From AISC Equation J4-5,

\[ R_n = 0.6F_u A_{nv} + U_{bt} F_u A_{mt} \]
\[ = 0.6(65)(1.688) + 1.0(65)(0.2500) = 82.08 \text{ kips} \]

with an upper limit of

\[ 0.6F_y A_{gy} + U_{bt} F_u A_{mt} = 0.6(50)(2.563) + 1.0(65)(0.2500) = 93.14 \text{ kips} \]

The nominal block shear strength is therefore 84.50 kips, and the design strength is

\[ \phi R_n = 0.75(82.08) = 61.6 \text{ kips} > 48.0 \text{ kips} \quad \text{(OK)} \]

**ANSWER**

Use an L3½ × 2½ × ¼ with the long leg connected. Use four ¼-inch-diameter, Group A bolts, as shown in Figure 7.23.

**FIGURE 7.23**

![Diagram of block shear calculation](image)

---

### 7.8 HIGH-STRENGTH BOLTS IN TENSION

When a tensile load is applied to a bolt with no initial tension, the tensile force in the bolt is equal to the applied load. If the bolt is pretensioned, however, a large part of the applied load is used to relieve the compression, or clamping forces, on the connected parts. This was determined by Kulak, Fisher, and Struik (1987) and is demonstrated here. Figure 7.24 shows a hanger connection consisting of a structural tee-shape bolted to the bottom flange of a W shape and subjected to a tensile load. A single bolt and a portion of the connected parts will be isolated and examined both before and after loading.
Before loading, all forces are internal, and a free-body diagram of the assembly is as shown in Figure 7.25a. For simplicity, all forces will be assumed to be symmetrical with respect to the axis of the bolt, and any eccentricity will be neglected. If the connected parts are considered as separate free bodies, the forces consist of the bolt tension $T_0$ and the normal clamping force $N_0$, shown here as uniformly distributed. Equilibrium requires that $T_0$ equals $N_0$. When the external tensile load is applied, the forces on the assembly are as shown in Figure 7.25b, with $F$ representing the total tensile force applied to one bolt (again, the actual distribution of the applied force per bolt has been idealized for simplicity). Figure 7.25c shows the forces acting on a free-body diagram of the segment of the structural tee flange and the corresponding segment of the bolt. Summing forces in the direction of the bolt axis gives

$$T = F + N$$
\[ S_{\text{plate}} = \frac{\Delta P_{\text{plate}}}{A_{\text{plate}} E_{\text{plate}}} \]

\[ S_{\text{bolt}} = \frac{\Delta P_{\text{bolt}}}{A_{\text{bolt}} E_{\text{bolt}}} \]

But \( S_{\text{plate}} = S_{\text{bolt}} \)

So \( \frac{\Delta P_{\text{bolt}}}{A_{\text{bolt}} E_{\text{bolt}}} = \frac{\Delta P_{\text{plate}}}{A_{\text{plate}} E_{\text{plate}}} \)

So \( \frac{\Delta P_{\text{bolt}}}{\Delta P_{\text{plate}}} = \frac{L_{\text{plate}}}{L_{\text{bolt}}} \cdot \frac{A_{\text{plate}}}{A_{\text{bolt}}} \cdot \frac{E_{\text{bolt}}}{E_{\text{plate}}} \]

\( = \frac{1}{2} \cdot \frac{\text{small}}{\text{small}} \cdot 1.0 \]

\( = \text{very small} \)

\( \approx 0.05 \text{ to } 0.10 \) by test

So when plates separate under tension load,

\( T_{\text{bolt}} \approx 1.1! \) Tnsalted
These gauges are used for measurement of tensile strain of bolt. These are simply inserted into a pre-drilled hole in the bolt head together with A-2 bonding adhesive and cured. The gauge series is recommendable if an ordinary strain gauge cannot be mounted on the bolt surface. Accurate tensile force measurement is possible by calibrating the bolt after installing the gauge.

- Single-element
The good thing.

Group A - 3/4" (No fatigue)
The application of force $F$ will increase the bolt tension and cause it to elongate by an amount $\delta_b$. Compression in the flange of the structural tee will be reduced, resulting in a distortion $\delta_{fr}$ in the same sense and amount as $\delta_b$. A relationship between the applied force and the change in bolt tension can be approximated as follows.

From elementary mechanics of materials, the axial deformation of an axially loaded uniform member is

$$\delta = \frac{PL}{AE}$$

(7.3)

where

- $P =$ applied axial force
- $L =$ original, undeformed length
- $A =$ cross-sectional area
- $E =$ modulus of elasticity

Equation 7.3 can be solved for the load:

$$P = \frac{AE\delta}{L}$$

(7.4)

The change in bolt force corresponding to a given axial displacement $\delta_b$ therefore is

$$\Delta T = \frac{A_bE_b\delta_b}{L_b}$$

(7.5)

where the subscript indicates a property or dimension of the bolt. Application of Equation 7.4 to the compression flange requires a somewhat more liberal interpretation of the load distribution in that $N$ must be treated as if it were uniformly applied over a surface area, $A_{fr}$. The change in the force $N$ is then obtained from Equation 7.4 as

$$\Delta N = \frac{A_{fr}E_{fr}\delta_{fr}}{L_{fr}}$$

(7.6)

where $L_{fr}$ is the flange thickness. As long as the connected parts (the two flanges) remain in contact, the bolt deformation, $\delta_b$, and the flange deformation, $\delta_{fr}$, will be equal. Because $E_{fr}$ approximately equals $E_b$ (Bickford, 1981), and $A_{fr}$ is much larger than $A_b$,

$$\frac{A_{fr}E_{fr}\delta_{fr}}{L_{fr}} \gg \frac{A_bE_b\delta_b}{L_b}$$

and therefore

$$\Delta N \gg \Delta T$$

The ratio of $\Delta T$ to $\Delta N$ is in the range of 0.05 to 0.1 (Kulak, Fisher, and Struik, 1987). Consequently, $\Delta T$ will be no greater than 0.1$\Delta N$, or equivalently, maximum $\Delta T/\Delta N = 0.1$, demonstrating that most of the applied load is devoted to relieving the compression of the connected parts. To estimate the magnitude of the load required
to overcome completely the clamping effect and cause the parts to separate, consider the free-body diagram in Figure 7.26. When the parts have separated,

\[ T = F \]

or

\[ T_0 + \Delta T = F \]  \( (7.7) \)

