Design of Tee Reinforced Beam

Usually, the design problem of T- beam can be considered as a design of a section with pre – specified dimensions (h_f, b, b_w, and h). Usually these dimensions have been determined as follows:

- h_f and b are both determined from slab design .
- b_w and h are determined based on one of following criteria:
  - Based on architectural requirements.
  - Based on shear requirements
  - Based on strength.

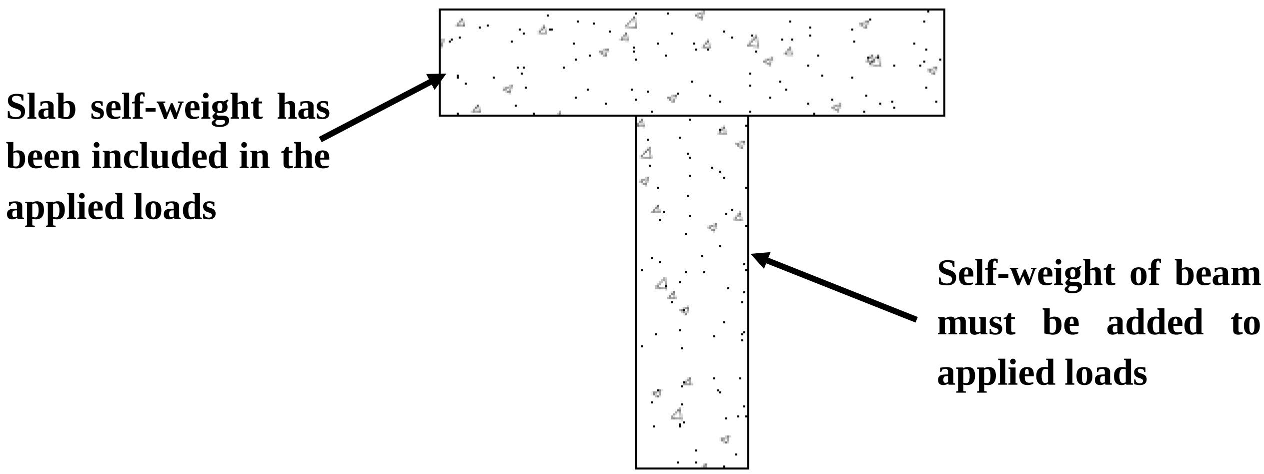
Therefore, the main unknown of design problem is to determine the required ***reinforcement (As)*** and its details.

Design Procedure

1. Compute required factored applied moment **Mu** based on given load (dead and live loads).

   And calculate $M_n = \frac{M_u}{\emptyset}$ and $\emptyset = 0.9$ and will be checked later.

   - In calculating Mu, the slab weight has been already included in the applied dead load, therefore only self-weight of beam stem should be added.



   - Based on slab and beam data, determine the effective flange width "b" and as was discussed in previous article.

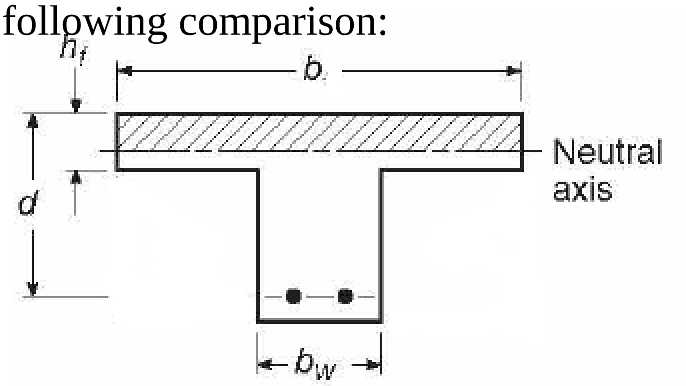
2. Compute the effective depth (d)

$$d_{\text{for one layer}} = h - \text{cover} - \text{stirrups} - \frac{\text{bar diameter}}{2}$$

$$d_{\text{for two layer}} = h - \text{cover} - \text{stirrups} - \text{bar diameter} - \frac{\text{spacing between layers}}{2}$$

3. Check if this section can be design with compression block in section flange or extend to section web based on following comparison:

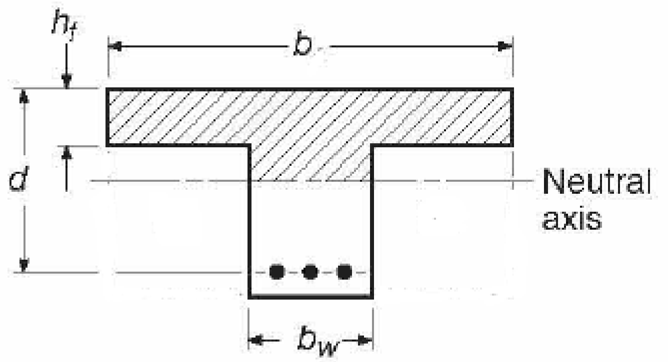
If



$M_n \leq 0.85fc`h_f b\left(d - \frac{h_f}{2}\right)$ then $a \leq hf$

Go to step 4.1

If else:



$M_n > 0.85fc`h_f b\left(d - \frac{h_f}{2}\right)$ then $a > h$

Go to step 4.2

4.1 Design of a section with $a \leq hf$

This section can be designed as a rectangular section with dimensions of b and d.

$$\rho_{required} = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2Rm}{fy}}\right)$$

Where:

$m = \frac{fy}{0.85fc`}$, $R = \frac{M_u \times 10^6}{\emptyset bd^2}$ and $\emptyset = 0.9$

$As_{Required} = \rho_{required}\, bd$

4.2 Design of a section with $a > hf$

i. Compute the nominal moment that can be supported by flange overhangs.

