Spacing and Edge-Distance Requirements

To maintain clearances between bolt nuts and to provide room for wrench sockets, AISC J3.3 requires that center-to-center spacing of fasteners (in any direction) be no less than $2\frac{3}{4}d$ and preferably no less than $3d$, where $d$ is the fastener diameter. Minimum edge distances (in any direction), measured from the center of the hole, are given in AISC Table J3.4 as a function of bolt size. The spacing and edge distance to be considered, denoted $s$ and $\ell_e$, are illustrated in Figure 7.9.

Summary of Bearing Strength, Spacing, and Edge-Distance Requirements (Standard Holes)

a. Bearing strength:

\[ R_n = 1.2\ell_e F_u \leq 2.4 dt F_u \]  
\[ (AISC \text{ Equation } J3-6a) \]

b. Minimum spacing and edge distance: In any direction, both in the line of force and transverse to the line of force,

\[ s \geq 2\frac{3}{4}d \quad \text{(preferably } 3d) \]
\[ \ell_e \geq \text{value from AISC Table J3.4} \]

For single- and double-angle shapes, the usual gage distances given in Table 1-7A in Part 1 of the Manual (see Section 3.6) may be used in lieu of these minimums.

---

**EXAMPLE 7.1**

Check bolt spacing, edge distances, and bearing for the connection shown in Figure 7.10.

\[ 3/4'' \text{ bolts} \]

**SOLUTION**

From AISC J3.3, the minimum spacing in any direction is

\[ 2\frac{3}{4}d = 2.667\left(\frac{3}{4}\right) = 2.00 \text{ in.} \]

\[ S = 2.5'' > 2.0'' \text{ OK} \]

Actual spacing = 2.50 in. > 2.00 in. (OK)
When Group B bolts over 1 in. (25 mm) in diameter are used in slotted or oversized holes in external plies, a single hardened washer conforming to ASTM F436, except with 5/16-in. (8 mm) minimum thickness, shall be used in lieu of the standard washer.

User Note: Washer requirements are provided in the RCSC Specification, Section 6.

Long-slotted holes are permitted in only one of the connected parts of either a slip-critical or bearing-type connection at an individual faying surface. Long-slotted holes are permitted without regard to direction of loading in slip-critical connections, but shall be normal to the direction of load in bearing-type connections. Where long-slotted holes are used in an outer ply, plate washers, or a continuous bar with standard holes, having a size sufficient to completely cover the slot after installation, shall be provided. In high-strength bolted connections, such plate washers or continuous bars shall be not less than 5/16-in. (8 mm) thick and shall be of structural grade material, but need not be hardened. If hardened washers are required for use of high-strength bolts, the hardened washers shall be placed over the outer surface of the plate washer or bar.

3. **Minimum Spacing**

The distance between centers of standard, oversized or slotted holes shall not be less than 2 2/3 times the nominal diameter, $d$, of the fastener; a distance of 3$d$ is preferred.

User Note: ASTM F1554 anchor rods may be furnished in accordance to product specifications with a body diameter less than the nominal diameter. Load effects such as bending and elongation should be calculated based on minimum diameters permitted by the product specification. See ASTM F1554 and the table, “Applicable ASTM Specifications for Various Types of Structural Fasteners,” in Part 2 of the AISC Steel Construction Manual.

4. **Minimum Edge Distance**

The distance from the center of a standard hole to an edge of a connected part in any direction shall not be less than either the applicable value from Table J3.4 or Table J3.4M, or as required in Section J3.10. The distance from the center of an oversized or slotted hole to an edge of a connected part shall be not less than that required for a standard hole to an edge of a connected part plus the applicable increment, $C_2$, from Table J3.5 or Table J3.5M.

User Note: The edge distances in Tables J3.4 and J3.4M are minimum edge distances based on standard fabrication practices and workmanship tolerances. The appropriate provisions of Sections J3.10 and J4 must be satisfied.

