Notation

- A_c : Area of concrete slab within effective width (= $D_s B_{eff}$), mm^2
- A_s : Area of steel section, mm^2
- A_{sa} : Cross-sectional area of steel headed stud anchor, mm^2
- A_{sr} : Area of developed longitudinal reinforcing steel within the effective width of the concrete slab, mm^2
- A_w : Area of web, the overall depth times the web thickness, mm^2
- B : Width of steel section; distance between outer faces of webs, mm
- B_{ay} : Distance between adjacent beams, mm
- B_{eff} : Effect width of slab, mm
- C : Compression force in the concrete slab, kN
- C_b : The lateral-torsional buckling modification factor, dimensionless
- C_f : Compression force in concrete slab for fully composite beam, kN
- C_v : The web shear strength coefficient, dimensionless
- C_y : Distance from the centroid of steel section to the outer surface of bottom flange, mm
- $C_{y,c}$: Distance from the centroid of composite section to the lower surface of bottom flange, mm
- C_{yp} : Distance from the center of mass to the outer surface of bottom flange, mm
- D_s : Depth of slab, mm
- D_{tr} : Distance from the centroid of top rebars to the top of the slab, mm
- E : Elastic modulus of the material, MPa
- E_c : Elastic modulus of concrete, MPa
- E_r : Elastic modulus of reinforcing bar, MPa
- E_s : Elastic modulus of steel, MPa
- F_{cr} : Lateral-torsional buckling stress for the section as determined by analysis, MPa
- $F_{cr,bp}$: Local buckling strength of bottom plate, MPa
- F_L : Nominal compressive strength above which the inelastic buckling limit states apply, MPa
- F_u : Specified minimum tensile strength of a steel headed stud anchor, MPa
- F_y : Yield strength of structural steel, MPa
- F_{yr}, f_{yr} : Yield strength of the slab reinforcements, MPa
- H : Overall height of steel (U-shaped) section, mm
- I_{equiv} : The equivalent moment of inertia of composite section, mm^4
- I_{tr} : Moment of inertia for the uncracked fully composite section , mm^4
- I_s : Moment of inertia for the structural section, mm^4
- I_x : Moment of inertia of steel section about the x-axis, mm^4
- I_y : Moment of inertial of steel section about the y-axis, mm^4
- I_{yc} : Moment of inertial of the compression flange about the y-axis, mm^4
- $I_{y,bf}$: Moment of inertia of the bottom flange about y-axis, mm^4
- $I_{y,tf}$: Moment of inertia of the top flanges about y-axis, mm^4
- $I_{y,w}$: Moment of inertia of the webs about the y-axis, mm^4