$M_{n1} = 0.85fc`h_f\,(b - b_w)\,(d - \frac{h_f}{2})$

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

ii. Compute the remaining nominal strength that must be supported by section web:

$M_{n2} = M_n - M_{n1}$

For this moment M_{n2}, the section can be designed a rectangular section with dimensions of b_w and d:

$$\rho_{required} = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2Rm}{fy}}\right)$$

Where:

$$m = \frac{fy}{0.85fc`} \quad , \quad R = \frac{M_{n2} \times 10^6}{b_w d^2}$$

$A_{s2} = \rho_{required}\, b_w d$

$As_{\text{ required total}} = A_{sf} + A_{s2}$

No. of bars = $\frac{A_{s\,required}}{A_{bar}}$ and check **b** $_{\textbf{required}}$ with **b** $_{\textbf{provided}}$

5. Check the $A_{s\text{ provided}}$ with the maximum steel area permitted by ACI Code:

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

   If $A_{s\text{ required}} > A_{s\text{ minimum}}$ O.k

   If else:

   Use $A_{s\text{ provided}} = A_{s\text{ minimum}}$

6. Check the $A_{s\text{ provided}}$ with the maximum steel area permitted by ACI code

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

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

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

   If else: $\rho_w > \rho_{w\,max}$

   - Then the designer must increase one or more of beam dimensions. In practice m compression reinforcement is not used in T sections.

7. Check the assumption of $\emptyset = 0.9$

   Compute "a"

   If $a \leq h_f$

   $a = \frac{A_s\, fy}{0.85fc`b}$

   If else: $a > h_f$

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

   Then compute "c":

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

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

   - If $\epsilon_t \geq 0.005$, then $\emptyset = 0.9$

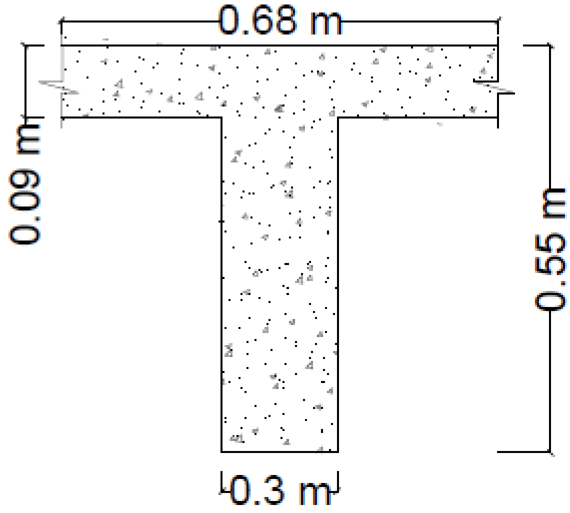
- If $\epsilon_t < 0.005$ then

  $\emptyset = 0.483 + 83.3 \times \epsilon_t$

  And retain to step of computing M_n

8. Draw final detail section ■

Example 1: Design a T –beam having cross section shown below according to ACI code -14 requirement. The beam is simply supported on span of (7.3152) m .the beam is subjected to service dead load (40.78) kN/m **(without self-weight)**, and service live load (10) kN/m, Assume that the effective flange width has been calculated:



Assume the designer intends to use:

- fc` = 21 MPa
- f_y = 414 MPa
- For longitudinal reinforcement use Ø35 mm
- One layer of reinforcement

Solution:

1. Compute required factored applied moment **Mu** based on given load (dead and live loads).

   $W_{self\text{-}weight}$ = (0.55 – 0.09) ×0.3 ×24=3.312 kN/m

   W_D = 3.312 + 40.78 =44.1 kN/m

   Wu = 1.2WD + 1.6WL = 1.2× 44.1 + 1.6×10 = 68.92 kN/m

   $Mu = \frac{W_u \ell^2}{8} = \frac{68.92\times 7.3152^2}{8} = 461$ kN.m

   $M_n = \frac{M_u}{\emptyset} = \frac{461}{0.9} = 512$ kN.m

2. Compute the effective depth (d)

   $d_{\text{ for one layer}} = h - cover - stirrups - \frac{\text{bar diameter}}{2}$

   $d_{\text{ for one layer}} = 550 - 40 - 10 - \frac{35}{2} = 482.5$ mm

3. Check if this section can be design with compression block in section flange or extend to section web based on following comparison

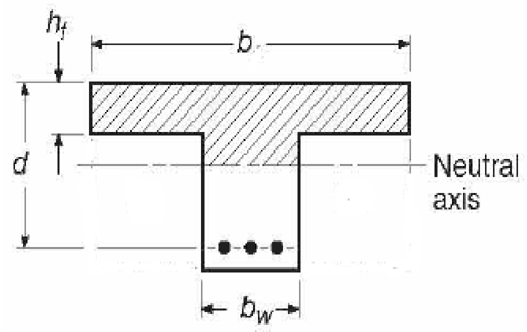
$M_n = 512$ kN.m

$M_{n\ flange} = 0.85 f_c` h_f b\left(d - \frac{h_f}{2}\right)$

$M_{n\ flange} = 0.85 \times 21 \times 90 \times 680 \times \left(482.5 - \frac{90}{2}\right) \times 10^{-6} = 478$ kN.m

$M_n > M_{n\ flange}$

∴ Design a section with $a > h_f$ go to step 4.2



4.2 Design of a section with $a > h_f$

i. Compute the nominal moment that can be supported by flange overhangs.

