Rectangular Panel, No drop, No column head

Example- Design an interior panel of a flat slab of panel size 4.5m x 6m without providing drop and column head.

Size of column = 300mm x 400mm

live load = 4 kN/m^2

Floor finish = 1 kN/m^2

height of column is 4m above and below the slab

Use M20 concrete and Fe415 steel.

Solution →

Step-1 - Calculation of depth of slab →

→ Because drops are not provided so $\frac{l}{d}$ ratio should be multiplied by 0.9 [clause no→31.2.1 Pg no 53]

→ At the time of depth calculation larger distance is used so, $l = 6m = 6000mm$

→ M.F. → $f_y = 415\ N/mm^2$ Page no - (38)

$$f_s = 0.58 f_y \times \frac{\text{Area of c/s of Steel required}}{\text{Area of c/s of Steel provided}}$$

Because we don't know about the r/f so assume

Area of c/s of steel required = Area of c/s of Steel provided.

$f_s = 0.58\ f_y \times 1 = 0.58 \times 415 = 240.7\ N/mm^2$

Because r/f is not provided till now so assume

$p_t\ \% = 0.12\%$

(From Fig 4 Page no- 38)

$f_s = 240.7$, $p_t = 0.12\%$, M.F. = 1.7

$\therefore \frac{l}{d} = 26 \times 0.9 \times 1.7 = 39.78$

$\frac{6000}{39.78} = d = 150.829 > 125mm$ OK

so provide $d > 151mm$ provide $d = 160mm$

because two layer of r/f has to be provided

so

$D = d + \phi +$ effective cover

$D = 160 + 20 + 30$

$D = 210$ mm

Step-2 → Loading Calculation -

Self weight of flat slab = $0.21 \times 25 \; kN/m^2 = 5.25 \; kN/m^2$

Live load = $4 \; kN/m^2$

Floor finish = $1 \; kN/m^2$

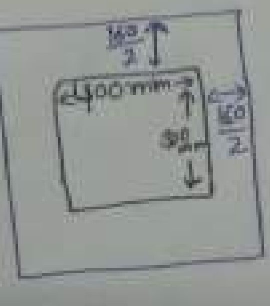
Total load = $5.25 + 4 + 1 = 10.25 \; kN/m^2$

Factored load = $10.25 \times 1.5 = 15.375 \; kN/m^2$

Step-3 → Check for 2-way shear →

Critical section for shear is at a distance of $\frac{d}{2}$ from the face of the column.

$d = 160$ mm



Perimeter of critical section

$= 2\left(400 + \frac{160}{2} + \frac{160}{2} + 300 + \frac{160}{2} + \frac{160}{2}\right)$

$= 2040$ mm

C/S area availiable = 4500 × 6000 − (400 + 160) (300 + 160)

= 26742400 mm^2

$V_u = \frac{15.375}{1000} \times 26742400$ N

= 411644 N

$\tau_v = \frac{V_u}{bd} = \frac{411644}{2040 \times 160} = 1.26 \; N/mm^2$

$\tau_c' = k_s \tau_c$

$\tau_c = 0.25 \sqrt{f_{ck}}$ (Page no-59)

$k_s = 0.5 + \beta_c$

$\beta_c = \frac{\text{Short side of column}}{\text{long side of column}}$ max $k_s = 1$

$\beta_c = \frac{300}{400} = 0.75$

$k_s = 0.5 + 0.75 = 1.25$ $k_s \not> 1$

so $k_s = 1$

$\tau_c = 0.25 \sqrt{20} = 1.118 \; N/mm^2$

$\tau_c' = 1 \times 1.118 \; N/mm^2 = 1.118 \; N/mm^2$

$\tau_c' < \tau_v < 1.5 \tau_c'$ so shear reinforcement is required.

Step-4 → Calculation of Stiffness and α_c – or Correction for pattern loading –

$l_{eff} = 1.2 \times l = 1.2 \times 4000 = 4800$ mm Page no-94, Table no-28

for shorter direction side →

K_c → $I = \frac{bd^3}{12} = \frac{300 \times (400)^3}{12} = 1.6 \times 10^9 \; mm^4$

$K_c = \frac{4EI}{l_{eff}} = \frac{4E \times 1.6 \times 10^9}{4800}$

$K_s \rightarrow$ $l_{eff} = 6000$ mm

$$I = \frac{bd^3}{12} = \frac{4500 \times (160)^3}{12} = 1.536 \times 10^9 \text{ mm}^4$$

$$K_s = \frac{4EI}{l_{eff}} = \frac{4E \times 1.536 \times 10^9}{6000}$$

$$\alpha_c = \frac{\Sigma K_c}{K_s}$$ (Page no - 55)

$$\alpha_c = \frac{2 \times 4E \times 1.6 \times 10^9 \times 6000}{4800 \times 4E \times 1.536 \times 10^9}$$

