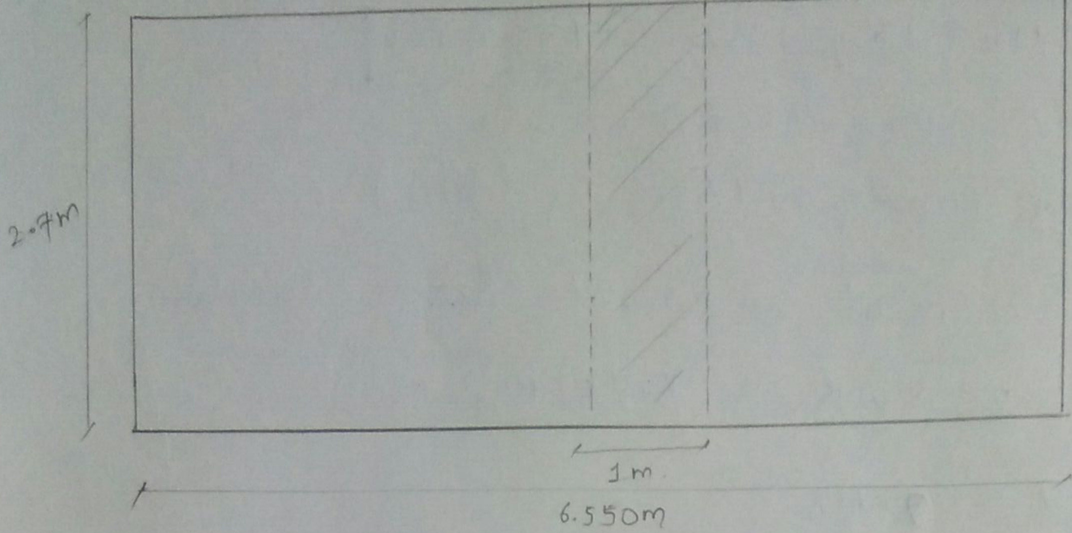
Phase 1: Designing of one-way slab.



Assumption:

$f_{ck} = 40MPa$
$f_y = 500MPa$

For interior span, the length of effective span will be $\frac{3\times7000 - 3\times0.4}{3}$

$= 6.55m.$

effective width (in smaller direction) $= \frac{15 - 5\times0.3}{5} = 2.7m.$

$\therefore$ Dimensions of each slab $= 6.55m \times 2.7m$

For design purpose, assume 1m wide strip.

Thickness of slab will be calculated from serviceability criteria

$$\therefore \left(\frac{l}{d}\right)_{max} = \left(\frac{l}{d}\right)_{basic} \times K_t \times K_c$$ (from 23.2.1)

K_t from graph 4 In IS456 will be → 1.1 $[f_s = 0.58 \times f_y$

K_c is assumed to be 1.

$$\therefore (l/d)_{basic} = \frac{20+26}{2} = 23$$ [the slab contains both continuous & simply supported].

$$\therefore \left(l/d\right)_{max} = 23 \times 1.1 \times 1$$

$\therefore$ $\boxed{d_{min} \simeq 110mm}$.

lets assume cover $= 32mm$

Bar diameter $= 16mm$.

$$\boxed{D = 110 + 16/_{2} + 32 = 150mm}$$

Length of interior span $= 2.7m$

Length of end span $= 2.755m$ $(l + d/_{2})$

To calculate end moments, we calculate factored loads.

$W_{self\ wt} = 25 \times 0.15 = 3.75 KN/m^2$

$W_{Dead\ load} = 2 KN/m^2$

$\therefore W_{total\ dead\ load} = 5.75 KN/m^2$

$W_{Live\ load} = 3 KN/m^2$

$\therefore$ factored loads $\Rightarrow W_{u,DL} = 1.5 \times 5.75 = 8.625 KN/m^2$

$W_{u,LL} = 1.5 \times 3 = 4.5 KN/m^2$

__End span__: $l = 2.755M$ (from 22.5, IS456)

$$M_u = \begin{cases} -\left(\frac{W_{u,DL} + W_{u,LL}}{24}\right) l^2 = -4.15 KNm & \text{at end support} \\ +\left(\frac{W_{u,DL}}{12} + \frac{W_{u,LL}}{10}\right) l^2 = 8.87 KNm & \text{at mid span} \\ -\left(\frac{W_{u,DL}}{10} + \frac{W_{u,LL}}{9}\right) l^2 = -10.34 KNm & \text{at interior support} \end{cases}$$

__Interior span__: $l = 2.7m$

$$M_u = \begin{cases} -\left(\frac{W_{u,DL}}{10} + \frac{W_{u,LL}}{9}\right) l^2 = -9.93 KNm & \text{at first interior support} \\ +\left(\frac{W_{u,DL}}{16} + \frac{W_{u,LL}}{12}\right) l^2 = 6.66 KNm & \text{at mid span} \\ -\left(\frac{W_{u,DL}}{12} + \frac{W_{u,LL}}{9}\right) l^2 = -8.88 KNm & \text{at interior support} \end{cases}$$

At the first interior support, avg. value of M_u = 10.135 KNm

for max. moment at first interior support,

$$R = \frac{M_u}{bd^2} = 0.837 \text{ MPa}$$

$$\therefore \frac{P_t}{100} = \frac{f_{ck}}{2 f_y}\left[1 - \sqrt{1 - 4.598 \times R / f_{ck}}\right]$$

$$P_t = 0.197 \Rightarrow (A_{st})_{req} = \frac{0.197}{100} \times 1000 \times 110 = 217 \text{ mm}^2$$