$M_{n1} = 0.85 f_c` h_f (b - b_w)\left(d - \frac{h_f}{2}\right)$

$M_{n1} = 0.85 \times 21 \times 90 \times (680 - 300)\left(482.5 - \frac{90}{2}\right) \times 10^{-6} = 267$ kN.m

Steel reinforcement for this part will be:

$A_{sf} = \frac{0.85 f_c` h_f (b - b_w)}{f_y} = \frac{0.85 \times 21 \times 90 \times (680 - 300)}{414} = 1474.6\ mm^2$

ii. Compute the remaining nominal strength that must be supported by section web:

$M_{n2} = M_n - M_{n1}$

$M_{n2} = 512 - 268 = 244$ kN.m

For this moment M_{n2}, the section can be designed a rectangular section with dimensions of b_w and d:

$\rho_{required} = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2Rm}{fy}}\right)$

$m = \frac{fy}{0.85 f_c`} = \frac{414}{0.85 \times 21} = 23.19, \quad R = \frac{M_{n2} \times 10^6}{b_w d^2} = \frac{244 \times 10^6}{300 \times 482.5^2} = 3.49$

$\rho_{required} = \frac{1}{23.19}\left(1 - \sqrt{1 - \frac{2 \times 3.49 \times 23.19}{414}}\right) = 9.47 \times 10^{-3}$

$A_{s2} = \rho_{required}\, b_w d = 9.47 \times 10^{-3} \times 300 \times 482.5 = 1371\ mm^2$

$A_{s\ required} = A_{sf} + A_{s2} = 1474.6 + 1371 = 2845.6\ mm^2$

No. of bars $= \frac{A_s}{A_b} = \frac{2845.6}{\frac{\pi}{4}\times 35^2} = \frac{2845.6}{962.11} = 2.95 \approx 3$

Try 3Ø35 mm

As provided = 3 × 962.11 = 2886.33 mm^2

Check $b_{required} = 40 \times 2 + 10 \times 2 + 3 \times 35 + 2 \times 35$

$b_{required}$ = 275mm < 300 mm O.k

5. Check the $A_{s\ provided}$ with the maximum steel area permitted by ACI Code:

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

$$A_{s\ minimum} = \frac{1.4}{fy} b_w d = \frac{1.4}{414} \times 300 \times 482.5 = 489.5\ mm^2 < A_{s\ provided}$$

6. Check the $A_{s\ provided}$ with the maximum steel area permitted by ACI code

$$\rho_w = \frac{As}{b_w d} = \frac{2886.33}{300\times 482.5} = 19.94 \times 10^{-3}$$

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

$$\rho_{w\ max} = 0.85 \times 0.85 \times \frac{21}{414} \times \frac{0.003}{0.003+0.004} + \frac{1474.6}{300\times 482.5} = 25.89 \times 10^{-3}$$

$\rho_w \leq \rho_{w\ max}$ O.K

7. Check the assumption of $\emptyset = 0.9$

$a > h_f$

$$a = \frac{(2886.33 - 1474.6)\times 414}{0.85\times 21\times 300} = 109.14\ mm$$

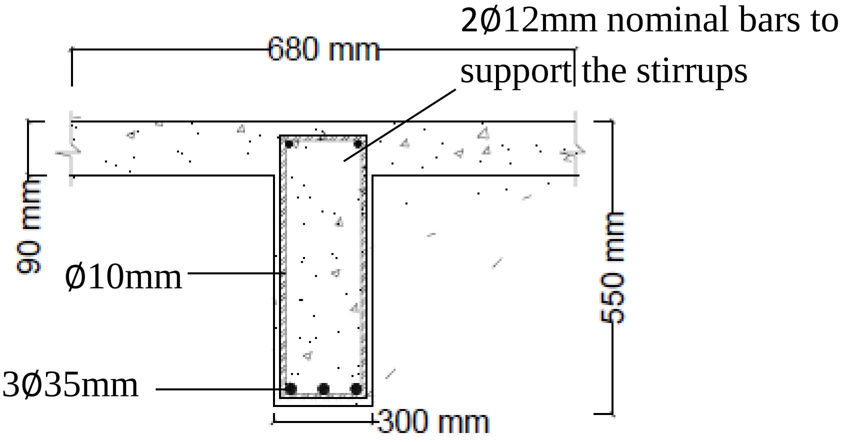
Then compute "c":

