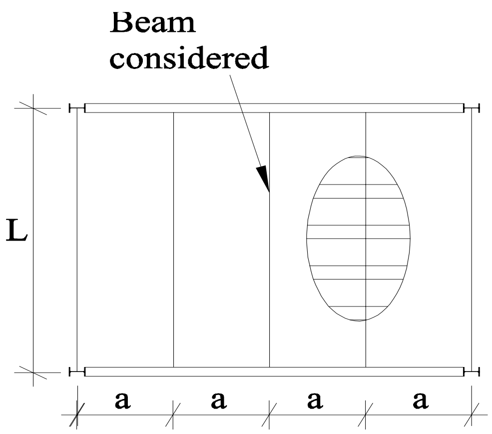
Design of Composite Beam Subjected to Bending about Its Major Axis



Materials

Grade:	SEL("Material/ASTM"; NAME;)	=	A992
F_y=	TAB("Material/ASTM";F_y;NAME=Grade)	=	50 ksi
F_u=	TAB("Material/ASTM";F_u;NAME=Grade)	=	65 ksi
E_s=			29000 ksi

Beam Length

Total length, L=	45.00 ft
Beam spacing, a=	10.0 ft

Concrete Details

f'_c=	4.0 ksi
Total thickness, t_s=	7.5 in
concrete weight, γ_c=	145.0 lb/ft^3

Loads

Superimposed (HVAC, ceiling, floor covering, etc.), w_{sd}=	10.0 lb/ft^2
Live load for construction (temporary loads during concrete placement), w_{Lc}=	25.0 lb/ft^2
Live load non-reducible, w_{LL}=	100.0 lb/ft^2

Section Details

sec.:	SEL("AISC/W";NAME;)	=	W21X50
Weight, w_{sec}=	TAB("AISC/W";W;NAME=sec.)	=	50.00 lb/ft
depth, d=	TAB("AISC/W";d;NAME=sec.)	=	20.80 in
Web th., t_w=	TAB("AISC/W";t_w;NAME=sec.)	=	0.38 in
Flange width, b_f=	TAB("AISC/W";b_f;NAME=sec.)	=	6.53 in
Flange th., t_f=	TAB("AISC/W";t_f;NAME=sec.)	=	0.54 in
Gross area, A_s=	TAB("AISC/W";A;NAME=sec.)	=	14.70 in^2

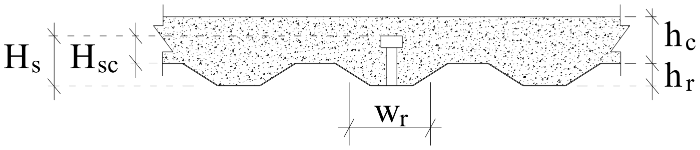
Plastic sec. modulus, Z_x= TAB("AISC/W";Z_x;NAME=sec.) = 110.00 in^3

Inertia about x-axis, I_x= TAB("AISC/W";I_x;NAME=sec.) = 984.00 in^4

AISC Specification Eqn. (F2-1):

Yielding Moment, M_p= Z_x*F_y*1/12 = 458 kip*ft

Metal Deck and Stud Connector Details (in accordance with metal deck manufacturer's data)



Rib height, h_r=	3.0 in
Average rib width, w_r=	6.0 in
weight of slab, w_s=	75.0 lb/ft^2
Diameter of stud, d_{sa}=	0.750 in
Height of stud (minimum is $4d_{sa}$), H_s=	4.50 in
Extension of the stud above the deck (minimum is 1.5 in), H_{sc}=	1.50 in

Composite Deck and Anchor Requirements

Check composite deck and anchor requirements stipulated in AISC Specification Sections I1.3, I3.2c and I8.

- Conc_strength_check =	IF(($f'_c \le 10$ AND $f'c \ge 3$) ; "o.k."; "change f'_c")	=	o.k.
- h_r _check=	IF($h_r \le 3$; "o.k."; "decrease h_r")	=	o.k.
- w_r _check=	IF($w_r \ge 2$; "o.k."; "increase w_r")	=	o.k.
- d_{sa}_check=	IF($d_{sa} \le 0.75$; "o.k."; "decrease d_{sa}")	=	o.k.
- t_f_check=	IF(tf $\ge d_{sa}/2.5$; "o.k."; "decrease d_{sa}")	=	o.k.
-H_{sc}_check=	IF(($H_s \ge (h_r+1.5)$ AND $H_s < t_s-0.5$); "o.k."; "unsafe")	=	o.k.
-H_s_check=	IF($H_s \ge 4*d_{sa}$; "o.k."; "increase H_s")	=	o.k.
- h_c_check=	IF((t_s-h_r) ≥ 2; "o.k."; "increase h_c")	=	o.k.

