

# 2. Design Procedure

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

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

- When PNA is located in the concrete slab,

$$M_p = Cd_s + P_{tf}d_{tf} + P_wd_w + P_{bp}d_{bp}$$

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

- 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;  $d_s = 0.5a$

### (3)-①\* Positive moment strength (I4b. Flexural strength)

- Yield strength  $M_y$  for noncompact section;

$$M_y = Cd_s + P_{tf}d_{tf} + P_{tw}d_{tw} + P_{bw}d_{bw} + P_{bp}d_{bp}$$

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

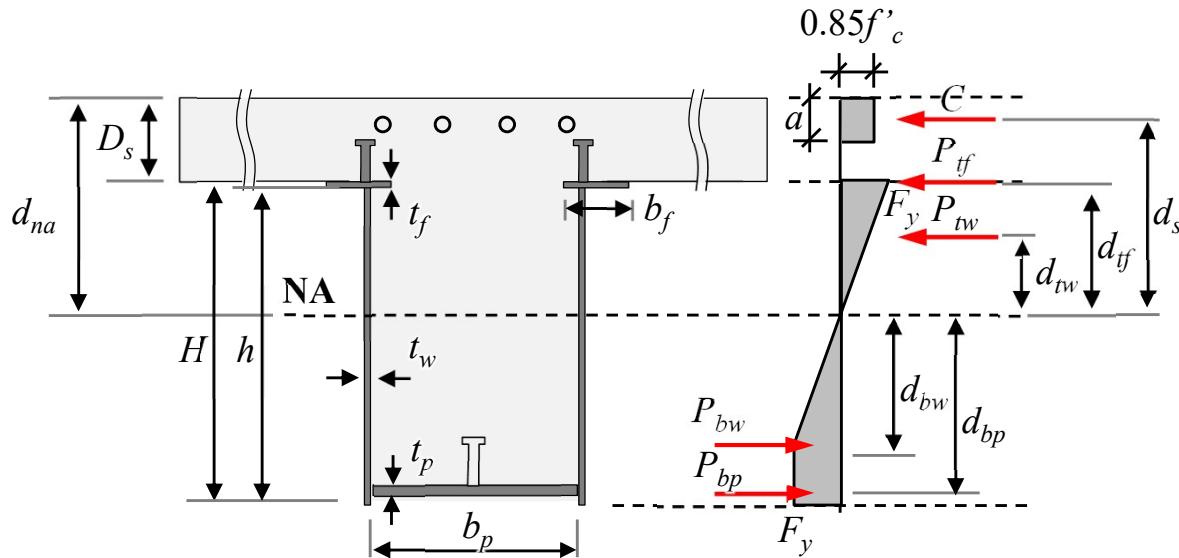
- yield strength of the top web

$$P_{tw} = 2 \times 0.5 \times F_y (d_{na} - D_s - t_f) t_w$$

- yield strength of the bottom web

$$P_{bw} = 2 \times 0.5 \times F_y (d_{na} - D_s - t_f) t_w + 2 \times F_y [(H + D_s - d_{na}) - (d_{na} - D_s - t_f)] t_w$$