$$c = \frac{a}{\beta 1} = \frac{109.14}{0.85} = 128.4\ mm$$

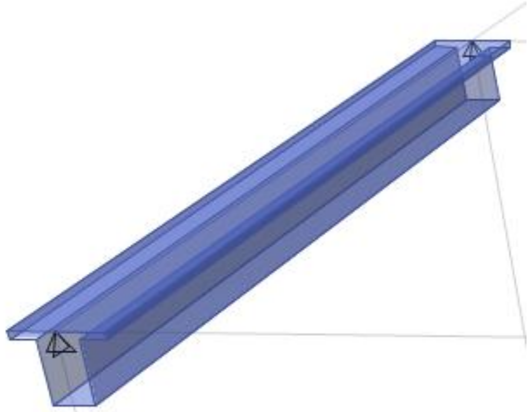
$$\epsilon_t = \frac{dt-c}{c}\epsilon_u = \frac{482.5-128.4}{128.4} \times 0.003 = 8.27\times 10^{-3} > 0.005$$

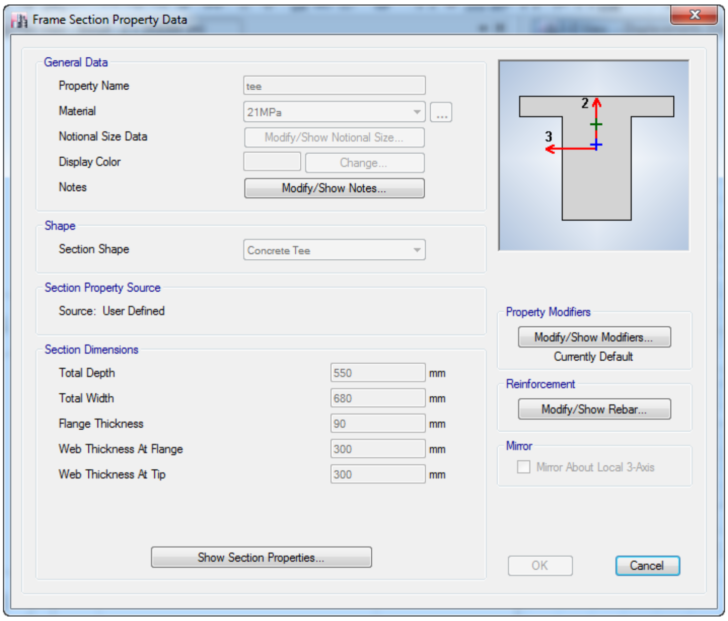
∴ $\emptyset = 0.9$ O.K

8. Draw final detail section



Re-Design the previous example by using **ETABS 2016** and compare the results of design and analysis





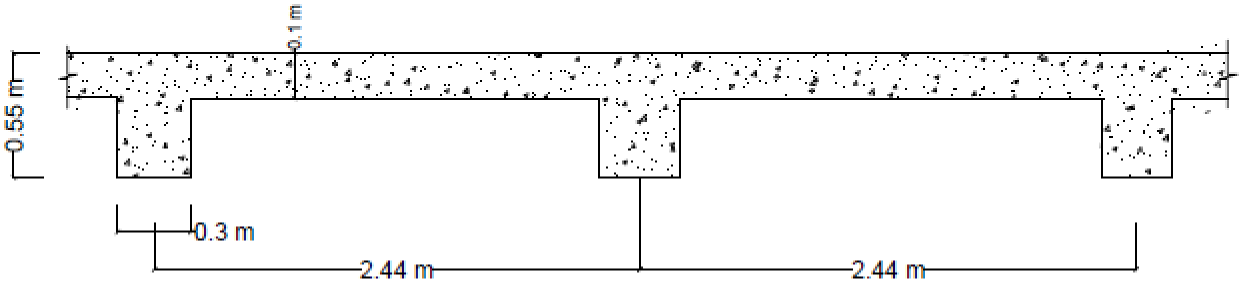
Design Moment and Flexural Reinforcement for Moment, M_{u3}

	Design -Moment kN-m	Design +Moment kN-m	-Moment Rebar mm²	+Moment Rebar mm²	Minimum Rebar mm²	Required Rebar mm²
Top (+2 Axis)	0		0	0	0	0
Bottom (-2 Axis)		460.6	0	2851	482	2851

Method of design	Hand Calculation	ETABS (2016)	Difference %
Mu kN.m	**461 (kN.m)**	**460.6 (kN.m)**	**0.08 %**
Tension Reinforcement (mm^2)	**2845.6 (mm^2)**	**2851 (mm^2)**	**0.19 %**

- In complex structure building when hand calculating is difficult to apply, it's useful to take one or two beams from that building and compare the results of analysis and design with results that obtained from structural software (like ETABS in our course), this can be considered as verification for the program.■

Example 2: Design the T-Beam shown below according to ACI-14 Code requirements. The floor slab is supported by 6.71 m simple span beams. Service loads are: W_L = 14.6 kN/m and W_{dead} = 29.2 kN/m



Assume the designer intend to use:

- fc` = 21 MPa and f_y = 414 MPa
- Stirrups diameter is 10mm
- A_{bar} = 500 mm^2 for Ø 25mm
- Use one layer of reinforcement

Solution:

1. Compute M_u

W self-weight = (0.55 – 0.1) × 0.3 ×24 = 3.24 kN/m

W_{dead} = 29.2 + 3.24 = 32.4 kN/m

W_u = 1.2W_D +1.6W_L= 62.24 kN/m

$$Mu = \frac{W_u \ell^2}{8} = \frac{62.24 \times 6.71^2}{8} = 350 \text{ kN.m}$$

- Compute the nominal flexure moment M_n

$$M_n = \frac{M_u}{\emptyset} = = \frac{350}{0.9} = 389 \text{ kN.m}$$

Compute the effective flange "b"

$$b = b_w + \text{minimum} \left[\frac{S_w}{2} \text{ or } 8h_f \text{ or } \frac{\ell_n}{8}\right] \times 2$$

$$b = 300 + \text{minimum} \left[\frac{(2440-300)}{2} \text{ or } 8 \times 100 \text{ or } \frac{6710}{8}\right] \times 2$$

$$b = 300 + \text{minimum} \left[1070 \text{ or } \mathbf{800} \text{ or } 839\right] \times 2 = 300 + 800 \times 2 = 1900$$

2. Compute the effective depth (d)

$$d_{\text{for one layer}} = h - \text{cover} - \text{stirrups} - \frac{\text{bar diameter}}{2}$$

$$d_{\text{for one layer}} = 550 - 40 - 10 - \frac{25}{2} = 487.5 \text{ mm}$$

3. Check if this section can be design with compression block in section flange or extend to section web based on following comparison

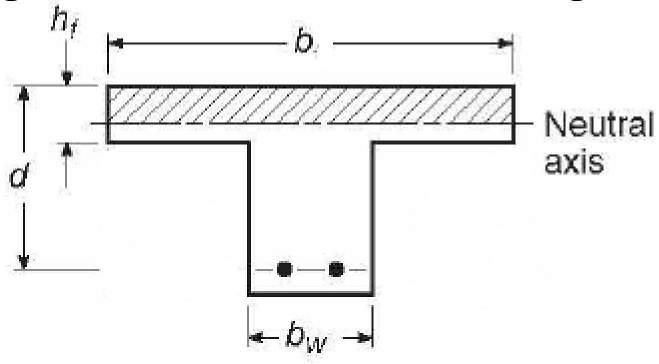
M_n = 389 kN.m

$M_{n\ flange} = 0.85 fc` h_f b\left(d - \frac{h_f}{2}\right) = 0.85 \times 21 \times 100 \times 1900 \times \left(487.5 - \frac{100}{2}\right)$

$M_{n\ flange}$ = 1484 kN.m

$M_n < M_{n\ flange}$

∴ Design a section with $a < h_f$ go to step 4.1



4.1 Design of a section with a ≤ hf

This section can be designed as a rectangular section with dimensions of b and d.

$\rho_{required} = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2Rm}{fy}}\right)$

$m = \frac{fy}{0.85fc`} = \frac{414}{0.85\times21} = 23.19$, $R = \frac{350\times10^6}{0.9\times1900\times487.5^2} = 0.861$

$\rho_{required} = \frac{1}{23.19}\left(1 - \sqrt{1 - \frac{2\times0.861\times23.19}{414}}\right) = 2.13 \times 10^{-3}$

$As_{\ Required} = \rho_{required}\ bd = 2.13 \times 10^{-3} \times 1900 \times 487.5 = 1973\ mm^2$

No. of bars $= \frac{A_s}{A_b} = \frac{1973}{500} = \frac{1973}{500} = 3.946 \approx 4$

Try 4Ø25 mm

As provided = 4 × 500 = 2000 mm^2

Check $b_{required}$ = 40 × 2 + 10 × 2 + 4 × 25 + 3 × 25

$b_{required}$ = 275mm < 300 mm O.k

5. Check the $A_{s\ provided}$ with the maximum steel area permitted by ACI Code:

$A_{s\ minimum} = \frac{1.4}{fy} b_w d = \frac{1.4}{414} \times 300 \times 487.5 = 494.6\ mm^2 < A_{s\ provided}$ o.k

6. Check the $A_{s\ provided}$ with the maximum steel area permitted by ACI code

$\rho_w = \frac{As}{b_w d} = \frac{2000}{300\times 487.5} = 13.67 \times 10^{-3}$

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

$A_{sf} = \frac{0.85 fc` h_f\,(b - b_w)}{f_y} = \frac{0.85 \times 21 \times 100 \times (1900 - 300)}{414} = 6899\ mm^2$

$\rho_{w\,max} = 0.85 \times 0.85 \times \frac{21}{414} \times \frac{0.003}{0.003 + 0.004} + \frac{6899}{300 \times 487.5} = 62.88 \times 10^{-3}$

$\rho_w < \rho_{w\,max}$ O.K

7. Check the assumption of $\emptyset = 0.9$

   $a \leq h_f$

   $a = \frac{A_s\, fy}{0.85 fc` b} = \frac{2000 \times 414}{0.85 \times 21 \times 1900}$ =24.4 mm

