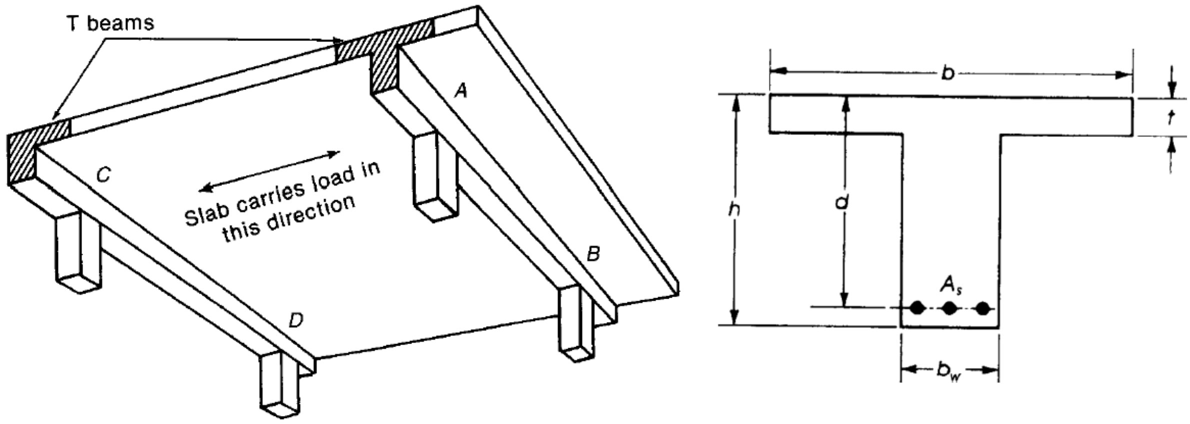
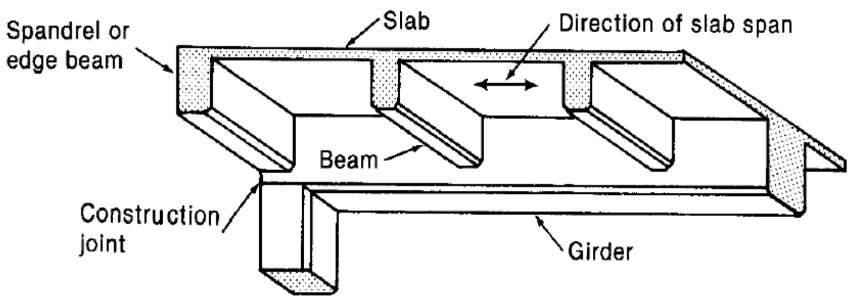
Design of Reinforced Concrete Structures I

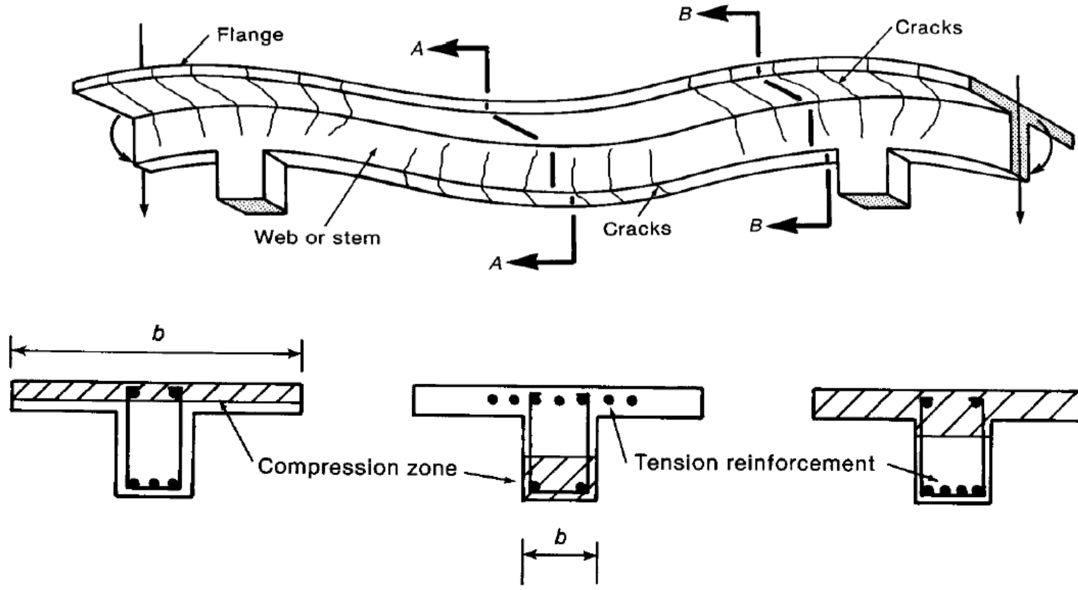
Flexural Analysis & Design of Beam Part6

Flexural Analysis & Design of T-Section

Reinforced concrete floor systems normally consist of slabs and beams that are placed monolithically. As a result, the two parts act together to resist loads. In effect, the beams have extra widths at their tops, called *flanges*, and the resulting T-shaped beams are called T beams. The part of a T beam below the slab is referred to as the *web*. (The beams may be *L shaped* if the stem is at the end of a slab.)





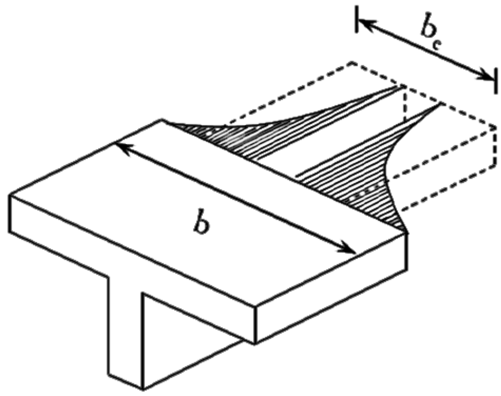


(b) Section *A-A* (rectangular compression zone).

(c) Section *B-B* (negative moment).

(d) Section *A-A* (T-shaped compression zone).

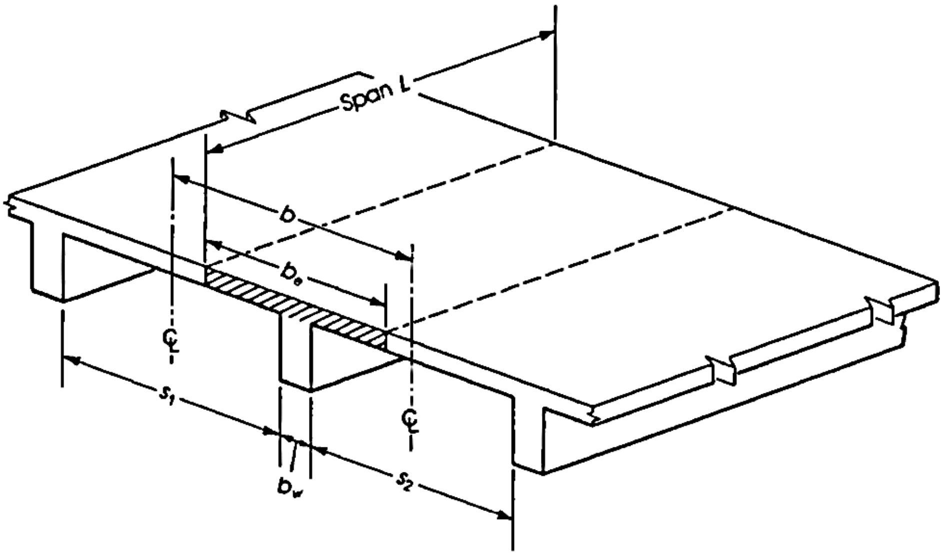
Effective Flange Width (b_e)