Similarly, we can calculate corresponding (A_{st}) required for all other values & formulate following table

Location	End span			Interior span	
	end support	midspan	first interior support	midspan	int. span
M_u (KNm/m)	-4.15	8.87	-10.135	6.66	-8.88
M_u/bd^2	0.343	0.733	0.837	0.55	0.732
$(P_t)_{req.}$	0.0796	0.172	0.197	0.128	0.172
$(A_{st})_{req}$ [$\frac{mm^2}{m}$]	87.61	189.5	217.	141	189.2
$(A_{st})_{req.min}$	$0.0012 bD = 180 mm^2$				
Required Spacing using 8mm bar	250mm (4 bars)	250mm (4 bars)	200mm (5 bars)	250mm (4 bars)	(250mm) 4 bars
Max. spacing	$3 \times d = 330$ mm > 300 mm				

In long direction, minimum steel reinforcement of 0.12%. is suggested by IS-456, 26.5.2.1

$$\therefore A_s = \frac{0.12}{100} \times 1000 \times 150 = 180 mm^2$$

take 8 mm diameter bar.

$$\therefore A_{one\ bar} = \pi/4 \times 8^2 = 50\ mm^2$$

$$\therefore \text{No. of bars required} = \frac{180}{50} = 3.6 \approxeq 4 \text{ bars}$$

Spacing of bars = 250 mm

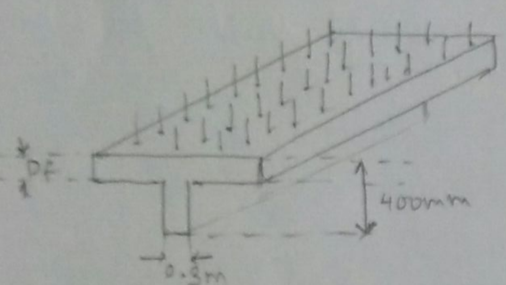
$\therefore$ 4 bars of diameter 8 mm will be provided at a distance of 250 mm per meter of long direction.

<u>Phase 2:</u> Moment envelope & Shear envelope.

The analysis to get moment & shear envelope was carried out in STAAD Pro software.

The self weight of the slab, superimposed dead load & live load were distributed on the adjacent short beams (according to the tributary area).

The total weight acting on all T-beams were considered equal ~~whether~~ irrespective of the position of T-beam (at the end or in the middle)



Dead load & Live load will be calculated per meter on T-beam

Self wt of T-beam (web part) = 0,25 × 25 KN/m³ =

The load case considered to generate envelope was

L.C. = 1.5 × (Dead load) + 1.5 (Live load)

$$\text{Total dead load per meter} = \frac{(6.25+5.75\ \text{KN/m}^2 \times 21\ \text{m}^2}{7\ \text{m}} = 36.00\ \frac{\text{KN}}{\text{m}}$$

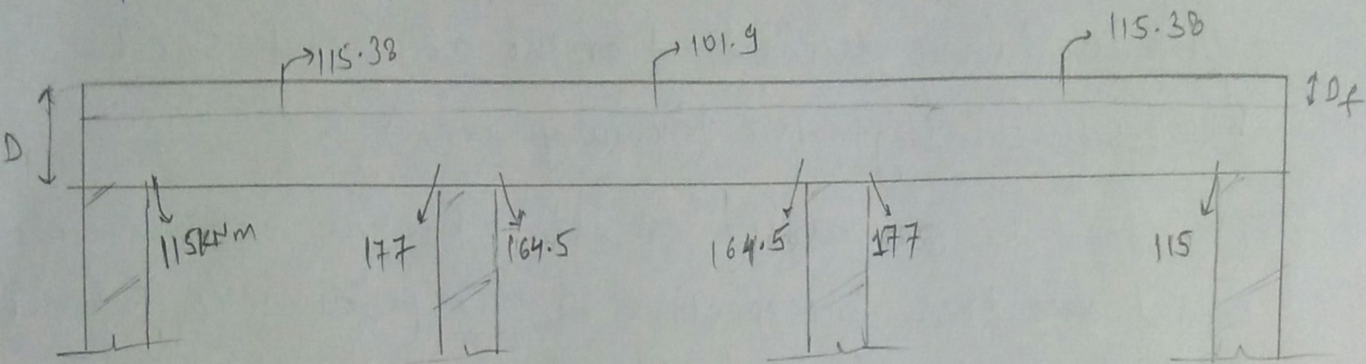
$$\text{Total live load per meter} = \frac{3\ \text{KN/m}^2 \times 21\ \text{m}^2}{7\ \text{m}} = 9\ \text{KN/m}$$

These values were used to get maximum & minimum bending moment & shear force along the length of beam.

The graph of moment & shear envelope is drawn in the report

Phase 3: Flexural Design of T-beam.

