### TABLE D3.1
Shear Lag Factors for Connections to Tension Members

<table>
<thead>
<tr>
<th>Case</th>
<th>Description of Element</th>
<th>Shear Lag Factor, $U$</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All tension members where the tension load is transmitted directly to each of the cross-sectional elements by fasteners or welds (except as in Cases 4, 5 and 6).</td>
<td>$U = 1.0$</td>
<td><img src="image" alt="Example Image" /></td>
</tr>
<tr>
<td>2</td>
<td>All tension members, except plates and HSS, where the tension load is transmitted to some but not all of the cross-sectional elements by fasteners or longitudinal welds or by longitudinal welds in combination with transverse welds. (Alternatively, for W, M, S and HP, Case 7 may be used. For angles, Case 8 may be used.)</td>
<td>$U = 1 - \frac{x}{D}$</td>
<td><img src="image" alt="Example Image" /></td>
</tr>
<tr>
<td>3</td>
<td>All tension members where the tension load is transmitted only by transverse welds to some but not all of the cross-sectional elements.</td>
<td>$U = 1.0$ and $A_o = \text{area of the directly connected elements}$</td>
<td><img src="image" alt="Example Image" /></td>
</tr>
</tbody>
</table>
| 4    | Plates where the tension load is transmitted by longitudinal welds only. | $a) I \geq 2w... U = 1.0$
$b) 2w > I \geq 1.5w... U = 0.87$
$c) 1.5w > I \geq w... U = 0.75$ | ![Example Image](image) |
| 5    | Round HSS with a single concentric gusset plate | $a) I \geq 1.3D... U = 1.0$
$b) D \leq I < 1.3D... U = 1 - \frac{x}{D}$
$c) \bar{x} = \frac{D}{\pi}$ | ![Example Image](image) |
| 6    | Rectangular HSS with a single concentric gusset plate | $I \geq H... U = 1 - \frac{x}{I}$
$\bar{x} = \frac{B^2 + 2BH}{4(B + H)}$ | ![Example Image](image) |
|      | with two side gusset plates | $I \geq H... U = 1 - \frac{x}{I}$
$\bar{x} = \frac{B^2}{4(B + H)}$ | ![Example Image](image) |
| 7    | W, M, S or HP Shapes or Tees cut from these shapes. (If $U$ is calculated per Case 2, the larger value is permitted to be used.) with flange connected with 3 or more fasteners per line in the direction of loading | $a) b_r \geq 2/3d... U = 0.90$
$b) b_r < 2/3d... U = 0.95$ | ![Example Image](image) |
|      | with web connected with 4 or more fasteners per line in the direction of loading | $c) U = 0.70$ | ![Example Image](image) |
| 8    | Single and double angles (If $U$ is calculated per Case 2, the larger value is permitted to be used.) with 4 or more fasteners per line in the direction of loading | $a) U = 0.90$ | ![Example Image](image) |
|      | with 3 fasteners per line in the direction of loading (With fewer than 3 fasteners per line in the direction of loading, use Case 2.) | $b) U = 0.60$ | ![Example Image](image) |

$L = \text{length of connection, in. (mm)}$; $w = \text{plate width, in. (mm)}$; $x = \text{eccentricity of connection, in. (mm)}$; $B = \text{overall width of rectangular HSS member, measured 90° to the plane of the connection, in. (mm)}$; $H = \text{overall height of rectangular HSS member, measured in the plane of the connection, in. (mm)}$

*Specification for Structural Steel Buildings, June 22, 2010*

AMERICAN INSTITUTE OF STEEL CONSTRUCTION
Case 3

L 5 x 5 x 1/2

Transverse weld connected area only

u = 1.0

But: \( A_{th} = (5\text{"})(1/2\text{"}) \)

Case 7

7a) 

7b) \( b_f < \frac{2}{3}d \)

\( u = 0.85 \)

\( b_f \geq \frac{2}{3}d \)
\[ \ell \leq 1.3D: \ U = 1.0 \]
\[ D \leq \ell < 1.3D: \ U = 1 - \frac{\bar{x}}{\ell} \]
\[ \bar{x} = \frac{D}{\pi} \]
\[ \ell < D; \ U = 0 \]

\[ \ell \geq H: \ U = 1 - \frac{\bar{x}}{\ell} \]
\[ \bar{x} = \frac{B^2 + 2BH}{4(B + H)} \]
\[ \ell < H; \ U = 0 \]

\[ \ell \geq H: \ U = 1 - \frac{\bar{x}}{\ell} \]
\[ \bar{x} = \frac{B^2}{4(B + H)} \]
\[ \ell < H; \ U = 0 \]
The Commentary of the AISC Specification further illustrates \( \bar{x} \) and \( l \). Figure C-D3.2 shows some special cases for \( \bar{x} \), including channels and I-shaped members and tees connected through the web, we can use Case 2 or Case 7 of Specification Table D3.1.