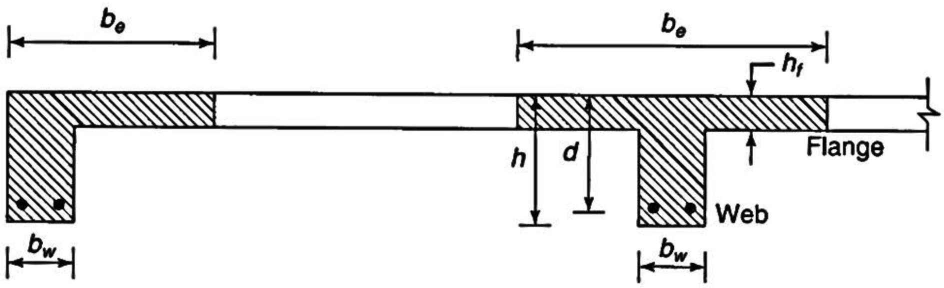


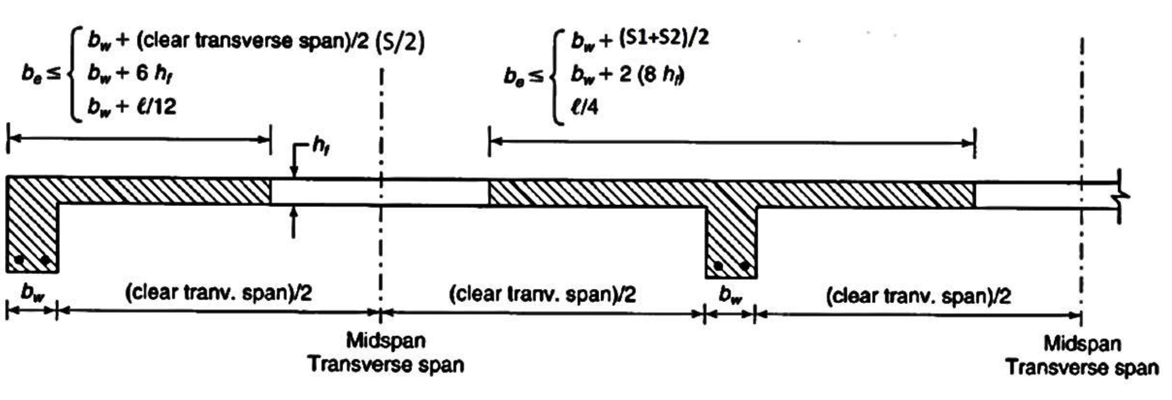
In a T-section, if the flange is very wide, the compressive stresses are at a maximum value at points adjacent to the beam and decrease approximately in a parabolic form to almost 0 at a distance x from the face of the beam. Stresses also vary vertically from a maximum at the top fibers of the flange to a minimum at the lower fibers of the flange. This variation depends on the position of the neutral axis and the change from elastic to inelastic deformation of the flange along its vertical axis. An equivalent stress area can be assumed to represent the stress distribution on the width (b) of the flange, producing an equivalent flange width, (b_e), of uniform stress.

ACI code Provisions for Estimate (b_e)……ACI 8.12

The ACI Code definitions for the effective compression flange width for T- and inverted L-shapes in continuous floor systems are illustrated in figure below



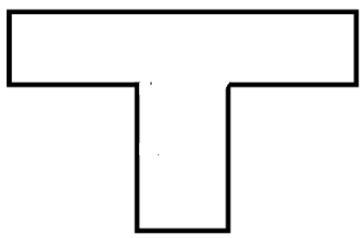




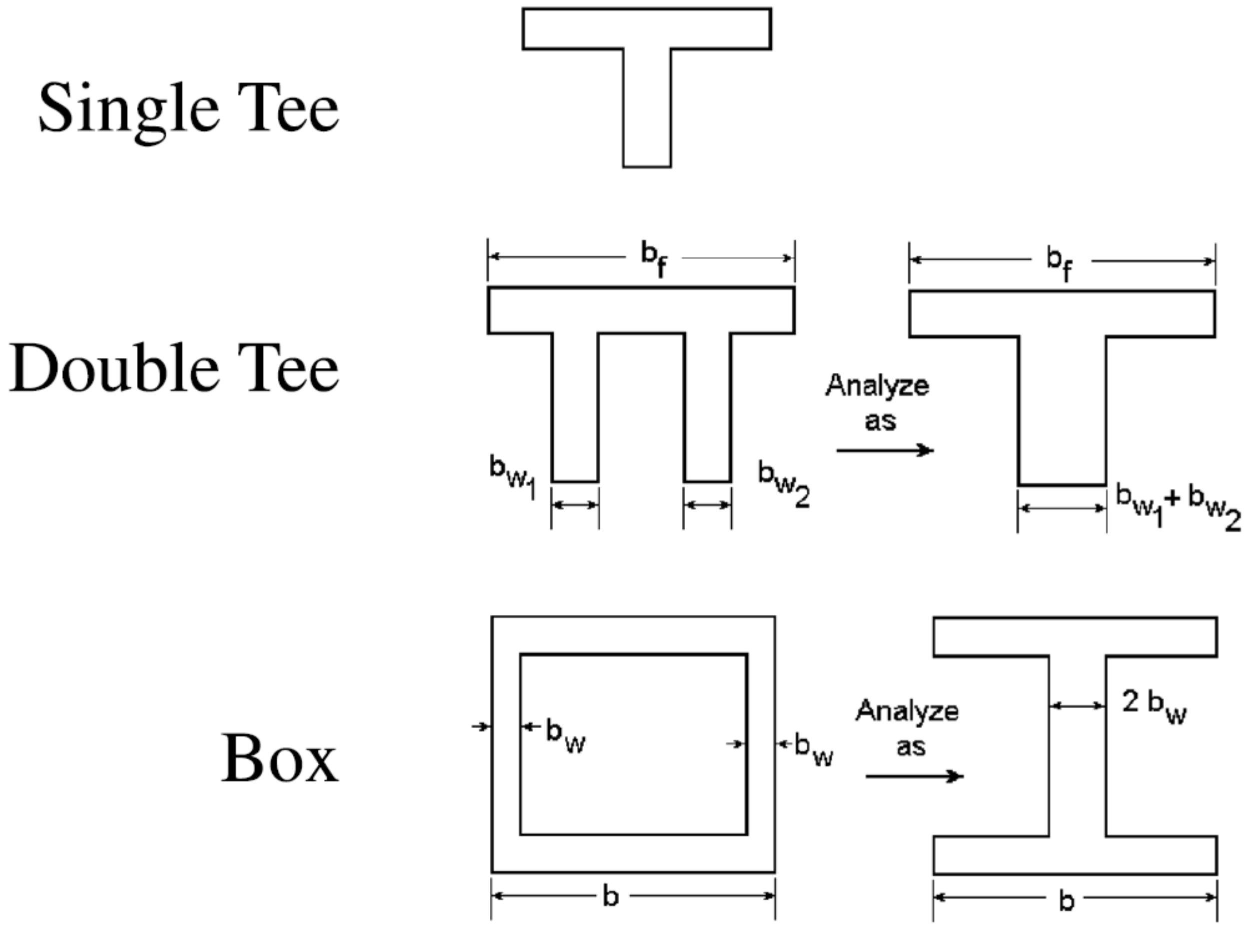
Isolated beams, in which the T-shape is used to provide a flange for additional compression area, shall have a flange thickness (ACI 8.12.4)

$$a)\ h_f \ge \frac{1}{2} b_w$$

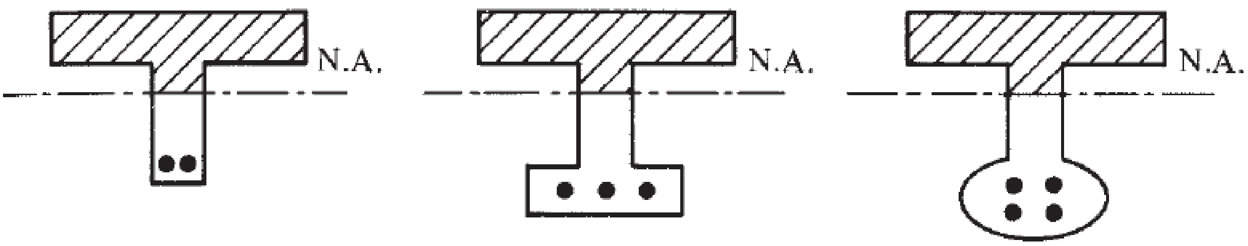
$$b)\ b \le 4b_w$$



Various Possible Geometric of T-beam



A beam does not really have to look like a T beam to be one. This fact is shown by the beam cross sections shown in Figure below. For these cases the compression concrete is T shaped, and the shape or size of the concrete on the tension side, which is assumed to be cracked, has no effect on the theoretical resisting moments.