$$\alpha_c = 2.6042$$

check for $\alpha_{c\,min}$

$$\frac{\text{Imposed load}}{\text{Dead load}} = \frac{4}{6.25} = 0.64$$

Table no-17, Page no - 56

value 0.64 exists between 0.5 to 1.0

at $\frac{I.L.}{D.L} \rightarrow \alpha_{c\,min}$

$0.5 \rightarrow 0$

$1.0 \rightarrow 0.6$

at 0.64 $\alpha_{c\,min} = \frac{0.14 \times 0.6}{0.5} = 0.168$

$\alpha_{c\,min} < \alpha_c \rightarrow$ safe

Ratio $\frac{l_2}{l_1} = \frac{6000}{4500} = 1.33$

Table no (17) Page no 56

value 1.33 exists between 1.25 and 2.0

$\frac{l_2}{l_1} \rightarrow \alpha_{c\,min}$

$1.25 \rightarrow 0.8$

$2.0 \rightarrow 1.2$

at 1.33 $\alpha_{c\,min} = 0.8 + \frac{0.08 \times 0.4}{0.75} = 0.843$

$\alpha_{c\,min} < \alpha \rightarrow$ Safe

No correction required on shorter side -

for longer direction side →

K_c → $I = \frac{bd^3}{12} = \frac{400 \times (300)^3}{12} = 0.9 \times 10^9 \text{ mm}^4$

$$K_c = \frac{4EI}{l_{eff}} = \frac{4E \times 0.9 \times 10^9}{4800}$$

K_s → $l_{eff} = 4500 \text{ mm}$

$$I = \frac{bd^3}{12} = \frac{6000 \times (160)^3}{12} = 2.048 \times 10^9 \text{ mm}^4$$

$$K_s = \frac{4EI}{l_{eff}} = \frac{4E \times 2.048 \times 10^9}{4500}$$

$$\alpha_c = \frac{\Sigma K_c}{K_s}$$ (Page no-55)

$$\alpha_c = \frac{2 \times 4E \times 0.9 \times 10^9 \times 4500}{4800 \times 4E \times 2.048 \times 10^9} = 0.824$$

check for $\alpha_{c\,min}$

$\frac{I.L.}{D.L.} = \frac{4}{0.25} = 0.64$ (calculated)

at 0.64, $\alpha_{c\,min} = 0.168$

$\alpha_{c\,min} < \alpha_c$ → Safe

$\frac{l_2}{l_1} = \frac{4500}{6000} = 0.75$

0.75 value exists between 0.5 and 0.8

$\frac{l_2}{l_1}$ → $\alpha_{c\,min}$ Table no (17) Page no 56

0.5 → 0.6

0.8 → 0.7

at 0.75, $\alpha_{c\,min} = 0.6 + \frac{0.25 \times 0.1}{0.3} = 0.683$

$\alpha_{c\,min} < \alpha_c$ → Safe

no correction required.

and middle strip →

Width of Column strip for both sides $= \frac{l_1}{4}$ or $\frac{l_2}{4}$ whichever is less