At the point of impending separation, the bolt elongation and plate decompression are the same, and

\[ \Delta T = \frac{A_b E_b}{L_b} \delta_b = \frac{A_b E_b}{L_b} \delta_f \]  \( (7.8) \)

where \( \delta_f \) is the elongation corresponding to the release of the initial compression force \( N_0 \). From Equation 7.3,

\[ \delta_f = \frac{N_0 L_{ft}}{A_{ft} E_{ft}} \]

Substituting this expression for \( \delta_f \) into Equation 7.8 yields

\[ \Delta T = \left( \frac{A_b E_b}{L_b} \right) \left( \frac{N_0 L_{ft}}{A_{ft} E_{ft}} \right) = \left( \frac{A_b E_b / L_b}{A_{ft} E_{ft} / L_{ft}} \right) N_0 = \left( \frac{\Delta T}{\Delta N} \right) T_0 \approx 0.1 T_0 \]

From Equation 7.7,

\[ T_0 + 0.1 T_0 = F \quad \text{or} \quad F = 1.1 T_0 \]

Therefore, at the instant of separation, the bolt tension is approximately 10% larger than its initial value at installation. Once the connected parts separate, however, any increase in external load will be resisted entirely by a corresponding increase in bolt tension. If the bolt tension is assumed to be equal to the externally applied force (as if there were no initial tension) and the connection is loaded until the connected parts separate, the bolt tension will be underestimated by less than 10%. Although this 10% increase is theoretically possible, tests have shown that the overall strength of a connection with fasteners in tension is not affected by the installation tension (Amrine and Swanson, 2004). However, the amount of pretension was found to affect the deformation characteristics of the connection.
In summary, the tensile force in the bolt should be computed without considering any initial tension.

**Prying Action**

In most connections in which fasteners are subjected to tension forces, the flexibility of the connected parts can lead to deformations that increase the tension applied to the fasteners. A hanger connection of the type used in the preceding discussion is subject to this type of behavior. The additional tension is called a *prying force* and is illustrated in Figure 7.27, which shows the forces on a free body of the hanger. Before the external load is applied, the normal compressive force, $N_0$, is centered on the bolt. As the load is applied, if the flange is flexible enough to deform as shown, the compressive forces will migrate toward the edges of the flange. This redistribution will change the relationship between all forces, and the bolt tension will increase from $B_0$ to $B$. If the connected parts are sufficiently rigid, however, this shifting of forces will not occur, and there will be no prying action. The maximum value of the prying force, $q$, will be reached when only the corners of the flange remain in contact with the other connected part. The corresponding bolt force, including the effects of prying, is $B_c$.

In connections of this type, bending caused by the prying action will usually control the design of the connected part. AISC J3.6 requires that prying action be included in the computation of tensile loads applied to fasteners.

A procedure for the determination of prying forces, based on research reported in *Guide to Design Criteria for Bolted and Riveted Joints* (Kulak, Fisher, and Struick, 1987), is given in the *Manual* in Part 9, "Design of Connection Elements."

**FIGURE 7.27**

![Diagram showing prying action](image)

Before external load

After external load

Maximum prying force
This method is presented here in a somewhat different form, but it gives the same results.

The method used is based on the model shown in Figure 7.28. All forces are for one fastener. Thus, $T$ is the external tension force applied to one bolt, $q$ is the prying force corresponding to one bolt, and $B_c$ is the total bolt force. The prying force has shifted to the tip of the flange and is at its maximum value.

The equations that follow are derived from consideration of equilibrium based on the free-body diagrams in Figure 7.28. From the summation of moments at $b-b$ in Figure 7.28b,

$$ Tb - M_{a-a} = qa $$  \hspace{2cm} (7.9)

From Figure 7.28c,

$$ M_{b-b} = qa $$  \hspace{2cm} (7.10)

Finally, equilibrium of forces requires that

$$ B_c = T + q $$  \hspace{2cm} (7.11)

These three equilibrium equations can be combined to obtain a single equation for the total bolt force, which includes the effects of prying action. We first define the
variable $\alpha$ as the ratio of the moment per unit length along the bolt line to the moment per unit length at the face of the stem. For the bolt line, the length is a net length, so

$$\alpha = \frac{M_{b-b}/(p-d')}{M_{a-a}/p} = \frac{M_{b-b}}{M_{a-a}} \left( \frac{1}{1 - d'/p} \right) = \frac{M_{b-b}}{\delta M_{a-a}}$$  \hspace{1cm} (7.12)

where

$$p = \text{length of flange tributary to one bolt, not to exceed } 2b \text{ (see Figure 7.28a)}$$

$$d' = \text{diameter of bolt hole}$$

$$\delta = 1 - \frac{d'}{p} = \frac{\text{net area at bolt line}}{\text{gross area at stem face}}$$

The numerical evaluation of $\alpha$ will require the use of another equation, which we develop shortly. With this notation, we can combine the three Equilibrium Equations 7.9 through 7.11 to obtain the total bolt force, $B_c$:

$$B_c = T \left[ 1 + \frac{\delta \alpha}{(1 + \delta \alpha)} \frac{b}{a} \right]$$  \hspace{1cm} (7.13)

At this level of loading, deformations are so large that the resultant of tensile stresses in the bolt does not coincide with the axis of the bolt. Consequently, the bolt force predicted by Equation 7.13 is conservative and does not quite agree with test results. Much better agreement is obtained if the force $B_c$ is shifted toward the stem of the tee by an amount $d/2$, where $d$ is the bolt diameter. The modified values of $b$ and $a$ are therefore defined as

$$b' = b - \frac{d}{2} \quad \text{and} \quad a' = a + \frac{d}{2}$$

(For best agreement with test results, the value of $a$ should be no greater than 1.25$b$.)