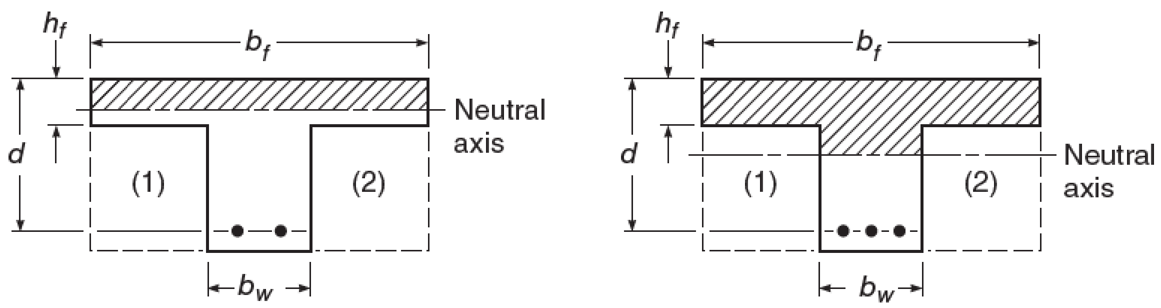


Analysis of T-section

The neutral axis of a T beam may be either in the flange or in the web, depending upon the proportions of the cross section, the amount of tensile steel, and the strengths of the materials.

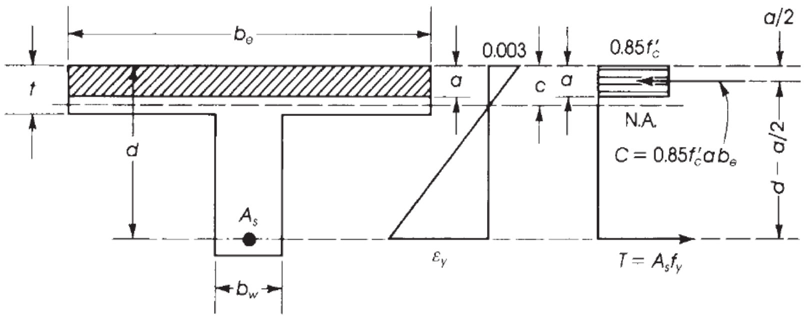
If the calculated depth to the neutral axis is less than or equal to the flange thickness h_f, the beam can be analyzed as if it were a rectangular beam of width equal to b_f, the effective flange width.

When the neutral axis is in the web, as in Fig. blow (b), the preceding argument no longer valid. In this case, methods must be developed to account for the actual T-shaped compressive zone.

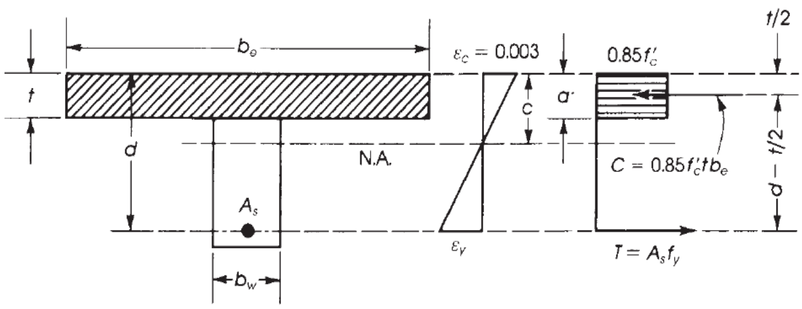


(a) (b)

Case 1: $a \leq h_f$ *the section analysis as rectangular section.*



(a)



(b)

$$\sum Fx = 0 \qquad \rightarrow T = C$$

$$A_s\, fy = 0.85\, f'_c a\, b_e$$

$$\rightarrow a = \frac{A_s\, fy}{0.85\, f'_c\, b_e} \leq h_f$$

$$\emptyset \mathrm{M_n} = \emptyset\, \rho\, b_e d^2 fy \left(1 - 0.59 \frac{fy}{f'_c}\, \rho\right)$$

Or

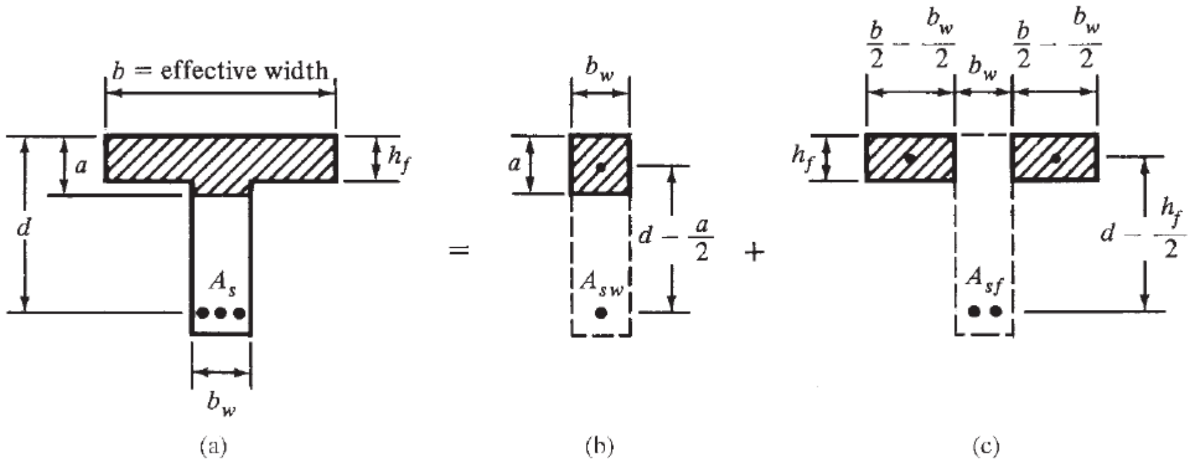
$$\emptyset \mathrm{M_n} = \emptyset\, A_s\, fy \left(d - \frac{a}{2}\right)$$

$$\rho = \frac{A_s}{b_e\, d}$$

$$\rho_{max.} = 0.85\, \beta_1 \frac{f'_c}{fy} \frac{0.003}{(0.003 + 0.004)}$$

$$\rho_{min.} = max.of \left\{ \frac{\sqrt{f'_c}}{4\, fy} * \frac{b_w}{b_e} \qquad \frac{1.4}{fy} * \frac{b_w}{b_e} \right\}$$

Case 2: $a > h_f$ *the section analysis as T − section.*



The analysis of T-section is similar to that in doubly reinforcement.

$$M_n = M_{n1} + M_{n2} = [(A_s - A_{sf})fy * (d - {}^{a}/_{2}) + A_{sf}\, fy\, (d - {}^{h_f}/_{2})]$$

$$\sum Fx = 0 \qquad for\ flange\ case$$

$$A_{sf}\, fy = 0.85 f_c' (b_e - b_w) * h_f \;\rightarrow\; A_{sf} = \frac{0.85 f_c' (b_e - b_w) * h_f}{fy}$$

$$\sum Fx = 0 \qquad for\ web\ case$$

$$(A_s - A_{sf})\, fy = 0.85 f_c' b_w * a \;\rightarrow\; a = \frac{(A_s - A_{sf})\, fy}{0.85 f_c' b_w}$$