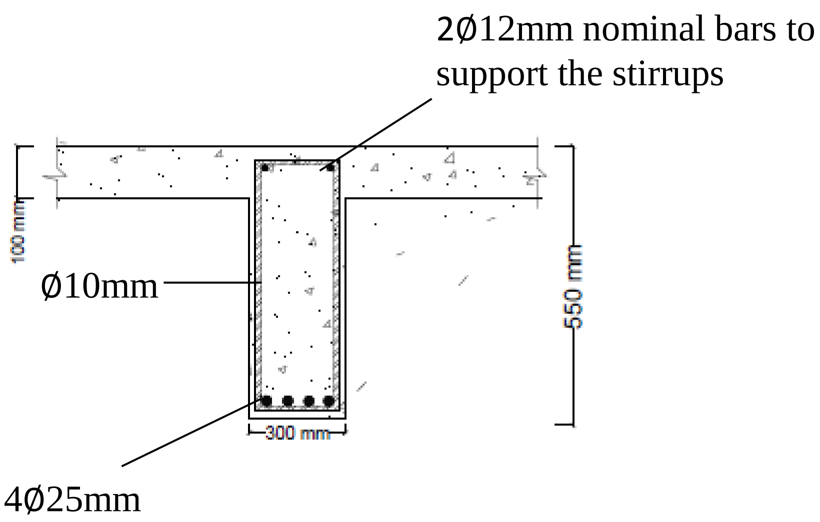
   Then compute "c":

   $c = \frac{a}{\beta 1} = \frac{24.4}{0.85} = 28.7$ mm

   $\epsilon_t = \frac{dt - c}{c} \epsilon_u = \frac{487.5 - 28.7}{28.7} \times 0.003 = 0.0479 > 0.005$

   $\therefore\ \emptyset = 0.9$ O.K

8. Draw final detail section ■



Example 3: Design a T- beam having a clear span of 6.0 m. a web thickness of 300mm, and an overall depth of 645 mm. The beams spacing is 1.2 m center to center and the slab thickness is 100 mm. Design this beam for flexure to carries a total factored moment of 1300 mm kN.m

Assume the designer intend to use:

- fc` = 28 MPa and fy = 400 MPa
- Ø32 mm for longitudinal reinforcement (A_{bar} = 819 mm^2)
- Ø10mm for stirrups
- Two layers of reinforcement.

Solution:

1. Compute M_u

M_u = 1300 kN.m

$M_n = \frac{M_u}{\emptyset} = \frac{1300}{0.9} = 1444.44$ kN.m

2. Compute the effective depth (d)

$d_{\text{for two layer}} = h - \text{cover} - \text{stirrups} - \text{bar diameter} - \frac{\text{spacing between layers}}{2}$

$d_{\text{for two layer}} = 645 - 40 - 10 - 32 - \frac{25}{2} = 550.5$ mm

$b = 300 + \text{minimum}\left[\frac{1200-300}{2}\ or\ 8 \times 100\ or\ \frac{6000}{8}\right] \times 2$

$b = 300 + \text{minimum}[\mathbf{450}\ or\ 800\ or\ 750\ ] \times 2 = 300 + 450 \times 2 = 1200$ mm

3. Check if this section can be design with compression block in section flange or extend to section web based on following comparison

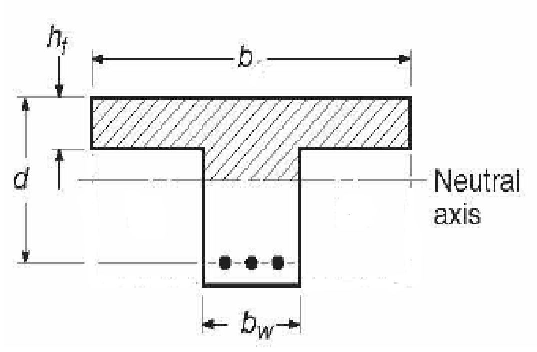
M_n = 1444.44 kN.m

$M_{n\ flange} = 0.85 fc` h_f b\left(d - \frac{h_f}{2}\right)$

$Mn_{flange} = 0.85 \times 28 \times 100 \times 1200 \times \left(550.5 - \frac{100}{2}\right) \times 10^{-6} = 1429$ kN.m

$M_n > M_{n\ flange}$

∴ Design a section with $a > h_f$ go to step 4.2



4.2 Design of a section with $a > hf$

i. Compute the nominal moment that can be supported by flange overhangs.

$M_{n1} = 0.85fc`h_f\,(b - b_w)\,(d - \frac{h_f}{2})$

$M_{n1} = 0.85 \times 28 \times 100 \times (1200 - 300)\left(550.5 - \frac{100}{2}\right) \times 10^{-6}$

$M_{n1} = 1072$ kN.m

Steel reinforcement for this part will be:

$A_{sf} = \frac{0.85fc`hf\,(b - b_w)}{f_y} = \frac{0.85 \times 28 \times 100 \times (1200 - 300)}{400} = 5355\ mm^2$

ii. Compute the remaining nominal strength that must be supported by section web:

$M_{n2} = M_n - M_{n1}$

$M_{n2} = 1444.44 - 1072$

$M_{n2} = 372.44$ kN.m

For this moment M_{n2}, the section can be designed a rectangular section with dimensions of b_w and d:

$\rho_{required} = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2Rm}{fy}}\right)$

$m = \frac{fy}{0.85fc`} = \frac{400}{0.85 \times 28} = 16.81, \quad R = \frac{M_{n2} \times 10^6}{b_w d^2} = \frac{372.44 \times 10^6}{300 \times 550.5^2} = 4.096$