The maximum & minimum values of moment obtained from envelope are as follows:



The maximum value at midspan = 115.4 kNm

∴ we design the T-section for moment value of 115.4 kNm

$f_{ck} = 40 MPa$

$f_y = 500 MPa$

$D_f = 150 mm$, $d = 0.35 m$ (assumed)

$b_f = \frac{l_0}{6} + b_w + 6D_f$

$= \frac{0.7 \times 6.550}{6} + 0.3 + 6 \times 0.150 = 1.964 m$

Assuming $x_u = D_f$

$(M_u)_{x_u = D_f} = 0.362 f_{ck} b_f D_f \times (d - 0.416 D_f)$

$= 0.362 \times 40 \times 1.964 \times 0.15 (0.35 - 0.416 \times 0.150)$

$= 1.226 MNm$

Since $M_u < (M_u)_{x_u = D_f}$, we have,

$115 = 0.362 f_{ck} b_f x_u (d - 0.416 x_u)$

by solving quadratic in x_u, we get $x_u = 11.7 mm$

$\therefore 0.87 f_y A_{st} = 0.362 f_{ck} b_f x_u$

$\therefore A_{st} = 765 mm^2$

we can provide 16mm diameter bars

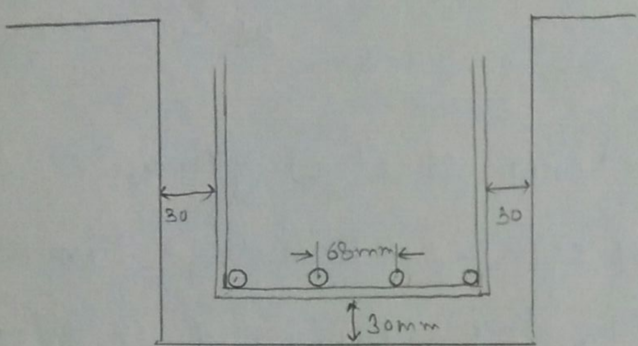
$\therefore A_{one\ bar} = \pi/4 \times 16 \times 16 \equiv 201 mm^2$

$\therefore$ No. of bars to be provided $= 4$.

Assume stirrup diameter = 10 mm

cover = 30mm

$\therefore$ spacing between the bars = 68mm.



For negative moment, we can see that 177 kNm is the highest value. So, we design T-beam in negative moment for the value of -177 kNm.

$\therefore 0.362 f_{ck} x_u b_w \times (D - d' - 0.416 x_u) = M_u$

assume $d' = 45mm$ (including cover, stirrup & bar dia)

$\therefore 0.362 \times 40 \times x_u \times 300 (0.4 - 0.045 - 0.416 x_u) = 177$

$\therefore x_u = 135mm$ by solving quadratic equation

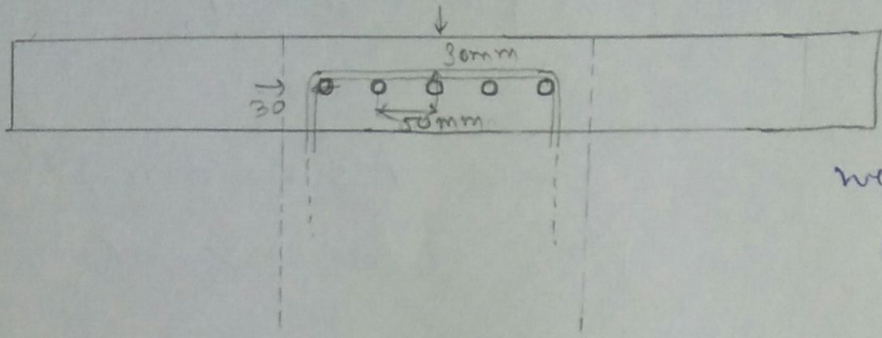
Now, $0.362 f_{ck} x_u b_w = 0.87 f_y A_{st}$

$A_{st} = 1358 mm^2$.

∴ we can provide 20mm diameter bars.

$A_{\text{one bar}} = 20^2 \times \pi/4 = 314\ mm^2$

∴ No. of bars $= 1358/314 \approx 5$ bars to be provided

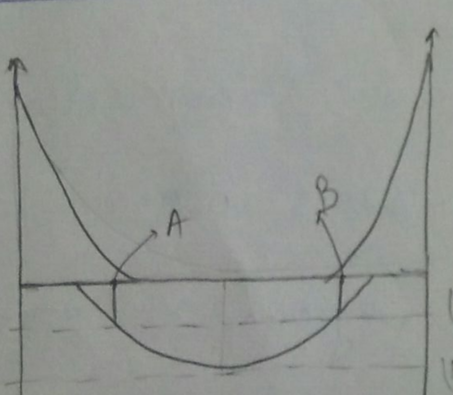


Assuming Stirrup = 10mm, we get the spacing as = 50mm

Now, the provision for maximum steel is completed But we donot need steel cross-section area same everywhere. So, we need to do curtailment in flexure.

For the curtailment, we need to decide actual cut-off point & thoritical cut-off point. (IS-456, 26.2.3)

Positive moment section curtailment:



$(M_u)_{Ast/2} = 50 KNm$

$(M_u)_R = 115 KNm$

For half of steel area (4 bars curtailed to 2 bars).

$\frac{705}{2} \times 0.87 \times 500 \times 10^6 = 0.362 \times 40 \times 10^6 \times 1.964 \times x_u$

using this value of x_u in

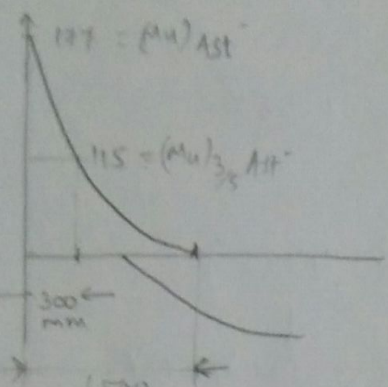
$(M_u)_{Ast/2} = 0.362\ f_{ck}\ b_f\ x_u\ (d - 0.416\ x_u)$,

we get $(M_u)_{Ast/2} = 50\ KNm$

∴ The points A & B obtained on length of beam for $(M_u)_{\frac{Ast}{2}} = 50\,kNm$ are → 1.6375 m & 4.9125 m

for actual cut-off points, these are extended by $d = 0.35\,m$.