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Balance Steel Ratio for T-beam

$$\rho = \frac{A_s}{b_w d}; \qquad \rho_f = \frac{A_{sf}}{b_w d}$$

$$\rho_b = 0.85 \frac{f_c'}{fy} \frac{600}{600 + fy} + \rho_f$$

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Maximum Steel Ratio for T-beam

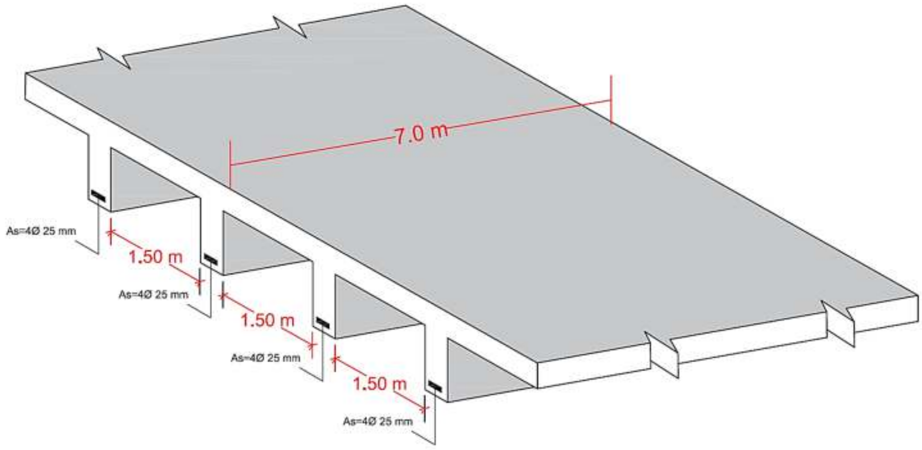
$$\rho_{max.} = 0.85\, \beta_1 \frac{f_c'}{fy} \frac{0.003}{(0.003 + 0.004)} + \rho_f$$

==

Minimum Steel Ratio for T-beam

$$\rho_{min.} = max.of \left\{ \frac{\sqrt{f_c'}}{4\, fy} \qquad \frac{1.4}{fy} \right\}$$

EX: : A series of reinforced concrete beams spaced at 1.5 m face to face have a simply supported span of 7.0m. The beams support a reinforced concrete floor slab of 75mm. thick. The effective depth = 538 mm, web width =300mm, f_c'=28 Mp, fy = 420 Mpa. Calculate the bending moment capacity of interior beam.



Solution:

1- Find the

$$b_e=\begin{cases} \frac{L}{4}=\frac{7000}{4} & =1750mm \\ b_w+16\,h_f=300+(16*75) & =1500mm \;\text{control} \\ b_w+\frac{s_1+s_2}{2}=300+\frac{1500+1500}{2} & =1800\,mm \end{cases}$$

2- Check if the section T or rectangular.

$$a=\frac{A_s\,fy}{0.85\,f_c'\,b_e}=\frac{1964*420}{0.85*28*1500}=23.1\,mm\;<h_f(75mm)$$

$$\rightarrow rectangular\ section$$

3- Find the moment capacity as previously discussed

$$\rho=\frac{As}{b\,d}=\frac{1964}{1500*538}=0.00243$$

$$\rho_{max.}=0.85\,\beta_1\,\frac{f_c'}{fy}\,\frac{0.003}{(0.003+0.004)}=0.0206$$

$$\rho_{min.}=max.of\left\{\frac{\sqrt{f_c'}}{4\,fy}*\frac{b_w}{b_e}\qquad\frac{1.4}{fy}*\frac{b_w}{b_e}\right\}=(0.00063,\;0.00066)$$

$$\rho_{min.}<\rho<\rho_{max.}$$

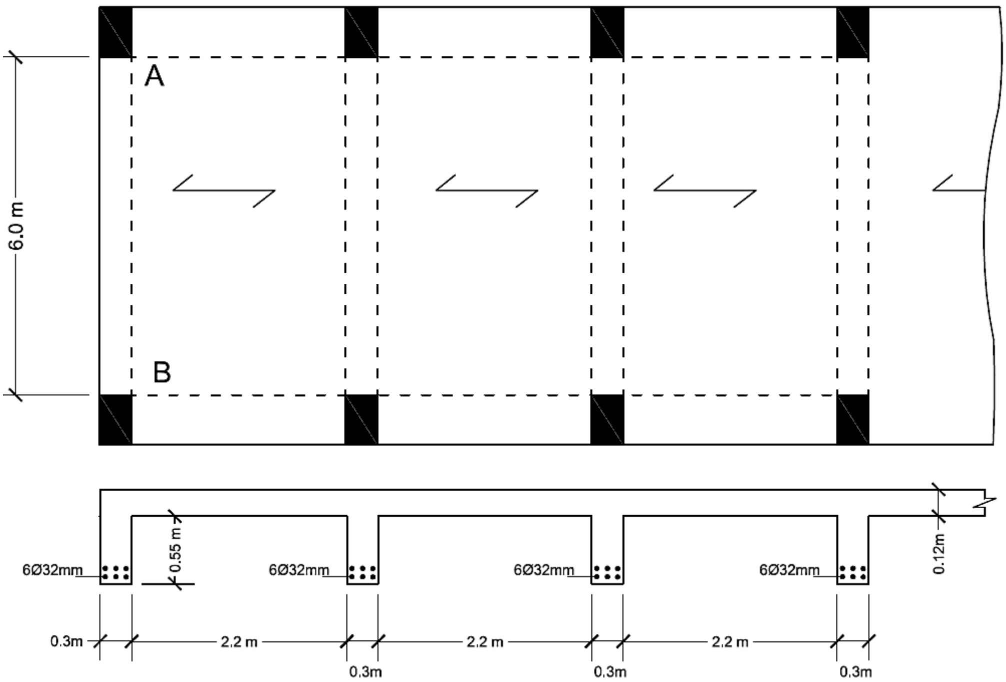
$$\rho_t=0.85\,\beta_1\,\frac{f_c'}{fy}\,\frac{0.003}{(0.003+0.005)}=0.018>\rho=0.00243\quad\rightarrow\emptyset=0.9$$

$$M_u=\emptyset\,\rho\,b_e d^2 fy\left(1-0.59\frac{fy}{f_c'}\,\rho\right)$$

$$M_u=0.9*0.00243*1500*\;538^2*420\left(1-0.59\frac{420}{28}\,0.00243\right)*10^{-6}$$

$$=390.2\,kN.m$$

EX: Determine the moment capacity of exterior beam of floor system shown in Fig. The beam have clear span 6.0 m and $\frac{f'_c}{fy} = \frac{20}{400}$ Mpa



Solution:

1- Find the b_e=
$$b_e = \begin{cases} \frac{L}{12} + b_w = \frac{6000}{12} + 300 = 800mm \quad \boxed{\text{Control}} \\ b_w + 6\,h_f = 300 + (6*120) = 1020mm \\ b_w + \frac{S}{2} = 300 + \frac{2200}{2} = 1400\ mm \end{cases}$$

As=4825.5 mm^2

d =670- 40- 10 -32-25/2 = 575.5 mm (2 layer)

2- Check if the section T or Rectangular

$$a = \frac{A_s\,fy}{0.85\,f'_c\,b_e} = \frac{4825.5*400}{0.85*20*800} = 141.9\ mm > h_f(120mm) \quad \rightarrow T-\ section$$

3- Find A_{sf}

$$A_{sf} = \frac{0.85\,f'_c(b_e - b_w)h_f}{fy} = \frac{0.85*20*(800-300)*120}{400} = 2550\ mm^2$$

4- Find (a)

$$a = \frac{(A_s - A_{sf})\,fy}{0.85 f'_c b_w} = \frac{(4825.5-2550)400}{0.85*20*300} = 178.47\ mm$$