$\rho_{required} = \frac{1}{16.81}\left(1 - \sqrt{1 - \frac{2 \times 4.096 \times 16.81}{400}}\right) = 11.36 \times 10^{-3}$

$A_{s2} = \rho_{required}\, b_w d = 11.36 \times 10^{-3} \times 300 \times 550.5 = 1876\ mm^2$

$A_{s\ required} = A_{sf} + A_{s2} = 1876 + 5355 = 7231\ mm^2$

No. of bars $= \frac{A_s}{A_{bar}} = \frac{7231}{819} = 8.8 \approx 9$

Try 9Ø32 mm

As provided $= 9 \times 819 = 7371\ mm^2$

Check $b_{required} = 40 \times 2 + 10 \times 2 + 5 \times 32 + 4 \times 32$

$b_{required} = 388mm > 300$ mm Not O.K. use bundle bar

5. Check the $A_{s\ provided}$ with the maximum steel area permitted by ACI Code:

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

$A_{s\ minimum} = \frac{1.4}{fy} b_w d = \frac{1.4}{414} \times 300 \times 550.5 = 578\ mm^2 < A_{s\ provided}$ O.K

6. Check the $A_{s\ provided}$ with the maximum steel area permitted by ACI code

$$\rho_w = \frac{As}{b_w d} = \frac{7371}{300\times 550.5} = 44.63 \times 10^{-3}$$

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

$$\rho_{w\ max} = 0.85\times 0.85\times \frac{28}{400}\times\frac{0.003}{0.003+0.004} + \frac{5355}{300\times 550.5} = 54.1 \times 10^{-3}$$

$\rho_w \leq \rho_{w\ max}$ O.K

7. Check the assumption of $\emptyset = 0.9$

$a > h_f$

$$a = \frac{(7231-5355)\times 400}{0.85\times 28\times 300} = 105.1 \text{ mm}$$

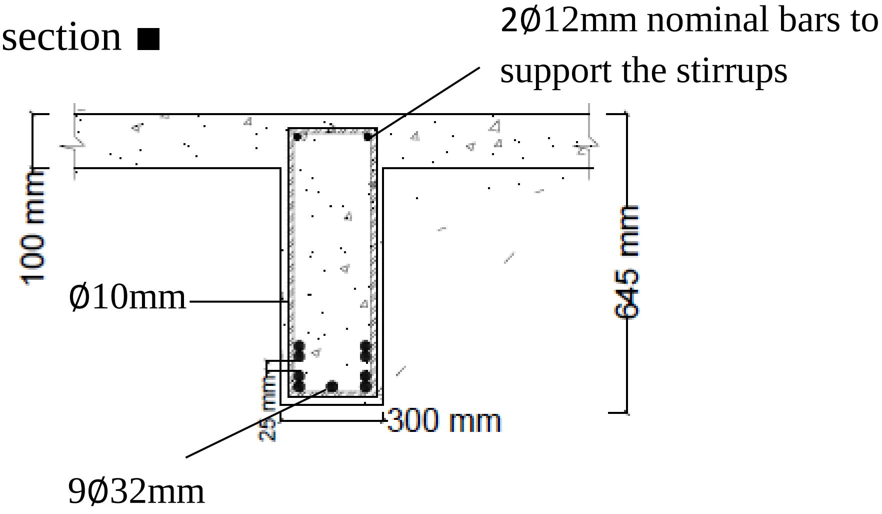
Then compute "c":

$$c = \frac{a}{\beta 1} = \frac{105.1}{0.85} = 123.6 \text{ mm}$$

$$\epsilon_t = \frac{dt-c}{c}\epsilon_u = \frac{579-123.6}{123.6}\times 0.003 = 0.01105\times 10^{-3} > 0.005$$

$\therefore$ $\emptyset = 0.9$ O.K

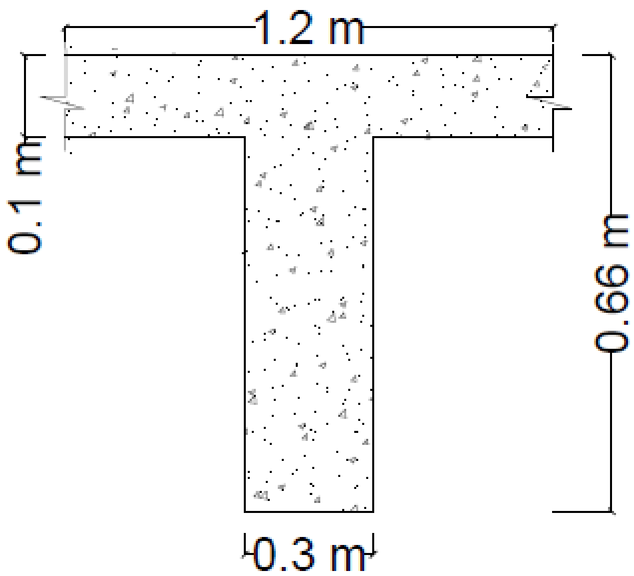
8. Draw final detail section ■



Example 4: In slab-beam floor system, the flange width determined and as shown below. Design a T-section to resist moment of 1101 kN.m

Assume the designer intend to use:

- fc` =21 MPa
- f_y = 420 MPa
- Ø35mm for longitudinal reinforcement (A_{bar} = 1000 mm^2)
- Ø10mm for stirrups
- Two layers of reinforcement.