5. **Maximum Spacing and Edge Distance**

The maximum distance from the center of any bolt to the nearest edge of parts in contact shall be 12 times the thickness of the connected part under consideration,
### TABLE J3.4
Minimum Edge Distance[a] from Center of Standard Hole[b] to Edge of Connected Part, in., in any direction

<table>
<thead>
<tr>
<th>Bolt Diameter, in.</th>
<th>Minimum Edge Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>⅛</td>
<td>⅜</td>
</tr>
<tr>
<td>⅜</td>
<td>⅞</td>
</tr>
<tr>
<td>⅝</td>
<td>1</td>
</tr>
<tr>
<td>⅞</td>
<td>1⅛</td>
</tr>
<tr>
<td>1</td>
<td>1½</td>
</tr>
<tr>
<td>1⅛</td>
<td>1¾</td>
</tr>
<tr>
<td>1¼</td>
<td>1⅝</td>
</tr>
<tr>
<td>Over 1¾</td>
<td>1⅞ × d</td>
</tr>
</tbody>
</table>

[a] If necessary, lesser edge distances are permitted provided the appropriate provisions from Sections J3.10 and J4 are satisfied, but edge distances less than one bolt diameter are not permitted without approval from the engineer of record.

[b] For oversized or slotted holes, see Table J3.5.

### TABLE J3.4M
Minimum Edge Distance[a] from Center of Standard Hole[b] to Edge of Connected Part, mm

<table>
<thead>
<tr>
<th>Bolt Diameter, mm</th>
<th>Minimum Edge Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>20</td>
<td>26</td>
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<td>22</td>
<td>28</td>
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<td>24</td>
<td>30</td>
</tr>
<tr>
<td>27</td>
<td>34</td>
</tr>
<tr>
<td>30</td>
<td>38</td>
</tr>
<tr>
<td>36</td>
<td>46</td>
</tr>
<tr>
<td>Over 36</td>
<td>1.25d</td>
</tr>
</tbody>
</table>

[a] If necessary, lesser edge distances are permitted provided the appropriate provisions from Sections J3.10 and J4 are satisfied, but edge distances less than one bolt diameter are not permitted without approval from the engineer of record.

[b] For oversized or slotted holes, see Table J3.5M.
From AISC Table J3.4, the minimum edge distance in any direction is 1 inch.

Actual edge distance = $\frac{1}{4}$ in. $> 1$ in. (OK)

For computation of the bearing strength, use a hole diameter of

$h = d + \frac{1}{16} = \frac{3}{4} + \frac{1}{16} = \frac{13}{16}$ in.

Check bearing on both the tension member and the gusset plate. For the tension member and the holes nearest the edge of the member,

$\ell_c = \ell_e - \frac{h}{2} = 1.25 - \frac{13/16}{2} = 0.8438$ in.

$R_n = 1.2\ell_c t_F u \leq 2.4t_F u$

$1.2\ell_c t_F u = 1.2(0.8438)\left(\frac{1}{2}\right)(58) = 29.36$ kips

Check upper limit:

$2.4t_F u = 2.4\left(\frac{3}{4}\right)\left(\frac{1}{2}\right)(58) = 52.20$ kips

29.36 kips < 52.20 kips $\therefore$ Use $R_n = 29.36$ kips/bolt.

(This result means that $\ell_c$ is small enough so that it must be accounted for.)

For the other holes,

$\ell_c = s - h = 2.5 - \frac{13}{16} = 1.688$ in. shear plug length

$R_n = 1.2\ell_c t_F u \leq 2.4t_F u$ same for all holes

$1.2\ell_c t_F u = 1.2(1.688)\left(\frac{1}{2}\right)(58) = 58.74$ kips shear plug strength

Upper limit (the upper limit is independent of $\ell_c$ and is the same for all bolts):

$2.4t_F u = 52.20$ kips $< 58.74$ kips $\therefore$ Use $R_n = 52.20$ kips/bolt.

(This result means that $\ell_c$ is large enough so that it does not need to be accounted for. Hole deformation controls.)
7.3 Bearing Strength, Spacing, and Edge-Distance Requirements

The bearing strength for the tension member is

\[ R_n = 2(29.36) + 2(52.20) = 163.1 \text{ kips} \]

For the gusset plate and the holes nearest the edge of the plate,

\[ \ell_c = \ell_e - \frac{h}{2} = 1.25 - \frac{13/16}{2} = 0.8438 \text{ in.} \]

\[ R_n = 1.2\ell_c t F_u \leq 2.4 dt F_u \]

\[ 1.2\ell_c t F_u = 1.2(0.8438) \left( \frac{3}{8} \right) (58) = 22.02 \text{ kips} \]

Upper limit = \[2.4 dt F_u = 2.4 \left( \frac{3}{4} \right) \left( \frac{3}{8} \right) (58) \]

\[ = 39.15 \text{ kips} > 22.02 \text{ kips} \quad \therefore \text{Use } R_n = 22.02 \text{ kips/bolt.} \]

