2. Design Procedure

Step 2. Construction Stage (AISC 360-16 F. Design of members for flexure)

(2) Positive moment and negative moment

- **Lateral-torsional buckling**(F4.2.)

  - L_b : length between points that are either braced against lateral displacement of the compression flange or braced against twice of the cross section.

  - L_p : the limiting laterally unraced length for the limit state of yielding $L_p = 1.1 r_t \sqrt{\dfrac{E}{F_y}}$ (F4-7)

  - L_r : the limiting unbraced length for the limit state of inelastic lateral-torsional buckling

$$L_r = 1.95 r_t \frac{E}{F_y} \sqrt{\frac{J}{S_{xc} h_o} + \sqrt{\left(\frac{J}{S_{sc} h_o}\right)^2 + 6.76\left(\frac{F_L}{E}\right)^2}} \quad \text{(F4-8)}$$

  - When $L_b \le L_p$, the limit state of lateral-torsional buckling does not apply.

  - When $L_p < L_b \le L_r$,

$$M_n = C_b \left[R_{pc} M_{yc} - \left(R_{pc} M_{yc} - F_L S_{sc} \right) \left(\frac{L_b - L_p}{L_r - L_p} \right) \right] \le R_{pc} M_{yc} \quad \text{(F4-2)}$$

  - When $L_b > L_r$,

$$M_n = F_{cr} S_{sc} \le R_{pc} M_{yc} \quad \text{(F4-3)}$$

  - where,

The yield moment in the compression flange is $M_{yc} = F_y S_{sc}$ (F4-4)

Given: Beam geometry, required shear and moment strengths, deflection limit
Find: nominal shear and moment strengths, deflection for steel and composite sections

Start

↓

Check limitations

↓

Check construction stage
(1) General provisions
(2) Positive and negative moments
(3) Shear strength
(4) Deflection

↓

Check composite section
(1) Effective width of concrete slab
(2) Load transfer for bending
(3) Positive and negative moments
(4) Shear strength
(5) Deflection

↓

End of procedure

2. Design Procedure

Step 2. Construction Stage (AISC 360-16 F. Design of members for flexure)

(2) Positive moment and negative moment

- **Lateral-torsional buckling** (F4.2.)

- where,

The critical stress $F_{cr} = \dfrac{C_b \pi^2 E}{(L_b / r_t)^2} \sqrt{1 + 0.078 \dfrac{J}{S_{sc} h_o} \left(\dfrac{L_b}{r_t} \right)^2}$ (F4-5)

For $I_{yc} / I_y \leq 0.23$, J shall be taken as zero,

where, I_{yc} = moment of inertia of the compression flange about the y-axis.

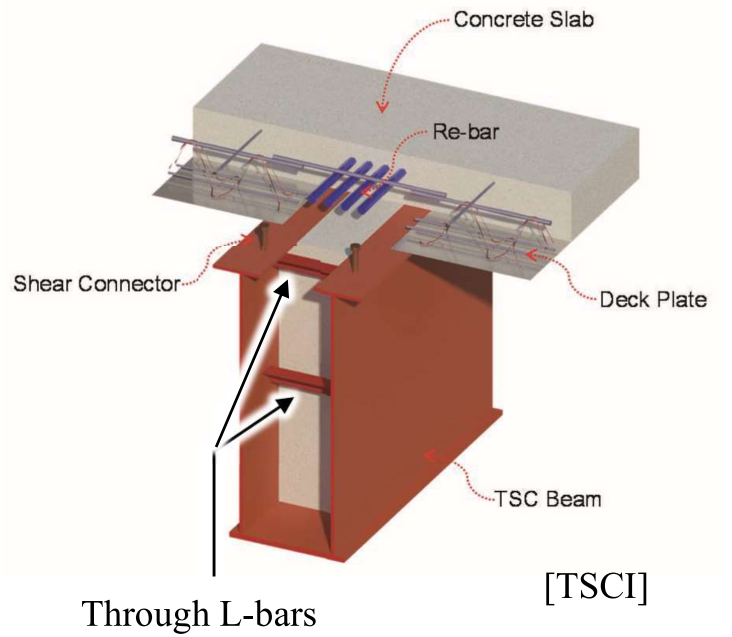
Nominal compression flange stress above which the inelastic buckling limit states