Negative moment section curtailment:



5 bars are provided to cater maximum demand.

But we can curtail the bars according to the necessity

moment capacity of 3 bars will be →

$$0.362\, f_{ck}\, x_u\, b_w = 0.87\, f_y \times 3/5\, A_{st}$$

getting the value of x_u & using it in

$$0.362\, f_{ck}\, x_u\, b_w \times (D - d' - 0.416\, x_u) = M_u$$

we get $(M_u)_{3/5 A_{st}}^{\ominus} = 115\,kNm$

The corresponding point = 300 mm from face of support

Moment value vanishes to zero at a distance of 1500 mm. from face of support.

∴ 5 bars will be curtailed to 3 & 3 bars will be further curtailed to 0.

development length criteria will be satisfied by either providing 90° bend at the support or extending it beyond certain point.

$$(L_d) = \frac{\phi \sigma_s}{4 \tau_{bd}}$$

∴ $(L_d)_{+ve\ moment} = 915\,mm$

$(L_d)_{-ve\ moment} = 1144\,mm.$

Phase 4: Shear design of T-beam

From the diagram of flexural curtailment provided in the report, we will check for the adequacy of the critical sections for shear capacity.

① At a distance 'd' from face of support,

$$P_t = \frac{5 \times \pi/4 \times 20^2 + 2 \times 16^2 \times \pi/4}{350 \times 300} = 1.88\%.$$

$$\tau_v = \frac{V_u}{bd} = \frac{145 \times 10^3}{350 \times 300} = 1.38 \text{MPa} \quad (< 4 \text{MPa})$$

for 40 MPa concrete

$$V_u = \left(\frac{168 - 26.08}{2.8}\right)(2.8 - 0.575) + 26.08 = 145 \text{kN}$$

corresponding to $P_t = 1.88\%$, $\tau_c = 0.860$ MPa < 1.38 MPa

Hence the section is adequate

Now, $V_{uc} = 0.860 \times 300 \times 350 = 90.3$.

$$S_{v,max} = \frac{0.87 f_y A_{sv}}{0.4 b}$$

$= 362.5$ mm (max. spacing should be 300mm)

But, we can assume $S_{v,req} = 200$ mm

$$\therefore V_{us} = 2 \times \pi/4 \times (8)^2 \times 0.87 \times 500 \times \frac{350}{200} = 76.125 \text{kN}$$

[8 mm bar assumed]

$\therefore V_{uR} = V_{us} + V_{uc} = 166.4$ kN $> V_u = 145$ kN

(Hence, no additional stirrups required)

② at a distance 650 mm from ~~face~~ center of support (curtailment of -ve steel to 3 bars)

$$v_u = \left(\frac{159 - 26.08}{2.8}\right)(2.8 - 0.65) + 26.08 = 128\,KN$$

But $\frac{2}{3} V_{uR} = 110 < V_u$

Hence, we need to provide extra stirrups over a distance of $0.75d = 262.5$ mm with a spacing less than that of $d/8\beta_b = 350/8(3/8) = 116$ mm.

excess stirrup area required $= \frac{0.4\,b\,S_v}{f_y} = 48\,mm^2$

spacing of stirrup $= 0.75 \times 350/3 = 87.5$ mm

∴ we can use same 2 legged 8 mm bar diameter for this purpose.

③ at a distance 1.85 m from ~~face~~ center of support (curtailment of -ve steel to zero)

$$V_u = \left(\frac{159 - 26.08}{2.8}\right)(2.8 - 1.85) + 26.08 = 72\,KN$$

∴ $\frac{2}{3} V_{uR} = 110 > V_u = 72\,KN$

∴ No need to provide additional stirrups.

④ at a distance 1.6375 m from ~~face~~ center of support, (curtailment of +ve steel to 2 bars)

$$V_u = \left(\frac{159 - 26.08}{2.8}\right)(2.8 - 1.6375) + 26.08 = 55\,KN$$

$\frac{2}{3} V_{uR} = 110 > 55\,KN$

∴ No need to provide extra stirrups.

Phase 5:

The details of curtailment & reinforcement in shown in the diagram in report.

Considering the development length criteria, 5 bars at the end support are bent by 90° & extended further by 335mm vertically downwards.

Phase 6: Column 1:

From the shear envelope obtained from STAAD Pro,

$(V_u)_{left} = 168\ kN$, $(V_u)_{right} = 176\ kN$

maximum value   maximum value

$\therefore P_u = (V_u)_L + (V_u)_R$

$= 345\ kN$

externally, load of 1300 kN is added.