For the other holes,

\[ \ell_c = s - h = 2.5 - \frac{13}{16} = 1.688 \text{ in.} \]

\[ R_n = 1.2\ell_c t F_u \leq 2.4 dt F_u \]

\[ 1.2\ell_c t F_u = 1.2(1.688) \left( \frac{3}{8} \right) (58) = 44.06 \text{ kips} \]

Upper limit = \[2.4 dt F_u = 39.15 \text{ kips} < 44.06 \text{ kips} \quad \therefore \text{Use } R_n = 39.15 \text{ kips/bolt.} \]

The bearing strength for the gusset plate is

\[ R_n = 2(22.02) + 2(39.15) = 122.3 \text{ kips} \]

The gusset plate controls. The nominal bearing strength for the connection is therefore

\[ R_n = 122.3 \text{ kips} \]

The design strength is \( \phi R_n = 0.75(122.3) = 91.7 \text{ kips.} \)

The required strength is

\[ R_n = 1.2D + 1.6L = 1.2(15) + 1.6(45) = 90.0 \text{ kips} < 91.7 \text{ kips} \quad \text{(OK)} \]

The allowable strength is \( R_n = \frac{122.3}{2.00} = 61.2 \text{ kips.} \)

The required strength is

\[ R_n = D + L = 15 + 45 = 60 \text{ kips} < 61.2 \text{ kips} \quad \text{(OK)} \]

Bearing strength, spacing, and edge-distance requirements are satisfied.
The bolt spacing and edge distances in Example 7.1 are the same for both the tension member and the gusset plate. In addition, the same material is used. Only the thicknesses are different, so the gusset plate will control. In cases such as this one, only the thinner component need be checked. If there is a combination of differences, such as different thicknesses, edge distances, and grades of steel, both the tension member and the gusset plate should be checked.

7.4 SHEAR STRENGTH

While bearing strength is independent of the type of fastener, shear strength is not. In Section 7.2, we saw that the shear load on a bolt is

\[ P = f_s A_b \]

where \( f_s \) is the shearing stress on the cross-sectional area of the bolt and \( A_b \) is the cross-sectional area. When the stress is at its limit, the shear load is the nominal strength, given by

\[ R_n = F_{nv} A_b \]

\[ R_n \leq \phi R_n = \phi F_{nv} A_b \]

where

- \( F_{nv} \) = nominal shear strength (expressed as a stress)
- \( A_b \) = cross-sectional area of the unthreaded part of the bolt (also known as the nominal bolt area or nominal body area)

High-strength bolts are available in two groups, defined by the strength of the bolts in those groups.

- Group B: ASTM A490, F2280, and A354 Grade BD.

ASTM A325 (from Group A) and A490 (from Group B) are the traditional high-strength bolts and are covered in the *Specification for Structural Joints Using High-Strength Bolts* (RCSC, 2009), which is the basis for the AISC provisions for high-strength bolts. A490 bolts have a higher ultimate tensile strength than A325 bolts and are assigned a higher nominal strength. They were introduced long after A325 bolts had been in general use, primarily for use with high-strength steels (Bethlehem Steel, 1969). The other bolts listed in Groups A and B have the same strengths, but have special distinguishing characteristics. For example, F1852 and F2280 bolts have special twist-off ends that simplify installation when a special bolt pretension is required. (We cover this later in this chapter.) In this book, we will use the designations Group A and Group B. For example, instead of referring to an ASTM A325 bolt, we will call it a Group A bolt. The usual selection process is to determine the number of Group A bolts needed in a connection, and if too many are required, use Group B bolts.
thickneses are different, so the gusset plate will control. In cases such as this one, only the thinner component need be checked. If there is a combination of differences, such as different thicknesses, edge distances, and grades of steel, both the tension member and the gusset plate should be checked.

**7.4 SHEAR STRENGTH**

While bearing strength is independent of the type of fastener, shear strength is not. In Section 7.2, we saw that the shear load on a bolt is

\[ P = f_s A_b \]

where \( f_s \) is the shearing stress on the cross-sectional area of the bolt, and \( A_b \) is the cross-sectional area. When the stress is at its limit, the shear load is the nominal strength, given by

\[ R_n = F_m A_b \]

where

- \( F_m \) = nominal shear stress
- \( A_b \) = cross-sectional area of the unthreaded part of the bolt (also known as the nominal bolt area or nominal body area)

The nominal shearing stress depends on the type of bolt material. Structural bolts are available in two general categories: common bolts and high-strength bolts. Common bolts, also known as unfinished bolts, are designated as ASTM A307. High-strength bolts are available in two grades: ASTM A325 and ASTM A490. A490 bolts have a higher ultimate tensile strength than A325 bolts and are assigned a higher nominal strength. They were introduced long after A325 bolts had been in general use, primarily for use with high-strength steels (Bethlehem Steel, 1969). A490 bolts are more expensive than A325 bolts, but usually fewer are required. The usual approach is to determine the number of A325 bolts needed in the connection, and if too many are required, use A490 bolts.