When $S_{xt} / S_{xc} \geq 0.7$, $F_L = 0.7 F_y$ (F4-6a)

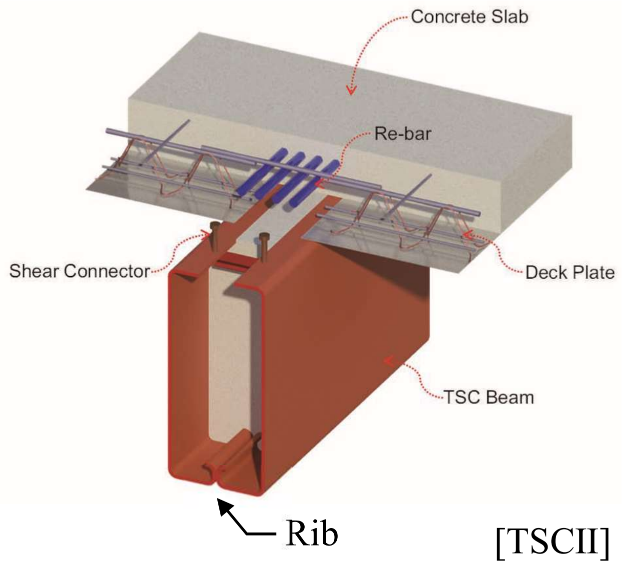
When $S_{xt} / S_{xc} < 0.7$, $F_L = F_y S_{xt} / S_{xc} \geq 0.5 F_y$ (F4-6b)

where, S_{xt} = elastic section modulus referred to tension flange.

Note that the lateral-torsional buckling resistance of the TSC beam is determined in accordance with the singly symmetric I-shaped members (i.e. opened steel section) in AISC 360-16, for a conservative method. The torsional constant, J, of the U-shaped steel section, is taken as the sum of the torsional constant of each steel section. The angle reinforcements welded to webs are not considered. <u>In the actual TSC beam, the LTB resistance may be enhanced due to the additional reinforcements such as through L-bars, butterfly-shaped ribs, and deck plates.</u>



[TSCI]



[TSCII]

2. Design Procedure

SEN ENGINEERING GROUP

Step 2. Construction Stage (AISC 360-16 F. Design of members for flexure)

(2) Positive moment and negative moment

- **Compression flange local buckling** (F4.3.)

$$M_n = R_{pc}M_{yc} - \left(R_{pc}M_{yc} - F_L S_{xc}\right)\left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}}\right)$$ for sections with noncompact flanges (F4-13)

$$M_n = \frac{0.9Ek_c S_{xc}}{\lambda^2}$$ for sections with slender flanges (F4-14)

- Nominal compression flange stress above which the inelastic buckling limit state apply

F_L: (When $S_{xt}/S_{xc} \geq 0.7$) $F_L = 0.7F_y$ (F4-6a), (When $S_{xt}/S_{xc} < 0.7$) $F_L = F_y S_{xt}/S_{xc} \geq 0.5F_y$ (F4-6b)

- The width-to-thickness ratio of compression flange λ (Table B4.1b)

- The limiting slenderness for a compact flange λ_{pf} (Table B4.1b)

- The limiting slenderness for a noncompact flange λ_{rf} (Table B4.1b)

- **Tension flange yielding** (F4.4.)