$\therefore (P_u)_{tot} = 1645\ kN$.

$$\therefore \frac{P_u}{f_{ck} bD} = \frac{1645 \times 10^3}{40 \times 10^6 \times 0.3 \times 0.450} = 0.3427.$$

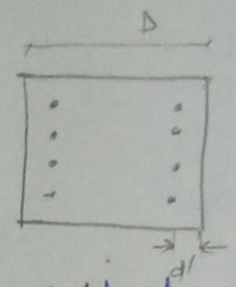
From moment envelope diagram,

$M_u = (M_u)_{left} - (M_u)_{right}$

$\therefore (M_u)_{tot} = 15\ kNm$

$$\therefore \frac{M_u}{f_{ck} bD^2} = \frac{15 \times 10^3}{40 \times 10^6 \times 0.3 \times 0.45^2} = 6.2 \times 10^{-3}$$

∴ From the moment interaction diagram given in SP-16, we choose $d'/D = 0.10$ & reinforcement distributed equally on both sides.



∴ $\frac{P_u}{f_{ck} bD}$ vs $\frac{M_u}{f_{ck} bD^2}$ value lies inside the innermost circle, which means that no steel is required.

But according to IS-456, 26.5.3.1, the min. steel should be 0.8%.

$$\therefore A_s = \frac{0.8 \times 300 \times 450}{100} = 1080 \text{ mm}^2$$

Assuming 16mm diameter bars, $A_{\text{one bar}} = 201 \text{ mm}^2$

∴ 6 bars are required ⇒ 3 on both sides.

$$\frac{d'}{D} = 0.10 \Rightarrow d' = 45\text{mm}.$$

According to 26.5.3.2(c) - ②, the diameter of ties will be 16mm.

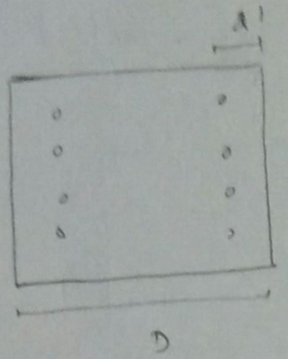
Acording to 26.5.3.2 (c) - ①, the pitch of ties will be 300 mm.

Column 2:

$$\frac{P_u}{f_{ck} bD} = \frac{2045 \times 10^3}{40 \times 10^6 \times 0.3 \times 0.45} = 0.378$$

$$\frac{M_u}{f_{ck} bD^2} = \frac{15 \times 10^3}{40 \times 10^6 \times 0.3 \times 0.45^2} = 6.2 \times 10^{-3}.$$

∴ From moment interaction diagram given in SP-16,



$\frac{d'}{D} = 0.10$

$d' = 45\,mm$.

min. reinforcement condition will be applied

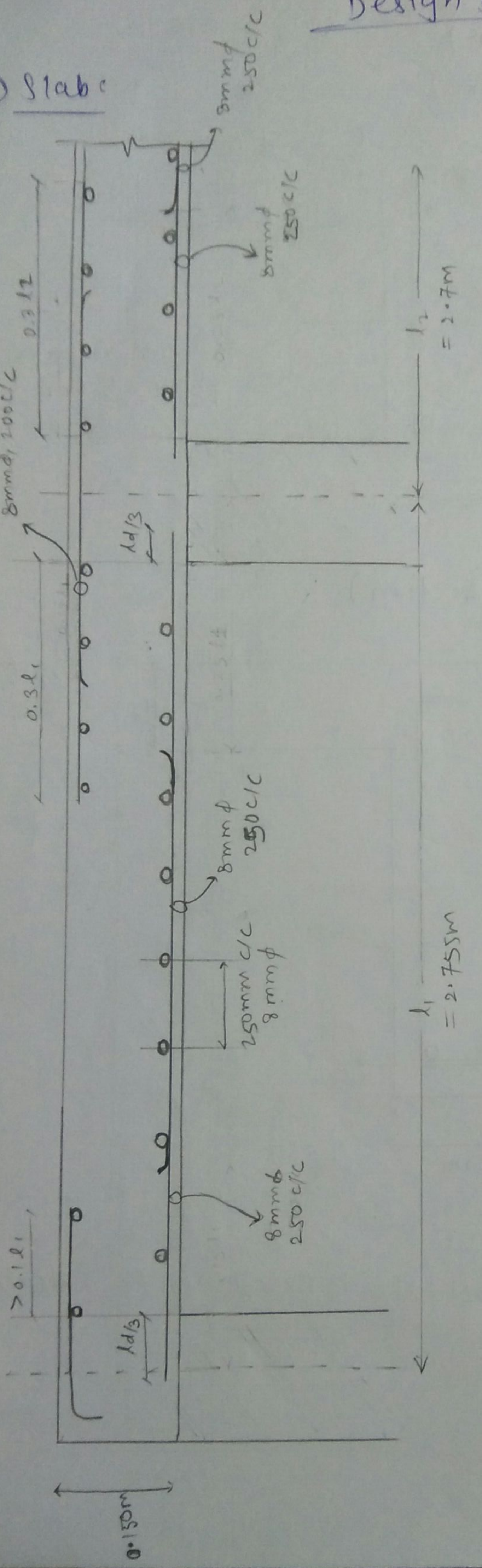
∴ No-of bars = 6 bars, 16mm diameter (3 on each side).

Diameter of ties = 16mm.

pitch of ties = 300mm.