The chief distinction between A307 bolts and high-strength bolts, other than the ultimate stress, is that the high-strength bolts can be tightened to produce a predictable tension in the bolt, which can be relied on to produce a calculable clamping force. Although A307 bolts are adequate for many applications, they are rarely used today.

The AISC provisions for high-strength bolts are based in part on the provisions of the specification of the Research Council on Structural Connections (RCSC, 2004). The nominal shear stress is taken as 50% of the ultimate tensile strength of the bolt. If the threads are in the plane of shear, a reduced (or net) area should be used. The Specification accounts for this by using 80% of the nominal bolt area. Instead of reducing the bolt area, a factor of 0.80 is applied to the nominal stress, resulting in a different nominal stress when the threads are in the shear plane. In this way, the nominal bolt area can be used for both cases. For example, the ultimate tensile
# Identification Markings On Bolt Heads

## ASTM and SAE Standards

**Specifications - Proof Loads - Tensile Strengths**

<table>
<thead>
<tr>
<th>Grade Marking</th>
<th>Specification</th>
<th>Material</th>
<th>Bolt and Screw Size Inches</th>
<th>Proof Load psi</th>
<th>Tensile Strength min psi</th>
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</thead>
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<tr>
<td>SAE-J429</td>
<td>Low or Medium Carbon Steel</td>
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<td>33,000</td>
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<td>33,000</td>
<td>60,000</td>
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<tr>
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<td>Low or Medium Carbon Steel</td>
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<td>55,000</td>
<td>74,000</td>
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<tr>
<td>Grade-2</td>
<td></td>
<td>Over 3/4 thru 1-1/2</td>
<td>33,000</td>
<td>60,000</td>
<td></td>
</tr>
<tr>
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<td>Medium Carbon Steel</td>
<td>1/4 thru 1</td>
<td>85,000</td>
<td>120,000</td>
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<tr>
<td>Grade 5</td>
<td>Quenched and Tempered</td>
<td>Over 1 thru 1-1/4</td>
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<td>105,000</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Over 1 thru 1-1/2</td>
<td>74,000</td>
<td>105,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over 1 thru 1-1/2</td>
<td>55,000</td>
<td>95,000</td>
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<td><strong>ASTM-A325 Type 1 High Strength</strong></td>
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<td>120,000</td>
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<td></td>
<td></td>
<td>Over 1 thru 1-1/2</td>
<td>74,000</td>
<td>105,000</td>
<td></td>
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<td></td>
<td><strong>ASTM-A325 Type 2</strong></td>
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<td><strong>ASTM-A325 Type 3</strong></td>
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<td>74,000</td>
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<td></td>
<td>1/2 thru 1</td>
<td>85,000</td>
<td>120,000</td>
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<td><strong>ASTM-A354 Grade BB</strong></td>
<td>Low Alloy Steel Quenched and Tempered</td>
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<td>Alloy Steel Quenched and Tempered</td>
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<td>GRADE 8</td>
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<td>60,000</td>
<td>60,000</td>
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<tr>
<td></td>
<td><strong>ASTM-A354 Grade BD</strong></td>
<td>Alloy Steel Quenched and Tempered</td>
<td>1/2 thru 1-1/2</td>
<td>120,000</td>
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<tr>
<td></td>
<td><strong>GROUP B</strong></td>
<td></td>
<td>60,000</td>
<td>60,000</td>
<td></td>
</tr>
</tbody>
</table>

*Radial lines on Type 1 bolts are optional to manufacturer.*

*On Type 2 bolts radial lines 60 degrees apart are required.*

*Bolt Head markings include manufacturers identity symbols.*
The chief distinction between A307 bolts and high-strength bolts, other than the ultimate stress, is that the high-strength bolts can be tightened to produce a predictable tension in the bolt, which can be relied on to produce a calculable clamping force. Although A307 bolts are adequate for many applications, they are rarely used today.