$= \frac{6000}{4}$ or $\frac{4500}{4}$

$= 1500$ or 1125 whichever is less

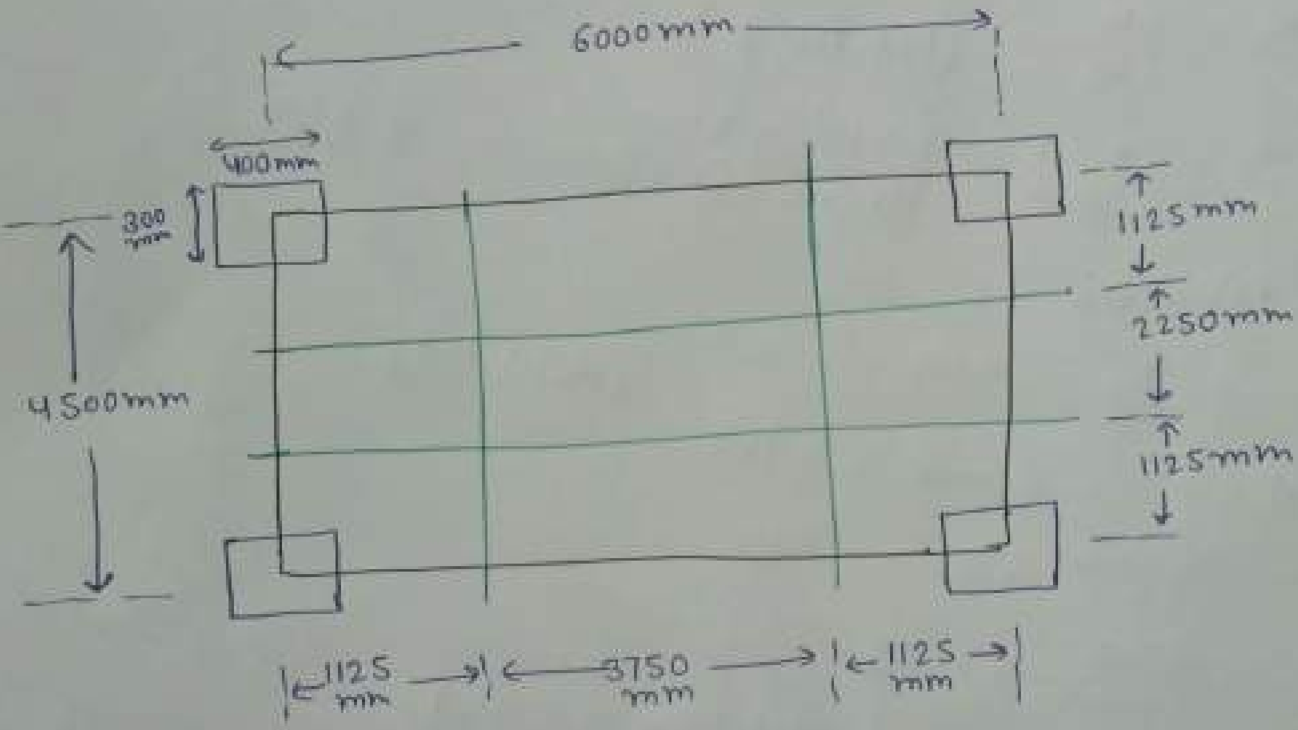
$= 1125$ mm

Middle strip for shorter side $= 4500 - (1125 + 1125)$

$= 2250$ mm

Middle strip for longer side $= 6000 - (1125 + 1125)$

$= 3750$ mm



Step-6 → Calculate moments in all strips

For longer direction →

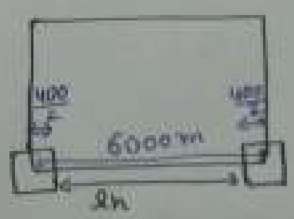
$l_n = 6000 - \frac{400}{2} - \frac{400}{2}$

$l_n = 5600$ mm

$l_1 = 6000$ mm

$l_2 = 4500$ mm

$w = 15.375 \ \frac{kN}{m^2} = \frac{15.375}{1000} \ N/mm^2$



$0.65 \, l_1$
$= 0.65 \times 6000$
$= 3900$ mm
$l_n > 0.65 \, l_1$
OK

$W = w\, l_2\, l_n$

$= \frac{15.375}{1000} \times 4500 \times 5600 = 387450\ N$

Page no 55

$M_o = \frac{W l_n}{8} = \frac{387450 \times 5600}{8} = 271215000\ Nmm$

Total -ve design moment $= 0.65\, M_o$ Page no - 55 clause no - 31.4.3.2

$= 0.65 \times 271215000$

$= 176289750\ Nmm$

Total +ve design moment $= 0.35\, M_o$

$= 0.35 \times 271215000$

$= 94925250\ Nmm$

Column Strip -

-ve moment = 0.75 × total -ve moment Page no 57, clause no 31.5.5.1

~~= 0.75 × 199568355.4~~

$= 0.75 \times 176289750 = 132217312.5\ Nmm$

+ve moment = 0.60 × total +ve moment Page no 57, clause no 31.5.5.3

$= 0.60 \times 94925250 = 56955150\ Nmm$

Middle Strip - Page no 57.