When $S_{xt} < S_{xc}$, $M_n = R_{pt}M_{yt}$ (F4-15)

- Yield moment in the tension flange $M_{yt} = F_y S_{xt}$

- The web plastification factor corresponding to the tension flange yielding limit state R_{pt}

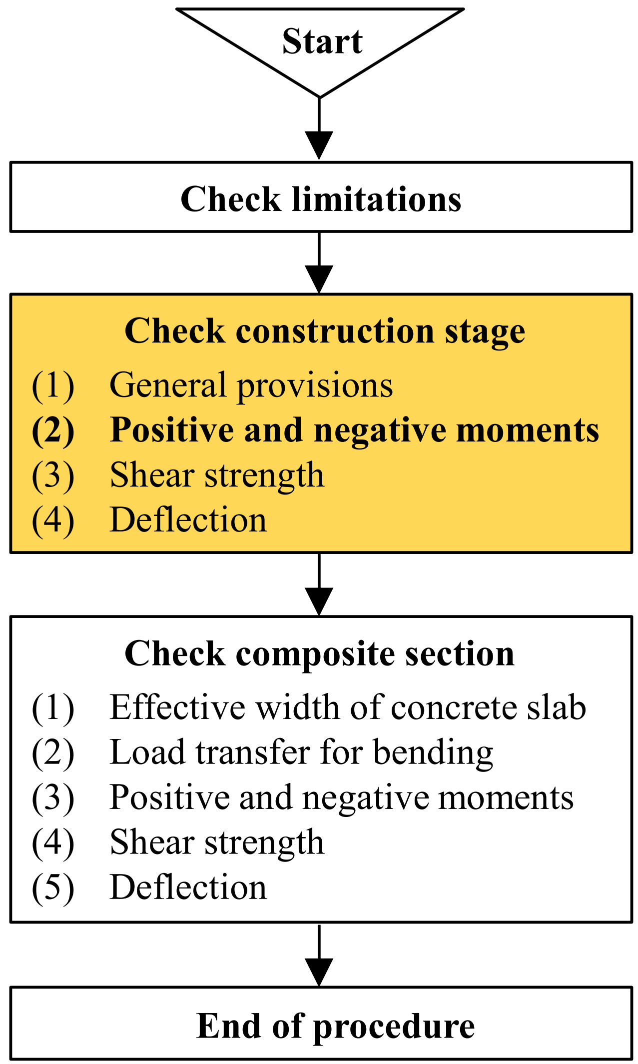
$I_{yc}/I_y > 0.23$ ➔

when $h_c/t_w \leq \lambda_{pw}$, $R_{pt} = M_p/M_{yt}$ (F4-16a)

when $h_c/t_w > \lambda_{pw}$, $$R_{pt} = \left[\frac{M_p}{M_{yt}} - \left(\frac{M_p}{M_{yt}} - 1\right)\left(\frac{\lambda - \lambda_{pw}}{\lambda_{rw} - \lambda_{pw}}\right)\right] \leq \frac{M_p}{M_{yt}}$$ (F4-16b)

$I_{yc}/I_y \leq 0.23$ ➔ $R_{pt} = 1.0$ (F4-17)

Given: Beam geometry, required shear and moment strengths, deflection limit
Find: nominal shear and moment strengths, deflection for steel and composite sections



2. Design Procedure

Step 2. Construction Stage (AISC 360-16 F. Design of members for flexure)

(3) Shear strength (G. Design of members for shear)

- For the TSC beam, nominal shear strength, V_n, is determined in accordance with G2.I-shaped members and G2.2.1(b). In general, transverse stiffeners are not considered in the calculation of web plate shear buckling coefficient, k_v.

- General provisions (G1.)

  - The design shear strength, $\Phi_v V_n$
  - $\Phi_v = 0.90$ (LRFD)

- I-shaped members and channels (G2.)

  - Shear strength of webs without tension filed action (G2.1.):

    The nominal shear strength, V_n, is: $V_n = 0.6 F_y A_w C_v$

    where, A_w = area of web, the overall depth times the web thickness (mm^2)

  - The web shear strength coefficient, C_v (G2.2.1.(b) For other I-shaped members):

    (i) when $h / t_w \le 1.10\sqrt{k_v E / F_y}$, $C_v = 1.0$ (G2-3)

    where h = for build-up welded sections, the clear distance between flanges

    (ii) when $h / t_w > 1.10\sqrt{k_v E / F_y}$, $C_v = 1.10\sqrt{k_v E / F_y} \,/\, (h / t_w)$ (G2-4)

  - The web plate shear buckling coefficient, k_v, is determined as follows:

    (i) For without transverse stiffeners, $k_v = 5.34$

Given: Beam geometry, required shear and moment strengths, deflection limit
Find: nominal shear and moment strengths, deflection for steel and composite sections

Start

↓

Check limitations

↓

Check construction stage
(1) General provisions
(2) Positive and negative moments
(3) Shear strength
(4) Deflection

↓

Check composite section
(1) Effective width of concrete slab
(2) Load transfer for bending
(3) Positive and negative moments
(4) Shear strength
(5) Deflection

↓

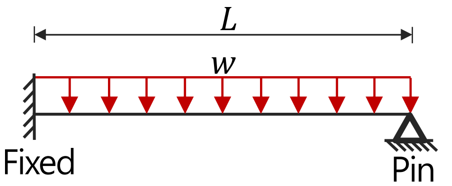
End of procedure

2. Design Procedure

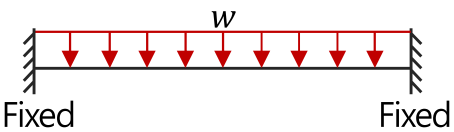
Step 2. Construction Stage (AISC 360-16 F. Design of members for flexure)

(4) Deflection (I3.1b. Strength during construction)

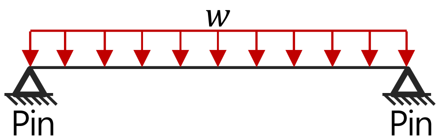
- **The self-weight of concrete for slab and beam, W_d and W_s, is considered as the applied load during concrete curing.**
- **Deflection**:



$$\delta_{const} = \frac{W_d B_{ay} + W_s}{185 E_s I_x} L^4 < \frac{L}{360}$$



$$\delta_{const} = \frac{W_d B_{ay} + W_s}{384 E_s I_x} L^4 < \frac{L}{360}$$



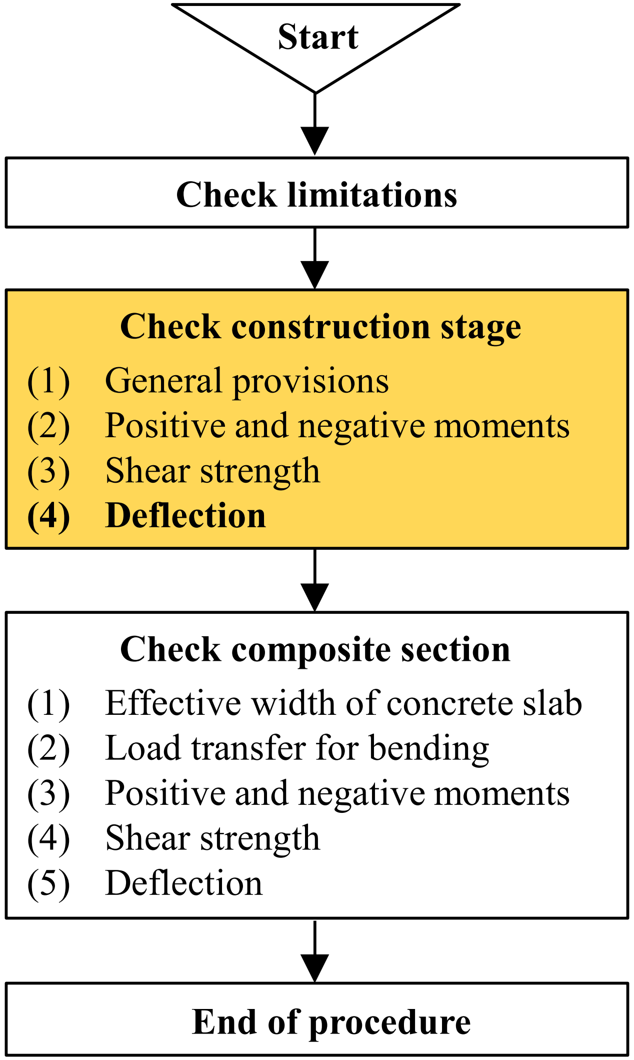
$$\delta_{const} = 5\frac{W_d B_{ay} + W_s}{384 E_s I_x} L^4 < \frac{L}{360}$$