The nominal shear strength, \( F_{nv} \), is based on the ultimate tensile stress of the bolt with several modification factors. First, the ultimate shear stress is taken as 0.625 times the ultimate tensile stress (Fisher et al., 1978). Next, there is a length factor of 0.90 for connections no longer than 38 inches (for longer connections, this factor is reduced to 0.75). If the threads are in the plane of shear, the reduction of the bolt area is accounted for by using 80% of the nominal bolt area. Instead of applying this reduction directly to the bolt area, a factor of 0.80 is applied to \( F_{nv} \). In this way, the nominal bolt area can be used whether the threads are in or out of the plane of shear. For example, the ultimate tensile strength of a Group A bolt is 120 ksi, so the nominal shear strength with the threads not in the shear plane is

\[
F_{nv} = 120(0.625)(0.90) = 67.5 \text{ ksi}
\]

If the threads are in the shear plane,

\[
F_{nv} = 0.8(67.5) = 54 \text{ ksi}
\]

The nominal shear strength of ASTM A307 bolts is based on the assumption that the threads will always be in the plane of shear. The shear strengths of A307, Group A, and Group B bolts, rounded to the nearest ksi, are summarized in Table 7.1. The values in Table 7.1 are also given in AISC Table J3.2.

AISC Table J3.2 refers to threads in a plane of shear as "not excluded from shear planes" and refers to threads not in a plane of shear as "excluded from shear planes." The first category, threads included in the shear plane, is sometimes referred to as connection type "N." The designation "X" can be used to indicate that threads are excluded from the plane of shear.

Although it is sometimes possible to determine in advance whether bolt threads will be in the plane of shear, it may depend on such things as which side of the connection the bolt is installed from. When it is not known whether the threads are in the plane of shear, assume that they are and use the lower shear strength. (In most cases, when the higher strength corresponding to threads not in shear is used, some limit

---

**TABLE 7.1**

<table>
<thead>
<tr>
<th>Fastener</th>
<th>Nominal Shear Strength ( R_n = F_{nv}A_b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A307</td>
<td>27A_b</td>
</tr>
<tr>
<td>Group A</td>
<td></td>
</tr>
<tr>
<td>threads in plane of shear</td>
<td>54A_b</td>
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<tr>
<td>threads not in plane of shear</td>
<td>68A_b</td>
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<tr>
<td>Group B</td>
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<tr>
<td>threads in plane of shear</td>
<td>68A_b</td>
</tr>
<tr>
<td>threads not in plane of shear</td>
<td>84A_b</td>
</tr>
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</table>
Table 7-17
Threading Dimensions for High-Strength and Non-High-Strength Bolts

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Min. Root $K_i$ in.</th>
<th>Gross Bolt Area, in.²</th>
<th>Min. Root Area, in.²</th>
<th>Net Tensile Area, in.²</th>
<th>Threads per Inch, $n^b$</th>
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</thead>
<tbody>
<tr>
<td>$\frac{1}{4}$</td>
<td>0.196</td>
<td>0.0490</td>
<td>0.0301</td>
<td>0.0320</td>
<td>20</td>
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<tr>
<td>$\frac{3}{8}$</td>
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<td>0.110</td>
<td>0.0742</td>
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<tr>
<td>$\frac{1}{2}$</td>
<td>0.417</td>
<td>0.196</td>
<td>0.136</td>
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<td>$\frac{5}{8}$</td>
<td>0.527</td>
<td>0.307</td>
<td>0.218</td>
<td>0.226</td>
<td>11</td>
</tr>
<tr>
<td>$\frac{3}{4}$</td>
<td>0.642</td>
<td>0.442</td>
<td>0.323</td>
<td>0.334</td>
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<tr>
<td>$\frac{7}{8}$</td>
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<td>0.601</td>
<td>0.447</td>
<td>0.462</td>
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<td>0.606</td>
<td>8</td>
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<tr>
<td>$\frac{11}{8}$</td>
<td>0.970</td>
<td>0.994</td>
<td>0.740</td>
<td>0.763</td>
<td>7</td>
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<tr>
<td>$\frac{13}{8}$</td>
<td>1.10</td>
<td>1.23</td>
<td>0.942</td>
<td>0.969</td>
<td>7</td>
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<tr>
<td>1½</td>
<td>1.19</td>
<td>1.48</td>
<td>1.12</td>
<td>1.16</td>
<td>6</td>
</tr>
<tr>
<td>1³⁄₄</td>
<td>1.32</td>
<td>1.77</td>
<td>1.37</td>
<td>1.41</td>
<td>6</td>
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<tr>
<td>2</td>
<td>1.53</td>
<td>2.41</td>
<td>1.85</td>
<td>1.90</td>
<td>5</td>
</tr>
<tr>
<td>2½</td>
<td>2.01</td>
<td>3.14</td>
<td>2.43</td>
<td>2.50</td>
<td>4.5</td>
</tr>
<tr>
<td>2⁵⁄₈</td>
<td>2.23</td>
<td>3.98</td>
<td>3.17</td>
<td>3.25</td>
<td>4.5</td>
</tr>
<tr>
<td>2³⁄₄</td>
<td>2.48</td>
<td>5.94</td>
<td>4.83</td>
<td>4.93</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>2.73</td>
<td>7.07</td>
<td>5.85</td>
<td>5.97</td>
<td>4</td>
</tr>
<tr>
<td>3½</td>
<td>2.98</td>
<td>8.30</td>
<td>6.97</td>
<td>7.10</td>
<td>4</td>
</tr>
<tr>
<td>3¹⁄₂</td>
<td>3.23</td>
<td>9.62</td>
<td>8.19</td>
<td>8.33</td>
<td>4</td>
</tr>
<tr>
<td>3³⁄₄</td>
<td>3.48</td>
<td>11.0</td>
<td>9.51</td>
<td>9.66</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>3.73</td>
<td>12.6</td>
<td>10.9</td>
<td>11.1</td>
<td>4</td>
</tr>
</tbody>
</table>

