position of these parts relative to the top fibers and relative to their distances from the beam. The part of the slab acting with the beam is called the flange. The rest of the section is called the stem, or web.
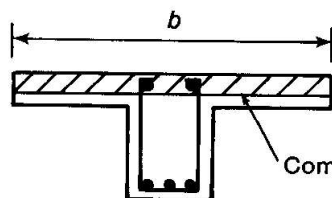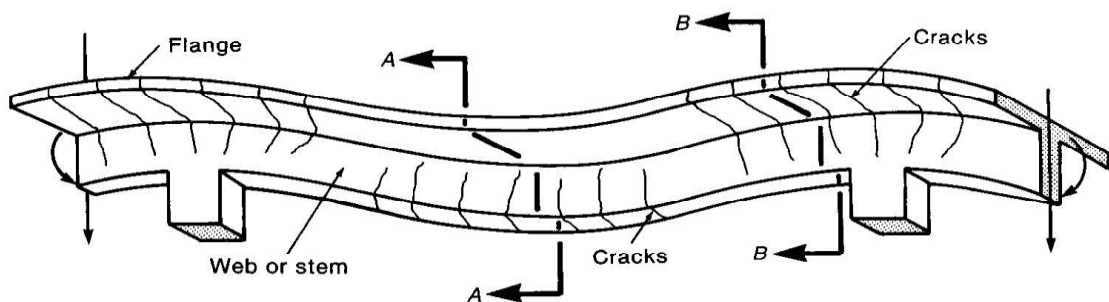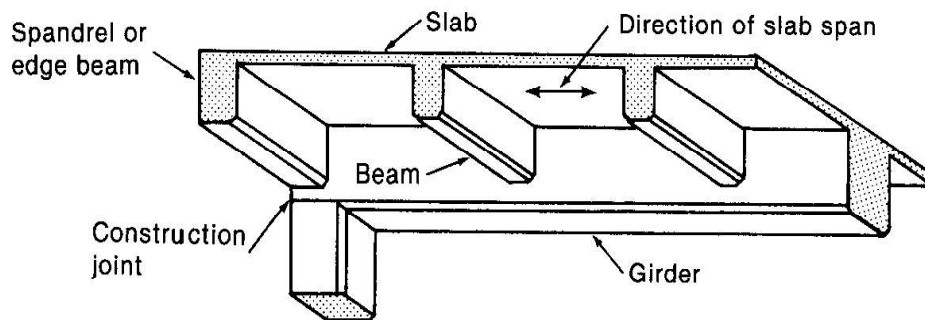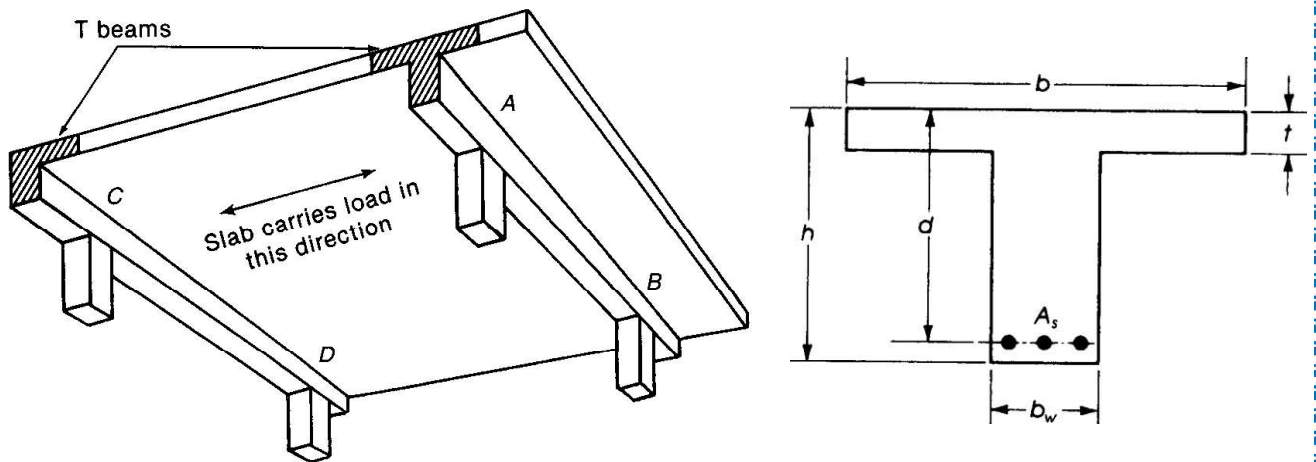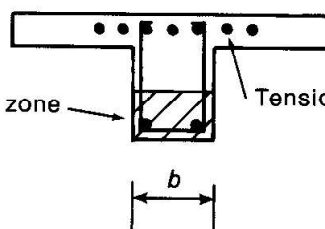








(b) Section A-A (rectangular compression zone).

