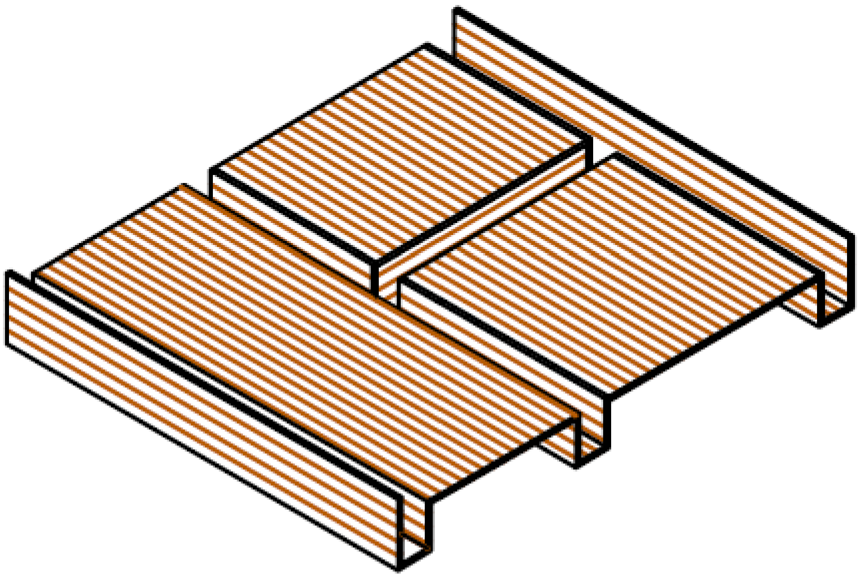
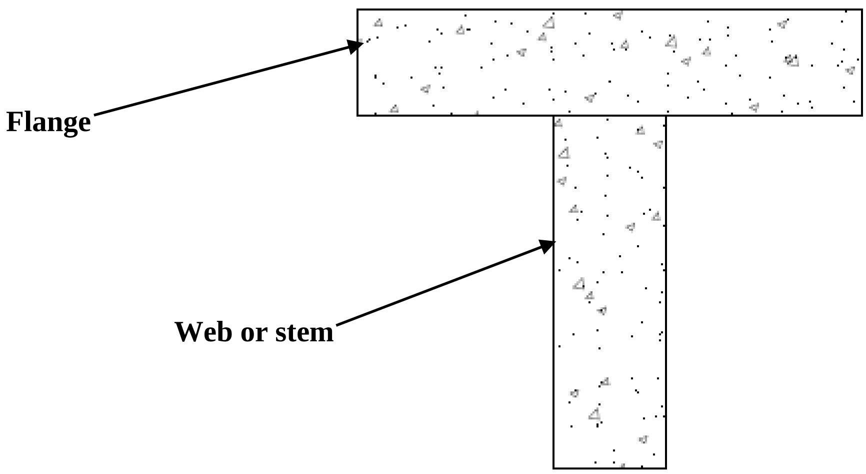
Analysis of Tee Reinforced Concrete Beam

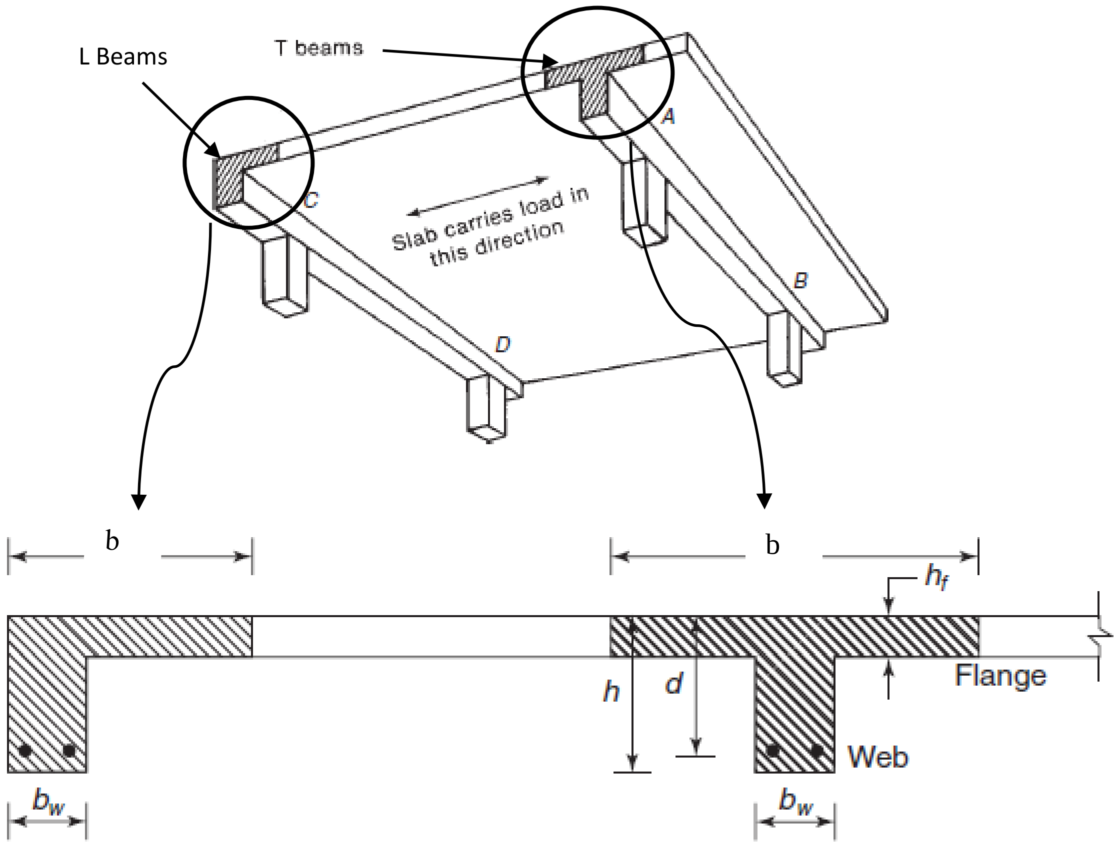
With the exception of precast system, reinforced concrete floors are almost always monolithic. Forms are built for beam soffits and sides and for the underside of slabs, and the entire construction in cast at once, from the bottom of the deepest beam to the top of the slab.



- Reinforced concrete floor system normally consists 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 as the ***web*** or **stem** (the beam may be ***L shaped*** if the stem is at ***the end*** of the slab).