a) Net tensile area $= 0.7854 \times \left( \frac{d - 0.9743}{d} \right)^2$

b) For diameters listed, thread series is UNC (coarse). For larger diameters, thread series is 4UN.

2A denotes Class 2A fit applicable to external threads;
2B denotes corresponding Class 2B fit for internal threads.
strength of an A325 bolt is 120 ksi, so the nominal shear stress with the threads not in the shear plane is

\[ F_{nv} = 0.5(120) = 60 \text{ ksi} \]

If the threads are in the shear plane,

\[ F_{nv} = 0.8(60) = 48 \text{ ksi} \]

The nominal shear stress of ASTM A307 bolts is based on the assumption that the threads will always be in the plane of shear. The shear strengths of A307, A325, and A490 bolts are summarized in Table 7.1. The values in Table 7.1 are also given in AISC Table J3.2.

AISC Table J3.2 refers to threads in a plane of shear as “not excluded from shear planes” and refers to threads not in a plane of shear as “excluded from shear planes.” The first category, threads included in the shear plane, is sometimes referred to as connection type “N,” and an A325 bolt of this type can be denoted as an A325-N bolt. The designation “X” can be used to indicate that threads are excluded from the plane of shear—for example, an A325-X bolt.

Although it is sometimes possible to determine in advance whether bolt threads will be in the plane of shear, it may depend on such things as which side of the connection the bolt is installed from. When it is not known whether the threads are in the plane of shear, assume that they are and use the lower shear strength. (In most cases, when the higher strength corresponding to threads not in shear is used, some limit state other than bolt shear will control the joint design.) For LRFD, the resistance factor is 0.75, and the design strength is

\[ \phi R_n = 0.75 F_{nv} A_b \]

For ASD, the safety factor is 2.00, and the allowable strength is

\[ R_n = \frac{F_{nv} A_b}{\Omega} \]

**Example 7.2** Determine the strength of the connection shown in Figure 7.11, based on bearing and shear, for the following bolts:

a. A307
b. A325, threads in the plane of shear
c. A325, threads not in the plane of shear
### 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 &quot;N&quot;</td>
<td>( 120 * 0.75 )</td>
<td>68 * 0.8 = 54 (372)</td>
</tr>
<tr>
<td>Group A (e.g., A325) bolts, when threads are excluded from shear planes &quot;X&quot;</td>
<td>90 (620)</td>
<td>120 * 0.625 * 0.9 = 68 (457)</td>
</tr>
<tr>
<td>Group B (e.g., A490) bolts, when threads are not excluded from shear planes &quot;N&quot;</td>
<td>150 * 0.75</td>
<td>84 * 0.8 = 68 (457)</td>
</tr>
<tr>
<td>Group B (e.g., A490) bolts, when threads are excluded from shear planes &quot;X&quot;</td>
<td>150 * 0.75</td>
<td>150 * 0.625 * 0.9 = 84 (579)</td>
</tr>
</tbody>
</table>

\( F_{nv} \) 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.