(c) Section B-B (negative moment).
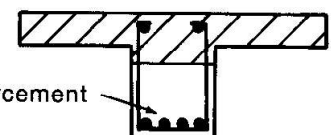
(d) Section A-A (T-shaped compression zone).

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### 4.11.1  Effective width.

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.



$\ell$ = length of beam span (longitudinal span)

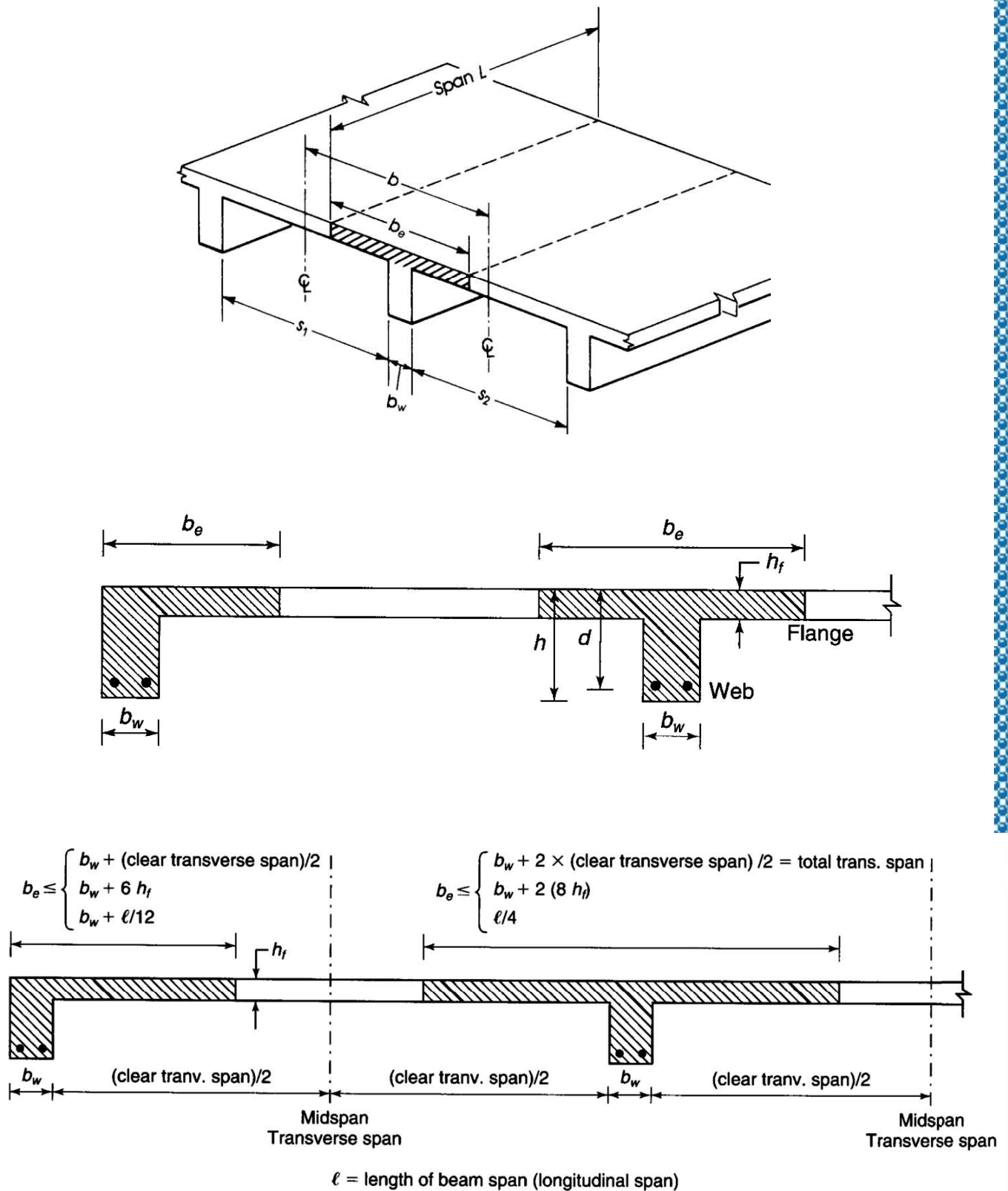For T-shapes, the total effective compression flange width, $b_e$, is limited to one-quarter of the span length of the beam ($L$), and the effective overhanging portions of the compression flange on each side of the web are limited to

    (a)   eight times the thickness of the flange (slab), and

    (b)   one-half the clear distance to the next beam web.

