Combined Shear and Tension in Fasteners

Example 7.10 below

(This reduction is not made for certain types of eccentric connections; that will be covered in Chapter 8.) The reduction is made by multiplying the slip-critical strength by a factor $k_{sc}$ as follows:

For LRFD,

$$k_{sc} = 1 - \frac{T_u}{D_u T_b N_b}$$

(AISC Equation J3-5a)

For ASD,

$$k_{sc}$$

(AISC Equation J3-5b)

where

$T_u$ = total factored tensile load on the connection

$T_p$ = total partial 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) / 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 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., $2.4 d F_u$), 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 both LRFD and ASD calculations.)

**Solution**

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

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

Crushing bearing nominal supply available

(WT10.5 × 31) (A

0.615" & 58 kpsi

W14 × 90 (A992

0.710" & 65 kpsi)
User Note: Note that when the required stress, \( f \), in either shear or tension, is less than or equal to 30% of the corresponding available stress, the effects of combined stress need not be investigated. Also note that Equations J3-3a and J3-3b can be rewritten so as to find a nominal shear stress, \( \sigma'_{nv} \), as a function of the required tensile stress, \( f_t \).

8. High-Strength Bolts in Slip-Critical Connections

_Slip-critical connections_ shall be designed to prevent slip and for the _limit states_ of _bearing-type connections_. When slip-critical bolts pass through _fillers_, all surfaces subject to slip shall be prepared to achieve design slip resistance.

The available slip resistance for the limit state of slip shall be determined as follows:

\[
R_n = \mu D_b h_f T_b n_x
\]

(J3-4)

(a) For standard size and short-slotted holes perpendicular to the direction of the load

\[ \phi = 1.00 \text{ (LRFD)} \quad \Omega = 1.50 \text{ (ASD)} \]

(b) For oversized and short-slotted holes parallel to the direction of the load

\[ \phi = 0.85 \text{ (LRFD)} \quad \Omega = 1.76 \text{ (ASD)} \]

(c) For long-slotted holes

\[ \phi = 0.70 \text{ (LRFD)} \quad \Omega = 2.14 \text{ (ASD)} \]

where

\( \mu = \) mean slip coefficient for Class A or B surfaces, as applicable, and determined as follows, or as established by tests:

(i) For Class A surfaces (unpainted clean _milled scale_ steel surfaces or surfaces with Class A coatings on blast-cleaned steel or hot-dipped galvanized and roughened surfaces)

\[ \mu = 0.30 \]

(ii) For Class B surfaces (unpainted blast-cleaned steel surfaces or surfaces with Class B coatings on blast-cleaned steel)

\[ \mu = 0.50 \]

\( D_u = 1.13 \), a multiplier that reflects the ratio of the mean installed bolt pretension to the specified minimum bolt pretension. The use of other values may be approved by the _engineer of record_.

\( T_b = \) minimum _fastener_ tension given in Table J3.1, kips, or Table J3.1M, kN

\( h_f = \) factor for fillers, determined as follows:

(i) Where there are no fillers or where bolts have been added to distribute loads in the filler

\[ h_f = 1.0 \]
(ii) Where bolts have not been added to distribute the load in the filler:
(a) For one filler between connected parts
\[ h_f = 1.0 \]
(b) For two or more fillers between connected parts
\[ h_f = 0.85 \]

\( n_s \) = number of slip planes required to permit the connection to slip

9. Combined Tension and Shear in Slip-Critical Connections

When a slip-critical connection is subjected to an applied tension that reduces the net clamping force, the available slip resistance per bolt, from Section J3.8, shall be multiplied by the factor, \( k_{sc} \), as follows:

\[ k_{sc} = 1 - \frac{T_n}{D_n T_b n_b} \quad (LRFD) \]  

\[ \text{where} \]
\[ T_n = \text{required tension force using LRFD load combinations, kips (kN)} \]
\[ n_b = \text{number of bolts carrying the applied tension} \]

10. Bearing Strength at Bolt Holes

The available bearing strength, \( \Phi R_n \) and \( R_n/\Omega \), at bolt holes shall be determined for the limit state of bearing as follows:

\[ \Phi = 0.75 \quad (LRFD) \quad \Omega = 2.00 \quad (ASD) \]

The nominal bearing strength of the connected material, \( R_n \), is determined as follows:

(a) For a bolt in a connection with standard, oversized and short-slotted holes, independent of the direction of loading, or a long-slotted hole with the slot parallel to the direction of the bearing force

(i) When deformation at the bolt hole at service load is a design consideration
\[ R_n = 1.2l_c t F_u \leq 2.4d t F_u \]  
\[ \text{(J3-6a)} \]

(ii) When deformation at the bolt hole at service load is not a design consideration
\[ R_n = 1.5l_c t F_u \leq 3.0d t F_u \]  
\[ \text{(J3-6b)} \]

(b) For a bolt in a connection with long-slotted holes with the slot perpendicular to the direction of force
\[ R_n = 1.0l_c t F_u \leq 2.0d t F_u \]  
\[ \text{(J3-6c)} \]
**TABLE J3.1**

Minimum Bolt Pretension, kips*

<table>
<thead>
<tr>
<th>Bolt Size, in.</th>
<th>Group A (e.g., A325 Bolts)</th>
<th>Group B (e.g., A490 Bolts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>5/8</td>
<td>19</td>
<td>24</td>
</tr>
<tr>
<td>3/4</td>
<td>28</td>
<td>35</td>
</tr>
<tr>
<td>7/8</td>
<td>39</td>
<td>49</td>
</tr>
<tr>
<td>1</td>
<td>51</td>
<td>64</td>
</tr>
<tr>
<td>1 1/8</td>
<td>56</td>
<td>80</td>
</tr>
<tr>
<td>1 1/4</td>
<td>71</td>
<td>102</td>
</tr>
<tr>
<td>1 5/8</td>
<td>85</td>
<td>121</td>
</tr>
<tr>
<td>1 1/2</td>
<td>103</td>
<td>148</td>
</tr>
</tbody>
</table>

*Equal to 0.70 times the minimum tensile strength of bolts, rounded off to nearest kip, as specified in ASTM specifications for A325 and A490 bolts with UNC threads.