- Live load: TSC beam weight W_s, Slab weight W_d

- The deflection limit for construction load (live load) is determined in accordance with IBC2016 Table 1604.3 Deflection limit as follows:

CONSTRUCTION	L	S or W[f]	D + L[d, g]
Roof members:[e]			
Supporting plaster or stucco ceiling	l/360	l/360	l/240
Supporting nonplaster ceiling	l/240	l/240	l/180
Not supporting ceiling	l/180	l/180	l/120
Floor members	l/360	—	l/240

Given: Beam geometry, required shear and moment strengths, deflection limit
Find: nominal shear and moment strengths, deflection for steel and composite sections



2. Design Procedure

Step 3. Check Composite Section (AISC 360-16 I. Design of composite members)

(1) Effective width of concrete slab (I3.1a.)

- The effective width of the concrete slab shall be the sum of the effective widths for each side of the beam centerlines, each of which shall not exceed:

(a) one-eight of the beam span, center-to-center of supports

(b) one-half the distance to the centerline of the adjacent beam

(c) the distance to the edge of the slab

(2) Load transfer for positive flexural strength (I.2d.1.)

- The nominal shear force between the steel beam and the concrete slab transferred by steel anchors, V', between the point of maximum positive moment and the point of zero moment shall be determined as the lowest value in accordance with the limit states of concrete crushing, tensile yielding of the steel section, or the shear strength of the steel anchors:

(a) Concrete crushing: $V' = 0.85 f_c' A_c$ (I3-1a)

(b) Tensile yielding of the steel section: $V' = F_y A_s$ (I3-1b)

(c) Shear strength of the steel headed stud or steel channel anchors: $V' = \sum Q_n$ (I3-1c)

Given: Beam geometry, required shear and moment strengths, deflection limit
Find: nominal shear and moment strengths, deflection for steel and composite sections

Start

Check limitations

Check construction stage
(1) General provisions
(2) Positive and negative moments
(3) Shear strength
(4) Deflection

Check composite section
(1) Effective width of concrete slab
(2) Load transfer for bending
(3) Positive and negative moments
(4) Shear strength
(5) Deflection

End of procedure

2. Design Procedure

Step 3. Check Composite Section (AISC 360-16 I. Design of composite members)

(2) Load transfer for negative flexural strength (I.2d.2.)

- In continuous composite beams where longitudinal reinforcing steel in the negative moment regions is considered to act compositely with the steel beam, the total horizontal shear between the point of maximum negative moment an the point of zero moment shall be determined as the lower in accordance with the following limit states:

  (a) For the limit state of tensile yielding of the slab reinforcement

  $V' = F_{ysr} A_{sr}$ (I3-2a)

  where, A_{sr} = area of developed longitudinal reinforcing steel within the effective width of the concrete slab

  (b) For the limit state of shear strength of steel headed stud, $V' = \sum Q_n$ (I3-2b)

(3) Flexural strength (I4 > **Filled composite members** > I4b.Flexural strength)

- The available flexural strength of filled composite members shall be determined as follows: $\Phi_b = 0.90$ (LRFD)

  The nominal flexural strength, Mn, shall be determined as follows:

  For compact sections $M_n = M_p$

  For noncompact sections $M_n = M_p - (M_p - M_y)(\lambda - \lambda_p)/(\lambda_r - \lambda_p)$

  For slender sections, M_n, shall be determined as the first yield moment. The compression flange stress shall be limited to the local buckling stress, F_{cr}.