Design for Pre-Composite Condition

- Construction Pre-composite Loads:

w_{D1}= 0.001*(w_s*a+w_{sec}) = 0.80 kip/ft

w_{L1}= 0.001*(w_{Lc}*a) = 0.25 kip/ft

- Construction Pre-composite flexural strength, from Chapter 2 of ASCE/SEI 7, the required flexural strength is:

w_{u1}= 1.2* w_{D1}+ 1.6*w_{L1} = 1.36 kip/ft

M_{u1}= $\frac{w_{u1} * L^2}{8}$ = 344 kip*ft

Assume that attachment of the deck perpendicular to the beam provides adequate bracing to the compression flange during construction, thus the beam can develop its full plastic moment capacity. The design flexural strength is determined as follows, from AISC Specification Equation F2-1:

Φ_b= 0.90

M_{n1}= $\Phi_b * M_p$ = 412 kip*ft

Flexural_safety1= IF($M_{n1} \geq M_{u1}$; "Safe"; "Unsafe") = Safe

- Pre-composite deflection:

$$\Delta_{nc} = \frac{5 * \frac{w_{D1}}{12} * (L * 12)^4}{384 * E_s * I_x} = 2.59 \text{ in}$$

$$\Delta_{recom} = \frac{L * 12}{360} = 1.50 \text{ in}$$

If pre-composite deflection exceeds the recommended limit. One possible solution is to increase the member size. A second solution is to induce camber into the member. So, the user in this step has to determine a solution in case of exceeding the recommended limit.

Camber= 2.00 in

deflection_check= IF((Δ_{nc} - Camber)< Δ_{recom}; "Safe"; "Unsafe") = Safe

Design for Composite Condition

- Required Flexural Strength:

w_{D2}= $0.001*((w_s+w_{sd})*a+w_{sec})$ = 0.90 kip/ft

w_{L2}= $0.001*(w_{LL}*a)$ = 1.00 kip/ft

From Chapter 2 of ASCE/SEI 7, the required flexural strength is:

w_{u2}= $1.2* w_{D2}+ 1.6*w_{L2}$ = 2.68 kip/ft

$$M_{u2} = \frac{w_{u2} * L^2}{8} = 678 \text{ kip*ft}$$

Determine The Effective Slab Width, b_e

The effective width of the concrete slab is the sum of the effective widths to each side of the beam centerline as determined by the minimum value of the three widths set forth in AISC Specification Section I3.1a:

$$b_{e1} = \frac{L}{8} * 2 = 11.25 \text{ ft}$$

$$b_{e2} = \frac{a}{2} * 2 = 10.00 \text{ ft}$$

b_e= MIN(b_{e1}; b_{e2}) = 10.00 ft

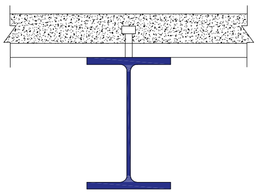
Available Flexural Strength

According to AISC Specification Section I3.2a, the nominal flexural strength shall be determined from the plastic stress distribution on the composite section when h / tw ≤ √(3.76 E / Fy)

$\lambda_w =$ $\frac{d}{t_w}$ = 54.74

Web_Class= IF($\lambda_w \leq 3.76 * \sqrt{(E_s/F_y)}$;"Compact"; "Non-Compact") = Compact

According to AISC Specification Commentary Section I3.2a, the number and strength of steel headed stud anchors will govern the compressive force, C, for a partially composite beam. The composite percentage is based on the minimum of the limit states of concrete crushing and steel yielding as follows:



- Concrete crushing:

A_c= Area of concrete slab within effective width. Assume that the deck profile is 50% void and 50% concrete fill.