**TABLE J3.1M**

Minimum Bolt Pretension, kN*

<table>
<thead>
<tr>
<th>Bolt Size, mm</th>
<th>Group A (e.g., A325M Bolts)</th>
<th>Group B (e.g., A490M Bolts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M16</td>
<td>91</td>
<td>114</td>
</tr>
<tr>
<td>M20</td>
<td>142</td>
<td>179</td>
</tr>
<tr>
<td>M22</td>
<td>176</td>
<td>221</td>
</tr>
<tr>
<td>M24</td>
<td>205</td>
<td>257</td>
</tr>
<tr>
<td>M27</td>
<td>267</td>
<td>334</td>
</tr>
<tr>
<td>M30</td>
<td>326</td>
<td>408</td>
</tr>
<tr>
<td>M36</td>
<td>475</td>
<td>595</td>
</tr>
</tbody>
</table>

*Equal to 0.70 times the minimum tensile strength of bolts, rounded off to nearest kN, as specified in ASTM specifications for A325M and A490M bolts with UNC threads.

When bolt requirements cannot be provided within the RCSC Specification limitations because of requirements for lengths exceeding 12 diameters or diameters exceeding 1 1/2 in. (38 mm), bolts or threaded rods conforming to Group A or Group B materials are permitted to be used in accordance with the provisions for threaded parts in Table J3.2.

When ASTM A354 Grade BC, A354 Grade BD, or A449 bolts and threaded rods are used in slip-critical connections, the bolt geometry including the thread pitch, thread length, head and nut(s) shall be equal to or (if larger in diameter) proportional to that required by the RCSC Specification. Installation shall comply with all applicable requirements of the RCSC Specification with modifications as required for the increased diameter and/or length to provide the design pretension.
Nominal shear strength of bolts:

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

Shear nominal supply:

\[ V_n = F_{nv} A_b = 54(0.6013) = 32.5 \text{ kips/Bolt} \]

**LRFD Solution**

\[ P_u = 1.2D + 1.6L = 1.2(15) + 1.6(45) = 90 \text{ kips} \]

a. The total shear/bearing load is

\[ V_n = \frac{3}{5} (90) = 54 \text{ kips} \]

The shear/bearing force per bolt is

\[ V_{nbolt} = \frac{54}{4} = 13.5 \text{ kips/Bolt} \]

The design bearing strength is

\[ \phi R_n = 0.75(74.91) = 56.2 \text{ kips} > 13.5 \text{ kips} \]

(OK)

The design shear strength is

\[ \phi R_n = 0.75(32.5) = 24.4 \text{ kips} > 13.5 \text{ kips} \]

(OK)

The total tension load is

\[ T_n = \frac{4}{5} (90) = 72 \text{ kips} \]

The tensile force per bolt is

\[ T_{nbolt} = \frac{72}{4} = 18 \text{ kips/Bolt} \]

To determine the available tensile strength, use AISC Equation J3-3a:

\[ F_{nt} = 1.3F_{nt} - \frac{F_{nt}}{\phi F_{nv}} F_{nt} = F_{nt}(1.3 - \frac{f_{nv}}{\phi F_{nv}}) \]

where

\[ F_{nt} = \text{nominal tensile stress in the absence of shear} = 90 \text{ ksi} \]

\[ F_{nv} = \text{nominal shear stress in the absence of tension} = 54 \text{ ksi} \]

\[ f_{nv} = \frac{V_{nbolt}}{A_b} = \frac{13.5}{0.6013} = 22.45 \text{ ksi} \]

Then

\[ F_{nt}' = 1.3(90) - \frac{90}{0.75(22.45)} = 22.45 \text{ ksi} < 90 \text{ ksi} \]

max table no shear limit

\[ F_{nt} = \text{nominal tensile stress left for you after accounting for presence of shear if bolt to slip.} \]
### 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)</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)</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 38 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 1/16 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 22, 2010
American Institute of Steel Construction*
7.9 Combined Shear and Tension in Fasteners

The nominal tensile strength is

\[ R_n = F'_n A_p = 67.1 \times 0.6013 = 40.1 \text{kips} \]

and the available tensile strength is

\[ R_{ax} = 0.75(40.4) = 30.3 \text{kips} \geq 18 \text{kips} \]

The connection is adequate as a bearing-type connection. (In order not to obscure the combined loading features of this example, prying action has not been included in the analysis.) No friction assumed. None given.

b. From Part a, the shear, bearing, and tensile strengths are satisfactory. From AISC Equation J3-4, the slip-critical strength is

\[ R_s = \mu D_p k T_b N_b \text{ (SLIP)} \]

From AISC Table J3.1, the prescribed tension for a 3/8-inch-diameter A325 bolt is

\[ T_b = 39 \text{kips} \]

If we assume Class A surfaces, the slip coefficient is \( \mu = 0.3 \) and for four bolts,

\[ R_n = \mu D_p k T_b N_b \times 4 = 0.3 \times (1.13)(1)(39)(4) = 52.9 \text{kips} \]

Since there is a tensile load on the bolts, the slip-critical strength must be reduced by a factor of

\[ k_s = 1 - \frac{T_n}{D_p T_b N_b} = 1 - \frac{72}{1.13(39)(4)} = 0.5916 \]

The reduced strength is therefore

\[ k_s(52.9) = 0.5916(52.9) = 31.3 \text{kips} < 54 \text{kips} \]

(N.G.)