-ve moment $= 176289750 - 132217312.5 = 44072437.5\ Nmm$

+ve moment $= 94925250 - 56955150 = 37970100\ Nmm$

$M_{ulim} = k b d^2$

$= 2.76 \times 2250 \times (160)^2$

$= 158976000\ Nmm$

for column strip & middle strip

$b = 2250\ mm$

$d = 160\ mm$

$M_{ulim} > {+M \atop -M}$

So depth provided is safe in Bending moment criteria

For Shorter direction -

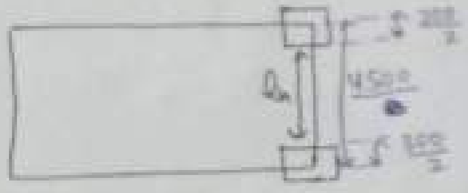
$l_1 = 4500\ mm$

$l_2 = 6000\ mm$

$0.65\, l_1 = 0.65 \times 4500 = 2925\ mm$

$l_n = 4500 - \frac{300}{2} - \frac{300}{2} = 4200$

$l_n > 0.65 l_1 \rightarrow$ OK



$W = w\, l_2\, l_n = \frac{15.375}{1000} \times 6000 \times 4200$

$= 387450$ N

Page no 55

$M_o = \frac{W l_n}{8} = \frac{387450 \times 4200}{8} = 203411250$ Nmm

Total -ve design moment = $0.65 M_o$ Page no 55, clause no. 31.4.3.2

$= 0.65 \times 203411250$

$= 132217312.5$ Nmm

Total +ve design moment = $0.35 M_o$

$= 0.35 \times 203411250$

$= 71193937.5$ Nmm

Column Strip -

-ve moment = $0.75 \times$ Total -ve moment Page no-57, clause no-31.5.5.1

$= 0.75 \times 132217312.5$

$= 99162984.38$ Nmm

+ve moment = $0.60 \times$ total +ve moment Page no-57, clause no 31.5.5.3

$= 0.60 \times 71193937.5$

$= 42716362.5$ Nm

Middle Strip -

-ve moment = $132217312.5 - 99162984.38$

$= 33054328.12$ Nmm

+ve moment = $71193937.5 - 42716362.5$

$= 28477575$ Nmm

$M_{ulim} = k\, b d^2$

for column strip

$b = 1125 + 1125 = 2250$ mm

$d = 160$ mm

$M_{ulim} = 2.76 \times 2250 \times (160)^2$

$= 158976000$ Nmm

$M_{ulim} > {}^{+M}_{-M} \rightarrow$ depth OK

for middle strip

$b = 3750$ mm

$d = 160$ mm

$M_{ulim} = 2.76 \times 3750 \times (160)^2$

$= 264960000$ Nmm

$M_{ulim} > {}^{+M}_{-M} \rightarrow$ depth OK

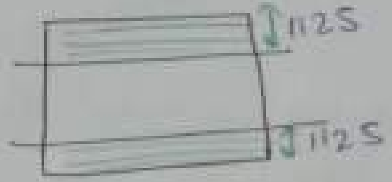
Step-7 → Reinforcement along longer direction.

r/f for −ve M in column strip −

$b = 1125 + 1125 = 2250\ mm$

$d = 160\ mm$

$M_u = 132217312.5\ Nmm$



$$M_u = 0.87\ f_y\ A_{st}\ d \left(1 - \frac{f_y A_{st}}{f_{ck}\ bd}\right)$$

$$132217312.5 = 0.87 \times 415 \times 160 \times A_{st} \left(1 - \frac{415 \times A_{st}}{20 \times 2250 \times 160}\right)$$

$$2288.764 = A_{st} - 5.764 \times 10^{-5} A_{st}^2$$

$$5.764 \times 10^{-5} A_{st}^2 - A_{st} + 2288.764 = 0$$

$A_{st1} = 14636.04\ mm^2$ (reject)

$A_{st2} = 2713.0228\ mm^2$ (accept)

$$A_{st\,min} = \frac{0.12}{100} \times bD = \frac{0.12}{100} \times 2250 \times 210 = 567\ mm^2$$

$A_{st} > A_{st\,min}$ → OK

take dia of bars = 16 mm

$$\text{Spacing} = \frac{\frac{\pi}{4} \times (16)^2 \times 2250}{2713.0228} = 166.747\ mm$$

provide 16 mm dia bars @ 160 mm c/c.

r/f for +ve M in column strip −

$$M_u = 0.87\ f_y\ A_{st}\ d \left(1 - \frac{f_y\ A_{st}}{f_{ck}\ bd}\right)$$

$$56955150 = 0.87 \times 415 \times 160 \times A_{st} \left(1 - \frac{415\ A_{st}}{20 \times 2250 \times 160}\right)$$

$$985.93 = A_{st} - A_{st}^2 \times 5.76 \times 10^{-5}$$

$$5.76 \times 10^{-5} A_{st}^2 - A_{st} + 985.93 = 0$$

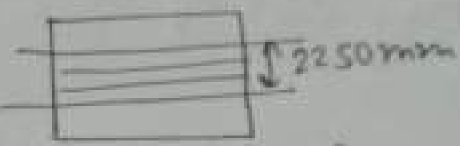
$A_{st1} = 16311.75\ mm^2$ (reject)

$A_{st2} = 1049.35\ mm^2$ (accept) $> A_{st\,min}$ → OK providing 10mm dia bars

$$\text{spacing} = \frac{\frac{\pi}{4}(10)^2 \times 2250}{1049.35} = 168.40 \text{ mm}$$

provide 10 mm dia bars @ 160 mm c/c.

r/f for -ve M in middle strip →



b = 2250 mm
d = 160 mm
D = 210 mm

$$Ast_{min} = \frac{0.12}{100} \cdot bD = \frac{0.12}{100} \times 2250 \times 210 = 567 \text{ mm}^2$$

$$Mu = 0.87\, fy\, Ast\, d \left(1 - \frac{fy\, Ast}{fck\, b\, d}\right)$$

$$44072437.5 = 0.87 \times 415 \times 160 \times Ast \left(1 - \frac{415 \times Ast}{20 \times 2250 \times 160}\right)$$

$$762.9 = Ast - 5.764 \times 10^{-5} Ast^2$$

$$5.764 \times 10^{-5} Ast^2 - Ast + 762.9 = 0$$

Ast_1 = 16549.29 mm² (reject)

Ast_2 = 799.76 mm² (accept) > Ast_{min} → OK

provide 12 mm dia bars

$$\text{spacing} = \frac{\frac{\pi}{4}(12)^2 \times 2250}{799.76} = 318.18 \text{ mm}$$

spacing_{max} = 2 × slab thickness   Page no - 59
Clause no - 31.7.1
= 2 × 210
= 420 mm > spacing provided → OK

provide 12 mm dia bars @ 300 mm c/c

r/f for +ve M in Middle Strip →

$$Mu = 0.87 f_y A_{st} d \left(1 - \frac{f_y A_{st}}{f_{ck} bd}\right)$$

$$37970100 = 0.87 \times 415 \times 160 A_{st} \left(1 - \frac{415 A_{st}}{20 \times 2250 \times 160}\right)$$

$$5.764 \times 10^{-5} A_{st}^2 - A_{st} + 657.29 = 0$$

$A_{st1} = 16676.85 \ mm^2$ (reject)