$A_c =$ $(b_e * 12)*(t_s - h_r) + 0.5 * (b_e * 12 * h_r)$ = 720.00 in^2

$C_c =$ $0.85 * f'_c * A_c$ = 2448 kips

- Steel yielding:

$C_s =$ $A_s * F_y$ = 735 kips

- Shear transfer:

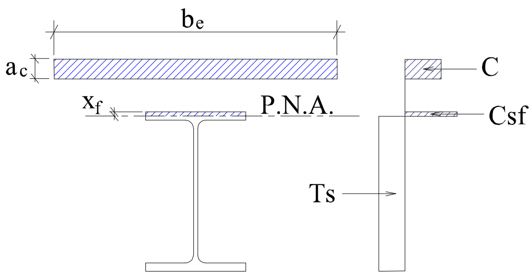
60% is used as a trial percentage of composite action as follows:

$C_1 = \Sigma Q_n$

$C_1 =$ $0.6 * MIN(C_c;C_s)$ = 441 kips

Location of The Plastic Neutral Axis

The plastic neutral axis (PNA) is located by determining the axis above and below which the sum of horizontal forces is equal. This concept assumes the trial PNA location is within the top flange of the beam.



P.N.A. inside flange

$\Sigma F_{above\ PNA} = \Sigma F_{below\ PNA}$

$C_1 + C_{sf1} = T_{s1} * F_y$

$C_{sf1} = x_{f1} * b_f * F_y$

$T_{s1} = (A_s - x_{f1} * b_f) * F_y$

x_{f1}=	$\frac{A_s * F_y - C_1}{2 * b_f * F_y}$	=	0.45 in
x_f=	IF($x_{f1} \le t_f$; x_{f1}; t_f)	=	0.45 in
C_{sf} =	$x_f * b_f * F_y$	=	147 kips
T_s=	$(A_s - x_f * b_f) * F_y$	=	588 kips
C=	$T_s - C_{sf}$	=	441 kips

Check the percentage of partial composite action:

α =	C / MIN(C_c; C_s)	=	0.60
Check_case=	IF($\alpha < 0.50$; "Conservative"; "o.k.")	=	o.k.

Determine the nominal moment resistance of the composite section following the procedure in Specification Commentary Section I3.2a: (calculating the sum. of moments about the P.N.A.)

$M_2 = \Sigma$ F*Y

a_c=	$\frac{C}{0.85 * f'_c * b_e * 12}$	=	1.08 in
M_{n2}=	$1/12 * (C * (t_s + x_f - a_c/2) + C_{sf} * (x_f/2) + T_s * (d/2 - x_f))$	=	763 kip*ft
Flexural_safety2=	IF($M_{n2} \ge M_{u2}$; "Safe"; "Unsafe")	=	Safe

Composite deflection: (AISC specs. I3.1 and Eqn. C-13-1)

Y_{ENA}=	$(A_s * d/2 + (C/F_y) * (d + (t_s - a_c/2))) / (A_s + C/F_y)$	=	16.91 in
I_{Lb}=	$I_x + A_s * (Y_{ENA} - d/2)^2 + (C/F_y) * (d + (t_s - a_c) - Y_{ENA})^2$	=	2545 in^3
Δ_c=	$\frac{5 * \frac{w_{L2}}{12} * (L * 12)^4}{384 * E_s * I_{Lb}}$	=	1.25 in
Δ_{recom}=	$\frac{L * 12}{360}$	=	1.50 in
Deflection_check2=	IF($\Delta_c < \Delta_{recom}$; "Safe"; "Unsafe")	=	Safe

Summary

Pre-composite condition:

M_{u1}=	$\frac{w_{u1} * L^2}{8}$	=	344 kip*ft
M_{n1}=	$\Phi_b * M_p$	=	412 kip*ft
Flexural_safety1=	IF($M_{n1} \ge M_{u1}$; "Safe"; "Unsafe")	=	Safe
Δ_{nc}=	$\frac{5 * \frac{w_{D1}}{12} * (L * 12)^4}{384 * E_s * I_x}$	=	2.59 in

$\Delta_{recom} = \frac{L*12}{360}$ = 1.50 in

Deflection_check= IF((Δ_{nc} - Camber)< Δ_{recom}; "Safe"; "Unsafe") = Safe

Composite condition:

$M_{u2} = \frac{w_{u2}*L^2}{8}$ = 678 kip*ft

M_{n2}= 1/12*(C*(t_s+x_f - a_c/2)+C_{sf}*(x_f/2)+T_s*(d/2-x_f)) = 763 kip*ft

Flexural_safety2= IF($M_{n2} \geq M_{u2}$; "Safe"; "Unsafe") = Safe

$\Delta_{nc} = \frac{5*\frac{w_{D1}}{12}*(L*12)^4}{384*E_s*I_x}$ = 2.59 in

Deflection_check= IF((Δ_{nc} - Camber)< Δ_{recom}; "Safe"; "Unsafe") = Safe