Notation

- J : Torsional constant, mm^4
- L : Length of beam, mm
- L_b : Length between points that are either braced against lateral of the compression flange or braced against twice of the cross section.
- L_p : The limiting laterally unbraced length for the limit state of yielding, mm
- L_r : The limiting unbraced length for the limit state of inelastic lateral-torsional buckling, mm
- M_A : Maximum absolute moment value at quarter point of the unbraced segment, kN-m
- M_B : Maximum absolute moment value at centerline of the unbraced segment, kN-m
- M_C : Maximum absolute moment value at three-quarter point of the unbraced segment, kN-m
- M_{cr} : Moment resistance corresponding to compression flange local buckling, kN-m
- M_{max} : Maximum absolute moment value in the unbraced segment, kN-m
- M_n : Nominal flexural strength, kN-m
- $M_{n,neg}$: Nominal flexural strength in negative bending, kN-m
- $M_{n,pos}$: Nominal flexural strength in positive bending, kN-m
- $M_{nc,pos1}$: Nominal moment for the compression flange yielding under positive bending, kN-m
- $M_{nc,pos3}$: Nominal moment for the tension flange yielding under positive bending, kN-m
- $M_{nc,pos4}$: Nominal moment for the lateral-torsional buckling under positive bending, kN-m
- $M_{nc,neg1}$: Nominal moment for the compression flange yielding under negative bending, kN-m
- $M_{nc,neg2}$: Nominal moment for the compression flange local buckling under negative bending, kN-m
- $M_{nc,neg3}$: Nominal moment for the tension flange yielding under negative bending, kN-m
- $M_{nc,neg4}$: Nominal moment for the lateral-torsional buckling under megative bending, kN-m
- M_p : plastic moment strength (= $F_y Z_x$), mm^4
- $M_{u,neg}$: Maximum required negative flexural strength, kN-m
- $M_{u,pos}$: Maximum positive flexural strength, kN-m
- M_y : Yield moment corresponding to yielding of the tension flange and first yield of the compression flange, kN-m
- M_{yc} : Yield moment in the compression flange, kN-m
- M_{yt} : Yield moment in the tensile flange, kN-m
- P_{bc} : Compressive strength of the bottom concrete, kN
- P_{bp} : Yield strength of the bottom flange, kN
- P_{bw} : Yield strength of the web in tension, kN
- P_{sh} : Shrinkage load, kN
- P_{slab} : Compressive force of the concrete slab, kN
- P_{sr} : Tensile yielding of the slab reinforcement, kN
- P_{steel} : Tensile yielding strength of the steel section, kN
- P_{tf}: Yield strength of the top flange, kN
- P_{tw} : Yield strength of the web in compression, kN

Notation

- P_w : Yield strength of the web, kN
- Q_n : Shear strength of the steel headed stud or steel channel anchor, kN
- R_g : Coefficient to account for group effect of shear studs, dimensionless
- R_m : Modifier for singly symmetric sections, dimensionless
- R_p : Position effect factor for shear studs, dimensionless
- R_{pc} : Web plastification factor corresponding to the compressive flange yielding limit state, dimensionless
- R_{pt} : Web plastification factor corresponding to the tension flange yielding limit state, dimensionless
- S_x : Elastic section modulus about the x-axis, mm^3
- $S_{x,bf}$: Elastic section modulus referred to bottom flange (= I_x / C_y), mm^3
- S_{xc} : Elastic section modulus referred to the compressive flange, mm^3
- S_{xt} : Elastic section modulus referred to the tensile flange [=I_x /(H – C_y)], mm^3
- $S_{x,tf}$: Elastic section modulus referred to top flange [=I_x /(H – C_y)], mm^3
- T : Tensile force in beam section, kN
- V_n : Nominal shear strength, kN
- $V_{q,neg}$: Shear force between the steel beam and the concrete slab transferred by steel anchors, in the region of beam carrying negative moment, kN
- $V_{q,pos}$: Shear force between the steel beam and the concrete slab transferred by steel anchors, in the region of beam carrying positive moment, kN
- V_{stud} : Shear strength of steel headed studs, kN
- V_u : Maximum required shear strength, kN
- V' : The nominal shear force between the steel beam and the concrete slab transferred by steel anchors, kN
- W_d : Self-weight of the TSC beam, kN/m
- W_f : Superimposed load, kN/m^2
- W_l : Live load, kN/m^2
- W_s : Self-weight of the concrete slab, kN/m^2
- Z_x : Plastic section modulus of steel section, mm^3
- a : Depth of the compression block in the concrete slab, mm
- a_w : Ratio of two times the web area in compression due to application of major axis bending moment alone to the area of the compression flange components, dimensionless
- b_f: Width of the top flange, mm
- b_{fc} : Width of the compression flange, mm
- $b_{f,in}$: Width of inner top flange, mm
- $b_{f,ou\,t}$: Width of outer top flange, mm
- b_p : Width of the bottom flange, mm
- d_{bp} : Distance from P_{bp} to NA, mm
- d_{bw} : Distance from P_{bw} to NA, mm
- d_{co} : Distance between the slab surface and the center of the longitudinal slab reinforcements, mm
- d_{na} : Distance from NA to the top of the slab, mm
- d_{rb} : Distance from T to NA, mm
- d_s : Distance from the centroid of the compression force C, in the concrete to NA (= d_{pna} – 0.5a), mm

