## Example D.1 W-Shape Tension Member

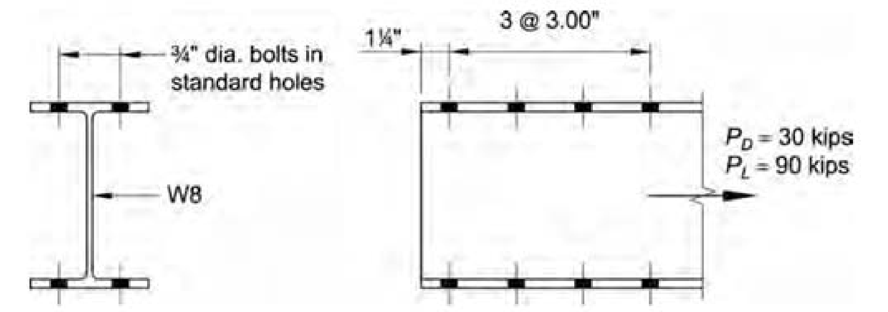



*Fig D.1-1. Connection geometry for Example D.1.*



**Section**

W8x21

$d := 8.28\ in = 210.312\ mm$

$b_f := 5.27\ in = 133.858\ mm$

$t_f := 0.4\ in = 10.16\ mm$

$t_w := 0.25\ in = 6.35\ mm$

**Material**

$F_u := 65\ ksi = 448.159\ MPa$

$F_y := 50\ ksi = 344.738\ MPa$

$$A_g := 2 \cdot t_f \cdot b_f + \left(d - 2 \cdot t_f\right) \cdot t_w = 6.086\ in^2$$

$$A_g := 2 \cdot t_f \cdot b_f + \left(d - 2 \cdot t_f\right) \cdot t_w = \left(3.926 \cdot 10^3\right)\ mm^2$$

$$I_x := \frac{b_f \cdot d^3}{12} - \frac{\left(b_f - t_w\right) \cdot \left(d - 2 \cdot t_f\right)^3}{12} = 74.223\ in^4$$

$$I_x := \frac{b_f \cdot d^3}{12} - \frac{\left(b_f - t_w\right) \cdot \left(d - 2 \cdot t_f\right)^3}{12} = \left(3.089 \cdot 10^7\right)\ mm^4$$

$$r_x := \sqrt{\frac{I_x}{A_g}} = 3.492\ in$$

$$r_x := \sqrt{\frac{I_x}{A_g}} = 88.703\ mm$$

$$I_y := \frac{\left(d - 2 \cdot t_f\right) \cdot {t_w}^3}{12} + \frac{t_f \cdot {b_f}^3}{12} \cdot 2 = 9.767\ in^4$$

$$I_y := \frac{\left(d - 2 \cdot t_f\right) \cdot {t_w}^3}{12} + \frac{t_f \cdot {b_f}^3}{12} \cdot 2 = \left(4.065 \cdot 10^6\right)\ mm^4$$

$$r_y := \sqrt{\frac{I_y}{A_g}} = 1.267\ in$$

$$r_y := \sqrt{\frac{I_y}{A_g}} = 32.178\ mm$$

Flange Connection

$$U_1 := \frac{2 \cdot b_f \cdot t_f}{A_g} = 0.693$$

$$L := 25\ ft = 7.62\ m$$

$$\frac{L}{r_x} = 85.905$$

$$\frac{L}{r_y} = 236.81$$

$$x := \frac{b_f \cdot t_f \cdot \frac{t_f}{2} + \left(\frac{d}{2} - t_f\right) \cdot t_w \cdot \left(\frac{\frac{d}{2} - t_f}{2} + t_f\right)}{b_f \cdot t_f + \left(\frac{d}{2} - t_f\right) \cdot t_w} = 21.235\ mm$$

$$l := 9\ in = 228.6\ mm \qquad d_b := \frac{13}{16}\ in = 20.638\ mm$$

$$U_2 := 1 - \frac{x}{l} = 0.907$$

For open cross sections such as W, M, S, C or HP shapes, WTs, STs, and single and double angles, the shear lag factor, $U$, need not be less than the ratio of the gross area of the connected element(s) to the member gross area. This provision does not apply to closed sections, such as *HSS* sections, nor to plates.