**Footnotes:**

\(^a\) 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 \( \frac{1}{2} \) in. (2 mm) over 5 diameters of length in the grip.

\(^d\) Threads permitted in shear planes.

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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.
state other than bolt shear will control the joint design. For LRFD, the resistance factor is 0.75, and the design strength is

$$\phi R_n = 0.75 F_m A_b \left( \alpha_0 J^3 - 1 \right) \left[ 16,1-125 \right]$$

For ASD, the safety factor is 2.00, and the allowable strength is

$$\frac{R_n}{\Omega} = \frac{F_m A_b}{2.00}$$

**EXAMPLE 7.2 Simple Connection**

Determine the strength of the connection shown in Figure 7.11, based on bearing and shear, for the following bolts:

a. A307
b. Group A, threads in the plane of shear
c. Group A, threads not in the plane of shear

**FIGURE 7.11**

1.5" 3" 1.5"

0.375" gusset PL

PL 3/8 x 2 1/2

1.5" A36 steel

3/4"-diam. bolts

**SOLUTION**

The connection can be classified as a simple connection, and each fastener can be considered to resist an equal share of the load. Because the bearing strength will be the same for parts a, b, and c, it will be calculated first.

Since the edge distances are the same for both the tension member and the gusset plate, the bearing strength of the gusset plate will control because it is thinner than the tension member. For bearing strength computation, use a hole diameter of

$$h = d + \frac{1}{16} = \frac{3}{4} + \frac{1}{16} = \frac{13}{16}\text{ in.}$$

For the hole nearest the edge of the gusset plate,

$$\ell_c = \ell_e - \frac{h}{2} = 1.5 - \frac{13/16}{2} = 1.094\text{ in.}$$

To check shear out plug:

$$R_n = 1.2 \ell_c \ell_t \phi = 1.2(1.094)\left( \frac{3}{8} \right)(58) = 28.55\text{ kips}$$

**End bolt**

Shear out plug from plate at end
7.4 Shear Strength

Check crushing of plate at end or anywhere else:
subject to a maximum of

\[ 2.4 d t F_u = 2.4 \left( \frac{3}{4} \right) \left( \frac{3}{8} \right) \]  

Crush plate anywhere on plate

\[ 39.15 \text{kips} > 28.55 \text{kips} \]  

Use \( R_n = 28.55 \) kips for this bolt due to shear plug at end hole.

For the other hole, at interior bolt:

\[ \ell_c = s - h = 3 - \frac{13}{16} = 2.188 \text{ in.} \]

Plate crushing:

\[ R_n = 1.2 \ell_c t F_u = 1.2(2.188) \left( \frac{3}{8} \right) \]  

\[ 57.11 \text{kips} \]

The upper limit is

\[ 2.4 d t F_u = 39.15 < 57.11 \text{kips} \]

Use \( R_n = 39.15 \) kips for this bolt.

Note that the upper limit is independent of \( \ell_c \) and is the same for all bolts.

BOLT SHEAR

The bearing and shear strengths of a bolted connection cannot be considered independently. The individual strength at a given bolt location is the minimum of the bearing and shear strengths at that location. This is explained in AISC Sections 13.6 and 13.10 in the User Notes. There is further discussion in the Commentary to the Specification.

\[ [16.1-402] \text{ \& } [16.1-410] \]

a. The bolts in this connection are subject to single shear, and the nominal strength \( R_n \) of one bolt is

\[ R_n = F_{nv} A_b \]

The nominal bolt area is

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

For A307 bolts, the nominal shear strength is \( F_{nv} = 27 \text{ ksi} \), and

\[ R_n = 27(0.4418) = 11.93 \text{kips} \]

This value is smaller than the bearing strength at each hole, so the total nominal strength for the connection is

\[ R_n = 11.93 + 11.93 = 23.86 \text{kips} \]

ANSWER

For LRFD, the design strength is \( \phi R_n = 0.75(23.86) = 17.9 \text{kips} \).

For ASD, the allowable strength is

\[ \frac{R_n}{\Omega} = \frac{23.96}{2.00} = 12.0 \text{kips} \]

b. For Group A bolts with the threads in the plane of shear (type N), the nominal shear strength is \( F_{nv} = 54 \text{ ksi} \), and

\[ R_n = F_{nv} A_b = 54(0.4418) = 23.86 \text{kips} \]
(c) For connections made using bolts that pass completely through an unstiffened box member or HSS, see Section J7 and Equation J7-1;

where

\[ F_u = \text{specified minimum tensile strength} \text{ of the connected material, ksi (MPa)} \]
\[ d = \text{nominal bolt diameter, in. (mm)} \]
\[ l_c = \text{clear distance, in the direction of the force, between the edge of the hole and the edge of the adjacent hole or edge of the material, in. (mm)} \]
\[ t = \text{thickness of connected material, in. (mm)} \]

For connections, the bearing resistance shall be taken as the sum of the bearing resistances of the individual bolts.