5- Find strength redaction factor ø

$$\varepsilon_t = 0.003*\left(\frac{d_t - C}{C}\right)$$

$$d_t = 670 - 40 - 10 - \left(\frac{32}{2}\right) = 604\ mm, \qquad a = \beta_1 C \rightarrow C = \frac{a}{\beta_1} = 209.96\ mm$$

$$\varepsilon_t = 0.003*\left(\frac{604-209.96}{209.96}\right) = 0.00563 \quad , \qquad \varepsilon_t > 0.005 \rightarrow \emptyset = 0.9$$

6- Calculate the moment capacity

$$\emptyset M_n = \emptyset[(A_s - A_{sf})fy*(d - {}^{a}/_{2}) + A_{sf}\,fy\,(d - {}^{h_f}/_{2})]$$

$$\emptyset M_n = 0.9[(4825.5-2550)*400*(575.5 - {}^{178.47}/_{2}) + 2550*400\,(575.5 - {}^{120}/_{2})]*10^{-6}$$

$$= 871.5\ kN.m$$

Design of T Beams for Positive Moments

Design Procedure

1- Establish (H) based on serviceability requirement and calculate (d).
2- Choose (bw) (2-3) of (d).
3- Find (be) according to ACI requirement.
4- Calculate (As) assume that $a \le h_f$ with beam width (be) and ø =0.9 and then check.

$$M_u = \emptyset M_n$$

$$\emptyset M_n = \emptyset\, \rho\, b_e d^2 fy \left(1 - 0.59 \frac{fy}{f_c'}\, \rho\right) \;\rightarrow\; \text{find As} \rightarrow \quad a = \frac{A_s\, fy}{0.85\, f_c'\, b_e}$$

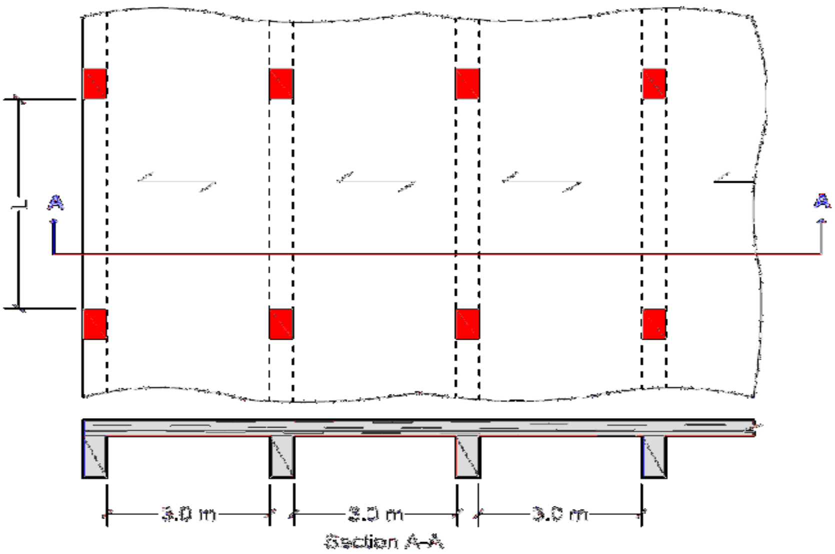
5- If $a \le h_f \quad \rightarrow \text{the assumption is right and continu as rectangular section}$
If $a > h_f \quad \rightarrow \text{the assumption is wrong and continu as T} - \text{ section}$

EX: A floor system consists of 140 mm concrete slab supported by continuous beam with:

$Span\ (L), b_w = 300\ mm, d = 550\ mm, f_c' = 28MPa\ and\ fy = 420\ MPa$

Determine the steel reinforcement required at mid span of interior beam to resist service dead load moment =320kN.m and service live load moment =250kN.m in the following case:

1- L= 8 m.
2- L =2 m.



Solution:

Case 1: L= 8m

$M_u = 1.2M_D + 1.6M_L$

$M_u = 1.2 * 320 + 1.6 * 250 = 784kN.m$

1- Find the

$$b_e = \begin{cases} \frac{L}{4} = \frac{8000}{4} & = 2000mm \\ b_w + 16\,h_f = 300 + (16 * 140) & = 2540mm \\ b_w + \frac{s_1+s_2}{2} = 300 + \frac{3000+3000}{2} & = 3300\ mm \end{cases}$$

2- Calculate (As) assume that $a = h_f$ with beam width (be) and ∅ =0.9 and then check.

$$M_u = \emptyset\,\rho\,b_e d^2 fy\left(1 - 0.59\frac{fy}{f_c'}\rho\right)$$

$$784 * 10^6 = 0.9 * \rho * 2000 * 550^2 * 420\left(1 - 0.59\frac{420}{28}\rho\right) \quad \rightarrow \rho = 0.00354$$

$$As = \rho b_e d = 0.00354 * 2000 * 550 = 3894\ mm^2$$

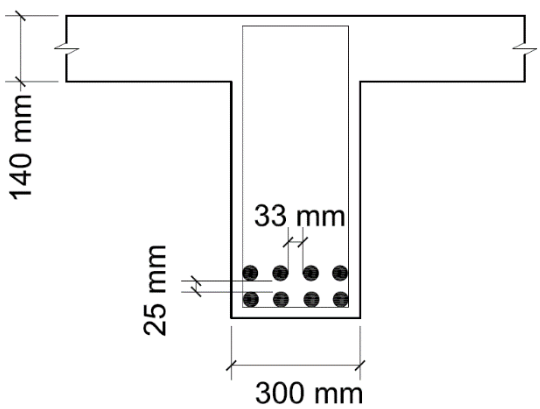
3- Check the assumption in (2)

$$a = \frac{A_s\,fy}{0.85\,f_c'\,b_e} = \frac{3894 * 420}{0.85 * 28 * 2000} = 34.35\ mm < h_f = 140\ mm \quad the\ section\ is\ rectangular\quad ok$$

The assumption is right and continuo as rectangular section.

$$\rho_{max.} = 0.85\,\beta_1\frac{f_c'}{fy}\frac{0.003}{(0.003+0.004)} = 0.0206$$

$$\rho_{min.} = max.of\left\{\frac{\sqrt{f_c'}}{4\,fy} * \frac{b_w}{b_e} \qquad \frac{1.4}{fy} * \frac{b_w}{b_e}\right\} = (0.0005)$$



$$\rho_{min.} = (0.0005) < \rho = (0.00345) < \rho_{max.} = (0.0206)$$

$$\rho_t = 0.85\,\beta_1\frac{f_c'}{fy}\frac{0.003}{(0.003+0.005)} = 0.018 \ > \rho \quad \rightarrow \emptyset = 0.9$$

$As = 3894\ mm^2$,$use\ 8\emptyset 25\ mm\ two\ layer$

$$s = \frac{300 - 2*40 - 2*10 - 4*25}{4-1} = 33.3 > 25\ mm\ ok$$

Case 2: L=2 m

1- Find the b_e= $\begin{cases} \frac{L}{4} = \frac{2000}{4} & = 500mm \\ b_w + 16\,h_f = 300 + (16 * 140) & = 2540mm \\ b_w + \frac{s_1+s_2}{2} = 300 + \frac{3000+3000}{2} & = 3300\ mm \end{cases}$

2- Calculate (As) assume that $a = h_f$ with beam width (be) and $\emptyset$ =*0.9* and then check.

$$\mathrm{M_u} = \emptyset\,\rho\,b_e d^2 fy\left(1 - 0.59\frac{fy}{f_c'}\rho\right)$$

$$784 * 10^6 = 0.9 * \rho * 500 * 550^2 * 420\left(1 - 0.59\frac{420}{28}\rho\right) \quad \rightarrow \rho = 0.0159$$

$$As = \rho b_e d = 0.0159 * 500 * 550 = 4373\ mm^2$$

3- Check the assumption in (2)

$$a = \frac{A_s\,fy}{0.85\,f_c'\,b_e} = \frac{4373 * 420}{0.85 * 28 * 500} = 154.3\ mm > h_f = 140\ mm \quad the\ section\ is\ T$$

The assumption is incorrect and continuo as T- section.