With this modification, we can write Equation 7.13 as

$$B_c = T \left[ 1 + \frac{\delta \alpha}{(1 + \delta \alpha)} \frac{b'}{a'} \right]$$  \hspace{1cm} (7.14)

We can evaluate $\alpha$ from Equation 7.14 by setting the bolt force $B_c$ equal to the bolt tensile strength, which we denote $B$. Doing so results in

$$\alpha = \frac{[(B/T) - 1](a'/b')}{\delta[1 - [(B/T) - 1](a'/b')]}$$  \hspace{1cm} (7.15)

Two limit states are possible: tensile failure of the bolts and bending failure of the tee. Failure of the tee is assumed to occur when plastic hinges form at section $a-a$, the face of the stem of the tee, and at $b-b$, the bolt line, thereby creating a beam mechanism. The moment at each of these locations will equal $M_p$, the plastic moment capacity of a length of flange tributary to one bolt. If the absolute value of $\alpha$, obtained from Equation 7.15, is less than 1.0, the moment at the bolt line is less than the moment
at the face of the stem, indicating that the beam mechanism has not formed and the controlling limit state will be tensile failure of the bolt. The bolt force \(B_c\) in this case will equal the strength \(B\). If the absolute value of \(\alpha\) is equal to or greater than 1.0, plastic hinges have formed at both a-a and b-b, and the controlling limit state is flexural failure of the tee flange. Since the moments at these two locations are limited to the plastic moment \(M_p\), \(\alpha\) should be set equal to 1.0.

The three Equilibrium Equations 7.9 through 7.11 can also be combined into a single equation for the required flange thickness, \(t_f\). From Equations 7.9 and 7.10, we can write

\[
Tb' - M_{a-a} = M_{b-b}
\]

where \(b'\) has been substituted for \(b\). From Equation 7.12,

\[
Tb' - M_{a-a} = \delta \alpha M_{a-a}
\]

\[
M_{a-a} = \frac{Tb'}{(1 + \delta \alpha)}
\]

For LRFD, let

\[
M_{a-a} = \text{design strength} = \phi_b M_p = \phi_b \left( \frac{pt_f^2 F_y}{4} \right)
\]

where \(\phi_b = 0.90\). Substituting into Equation 7.17, we get

\[
\phi_b \frac{pt_f^2 F_y}{4} = \frac{Tb'}{(1 + \delta \alpha)}
\]

\[
t_f = \sqrt{\frac{4Tb'}{\phi_b pF_y(1 + \delta \alpha)}}
\]

where \(T\) is the factored load per bolt.

Kulak, Fisher, and Struik (1987) recognized that this procedure is conservative when compared with test results. If the ultimate stress \(F_u\) is substituted for the yield stress \(F_y\) in the expression for flexural strength, much better agreement with test results is obtained (Thornton, 1992 and Swanson, 2002). Making this substitution, we obtain

\[
\text{Required } t_f = \sqrt{\frac{4Tb'}{\phi_b pF_u(1 + \delta \alpha)}} \quad (7.18)
\]

For ASD, when we substitute \(F_u\) for \(F_y\), we get

\[
M_{a-a} = \text{allowable strength} = \frac{M_p}{\Omega_b} = \frac{1}{\Omega_b} \left( \frac{pt_f^2 F_u}{4} \right)
\]

\[
\text{Required } t_f = \sqrt{\frac{\Omega_b 4Tb'}{pF_u(1 + \delta \alpha)}} \quad (7.19)
\]
where $\Omega_b = 1.67$ and $T$ is the applied service load per bolt. Equations 7.18 and 7.19 are the same as those given in Part 9 of the Manual.

The design of connections subjected to prying is essentially a trial-and-error process. When selecting the size or number of bolts, we must make an allowance for the prying force. The selection of the tee flange thickness is more difficult in that it is a function of the bolt selection and tee dimensions. Once the trial shape has been selected and the number of bolts and their layout estimated, Equation 7.18 or 7.19 can be used to verify or disprove the choices. (If the flange thickness is adequate, the bolt strength will also be adequate.)

If the actual flange thickness is different from the required value, the actual values of $\alpha$ and $B_c$ will be different from those previously calculated. If the actual bolt force, which includes the prying force $q$, is desired, $\alpha$ will need to be recomputed as follows.

First, combine Equations 7.9 and 7.10, using $b'$ instead of $b$:

$$M_{b-b} = Tb' - M_{a-a}$$

From Equation 7.12,

$$\alpha = \frac{M_{b-b}}{\delta M_{a-a}} = \frac{Tb' - M_{a-a}}{\delta M_{a-a}} = \frac{Tb'/M_{a-a} - 1}{\delta}$$

subject to the limits

$$0 \leq \alpha \leq 1$$

For LRFD, set

$$M_{a-a} = \phi_b M_p = \phi_b \left( \frac{pt_f^2 F_u}{4} \right)$$

then

$$\alpha = \frac{\phi_b pt_f^2 F_u / 4}{\delta} - 1 = \frac{4Tb'/\phi_b pt_f^2 F_u}{\delta} - 1 = \frac{4Tb'/4Tb'}{\phi_b pt_f^2 F_u - 1}$$

(0 $\leq \alpha \leq 1$) (7.20)

where $t_f$ is the actual flange thickness. The total bolt force can then be found from Equation 7.14.

For ASD, set $M_{a-a}$ equal to the allowable moment:

$$M_{a-a} = \frac{M_p}{\Omega_b} = \frac{1}{\Omega_b} \left( \frac{pt_f^2 F_u}{4} \right)$$

Then

$$\alpha = \frac{(pt_f^2 F_u / 4)/\Omega_b}{\delta} - 1 = \frac{1}{\delta} \left( \frac{\Omega_b 4Tb'}{pt_f^2 F_u} - 1 \right)$$

(0 $\leq \alpha \leq 1$) (7.21)

where $t_f$ is the actual flange thickness. Find the total bolt force from Equation 7.14.
Although the prying analysis presented here is for tee sections, with a slight modification it can be used for double angles. For \( b \), use the distance from the bolt centerline to the mid-thickness of the angle leg, rather than to the face of the leg.

**EXAMPLE 7.9**

An 8-inch-long WT10.5 × 66 is attached to the bottom flange of a beam as shown in Figure 7.29. This hanger must support a service dead load of 20 kips and a service live load of 60 kips. Determine the number of \( \frac{3}{8} \)-inch-diameter, Group A bolts required and investigate the adequacy of the tee. A992 steel is used.

