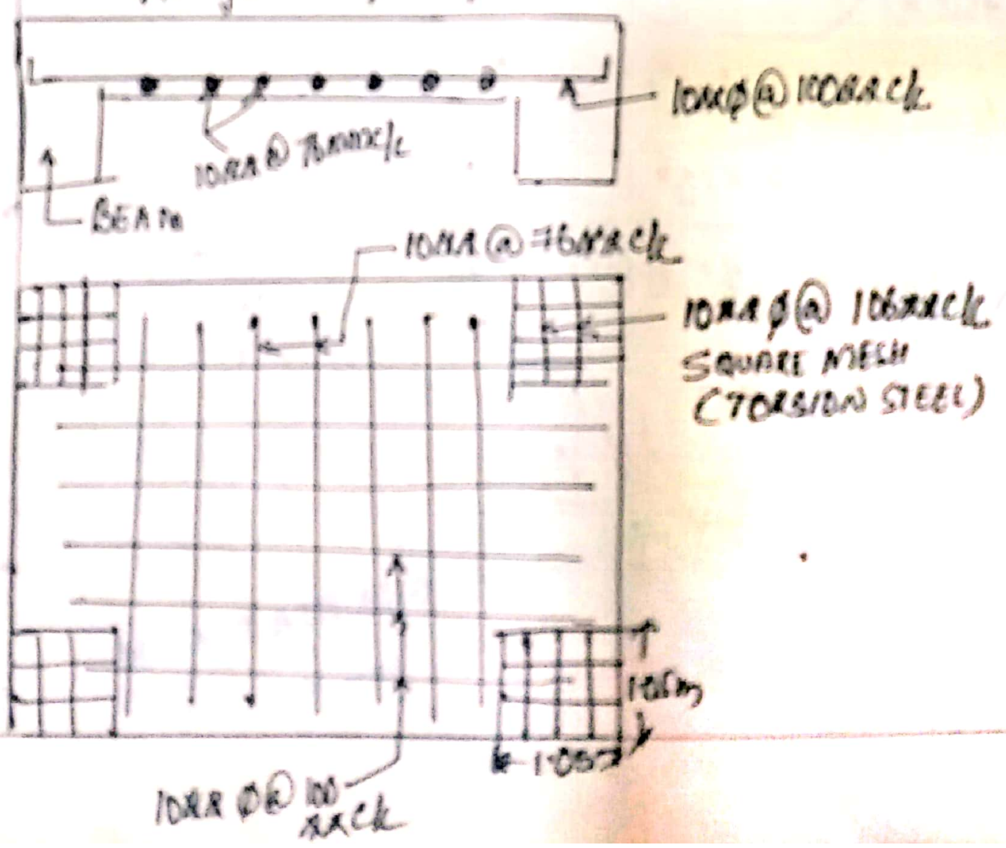
$$= \frac{3}{4} \times 1022$$

$$= 766.5\,mm^2.$$

This steel may be provided in the form of square mesh at top & bottom (As per IS 456)

→ Size of square mesh $= \frac{l_x}{5} = 1.05m = 1050mm$

provide 10mm ϕ bar @ $\frac{\pi(10)^2/4}{766.5} \times 1050 = 106mm\,c/c$ in form of square mesh.



YIELD LINE THEORY AND DESIGN OF SLABS

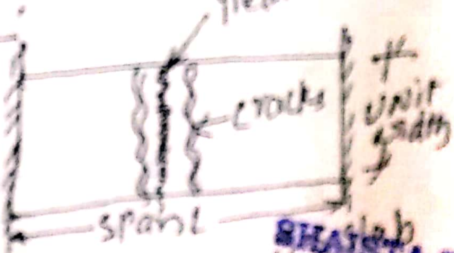
The yield line theory is one of the most important developments in the analysis and design of slab systems. The yield line theory is the ultimate load theory for the analysis of RC slabs.

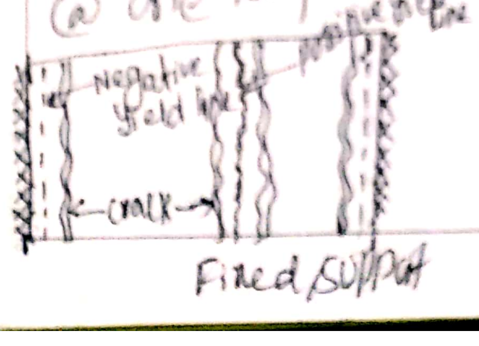
In case of slabs, the computation of ultimate load is quite complicated. In yield line method the computation of ultimate load is based on the pattern of yield lines developed in the slab under conditions approaching collapse.