4- Find A_{sf} then find M_{uf}

$$A_{sf}\,fy = 0.85f_c^{'}(b_e - b_w) * h_f \quad \rightarrow \quad A_{sf} = \frac{0.85f_c^{'}(b_e - b_w) * h_f}{fy} = 1587\ mm^2$$

$$M_{uf} = \emptyset\,A_{sf} fy\left(d - {}^{hf}/_2\right) = 288\ kN.m$$

$$M_{u,total} = M_{uf} + M_{u\,w} \quad \rightarrow M_{u\,w} = M_{u,total} - M_{uf} = 784 - 288 = 496\ kN.m$$

$$\mathrm{M_{uw}} = \emptyset\,\rho\,b_w d^2 fy\left(1 - 0.59\frac{fy}{f_c'}\rho\right)$$

$$496 * 10^6 = 0.9\,\rho\,300 * 550^2 * 420\left(1 - 0.59\frac{420}{28}\rho\right) \rightarrow \rho = 0.017$$

$$A_{sw} = \rho b_w d = 0.017 * 300 * 550 = 2805\ mm^2$$

$$A_s = A_{sf} + A_{s\,w} = 1587 + 2805 = 4392\ mm^2$$

5- Check the limit of steel reinforcement

$$\rho = \frac{A_s}{b_w d} = \frac{4392}{300 * 550} = 0.0266$$

$$\rho_{max.} = 0.85\,\beta_1\,\frac{f_c'}{fy}\,\frac{0.003}{(0.003 + 0.004)} + \rho_f$$

$$\rho_{max.} = 0.85 * 0.85\,\frac{28}{420}\,\frac{0.003}{(0.003 + 0.004)} + \frac{1587}{300 * 550} = 0.03$$

$$\rho_{min.} = max.of\left\{\frac{\sqrt{f_c'}}{4\,fy} \quad \frac{1.4}{fy}\right\} = 0.0033$$

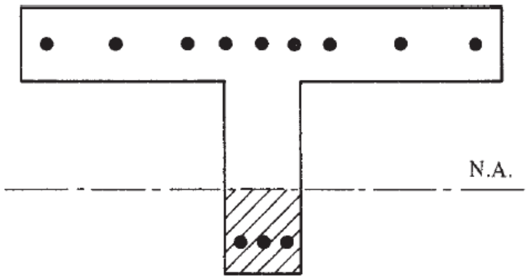
$$\rho_t = 0.85\,\beta_1\,\frac{f_c'}{fy}\,\frac{0.003}{(0.003 + 0.004)} + \rho_f = 0.0276 > \rho = 0.0266 \quad \rightarrow \emptyset = 0.9$$

$$\rho_{min.} = (0.0033) < \rho = (0.0266) < \rho_{max.} = (0.03)$$

6- Sketch the section and show detail

Design of T Beams for Negative Moments

When T beams are resisting negative moments, their flanges will be in tension and the bottom of their stems will be in compression, as shown in Figure. Obviously, for such situations, the rectangular beam design formulas will be used. Section 10.6.6 of the ACI Code requires that part of the flexural steel in the top of the beam in the negative-moment region be distributed over the effective width of the flange or over a width equal to one-tenth of the beam span, whichever is smaller. Should the effective width be greater than one-tenth of the span length, the code requires that some additional longitudinal steel be placed in the outer portions of the flange. The intention of this part of the code is to minimize the sizes of the flexural cracks that will occur in the top surface of the flange perpendicular to the stem of a T beam subject to negative moments.



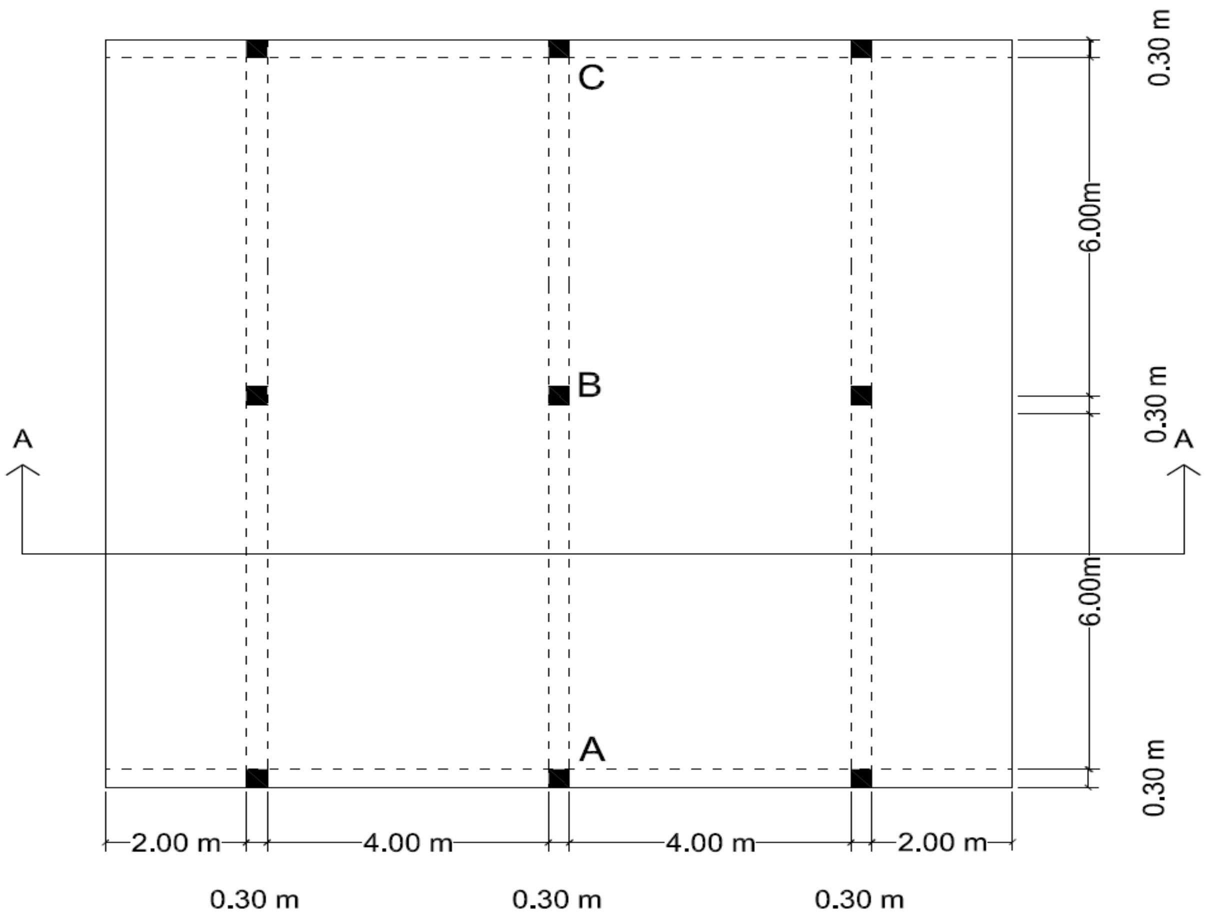
In Section 3.8, it was stated that if a rectangular section had a very small amount of tensile reinforcing, it's design-resisting moment, ϕMn, might very well be less than its cracking moment. If this were the case, the beam might fail without warning when the first crack occurred. The same situation applies to T beams with a very small amount of tensile reinforcing.

