CHAPTER 2: Structural Steel Beams

2.1 Composite Beam Section Properties

Description

This application calculates the horizontal shear and section properties for composite steel beam and concrete slab sections with solid slabs, composite steel decks, or haunches. Computations are made for beams and slabs over a complete usable range of composite action from 25% to 100%.

The user must identify the steel section that is used. The user must also enter the dimensions and section properties of the steel section, the dimensions of the slab section and "haunch", the compressive strength of the concrete, the unit weight of concrete and the yield strength of the steel section.

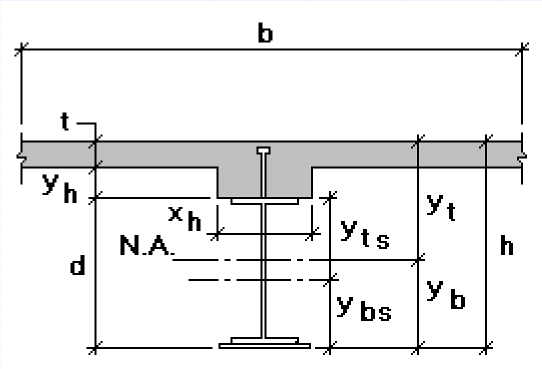
Composite steel beams consisting of rolled structural beams and either solid slabs or slabs of composite steel deck and concrete in-fill are commonly used, especially in office construction. In composite construction the slab and beam are connected together and made to act as one unit by field welding steel shear studs to the beam prior to placing the concrete. Some added economy may be achieved by using the AISC Specifications provisions of Section I1 for partial composite action. These provisions permit the use of fewer studs than required for full composite behavior when the strength and stiffness of a given beam section is adequate with partial composite behavior.

A summary of input and computed values is shown on pages 11-13.

Reference: AISC "Specification for Structural Steel Buildings -- Allowable Stress Design and Plastic Design with Commentary." June 1, 1989

Input

Notation



Input Variables

The user should enter the steel section designation and plate size in text.

Steel Section: W16x26	**Plate: None**
Depth of the steel beam:	$d := 15.69 \cdot in$
Dimension from bottom of steel section to neutral axis of steel section:	$y_{bs} := \frac{d}{2}$
Cross-sectional area of the steel section:	$A_s := 7.68 \cdot in^2$
Moment of inertia of steel section:	$I_s := 298.10 \cdot in^4$
Thickness of solid slab or thickness of concrete above top of steel deck:	$t := 3.5 \cdot in$
Effective concrete flange width:	$b := 77.5 \cdot in$
Width of concrete haunch or equivalent width of the concrete filled ribs of a steel deck parallel to the beam span of steel deck ribs:	$x_h := 0 \cdot in$

Depth of concrete haunch or depth of steel deck parallel to beam span: $y_h := 2 \cdot in$

Notes

For sections with a composite steel deck parallel to the span, x_h is equal to the equivalent width of concrete in the ribs of the deck and y_h is equal to the depth of the steel deck.

For sections with a composite steel deck transverse to the beam span, x_h is equal to 0 inches and y_h is equal to the depth of steel deck.

Computed Variables

h total depth of composite section

y_t dimension from top of slab to neutral axis of composite section

y_b dimension from bottom of steel section to neutral axis of composite section

A_c cross-sectional area of concrete

I_{tr} moment of inertia of composite section with 100% composite action

I_{eff} effective moment of inertia of composite section with partial composite action

S_s section modulus of steel section referred to bottom of section

S_{tr} section modulus of fully composite section to bottom of steel section

S_t section modulus of composite section to top of slab

S_{eff} effective section modulus to bottom of steel beam for section with partial composite action

V_h total horizontal shear between point of maximum positive moment and points of zero moment for full composite action

V'_h total horizontal shear between point of maximum positive moment and points of zero moment for partial composite action

N.A. neutral axis of composite section

Material Properties

Enter the compressive strength of concrete, yield strength of steel section and the unit weight of concrete.

Specified compressive strength of concrete: $f'_c := 4 \cdot ksi$

Specified yield strength of steel section: $f_y := 36 \cdot ksi$

Weight of concrete (minimum weight of 90 pcf): $w_c := 145 \cdot pcf$

Modulus of elasticity of steel: $E_s := 29000 \cdot ksi$

The following variables are computed from the entered material properties.