A yield line is defined as a line in the plane of slab across which reinforcing bars have yielded and about which excessive deformation under constant ultimate moment continues to occur leading to failure.

Yield Line Pattern:

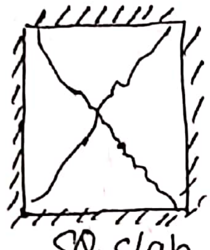
(a) one way slab



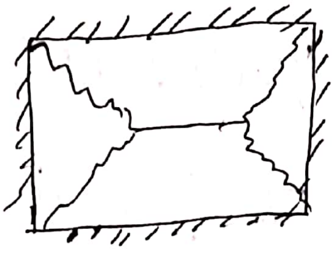


Two way Slabs :

Yield lines starts from centre & extend to corners.



SQ. slab



rect. slab

Characteristic~~s~~ features of yield lines:

i) Yield lines are straight lines

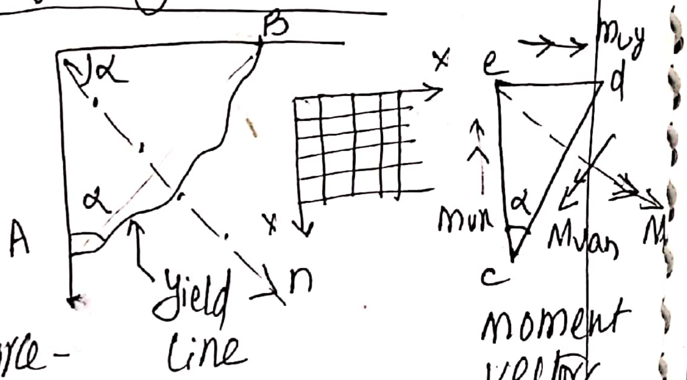
ii) Yield lines terminates at a slab boundary

iii) Yield lines act as axes of rotation

iv) In one-way s.s slab, the yield line will form at the centre of slab at bottom. They are referred as Positive yield line (due to sagg BM)

Moment Capacity along a yield line

In case of one way slab, the yield line is perpendicular to the direction of reinforcement.



In case of two way slab, the direction of yield line may be inclined to the principal directions of reinforcement

$$m_{u\alpha n}(ce) = m_{ux}(cd)\cos\alpha + m_{uy}(de)\sin\alpha$$

$$= m_{ux}\cos^2\alpha + m_{uy}\sin^2\alpha$$

v) ~~In two way slabs~~, In one way continuous slab, the yield line will occur at supports in addition to those at midspan. (due to hogg BM) ← these line are called negative y.L

A RC slab 5m x 5m is simply supported along the four edges and is reinforced with 10mm ϕ, Fe415 steel bars @ 150mm c/c both ways. The average Eff. depth of the slab is 100mm and the over all depth is 130mm. The slab carries a flooring of 50mm thick having unit wt of 22 kN/m². Determine the max. permissible service load (ultimate load), if M_{20} concrete is used.

sol → Spacing = $\frac{a_{st}}{A_{st}} \times 1000$

⇒ $A_{st} = \frac{a_{st} \times 1000}{S_v} = \frac{\frac{\pi (10)^2}{4} \times 1000}{150} = 523.6 mm^2$ per metre width

⇒ $M_u = 0.87 f_y A_{st} (d - 0.42 x_{umax})$

$= 0.87 \times 415 \times 523.6 [100 - 0.42 \times 0.48 \times 100]$

$M_u = 16.85 \times 10^6$ N-mm

$M_{ulim} = 2.76 bd^2 = 2.76 \times 1000 \times 100^2$

$M_{ulim} = 27.61 \times 10^6$ N-mm

Note1 If the slab is isotropically reinforced (i.e equal Reinforcement in both dir.)

$\Rightarrow m_{ux} = m_{uy} = m_u$.

2: If the Reinforcement is two direction is not same, it is said to be orthotropically reinforced.

In this case $m_{ux} = m_u(\cos^2\alpha + \mu \sin^2\alpha)$

where $\mu = \frac{m_{ux}}{m_{uy}}$.