- yield strength of the bottom flange  $P_{bp} = b_p t_p F_y$



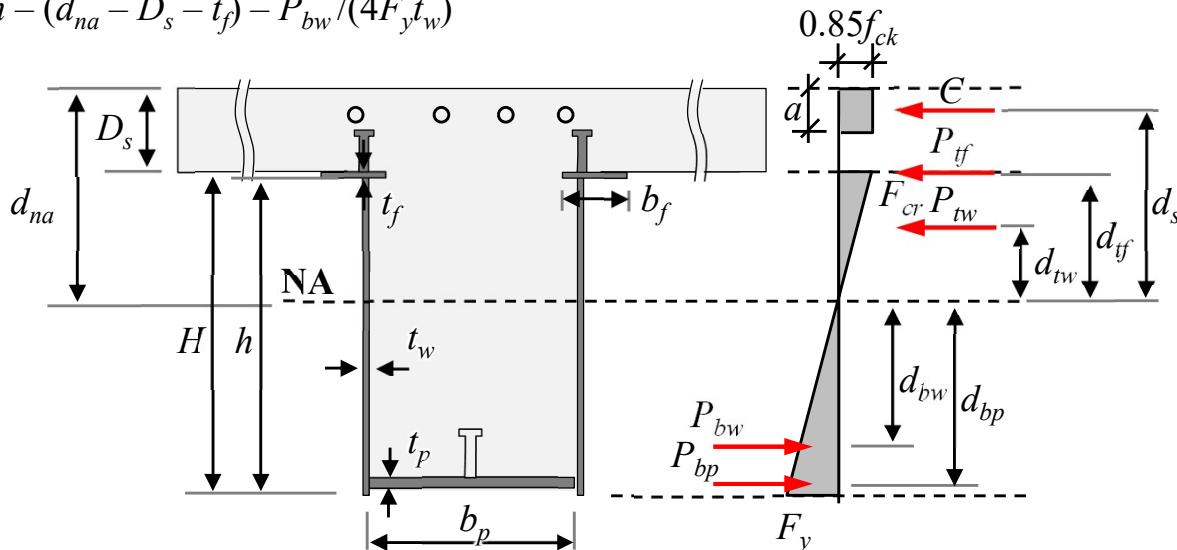
<Stress distributions for calculating  $M_y$  - Noncompact section>

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### (3)-①\* Positive moment strength (I4b. Flexural strength)

- distance from the centroid of the compression force,  $C$ , in the concrete to PNA;  $d_s = d_{na} - 0.5a$
  - distance from  $P_{tf}$  to NA;  $d_{tf} = d_{na} - D_s - t_f/2$
  - distance from  $P_{tw}$  to NA;  $d_{tw} = 2/3 \times (d_{na} - D_s - t_f)$
  - distance from the center of web tension to PNA;  $d_{bw} = h - (d_{na} - D_s - t_f) - P_{bw}/(4F_y t_w)$
  - distance from  $P_{bp}$  to NA;  $d_{bp} = H + D_s - d_{na} - t_p/2 - c_o$
  - First yield strength  $M_{cr}$  for slender section;
- $$M_{cr} = Cd_s + P_{tf}d_{tf} + P_{tw}d_{tw} + P_{bw}d_{bw} + P_{bp}d_{bp}$$
- yield strength of the top flange  $P_{tf} = 2 \times F_{cr} b_f t_f$
  - yield strength of the top web in compression
- $$P_{tw} = F_{cr} (d_{na} - D_s - t_f) t_w$$
- yield strength of the top web in tension
- $$P_{bw} = F_y (H + D_s - d_{na}) t_w$$
- 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  $P_{tf}$  to NA;  $d_{tf} = d_{na} - D_s - t_f/2$
  - distance from  $P_{tw}$  to NA;  $d_{tw} = 2(d_{na} - D_s - t_f)/3$
  - distance from  $P_{bw}$  to NA;  $d_{bw} = 2(H + D_s - d_{na})/3$
  - distance from  $P_{bp}$  to NA;  $d_{bp} = H + D_s - d_{na} - t_p/2 - c_o$



<Stress distributions for first yield moment,  $M_{cr}$  – Slender section>

# 2. Design Procedure

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

### (3)-② Negative moment strength (I4b. Flexural strength)

- This section applies to three types of composite members subject to flexure: composite beams with steel anchors consisting of steel headed stud anchors or steel channel anchors, concrete encased members, and **concrete filled members**. (I3. Flexure)
- When an adequately braced **compact steel section** and adequately developed longitudinal reinforcing bars act compositely in the negative moment region, the nominal flexural strength is determined from the **plastic distribution**. (comment 2b. Negative flexural strength)
- Compact section classification** of TSC webs and bottom flange under compression:

$$(\text{Web}) \quad h/t_w \leq 3.00\sqrt{E/F_y} \quad (\text{bottom flange}) \quad b/t_p \leq 2.26\sqrt{E/F_y}$$

- The tensile force,  $T$ , in the reinforcing bars is the smaller of:  $T = F_{yr}A_r$  (C-I3-11),  $T = \sum Q_n$  (C-I3-12) where,  $A_r$  = area of properly developed slab reinforcement parallel to the steel beam and within the effective width of the slab,  $F_{yr}$  = specified minimum yield stress of the slab reinforcement,  $\sum Q_n$  = sum of the nominal strengths of steel headed anchors between the point of maximum negative moment and the point of zero moment to either side.