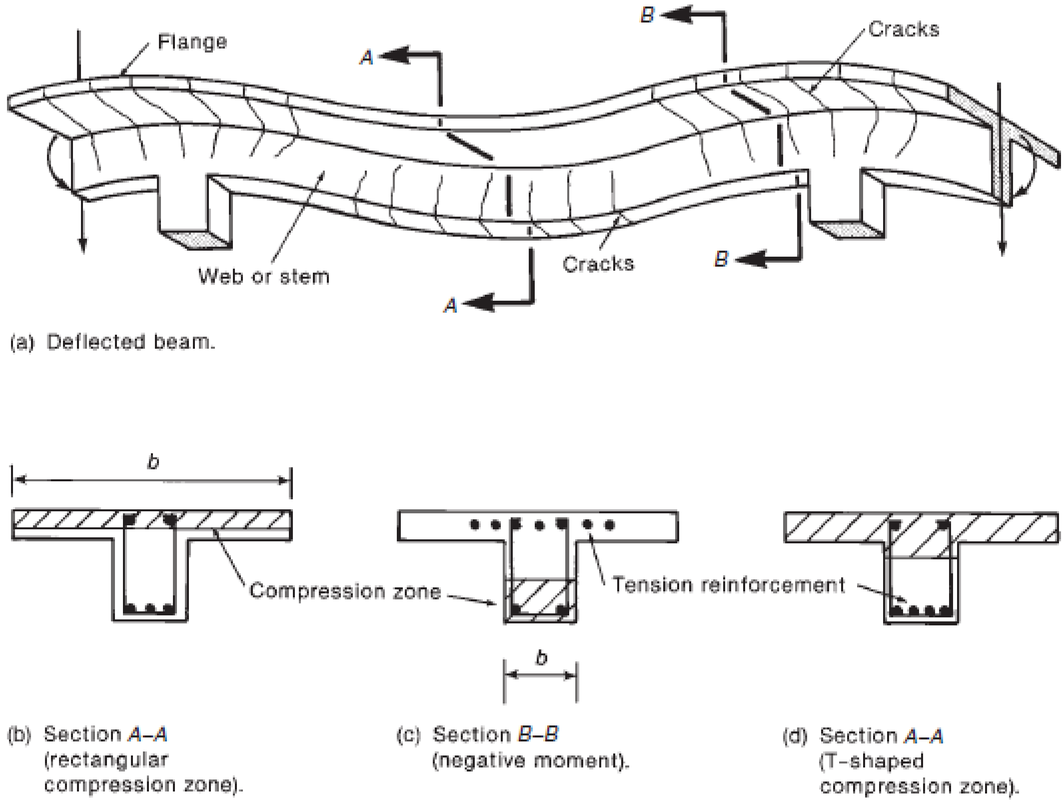


- In the figure shown below the slab is assumed to carry the load to supporting beam, during construction, the concrete in the columns is placed and allowed to harden before the concrete in the floor is placed. In the next construction operation, concrete is placed in the beams and slab in a monolithic As a result; the slab serves as the top flange of the beams, as indicated by the shading in the figure .Such a beam is referred to as a ***T-beam***. The interior beam, *AB*, has a flange on both sides. The *spandrel beam*, *CD*, with a flange on one side only, is often referred to as an ***inverted L-beam.***



Notation for analysis and design of Tee beam shape

- An exaggerated deflected view of the interior beam is shown in Fig. below this beam develops positive moments at mid-span (section A–A) and negative moments over the supports (section B–B).



At midspan, the compression zone is in the flange, as shown in Figs. b and d. Generally, it is rectangular, as shown in Fig. b, although, in very rare cases for typical reinforced concrete construction, the neutral axis may shift down into the web, giving a T-shaped compression zone, as shown in Fig. d. At the support, the compression zone is at the bottom of the beam and is rectangular,

- One can conclude that for the analyzing of T beams the neutral axis (N.A) can fall either on the flange or in the stem (web).
    - If the (N.A) falls in the flange, ***the rectangular*** formulas apply.
    - If the (N.A) falls in the web, the section above the (N.A) no longer consists of a single rectangular, and thus the ***Tee beam*** formulas apply.
    - For regular[1] Tee beam subjected to negative moment, the beam formulas will always apply.

[1]**Regular Tee beam:** is flange at top and stem (web) at bottom T

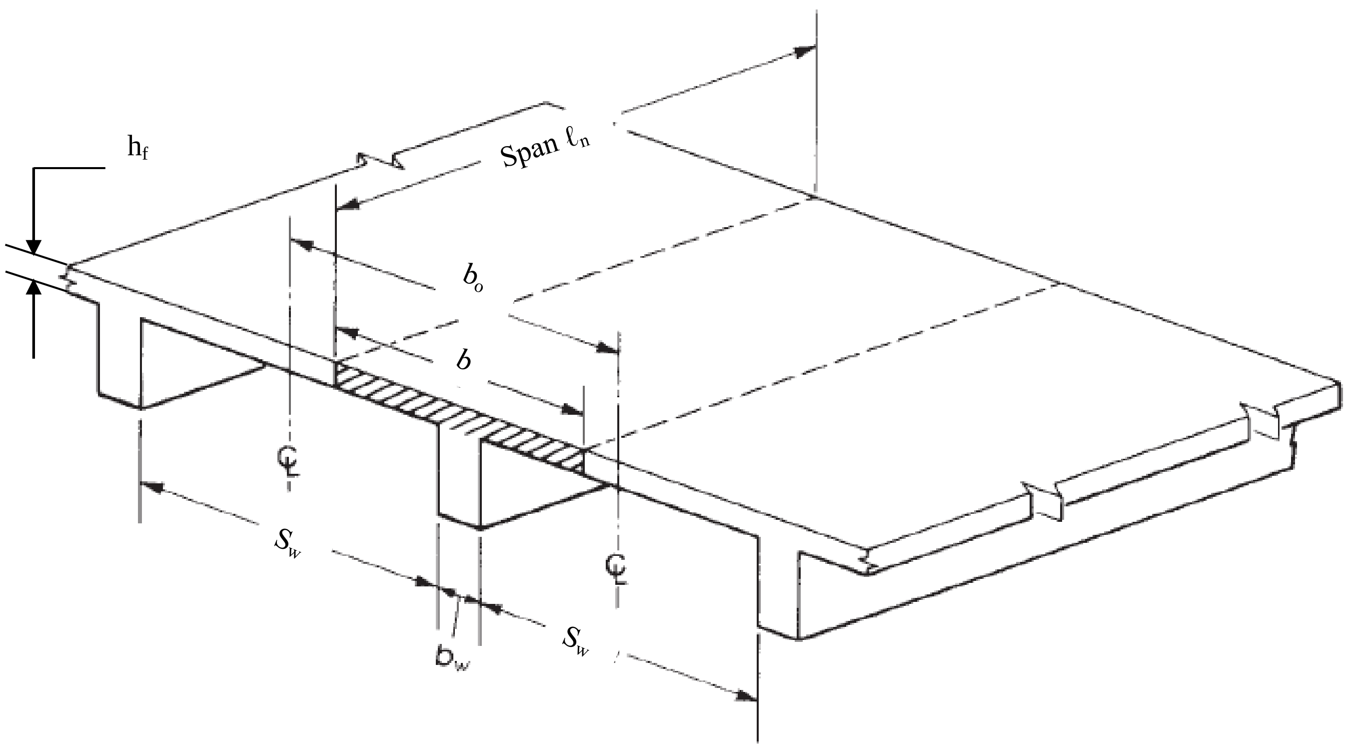
Effective flange width

There is a problem involved in estimating how much of the slab acts as part of the beam.

According to **ACI Code (6.3.2.1)** for nonprestressed T-beams supporting monolithic or composite slabs, the effective flange width, b, shall include the beam web width, $\mathbf{b_w}$, plus an effective overhanging flange width, where **h** is the slab thickness and $\mathbf{S_w}$ is the clear distance to the adjacent web:

Table 6.3.2.1—Dimensional limits for effective overhanging flange width for T-beams

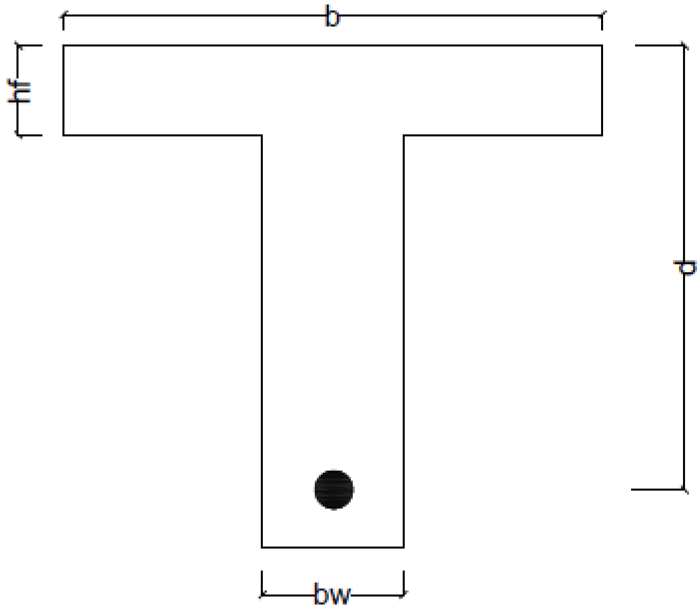
Flange location	Effective overhanging flange width, beyond face of web	
Each side of web	Least of:	$8h_f$
		$s_w/2$
		$\ell_n/8$
One side of web	Least of:	$6h_f$
		$s_w/2$
		$\ell_n/12$



For isolated T-beams in which the flange is used to provide additional compression area shall have a flange thickness greater than or equal to 0.5bw and an effective flange width less than or equal to 4bw **ACI Code 6.3.2.2**

$h_f \geq \frac{b_w}{2}$

$b \leq 4b_w$



Isolated Tee Beam

Minimum Reinforcement Area (As minimum)

- According to ACI-Code article 9.6.1 at every section of a flexural member where tensile reinforcement is required by analysis. As provided shall not be less than that given by:

$$\frac{0.25\sqrt{fc`}}{fy} b_w d \geq \frac{1.4}{fy} b_w d \quad \textbf{(Choose larger)}$$

- For members that have following properties
  - Statically determinate
  - With a flange in tension

  As min shall be computed based on following equations:

$$\text{As}_{\text{min}} = \text{minimum}\left(\frac{0.25\sqrt{fc`}}{fy} bd, \frac{0.5\sqrt{fc`}}{fy} b_w d\right)$$

The above two conditions usually stratify in cantilever beam and simply supported beam with inverted tee beam.