Design Drawing

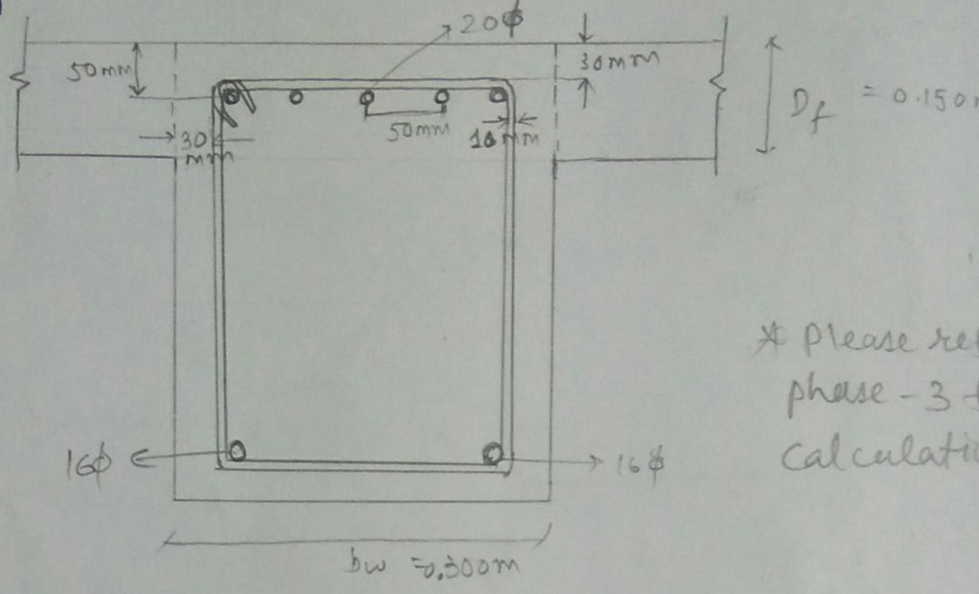
① Slab:



* Please refer to phase-1 for Calculations.

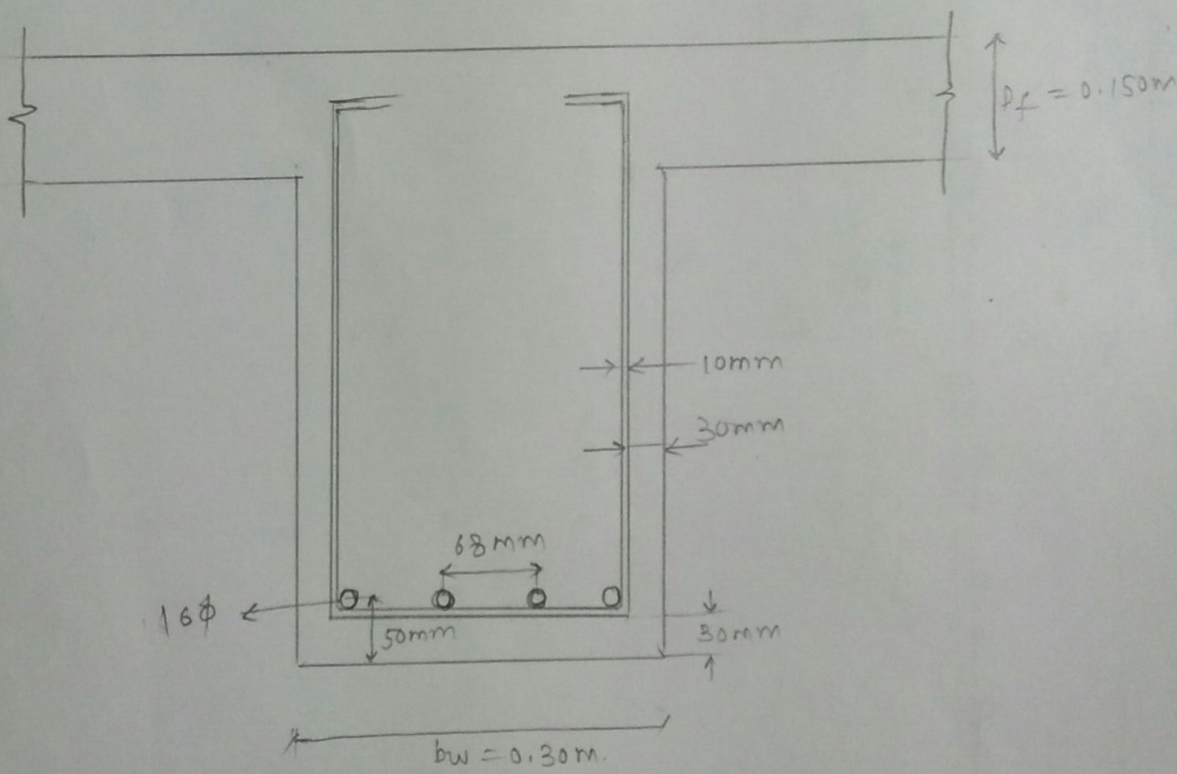
(2) T-beam. (flexural design)

(a) At support. (cross-section)