**SOLUTION**

Compute the constants that are based on the geometry of the connection.

\[
\begin{align*}
    b &= \frac{(5.5 - 0.650)}{2} = 2.425 \text{ in.} \\
    a &= \frac{(12.4 - 5.5)}{2} = 3.450 \text{ in.}
\end{align*}
\]

**FIGURE 7.29**
Since \( 1.25b = 1.25(2.425) = 3.031 \) in. < 3.450 in., use \( a = 3.031 \) in.

\[
b' = b - \frac{d}{2} = 2.425 - \frac{7/8}{2} = 1.988 \text{ in.}
\]

\[
a' = a + \frac{d}{2} = 3.031 + \frac{7/8}{2} = 3.469 \text{ in.}
\]

\[
d' = d + \frac{1}{8} = \frac{7}{8} + \frac{1}{8} = 1 \text{ in.}
\]

\[
\delta = 1 - \frac{d'}{p} = 1 - \frac{1}{4} = 0.75
\]

The bolt cross-sectional area will also be needed in subsequent calculations:

\[
A_b = \frac{\pi (7/8)^2}{4} = 0.6013 \text{ in.}^2
\]

**LRFD SOLUTION**

The design strength of one bolt is

\[
B = \phi R_n = \phi F_p A_b = 0.75(90.0)(0.6013) = 40.59 \text{ kips}
\]

The total factored load is

\[
1.2D + 1.6L = 1.2(20) + 1.6(60) = 120 \text{ kips}
\]

and the number of bolts required (without considering prying action) is \( 120/40.59 = 2.96 \). A minimum of four bolts will be needed to maintain symmetry, so **try four bolts**. The factored external load per bolt, excluding prying force, is \( T = 120/4 = 30 \) kips.

\[
p = \frac{8}{2} = 4 \text{ in.}
\]

\[
2b = 2(2.425) = 4.85 \text{ in.} > 4 \text{ in.} \quad \therefore \text{ Use } p = 4 \text{ in.}
\]

Compute \( \alpha \):

\[
\frac{B}{T} - 1 = \frac{40.59}{30} - 1 = 0.353
\]

From Equation 7.15,

\[
\alpha = \frac{[(B/T - 1)](a'/b')}{\delta[1 - [(B/T) - 1](a'/b')]} = \frac{0.353(3.469/1.988)}{0.75[1 - 0.353(3.469/1.988)]} = 2.139
\]

Because \( |\alpha| > 1.0 \), use \( \alpha = 1.0 \). From Equation 7.18,

\[
\frac{T_f}{\phi B_p F_p (1 + \delta \alpha)} = \frac{4(30)(1.988)}{0.90(4)(65)(1 + 0.75(1.0))} = 0.763 \text{ in.} \quad \text{< 1.04 in.} \quad \text{(OK)}
\]
Both the number of bolts selected and the flange thickness are adequate, and no further computations are required. To illustrate the procedure, however, we compute the prying force, using Equations 7.20 and 7.14. From Equation 7.20,

\[
\alpha = \frac{1}{\delta} \left( \frac{4Tb'}{pF_b} - 1 \right) = \frac{1}{0.75} \left( \frac{4(30)(1.988)}{0.90(4)(1.04)^2(65)} - 1 \right) = -0.07657
\]

Since \( \alpha \) must be between 0 and 1 inclusive, use \( \alpha = 0 \).

From Equation 7.14, the total bolt force, including prying, is

\[
B_c = T \left[ 1 + \frac{\delta\alpha}{1 + \delta\alpha} \frac{b'}{a'} \right] = 30 \left[ 1 + \frac{0.75(0)}{1 + 0.75 \times 0} \left( \frac{1.988}{3.469} \right) \right] = 30 \text{ kips}
\]

The prying force is

\[ q = B_c - T = 30 - 30 = 0 \text{ kips} \]

This indicates that the tee section is not flexible enough to produce prying action.

**ANSWER**

**ASD SOLUTION**

A WT10.5 \( \times \) 66 is satisfactory. Use four \( \frac{3}{4} \)-inch-diameter Group A bolts.

The allowable tensile strength of one bolt is

\[
B = \frac{R_n}{\Omega} = \frac{F_a}{\Omega} = \frac{96.0(0.6013)}{2.00} = 27.06 \text{ kips}
\]

The total applied load is

\[ D + L = 20 + 60 = 80 \text{ kips} \]

and the number of bolts required (without considering prying action) is \( \frac{80}{27.06} = 2.96 \). A minimum of four bolts will be needed to maintain symmetry, so try four bolts. The external load per bolt, excluding prying force, is \( T = 80/4 = 20 \text{ kips} \).

Compute \( \alpha \):

\[
\frac{B}{T} - 1 = \frac{27.06}{20} - 1 = 0.353
\]

\[
\alpha = \frac{[(B/T - 1)(a'/b')]}{\delta(1 - [(B/T) - 1](a'/b'))} = \frac{0.353(3.469/1.988)}{0.75[1 - 0.353(3.469/1.988)]} = 2.139
\]

Since \( |\alpha| > 1.0 \), use \( \alpha = 1.0 \). From Equation 7.19,

\[
\text{Required } \tau_f = \sqrt{\frac{\Omega_b 4Tb'}{pF_b(1 + \delta\alpha)}} = \sqrt{\frac{1.67(4)(30)(1.988)}{4(65)[1 + 0.75(1.0)]}} = 0.936 \text{ in. } < 1.04 \text{ in.} \quad (\text{OK})
\]
Determine the prying force (this is not required). From Equation 7.21,
\[ \alpha = \frac{1}{\delta} \left( \frac{\Omega_b 4Tb'}{p_i t^2 F_u} - 1 \right) = \frac{1}{0.75} \left( \frac{1.67(4)(20)(1.988)}{4(1.04)^2 (65)} - 1 \right) = -0.07406 \]

Since \( \alpha \) must be between 0 and 1 inclusive, use \( \alpha = 0 \).

\[ B_c = T \left[ 1 + \frac{\delta \alpha}{(1 + \delta \alpha) \, a'} \right] = 20 \left[ 1 + \frac{0.75(0)}{(1 + 0.75 \times 0) \, \left( \frac{1.988}{3.469} \right)} \right] = 20 \text{ kips} \]

The prying force is
\[ q = B_c - T = 20 - 20 = 0 \text{ kips} \]

This indicates that the tee section is not flexible enough to produce prying action.