Analysis Versus Design

In analysis, the engineer deals with given beams, known for both dimensions and steel. The engineer has no control over the location of neutral axis.

In design, loads are known and some or all the dimensions remain to be fixed. In this case designers have some control over the location of neutral axis.

The student should understand clearly this fundamental difference between analysis and design problem. In every subject in our text book analysis of beams is discussed first, then design.

Procedure Analysis for T Beam

1. Define of section dimensions
2. Checking the section type:

   $\rho_w = \frac{As}{b_w d}$

   $\rho_{w\,max} = 0.85\beta_1 \frac{fc`}{fy} \frac{\epsilon u}{\epsilon u + 0.004} + \frac{A_{sf}}{b_w d}$

   $A_{sf} = \frac{0.85 fc`\, h_f (b - b_w)}{fy}$

   Or

   $\rho_{w\,max} = \rho_{max} + \rho_f$

   If $\rho_w \leq \rho_{w\,max}$ **tension failure** O.K

   Else if $\rho_w > \rho_{w\,max}$ **compression failure** Not O.K
3. Checking $A_{s\,minimum}$ limitation

   $A_{s\,minimum} = \frac{0.25\sqrt{fc`}}{fy} b_w d \geq \frac{1.4}{fy} b_w d$ **(choose larger)**
4. Computing of nominal moment strength M_n

   As the relation for computing of M_n depends on location of compression block, if it is in the flange or extend to the web, then the analyzer must first check to see if "a" is less than h_f or not:

   - if $a = \frac{Asfy}{0.85 fc` b} \leq h_f$

     Then the beam is considered as a rectangular with width equal to ***b***.

     Find:

     $M_n = A_s f_y \left(d - \frac{a}{2}\right)$ and go to step 5
   - if $a = \frac{Asfy}{0.85 fc` b} > h_f$

     Correct the value of "a" based on:

     $a = \frac{(A_s - A_{sf}) fy}{0.85 fc` b_w}$

     Compute M_n based on following relation:

     $$M_n = \underbrace{[0.85 fc` h_f (b - b_w)] \left(d - \frac{h_f}{2}\right)}_{\text{Part one}} + \underbrace{[0.85 fc` a b_w] \left(d - \frac{a}{2}\right)}_{\text{Part two}}$$

5. Compute c:

   $c = \frac{a}{\beta 1}$

   $\epsilon_t = \frac{dt - c}{c} \epsilon_u$ where $\epsilon_u = 0.003$

   $\epsilon_t \geq 0.005 \therefore \emptyset = 0.9$

   Otherwise find $\emptyset$ from relation $\emptyset = 0.483 + 83.3\epsilon_t$

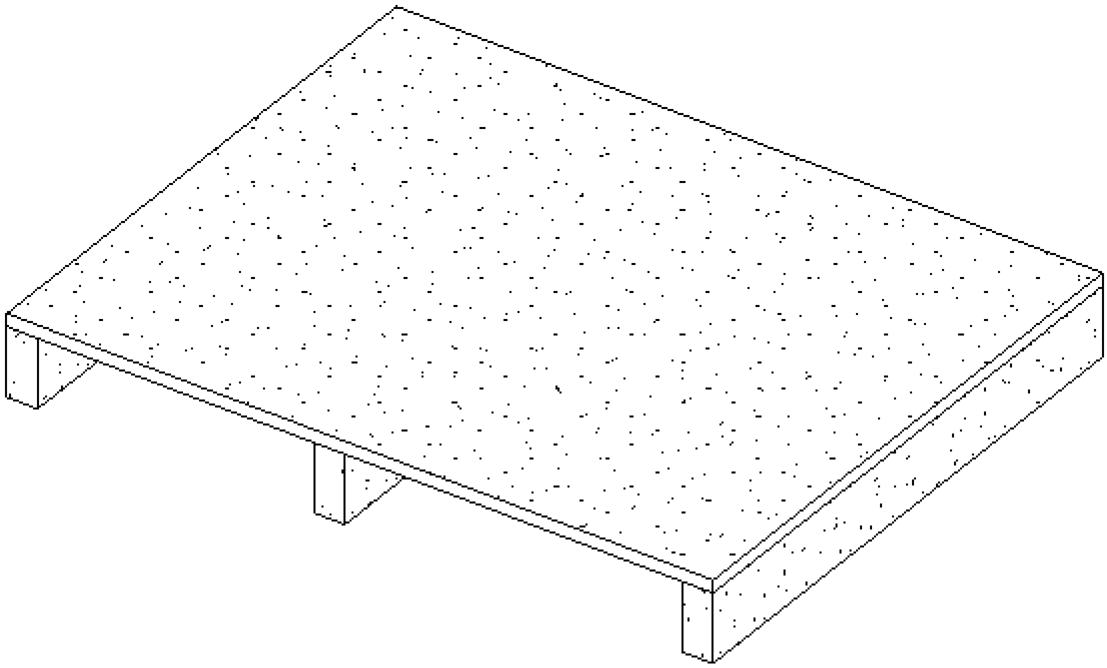
   Then find $\emptyset M_n$ ■

Example 1: Check the adequacy of the beam shown below according to ACI code requirements and determine its design strength:

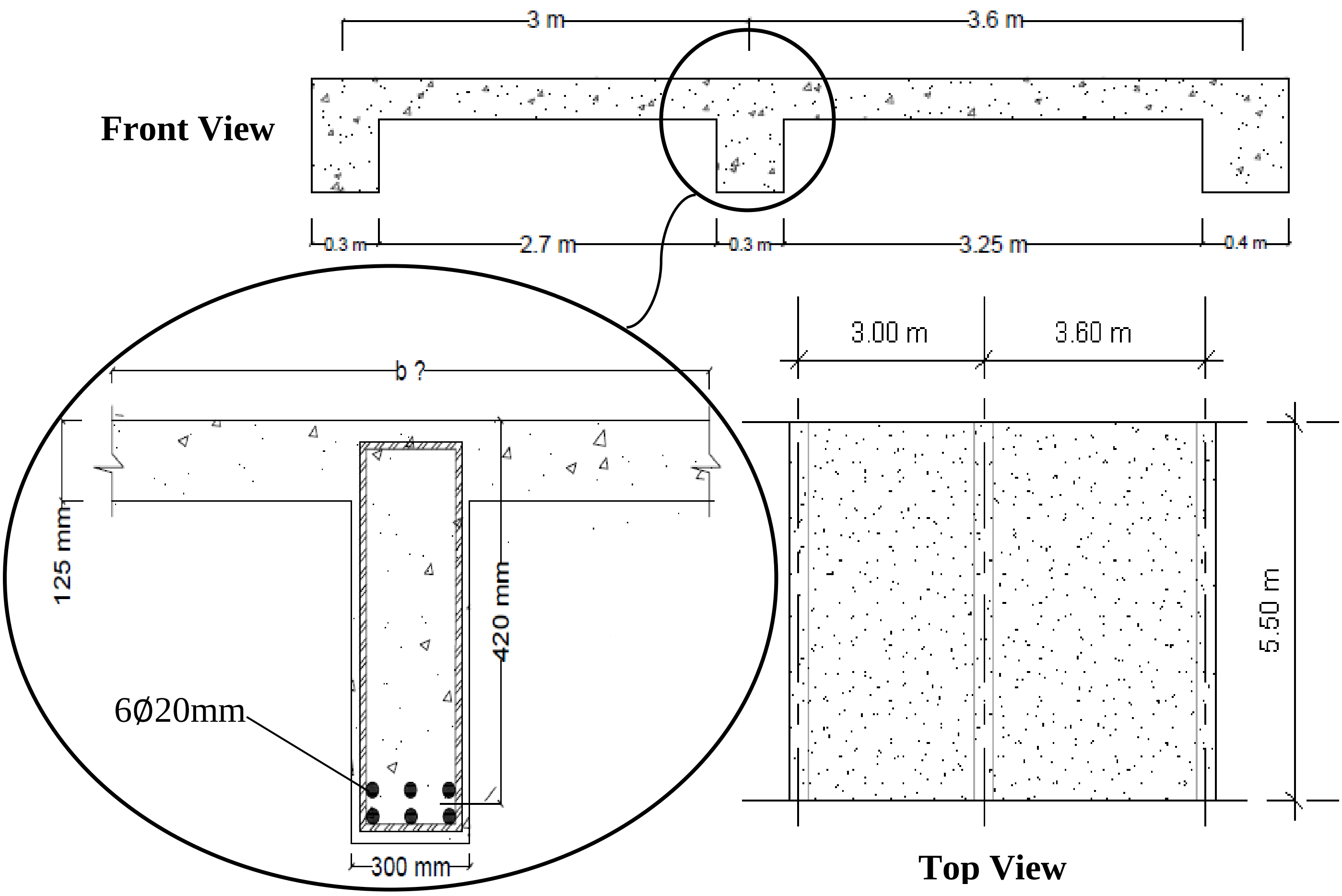
Use in your solution:

- f_c' = 20 MPa
- f_y = 300 MPa
- Beam span 5.5 m

3D View



Front View



Top View

Solution:

1. Define of section dimensions.

$b = b_w + \min\left[\frac{S_{w\,left}}{2}\ or\ 8h\ or\ \frac{\ell_n}{8}\right] + \min\left[\frac{S_{w\,right}}{2}\ or\ 8h\ or\ \frac{\ell_n}{8}\right]$

$b = 0.3 + \min\left[\frac{2.7}{2}\ or\ 8 \times 0.125\ or\ \frac{5.5}{8}\right] + \min\left[\frac{3.25}{2}\ or\ 8 \times 0.125\ or\ \frac{5.5}{8}\right]$

$b = 0.3 + \min[1.35\ or\ 1\ or\ 0.688] + \min[1.63\ or\ 1\ or\ 0.688]$

$b = 0.3 + 0.688 + 0.688 = 1.68$ m

2. Checking the section type:

Check if the failure is tension or compression failure through the following comparison: ρ_w ? $\rho_{w\,max}$

$\rho_w = \frac{As}{b_w d} = \frac{6 \times \frac{\pi}{4} \times 20^2}{300 \times 420} = \frac{1884.95}{300 \times 420} = 0.0149$

$\rho_{w\,max} = 0.85\beta_1 \frac{fc`}{fy} \frac{\epsilon u}{\epsilon u + 0.004} + \frac{A_{sf}}{b_w d}$

$A_{sf} = \frac{0.85 fc`\ h_f (b - b_w)}{fy} = \frac{0.85 \times 20 \times 125(1680 - 300)}{300} = 9775\ mm^2$

$\rho_{w\,max} = 0.85 \times 0.85 \times \frac{20}{300} \frac{0.003}{0.003 + 0.004} + \frac{9775}{300 \times 420} = 0.0982$

$\rho_w < \rho_{w\,max}$ ∴ Tension failure O.K ■

3. Checking $A_{s\ minimum}$ limitation

$A_{s\ minimum} = \frac{0.25\sqrt{fc`}}{fy} b_w d \geq \frac{1.4}{fy} b_w d$ **(choose larger)**

$A_{s\ minimum} = \frac{0.25\sqrt{20}}{300} \times 300 \times 420 \geq \frac{1.4}{300} \times 300 \times 420$

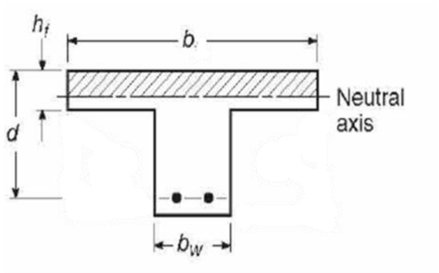
$A_{s\ minimum} = 469.57\ mm^2 < \mathbf{588\ mm^2}$

$A_{s\ minimum} = 588\ mm^2 < As_{provided} = 1884.95\ mm^2$ o.k

4. Computing of nominal moment strength Mn

Assume $a \leq h_f$

$a = \frac{Asfy}{0.85 fc` b} = \frac{1884.95 \times 300}{0.85 \times 20 \times 1680} = 19.799\ mm < 125mm$ O.k



Then the beam is considered as ***a rectangular*** will width equal to ***b***.

Find:

$M_n = A_s f_y \left(d - \frac{a}{2}\right) = 1884.95 \times 300 \times \left(420 - \frac{19.799}{2}\right) \times 10^{-6}$

$M_n = 231.9$ kN.m

5. Compute c:

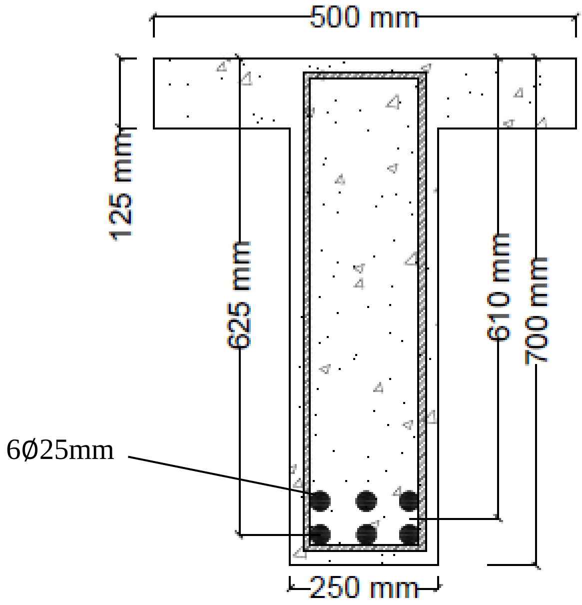
$c = \frac{a}{\beta 1} = \frac{19.799}{0.85} = 23.29$ mm

$\epsilon_t = \frac{dt-c}{c}\epsilon_u = \frac{442.5-23.29}{23.29} \times 0.003 = 0.0539 > 0.005 \therefore \quad \emptyset = 0.9$

$\emptyset M_n = 0.9 \times 231.9 = 208.71$ kN.m ■

Example 2: Check the adequacy of isolated T-beam shown below according to ACI requirements and compute it's design strength, use:

- fc` = 20 MPa
- fy = 420 MPa



Solution:

1. Define of section dimensions.

As the beam is an isolated T- beam, then its flange width and thickness must satisfy the following limitations:

$h_f \geq \frac{b_w}{2}$

$h_f = 125\text{mm} > \frac{250}{2} = 125$ mm O.K

And $b \leq 4b_w$

$b = 500 \text{ mm} < 4 \times 250 = 1000$ mm O.K

2. Checking the section type:

Check if the failure is tension or compression failure through the following comparison: ρ_w ? $\rho_{w\,max}$

$\rho_w = \frac{As}{b_w d} = \frac{6\times\frac{\pi}{4}\times 25^2}{250\times 610} = \frac{2945.2}{250\times 610} = 0.0193$

$\rho_{w\,max} = 0.85\beta_1 \frac{fc`}{fy}\frac{\epsilon u}{\epsilon u + 0.004} + \frac{A_{sf}}{b_w d}$

$A_{sf} = \frac{0.85 fc`\, h_f (b - b_w)}{fy} = \frac{0.85 \times 20 \times 125(500 - 250)}{420} = 1265\ mm^2$

$\rho_{w\,max} = 0.85 \times 0.85 \times \frac{20}{420}\frac{0.003}{0.003 + 0.004} + \frac{1265}{250 \times 610} = 0.023$

$\rho_w < \rho_{w\,max}$ ∴ Tension failure O.K ■

3. Checking $A_{s\ minimum}$ limitation

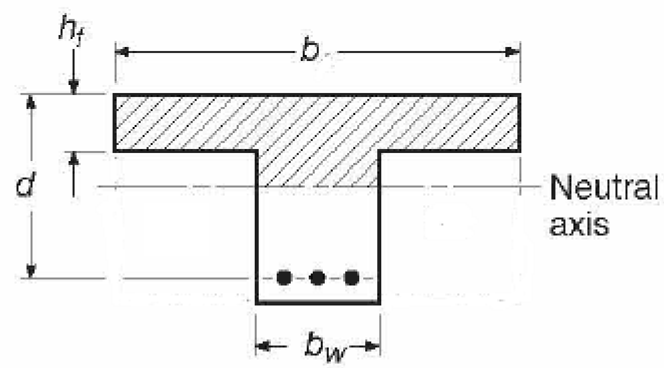
fc`< 31 MPa ∴

$A_{s\ minimum} = \frac{1.4}{fy} b_w d = \frac{1.4}{420} \times 250 \times 610 = 508.33\ mm^2 < 2945.2\ mm^2$ O.K