The ACI Code, 8.12.2, prescribes a limit on the effective flange width, $b_e$, of interior T-section to the smallest of the following:

$$(a) \quad b_e \leq \frac{L}{4}$$

$$(b) \quad b_e \leq b_w + 16h_f$$

$$(c) \quad b_e \leq b_w + \frac{1}{2} \text{ the clear distance to the next beam web from both sides}$$

For symmetrical T-section (the clear distance to the next beam web from both sides is the same ) the previous $(c)$ will be

$$(c) \quad b_e \leq \text{Center to Center spacing between adjacent beams}$$

For inverted L-shapes, the following three limits are given for the effective width of the overhanging portion of the compression flange:

    (a)   one-twelfth of the span length of the beam,

    (b)   six times the thickness of the flange (slab), and

    (c)   one-half the clear transverse distance to the next beam web.

The ACI Code, 8.12.3, prescribes a limit on the effective flange width, $b_e$, of exterior T-section (L-shape) to the smallest of the following:

$$(a) \quad b_e \leq b_w + \frac{L}{12}$$

$$(b) \quad b_e \leq b_w + 6h_f$$

$$(c) \quad b_e \leq b_w + \frac{1}{2} \text{ the clear distance to the next beam web.}$$

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)

$$(a) \quad b_e \leq 4b_w$$

$$(b) \quad t \geq \frac{1}{2}b_w$$

### 4.11.2 Analysis of T-sections.

The neutral axis of a T-section 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 strength of the materials.
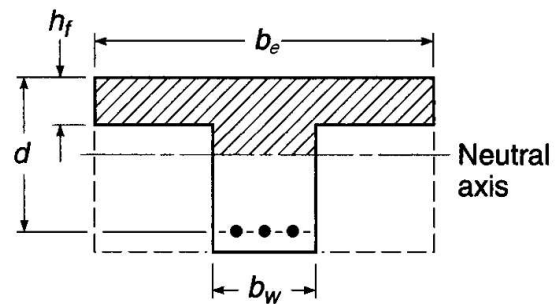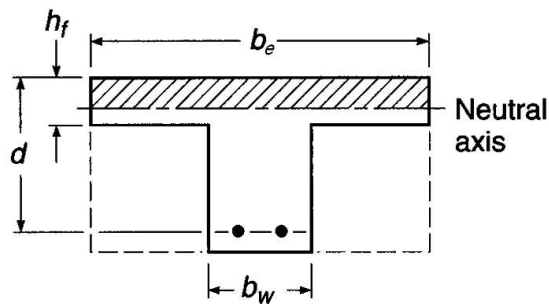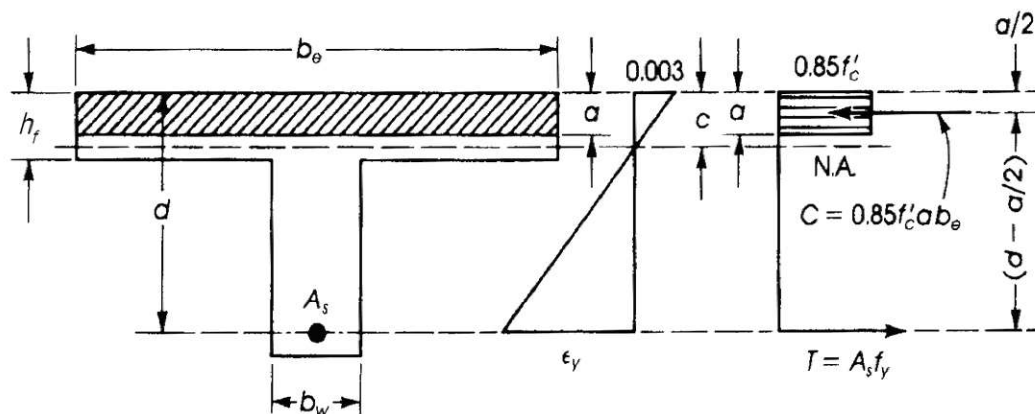
**Procedure of analysis**:

1. Assume that T-section is a rectangular section with total $b_e$ width.

$$T = C \qquad \Longrightarrow \qquad A_s f_y = 0.85\, f_c' a b_e \qquad \Longrightarrow \qquad a = \frac{A_s f_y}{0.85\, f_c' b_e}$$

2. Compare $a$ with $h_f$ — the thickness of flange.
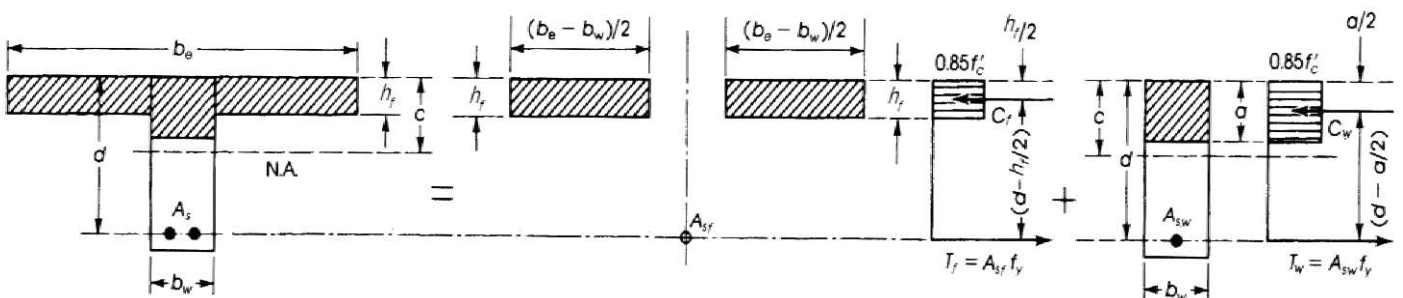
Here may be TWO CASES:

**Case I:** $\quad a \leq h_f$ analyze as rectangular section.



$$M_n = A_s f_y \left(d - \frac{a}{2}\right) \qquad or \qquad M_n = 0.85\, f_c' a b_e \left(d - \frac{a}{2}\right)$$

$$A_s = \frac{0.85\, f_c' a b_e}{f_y}$$

**Case II:** $\quad a > h_f$ analyze as T-section.



1. $M_n = M_{nf} + M_{nw}$

where $\quad M_n$ — Moment capacity of the T-section,

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$M_{nf}$ — Moment capacity of the flange,

$M_{nw}$ — Moment capacity of the web.

2. $M_{nf} = A_{sf}f_y\left(d - \dfrac{h_f}{2}\right) = 0.85\, f_c'(b_e - b_w)h_f\left(d - \dfrac{h_f}{2}\right)$

$T_f = C_f \quad \Rightarrow \quad A_{sf}f_y = 0.85\, f_c'(b_e - b_w)h_f \quad \Rightarrow \quad A_{sf} = \dfrac{0.85\, f_c'(b_e - b_w)h_f}{f_y}$

3. $M_{nw} = A_{sw}f_y\left(d - \dfrac{a}{2}\right) = 0.85\, f_c'b_w a\left(d - \dfrac{a}{2}\right),\qquad A_{sw} = A_s - A_{sf}$

$T_w = C_w \quad \Rightarrow \quad A_{sw}f_y = 0.85\, f_c'b_w a \quad \Rightarrow \quad a = \dfrac{A_{sw}f_y}{0.85\, f_c'b_w}$

$$M_n = A_{sf}f_y\left(d - \frac{h_f}{2}\right) + A_{sw}f_y\left(d - \frac{a}{2}\right)$$

or

$$M_n = 0.85\, f_c'(b_e - b_w)h_f\left(d - \frac{h_f}{2}\right) + 0.85\, f_c'b_w a\left(d - \frac{a}{2}\right)$$