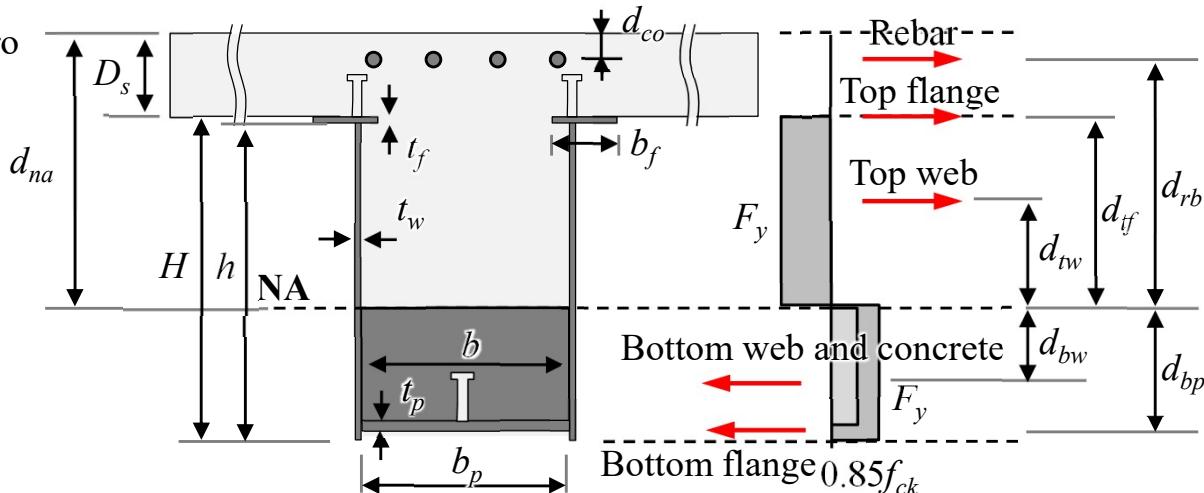
- For the compact section,

$$M_p = Td_{rb} + P_{tf}d_{tf} + P_{tw}d_{tw} + P_{bw}d_{bw} + P_{bc}d_{bw} + P_{bp}d_{bp}$$

- tensile force  $T = \min\{F_{yr}A_r, \sum Q_n\}$

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

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



# 2. Design Procedure

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

### (3)-② Negative moment strength (I4b. Flexural strength)

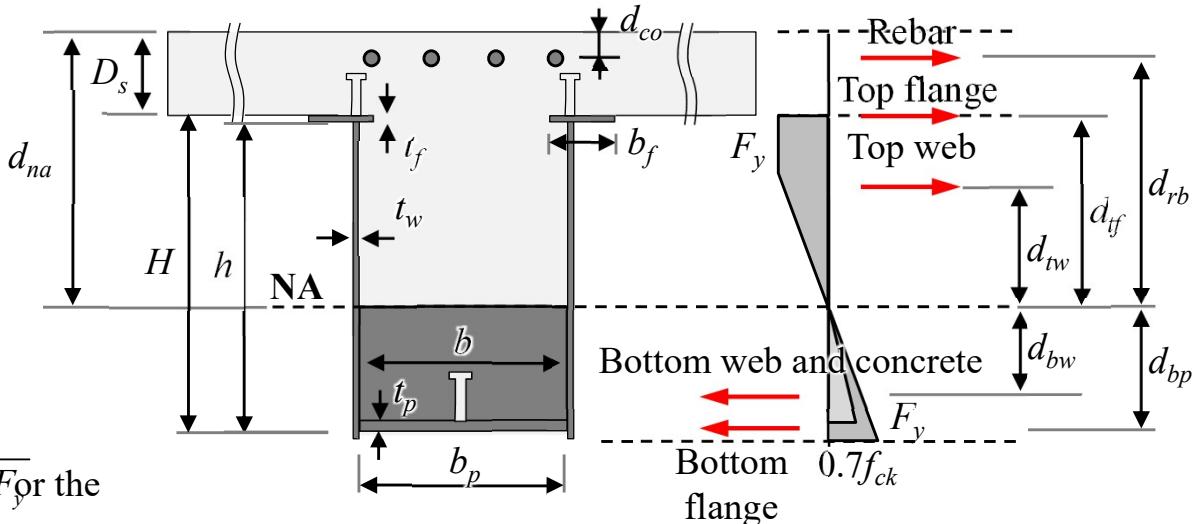
- Yield strength of bottom web  $P_{bw} = 2 \times F_y (H + D_s - d_{na}) t_w$
- Compressive strength bottom concrete  $P_{bc} = 0.85 f'_c (H + D_s - d_{na}) b$
- Yield strength of bottom flange  $P_{bp} = F_y b_p t_p$
- Distance from T to NA;  $d_{rb} = d_{na} - d_{co}$
- Distance from  $P_{tf}$  to NA;  $d_{tf} = d_{na} - D_s - 0.5t_f$
- 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  $P_{bc}$  to NA;  $d_{bw} = (H + D_s - d_{na} - t_p - c_o)/2$
- Distance from  $P_{bp}$  to NA;  $d_{bp} = H + D_s - d_{na} - 0.5t_p - c_o$