The connection is inadequate as a slip-critical connection.

ASD Solution

\[ P = D + L = 15 + 45 = 60 \text{kips} \]

a. The total shear/bearing load is

\[ V_a = \frac{3}{5}(60) = 36 \text{kips} \]

The shear/bearing force per bolt is

\[ V_{a,bolt} = \frac{36}{4} = 9.0 \text{kips} \]

The allowable bearing strength is

\[ \frac{R_n}{\Omega} = \frac{74.91}{2.00} = 37.5 \text{kips} > 9.0 \text{kips} \]

(OK)
User Note: Note that when the required stress, $f_t$, in either shear or tension, is less than or equal to 30% of the corresponding available stress, the effects of combined stress need not be investigated. Also note that Equations J3-3a and J3-3b can be rewritten so as to find a nominal shear stress, $F''_{n}$, as a function of the required tensile stress, $f_t$.

8. High-Strength Bolts in Slip-Critical Connections

Slip-critical connections shall be designed to prevent slip and for the limit states of bearing-type connections. When slip-critical bolts pass through fillers, all surfaces subject to slip shall be prepared to achieve design slip resistance.

The available slip resistance for the limit state of slip shall be determined as follows:

$$R_n = \mu D_u h_f T_b n_e$$  \hspace{1cm} (J3-4)

(a) For standard size and short-slotted holes perpendicular to the direction of the load

$$\phi = 1.00 \ (LRFD) \hspace{0.5cm} \Omega = 1.50 \ (ASD)$$

(b) For oversized and short-slotted holes parallel to the direction of the load

$$\phi = 0.85 \ (LRFD) \hspace{0.5cm} \Omega = 1.76 \ (ASD)$$

(c) For long-slotted holes

$$\phi = 0.70 \ (LRFD) \hspace{0.5cm} \Omega = 2.14 \ (ASD)$$

where

$\mu$ = mean slip coefficient for Class A or B surfaces, as applicable, and determined as follows, or as established by tests:

(i) For Class A surfaces (unpainted clean mill scale steel surfaces or surfaces with Class A coatings on blast-cleaned steel or hot-dipped galvanized and roughened surfaces)

$$\mu = 0.30$$

(ii) For Class B surfaces (unpainted blast-cleaned steel surfaces or surfaces with Class B coatings on blast-cleaned steel)

$$\mu = 0.50$$

$D_u = 1.13$, a multiplier that reflects the ratio of the mean installed bolt pretension to the specified minimum bolt pretension. The use of other values may be approved by the engineer of record.

$T_b = \text{minimum fastener tension given in Table J3.1, kips, or Table J3.1M, kN}$

$h_f = \text{factor for fillers, determined as follows:}$

(i) Where there are no fillers or where bolts have been added to distribute loads in the filler

$$h_f = 1.0$$

Specification for Structural Steel Buildings, June 22, 2010
AMERICAN INSTITUTE OF STEEL CONSTRUCTION
friction force. The AISC Specification reduces the slip-critical strength for this case. (This reduction is not made for certain types of eccentric connections; that will be covered in Chapter 8.) The reduction is made by multiplying the slip-critical strength by a factor $k_{sc}$ as follows:

For LRFD,

$$k_{sc} = 1 - \frac{T_u}{D_u T_b n_b}$$  \hspace{1cm} \text{(AISC Equation J3-5a)}

For ASD,

$$k_{sc} = 1 - \frac{1.5 T_u}{D_u T_b n_b}$$  \hspace{1cm} \text{(AISC Equation J3-5b)}

where:

- $T_u =$ total factored tensile load on the connection
- $T_s =$ total service tensile load on the connection
- $D_u =$ 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 7/8-inch-diameter Group A 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., $2.4 d_i F_{pt}$), 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 both the LRFD and ASD solutions.)

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

\[ R_u = 2.4dtF_u = 2.4 \left( \frac{7}{8} \right)(0.615)(58) = 74.91 \text{ kips} \]

Nominal shear strength:

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

\[ R_u = F_{nv}A_b = 54(0.6013) = 32.47 \text{ kips} \]

\[ P_u = 1.2D + 1.6L = 1.2(15) + 1.6(45) = 90 \text{ kips} \]

a. The total shear/bearing load is

\[ V_u = \frac{3}{5}(90) = 54 \text{ kips} \]

The shear/bearing force per bolt is

\[ V_{u,bolt} = \frac{54}{4} = 13.5 \text{ kips} \]

The design bearing strength is

\[ \phi R_u = 0.75(74.91) = 56.2 \text{ kips} > 13.5 \text{ kips} \quad \text{(OK)} \]

The design shear strength is

\[ \phi R_u = 0.75(32.47) = 24.4 \text{ kips} > 13.5 \text{ kips} \quad \text{(OK)} \]

The total tension load is

\[ T_u = \frac{4}{5}(90) = 72 \text{ kips} \]

The tensile force per bolt is

\[ T_{u,bolt} = \frac{72}{4} = 18 \text{ kips} \]

To determine the available tensile strength, use AISC Equation J3-3a:

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

where

\[ F_{nt} = \text{nominal tensile stress in the absence of shear} = 90 \text{ ksi} \]

\[ F_{nv} = \text{nominal shear stress in the absence of tension} = 54 \text{ ksi} \]

\[ f_{rv} = \frac{V_{u,bolt}}{A_b} = \frac{13.5}{0.6013} = 22.45 \text{ ksi} \]
Then
\[
F'_{n} = 1.3(90) - \frac{90}{0.75(54)}(22.45) = 67.11 \text{ ksi} < 90 \text{ ksi}
\]

The nominal tensile strength is
\[
R_n = F'_{n}/A_b = 67.11(0.6013) = 40.35 \text{ kips}
\]

and the available tensile strength is
\[
\phi R_n = 0.75(40.35) = 30.3 \text{ kips} > 18 \text{ kips} \quad \text{(OK)}
\]

**ANSWER**

The connection is adequate as a bearing-type connection.  (In order not to obscure the combined loading features of this example, prying action has not been included in the analysis.)

b. From Part a, the shear, bearing, and tensile strengths are satisfactory. From AISC Equation J3–4, the slip-critical strength is

\[
R_n = \mu D_u h_t T_b n_s
\]

From AISC Table J3.1, the prescribed tension for a 7/8-inch-diameter Group A bolt is

\[
T_b = 39 \text{ kips}
\]

If we assume Class A surfaces, the slip coefficient is \( \mu = 0.30 \), and for four bolts,

\[
R_n = \mu D_u h_t T_b n_s \times 4 = 0.30(1.13)(1.0)(39)(1) \times 4 = 52.88 \text{ kips}
\]

\[
\phi R_n = 1.0(61.70) = 61.70 \text{ kips}
\]

Since there is a tensile load on the bolts, the slip-critical strength must be reduced by a factor of

\[
k_{sc} = 1 - \frac{T_n}{D_u T_b n_b} = 1 - \frac{72}{1.13(39)(4)} = 0.5916
\]

The reduced strength is therefore

\[
k_{sc}(52.88) = 0.5916(52.88) = 31.3 \text{ kips} < 54 \text{ kips} \quad \text{(N.G.)}
\]

**ANSWER**

The connection is inadequate as a slip-critical connection.

**ASD SOLUTION**

\[
P_a = D + L = 15 + 45 = 60 \text{ kips}
\]

a. The total shear/bearing load is

\[
V_a = \frac{3}{5}(60) = 36 \text{ kips}
\]
The shear/bearing force per bolt is

\[ V_a \text{ bolt} = \frac{36}{4} = 9.0 \text{ kips} \]

The allowable bearing strength is

\[ \frac{R_n}{\Omega} = \frac{74.91}{2.00} = 37.5 \text{ kips} > 9.0 \text{ kips} \quad \text{(OK)} \]

The allowable shear strength is

\[ \frac{R_n}{\Omega} = \frac{32.47}{2.00} = 16.24 \text{ kips} > 9.0 \text{ kips} \quad \text{(OK)} \]

The total tension load is

\[ T_a = \frac{4}{5} (60) = 48 \text{ kips} \]

The tensile force per bolt is

\[ T_a \text{ bolt} = \frac{48}{4} = 12 \text{ kips} \]

To determine the available tensile strength, use AISC Equation J3-3b:

\[ F_{nt}' = 1.3F_{nt} - \frac{\Omega F_{nt}}{F_{nv}} f_r \leq F_{nt} \]

where

- \( F_{nt} \) = nominal tensile stress in the absence of shear = 90 ksi
- \( F_{nv} \) = nominal shear stress in the absence of tension = 54 ksi

\[ f_r = \frac{V_a \text{ bolt}}{A_b} = \frac{9.0}{0.6013} = 14.97 \text{ ksi} \]

Then

\[ F_{nt}' = 1.3(90) - \frac{2.00(90)}{54} (14.97) = 67.10 \text{ ksi} < 90 \text{ ksi} \]

The nominal tensile strength is

\[ R_n = F_{nt}' A_b = 67.10(0.6013) = 40.35 \text{ kips} \]
and the available tensile strength is

\[
\frac{R_a}{\Omega} = \frac{40.35}{2.00} = 20.2 \text{ kips} > 12 \text{ kips} \quad \text{(OK)}
\]

**ANSWER** The connection is adequate as a bearing-type connection. (In order not to obscure the combined loading features of this example, prying action has not been included in the analysis.)

b. From Part a, the shear, bearing, and tensile strengths are satisfactory. From AISC Equation J3-4, the slip-critical strength is

\[
R_s = \mu D_u h_f T_b n_s
\]

From AISC Table J3.1, the prescribed tension for a \( \frac{7}{8} \)-inch-diameter Group A bolt is

\[
T_b = 39 \text{ kips}
\]

If we assume Class A surfaces, the slip coefficient is \( \mu = 0.30 \), and for four bolts,

\[
\frac{R_s}{\Omega} = \frac{52.88}{1.50} = 35.25 \text{ kips}
\]

Since there is a tensile load on the bolts, the slip-critical strength must be reduced by a factor of

\[
k_{sc} = 1 - \frac{1.5T_s}{D_u T_b n_b} = 1 - \frac{1.5(48)}{1.13(39)(4)} = 0.5916
\]

The reduced strength is therefore

\[
k_{sc}(35.25) = 0.5916(35.25) = 20.9 \text{ kips} < 36 \text{ kips} \quad \text{(N.G.)}
\]

**ANSWER** The connection is inadequate as a slip-critical connection.

Connections with fasteners in shear and tension can be designed by trial, but a more direct procedure can be used if one assumes that the design is controlled by the strength that is reduced. If the assumption turns out to be correct, no iteration is required. This technique will be illustrated in the following example.
A concentrically loaded connection is subjected to a service-load shear force of 50 kips and a service-load tensile force of 100 kips. The loads are 25% dead load and 75% live load. The fasteners will be in single shear, and bearing strength will be controlled by a 3/4-inch-thick connected part of A36 steel. Assume that all spacing and edge distances are satisfactory, including those that permit the maximum nominal bearing strength of \( 2.4dF_u \) to be used. Determine the required number of 3/4-inch-diameter Group A bolts for the following cases: (a) a bearing-type connection with threads in the plane of shear and (b) a slip-critical connection with threads in the plane of shear. All contact surfaces have clean mill scale.