**ANSWER**
A WT10.5 × 66 is satisfactory. Use four 7/8-inch-diameter Group A bolts.

If the flange thickness in Example 7.9 had proved to be inadequate, the alternatives would include trying a larger tee-shape or using more bolts to reduce \( T \), the external load per bolt.

### 7.9 COMBINED SHEAR AND TENSION IN FASTENERS

In most of the situations in which a bolt is subjected to both shear and tension, the connection is loaded eccentrically and falls within the realm of Chapter 8. However, in some simple connections the fasteners are in a state of combined loading. Figure 7.30 shows a structural tee segment connected to the flange of a column for the purpose of attaching a bracing member. This bracing member is oriented in such a way that the line

![Figure 7.30](image-url)
of action of the member force passes through the center of gravity of the connection. The vertical component of the load will put the fasteners in shear, and the horizontal component will cause tension (with the possible inclusion of prying forces). Since the line of action of the load acts through the center of gravity of the connection, each fastener can be assumed to take an equal share of each component.

As in other cases of combined loading, an interaction formula approach can be used. The shear and tensile strengths for bearing-type bolts are based on test results (Chesson et al., 1965) that can be represented by the elliptical interaction curve shown in Figure 7.31. The equation of this curve can be expressed in a general way as

\[
\left( \frac{\text{required tensile strength}}{\text{available tensile strength}} \right)^2 + \left( \frac{\text{required shear strength}}{\text{available shear strength}} \right)^2 = 1.0
\]  
\[
(7.22)
\]

where the strengths can be expressed as forces or stresses and in either LRFD or ASD format. If stresses are used, Equation 7.22 becomes

\[
\left( \frac{f_t}{F_t} \right)^2 + \left( \frac{f_v}{F_v} \right)^2 = 1.0
\]

\[
\left[ 16.1 - 4.04 \right]_{\text{comm.}}
\]  
\[
(7.23)
\]

where

\( f_t \) = requested required tensile strength (stress)  
\( F_t \) = available required tensile strength (stress)  
\( f_v \) = requested required shear strength (stress)  
\( F_v \) = available required shear strength (stress)

An acceptable combination of shear and tension is one that lies under this curve. This fact leads to the requirement that

\[
\left( \frac{f_t}{F_t} \right)^2 + \left( \frac{f_v}{F_v} \right)^2 \leq 1.0
\]
The distortion energy density in a tensile test specimen at the yield stress \( \sigma_y \) is

\[
(\bar{u}_d)_y = \frac{1}{6G} \sigma_y^3
\]  

(12.11)

since \( \sigma_1 = \sigma_y \) and \( \sigma_2 = \sigma_3 = 0 \). Therefore, yielding occurs when the distortion energy for general loading, given by Eq. 12.10, equals or exceeds the value of \((\bar{u}_d)_y\) in Eq. 12.11. Therefore, the maximum-distortion-energy failure criterion can be stated in terms of the three principal stresses as

\[
\frac{1}{2} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2] = \sigma_y^3
\]  

(12.12a)

In terms of the normal stresses and shear stresses on three arbitrary mutually orthogonal planes, the maximum-distortion-energy failure criterion can be shown to have the form

\[
\frac{1}{2} [((\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{xz}^2)] = \sigma_y^3
\]  

(12.12b)

For the case of plane stress, the corresponding expressions for the maximum-distortion-energy yield criterion can easily be obtained from Eqs. 12.12 by setting \( \sigma_3 = \sigma_2 = \tau_{zx} = \tau_{zy} = 0 \). In terms of the principal stresses, then,

\[
\sigma_1^3 - 3\sigma_1 \sigma_2 + \sigma_3^3 = \sigma_y^3
\]  

(12.13)

This is the equation of an ellipse in the \( \sigma_1 - \sigma_2 \) plane, as depicted in Fig. 12.13. For comparison purposes, the failure hexagon for the maximum-shear-stress yield theory is also shown in dashed lines in Fig. 12.13. At the six vertices of the hexagon the two failure theories coincide; that is, both theories predict that yielding will occur if the state of (plane) stress at a point corresponds to any one of these six stress states. Otherwise, the maximum-shear-stress theory gives the more conservative (i.e., smaller-valued) estimate of the stresses required to produce yielding, since the hexagon falls either on or inside the ellipse.

A convenient way to apply the maximum-distortion-energy theory is to take the square root of the left-hand side of Eq. 12.12a (or Eq. 12.12b) to form an equivalent stress quantity that is called the Mises equivalent stress. Either of the following two equations can be used to compute the Mises equivalent stress, \( \sigma_M \):

\[
\sigma_M = \sqrt{\frac{1}{2} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2}}
\]  

(12.14a)

or

\[
\sigma_M = \sqrt{\frac{1}{2} [((\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{xz}^2)]^{1/2}}
\]  

(12.14b)

For the case of plane stress, the corresponding expressions for the Mises equivalent stress can easily be obtained from Eqs. 12.14 by setting \( \sigma_3 = \sigma_2 = \tau_{zx} = \tau_{zy} = 0 \).

*See Sections 78 and 90 of Ref. 12.1.
7.9 Combined Shear and Tension in Fasteners

The AISC Specification approximates the elliptical curve with three straight line segments as shown in Figure 7.32. The equation of the sloping line is given by

\[
\frac{f_t}{f_{t0}} + \frac{f_v}{f_{v0}} = 1.3
\]  

To avoid going above the line,

\[
\left( \frac{f_t}{f_{t0}} \right) + \left( \frac{f_v}{f_{v0}} \right) \leq 1.3
\]

If Equation 7.24 is solved for the required tensile strength \( f_t \), we obtain, for a given \( f_v \),

\[
f_t = 1.3 f_v - \frac{f_v}{f_{t0}}
\]

available strength = \( \Phi \times \) nominal strength

or then

nominal strength = \( \frac{\text{available strength}}{\Phi} \)

where

\( \Phi \) for LRFD

If \( f_t \) is viewed as the available tensile strength in the presence of shear, then from Equation 7.25, the corresponding nominal strength is

\[
\frac{f_t}{f_{t0}} = \frac{1.3 f_v}{f_{t0}} - \frac{f_v}{f_{t0}}
\]

turn \( f_t \) into nominal available tensile stress left for you after you account for shear stress

\[
\text{turn } f_t \text{ into nominal available tensile stress left for you after you account for shear stress}
\]
### Available Shear Strength of Bolts, kips