ULTIMATE LOAD ON SLABS

There are two methods of determining the ultimate load capacity of RC slabs.

1. Virtual work method (2) Equilibrium Method

Work done by External forces in undergoing a small virtual displacement is equal to the internal work done in rotation along the yield lines.

$\frac{m_{ux}}{m_{uy}} = \mu$

$m_{ux} = \mu\, m_{uy}$

$M_U < M_{ULim}$, The slab is under reinforced

Again, $m_U = M_U = 16.85 \times 10^6$ N mm $= 16.85$ kN m.

But $m_U = \frac{w_U L^2}{24}$ (By virtual work method analysis) square slab

$\Rightarrow w_U = 24 \cdot \frac{m_U}{L^2} = \frac{24 \times 16.85}{(5)^2} = 16.176$ kN/m² ultimate load

$\Rightarrow$ Service load $= \frac{w_U}{1.5} = 10.78$ kN/m²

DL of slab $= 0.13 \times 25 = 3.25$ kN/m²

DL of finishing $= 0.05 \times 22 = 1.1$ kN/m²

$\therefore$ Total DL $= 3.25 + 1.1 = 4.35$ kN/m²

$\therefore$ Permissible service load $= 10.78 - 4.35$
$= 6.43$ kN/m²

or ult. load capacity $= 16.176 - 4.35 =$ kN/m².

Rectangular Slab:

① A RC slab 4m×6m is reinforced with 10mm ϕ bars @ 150mm spacing in the short direction and 200 mm spacing in the long direction. The slab is 100mm thick with average eff. depth of 80mm. If the yield lines are inclined

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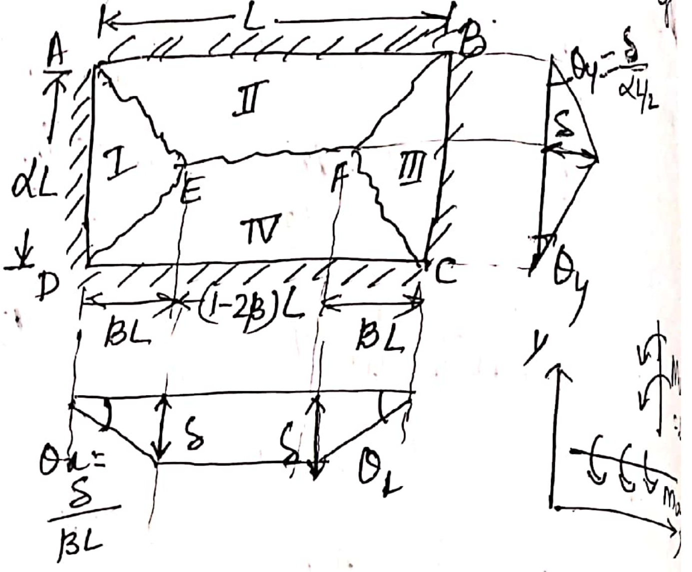
at 45° to either direction of reinforcement ... the (ultimate ~~moment~~ load) safe permissible serv... live load. The DL of flooring may be ... as 1 kN/m².



Sol $\frac{L}{B} = \alpha$

Step 1

Given: L = 6m

B = αL = 4m

$\alpha = \frac{4}{6} = 0.667$

D = 100mm; d = 80mm

Step 2 m_u

$M_{uy} = m_{uy}$ = moment across plane whose norm... is in Y-direction.

$= 0.87 f_y A_{st} (d - 0.42 x_{u\,max})$

$A_{st_y} = \frac{\frac{\pi (10)^2}{4} \times 1000}{150} = 524 mm^2$

$\therefore m_{uy} = 0.87 \times 415 \times 524 (80 - 0.42 \times 0.48 \times 80) / 10^6$

$m_{uy} = 13.078$ kNm

Also $M_{vx} = M_{ox}$ = moment across plane whose normal is in x-dir.