$A_{st2} = 684 \ mm^2$ (accept) $> A_{st min}$ → OK

provide 12mm dia bars

$$\text{spacing} = \frac{\frac{\pi}{4} \times (12)^2 \times 2250}{684} = 372.03 mm < \text{Spacing}_{max} \rightarrow OK$$

provide 12 mm dia bars @ 360mm c/c

Step-8 → Reinforcement along shorter direction -

r/f for -ve M in columnstrip -

b = 1125 + 1125 = 2250 mm

d = 160 mm

D = 210 mm

$\text{spacing}_{max} = 2 \times 210 = 420 \ mm$

$$A_{st min} = \frac{0.12}{100} \times 2250 \times 210 = 567 \ mm^2$$

$$Mu = 0.87 f_y A_{st} d \left(1 - \frac{f_y A_{st}}{f_{ck} bd}\right)$$

$$99162984.38 = 0.87 \times 415 \times 160 A_{st} \left(1 - \frac{415 A_{st}}{20 \times 2250 \times 160}\right)$$

$$1716.57 = A_{st} - 5.764 \times 10^{-5} A_{st}^2$$

$$5.764 \times 10^{-5} A_{st}^2 - 1 + 1716.57 = 0$$

$A_{st1} = 15417.425 \ mm^2$ (reject)

$A_{st2} = 1931.64 \ mm^2$ (accept) $> A_{st min}$ → OK

provide 12 mm dia bars

$$\text{spacing} = \frac{\frac{\pi}{4} \times (12)^2 \times 2250}{1931.64} = 131.73 mm < \text{spacing}_{max}$$

provide 12mm dia bars @130 mm c/c

r/f for +ve M in Column Strip →

$$M_u = 0.87\ f_y\ A_{st}\ d\left(1 - \frac{f_y A_{st}}{f_{ck}\ b d}\right)$$

$$42716362.5 = 0.87 \times 415 \times 160 \times A_{st}\left(1 - \frac{415\ A_{st}}{20 \times 2250 \times 160}\right)$$

$$739.447 = A_{st} - 5.764 \times 10^{-5} A_{st}^2$$

$$5.764 \times 10^{-5} A_{st}^2 - A_{st} + 739.447 = 0$$

$A_{st_1} = 16587.16\ mm^2$ (reject)

$A_{st_2} = 773.95\ mm^2$ (accept) $> A_{st\,min}$ → OK

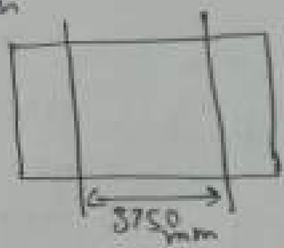
provide 10 mm dia bars

$$\text{Spacing} = \frac{\frac{\pi}{4}(10)^2 \times 2250}{773.95} = 228.328\ mm < \text{Spacing}_{max} \rightarrow OK$$

provide 10 mm dia bars @ 220 mm c/c

r/f in -ve moment in middle strip →

b = 3750 mm, d = 160 mm, D = 210 mm



$\text{Spacing}_{max} = 2 \times 210 = 420\ mm$

$$A_{st\,min} = \frac{0.12}{100} \times 3750 \times 210 = 945\ mm^2$$

$$M_u = 0.87\ f_y\ A_{st}\ d\left(1 - \frac{f_y A_{st}}{f_{ck}\ b d}\right)$$

$$33054328.12 = 0.87 \times 415 \times A_{st} \times 160\left(1 - \frac{415 \times A_{st}}{20 \times 3750 \times 160}\right)$$

$$572.191 = A_{st} - 3.458 \times 10^{-5} A_{st}^2$$

$$3.458 \times 10^{-5} A_{st}^2 - A_{st} + 572.191 = 0$$

$A_{st_1} = 28334.47\ mm^2$ (reject)

$A_{st_2} = 583.98\ mm^2$ (accept) $< A_{st\,min}$

provide $A_{st} = 945\ mm^2$

provide 8 mm dia bars

$$\text{Spacing} = \frac{\frac{\pi}{4}(8)^2 \times 3750}{945} = 199.4\ mm$$

provide 8 mm dia bars @ 190 mm c/c

R/f in +ve moment in middle strip →

$$Mu = 0.87\ fy\ Ast\ d\left(1 - \frac{fy\ Ast}{fck\ bd}\right)$$

$$28477575 = 0.87 \times 415 \times Ast \times 160 \times \left(1 - \frac{415\ Ast}{20 \times 3750 \times 160}\right)$$

$$492.965 = Ast - 3.458 \times 10^{-5}\ Ast^2$$

$$3.458 \times 10^{-5}\ Ast^2 - Ast + 492.965 = 0$$

$Ast_1 = 2841678$ mm^2 (reject)

$Ast_2 = 501.67$ mm^2 (~~rej~~ accept) < Astmin

$Ast = 945$ mm^2

provide 8 mm dia bars @ 190 mm c/c

Step-9 → Shear reinforcement →

for shorter direction →

$$Vus = Vu - 0.5\tau_c bd$$

$$= 4111644 - 0.5 \times 1.118 \times 160 \times 4500$$

Vus = ~~3929186.4 N~~ 3709164 N

Provide 400, 8mm dia bars

$$Vus = \frac{0.87\ fy\ Asv\ d}{Sv}$$

$$\text{~~3929186.4~~}\ 3709164 = \frac{0.87 \times 415 \times 400 \times \frac{\pi}{4} \times (8)^2 \times 160}{Sv}$$