Table 7-1

<table>
<thead>
<tr>
<th>Nominal Bolt Diameter, d, in.</th>
<th>( \frac{3}{8} )</th>
<th>( \frac{1}{4} )</th>
<th>( \frac{5}{32} )</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Bolt Area, in.²</td>
<td>0.307</td>
<td>0.442</td>
<td>0.601</td>
<td>0.785</td>
</tr>
<tr>
<td><strong>ASTM Desig.</strong></td>
<td><strong>Thread Cond.</strong></td>
<td><strong>F_{nv}/\Omega</strong> (ksi)</td>
<td><strong>( \phi F_{nv} )</strong> (ksi)</td>
<td><strong>Loading</strong></td>
</tr>
<tr>
<td><strong>Group A</strong></td>
<td>N 27.0</td>
<td>40.5</td>
<td>S</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>X 34.0</td>
<td>51.0</td>
<td>S</td>
<td>20.9</td>
</tr>
<tr>
<td><strong>Group B</strong></td>
<td>N 34.0</td>
<td>51.0</td>
<td>S</td>
<td>25.8</td>
</tr>
<tr>
<td></td>
<td>X 42.0</td>
<td>63.0</td>
<td>S</td>
<td>12.9</td>
</tr>
<tr>
<td><strong>A307</strong></td>
<td>– 13.5</td>
<td>20.3</td>
<td>D</td>
<td>8.29</td>
</tr>
<tr>
<td><strong>Nominal Bolt Diameter, d, in.</strong></td>
<td>1( \frac{1}{8} )</td>
<td>1( \frac{1}{4} )</td>
<td>1( \frac{5}{32} )</td>
<td>1( \frac{1}{2} )</td>
</tr>
<tr>
<td>Nominal Bolt Area, in.²</td>
<td>0.994</td>
<td>1.23</td>
<td>1.48</td>
<td>1.77</td>
</tr>
<tr>
<td><strong>ASTM Desig.</strong></td>
<td><strong>Thread Cond.</strong></td>
<td><strong>F_{nv}/\Omega</strong> (ksi)</td>
<td><strong>( \phi F_{nv} )</strong> (ksi)</td>
<td><strong>Loading</strong></td>
</tr>
<tr>
<td><strong>Group A</strong></td>
<td>N 27.0</td>
<td>40.5</td>
<td>S</td>
<td>53.7</td>
</tr>
<tr>
<td></td>
<td>X 34.0</td>
<td>51.0</td>
<td>S</td>
<td>33.8</td>
</tr>
<tr>
<td><strong>Group B</strong></td>
<td>N 34.0</td>
<td>51.0</td>
<td>S</td>
<td>67.6</td>
</tr>
<tr>
<td></td>
<td>X 42.0</td>
<td>63.0</td>
<td>S</td>
<td>41.7</td>
</tr>
<tr>
<td><strong>A307</strong></td>
<td>– 13.5</td>
<td>20.3</td>
<td>D</td>
<td>13.4</td>
</tr>
<tr>
<td><strong>ASD</strong></td>
<td><strong>LRFD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>( \Omega = 2.00 )</strong></td>
<td><strong>= 0.75</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For end loaded connections greater than 38 in., see AISC Specification Table J3.2 footnote b.

---

American Institute of Steel Construction
### Table 7-2
**Available Tensile Strength of Bolts, kips**

<table>
<thead>
<tr>
<th>Nominal Bolt Diameter, d, in.</th>
<th>6/8</th>
<th>3/4</th>
<th>7/8</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Bolt Area, in.²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM Desig.</td>
<td>ASD</td>
<td>ASD</td>
<td>ASD</td>
<td>ASD</td>
</tr>
<tr>
<td></td>
<td>LRFD</td>
<td>LRFD</td>
<td>LRFD</td>
<td>LRFD</td>
</tr>
<tr>
<td>Group A</td>
<td>45.0</td>
<td>67.5</td>
<td>13.8</td>
<td>20.7</td>
</tr>
<tr>
<td>Group B</td>
<td>56.5</td>
<td>84.8</td>
<td>17.3</td>
<td>26.0</td>
</tr>
<tr>
<td>A307</td>
<td>22.5</td>
<td>33.8</td>
<td>6.90</td>
<td>10.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nominal Bolt Diameter, d, in.</th>
<th>1 1/8</th>
<th>1 1/4</th>
<th>1 3/8</th>
<th>1 1/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Bolt Area, in.²</td>
<td>0.994</td>
<td>1.23</td>
<td>1.48</td>
<td>1.77</td>
</tr>
<tr>
<td>ASTM Desig.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASD</td>
<td>ASD</td>
<td>ASD</td>
<td>ASD</td>
</tr>
<tr>
<td></td>
<td>LRFD</td>
<td>LRFD</td>
<td>LRFD</td>
<td>LRFD</td>
</tr>
<tr>
<td>Group A</td>
<td>45.0</td>
<td>67.5</td>
<td>44.7</td>
<td>67.1</td>
</tr>
<tr>
<td>Group B</td>
<td>56.5</td>
<td>84.8</td>
<td>58.2</td>
<td>84.2</td>
</tr>
<tr>
<td>A307</td>
<td>22.5</td>
<td>33.8</td>
<td>22.4</td>
<td>33.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ASD</th>
<th>LRFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Omega = 2.00 )</td>
<td></td>
</tr>
<tr>
<td>( \phi = 0.75 )</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- ASD: Allowable Stress Design
- LRFD: Load and Resistance Factor Design