4. Check for strain $\varepsilon_s \geq 0.005$.

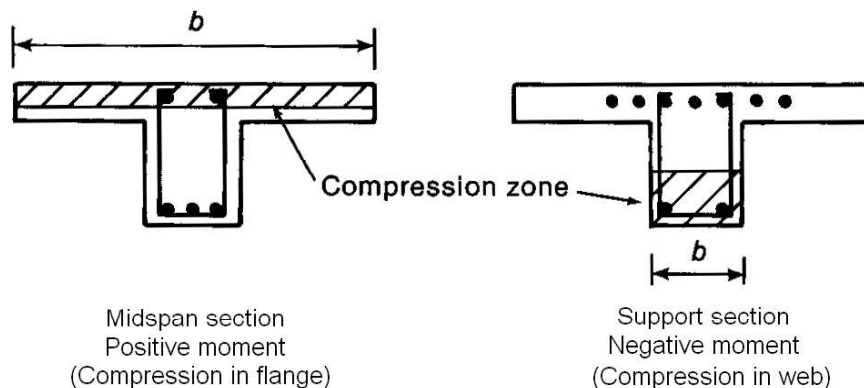### 4.11.3 Minimum reinforcement of flexural T-section members.

$A_{s,min}$ for T-sections is as in 4.6 (page 23).

For statically determinate members with a flange in tension, ACI Code, 10.5.2., as in the case of cantilever beams, $A_{s,min}$ shall not be less than the value given by equations in section 4.6 (see page 23), except that $b_w$ is replaced by either $2b_w$ or the width of the flange, whichever is smaller.

$$A_{s,min} = \frac{0.5\sqrt{f_c'}}{f_y}\, b_w d, \qquad\qquad A_{s,min} = \frac{0.25\sqrt{f_c'}}{f_y}\, bd.$$

According to ACI code, 10.6.6, where flanges of T-beam construction are in tension, part of the flexural tension reinforcement shall be distributed over an effective flange width as defined in 8.12, or a width equal to one-tenth the span, whichever is smaller. If the effective flange width exceeds one-tenth the span, some longitudinal reinforcement shall be provided in the outer portions of the flange.
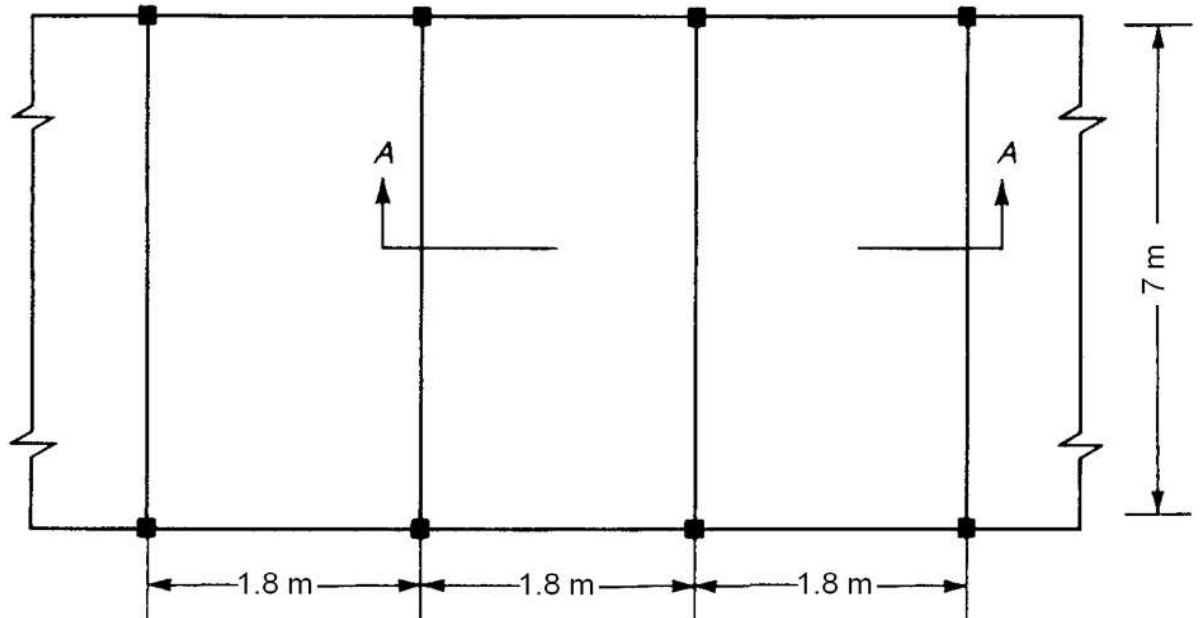
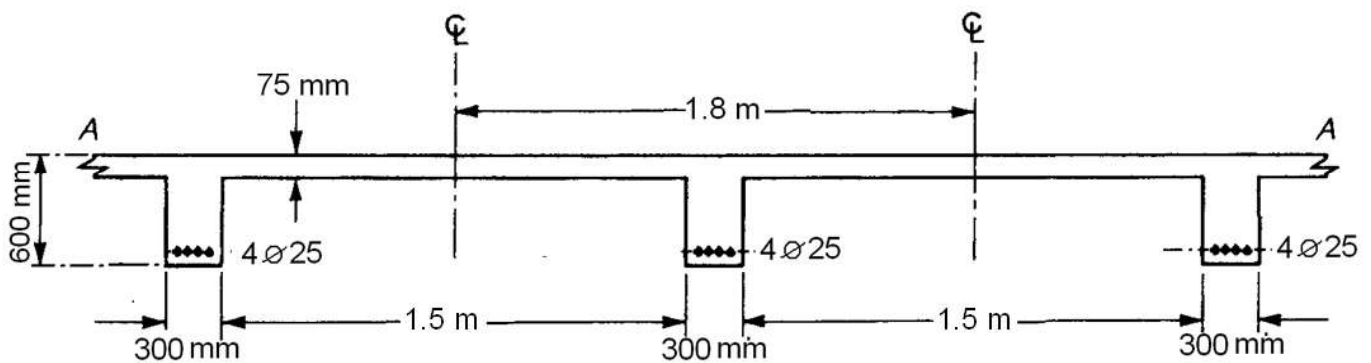### 4.11.4 Analysis of the positive-moment capacity of a T-section.