$Sv = 313.14$ mm

Provide 400, 8mm dia strips @ 300 mm c/c

for longer direction

$$Vus = Vu - 0.5\tau_c bd$$

$$= 4111644 - 0.5 \times 1.118 \times 6000 \times 160$$

$$= 3575004\ N$$

Provide 370, 8mm dia strips

$$Vus = \frac{0.87\ fy\ Asv\ d}{Sv}$$

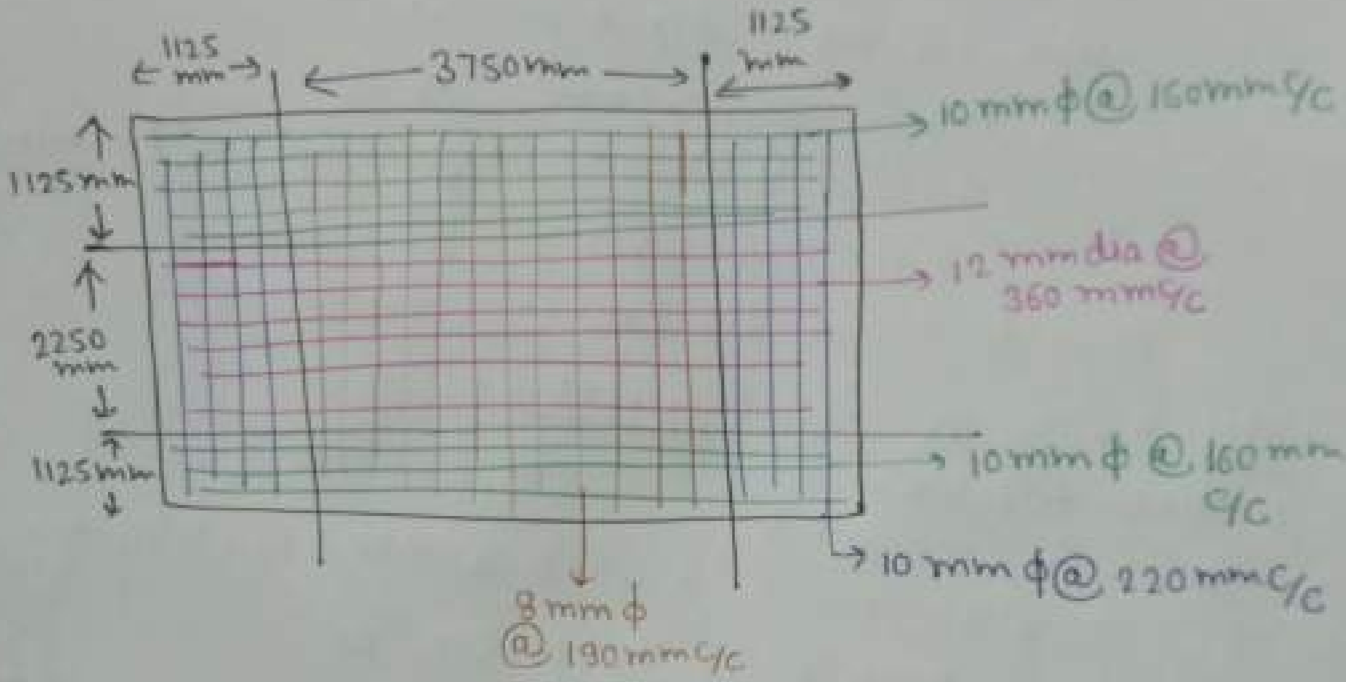
$$3575004 = \frac{0.87 \times 415 \times 160 \times 370 \times \frac{\pi}{4} \times (8)^2}{Sv}$$