Consider this to be a preliminary design so that no consideration of prying action is necessary.

Factored load shear = \( 1.2[0.25(50)] + 1.6[0.75(50)] = 75 \) kips
Factored load tension = \( 1.2[0.25(100)] + 1.6[0.75(100)] = 150 \) kips

a. For the bearing-type connection with threads in the shear plane, assume that tension controls:

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

\[
= 1.3(90) - \frac{90}{0.75(54)} f_{rv} \leq 90
\]

\[
= 117 - 2.222 f_{rv} \leq 90
\]

\[
\phi F'_{nt} = 0.75(117 - 2.222 f_{rv}) \leq 0.75(90)
\]

\[
= 87.75 - 1.667 f_{rv} \leq 67.5
\]

Let

\[
f_{vk} = \phi F'_{nt} = \frac{150}{\Sigma A_b} \quad \text{and} \quad f_{rv} = \frac{75}{\Sigma A_b}
\]

where \( \Sigma A_b \) is the total bolt area. Substituting and solving for \( \Sigma A_b \), we get

\[
\frac{150}{\Sigma A_b} = 87.75 - 1.667 \left( \frac{75}{\Sigma A_b} \right)
\]

\[
150 = 87.75 \Sigma A_b - 1.667(75)
\]

\[
\Sigma A_b = 3.134 \text{ in.}^2
\]

The area of one bolt is

\[
A_b = \frac{\pi(3/4)^2}{4} = 0.4418 \text{ in.}^2
\]
### TABLE J3.1
Minimum Bolt Pretension, kips*

<table>
<thead>
<tr>
<th>Bolt Size, in.</th>
<th>Group A (e.g., A325 Bolts)</th>
<th>Group B (e.g., A490 Bolts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>9/16</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>3/4</td>
<td>28</td>
<td>35</td>
</tr>
<tr>
<td>7/8</td>
<td>39</td>
<td>49</td>
</tr>
<tr>
<td>1</td>
<td>51</td>
<td>64</td>
</tr>
<tr>
<td>1 1/8</td>
<td>56</td>
<td>80</td>
</tr>
<tr>
<td>1 1/4</td>
<td>71</td>
<td>102</td>
</tr>
<tr>
<td>1 3/8</td>
<td>85</td>
<td>121</td>
</tr>
<tr>
<td>1 1/2</td>
<td>103</td>
<td>148</td>
</tr>
</tbody>
</table>

*Equal to 0.70 times the minimum tensile strength of bolts, rounded off to nearest kip, as specified in ASTM specifications for A325 and A490 bolts with UNC threads.

### TABLE J3.1M
Minimum Bolt Pretension, kN*

<table>
<thead>
<tr>
<th>Bolt Size, mm</th>
<th>Group A (e.g., A325M Bolts)</th>
<th>Group B (e.g., A490M Bolts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M16</td>
<td>91</td>
<td>114</td>
</tr>
<tr>
<td>M20</td>
<td>142</td>
<td>179</td>
</tr>
<tr>
<td>M22</td>
<td>176</td>
<td>221</td>
</tr>
<tr>
<td>M24</td>
<td>205</td>
<td>257</td>
</tr>
<tr>
<td>M27</td>
<td>267</td>
<td>334</td>
</tr>
<tr>
<td>M30</td>
<td>326</td>
<td>408</td>
</tr>
<tr>
<td>M36</td>
<td>475</td>
<td>595</td>
</tr>
</tbody>
</table>

*Equal to 0.70 times the minimum tensile strength of bolts, rounded off to nearest kN, as specified in ASTM specifications for A325M and A490M bolts with UNC threads.

When bolt requirements cannot be provided within the RCSC Specification limitations because of requirements for lengths exceeding 12 diameters or diameters exceeding 1 1/2 in. (38 mm), bolts or threaded rods conforming to Group A or Group B materials are permitted to be used in accordance with the provisions for threaded parts in Table J3.2.

When ASTM A354 Grade BC, A354 Grade BD, or A449 bolts and threaded rods are used in slip-critical connections, the bolt geometry including the thread pitch, thread length, head and nut(s) shall be equal to or (if larger in diameter) proportional to that required by the RCSC Specification. Installation shall comply with all applicable requirements of the RCSC Specification with modifications as required for the increased diameter and/or length to provide the design pretension.
### TABLE J3.2
Nominal Strength of Fasteners and Threaded Parts, ksi (MPa)