4. Computing of nominal moment strength Mn

Assume $a \le h_f$

$a = \frac{Asfy}{0.85 fc`b} = \frac{2945.2 \times 420}{0.85 \times 20 \times 500} = 145.52\ mm > 125mm$ Not O.k



Correct the value of "a" based on:

$a = \frac{(A_s - A_{sf})fy}{0.85 fc` b_w}$

$a = \frac{(2945.2 - 1265) \times 420}{0.85 \times 20 \times 250} = 166\ mm$

Compute M_n based on following relation:

$M_n = [0.85 fc` h_f (b - b_w)]\left(d - \frac{h_f}{2}\right) + [0.85 fc` a b_w]\left(d - \frac{a}{2}\right)$

$M_n = [0.85 \times 20 \times 125 \times (500 - 250)]\left(610 - \frac{125}{2}\right) \times 10^{-6} + [0.85 \times 20 \times 166 \times 250]\left(610 - \frac{166}{2}\right) \times 10^{-6}$

$M_n = 290.85\ kN.m + 371.8\ kN.m = 662.65\ kN.m$

6. Compute c:

$c = \frac{a}{\beta 1} = \frac{166}{0.85} = 195.3\ mm$

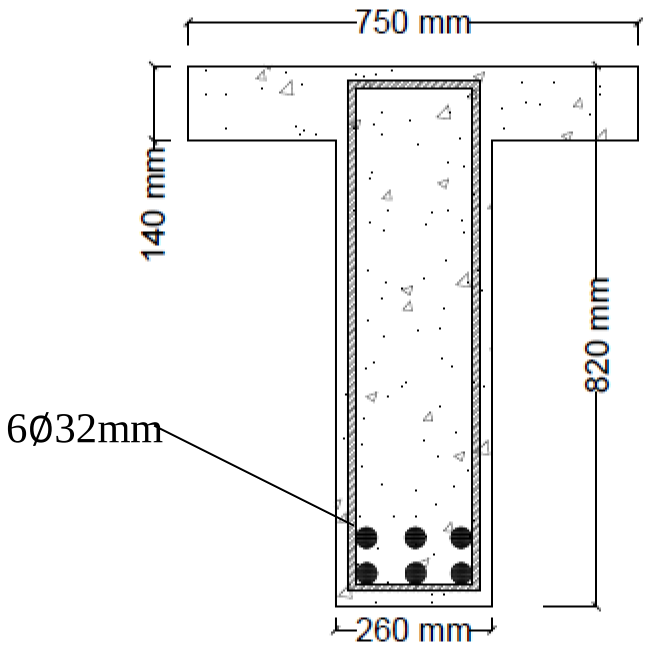
$\epsilon_t = \frac{dt - c}{c}\epsilon_u = \frac{625 - 195.3}{195.3} \times 0.003 = 6.6 \times 10^{-6} > 0.005$

∴ $\emptyset = 0.9$

Find $\emptyset M_n = 0.9 \times 662.65 = 596.025\ kN.m$ ■

Example 3: Check the adequacy of isolated T-beam shown below according to ACI Code requirements and determine its design strength, use:

- fc = 20 MPa
- fy = 400 MPa



Solution:

1. Define of section dimensions.

   As the beam is an isolated T- beam, then its flange width and thickness must satisfy the following limitations:

   $h_f \geq \frac{b_w}{2}$

   $h_f = 140\text{mm} > \frac{260}{2} = 130$ mm O.K

   And $b \leq 4b_w$

   $b = 750$ mm $< 4 \times 140 = 560$ mm O.K

2. Checking the section type:

   Check if the failure is tension or compression failure through the following comparison: ρ_w ? $\rho_{w\,max}$

   $d = 820 - 40 - 10 - 32 - 12.5 = 725.5$ mm

   $\rho_w = \frac{As}{b_w d} = \frac{6\times\frac{\pi}{4}\times32^2}{260\times725.5} = \frac{4825.5}{250\times725.5} = 0.0266$

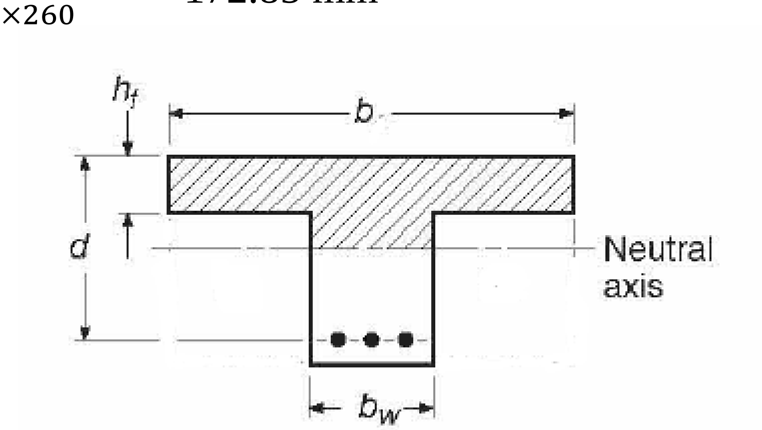
   $\rho_{w\,max} = 0.85\beta_1\frac{fc`}{fy}\frac{\epsilon u}{\epsilon u + 0.004} + \frac{A_{sf}}{b_w d}$

   $A_{sf} = \frac{0.85fc`\,h_f(b - b_w)}{fy} = \frac{0.85\times20\times140\times(750-260)}{400} = 2915.5\ \text{mm}^2$

   $\rho_{w\,max} = 0.85\times0.85\times\frac{20}{400}\frac{0.003}{0.003+0.004} + \frac{2915.5}{260\times725.5} = 0.0309$

   $\rho_w < \rho_{w\,max}$ ∴ Tension failure O.K ■

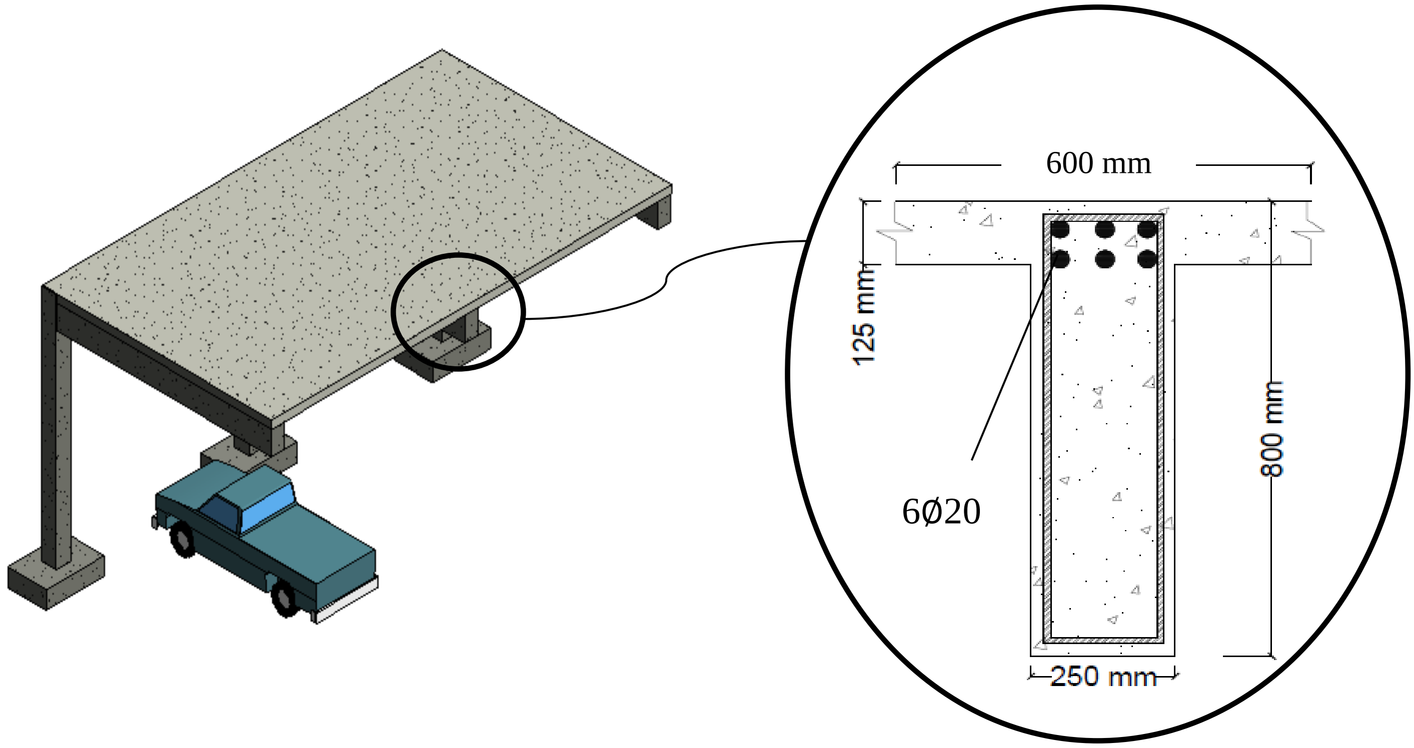
3. Checking $A_{s\ minimum}$ limitation
   fc`< 31 MPa ∴
   $A_{s\ minimum} = \frac{1.4}{fy} b_w d = \frac{1.4}{400} \times 260 \times 725.5$ = 660.2 mm^2 < 4825.5 mm^2 O.K
4. Computing of nominal moment strength Mn
   Assume $a \leq h_f$
   $a = \frac{Asfy}{0.85fc`b} = \frac{4825.5 \times 400}{0.85 \times 20 \times 750}$ = 151.4 mm > 140mm Not O.k
   Correct the value of "a" based on:
   $a = \frac{(A_s - A_{sf})fy}{0.85fc`b_w}$
   $a = \frac{(4825.5 - 2915.5) \times 400}{0.85 \times 20 \times 260}$ = 172.85 mm