Compression zone

Midspan section
Positive moment
(Compression in flange)

Support section
Negative moment
(Compression in web)

**Example:**

Calculate the design strength $\phi M_n$ for one of the T beams in the positive moment region. The beam has a clear span of 7 m (face to face).

$f_c' = 28\ MPa, \qquad f_y = 420\ MPa.$



(a)



(b)

**Solution:**

From the Geometry of T-section:

$b_w = 300\ mm, \qquad\qquad h = 600\ mm, \qquad\qquad t = h_f = 75\ mm$

$A_s(4\varnothing\,25) = 1963.5\ mm^2$

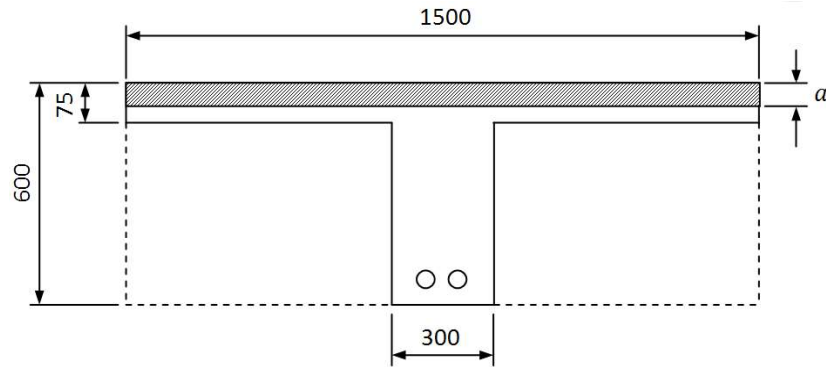$b_e$ is the smallest of:

$$(a)\quad b_e \leq \frac{L}{4} = \frac{7000}{4} = 1750\ mm,$$

$$(b)\quad b_e \leq b_w + 16h_f = 300 + 16 \cdot 75 = 1500\ mm, \qquad - control$$

$$(c)\quad b_e \leq \text{Center to Center spacing between adjacent beams} = 1800\ mm.$$

Take $b_e = 1500 \ mm$.



$$a = \frac{A_s f_y}{0.85 \ f_c' b_e} = \frac{1963.5 \cdot 420}{0.85 \ \cdot 28 \cdot 1500} = 23.1 \ mm \quad < h_f = 75 \ mm$$

The beam section will be considered as rectangular with $b = b_e = 1500 \ mm$.

$$d = 600 - 40 - 10 - \frac{25}{2} = 537.5 \ mm$$

$$M_n = A_s f_y \left(d - \frac{a}{2}\right) = 1963.5 \cdot 420 \left(537.5 - \frac{23.1}{2}\right) \times 10^{-6} = 433.74 \ KN \cdot m$$