**Calculation:**
\[ T_u = \frac{F_{mt}}{\phi_f} \]

**Designation:**
- Pure Tension Only
### TABLE J3.2
Nominal Strength of Fasteners and Threaded Parts, ksi (MPa)

<table>
<thead>
<tr>
<th>Description of Fasteners</th>
<th>Nominal Tensile Strength, ( F_{nt} ), ksi (MPa)[a]\</th>
<th>Nominal Shear Strength in Bearing-Type Connections, ( F_{nv} ), ksi (MPa)[b]\</th>
</tr>
</thead>
<tbody>
<tr>
<td>A307 bolts</td>
<td>45 (310)</td>
<td>27 (188)[c][d]</td>
</tr>
<tr>
<td>Group A (e.g., A325) bolts, when threads are not excluded from shear planes</td>
<td>90 (620)</td>
<td>54 (372)[c][d]</td>
</tr>
<tr>
<td>Group A (e.g., A325) bolts, when threads are excluded from shear planes</td>
<td>90 (620)</td>
<td>68 (457)</td>
</tr>
<tr>
<td>Group B (e.g., A490) bolts, when threads are not excluded from shear planes</td>
<td>113 (780)</td>
<td>68 (457)[c][d]</td>
</tr>
<tr>
<td>Group B (e.g., A490) bolts, when threads are excluded from shear planes</td>
<td>113 (780)</td>
<td>84 (579)</td>
</tr>
<tr>
<td>Threaded parts meeting the requirements of Section A3.4, when threads are not excluded from shear planes</td>
<td>0.75(F_{u})</td>
<td>0.450(F_{u})</td>
</tr>
<tr>
<td>Threaded parts meeting the requirements of Section A3.4, when threads are excluded from shear planes</td>
<td>0.75(F_{u})</td>
<td>0.563(F_{u})</td>
</tr>
</tbody>
</table>

\[a\] For high-strength bolts subject to tensile fatigue loading, see Appendix 3.

\[b\] For end loaded connections with a fastener pattern length greater than 39 in. (965 mm), \( F_{nv} \) shall be reduced to 83.3% of the tabulated values. Fastener pattern length is the maximum distance parallel to the line of force between the centerline of the bolts connecting two parts with one faying surface.

\[c\] For A307 bolts the tabulated values shall be reduced by 1% for each \(\frac{1}{8}\) in. (2 mm) over 5 diameters of length in the grip.

\[d\] Threads permitted in shear planes.

2. **Size and Use of Holes**

The maximum sizes of holes for bolts are given in Table J3.3 or Table J3.3M, except that larger holes, required for tolerance on location of anchor rods in concrete foundations, are permitted in column base details.

*Standard holes* or *short-slotted holes* transverse to the direction of the load shall be provided in accordance with the provisions of this specification, unless oversized holes, short-slotted holes parallel to the load, or *long-slotted holes* are approved.

*Specification for Structural Steel Buildings, June 27, 2010*

*American Institute of Steel Construction*
Simple Connections

\[ F_{nt} = 1.3F'_{nt} - \frac{F_{nt}}{f_{m}} \]

or

\[ F'_{nt} = F_{nt}(1.3 - \frac{r_{n}}{\phi F_{m}}) \]

where

- \( F'_{nt} \) = nominal tensile stress in the presence of shear
- \( F_{nt} \) = nominal tensile stress in the absence of shear
- \( F_{m} \) = nominal shear stress in the absence of tension
- \( F_{nv} \) = required shear stress (induced in your bolting by shear loads)

Note that \( F'_{nt} \) must not exceed \( F_{nt} \), and \( f_{m} \) must not exceed \( F_{nv} \). The nominal tensile strength is then

\[ R_{nt} = F_{nt} A_{bolting} \]

Equation 7.26 will now be presented in the two design formats.

**LRFD**

\[ \Phi = \phi = 0.75 \]

and

\[ F'_{nt} = 1.3F_{nt} - \frac{F_{nt}}{\phi F_{nv}} f_{m} \leq F_{nt} \]

(AISC Equation J3-3a)

**ASD**

\[ \Phi = \frac{1}{\Omega} \]

and

\[ F'_{nt} = 1.3F_{nt} - \frac{\Omega F_{nt}}{F_{nv}} f_{m} \leq F_{nt} \]

(AISC Equation J3-3b)

where \( \Omega = 2.00 \).

The Commentary to AISC J3.7 gives alternative interaction equations based on the elliptical solution. Either these alternative equations or the elliptical equation itself, Equation 7.23, may be used in lieu of AISC Equations J3-3a and J3-3b. In this book, we use AISC Equations J3-3a and J3-3b.

In slip-critical connections subject to both shear and tension, interaction of shear and tension need not be investigated. However, the effect of the applied tensile force is to relieve some of the clamping force, thereby reducing the available friction force. The AISC Specification reduces the slip-critical strength for this case.
2. **Size and Use of Holes**

The maximum sizes of holes for bolts are given in Table J3.3 or Table J3.3M, except that larger holes, required for tolerance on location of anchor rods in concrete foundations, are permitted in column base details.

*Standard holes* or *short-slotted holes* transverse to the direction of the load shall be provided in accordance with the provisions of this specification, unless oversized holes, short-slotted holes parallel to the load, or *long-slotted holes* are approved.
6. Tensile and Shear Strength of Bolts and Threaded Parts

The design tensile or shear strength, $\phi R_n$, and the allowable tensile or shear strength, $R_n/\Omega$, of a snug-tightened or pretensioned high-strength bolt or threaded part shall be determined according to the limit states of tension rupture and shear rupture as follows:

$$ R_n = F_n A_b $$

(J3-1)

where

$$ Ru \leq \phi R_n $$

$A_b$ = nominal unthreaded body area of bolt or threaded part, in.$^2$ (mm$^2$)

$F_n$ = nominal tensile stress, $F_{nt}$, or shear stress, $F_{nv}$, from Table J3.2, ksi (MPa)

The required tensile strength shall include any tension resulting from prying action produced by deformation of the connected parts.

User Note: The force that can be resisted by a snug-tightened or pretensioned high-strength bolt or threaded part may be limited by the bearing strength at the bolt hole per Section J3.10. The effective strength of an individual fastener may be taken as the lesser of the fastener shear strength per Section J3.6 or the bearing strength at the bolt hole per Section J3.10. The strength of the bolt group is taken as the sum of the effective strengths of the individual fasteners.