   Compute M_n based on following relation:
   $M_n = [0.85fc`h_f(b - b_w)]\left(d - \frac{h_f}{2}\right) + [0.85fc`ab_w]\left(d - \frac{a}{2}\right)$
   $M_n = [0.85 \times 20 \times 140 \times (750 - 260)]\left(725.5 - \frac{140}{2}\right) \times 10^{-6} + [0.85 \times 20 \times 172.85 \times 260]\left(725.5 - \frac{172.85}{2}\right) \times 10^{-6}$
   M_n = 764.44 kN.m + 488.25 kN.m = 1252.7 kN.m
5. Compute c:
   $c = \frac{a}{\beta 1} = \frac{172.85}{0.85}$ = 203.35 mm
   $\epsilon_t = \frac{dt - c}{c} \epsilon_u = \frac{754 - 203.35}{203.35} \times 0.003 = 8.12 \times 10^{-6} > 0.005$
   ∴ $\emptyset = 0.9$
   Find $\emptyset M_n = 0.9 \times 1252.7$=1127.43 kN.m ■

Example 4: Check the adequacy of the cantilever beam shown below according to ACI- Code requirements if the beam is subjected to uniform factored load 10 kN/m (include self-weight) from slab .use in your analyze:

- fc` = 25 MPa
- fy = 420 MPa
- Beam span 4 m



Solution:

As the flange is on the tension side, section should be analyzed as ***rectangular*** section

1. Calculate $\rho = \frac{As}{bd}$

d = 800 – 40 – 10 – 20 – 12.5 = 717.5 mm

As = $6 \times \frac{\pi}{4} \times 20^2$ =1884.95 mm

$\rho = \frac{As}{bd} = \frac{1884.95}{250 \times 717.5} = 0.0105$

Check if the provided ρ is in agreement with ACI requirements.

$\rho_{max} = 0.85\beta_1 \frac{fc`}{fy} \frac{\epsilon u}{\epsilon u + 0.004} = 0.85 \times 0.85 \frac{25}{420} \frac{0.003}{0003 + 0.004} = 0.0184$

$\rho < \rho_{max}$ Tension Failure O.K

For statically determinate span with a flange in tension, minimum flexure reinforcement should compute based on:

As $_{min}$ = minimum $\left(\frac{0.25\sqrt{fc`}}{fy}bd, \frac{0.5\sqrt{fc`}}{fy}b_w d\right)$

As $_{min}$ = min (1281.25, **1067.7**) mm^2 < 1884.95 mm^2 O.k

2. Calculate Ø

$a = \frac{Asfy}{0.85fc`b} = \frac{1884.95 \times 420}{0.85 \times 25 \times 250} = 149$ mm

$c = \frac{a}{\beta 1} = \frac{149}{0.85} = 175.3$ mm

$\epsilon_t = \frac{dt - c}{c}\epsilon_u = \frac{740 - 175.3}{175.3} \times 0.003 = 9.664 \times 10^{-3} > 0.005$

∴ Ø = 0.9

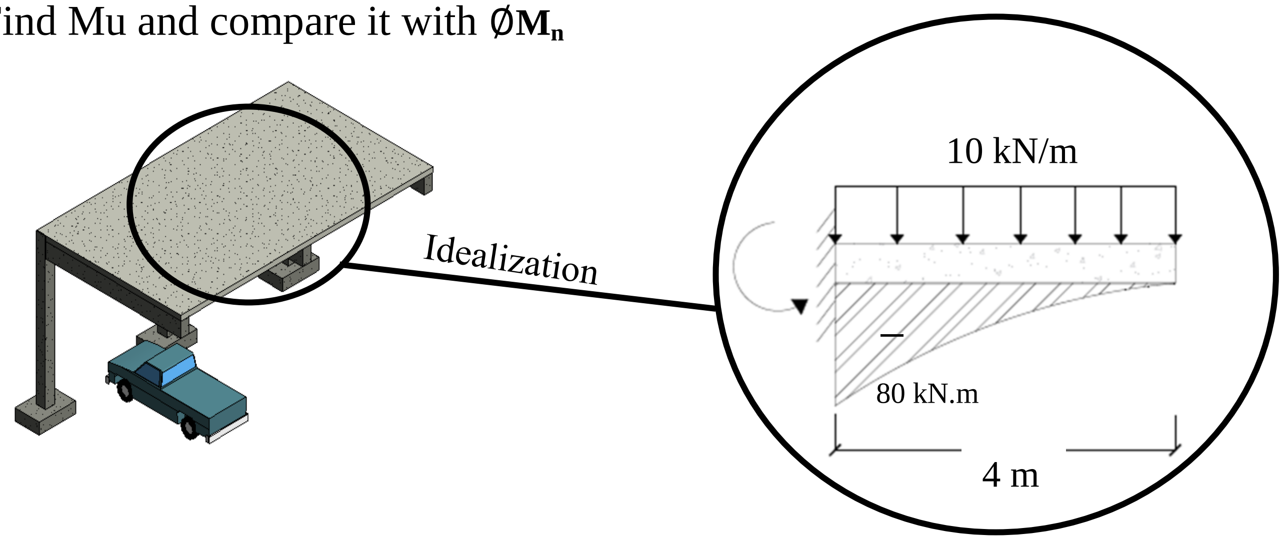
3. Calculate $\emptyset \mathbf{M_n}$

$\emptyset \mathbf{M_n}$ can be calculated from:

$\emptyset M_n = \emptyset A_s f_y\left(d - \frac{a}{2}\right) = 0.9 \times 1884.95 \times 420 \times \left(717.5 - \frac{149}{2}\right) \times 10^{-6}$