When the flange of a T beam is in tension, the amount of tensile reinforcing needed to make its ultimate resisting moment equal to its cracking moment is about twice that of a rectangular section or that of a T section with its flange in compression. As a result, ACI Section 10.5.1 states that the minimum amount of reinforcing required equals the larger of the two values that follow:

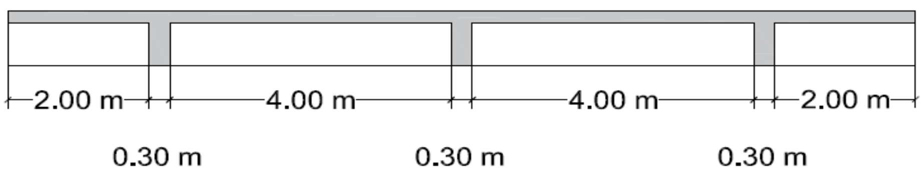
$$\rho_{min.} = max.of \begin{Bmatrix} \frac{\sqrt{f_c'}}{4\,fy} & \frac{1.4}{fy} \end{Bmatrix}$$

For statically determinate members with their flanges in tension, (bw) in the above expression is to be replaced with either (2bw) or the width of the flange, whichever is smaller.

Ex: The floor system shown below having 200 mm slab thickness, support uniform ultimate load of 15kN/m^2, use $f_c' = 28MPa\ and\ fy = 400\ MPa$. Design the flexural reinforcement for interior beam A, B and C.



Floor Plane



Section A-A

Solution

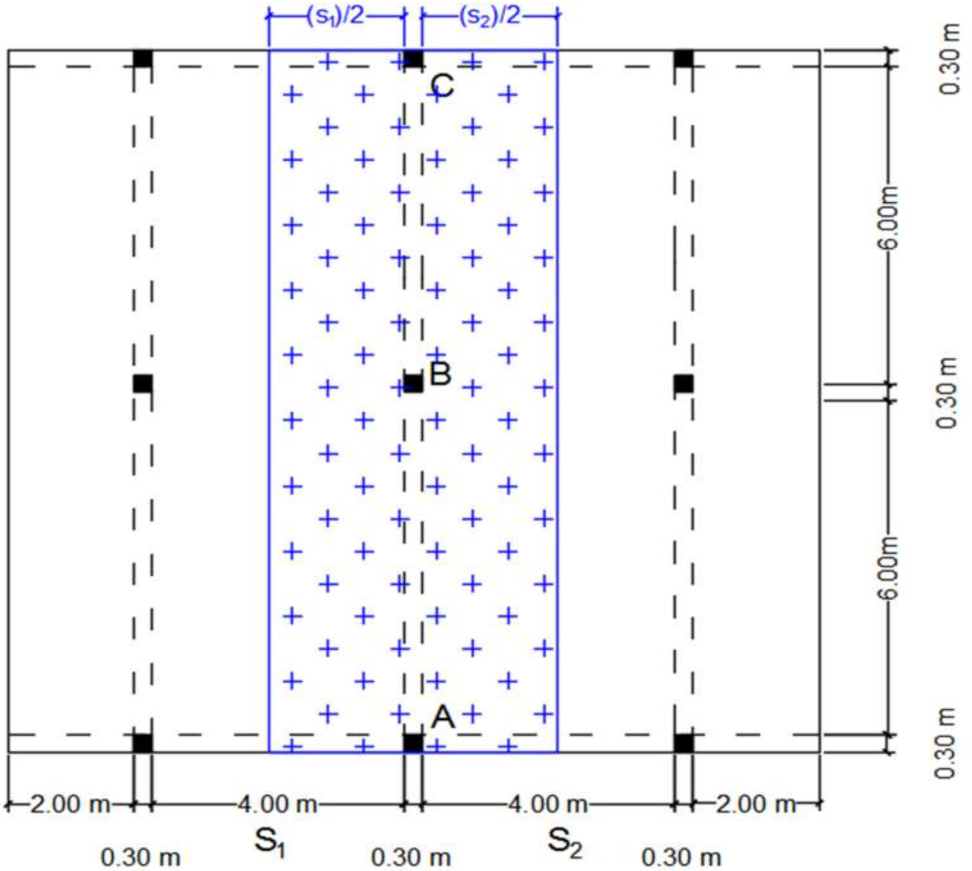
1- Find the load transformed from slab to beam

$$w_u = 15\frac{kN}{m^2}$$

$$L/_S = {}^{12.3}/_4 = 3 > 2 \quad \rightarrow one\ way\ slab$$

$$where: L = length\ of\ slab\ , S = width\ of\ slab$$

$$so, the\ load\ will\ transformed\ form\ slab\ to\ beam\ as\ shown\ below$$

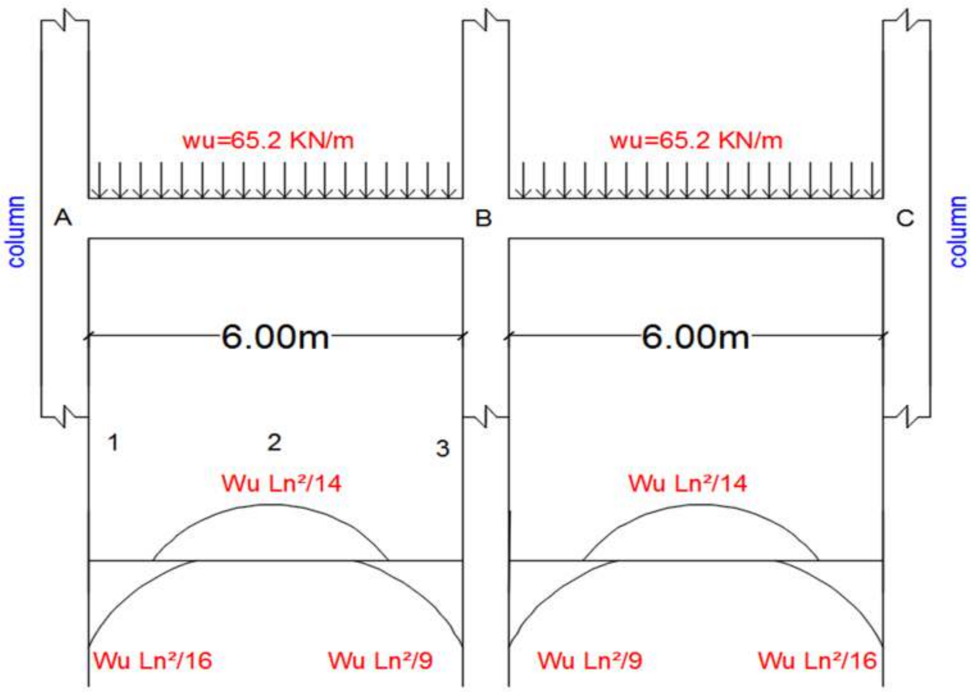


$$w_u \; of \; beam = w_u \; of \; slab * \left(\frac{S_1}{2} + \frac{S_2}{2}\right) = 15 * \left(\frac{4}{2} + \frac{4}{2}\right) = 60 \; kN/m$$

Self-weight of beam =1.2*(0.6*0.3*24) =5.2 kN/m

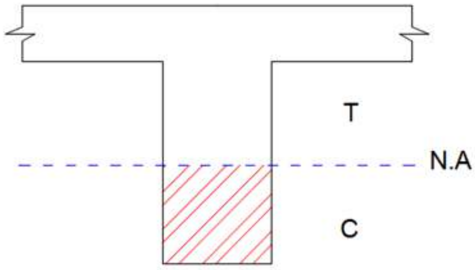
The beam support (60+5.2) =65.2kN/m

2- Find the ultimate moment supported beam



3- Design the sections 1,2 and 3

a. Section 1-1 $M_u^- = \frac{w_u l^2}{16} = 146.7\ kN.m$



$$M_u = \emptyset\, \rho\, b_e d^2 fy \left(1 - 0.59 \frac{fy}{f_c'} \rho\right)$$

$$146.7 * 10^6 = 0.9 * \rho * 300 * 538^2 * 400 \left(1 - 0.59 \frac{400}{28} \rho\right)$$

$$\rightarrow \rho = 0.00475$$

$$\rho_{max.} = 0.85\, \beta_1 \frac{f_c'}{fy} \frac{0.003}{(0.003 + 0.004)} = 0.0217$$

$$\rho_{min.} = max. of \begin{Bmatrix} \frac{\sqrt{f_c'}}{4\, fy} & \frac{1.4}{fy} \end{Bmatrix} = (0.0035)$$

$$\rho_{min.} = (0.0035) < \rho = (0.00475) < \rho_{max.} = (0.0217)$$

$$\rho_t = 0.85\, \beta_1 \frac{f_c'}{fy} \frac{0.003}{(0.003 + 0.005)} = 0.0189 \ > \rho \quad \rightarrow \emptyset = 0.9$$