### (3)-②\* Negative moment strengths for noncompact and slender sections

- Width-to-thickness ratio of webs (table I1.1b)
 
$$3.00\sqrt{E/F_y} < h/t_w \leq 5.70\sqrt{E/F_y} \rightarrow \text{Noncompact s.}$$

$$5.70\sqrt{E/F_y} < h/t_w \rightarrow \text{Slender section}$$
- Width-to-thickness ratio of bottom flange (table I1.1b)
 
$$2.26\sqrt{E/F_y} < b/t_p \leq 3.00\sqrt{E/F_y} \rightarrow \text{Noncompact s.}$$

$$3.00\sqrt{E/F_y} < b/t_p \rightarrow \text{Slender section}$$
- If the width-to-thickness ratio of webs  $h/t_w > 3.00\sqrt{E/F_y}$  or the bottom flange is classified as noncompact section,  $M_n$  is determined from the elastic stresses, considering yield moment  $M_y$ .
- If the bottom flange is classified as slender section,  $M_n$  is determined from the elastic stresses, considering first buckling strength moment  $M_{cr}$ .



<Stress distribution for calculating  $M_y$ >

# 2. Design Procedure

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

(3)-②\* Negative moment strengths for noncompact and slender sections

- (Noncompact section) Yield strength  $M_y = Td_{rb} + P_{tf}d_{tf} + P_{tw}d_{tw} + P_{bw}d_{bw} + P_{bc}d_{bw} + P_{bp}d_{bp}$ 
  - tensile force  $T = \min\{F_{yr}A_r, \sum Q_n\}$
  - Yield strength of the top web  $P_{tw} = 2F_y(d_{na} - D_s - t_f - d_{bp})t_w + F_yd_{bf}t_w$
  - yield strength of the top flange  $P_{tf} = 2 \times F_y b_f t_f$
  - Yield strength of the bottom web  $P_{bw} = F_y(d_{bp} - t_p / 2)t_w$
  - Compressive strength of bottom concrete  $P_{bc} = 0.7f_{ck}(d_{bp} - t_p / 2)b / 2$
  - Yield strength of the bottom flange  $P_{bp} = F_y b_p t_p$
  - Distance from  $T$  to NA;  $d_{rb} = d_{na} - d_{co}$
  - Distance from  $P_{tf}$  to NA;  $d_{tf} = d_{na} - D_s - t_f / 2$
  - Distance from  $P_{tw}$  to NA;  $d_{tw} = d_{na} - D_s - t_f - P_{tw} / (4F_y t_w)$
  - Distance from  $P_{bw}$  to NA;  $d_{bw} = 2/3(H + D_s - d_{na})$
  - Distance from  $P_{bc}$  to NA;  $d_{bc} = 2/3(H + D_s - d_{na} - c_o - t_p)$
  - Distance from  $P_{bf}$  and to NA;  $d_{bp} = H + D_s - t_p / 2 - d_{na} - c_o$