<table>
<thead>
<tr>
<th>Description of Fasteners</th>
<th>Nominal Tensile Strength, $F_{tn}$, 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)</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)</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>$0.75F_u$</td>
<td>$0.450F_u$</td>
</tr>
<tr>
<td>Threaded parts meeting the requirements of Section A3.4, when threads are excluded from shear planes</td>
<td>$0.75F_u$</td>
<td>$0.563F_u$</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 $38$ 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 $1/4$ 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.
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:

\[
R_n = F_n A_b \\
\phi = 0.75 \text{ (LRFD)} \quad \Omega = 2.00 \text{ (ASD)}
\]  

where

- \( A_b \) = nominal unthreaded body area of bolt or threaded part, in.\(^2\) (mm\(^2\))
- \( F_n \) = nominal tensile stress, \( F_{nt} \), or shear stress, \( F_{mv} \), 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:

\[
R_n = F'_{nt} A_b \\
\phi = 0.75 \text{ (LRFD)} \quad \Omega = 2.00 \text{ (ASD)}
\]

where

- \( F'_{nt} \) = nominal tensile stress modified to include the effects of shear stress, ksi (MPa)

\[
F'_{nt} = 1.3 F_{nt} - \frac{F_{nt}}{\phi F_{nv}} f_{rv} \leq F_{nt} \quad \text{(LRFD)}
\]

\[
F_{nt} = \text{nominal tensile stress from Table J3.2, ksi (MPa)}
\]

\[
F_{mv} = \text{nominal shear stress from Table J3.2, ksi (MPa)}
\]

\[
f_{rv} = \text{required shear stress using LRFD or ASD load combinations, ksi (MPa)}
\]

The available shear stress of the *fastener* shall equal or exceed the required shear stress, \( f_{rv} \).
8. **High-Strength Bolts in Slip-Critical Connections**

*Slip-critical connections* shall be designed to prevent *slip* and for the *limit states* of *bearing-type connections*. When slip-critical bolts pass through *fillers*, all surfaces subject to slip shall be prepared to achieve design slip resistance.

The available slip resistance for the limit state of slip shall be determined as follows:

\[ R_s = \mu D_u h_f T_b n_s \]  \hspace{1cm} (J3-4)

(a) For standard size and short-slotted holes perpendicular to the direction of the *load*

\[ \phi = 1.00 \text{ (LRFD)} \quad \Omega = 1.50 \text{ (ASD)} \]

(b) For oversized and short-slotted holes parallel to the direction of the *load*

\[ \phi = 0.85 \text{ (LRFD)} \quad \Omega = 1.76 \text{ (ASD)} \]

(c) For long-slotted holes

\[ \phi = 0.70 \text{ (LRFD)} \quad \Omega = 2.14 \text{ (ASD)} \]

where

\[ \mu = \text{mean slip coefficient for Class A or B surfaces, as applicable, and determined as follows, or as established by tests:} \]

(i) For Class A surfaces (unpainted clean *mill scale* steel surfaces or surfaces with Class A coatings on blast-cleaned steel or hot-dipped galvanized and roughened surfaces)

\[ \mu = 0.30 \]

(ii) For Class B surfaces (unpainted blast-cleaned steel surfaces or surfaces with Class B coatings on blast-cleaned steel)

\[ \mu = 0.50 \]

\[ D_u = 1.13 \text{ a multiplier that reflects the ratio of the mean installed bolt pretension to the specified minimum bolt pretension. The use of other values may be approved by the engineer of record.} \]

\[ T_b = \text{minimum fastener tension given in Table J3.1, kips, or Table J3.1M, kN} \]

\[ h_f = \text{factor for fillers, determined as follows:} \]

(i) Where there are no fillers or where bolts have been added to distribute loads in the filler

\[ h_f = 1.0 \]
(ii) Where bolts have not been added to distribute the load in the filler:

(a) For one filler between connected parts

\[ h_f = 1.0 \]

(b) For two or more fillers between connected parts

\[ h_f = 0.85 \]

\[ n_s = \text{number of slip planes required to permit the connection to slip} \]

9. **Combined Tension and Shear in Slip-Critical Connections**

When a slip-critical connection is subjected to an applied tension that reduces the net clamping force, the available slip resistance per bolt, from Section J3.8, shall be multiplied by the factor, \( k_{sc} \), as follows:

\[ k_{sc} = 1 - \frac{T_u}{D_u T_b n_b} \quad (LRFD) \]  \hspace{1cm} (J3-5a)

\[ k_{sc} = 1 - \frac{1.5T_u}{D_u T_b n_b} \quad (ASD) \]  \hspace{1cm} (J3-5b)

where

\( T_u = \text{required tension force using ASD load combinations, kips (kN)} \)

\( T_u = \text{required tension force using LRFD load combinations, kips (kN)} \)

\( n_b = \text{number of bolts carrying the applied tension} \)

10. **Bearing Strength at Bolt Holes**

The available bearing strength, \( \phi R_n \) and \( R_n/\Omega \), at bolt holes shall be determined for the limit state of bearing as follows:

\[ \phi = 0.75 \quad (LRFD) \quad \Omega = 2.00 \quad (ASD) \]

The nominal bearing strength of the connected material, \( R_n \), is determined as follows:

(a) For a bolt in a connection with standard, oversized and short-slotted holes, independent of the direction of loading, or a long-slotted hole with the slot parallel to the direction of the force

(i) When deformation at the bolt hole at service load is a design consideration

\[ R_n = 1.2l_c t F_u \leq 2.4 dt F_u \]  \hspace{1cm} (J3-6a)

(ii) When deformation at the bolt hole at service load is not a design consideration

\[ R_n = 1.5l_c t F_u \leq 3.0 dt F_u \]  \hspace{1cm} (J3-6b)

(b) For a bolt in a connection with long-slotted holes with the slot perpendicular to the direction of force

\[ R_n = 1.0l_c t F_u \leq 2.0 dt F_u \]  \hspace{1cm} (J3-6c)
and the number of bolts required is

\[ n_b = \frac{\Sigma A_b}{A_b} = \frac{3.134}{0.4418} = 7.09 \]

(Maybe! First trial)