Given: Beam geometry, required shear and moment strengths, deflection limit
Find: nominal shear and moment strengths, deflection for steel and composite sections

Start

↓

Check limitations

↓

Check construction stage
(1) General provisions
(2) Positive and negative moments
(3) Shear strength
(4) Deflection

↓

Check composite section
(1) Effective width of concrete slab
(2) Load transfer for bending
(3) Positive and negative moments
(4) Shear strength
(5) Deflection

↓

End of procedure

2. Design Procedure

Step 3. Check Composite Section (AISC 360-16 I. Design of composite members)

(3)-① Positive moment strength (I4. Filled Composite Members)

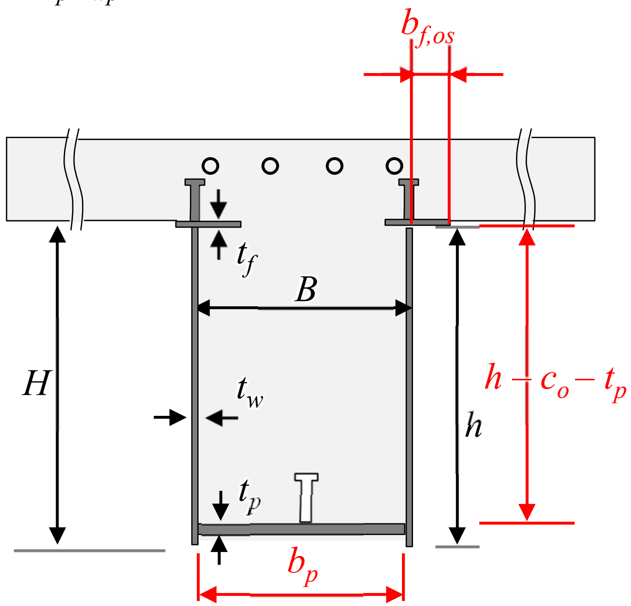
- The TSC beams are filled with concrete; thus the web and bottom flange sections are classified using limitations of width-to-thickness ratios of walls of rectangular Box sections specified in Table I1.1b.

(a) Top flange : width-to-thickness ratio $\lambda_{tf} = b_{f,os}/t_f$

- $\lambda_p \le 0.38\sqrt{E/F_y}$, $\lambda_r \le 1.00\sqrt{E/F_y}$ (Table B4.1b)

(b) Web and bottom flange ($\lambda_w = (h\text{-}c_o\text{-}t_p)/t_w$; $\lambda_{bf} = b_p/t_{wp}$)

- $\lambda \le 3.00\sqrt{E/F_y}$: Compact section
- $3.00\sqrt{E/F_y} < \lambda \le 5.70\sqrt{E/F_y}$: Noncompact section
- $\lambda > 5.70\sqrt{E/F_y}$: Slender section



Given: Beam geometry, required shear and moment strengths, deflection limit
Find: nominal shear and moment strengths, deflection for steel and composite sections

Start

Check limitations

Check construction stage
(1) General provisions
(2) Positive and negative moments
(3) Shear strength
(4) Deflection

Check composite section
(1) Effective width of concrete slab
(2) Load transfer for bending
(3) Positive and negative moments
(4) Shear strength
(5) Deflection

End of procedure

2. Design Procedure

Step 3. Check Composite Section (AISC 360-16 I. Design of composite members)

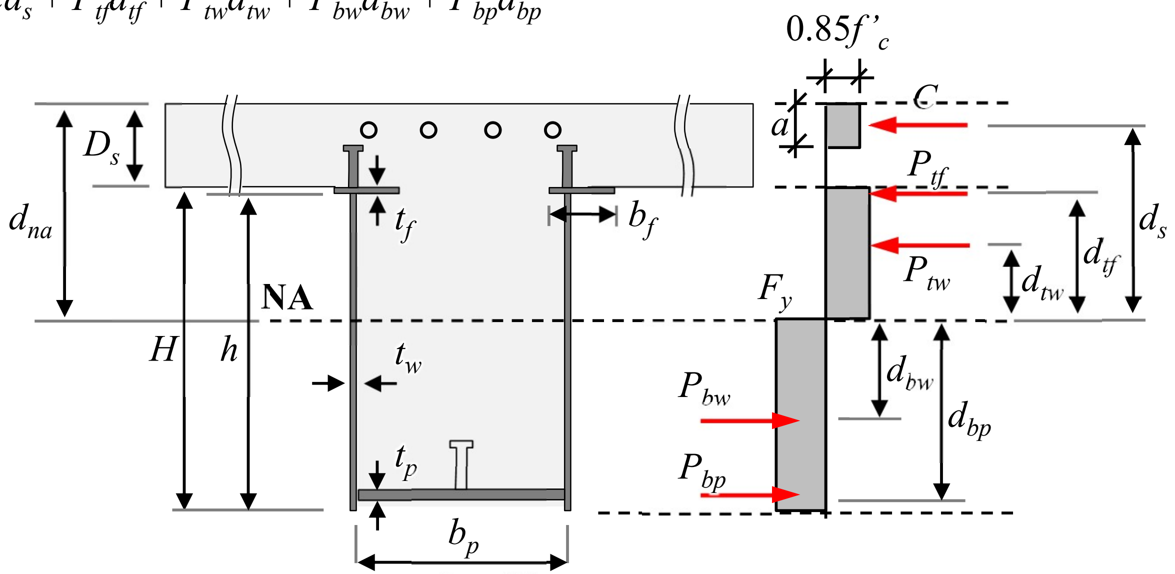
(3)-① Positive moment strength (I4b. Flexural strength)