Solution:

1. Compute M_u

M_u = 1101 kN.m

$M_n = \frac{M_u}{\emptyset} = \frac{1101}{0.9}$ = 1223 kN.m

2. Compute the effective depth (d)

$d_{\text{for two layer}} = h - \text{cover} - \text{stirrups} - \text{bar diameter} - \frac{\text{spacing between layers}}{2}$

$d_{\text{for two layer}} = 660 - 40 - 10 - 35 - \frac{25}{2} = 562.5$ mm

b = 1200 mm

3. Check if this section can be design with compression block in section flange or extend to section web based on following comparison

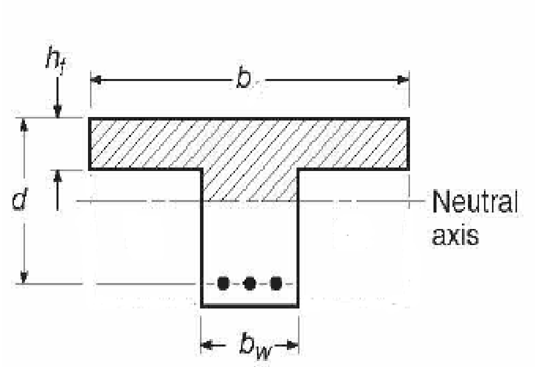
M_n = 1223 kN.m

$M_{n\ flange} = 0.85 fc` h_f b\left(d - \frac{h_f}{2}\right)$

$Mn_{\ flange} = 0.85 \times 21 \times 100 \times 1200 \times \left(562.5 - \frac{100}{2}\right) \times 10^{-6} = 1097.8$ kN.m

$M_n > M_{n\ flange}$

∴ Design a section with $a > h_f$ go to step 4.2



4.2 Design of a section with $a > hf$

i. Compute the nominal moment that can be supported by flange overhangs.

$M_{n1} = 0.85fc`h_f\,(b - b_w)\,(d - \frac{h_f}{2})$

$M_{n1} = 0.85\times21\times100\times(1200 - 300)\left(562.5 - \frac{100}{2}\right)\times10^{-6}$

$M_{n1} = 823.23$ kN.m

Steel reinforcement for this part will be:

$A_{sf} = \frac{0.85fc`hf\,(b - b_w)}{f_y} = \frac{0.85\times21\times100\times(1200-300)}{420} = 3825\ mm^2$

ii. Compute the remaining nominal strength that must be supported by section web:

$M_{n2} = M_n - M_{n1}$

$M_{n2} = 1223 - 823.32$

$M_{n2} = 400$ kN.m

For this moment M_{n2}, the section can be designed a rectangular section with dimensions of b_w and d:

$\rho_{required} = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2Rm}{fy}}\right)$

$m = \frac{fy}{0.85fc`} = \frac{420}{0.85\times21} = 23.53$, $R = \frac{M_{n2}\times10^6}{b_w d^2} = \frac{400\times10^6}{300\times562.5^2} = 4.21$

$\rho_{required} = \frac{1}{23.53}\left(1 - \sqrt{1 - \frac{2\times4.21\times23.53}{420}}\right) = 11.6\times10^{-3}$

$A_{s2} = \rho_{required}\,b_w d = 11.6\times10^{-3}\times300\times562.5 = 1958\ mm^2$

$A_{s\ required} = A_{sf} + A_{s2} = 3825 + 1958 = 5783\ mm^2$

No. of bars $= \frac{A_s}{A_{bar}} = \frac{5783}{1000} = 5.8 \approx 6$

Try 6Ø35 mm

As provided = 6 × 1000 = 6000 mm^2

Check $b_{required}$ = 40 × 2 + 10 × 2 + 3 × 35 + 2× 35

$b_{required}$ = 275mm < 300 mm O.K.

5. Check the $A_{s\ provided}$ with the maximum steel area permitted by ACI Code:

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

$A_{s\ minimum} = \frac{1.4}{fy} b_w d = \frac{1.4}{420} \times 300 \times 562.5 = 562.5\ mm^2 < A_{s\ provided}$ O.K

6. Check the $A_{s\ provided}$ with the maximum steel area permitted by ACI code

$\rho_w = \frac{As}{b_w d} = \frac{6000}{300\times 562.5} = 35.56 \times 10^{-3}$

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

$\rho_{w\ max} = 0.85\times 0.85\times \frac{21}{420} \times \frac{0.003}{0.003+0.004} + \frac{3825}{300\times 562.5} = 36.37 \times 10^{-3}$

$\rho_w \leq \rho_{w\ max}$ O.K

7. Check the assumption of $\emptyset = 0.9$

$a > h_f$

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

$a = \frac{(6000 - 3825)\times 420}{0.85\times 21\times 300} = 170.5$ mm

Then compute "c":

$c = \frac{a}{\beta 1} = \frac{170.5}{0.85} = 200.6$ mm

$\epsilon_t = \frac{dt-c}{c}\epsilon_u = \frac{592.5-200.6}{200.6} \times 0.003 = 5.86\times 10^{-3} > 0.005$

∴ $\emptyset = 0.9$ O.K

8. Draw final detail section ■