Try eight bolts. First, check the upper limit on \( F_n' \):

\[ f_n = \frac{75}{\Sigma A_b} = \frac{75}{8(0.4418)} = 21.22 \text{ksi} < (0.75)(54 \text{ksi}) = 40.5 \text{ksi} \]

Check tensile load:

\[ F_n' = 117 - 2f_n = 117 - 2(21.22) = 69.8 \text{ksi} < 90 \text{ksi} \quad \text{(OK)} \]

Check shear load:

\[ \phi R_n = \phi F_{av} A_b \times n_b = 0.75(54)(0.4418)(8) = 143 \text{ kips} > 75 \text{ kips} \quad \text{(OK)} \]

Check bearing:

\[ \phi R_n = \phi (2.4d F_e) \times 8 \text{ bolts} = 0.75(2.4) \left( \frac{3}{4} \right) \left( \frac{5}{16} \right)(58)(8) = 196 \text{ kips} > 75 \text{ kips} \quad \text{(OK)} \]

ANSWER  Use eight bolts.

b. Slip-critical connection. Assume that the slip load controls. The reduced slip-critical strength is

\[ k_{sc} \phi R_n \]

where

\[ k_{sc} = 1 - \frac{T_u}{D_u T_n b_n} = 1 - \frac{150}{1.13(28) n_b} = 1 - \frac{4.741}{n_b} \]

(437e) [16.1-127]

where \( T_u = 28 \text{ kips} \) (from AISC Table J3.1).

For one bolt,

\[ \phi R_n = \phi (\mu D_n h_T T_n) = 1.0(0.30)(1.13)(1.0)(28)(1.0) = 9.492 \text{ kips} \]

Setting the total factored-load shear to the reduced slip-critical strength for \( n_b \) bolts,

\[ 75 = n_b \left( 1 - \frac{4.741}{n_b} \right)(9.492) \]

\[ = 9.492 n_b - 45.0 \]

\[ n_b = 12.6 \]

Since eight bolts are adequate for shear, bearing, and tension (with a reduced tensile strength), these limit states will not have to be checked.
Has not yet

Must still

check tensile stress actual = left for you!

\[ P = \frac{\text{tension}}{A} \]

(Not fnt)

Check tension load (not required)

\[ R_{ut} = \Phi R_{nt} = \Phi \frac{F_{nt} A_b M_b}{A} \]

\[ = 0.75(69.8 \text{ ksi})(0.4418 \text{ in}^2)(8 \text{ bolts}) \]

\[ = 185 \text{ k} \]

So \( R_{ut} = 150 \text{ k} \leq 185 \text{ k} \) \( \Phi K \)
7.9 Combined Shear and Tension in Fasteners

ANSWER

For symmetry, use fourteen $\frac{3}{4}$-inch-diameter, Group A bolts.

ASD SOLUTION

Applied service-load shear = 50 kips
Applied service-load tension = 100 kips

a. For the bearing-type connection with threads in the shear plane, assume that tension controls:

$$F_{nt}' = 1.3F_{nt} - \frac{\Omega F_{mt}}{F_{rv}} f_r \leq F_{nt}$$

$$= 1.3(90) - \frac{2.00(90)}{54} f_r \leq 90$$

$$= 117 - 3.333 f_r \leq 90$$

$$\frac{F_{nt}'}{\Omega} = \frac{(117 - 3.333 f_r)}{2.00} \leq \frac{90}{2.00}$$

$$= 58.5 - 1.667 f_r \leq 45$$

Let

$$\frac{F_{nt}'}{\Omega} = \frac{100}{\sum A_b}$$

and

$$f_r = \frac{50}{\sum A_b}$$

where $\sum A_b$ is the total bolt area. Substituting and solving for $\sum A_b$, we get

$$\frac{100}{\sum A_b} = 58.5 - 1.667 \left( \frac{50}{\sum A_b} \right)$$

$$100 = 58.5 \sum A_b - 83.35$$

$$\sum A_b = 3.134 \text{ in.}^2$$

The area of one bolt is

$$A_b = \frac{\pi(3/4)^2}{4} = 0.4418 \text{ in.}^2$$

And the number of bolts required is

$$n_b = \frac{\sum A_b}{A_b} = \frac{3.134}{0.4418} = 7.09$$

Try eight bolts. First, check the upper limit on $F_{nt}'$:

$$f_r = \frac{50}{\sum A_b} = \frac{50}{8(0.4418)} = 14.15 \text{ ksi}$$

$$F_{nt}' = 117 - 3.333 f_r = 117 - 3.333(14.15) = 69.8 \text{ ksi} < 90 \text{ ksi}$$ (OK)

Check shear. The nominal shear stress for one bolt is

$$R_n = F_{nt} A_b = 54(0.4418) = 23.86 \text{ kips}$$
and the allowable strength for eight bolts is

\[
\frac{R_n}{\Omega} \times 8 = \frac{23.86}{2.00} \times 8 = 95.44 \text{ kips} > 50 \text{ kips} \quad \text{(OK)}
\]

Check bearing:

\[
\frac{R_n}{\Omega} = \frac{2.4d_fT_u}{\Omega} \times 8 \text{ bolts}
\]

\[
= \frac{2.4(3/4)(5/16)(58)}{2.00} \times 8 = 131 \text{ kips} > 50 \text{ kips} \quad \text{(OK)}
\]

**Answer**

Use eight bolts.

b. Slip-critical connection: assume that the slip load controls. The reduced slip-critical strength is

\[
k_{sc} = \frac{R_n}{\Omega}
\]

where

\[
k_{sc} = 1 - \frac{1.5T_a}{D_bT_bn_b} = 1 - \frac{1.5(100)}{1.13(28)n_b} = 1 - \frac{4.741}{n_b}
\]

where \(T_b = 28 \text{ kips} \) (from AJSC Table J3.1).