2. Plates

In g

The following values apply:

- **a)** \( \cdot \) For \( l \geq 2w \) \( U = 1.0 \)
- **b)** \( \cdot \) \( F_c \)
- **c)** \( \cdot \) \( F_c \)
- **d)** \( \cdot \) For \( l \leq w \) \( U = 0 \)

3. Round HSS with \( l \geq 1.3D \) (see Figure 3.7e):

\[ U = 1.0 \]
4. Alternatives to Equation 3.1 for 

The following values may be used in 
- For four or more fasteners in 
- For three fasteners in the direction of loading, \( U = 0.60 \).

5. Alternatives to Equation 3.1 for W, M, S, HP, or Tees Cut from These Shapes:

If the following conditions are satisfied, the corresponding values may be used in lieu of Equation 3.1. (§EGUI, pg 51)

- Connected through the flange with three or more fasteners in the direction of loading, with
- Connected to loading, with
- Connected to loading: \( U = \)

Figure 3.10 illustrates
If a tension member the area of the connected
verse and longitudin
There are some
- For bolted splices and is from a requirement in Chapter 1 of the Specification “Design of Connections.”
- For open cross-sectional shapes (such as W, M, S, C, HP, WT, and ST) and (angles), the value of \( U \) need not be less than the ratio of the connected element gross area to the total gross area. \( D3 \) [16.1-27]

EXAMPLE 3.4

Determine the effective net area for the tension member shown in Figure 3.12.

\[ A_n = A_8 - A_{holes} \]
\[ = 5.77 - 1 \left( \frac{5}{2} + \frac{1}{8} \right) (2) = 5.02 \text{ in}^2 \]

Only one element (one leg) of the cross section is connected, so the net area must

\[ \bar{x} = 1.67 \text{ in.} \]
Table 1-7
Angles
Properties

<table>
<thead>
<tr>
<th>Shape</th>
<th>K</th>
<th>Wt.</th>
<th>Area, A</th>
<th>Axis X-X</th>
<th>Flexural-Torsional Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>in²</td>
<td>in.³</td>
<td>in.²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>in.³</td>
<td>in.</td>
<td>in.²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>in.³</td>
<td>in.</td>
<td>in.²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>in.³</td>
<td>in.</td>
<td>J</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cw</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Te</td>
</tr>
<tr>
<td>L8x8x1½</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x1</td>
<td>1½</td>
<td>56.9</td>
<td>18.5</td>
<td>98.1</td>
<td>17.5</td>
</tr>
<tr>
<td>x7/8</td>
<td>1½</td>
<td>51.0</td>
<td>15.1</td>
<td>89.1</td>
<td>15.8</td>
</tr>
<tr>
<td>x7/8</td>
<td>1</td>
<td>45.0</td>
<td>13.3</td>
<td>79.7</td>
<td>14.0</td>
</tr>
<tr>
<td>x7/8</td>
<td>1</td>
<td>38.9</td>
<td>11.5</td>
<td>69.9</td>
<td>12.2</td>
</tr>
<tr>
<td>x7/8</td>
<td>1</td>
<td>32.7</td>
<td>9.69</td>
<td>59.6</td>
<td>10.3</td>
</tr>
<tr>
<td>x7/8</td>
<td>1</td>
<td>28.0</td>
<td>7.77</td>
<td>45.0</td>
<td>8.06</td>
</tr>
<tr>
<td>x7/8</td>
<td>1</td>
<td>24.2</td>
<td>5.77</td>
<td>31.9</td>
<td>6.64</td>
</tr>
<tr>
<td>x7/8</td>
<td>1</td>
<td>21.9</td>
<td>4.95</td>
<td>24.1</td>
<td>5.64</td>
</tr>
<tr>
<td>x7/8</td>
<td>1</td>
<td>19.6</td>
<td>4.59</td>
<td>19.9</td>
<td>4.59</td>
</tr>
<tr>
<td>x7/8</td>
<td>1</td>
<td>17.2</td>
<td>3.95</td>
<td>15.4</td>
<td>3.51</td>
</tr>
<tr>
<td>x7/8</td>
<td>1</td>
<td>15.0</td>
<td>3.67</td>
<td>13.0</td>
<td>2.95</td>
</tr>
</tbody>
</table>