7. Combined Tension and Shear in Bearing-Type Connections

The available tensile strength of a bolt subjected to combined tension and shear shall be determined according to the limit states of tension and shear rupture as follows:

$$ R_{nt} = F'_{nt} A_b $$

(J3-2)

where

$$ F'_{nt} = \frac{F_{nt}}{\phi F_{nv}} \leq F_{nt} \quad \text{(LRFD)} $$

(J3-3a)

$$ F_{nv} = \frac{F_{nv}}{\phi F_{nt}} \leq F_{nv} \quad \text{(ASD)} $$

(J3-3b)

$F_{nt}$ = nominal tensile stress from Table J3.2, ksi (MPa)

$F_{nv}$ = nominal shear stress from Table J3.2, ksi (MPa)

$f_{rv}$ = required shear stress using LRFD or ASD load combinations, ksi (MPa)

The available shear stress of the fastener shall equal or exceed the required shear stress, $f_{rv}$. 

Specification for Structural Steel Buildings, June 22, 2010
AMERICAN INSTITUTE OF STEEL CONSTRUCTION
The AISC Specification approximates the elliptical curve with three straight line segments as shown in Figure 7.32. The equation of the sloping line is given by

\[
\left( \frac{f_t}{F_t} \right) + \left( \frac{f_v}{F_v} \right) = 1.3 \\
\frac{f_t}{F_t} + \frac{f_v}{F_v} = 1.3 \frac{F_t}{F_v}
\]  \hspace{1cm} (7.24)

To avoid going above the line,

\[
\left( \frac{f_t}{F_t} \right) + \left( \frac{f_v}{F_v} \right) \leq 1.3
\]

If Equation 7.24 is solved for the required tensile strength \( f_t \), we obtain, for a given \( f_v \),

\[
f_t = 1.3F_t - \frac{f_v}{F_v} F_t
\]  \hspace{1cm} (7.25)

Let

\[
\text{Design strength} = \Phi \times \text{nominal strength}
\]

or

\[
\text{Available strength} = \Phi \times \text{nominal strength}
\]

Nominal strength = \( \frac{\text{available strength}}{\Phi} \)

where

\[
\Phi = \phi \text{ for LRFD} \\
= \frac{1}{\Omega} \text{ for ASD}
\]

If \( f_t \) is viewed as the available tensile strength in the presence of shear, then from Equation 7.25, the corresponding nominal strength is

\[
\frac{f_t}{\Phi} = 1.3 \frac{F_t}{\Phi} - \frac{f_v}{\Phi F_v}
\]
or

\[ F'_{nt} = 1.3F_{nt} - \frac{F_{nt}}{F_v} f_v \]

or

\[ F'_{nt} = 1.3F_{nt} - \frac{F_{nt}}{\Phi F_{nv}} f_{rv} \]  \hspace{1cm} (7.26)

where

- \( F'_{nt} \) = nominal tensile stress in the presence of shear
- \( F_{nt} \) = nominal tensile stress in the absence of shear
- \( F_{nv} \) = nominal shear stress in the absence of tension
- \( f_{rv} \) = required shear stress

Note that \( F'_{nt} \) must not exceed \( F_{nt} \), and \( f_{rv} \) must not exceed \( F_{nv} \). The nominal tensile strength is then

\[ R_n = F'_{nt} A_b \]  \hspace{1cm} (AISC Equation J3-2)

Equation 7.26 will now be presented in the two design formats.

**LRFD**

\[ \Phi = \phi \]

and

\[ F'_{nt} = 1.3F_{nt} - \frac{F_{nt}}{\phi F_{nv}} f_{rv} \leq F_{nt} \]  \hspace{1cm} (AISC Equation J3-3a)

where \( \phi = 0.75 \).

**ASD**

\[ \Phi = \frac{1}{\Omega} \]

and

\[ F'_{nt} = 1.3F_{nt} - \frac{\Omega F_{nt}}{F_{nv}} f_{rv} \leq F_{nt} \]  \hspace{1cm} (AISC Equation J3-3b)

where \( \Omega = 2.00 \).

The Commentary to AISC J3.7 gives alternative interaction equations based on the elliptical solution. Either these alternative equations or the elliptical equation itself, Equation 7.23, may be used in lieu of AISC Equations J3-3a and J3-3b. In this book, we use AISC Equations J3-3a and J3-3b.

In slip-critical connections subject to both shear and tension, interaction of shear and tension need not be investigated. However, the effect of the applied tensile force is to relieve some of the clamping force, thereby reducing the available
Combined Shear and Tension in Fasteners

For LRFD,

\[ k_{sc} = 1 - \frac{T_n}{D_u T_{b} N_{b}} \]

where

- \( T_n \) = total factored tensile load on the connection
- \( T_{b} \) = total service tensile load on the connection (ASD)
- \( D_u \) = ratio of mean bolt pretension to specified minimum pretension; default value is 1.13
- \( T_{b} \) = prescribed initial bolt tension from AISC Table J3.1
- \( N_{b} \) = number of bolts in the connection

The AISC Specification approach to the analysis of bolted connections loaded in both shear and tension can be summarized as follows:

**Bearing-type connections:**
1. Check shear and bearing against the usual strengths.
2. Check tension against the reduced tensile strength using AISC Equation J3-3a (LRFD) or J3-3b (ASD)

**Slip-critical connections:**
1. Check tension, shear, and bearing against the usual strengths.
2. Check the slip-critical load against the reduced slip-critical strength.

---

**Example 7.10**

A WT10.5 × 31 is used as a bracket to transmit a 60-kip service load to a W14 × 90 column, as previously shown in Figure 7.30. The load consists of 15 kips dead load and 45 kips live load. Four \( \frac{3}{8} \)-inch-diameter A325 bolts are used. The column is of A992 steel, and the bracket is A36. Assume all spacing and edge-distance requirements are satisfied, including those necessary for the use of the maximum nominal strength in bearing (i.e., \( 2.4d F_u \)), and determine the adequacy of the bolts for the following types of connections: (a) bearing-type connection with the threads in shear and (b) slip-critical connection with the threads in shear.

(The following values are used in the LRFD and ASD solutions.)

**Solution**

Compute the nominal bearing strength (flange of tee controls).

\[ R_n = 2.4d F_u = 2.4 \left( \frac{7}{8} \right) (0.615)(58) = 74.91 \text{ kips/bolt} \]