Notation

- d_{tf} : Distance from P_{tf} to NA, mm
- d_{tw} : Distance from P_{tw} to NA, mm
- d_w : Distance from P_w to NA, mm
- f_{ck} : Compressive strength of concrete, MPa
- f'_c : Specified compressive strength of concrete, MPa
- h : height of the web plate, mm
- h_o : Distance between flange centroids, mm
- h_s : Height of the stud, mm
- k_c : Coefficient for slender unstiffened elements, dimensionless
- k_v : Coefficient of plate shear buckling, dimensionless
- l_{neg} : Negative moment region
- l_{pos} : Positive moment region
- $n_{s,neg}$: The number of shear studs in the region of beam carrying negative moment, dimensionless (EA)
- $n_{s,pos}$: The number of shear studs in the region of beam carrying positive moment, dimensionless (EA)
- r_t : Effective radius of gyration for lateral-torsional buckling, mm
- t_f : Thickness of the top flange, mm
- t_p : Thickness of the bottom flange, mm
- t_w : Thickness of the web, mm
- w_c : Weight of concrete per unit volume, kN/m^3
- δ_{add} : Additional deflection after concrete curing, mm
- δ_{comst} : Short-term deflection of the composite TSC beam (= δ_{const} + δ_{add}), mm
- δ_{const} : Deflection caused by load combination considered in construction stage, mm
- ϕ_b : The reduction factor for the design flexural strength (= 0.90), dimensionless
- ϕ_v : The reduction factor for the design shear strength (= 0.90), dimensionless
- λ : Width-to-thickness ratio of the element, dimensionless
- λ_{bp} : Width-to-thickness ratio of bottom plate, dimensionless
- λ_{pf} : The limiting slenderness parameter for compact flange, dimensionless
- λ_{pw} : The limiting slenderness parameter for compact web, dimensionless
- λ_{rf} : The limiting slenderness parameter for non-compact flange, dimensionless
- λ_{rw} : The limiting slenderness parameter for non-compact web, dimensionless
- λ_{tf} : Width-to-thickness ratio of top flange, dimensionless
- λ_w : Width-to-thickness ratio of web, dimensionless

2. Design Procedure

Design guide of the TSC beam according to AISC 360-16

Design	Category	Chapter	Provision
General provisions	U-shaped steel section	Chapter B.	B.4.1. Classification of sections for local buckling
	Composite section	Chapter I.	I.1.3. Material limitations I.1.4 Classification of **filled composite sections** for local buckling
Flexure	U-shaped steel section	Chapter F.	F1. General provisions F4. Other I-shaped members with compact or noncompact webs bent about their major axis F5. Doubly and symmetric and singly symmetric I-shaped members with slender webs about their major axis
	Composite section	Chapter I.	I3.1 General I.3.2c Composite beams with formed steel deck I.3.2d **Load transfer between steel beam and concrete slab** I.3.4 **Filled composite members** > 4b. Flexural strength
Shear	U-shaped steel section	Chapter G.	G1. General provisions G4. I-shaped members and channels
	Composite section	Chapter I.	I4.1 Filled and encased composite members
Deflection	U-shaped steel section	Chapter I.	I3.1b Strength during construction *Comment I3.2*
	Composite section		

Section Properties of the TSC beam

- U-shaped steel section without concrete infill

  - Area of steel section $A_s = 2b_f t_f + 2ht_w + b_p t_p$, mm^2

  - Distance from the centroid of steel section to the outer surface of bottom flange, mm

$$C_y = \frac{2b_f t_f \times (H - t_f/2) + 2ht_w \times (h/2) + b_p t_p \times (t_p/2 + c_o)}{A_s}$$