Bearing strength shall be checked for both bearing-type and slip-critical connections. The use of oversized holes and short- and long-slotted holes parallel to the line of force is restricted to slip-critical connections per Section J3.2.

\{ User Note: The effective strength of an individual fastener is 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 the sum of the effective strengths of the individual fasteners. \}

11. Special Fasteners

The nominal strength of special fasteners other than the bolts presented in Table J3.2 shall be verified by tests.

12. Tension Fasteners

When bolts or other fasteners in tension are attached to an unstiffened box or HSS wall, the strength of the wall shall be determined by rational analysis.

J4. AFFECTED ELEMENTS OF MEMBERS AND CONNECTING ELEMENTS

This section applies to elements of members at connections and connecting elements, such as plates, gussets, angles and brackets.

1. Strength of Elements in Tension

The design strength, \( \phi R_n \), and the allowable strength, \( R_n/\Omega \), of affected and connecting elements loaded in tension shall be the lower value obtained according to the limit states of tensile yielding and tensile rupture.

(a) For tensile yielding of connecting elements

\[ R_n = F_y A_g \]  \hfill (J4-1)

\[ \phi = 0.90 \text{ (LRFD)} \quad \Omega = 1.67 \text{ (ASD)} \]

(b) For tensile rupture of connecting elements

\[ R_n = F_u A_e \]  \hfill (J4-2)
As in Part a, this value is smaller than the bearing strength at each hole, so the total nominal strength for the connection is

\[ R_n = 23.86 + 23.86 = 47.72 \text{ kips} \]

**ANSWER** For LRFD, the design strength is \( \phi R_n = 0.75(47.72) = 35.8 \text{ kips} \).

For ASD, the allowable strength is \( \frac{R_n}{\Omega} = \frac{47.72}{2.00} = 23.9 \text{ kips} \).

**ANSWER**

- **c.** For Group A bolts with the threads not in the plane of shear (type X), the nominal shear strength is \( F_{ns} = 68 \text{ ksi} \), and

\[ R_n = F_{ns} A_b = 68(0.4418) = 30.04 \text{ kips} \]

At the hole nearest the edge, the bearing strength of 28.55 kips is less than the bolt shearing strength of 30.04 kips. At the other hole, the shearing strength is smaller. The total strength is therefore

\[ R_n = 28.55 + 30.04 = 58.59 \text{ kips} \]

**ANSWER** For LRFD, the design strength is \( \phi R_n = 0.75(58.59) = 43.9 \text{ kips} \).

For ASD, the allowable strength is \( \frac{R_n}{\Omega} = \frac{58.59}{2.00} = 29.3 \text{ kips} \).

All spacing and edge-distance requirements are satisfied. The minimum edge distance required by AISC Table J3.4 is 1 inch, and this requirement is satisfied in both the longitudinal and transverse directions. The bolt spacing \( s \) is 3 inches, which is greater than \( 2\frac{3}{4}d = 2.667(\frac{3}{4}) = 2 \text{ in} \).

Note that some other limit state that has not been checked, such as tension on the net area of the member, may govern the strength of the connection of Example 7.2.

**EXAMPLE 7.3**

A plate \( 3\frac{1}{8} \times 6'' \) is used as a tension member to resist a service dead load of 12 kips and a service live load of 33 kips. This member will be connected to a \( 3\frac{1}{8}'' \)-inch gusset plate with \( 3\frac{1}{4}'' \)-inch-diameter Group A bolts. A36 steel is used for both the tension member and the gusset plate. Assume that the bearing strength is adequate, and determine the number of bolts required based on bolt shear.
For A325-X Bolts

P.P. = 28.55 k
P.C. = 39.15 k
S.B. = 30.04 k

R_n = 28.55 k (smallest)

Shear bolt = 30.04 k
Plug pullout = 57.11 k
Plate crush = 39.15 k

R_m = 30.04 k (smallest)

\[ \phi R_n = 0.75 (28.55 + 30.04) = 43.9 k \]