$A_{stx} = \frac{\frac{\pi(10)^2}{4} \times 1000}{200} = 393\,mm^2$

$M_{ox} = \frac{0.87 \times 415 \times 393(80 - 0.42 \times 0.48 \times 80)}{10^6}$

$$\boxed{M_{ox} = 10.194\ kN\text{-}m}$$

$\mu = \frac{10.194}{13.078} = 0.779$

Using Eqn

$$M_o = \frac{w_o \alpha^2 L^2}{24}\left[\sqrt{3 + \mu\alpha^2} - \alpha\sqrt{\mu}\right]^2 ; \alpha = 4/B$$

$$13.078 = \frac{w_u \times 0.667^2 \times 6^2}{24}\left[\sqrt{3 + 0.779(0.667)^2} - 0.667\sqrt{0.779}\right]^2$$

$\Rightarrow \boxed{w_u = 12.729\ kN/m^2}$

$\Rightarrow$ Service load $= \frac{12.729}{1.5} = 8.486\,kN/m^2$

$\Rightarrow$ DL of slab $= 0.1 \times 25 = 2.5\,kN/m^2$

DL of flooring ---- $1.0\,kN/m^2$

$\therefore$ Service LL $= 8.486 - 3.5 = 4.986\,kN/m^2$

$\therefore$ Ult. Load Capacity $= 12.729 - 3.5 = 8 \ldots\ kN/m^2$

Q. A rectangular slab 3.5×5.0m in size, simply supported at the edges. The slab is expected to carry a service LL of 3kN/m² and FF load of 1kN/m². Use M20 concrete & Fe415 grade steel. Design the slab if (a) It is isotropically reinforced (b) If it is orthotropically reinforced. with $\mu = 0.75$. $\alpha = B/L$

Sol step1

Given : $L = 5m$; $B = 3.5m$; $\alpha = \frac{3.5}{5} = 0.7$

step2

→ depth of slab from stiffness consideration :

$$D = \frac{\text{Span}}{35 \times 0.8} = \frac{3.5 \times 1000}{35 \times 0.8} = 125mm$$

$d' = 25mm$.

⇒ $d = 100mm$ with $d' = 25mm$

step3 Loading:

(i) DL of Slab (0.125×25) ---------- 3.125 kN/m²

ii) F.F ---------- 1.0 kN/m²

(iii) L.L ---------- 3.0 kN/m²

∴ Total service load = 7.125 kN/m²

∴ Ultimate design load = $W_u = 1.5 \times 7.125$

= 10.6875 kN/m²

≃ 10.69 kN/m²

(A) Isotropically reinforce slab : $\mu = 1$

→ Ultimate moment on slab is given by

$$m_u = \frac{w_u \alpha^2 L^2}{24}\left[\sqrt{3+\mu\alpha^2} - \alpha\sqrt{\mu}\right]^2$$

$$= \frac{10.69 \times 0.7^2 \times 5^2}{24}\left[\sqrt{3+(1)(0.7)^2} - 0.7\sqrt{1}\right]^2$$

$m_u = 7.45$ kN-m /m width

$\frac{M_{or}}{m_u}$

→ Area of Steel

$m_u = 0.87 f_y A_{st} (d - 0.42 x_{umax})$

$$\Rightarrow A_{st} = \frac{7.45 \times 10^6}{0.87 \times 415 (100 - 0.42 \times 0.48 \times 100)}$$

$A_{st} = 258.45 \, mm^2$

use 8mm ϕ bar, spacing $= \frac{1000 \times \pi (8)^2/4}{258.45} = 195$ mm c/c both ways

(B) Orthotropically reinforced slab:

$\mu = 0.75$ (Given)

$$\therefore m_u = \frac{w_u \alpha^2 L^2}{24}\left[\sqrt{3+\mu\alpha^2} - \alpha\sqrt{\mu}\right]^2$$

$$= \frac{10.69 \times 0.7^2 \times 5^2}{24}\left[\sqrt{3+0.75(0.7)^2} - \underbrace{0.7\sqrt{0.75}}_{0.606}\right]^2$$

$m_u = 8.24$ kN-m

⇒ A_{st}:

$M_u = 0.87 f_y A_{st}(d - 0.42 x_{umax})$ ⇒ Check

$\Rightarrow A_{st_2} = \dfrac{8.24 \times 10^6}{0.87 \times 415 \times (d - 0.42 \times 0.48 \times 100)}$

$\Rightarrow A_{st_2} = 285.8\ mm^2$

∴ Spacing of 8mm ϕ bars in short direction

$= \dfrac{1000 \times 50.3}{285.8} = 185\ mm\ c/c$

and spacing of 8mm ϕ bars in longer direction

$= \dfrac{185}{0.75} = 245\ mm\ c/c$

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