For one bolt,

\[
\frac{R_n}{\Omega} = \frac{\mu D_b h_f T_b n_b}{\Omega} = \frac{0.30(1.13)(1.0)(28)(1.0)}{1.50} = 6.328 \text{ kips}
\]

Setting the total shear load to the reduced slip-critical strength for \(n_b\) bolts,

\[
50 = n_b \left(1 - \frac{4.741}{n_b}\right)(6.328)
\]

\[
= 6.328n_b - 30.00
\]

\[n_b = 12.6\]

From Part a, the connection is adequate in shear, bearing, and tension with eight bolts, so it will be adequate if more bolts are used.

**Answer**

Use 14 bolts (one extra to provide symmetry).
7.10 WELDED CONNECTIONS

Structural welding is a process whereby the parts to be connected are heated and fused, with supplementary molten metal added to the joint. For example, the tension member lap joint shown in Figure 7.33 can be constructed by welding across the ends of both connected parts. A relatively small depth of material will become molten, and upon cooling, the structural steel and the weld metal will act as one continuous part where they are joined. The additional metal, sometimes referred to as filler metal, is deposited from a special electrode, which is part of an electrical circuit that includes the connected part, or base metal. In the shielded metal arc welding (SMAW) process, shown schematically in Figure 7.34, current arcs across a gap between the electrode and base metal, heating the connected parts and depositing part of the electrode into the molten base metal. A special coating on the electrode vaporizes and forms a protective gaseous shield, preventing the molten weld metal from oxidizing before it solidifies. The electrode is moved across the joint, and a weld bead is deposited, its size depending on the rate of travel of the electrode. As the weld cools, impurities rise to the surface, forming a coating called slag that must be removed before the member is painted or another pass is made with the electrode.

Shielded metal arc welding is normally done manually and is the process universally used for field welds. For shop welding, an automatic or semiautomatic process is usually used. Foremost among these processes is submerged arc welding (SAW). In this process, the end of the electrode and the arc are submerged in a granular flux that melts and forms a gaseous shield. There is more penetration into the base...

---

**FIGURE 7.33**

(a) (b)

---

**FIGURE 7.34**

Direction of travel

Coated electrode

Arc

Slag

Gaseous shield

Bead

Molten

Base metal
metal than with shielded metal arc welding, and higher strength results. Other commonly used processes for shop welding include gas shielded metal arc, flux cored arc, and electroslag welding.

Quality control of welded connections is particularly difficult, because defects below the surface, or even minor flaws at the surface, will escape visual detection. Welders must be properly certified, and for critical work, special inspection techniques such as radiography or ultrasonic testing must be used.

The two most common types of welds are the fillet weld and the groove weld. The lap joint illustrated in Figure 7.33a is made with fillet welds, which are defined as those placed in a corner formed by two parts in contact. Fillet welds can also be used in a tee joint, as shown in Figure 7.33b. Groove welds are those deposited in a gap, or groove, between two parts to be connected. They are most frequently used for butt, tee, and corner joints. In most cases, one or both of the connected parts will have beveled edges, called prepared edges, as shown in Figure 7.35a, although relatively thin material can be groove welded with no edge preparation. The welds shown in Figure 7.35a are complete penetration welds and can be made from one side, sometimes with the aid of a backing bar. Partial penetration groove welds can be made from one or both sides, with or without edge preparation (Figure 7.35b).

Figure 7.36 shows the plug or slot weld, which sometimes is used when more weld is needed than length of edge is available. A circular or slotted hole is cut in one of the parts to be connected and is filled with the weld metal.

**FIGURE 7.35**

(a) Complete penetration groove welds

(b) Partial penetration groove welds

**FIGURE 7.36**

Plug Welds
Of the two major types of welds, fillet welds are the most common and are considered here in some detail. The design of complete penetration groove welds is a trivial exercise in that the weld will have the same strength as the base metal and the connected parts can be treated as completely continuous at the joint. The strength of a partial penetration groove weld will depend on the amount of penetration; once that has been determined, the design procedure will be essentially the same as that for a fillet weld.

7.11 FILLET WELDS

The design and analysis of fillet welds is based on the assumption that the cross section of the weld is a 45° right triangle, as shown in Figure 7.37. Any reinforcement (buildup outside the hypotenuse of the triangle) or penetration is neglected. The size of a fillet weld is denoted \( w \) and is the length of one of the two equal sides of this idealized cross section. Standard weld sizes are specified in increments of \( \frac{1}{16} \) inch. Although a length of weld can be loaded in any direction in shear, compression, or tension, a fillet weld is weakest in shear and is always assumed to fail in this mode.

Specifically, failure is assumed to occur in shear on a plane through the throat of the weld. For fillet welds made with the shielded metal arc process, the throat is the perpendicular distance from the corner, or root, of the weld to the hypotenuse and is equal to 0.707 times the size of the weld. (The effective throat thickness for a weld made with the submerged arc welding process is larger. In this book, we conservatively assume that the shielded metal arc welding process is used.) Thus, for a given length of weld \( L \) subjected to a load of \( P \), the critical shearing stress is

\[
f_r = \frac{P}{0.707wL},
\]

where \( w \) is the weld size.

**FIGURE 7.37**

\[ \text{Throat} = w \times \cos 45° = w \times 0.707 \]

\[ A = 0.707wL \]

\[ \text{Failure plane} \]

\[ w \]