$\emptyset M_n = 458.14$ kN.m

4. Find Mu and compare it with $\emptyset \mathbf{M_n}$

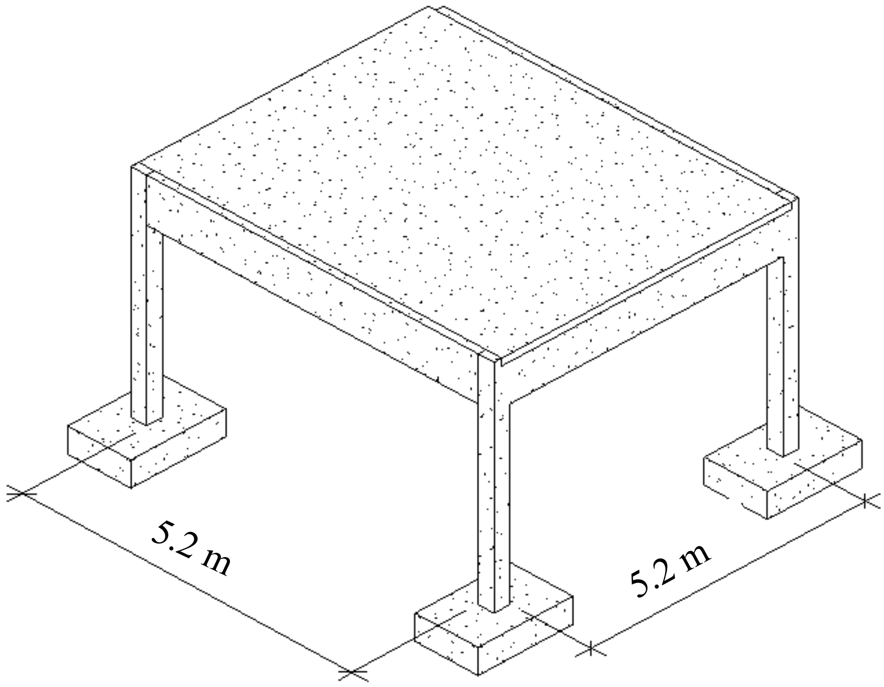


$Mu = \frac{w_u \ell^2}{2} = \frac{10 \times 4^2}{2} = 80$ kN.m

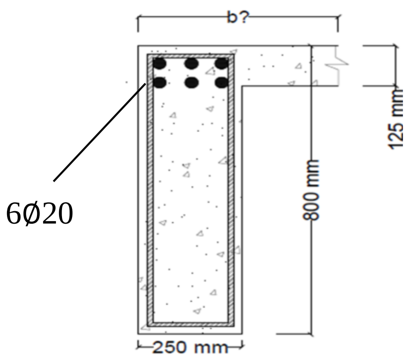
$\emptyset \mathbf{M_n}$ > Mu the section is adequate according to ACI-14 ■

Example 5: For the edge beam shown in figure below, negative and positive moments have been determined based on statically indeterminate analysis and shown in figure below, use fc` = 25 MPa , fy =420 MPa, check the adequacy of edge beam at:

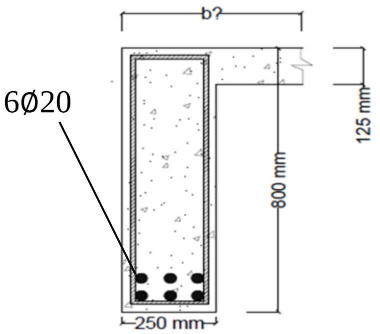
a. Section A-A
b. Section B-B

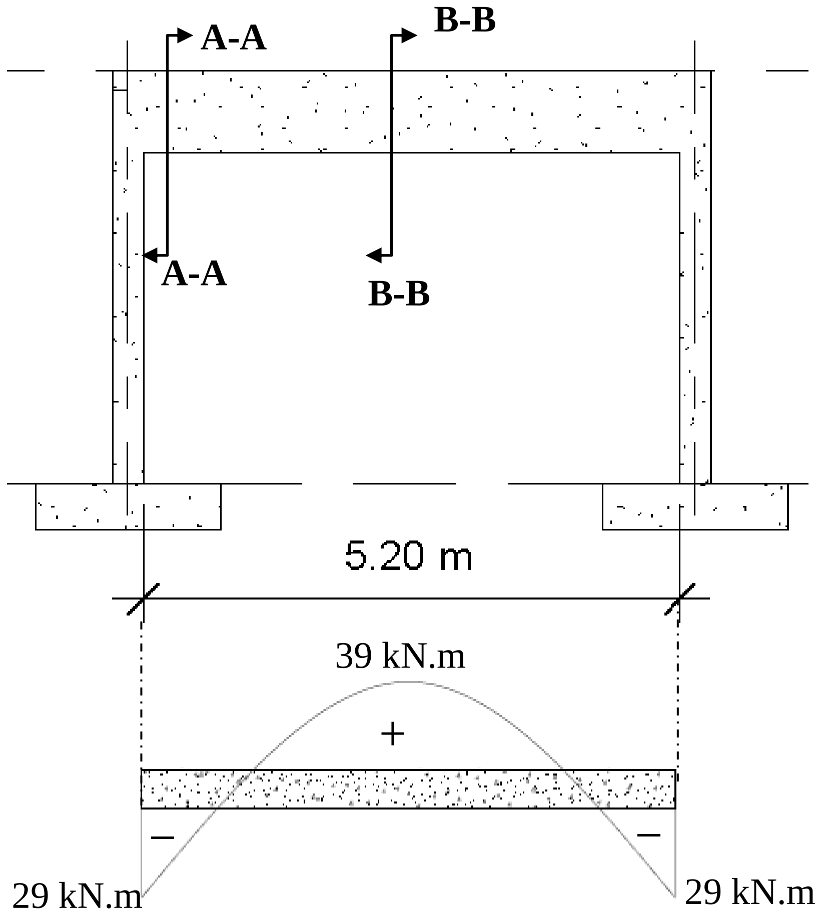


Section A-A



Section B-B



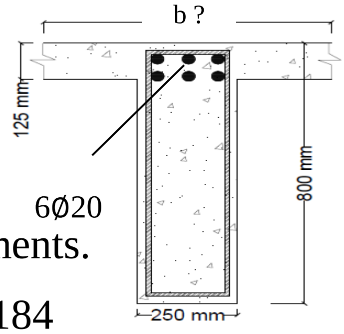


Solution:

a. Section A-A

As the flange is on the tension side, section should be analyzed as ***rectangular*** section.

Section A-A



1. Calculate $\rho = \frac{As}{bd}$

d = 800 – 40 – 10 – 20 – 12.5 = 717.5 mm

As = $6 \times \frac{\pi}{4} \times 20^2$ =1884.95 mm

$\rho = \frac{As}{bd} = \frac{1884.95}{250 \times 717.5} = 0.0105$

Check if the provided ρ is in agreement with ACI requirements.

$\rho_{max} = 0.85\beta_1 \frac{fc`}{fy} \frac{\epsilon u}{\epsilon u+0.004} = 0.85 \times 0.85 \frac{25}{420} \frac{0.003}{0003+0.004} = 0.0184$

$\rho < \rho_{max}$ Tension Failure O.K

2. Calculate Ø

$a = \frac{Asfy}{0.85fc`b} = \frac{1884.95 \times 420}{0.85 \times 25 \times 250} = 149$ mm

$c = \frac{a}{\beta 1} = \frac{149}{0.85} = 175.3$ mm

$\epsilon_t = \frac{dt-c}{c} \epsilon_u = \frac{740-175.3}{175.3} \times 0.003 = 9.664 \times 10^{-3} > 0.005$

$\therefore$ Ø = 0.9

3. Calculate $ØM_n$

$ØM_n$ can be calculated from:

$ØM_n = ØA_s f_y \left(d - \frac{a}{2}\right) = 0.9 \times 1884.95 \times 420 \times \left(717.5 - \frac{149}{2}\right) \times 10^{-6}$

$ØM_n$ = 458.14 kN.m

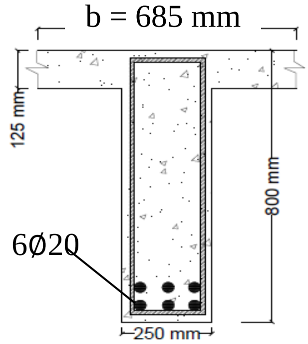
4. Find Mu and compare it with $ØM_n$

From question statement Mu at section A-A =29 kN.m

Mu < 458.14 kN.m $\therefore$ beam at section A-A is adequate according to ACI code ■

b. Section A-A

Section B-B



1. Define of section dimensions.

$b = b_w + \min\left[\frac{S_{w\,right}}{2} \text{ or } 6h_f \text{ or } \frac{\ell_n}{12}\right]$

$b = 250 + \min\left[\frac{5200}{2} \text{ or } 6 \times 125 \text{ or } \frac{5200}{12}\right]$