Modulus of elasticity of concrete:

$$E_c := \left(\frac{w_c}{pcf}\right)^{1.5} \cdot 33 \cdot \sqrt{\frac{f'_c}{psi}} \cdot psi \qquad E_c = 3644\ ksi$$

Modular ratio: $n := \frac{E_s}{E_c}$ $\qquad n = 7.958$

For lightweight concrete the modular ratio for normal weight is used for stress calculations, and the modular ratio for lightweight concrete is used for deflection calculations.

Defined Units

$pcf := lb \cdot ft^{-3}$

ORIGIN defined equal to 1 to match Case numbers defined on page 6:

$\mathrm{ORIGIN} := 1$

Calculations

Cross-sectional area of concrete:

$$A_c := b \cdot t + x_h \cdot y_h \qquad A_c = 271.25\ in^2$$

Total horizontal shear for 100% composite action, using AISC Specification, Eqs. (14-1) and (14-2), combined:

$$V_h := \text{if}\left(\frac{A_s \cdot f_y}{2} \ge \frac{0.85 \cdot f'_c \cdot A_c}{2}, \frac{0.85 \cdot f'_c \cdot A_c}{2}, \frac{A_s \cdot f_y}{2}\right)$$

$$V_h = 138.24\ kip$$

Section modulus of the steel section referred to the bottom flange:

$$S_s := \frac{I_s}{y_{bs}} \qquad S_s = 37.999\ in^3$$

Dimension from the neutral axis of the steel section to the top of the steel section:

$$y_{ts} := d - y_{bs} \qquad y_{ts} = 7.845\ in$$

Total depth of composite section:

$$h := t + y_h + d \qquad h = 21.19\ in$$

Test for Location of Neutral Axis

This section determines if the neutral axis for the 100% composite section lies within the steel beam, within the haunch or the ribs of the steel deck parallel to the beam span, between the slab and the steel beam, or within the slab.

These conditions are summarized by the following four cases:

Case 1: The neutral axis lies within the steel beam.

Case 2: The neutral axis lies within the haunch or the ribs of the steel deck parallel to the beam span.

Case 3: The neutral axis lies between the slab and the steel beam with the steel deck transverse to the beam.

Case 4: The neutral axis lies within the slab.

$$Case := \textbf{if}\left(n \cdot A_s \cdot y_{ts} \ge b \cdot t \cdot \left(\frac{t}{2} + y_h\right) + \frac{x_h \cdot y_h^{\,2}}{2}, 1, \textbf{if}\left(n \cdot A_s \cdot (y_{ts} + y_h) \ge \frac{b \cdot t^2}{2}, \textbf{if}\,(x_h > 0 \cdot in, 2, 3), 4\right)\right)$$

$$Case = 3$$

Case 1 The neutral axis lies within the steel beam.

Dimension from top of slab to neutral axis of composite section:

$$y_{t_1} := \textbf{if}\left(Case = 1, \frac{\frac{b \cdot t^2}{2} + x_h \cdot y_h \cdot \left(t + \frac{y_h}{2}\right) + n \cdot A_s \cdot (h - y_{bs})}{A_c + n \cdot A_s}, 0 \cdot in\right)$$

$$y_{t_1} = 0\ in$$

Dimension from bottom of steel section to the neutral axis of composite section:

$$y_{b_1} := \textbf{if}\left(Case = 1, h - y_{t_1}, 0 \cdot in\right)$$

$$y_{b_1} = 0\ in$$

Moment of inertia of composite section with 100% composite action:

$$I_{tr_1} := \textbf{if}\left(Case = 1, \left(\frac{b \cdot t^3}{12} + b \cdot t \cdot \left(y_{t_1} - \frac{t}{2}\right)^2 + n \cdot I_s + n \cdot A_s \cdot \left(y_{b_1} - y_{bs}\right)^2 + \frac{x_h \cdot y_h^{\,3}}{12} + x_h \cdot y_h \cdot \left(y_{t_1} - t - \frac{y_h}{2}\right)^2\right) \cdot \frac{1}{n}, 0 \cdot in^4\right)$$

$$I_{tr_1} = 0\ in^4$$

Case 2 The neutral axis lies within the haunch or the ribs of a steel deck parallel to beam span.