Note: For workable gages, refer to Table 1-7A. For compactness criteria, refer to Table 1-7B.
Table 1-7 (continued)

Angles

Properties

<table>
<thead>
<tr>
<th>Shape</th>
<th>Axis Y-Y</th>
<th></th>
<th>Axis Z-Z</th>
<th></th>
<th>Qs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>S</td>
<td>r</td>
<td>$\bar{x}$</td>
<td>Z</td>
</tr>
<tr>
<td></td>
<td>in.³</td>
<td>in.³</td>
<td>in.</td>
<td>in.³</td>
<td>in.</td>
</tr>
<tr>
<td>L8×8×1 1/8</td>
<td>98.1</td>
<td>17.5</td>
<td>2.41</td>
<td>2.40</td>
<td>31.6</td>
</tr>
<tr>
<td>×1</td>
<td>89.1</td>
<td>15.8</td>
<td>2.43</td>
<td>2.36</td>
<td>28.5</td>
</tr>
<tr>
<td>×7/8</td>
<td>79.7</td>
<td>14.0</td>
<td>2.45</td>
<td>2.31</td>
<td>25.3</td>
</tr>
<tr>
<td>×3/4</td>
<td>69.9</td>
<td>12.2</td>
<td>2.46</td>
<td>2.26</td>
<td>22.0</td>
</tr>
<tr>
<td>×5/8</td>
<td>59.6</td>
<td>10.3</td>
<td>2.48</td>
<td>2.21</td>
<td>18.6</td>
</tr>
<tr>
<td>×7/16</td>
<td>54.2</td>
<td>9.33</td>
<td>2.49</td>
<td>2.19</td>
<td>16.8</td>
</tr>
</tbody>
</table>

Note: For workable gages, refer to Table 1-7A. For compactness criteria, refer to Table 1-7B.
**FIGURE 3.10**

- Case 8b
  - Known variable: $x$
  - Unknown variable: $l$
  - $U = 0.60$

- Case 8a
  - Known variable: $x$
  - Unknown variable: $l$
  - $U = 0.80$

**Single and double angles**

- Case 7b
  - $W_{10} \times 19$
  - Known variable: $x$
  - Unknown variable: $l$
  - $U = 0.85$
  - $\frac{b_f}{d} = 0.394 < \frac{2}{3}$

- Case 7a
  - $W_{8} \times 24$
  - Known variable: $x$
  - Unknown variable: $l$
  - $U = 0.90$
  - $\frac{b_f}{d} = 0.820 > \frac{2}{3}$

**Case 7c**

- $W_{10} \times 45$
- Known variable: $x$
- Unknown variable: $l$
- $U = 0.90$

- $\frac{b_f}{d} = 0.794 > \frac{2}{3}$ (for parent shape)

**Definitions**

- Transverse
- Longitudinal

**FIGURE 3.11**

- $b_f = 8.02''$
  - $d = 10.1''$
  - $0.794 \checkmark$
The length of the connection is
\[ \ell = 3 + 3 = 6 \text{ in.} \]
\[ U = 1 - \left( \frac{x}{\ell} \right) = 1 - \left( \frac{1.67}{6} \right) = 0.7217 \]
\[ A_e = A_n U = 5.02(0.7217) = 3.623 \text{ in.}^2 \]

be used. Because the angle has three bolts in
factor \( U \) can be taken as 0.60, and

specification permits the larger one to be used.

 accident 3.1 is more accurate. The alternative val-

dary design, when actual section properties and

---

**EXAMPLE 3.5**

If the tension member of Example 3.4 is welded as shown in Figure 3.13, determine the effective area.