Check for strain $\varepsilon_s \geq 0.005$

$$c = \frac{a}{\beta_1} = \frac{23.1}{0.85} = 27.18 \ mm, \qquad\qquad \beta_1 = 0.85$$

$$\varepsilon_s = 0.003 \left(\frac{d-c}{c}\right) = 0.003 \left(\frac{537.5 - 27.18}{27.18}\right) = 0.0565 > 0.005 \qquad OK$$
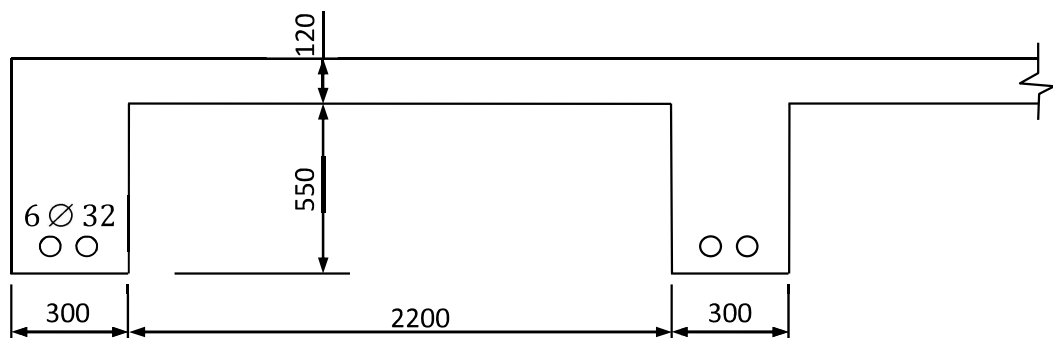
Take $\phi = 0.9$ for flexure as tension-controlled section.

$$M_u = \phi M_n = 0.9 \cdot 433.74 = 390.37 \ KN \cdot m$$

**Example:**

Determine the positive moment capacity of the edge L-section beam. The beam has a clear span of 6 m (face to face).
$f_c' = 20 \ MPa, \qquad f_y = 400 \ MPa.$



**Solution:**

From the Geometry of T-section:

$$b_w = 300 \ mm, \qquad\qquad h = 670 \ mm, \qquad\qquad t = h_f = 120 \ mm$$

$$A_s(6\varnothing\,32) = 4825.5 \ mm^2$$

$b_e$ is the smallest of:

(a) $b_e \leq b_w + \dfrac{L}{12} = 300 + \dfrac{6000}{12} = 800 \ mm, \qquad -control$

(b) $b_e \leq b_w + 6h_f = 300 + 6 \cdot 120 = 1020 \ mm,$

(c) $b_e \leq b_w + \dfrac{1}{2}$ the clear distance to the next beam web $= 300 + \dfrac{2200}{2} = 1400 \ mm.$

Take $b_e = 800 \ mm.$

Check if $a > h_f$

$$a = \frac{A_s f_y}{0.85 \ f_c' b_e} = \frac{4825.5 \cdot 400}{0.85 \ \cdot 20 \cdot 800} = 141.93 \ mm \ > h_f = 120 \ mm$$

The beam section will be considered as L-section with

$b_e = 800 \ mm.$

$$A_{sf} = \frac{0.85 \ f_c'(b_e - b_w)h_f}{f_y} =$$

$$= \frac{0.85 \ \cdot 20(800 - 300)120}{400} = 2550 \ mm^2$$

$$A_{sw} = A_s - A_{sf} = 4825.5 - 2550 = 2275.5 \ mm^2$$

$$a = \frac{A_{sw} f_y}{0.85 \ f_c' b_w} = \frac{2275.5 \cdot 400}{0.85 \ \cdot 20 \cdot 300} = 178.47 \ mm$$