Sv = 300.52 mm²

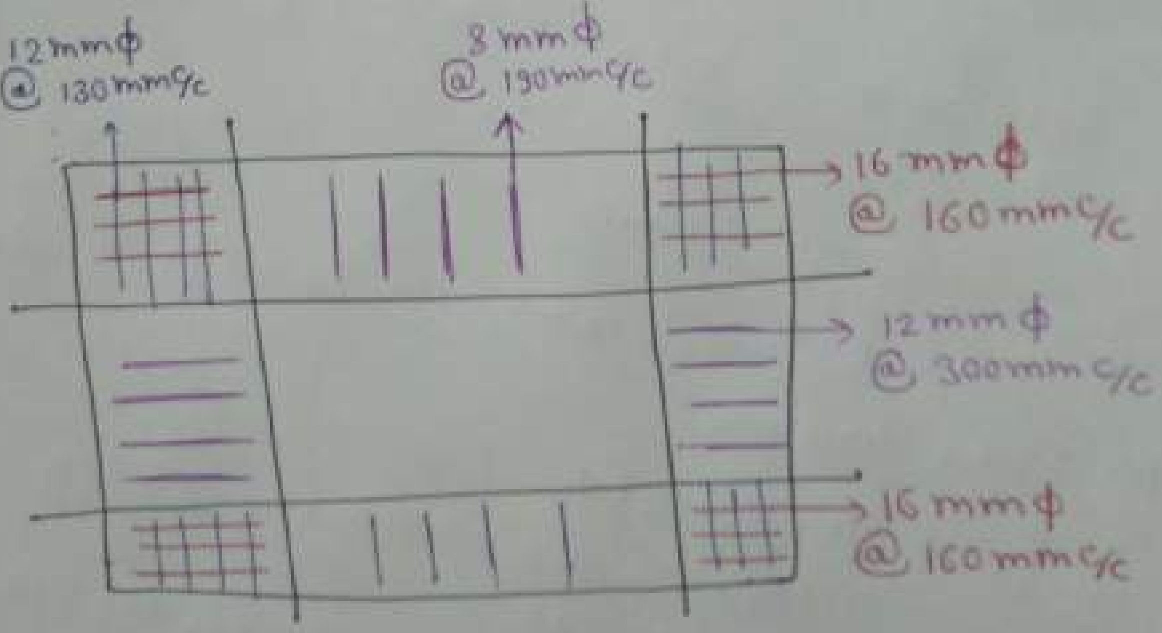
provide 370, 8 mm dia strips @ 300 mm C/c