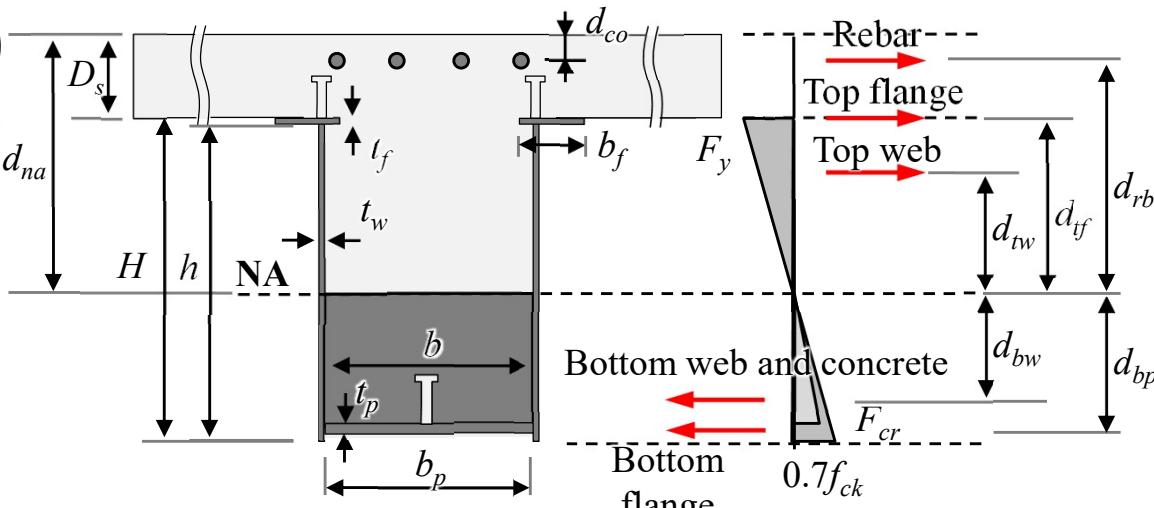
- (Slender section) First yield strength

$$M_{cr} = Td_{rb} + P_{tf}d_{tf} + P_{tw}d_{tw} + P_{bw}d_{bw} + P_{bc}d_{bw} + P_{bp}d_{bp}$$

- Critical buckling strength of bottom flange (I2-10; buckling strength for rectangular filled section)  $F_{cr,bf} = 9E_s / (b/t_p)^2$

- Tensile force  $T = \min\{F_{yr}A_r, \sum Q_n\}$

- Yield strength of the top flange  $P_{tf} = 2 \times F_y b_f t_f$



<Stress distribution for slender section>

# 2. Design Procedure

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

(3)-②\* Negative moment strengths for noncompact and slender sections

- (Slender section) First yield strength

- Yield strength of the top web  $P_{tw} = F_y(d_{na} - D_s - t_f)t_w$

- Yield strength of the bottom web  $P_{bw} = F_{cr}(H + D_s - d_{na})t_w$

- Compressive strength of the concrete  $P_{bc} = 0.7f_{ck}b(H + D_s - d_{na} - c_o - t_p)/2$