  - Moment of inertia of steel section about the x-axis, mm^4

$$I_x = 2\left\{\frac{b_f}{12} t_f^{\,3} + b_f t_f \left(H - C_y - t_f/2\right)^2\right\} + 2\left\{\frac{t_w}{12} h^3 + t_w h \left(h/2 - C_y\right)^2\right\}$$
$$+\left\{\frac{b_p}{12} t_p^{\,3} + b_p t_p \left(C_y - t_p/2 - c_o\right)^2\right\}$$

  - Elastic section modulus referred to bottom flange $S_{x,bf} = I_x/(C_y - c_o)$, mm^3

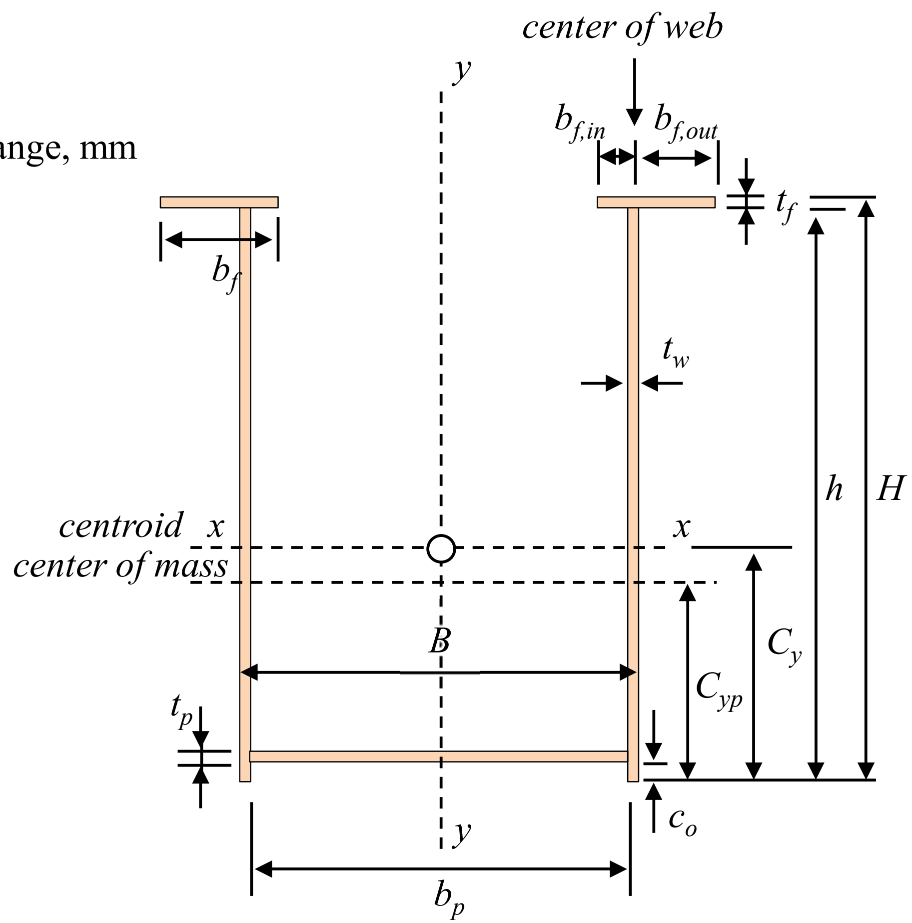
  - Elastic section modulus referred to top flange $S_{x,tf} = I_x/(H - C_y)$, mm^3

  - Distance from the center of mass to the outer surface of bottom flange, mm

$$C_{yp} = \frac{(A_s/2 - t_p b_p)}{2t_w}$$

  - Plastic section modulus

$$Z_x = 2b_f t_f \times (H - C_{yp} - t_f/2) + 2(h - C_{yp}) t_w \times (h - C_{yp})/2 + 2t_w C_{yp} \times C_{yp}/2 + b_p t_p \times (C_{yp} - t_p/2 - c_o)$$