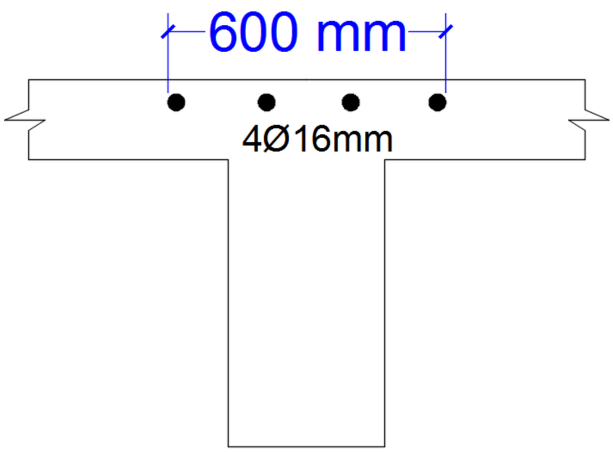
$As = 767\ mm^2$ $, use\ 4\emptyset 16\ mm$

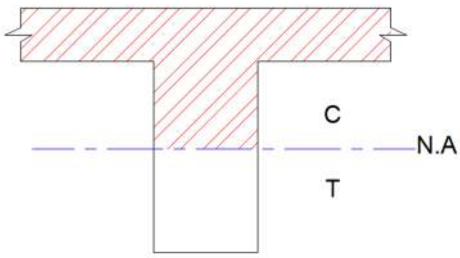
Section 10.6.6 of the ACI Code requires that part of the flexural steel in the top of the beam in the negative-moment region be distributed over the effective width of the flange or over a width equal to one-tenth of the beam span, whichever is smaller.

Find the b_e= $\begin{cases} \frac{L}{4} = \frac{6000}{4} & = 1500mm \\ b_w + 16\, h_f = 300 + (16 * 200) & = 3500mm \\ b_w + \frac{s_1 + s_2}{2} = 300 + \frac{4000+4000}{2} & = 4300\ mm \end{cases}$

The steel reinforcement will be distributed over the min. of (be=1500mm, $\frac{l}{10} = 600mm$)

$$s = \frac{600 - 4*16}{4-1} = 179 > 25\ mm\ ok$$





b. Section 2-2 $M_u{}^{+} = \frac{w_u\, l^2}{14} = 167.65\ kN.m$

1- Find the

$$b_e = \begin{cases} \frac{L}{4} = \frac{6000}{4} & = 1500mm \\ b_w + 16\,h_f = 300 + (16 * 200) & = 3500mm \\ b_w + \frac{s_1+s_2}{2} = 300 + \frac{4000+4000}{2} & = 4300\ mm \end{cases}$$

2- Calculate (As) assume that $a = h_f$ with beam width (be) and ø =0.9 and then check.

$$M_u = \emptyset\, \rho\, b_e d^2 fy \left(1 - 0.59 \frac{fy}{f_c'}\, \rho\right)$$

$$167.65 * 10^6 = 0.9 * \rho * 1500 * 538^2 * 400 \left(1 - 0.59 \frac{400}{28}\, \rho\right) \qquad \rightarrow \rho = 0.00108$$

$$As = \rho b_e d = 0.00108 * 1500 * 538 = 871.56\ mm^2$$

3- Check the assumption in (2)

$$a = \frac{A_s\, fy}{0.85\, f_c'\, b_e} = \frac{871.56 * 400}{0.85 * 28 * 1500} = 9.76\ mm < h_f = 200\ mm \quad ok$$

The assumption is right and continuo as rectangular section.

$$\rho_{max.} = 0.85\, \beta_1 \frac{f_c'}{fy} \frac{0.003}{(0.003 + 0.004)} = 0.02017$$

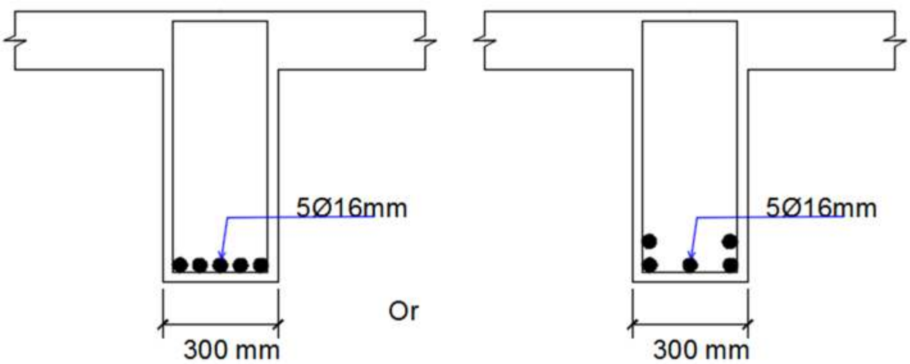
$$\rho_{min.} = max. of \left\{ \frac{\sqrt{f_c'}}{4\, fy} * \frac{b_w}{b_e} \qquad \frac{1.4}{fy} * \frac{b_w}{b_e} \right\} = (0.0007)$$

$$\rho_{min.} = (0.0007) < \rho = (0.00108) < \rho_{max.} = (0.0217)$$

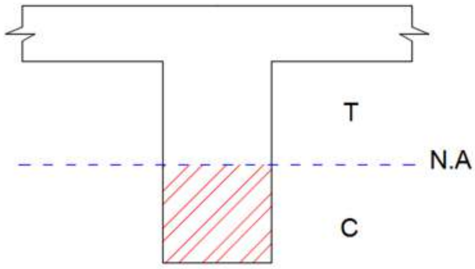
$$\rho_t = 0.85\, \beta_1 \frac{f_c'}{fy} \frac{0.003}{(0.003 + 0.005)} = 0.0189 \ > \rho \quad \rightarrow \emptyset = 0.9$$

$$As = 871.56\ mm^2 \ \ , use\ 5\emptyset 16\ mm$$

$$s = \frac{300 - 2 * 40 - 2 * 10 - 5 * 16}{5 - 1} = 30 > 25\ mm\ ok$$



c. Section 3-3 $M_u^{-} = \frac{w_u l^2}{9} = 260.8\ kN.m$



$$M_u = \emptyset\, \rho\, b_e d^2 fy \left(1 - 0.59 \frac{fy}{f_c'} \rho\right)$$

$$260.8 * 10^6 = 0.9 * \rho * 300 * 538^2 * 400 \left(1 - 0.59 \frac{400}{28} \rho\right)$$

$$\rightarrow \rho = 0.00903$$

$$\rho_{max.} = 0.85\, \beta_1 \frac{f_c'}{fy} \frac{0.003}{(0.003 + 0.004)} = 0.0217$$

$$\rho_{min.} = max. of \begin{Bmatrix} \frac{\sqrt{f_c'}}{4\, fy} & \frac{1.4}{fy} \end{Bmatrix} = (0.0035)$$

$$\rho_{min.} = (0.0035) < \rho = (0.00903) < \rho_{max.} = (0.0217)$$

$$\rho_t = 0.85\, \beta_1 \frac{f_c'}{fy} \frac{0.003}{(0.003 + 0.005)} = 0.0189 \quad > \rho \quad \rightarrow \emptyset = 0.9$$

$As = 1457.44\ mm^2$, $use\ 8\emptyset 16\ mm\ in\ two\ layer$