- The compression force, C, in the concrete slab is smallest of: $C = A_sF_y$ (C-I3-6) $C = 0.85f_c'A_c$ (C-I3-7) $C = \sum Q_n$ (C-I3-8)
- Longitudinal slab reinforcement makes a negligible contribution to the compression force.
- The depth of the compression block is: $a = C/\left(0.85 f_c' B_{eff}\right)$
- The plastic stress distribution may have the plastic neutral axis, PNA, in the web, in the top flange of the steel section, or in the slab, depending on the governing C. In general, PNA of composite beam is located in the slab or top flange when the full composite action between slab and steel section can be expected. However, in the case of partial composite member (compression force governed by headed studs), PNA is located in the web.
- (Compact section) When PNA is located in the web, $M_p = Cd_s + P_{tf}d_{tf} + P_{tw}d_{tw} + P_{bw}d_{bw} + P_{bp}d_{bp}$

  - yield strength of the top flange $P_{tf} = 2\times F_y b_f t_f$
  - yield strength of the web in compression

    $P_{tw} = 2\times F_y(d_{na} - D_s - t_f)t_w$
  - yield strength of the web in tension

    $P_{bw} = 2\times F_y(H + D_s - d_{na})t_w$
  - yield strength of the bottom flange $P_{bp} = F_y b_p t_p$



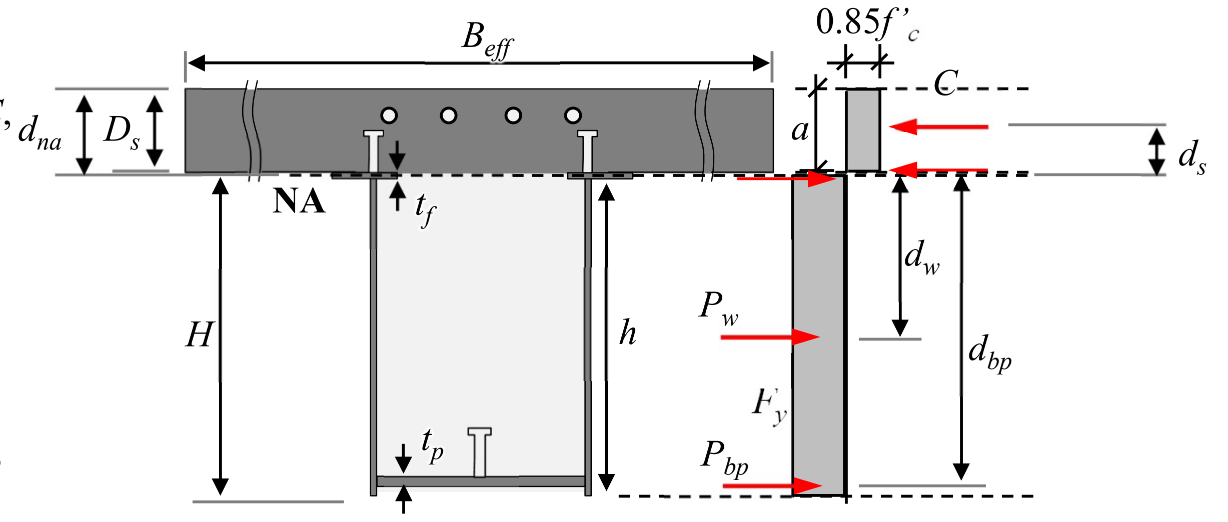
<Stress distribution when PNA is located in the web of TSC beam>