2. Design Procedure

Section Properties of the TSC beam

- U-shaped steel section without concrete infill

  - Moment of inertia of the top flange about the y-axis $I_{y,tf} = 2\left\{\frac{t_f}{12}b_f^3 + b_f t_f\left(B/2 + t_w/2 + b_{f,out} - b_f/2\right)^2\right\}$

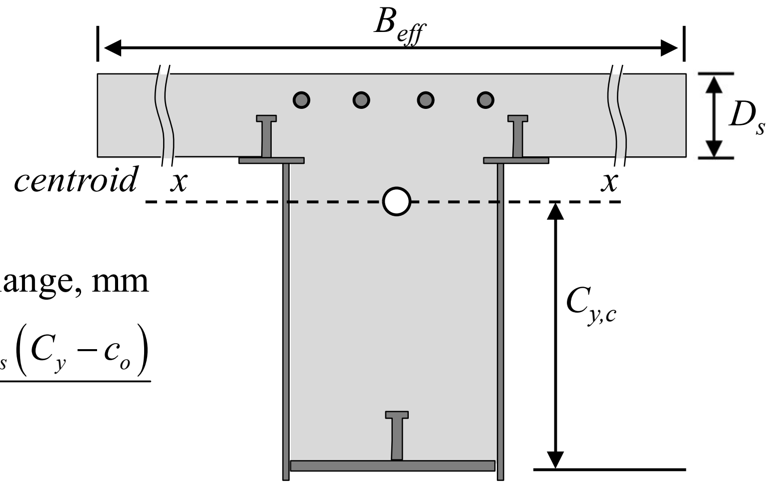
  - Moment of inertia of the web about the y-axis $I_{y,w} = 2\left\{\frac{h}{12}t_w^3 + ht_w\left(B/2 - t_w/2\right)^2\right\}$

  - Moment of inertia of the bottom flange about the y-axis $I_{y,bf} = \frac{t_p}{12}b_p^3$ - Moment of inertia about the y-axis $I_y = I_{y,tf} + I_{y,w} + I_{y,bf}$

  - Torsional constant $J = \frac{1}{3}\left[2ht_w^3 + 2b_f t_f^3 + b_p t_p^3\right]$

  - Width-to-thickness ratio of top flange $\lambda_{tf} = \frac{\max\{b_{f,out}, b_{f,in}\}}{t_f}$ - Width-to-thickness ratio of web $\lambda_w = \frac{h}{t_w} = \frac{H - t_f - t_p}{t_w}$

  - Width-to-thickness ratio of bottom flange $\lambda_{bf} = \frac{b_p}{t_p}$



- U-shaped steel section with concrete infill

  - Area of slab reinforcements A_{sr}

  - Distance from the centroid of composite section to the outer surface of bottom flange, mm

$$C_{y,c} = \frac{B_{eff}D_s E_c/E_s \times \left(H + D_s/2 - c_o\right) + b_p\left(h - c_o - t_p\right)E_c/E_s \times \left(h/2 - c_o/2\right) + A_s\left(C_y - c_o\right)}{B_{eff}D_s E_c/E_s + b_p\left(h - c_o - t_p\right)E_c/E_s + A_s}$$

  - Moment of inertia for the fully composite uncracked transformed section

$$I_{tr} = B_{eff}D_s E_c/E_s \times \left(H + D_s/2 - C_{y,c}\right)^2 + b_p\left(h - c_o - t_p\right)E_c/E_s \times \left(\left(h - c_o - t_p\right)/2 + t_p - C_{y,c}\right)^2 + A_s \times \left(C_y - C_{y,c}\right)^2$$

2. Design Procedure

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Step 1. Check Limitations (AISC 360-16)

- Material limitations (I1.3.)

  - The compressive strength of concrete: 21 MPa $\leq f_{ck} \leq$ 69 MPa

  - The yield strength of structural steel: $F_y \leq$ 525 MPa

  - The yield strength of reinforcing bars: $F_{yr} \leq$ 550 MPa

- (Construction stage) Classification of steel sections for local buckling

  - Flanges of singly symmetric I-shaped built-up sections (B4 > Table B4.1b > Case 12)

  - Webs of singly symmetric I-shaped sections (B4 > Table B4.1b > Case 16)

- (Composite section) Classification of filled composite sections for local buckling (I4 > Table I1.1b)

- Composite beams with formed steel deck (I3 > 2c.)