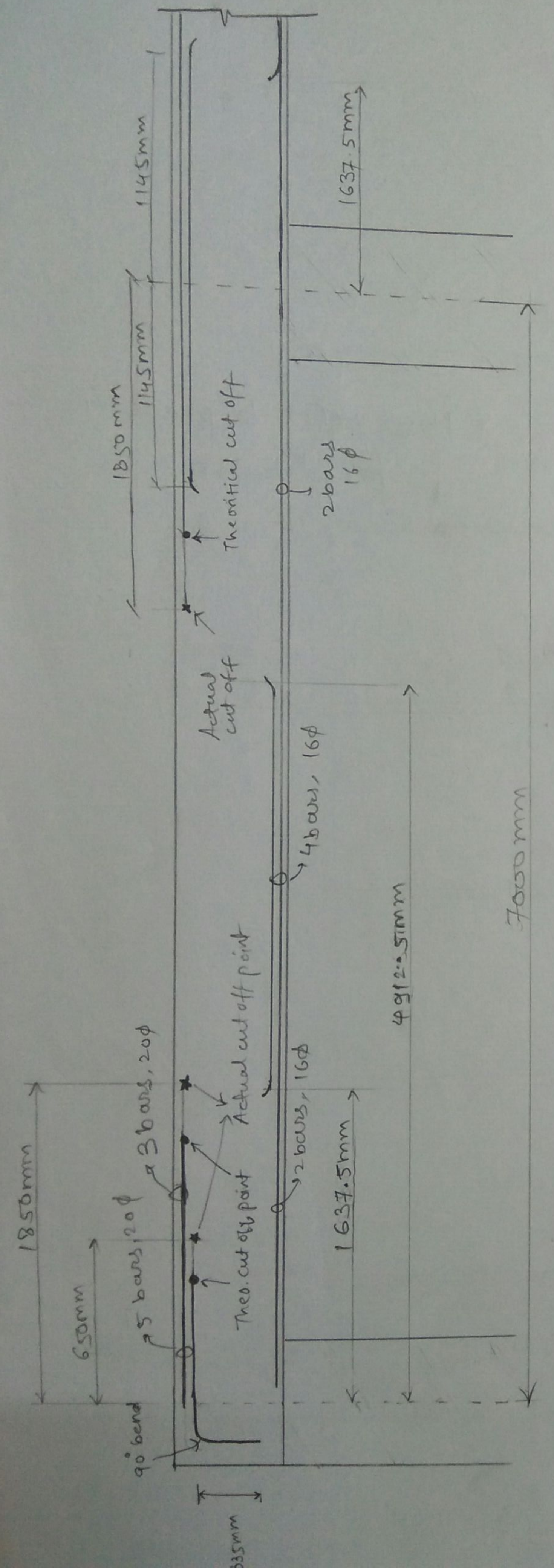
* Please refer to phase-3 for calculations

(b) At mid-span (cross-section)



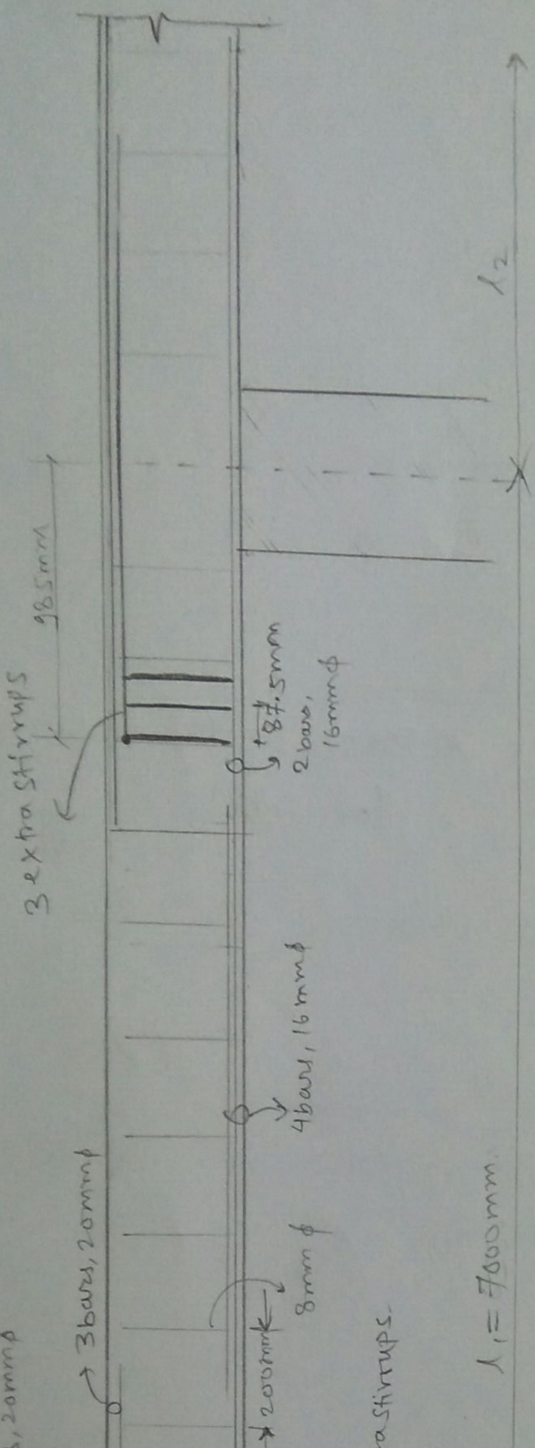
* Please refer to phase-4 for calculation

Beam (Flexural design) [side view]:



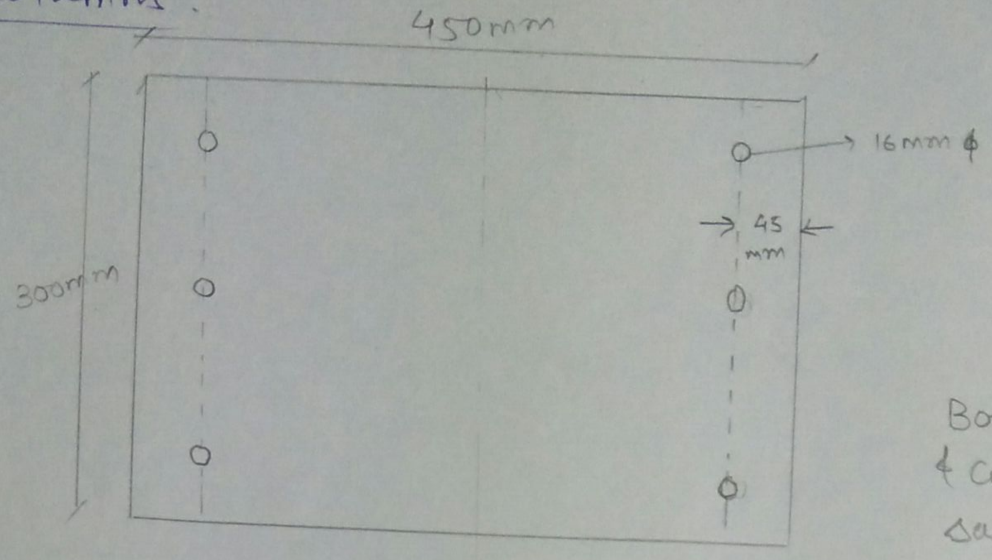
* Please refer to phase-3 for details

④ T-beam (shear Design) [side view]:

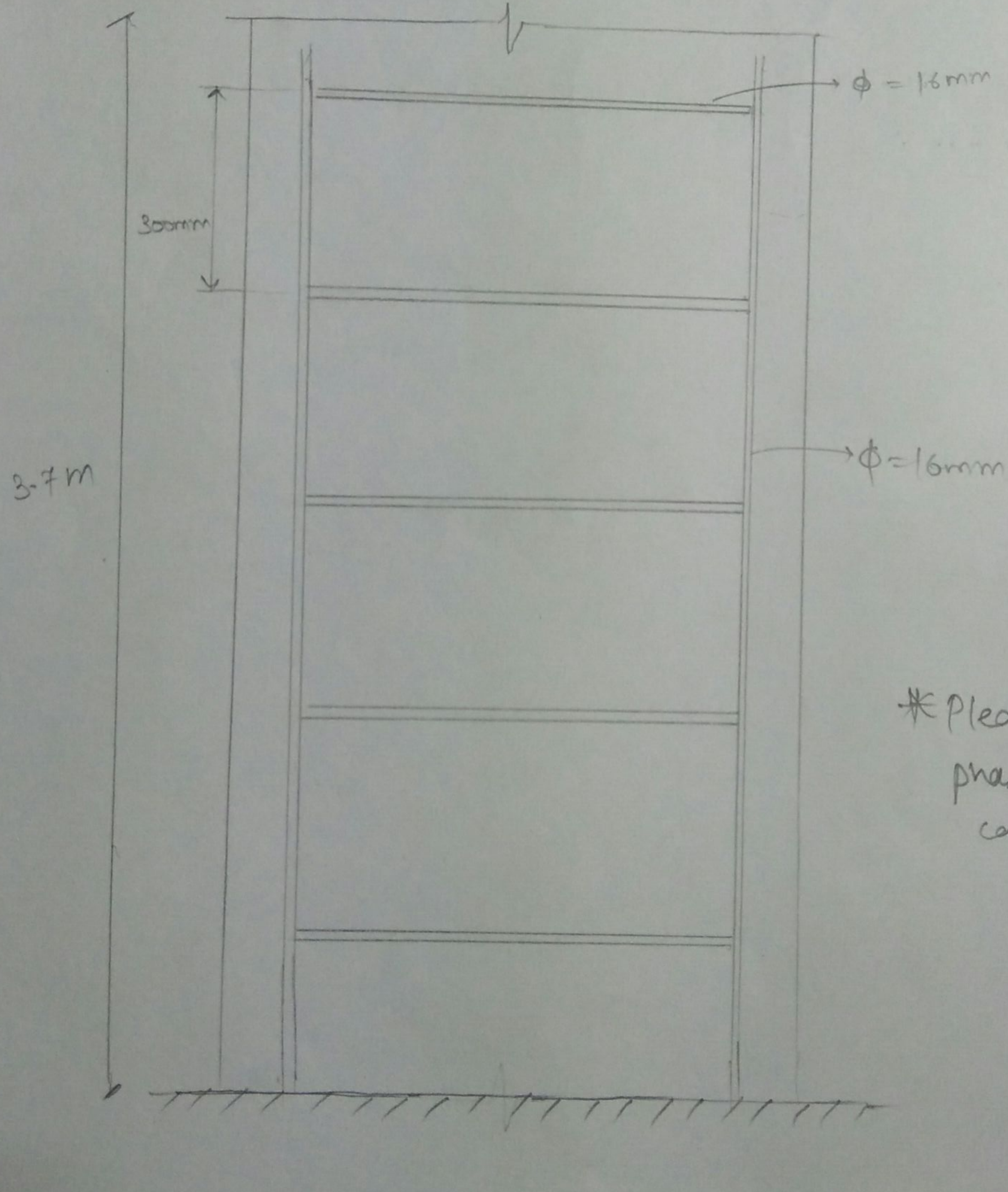


* Please refer to phase-4 for details.

(5) Columns.



Both column-1 & Column-2 has same design.



* Please refer to phase 6 for calculations.