- Yield strength of the bottom flange  $P_{bf} = F_{cr}b_p t_p$

- Distance from  $T$  to NA;  $d_{rb} = d_{na} - d_{co}$

- Distance from  $P_{tf}$  to NA;  $d_{tf} = d_{na} - D_s - t_f / 2$

- Distance from  $P_{tw}$  to NA;  $d_{tw} = 2/3(d_{na} - D_s - t_f)$

- Distance from  $P_{bw}$  to NA;  $d_{bw} = 2/3(H + D_s - d_{na})$

- Distance from  $P_{bc}$  to NA;  $d_{bw} = 2/3(H + D_s - d_{na} - c_o - t_p)$

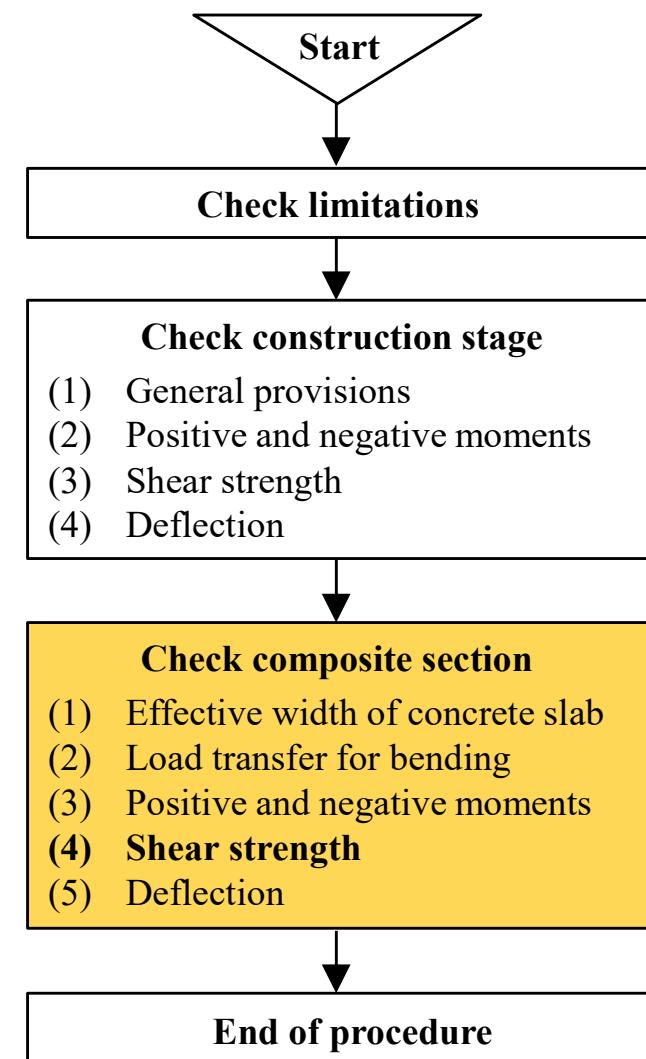
- Distance from  $P_{bf}$  to NA;  $d_{bp} = H + D_s - t_p / 2 - d_{na}$

(4) The nominal shear strength (I.4.2. Composite beams with formed steel deck)

- The design shear strength  $\Phi_v V_n$  shall be determined based on the available shear strength of steel section alone as specified in Chapter G.
  - The nominal shear strength,  $V_n$ , is:  $V_n = 0.6F_yA_wC_v$

**Given:** Beam geometry, required shear and moment strengths, deflection limit

**Find:** nominal shear and moment strengths, deflection for steel and composite sections



# **3. Example (Calculation sheet TG1)**

# 3. Calculation sheet (TG1)

## 1. Design Conditions > 1.1 Material Properties

- Steel plate for SM355 grade
  - Specified yield strength of steel plate  $F_y = 355$  MPa
  - Modulus of elasticity  $E_s = 210000$  MPa

(KS D 3515) SM490A-Rolled steels for welded structures similar to A572 GR. 50

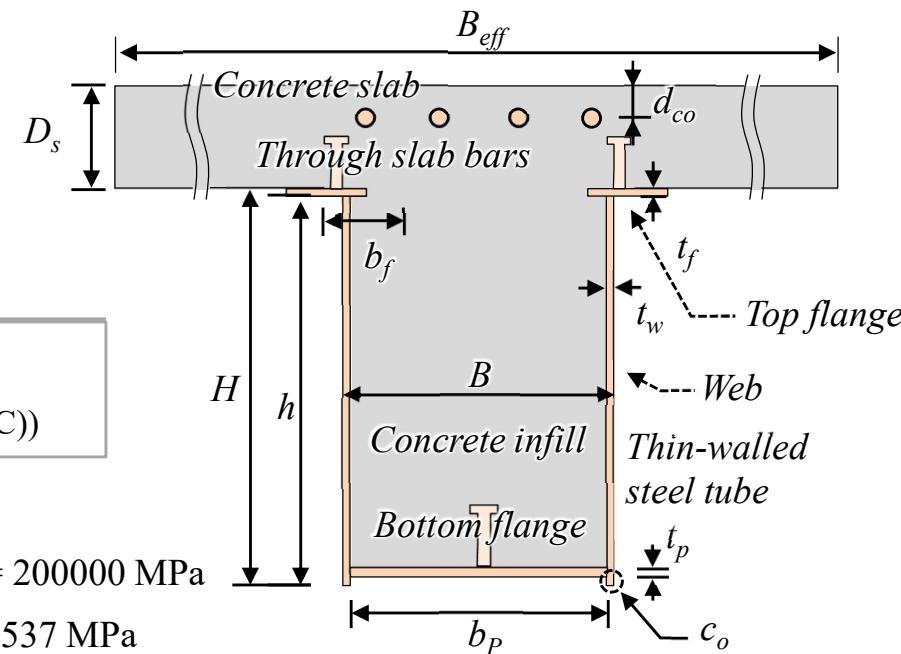
- SM: Steel marine (plate/rolled H); 490: Tensile strength; A: CVN grade ( $\geq 27J(20^\circ C)$ )