$b = 250 + \min[2600 \text{ or } 750 \text{ or } \mathbf{433.33}]$

b = 250 + 433.33 ≈ 685 mm

2. Checking the section type:

Check if the failure is tension or compression failure through the following comparison: ρ_w ? $\rho_{w\,max}$

d = 800 – 40 – 10 – 20 – 12.5 = 717.5 mm

$\rho_w = \frac{As}{b_w d} = \frac{6\times\frac{\pi}{4}\times 20^2}{250\times 717.5} = \frac{1884.95}{250\times 717.5} = 0.0105$

$\rho_{w\,max} = 0.85\beta_1 \frac{fc`}{fy} \frac{\epsilon u}{\epsilon u + 0.004} + \frac{A_{sf}}{b_w d}$

$A_{sf} = \frac{0.85 fc`\, h_f (b - b_w)}{fy} = \frac{0.85\times 25\times 125(685 - 250)}{420} = 2751.11\ mm^2$

$\rho_{w\,max} = 0.85\times 0.85\times \frac{25}{420} \frac{0.003}{0.003 + 0.004} + \frac{2751.11}{250\times 717.5} = 0.0337$

$\rho_w < \rho_{w\,max}$ ∴ Tension failure O.K ■

3. Checking $A_{s\ minimum}$ limitation

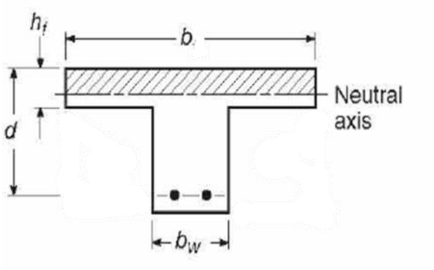
fc `< 31 ∴$A_{s\ minimum} = \frac{1.4}{fy} b_w d = \frac{1.4}{420} \times 250 \times 717.5 = 598\ mm^2$

$A_{s\ minimum} = 598\ mm^2 < As_{provided} = 1884.95\ mm^2$ o.k

4. Computing of nominal moment strength Mn

Assume $a \le h_f$

$a = \frac{Asfy}{0.85 fc`b} = \frac{1884.95\times 420}{0.85\times 25\times 685} = 54.38$ mm < 125mm O.k



Then the beam is considered as ***a rectangular*** will width equal to ***b***.

Find:

$M_n = A_s f_y\left(d - \frac{a}{2}\right) = 1884.95 \times 420 \times \left(717.5 - \frac{54.38}{2}\right) \times 10^{-6}$

$M_n = 546.5$ kN.m

6. Compute c:

$c = \frac{a}{\beta 1} = \frac{54.38}{0.85} = 63.98$ mm

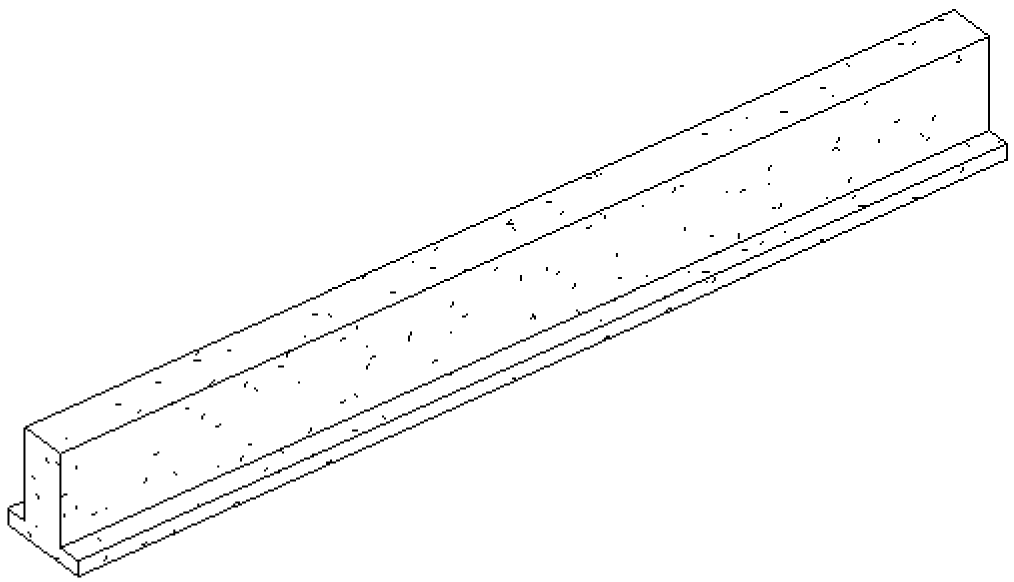
$\epsilon_t = \frac{dt - c}{c} \epsilon_u = \frac{740 - 63.98}{63.98} \times 0.003 = 0.0316 > 0.005$ ∴ $\emptyset = 0.9$

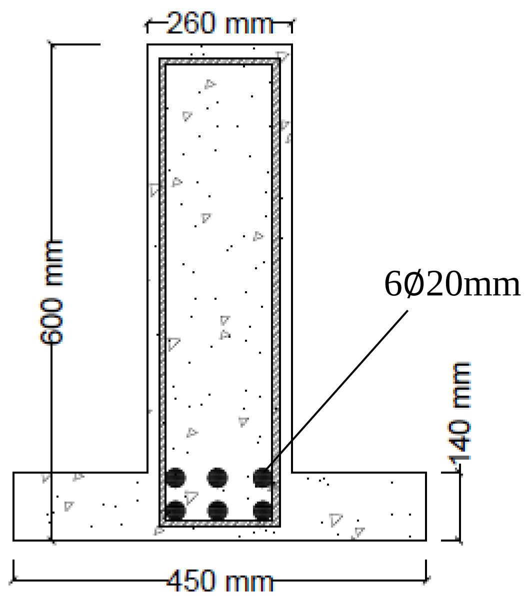
$\emptyset M_n = 0.9 \times 546.5 = 491.85$ kN.m > Mu = 39 kN.m the section is O.K ■

Example 6: For the inverted Tee beam shown below is commonly used in Iraq streets, assume the beam is subjected to uniform factored load Wu 10 kN/m, check the adequacy of the beam according to ACI Code requirements and compute its design strength. Assume in your solution that the beam is simply supported

Use:

- fc =25 MPa
- fy = 420 MPa
- span length 5 m





Solution:

As the flange is on the tension side, section should be analyzed as ***rectangular*** section.

1. Calculate $\rho = \frac{As}{bd}$

   d = 600 – 40 – 10 – 20 – 12.5 = 537.5 mm

   $As = 6 \times \frac{\pi}{4} \times 20^2 = 1884.95\ mm^2$

   $\rho = \frac{As}{bd} = \frac{1884.95}{260 \times 537.5} = 0.0134$

   Check if the provided ρ is in agreement with ACI requirements.

   $\rho_{max} = 0.85\beta_1 \frac{fc`}{fy} \frac{\epsilon u}{\epsilon u + 0.004} = 0.85 \times 0.85 \frac{25}{420} \times \frac{0.003}{0003+0.004} = 0.0184$

   $\rho < \rho_{max}$ Tension Failure O.K

   For statically determinate span with a flange in tension, minimum flexure reinforcement should compute based on:

   $As_{min} = \text{minimum}\left(\frac{0.25\sqrt{fc`}}{fy} bd, \frac{0.5\sqrt{fc`}}{fy} b_w d\right)$

   As_{min} = min (**720**, 832) $mm^2 < 1884.95 mm^2$ O.k

2. Calculate Ø

   $a = \frac{Asfy}{0.85fc`b} = \frac{1884.95 \times 420}{0.85 \times 25 \times 260} = 143.3\ mm$

   $c = \frac{a}{\beta 1} = \frac{143.3}{0.85} = 168.23\ mm$

   $\epsilon_t = \frac{dt - c}{c} \epsilon_u = \frac{540 - 168.23}{168.23} \times 0.003 = 6.63 \times 10^{-3} > 0.005$

   ∴ Ø = 0.9

3. Calculate ØM_n

   ØM_n can be calculated from:

   $ØM_n = ØA_s f_y\left(d - \frac{a}{2}\right) = 0.9 \times 1884.95 \times 420 \times \left(537.5 - \frac{143.3}{2}\right) \times 10^{-6}$

   ØM_n = 331.9 kN.m

4. Find Mu and compare it with ØM_n

   $Mu = \frac{w_u \ell^2}{8} = \frac{10 \times 5^2}{8} = 31.25\ kN.m$

   Mu < 331.9 kN.m

   ∴ Beam is adequate according to ACI code ■