Dimension from top of slab to the neutral axis of composite section:

$$y_{t_2} := \text{if}\left(Case = 2, \frac{-\left(-x_h \cdot t + b \cdot t + n \cdot A_s\right) + \sqrt{\left(-x_h \cdot t + b \cdot t + n \cdot A_s\right)^2 - 4 \cdot \frac{x_h}{2} \cdot \left(\frac{-b \cdot t^2}{2} - n \cdot A_s \cdot \left(h - y_{bs}\right) + \frac{x_h \cdot t^2}{2}\right)}}{x_h}, 0 \cdot in\right)$$

$$y_{t_2} = 0\ in$$

Dimension from bottom of steel section to the neutral axis of composite section:

$$y_{b_2} := \text{if}\left(Case = 2, h - y_{t_2}, 0 \cdot in\right)$$

$$y_{b_2} = 0\ in$$

Moment of inertia of composite section with 100% composite action:

$$I_{tr_2} := \text{if}\left(Case = 2, \left(\left(\frac{b \cdot t^3}{12} + b \cdot t \cdot \left(y_{t_2} - \frac{t}{2}\right)^2 + n \cdot I_s\right) + \left(n \cdot A_s \cdot \left(y_{b_2} - y_{bs}\right)^2 + \frac{1}{3} \cdot x_h \cdot \left(y_{t_2} - t\right)^3\right)\right) \cdot \frac{1}{n}, 0 \cdot in^4\right)$$

$$I_{tr_2} = 0\ in^4$$

Case 3 The neutral axis lies between the slab and the steel beam.
(Note: The steel deck is transverse to the beam span)

Dimension from top of slab to neutral axis of composite section:

$$y_{t_3} := \text{if}\left(Case = 3, \frac{\frac{1}{2} \cdot b \cdot t^2 + n \cdot A_s \cdot \left(h - y_{bs}\right)}{b \cdot t + n \cdot A_s}, 0 \cdot in\right)$$

$$y_{t_3} = 3.882\ in$$

Dimension from bottom of steel section to the neutral axis of composite section:

$$y_{b_3} := \text{if}\left(Case = 3, h - y_{t_3}, 0 \cdot in\right)$$

$$y_{b_3} = 17.308\ in$$

Moment of inertia of composite section with 100% composite action:

$$I_{tr_3} := \text{if}\left(Case = 3, \left(\frac{b \cdot t^3}{12} + b \cdot t \cdot \left(y_{t_3} - \frac{t}{2}\right)^2 + n \cdot I_s + n \cdot A_s \cdot \left(y_{b_3} - y_{bs}\right)^2\right) \cdot \frac{1}{n}, 0 \cdot in^4\right)$$

$$I_{tr_3} = 1175.559\ in^4$$

Case 4 The neutral axis lies within the slab.

Dimension from top of slab to the neutral axis of composite section:

$$y_{t_4} := \text{if}\left(Case = 4, \frac{-n \cdot A_s + \sqrt{\left(n \cdot A_s\right)^2 + 2 \cdot b \cdot n \cdot A_s \cdot \left(h - y_{bs}\right)}}{b}, 0 \cdot in\right)$$

$$y_{t_4} = 0\ in$$

Dimension from bottom of steel section to the neutral axis of composite section:

$$y_{b_4} := \text{if}\left(Case = 4, h - y_{t_4}, 0 \cdot in\right)$$

$$y_{b_4} = 0\ in$$

Moment of inertia of composite section with 100% composite action:

$$I_{tr_4} := \text{if}\left(Case = 4, I_s + A_s \cdot \left(y_{b_4} - y_{bs}\right)^2 + \frac{b \cdot \left(y_{t_4}\right)^3}{3 \cdot n}, 0 \cdot in^4\right)$$

$$I_{tr_4} = 0\ in^4$$

Section Properties for 100% Composite Action

Dimension from top of slab to neutral axis of composite section:

$y_t := \sum y_t$ $\qquad y_t = 3.882\ in$

Dimension from bottom of steel section to neutral axis of composite section:

$y_b := \sum y_b$ $\qquad y_b = 17.308\ in$

Moment of inertia of composite section with 100% composite action:

$I_{tr} := \sum I_{tr}$ $\qquad I_{tr} = 1175.559\ in^4$

Transformed section modulus of composite section with 100% composite action referred to the bottom flange of the steel section:

$S_{tr} := \frac{I_{tr}}{y_b}$ $\qquad S_{tr} = 67.921\ in^3$

Transformed section modulus of composite section with 100% composite action referred to the bottom flange of the steel section:

$S_t := \frac{I_{tr}}{y_t}$ $\qquad S_t = 302.812\ in^3$

Seff and V'h as Functions of the Percent of Composite Action (CA) from 25% to 100%

Values for the horizontal shear, effective section modulus and effective moment of inertia are displayed in the **Summary** section that begins on the following page:

$V'_h(CA) := \frac{CA \cdot V_h}{100}$ $\qquad CA := 25, 30 .. 100$

Effective section modulus computed using a AISC Specification, Eq. (I2-1) with percent of composite action substituted for Vh and V'h:

$$S_{eff}(CA) := S_s + \sqrt{\frac{CA}{100}} \cdot \left(S_{tr} - S_s\right)$$

Effective moment of inertia computed using a AISC Specification, Eq. (I4-4) with percent of composite action substituted for Vh and V'h:

$$I_{eff}(CA) := I_s + \sqrt{\frac{CA}{100}} \cdot \left(I_{tr} - I_s\right)$$

Summary

Steel Section Designation: W16x26 **Cover Plate: None**

Input

Specified compressive strength of concrete:	$f'_c = 4$ ***ksi***
Specified yield strength of steel section:	$f_y = 36$ ***ksi***
Weight of concrete (minimum weight of 90 pcf):	$w_c = 145$ ***pcf***
Modulus of elasticity of steel:	$E_s = 29000$ ***ksi***
Depth of the steel beam:	$d = 15.69$ ***in***
Dimension from bottom of steel section to neutral axis of steel section:	$y_{bs} = 7.845$ ***in***
Cross sectional area of the steel section:	$A_s = 7.68\ in^2$
Moment of inertia of steel section:	$I_s = 298.1\ in^4$

Thickness of solid slab or thickness of concrete above top of steel deck: $t = 3.5\ in$

Effective concrete flange width: $b = 77.5\ in$

Width of concrete haunch or equivalent width of the concrete filled ribs of a steel deck parallel to the beam span of steel deck ribs: $x_h = 0\ in$

Depth of concrete haunch or depth of steel deck parallel to beam span: $y_h = 2\ in$

Computed Variables

Modulus of elasticity of concrete: $E_c = 3644\ ksi$

Modular ratio: $n = 7.958$

Total depth of composite section: $h = 21.19\ in$

Dimension from top of slab to neutral axis of composite section: $y_t = 3.882\ in$

Dimension from bottom of steel section to neutral axis of composite section: $y_b = 17.308\ in$

Cross section area of concrete: $A_c = 271.25\ in^2$

Moment of inertia of composite section with 100% composite action: $I_{tr} = 1175.6\ in^4$

Section modulus of steel section referred to bottom of section:

$S_s = 37.999\ in^3$

Section modulus of fully composite section to bottom of steel section:

$S_{tr} = 67.921\ in^3$

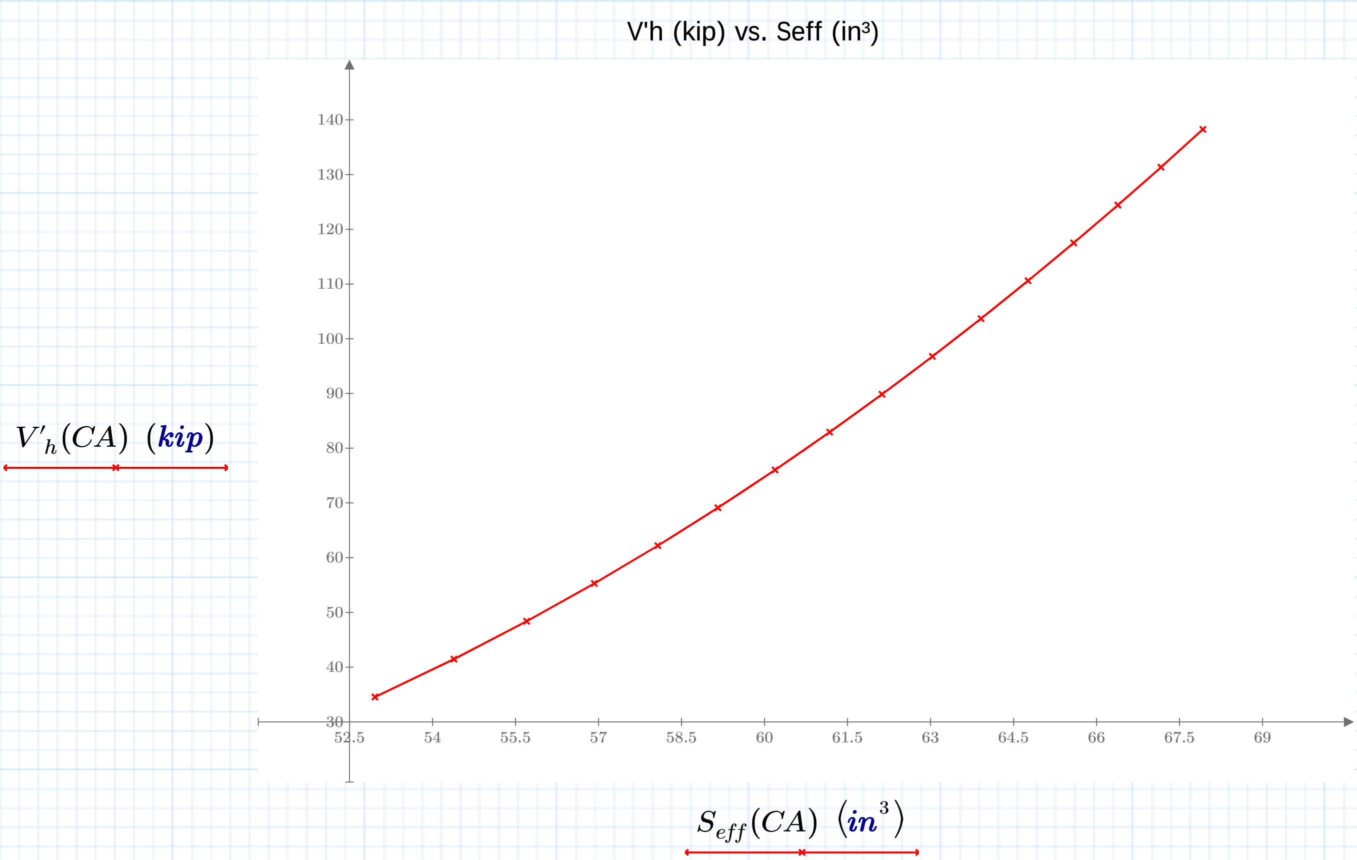
Section modulus of fully composite section to top of slab:

$S_t = 302.812\ in^3$

Total horizontal shear between point of maximum positive moment and points of zero moment for full composite action:

$V_h = 138.24\ kip$

Plot V'h in kip for (25% to 100% Composite Action) versus Seff in in³:



$$CA = \begin{bmatrix} 25 \\ 30 \\ 35 \\ 40 \\ 45 \\ 50 \\ 55 \\ 60 \\ 65 \\ 70 \\ 75 \\ 80 \\ 85 \\ 90 \\ 95 \\ 100 \end{bmatrix} \qquad V'_h(CA) = \begin{bmatrix} 34.56 \\ 41.472 \\ 48.384 \\ 55.296 \\ 62.208 \\ 69.12 \\ 76.032 \\ 82.944 \\ 89.856 \\ 96.768 \\ 103.68 \\ 110.592 \\ 117.504 \\ 124.416 \\ 131.328 \\ 138.24 \end{bmatrix} \textbf{kip} \qquad S_{eff}(CA) = \begin{bmatrix} 52.96 \\ 54.388 \\ 55.701 \\ 56.923 \\ 58.071 \\ 59.157 \\ 60.189 \\ 61.176 \\ 62.122 \\ 63.033 \\ 63.912 \\ 64.762 \\ 65.585 \\ 66.385 \\ 67.163 \\ 67.921 \end{bmatrix} \textbf{in}^3 \qquad I_{eff}(CA) = \begin{bmatrix} 736.83 \\ 778.704 \\ 817.212 \\ 853.054 \\ 886.718 \\ 918.557 \\ 948.841 \\ 977.777 \\ 1.006 \cdot 10^3 \\ 1.032 \cdot 10^3 \\ 1.058 \cdot 10^3 \\ 1.083 \cdot 10^3 \\ 1.107 \cdot 10^3 \\ 1.131 \cdot 10^3 \\ 1.153 \cdot 10^3 \\ 1.176 \cdot 10^3 \end{bmatrix} \textbf{in}^4$$