2. Design Procedure

Step 3. Check Composite Section (AISC 360-16 I. Design of composite members)

(3)-① Positive moment strength (I4b. Flexural strength)

- distance from the centroid of the compression force, C, in the concrete to NA; $d_s = d_{na} - 0.5a$
- distance from P_{tf} to NA; $d_{tf} = d_{na} - D_s - t_f/2$
- distance from P_{tw} to NA; $d_{tw} = (d_{na} - D_s - t_f)/2$
- distance from P_{bw} to NA; $d_{bw} = (H + D_s - d_{na})/2$
- distance from P_{bp} to NA; $d_{bp} = H + D_s - d_{na} - t_p/2 - c_o$



<Stress distribution when PNA is located in the top flange of TSC beam>

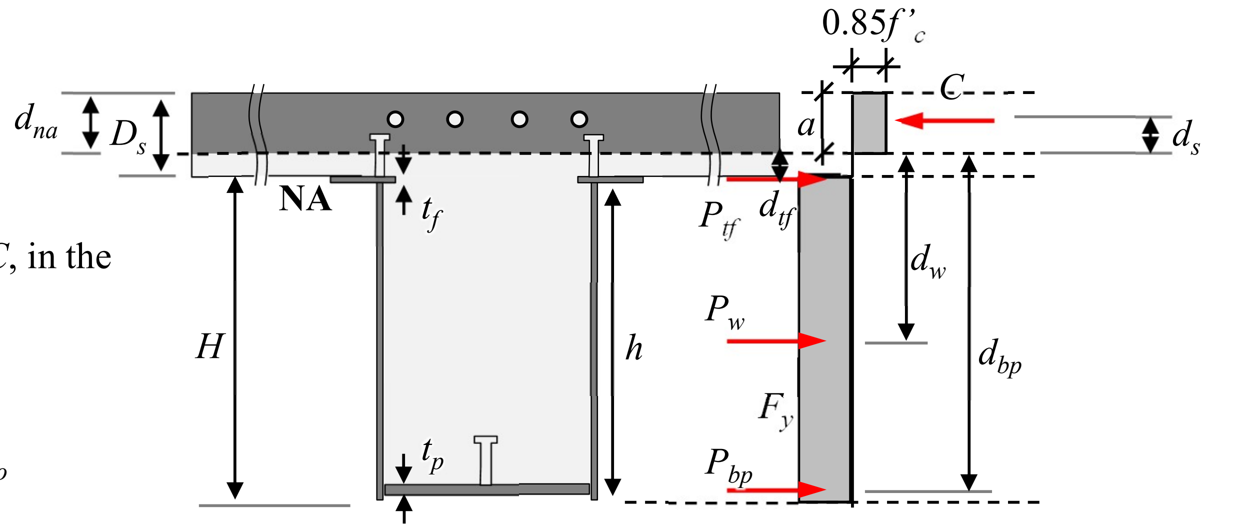
- When PNA is located in the top flange,

$$M_p = Cd_s + P_w d_w + P_{bp} d_{bp}$$

- yield strength of the entire section of web

$$P_w = 2 \times F_y h t_w$$

- yield strength of the bottom flange $P_{bp} = F_y b_p t_p$
- distance from the centroid of the compression force, C, in the concrete to NA; $d_s = d_{na} - 0.5a$
- distance from P_w to NA; $d_w = D_s + t_f + h/2 - d_{na}$
- distance from P_{bp} to NA; $d_{bp} = H + D_s - d_{na} - t_p/2 - c_o$



<Stress distribution when PNA is located in the slab of TSC beam>