- Headed stud anchor (shear connector): Tensile strength  $F_u = 400$  MPa
- Reinforcement bar: Yield strength  $F_{yr} = 600$  MPa; Modulus of elasticity  $E_r = 200000$  MPa
- Concrete : Compressive strength  $f_{ck} = 30$  MPa, Modulus of elasticity  $E_c = 27537$  MPa

$$(\text{AISC 360-16}) E_c = 0.043 w_c^{1.5} \sqrt{f'_c} = 13682 \sim 29440 \text{ MPa}$$

where  $f'_c$  = specified compressive strength of concrete (30 MPa) and  $w_c$  = weight of concrete per unit volume ( $1500 \leq w_c \leq 2500 \text{ kg/m}^3$ )

(AISC 360-16; I1.3 Material limitations) For the determination of the available strength, concrete shall have a compressive strength,  $f'_c$ , of not less than 21 MPa nor more than 69 MPa for normal weight concrete.



## 1. Design Conditions > 1.2 TSC Beam Conditions

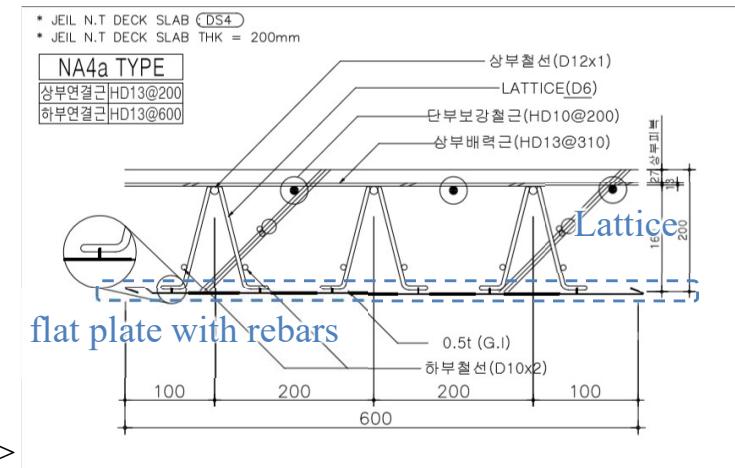
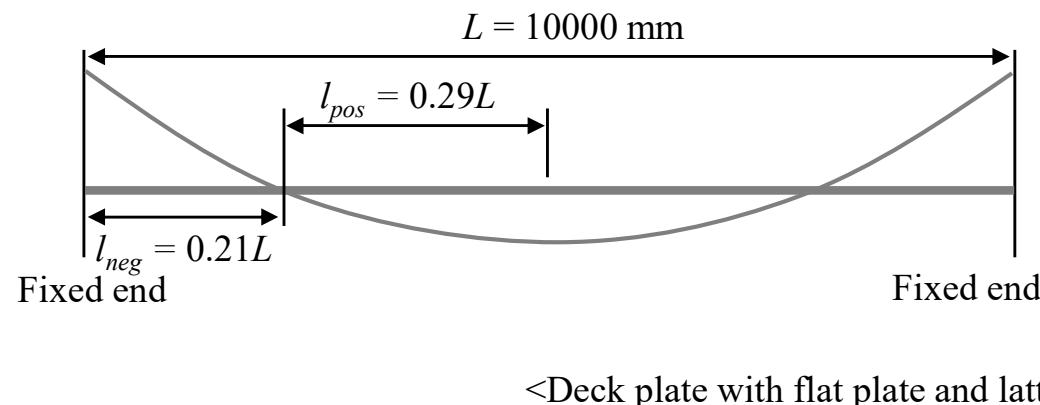
- Dimensions: U-600×400×9×12;  $H = 600$  mm;  $B = 400$  mm;  $b_f = 120$  mm;  $b_p = 382$  mm;  $t_f = 9$  mm;  $t_w = 9$  mm,  $t_p = 12$  mm,  $c_o = 15$  mm
- Top slab bars: 4-D25 ( $A_{sr} = 1962 \text{ mm}^2$ ); concrete cover  $d_{co} = 40$  mm
- Slab thickness  $D_s = 200$  mm
- Beam length  $L = 10000$  mm; Beam spacing  $B_{ay} = 3000$  mm