**User Note:** For bolted *splice* plates $A_e = A_n \le 0.85A_g$, according to Section J4.1.

$$BoltN := 4$$

Flange Connection

$$U_3 := \text{if}\left(BoltN \ge 3, \text{if}\left(b_f < \frac{2}{3} \cdot d, 0.85, 0.9\right), 0\right) = 0.85$$

$$U := \max\left(U_1, U_2, U_3\right) = 0.907$$

$$A_n := A_g - 4 \cdot \left(d_b + \frac{1}{16}\ in\right) \cdot t_f = 4.686\ in^2$$

$$A_n := A_g - 4 \cdot \left(d_b + \frac{1}{16}\ in\right) \cdot t_f = \left(3.023 \cdot 10^3\right)\ mm^2$$

$$A_e := A_n \cdot U = 4.251\ in^2$$

$$A_e := A_n \cdot U = \left(2.742 \cdot 10^3\right)\ mm^2$$

$$\phi P_{n1} := 0.9 \cdot A_g \cdot F_y = 273.87\ kip \qquad \phi P_{n1} := 0.9 \cdot A_g \cdot F_y = \left(1.218 \cdot 10^3\right)\ kN$$

$$\phi P_{n2} := 0.75 \cdot A_e \cdot F_u = 207.222\ kip \qquad \phi P_{n2} := 0.75 \cdot A_e \cdot F_u = 921.769\ kN$$

$$\phi P_n := \min\left(\phi P_{n1}, \phi P_{n2}\right) = 207.222\ kip \qquad \phi P_n := \min\left(\phi P_{n1}, \phi P_{n2}\right) = 921.769\ kN$$

**D2. TENSILE STRENGTH**

The *design tensile strength*, $\phi_t P_n$, and the *allowable tensile strength*, $P_n/\Omega_t$, of tension members shall be the lower value obtained according to the *limit states* of *tensile yielding* in the gross section and *tensile rupture* in the net section.

(a) For tensile yielding in the gross section:

$$P_n = F_y A_g \tag{D2-1}$$

$\phi_t = 0.90$ (LRFD) $\quad \Omega_t = 1.67$ (ASD)

(b) For tensile rupture in the net section:

$$P_n = F_u A_e \tag{D2-2}$$

$\phi_t = 0.75$ (LRFD) $\quad \Omega_t = 2.00$ (ASD)

## DESIGN TABLE DISCUSSION

Available tensile strengths for various types of tension members (see individual descriptions below) are given in Tables 5-1 through 5-8 for the limit states of tensile yielding and tensile rupture. In each case, the tabulated values for available tensile rupture strength are based upon the assumption that $A_e = 0.75A_g$, which is arbitrarily selected as a value that is practical to achieve with typical end connections. Such consideration of the effective net area during the design of the member will simplify the design of its end connections, which can be difficult to configure and costly if tension members are selected based upon available tensile yielding strength only, without considering the reduction in strength due to the connection.

When $A_e > 0.75A_g$, either the tabulated values for available tensile rupture strength can be used conservatively or the available tensile rupture strength can be calculated based upon the actual value of $A_e$. When $A_e < 0.75A_g$, the tabulated values of the available tensile rupture strength cannot be used, but rather must be calculated based upon the actual value of $A_e$.

$$A_e := 0.75 \cdot A_g = 4.565\ in^2$$

$$A_e := 0.75 \cdot A_g = \left(2.945 \cdot 10^3\right)\ mm^2$$

$$\phi P_{n1} := 0.9 \cdot A_g \cdot F_y = 273.87\ kip$$

$$\phi P_{n2} := 0.75 \cdot A_e \cdot F_u = 222.519\ kip$$

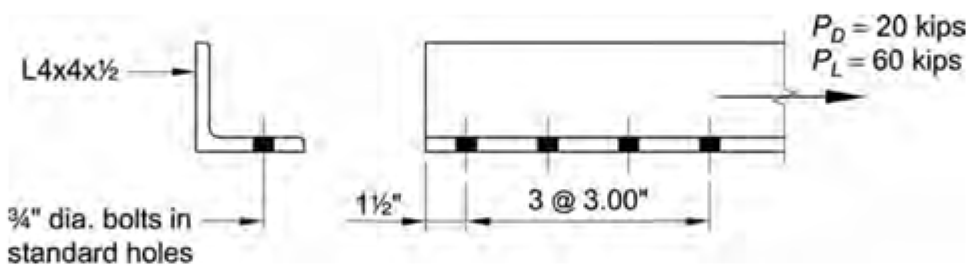
$$\phi P_n := min\left(\phi P_{n1}, \phi P_{n2}\right) = 222.519\ kip$$

$$\phi P_{n1} := 0.9 \cdot A_g \cdot F_y = \left(1.218 \cdot 10^3\right)\ kN$$

$$\phi P_{n2} := 0.75 \cdot A_e \cdot F_u = 989.815\ kN$$

$$\phi P_n := min\left(\phi P_{n1}, \phi P_{n2}\right) = 989.815\ kN$$

Example D.2 Single Angle Tension Member




Section

L shape

Material

$F_y := 36\ ksi$ $\quad F_u := 58\ ksi$

$h := 4\ in = 101.6\ mm$
$b := 4\ in = 101.6\ mm$
$t := 0.5\ in = 12.7\ mm$

$$x := \frac{b \cdot t \cdot \frac{t}{2} + (h - t) \cdot t \cdot \left(t + \frac{h - t}{2}\right)}{b \cdot t + (h - t) \cdot t} = 1.183\ in$$

$$x := \frac{b \cdot t \cdot \frac{t}{2} + (h - t) \cdot t \cdot \left(t + \frac{h - t}{2}\right)}{b \cdot t + (h - t) \cdot t} = 30.057\ mm$$