**SOLUTION**
As in Example 3.4, only part of the cross section is connected and a reduced effective area must be used.

\[ U = 1 - \left( \frac{x}{\ell} \right) = 1 - \left( \frac{1.67}{5.5} \right) = 0.6964 \]

**ANSWER**
\[ A_e = A_g U = 5.77(0.6964) = 4.02 \text{ in.}^2 \]
3.4 STAGGERED FASTENERS

If a tension member connection is made with bolts, the net area will be maximized if the fasteners are placed in a single line. Sometimes space limitations, such as a limit on the diameter of bolts, influence the selection of the fastener arrangement.
If the amount of stagger is small enough, the influence of an offset hole may be

sponding to a staggered hole, use a reduced diameter, given by

\[
d' = d - \frac{s^2}{4g}
\]

Added length = \( + \frac{S^2}{4g} \) \hspace{1cm} (3.2)

where \( d \) is the hole diameter, \( s \) is the stagger, or pitch, of the bolts (spacing in the
diameter from equation 3.2 is used for all holes (since \( a = a \) when the stagger \( s = 0 \)),
the net width in a failure line consisting of both staggered and unstaggered holes is

\[
w_n = w_g - \sum d'
\]

\[
= w_g - \sum \left( d - \frac{s^2}{4g} \right)
\]

\[
= w_g - \sum d + \sum \frac{s^2}{4g}
\]

where \( w_n \) is the net width and \( w_g \) is the gross width. The second term is the sum of all
hole diameters, and the third
ure pattern.

When more than one f
investigated, and the one co
Note that this method will not accommodate failure patterns with lines parallel to the
applied load.

**EXAMPLE 3.6**

Compute the smallest net area for the plate shown in Figure 3.15. The holes are
for 1-inch-diameter bolts.

The effective hole diameter is \( 1 + \frac{S}{2} = 1\frac{1}{8} \) in. For line \( abde \),

\[
w_n = 16 - 2(1.125) = 13.75 \text{ in.}
\]

\[
A_n = (13.75 \text{ in})(3\frac{1}{4}'' \text{ in}) = 10.3 \text{ in}^2 \hspace{1cm} \text{Pu} = 1100 \text{ K}
\]
Equation 3.2 can be used directly when staggered holes are present. In the computation of the net area for line abcde in Example 3.6,

\[ A_n = A_s - \sum t \times (d \text{ or } d') \]

\[ = 0.75(16) - 0.75(1.125) - 0.75 \left[ 1.125 - \frac{(3)^2}{4(5)} \right] \times 2 = 10.1 \text{ in.}^2 \]

As each fastener resists an equal share of the load (an assumption used in the design of simple connections; see Chapter 7), different potential failure lines may be considered.

The use of areas and Equation 3.2 is preferable to the net-width approach of the AISC Specification. If the shape is an angle, it can be visualized as a plate formed by "unfolding" the legs to more clearly identify the pitch and gage distances. AISC 16.1-18 B4.3b specifies that any gage line crossing the heel of the angle be reduced by an amount that equals the angle thickness. Thus, the distance \( g \) in Figure 3.16, to be used in the \( s^2/4g \) term, would be \( 3 + 2 - \frac{1}{2} = 4\frac{1}{2} \) inches.
EXAMPLE 3.7

An angle with staggered fasteners in each leg is shown in Figure 3.17. A36 steel is used, and holes are for \( \frac{3}{8} \)-inch-diameter bolts.

a. Determine the design strength for LRFD.

b. Determine the allowable strength for ASD.

SOLUTION

From the dimensions and properties tables, the gross area is \( A_g = 6.80 \text{ in.}^2 \). The effective hole diameter is \( \frac{3}{8} + \frac{1}{8} = 1 \text{ in.} \).

For line \( abdf \), the net area is

\[
A_n = A_g - \sum t_w \times (d \text{ or } d')
\]

\[
= 6.80 - 0.5(1.0)\times 2 = 5.80 \text{ in.}^2
\]

For line \( abceg \),

\[
A_n = 6.80 - 0.5(1.0) - 0.5 \left[ 1.0 - \frac{1.5^2}{4.25^2} \right] - 0.5(1.0) = 5.413 \text{ in.}^2
\]

Because \( \frac{1}{10} \) of the load has been transferred from the member by the fastener at \( d \), this potential failure line must resist only \( \frac{9}{10} \) of the load. Therefore, the net area

\[
2/4g \text{ for line } bc = 1.5\frac{2}{4}(2.5) = 0.225\text{ in.}^2
\]

\[
A_n (1/9)
\]

\[
L8 \times 6 \times \frac{1}{2}
\]

\[
2^{\frac{1}{2}} - \frac{1}{2}(1\frac{1}{2}) + 3 - \frac{1}{2}(\frac{1}{2}) = 2.25 + 3
\]

\[
5.25 - \frac{1}{2} = 4.75
\]