# 3. Calculation sheet (TG1)

## ■ 1. Design Conditions > 1.1 Material Properties > (3) Shear connector

- Shear connector: 2Row- $\Phi 19@200$ ; height of the stud  $h_s = 80$  mm;  $D_{snet} - h_s = 120$  mm

→ spacing 200 mm >  $6 \times d_h$



AISC 360-16 > I8. Steel anchors > 2. Steel anchors in composite beams > 2d. Detailing requirements

- Steel anchors required on each side of the point of maximum bending moment, positive or negative, shall be distributed uniformly between that point and the adjacent points of zero moment.
- The minimum distance from the center of a steel anchor to a free edge in the direction of the shear force shall be 200 mm (normal weight conc.).
- Minimum center-to-center spacing of steel headed stud anchors shall be four diameters in any direction. For composite beams that do not contain anchors located within formed steel deck oriented perpendicular to the beam span, an additional minimum spacing limit of six diameters along the longitudinal axis of the beam shall apply.

(AISC 360-16 > I3. Flexure > 2. Composite beams with steel headed stud > 2c. Composite beams with formed steel deck)

- Limitations for formed steel deck → Deck plate with flap plate and lattice is used for the TSC beam.

# 3. Calculation sheet (TG1)

## ■ 1. Design Conditions > 1.4 Section Forces

- Maximum required moment strength under positive moment region,  $M_{u, pos} = 712 \text{ kN}\cdot\text{m}$
- Maximum required moment strength under negative moment region,  $M_{u, neg} = 1425 \text{ kN}\cdot\text{m}$
- Maximum Required shear strength,  $V_u = 610 \text{ kN}$

## ■ 2. Check Construction Stage > 2.1 TSC Section Properties

- Area of steel section  $A_s = 2b_f t_f + 2ht_w + b_p t_p = 17382 \text{ mm}^2$
- Distance from the centroid of steel section to the outer surface of bottom flange  $C_y = 260 \text{ mm}$
- Moment of inertia  $I_x = 82808 \times 10^4 \text{ mm}^4$
- (bottom) Elastic section modulus  $S_{x,bf} = I_x / (C_y - c_o) = 338 \times 10^4 \text{ mm}^3$
- (top) Elastic section modulus  $S_{x,tf} = I_x / (H - C_y) = 243 \times 10^4 \text{ mm}^3$
- Plastic section modulus  $Z_x = 3396 \times 10^3 \text{ mm}^3$

## ■ 2. Check Construction Stage > 2.2 Width-to-Thickness Ratio

(1) Positive moment (Compression region : top flange and web)

- Top flange (Case 11):  $\lambda_{p,tf} = 0.38\sqrt{E_s / F_y} = 9.2 < b_{f,out} / t_f = 10.1 < \lambda_{r,tf} = 0.95\sqrt{k_c E_s / F_L} = 19.5 \rightarrow \text{Noncompact section}$
- Web (Case 16):  $\lambda_{pw} = 49.1 < 2(h - bC_y) / t_w = 73.5 < \lambda_{rw} = 5.70 \sqrt{E_s / F_y} = 138.6 \rightarrow \text{Noncompact section}$

AISC 360-16 > B4. Member properties > Table B4.1b width-to-thickness ratios: compression elements members subject to flexure

- (Case 11) Flanges of doubly and **singly symmetric I-shaped built-up sections**
- (Case 16) Webs of **singly symmetric I-shaped sections**