$A_g := b \cdot t + (h - t) \cdot t = 3.75\ in^2$

$A_g := b \cdot t + (h - t) \cdot t = \left(2.419 \cdot 10^3\right)\ mm^2$

$l := 9\ in$

$l = 228.6\ mm$

For open cross sections such as W, M, S, C or HP shapes, WTs, STs, and single and double angles, the shear lag factor, $U$, need not be less than the ratio of the gross area of the connected element(s) to the member gross area. This provision does not apply to closed sections, such as *HSS* sections, nor to plates.

**User Note:** For bolted *splice* plates $A_e = A_n \le 0.85 A_g$, according to Section J4.1.

$$U_1 := \frac{b \cdot t - \frac{t^2}{2}}{A_g} = 0.5$$

$$U_2 := 1 - \frac{x}{l} = 0.869$$

$U_3 := 0.8$

$U := \max\left(U_1, U_2, U_3\right) = 0.869$

$d_b := \frac{13}{16}\ in$

$A_n := A_g - \left(d_b + \frac{1}{16}\ in\right) \cdot t = 3.313\ in^2$

$A_n := A_g - \left(d_b + \frac{1}{16}\ in\right) \cdot t = \left(2.137 \cdot 10^3\right)\ mm^2$

$A_e := A_n \cdot U = 2.877\ in^2$

$A_e := A_n \cdot U = \left(1.856 \cdot 10^3\right)\ mm^2$

$\phi P_{n1} := 0.9 \cdot A_g \cdot F_y = 121.5\ kip$

$\phi P_{n2} := 0.75 \cdot A_e \cdot F_u = 125.148\ kip$

$\phi P_n := min\left(\phi P_{n1}, \phi P_{n2}\right) = 121.5\ kip$

$\phi P_{n1} := 0.9 \cdot A_g \cdot F_y = 540.459\ kN$

$\phi P_{n2} := 0.75 \cdot A_e \cdot F_u = 556.686\ kN$

$\phi P_n := min\left(\phi P_{n1}, \phi P_{n2}\right) = 540.459\ kN$

**D2. TENSILE STRENGTH**

The *design tensile strength*, $\phi_t P_n$, and the *allowable tensile strength*, $P_n/\Omega_t$, of tension members shall be the lower value obtained according to the *limit states* of *tensile yielding* in the gross section and *tensile rupture* in the net section.

(a) For tensile yielding in the gross section:

$$P_n = F_y A_g \qquad \text{(D2-1)}$$

$\phi_t = 0.90$ (LRFD) $\quad \Omega_t = 1.67$ (ASD)

(b) For tensile rupture in the net section:

$$P_n = F_u A_e \qquad \text{(D2-2)}$$

$\phi_t = 0.75$ (LRFD) $\quad \Omega_t = 2.00$ (ASD)

## DESIGN TABLE DISCUSSION

Available tensile strengths for various types of tension members (see individual descriptions below) are given in Tables 5-1 through 5-8 for the limit states of tensile yielding and tensile rupture. In each case, the tabulated values for available tensile rupture strength are based upon the assumption that $A_e = 0.75A_g$, which is arbitrarily selected as a value that is practical to achieve with typical end connections. Such consideration of the effective net area during the design of the member will simplify the design of its end connections, which can be difficult to configure and costly if tension members are selected based upon available tensile yielding strength only, without considering the reduction in strength due to the connection.

When $A_e > 0.75A_g$, either the tabulated values for available tensile rupture strength can be used conservatively or the available tensile rupture strength can be calculated based upon the actual value of $A_e$. When $A_e < 0.75A_g$, the tabulated values of the available tensile rupture strength cannot be used, but rather must be calculated based upon the actual value of $A_e$.

$A_e := 0.75 \cdot A_g = 2.813\ in^2$

$A_e := 0.75 \cdot A_g = \left(1.815 \cdot 10^3\right)\ mm^2$

$\phi P_{n1} := 0.9 \cdot A_g \cdot F_y = 121.5\ kip$

$\phi P_{n2} := 0.75 \cdot A_e \cdot F_u = 122.344\ kip$

$\phi P_n := min\left(\phi P_{n1}, \phi P_{n2}\right) = 121.5\ kip$

$\phi P_{n1} := 0.9 \cdot A_g \cdot F_y = 540.459\ kN$

$\phi P_{n2} := 0.75 \cdot A_e \cdot F_u = 544.212\ kN$

$\phi P_n := min\left(\phi P_{n1}, \phi P_{n2}\right) = 540.459\ kN$