$A_s \ (6\varnothing\,32)$ are arranged in two layers

$$d = 670 - 40 - 10 - 32 - \frac{25}{2} = 575.5 \ mm$$

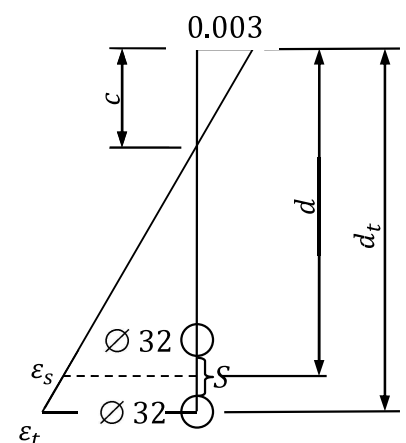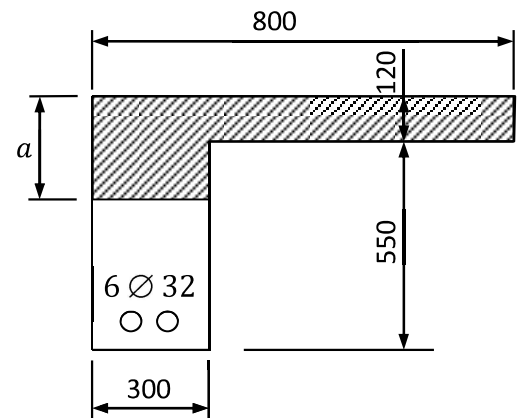$$M_n = A_{sf} f_y \left(d - \frac{h_f}{2}\right) + A_{sw} f_y \left(d - \frac{a}{2}\right) =$$

$$= \left[2550 \cdot 400 \left(575.5 - \frac{120}{2}\right) + 2275.5 \cdot 400 \left(575.5 - \frac{178.47}{2}\right)\right] \times 10^{-6} = 968.4 \ KN \cdot m$$

Check for strain $\varepsilon_s \geq 0.005$

$$c = \frac{a}{\beta_1} = \frac{178.47}{0.85} = 209.96 \ mm, \qquad \beta_1 = 0.85$$

$$d_t = d + \frac{S}{2} + \frac{d_b}{2} = 575.5 + \frac{25}{2} + \frac{32}{2} = 604 \ mm$$

$$\varepsilon_t = 0.003 \left(\frac{d_t - c}{c}\right) = 0.003 \left(\frac{604 - 209.96}{209.96}\right) =$$

$$= 0.00563 > 0.005 \qquad OK$$

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Take $\phi = 0.9$ for flexure as tension-controlled section.

$$M_u = \phi M_n = 0.9 \cdot 961.65 = 865.49 \; KN \cdot m$$

**Example:**

Compute the positive design moment capacity of the T-section beam.

$f'_c = 20 \; MPa, \qquad f_y = 420 \; MPa.$

**Solution:**

From the Geometry of T-section:

$b_w = 200 \; mm, \qquad h = 650 \; mm, \qquad t = h_f = 80 \; mm$

$A_s(4\varnothing\,28) = 2463 \; mm^2$

Check if $a > h_f$

$$a = \frac{A_s f_y}{0.85\, f'_c b_e} = \frac{2463 \cdot 420}{0.85 \cdot 20 \cdot 600} = 101.42 \; mm$$

$a = 101.42 \; mm > h_f = 80 \; mm$ . The beam section will be considered as T-section.

$$A_{sf} = \frac{0.85\, f'_c (b_e - b_w) h_f}{f_y} = \frac{0.85 \cdot 20(600 - 200)80}{420} = 1295.2 \; mm^2$$

$$A_{sw} = A_s - A_{sf} = 2463 - 1295.2 = 1167.76 \; mm^2$$

$$a = \frac{A_{sw} f_y}{0.85\, f'_c b_w} = \frac{1167.76 \cdot 420}{0.85 \cdot 20 \cdot 200} = 144.25 \; mm$$

$A_s\,(4\varnothing\,28)$ are arranged in two layers

$$d = 650 - 40 - 10 - 28 - \frac{30}{2} = 557 \; mm$$

$$M_n = A_{sf} f_y \left(d - \frac{h_f}{2}\right) + A_{sw} f_y \left(d - \frac{a}{2}\right) =$$

$$= \left[1295.2 \cdot 420\left(557 - \frac{80}{2}\right) + 1167.76 \cdot 420\left(557 - \frac{144.25}{2}\right)\right] \times 10^{-6} = 519.05 \; KN \cdot m$$

Check for strain $\varepsilon_s \geq 0.005$

$$c = \frac{a}{\beta_1} = \frac{144.25}{0.85} = 169.7 \; mm, \qquad \beta_1 = 0.85$$

$$d_t = d + \frac{S}{2} + \frac{d_b}{2} = 557 + \frac{30}{2} + \frac{28}{2} = 586 \; mm$$

$$\varepsilon_t = 0.003\left(\frac{d_t - c}{c}\right) = 0.003\left(\frac{586 - 169.7}{169.7}\right) =$$

$$= 0.00736 > 0.005 \qquad OK$$

Take $\phi = 0.9$ for flexure as tension-controlled section.

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