Step-10 → Detailing Diagram →

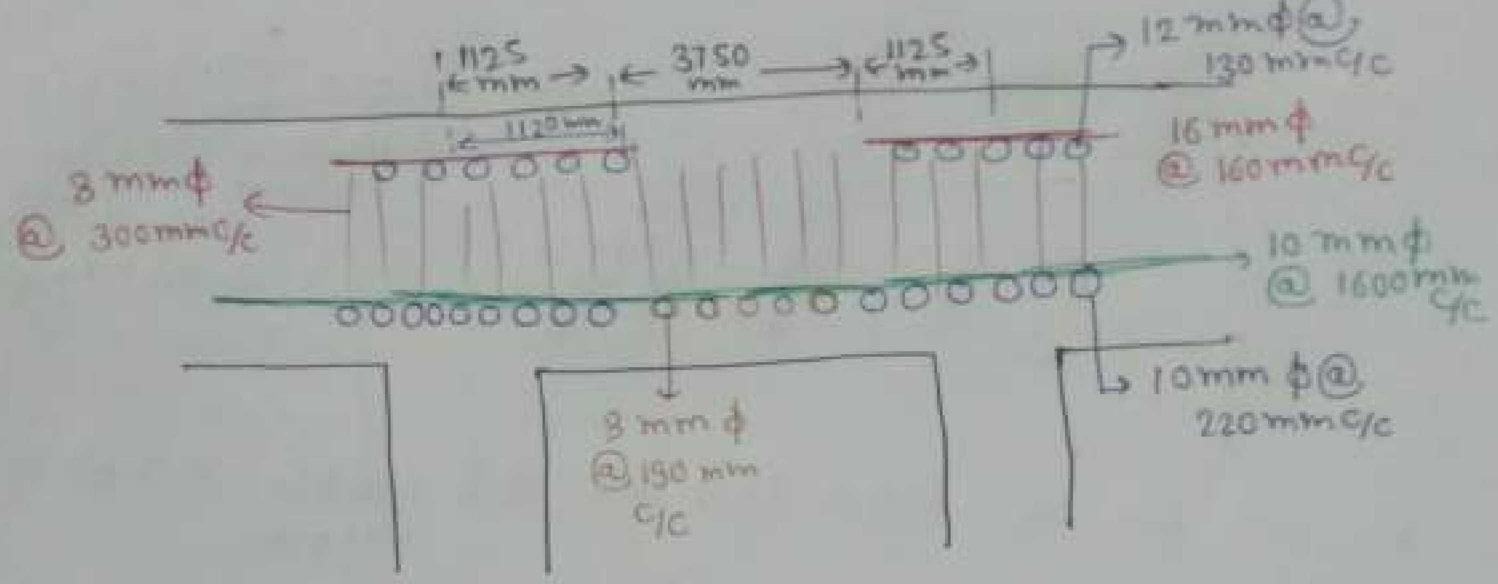
Down Side panel →



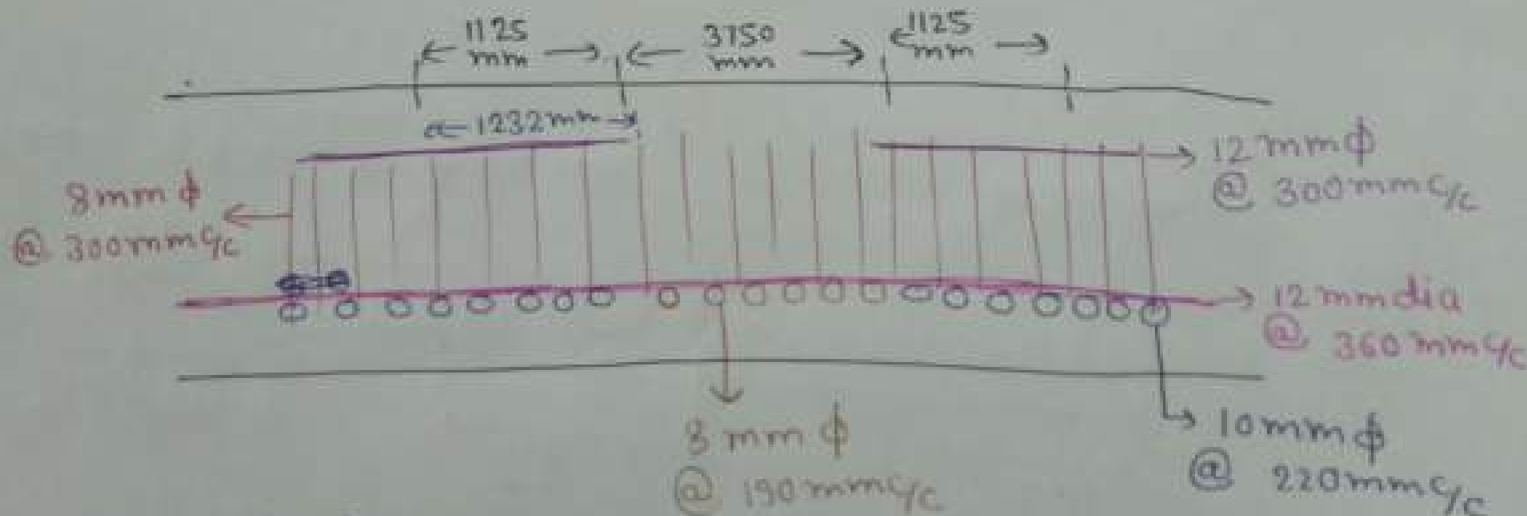
Up Side panel →



Column Strip → (longer direction)



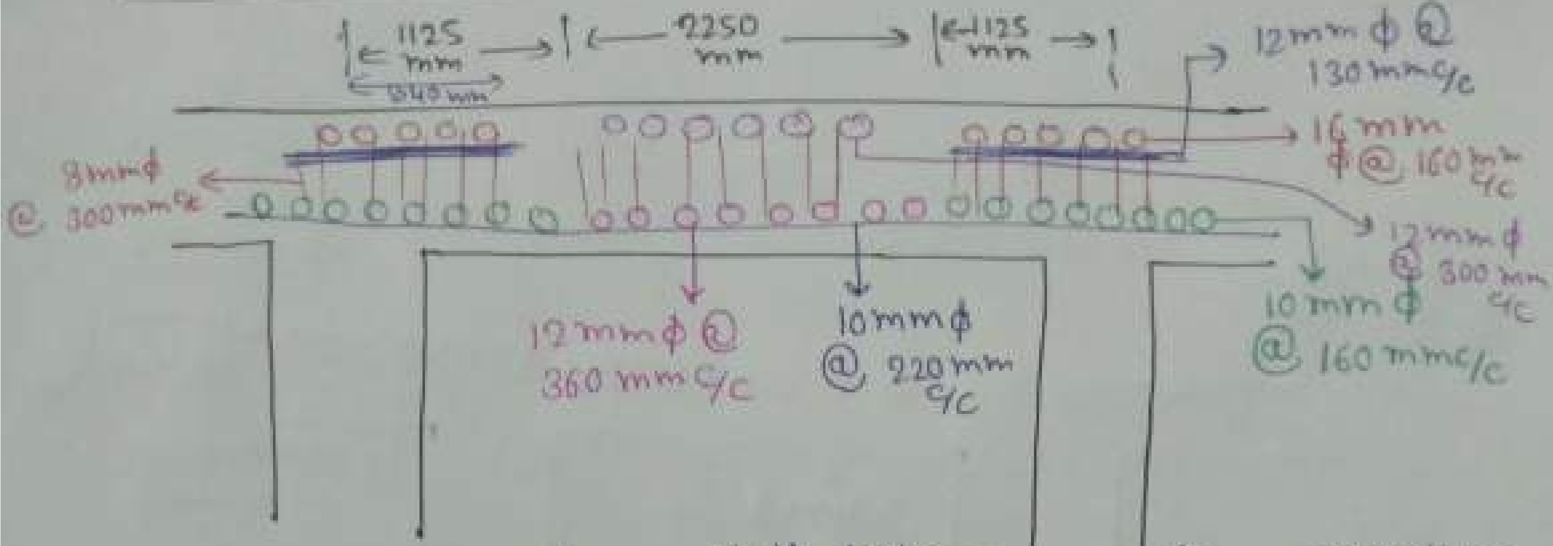
middle strip (longer direction) →



for -ve BM r/f column strip distance $= 0.20\, l_n = 0.20 \times 5600$
$= 1120$ mm

for -ve BM r/f middle strip distance $= 0.22\, l_n = 0.22 \times 5600$
$= 1232$ mm

Column Strip (Shorter direction) →



for -ve BM r/f column strip distance = 0.20 ln = 0.20 x 4200
= 840 mm

for -ve BM r/f middle strip distance = 0.22 ln = 0.22 x 4200
= 924 mm

Middle strip (shorter direction) →