  - The concrete slab shall be connected to the steel beam with steel headed stud anchors welded either through the deck or directly to the steel cross section.

  - Steel headed stud anchors, after installation, shall extend not less than <u>38 mm above the top of the steel deck</u> and there shall be at least <u>13 mm of specified concrete cover above the top of the steel headed stud anchors</u>.

  - <u>The slab thickness above the steel deck shall be not less than 50 mm</u>.

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

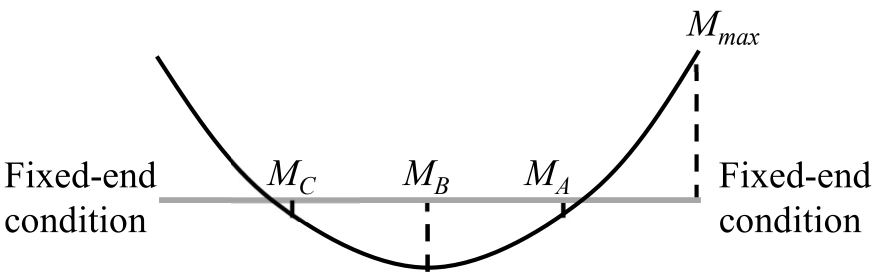
Step 2. Construction Stage (AISC 360-16 F. Design of members for flexure)

(1) General provisions(F1.)

- The reduction factor for the design flexural strength $\Phi_b = 0.9$
- **The lateral-torsional buckling modification factor** for single symmetric sections in single and reverse curvature.(C-F1-3)

$$C_b = \left(\frac{12.5M_{\max}}{2.5M_{\max} + 3M_A + 4M_B + 3M_C} \right) R_M \leq 3.0$$

- M_{max} = Absolute value of moment in the unbraced segment
- M_A = Absolute value of moment at quarter point of the unbraced segment
- M_B = Absolute value of moment at centerline of the unbraced segment
- M_C = Absolute value of moment at three-quarter point of the unbraced segment
- For single curvature bending, $R_m = 1.0$
- For reverse curvature bending, $R_m = 0.5 + 2\left(I_{y,tf} / I_y\right)^2$ (C-F1-4)



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

- The flexural capacity of U-shaped steel section is computed according to **F4 (singly symmetric I-shaped members with compact and noncompact webs)** and **F5 (singly symmetric I-shaped members with slender webs)**
- **The nominal flexural strength, M_n,** shall be the lowest value obtained according to the limit states of <u>compression flange yielding, lateral-torsional buckling, compression flange local buckling, and tension flange yielding</u>.
- The top flanges and webs are compression members under positive bending.
- The bottom flanges and webs are compression members under negative bending.
- **Compression flange yielding $M_n = R_{pc} M_{yc}$**

  - Yield moment in the compression flange $M_{yc} = F_y S_{xc}$ (F4-1)

  - The web plastification factor R_{pc} is determined as follows:

  when $I_{yc}/I_y > 0.23$

  when $h_c/t_w \le \lambda_{pw}$, $R_{pc} = M_p/M_{yc}$ (F4-9a)

  when $h_c/t_w > \lambda_{pw}$, $R_{pc} = \left[\dfrac{M_p}{M_{yc}} - \left(\dfrac{M_p}{M_{yc}} - 1\right)\left(\dfrac{\lambda - \lambda_{pw}}{\lambda_{rw} - \lambda_{pw}}\right)\right] \le \dfrac{M_p}{M_{yc}}$ (F4-9b)

  when $I_{yc}/I_y \le 0.23$

  $R_{pc} = 1.0$ (F4-10) where $M_p = F_y Z_x \le 1.6 F_y S_x$

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