steelwise

DESIGNING WELDS FOR SKEWED SHEAR TABS

How to choose the best welding option for skewed single-plate shear tabs.

BY CARLO LINI, P.E.

IMAGINE YOU'VE BEEN ASKED to design a skewed single-plate shear connection.

Everything seems to be going well, you're making all of the same calculations that you normally would… and then you get to the welds and ask yourself, now what?

What part of the AISC *Specification* should I use? Am I limited to the designs shown in Table 10-14C of the 14th Edition AISC *Manual*? What if a connection has a skew angle greater than 45° and doesn't fall within the required angle ranges provided in the design tables??

Fear not! We have answers for you.

Welding Well

Before we get started, let's make sure we're all on the same page. If we are talking about a shear tab with a skew angle of 10°, the connection configuration should look something like what is shown in Figure 1. Essentially, the shear tab is skewed 10° off of a standard perpendicular shear tab connection.

This is also a good time to talk briefly about potential edge conditions for shear tabs. Figure 2 compares a shear tab that has a square edge versus one that is beveled. In most cases, leaving a square edge will be more economical than beveling. However, it will also result in a gap or root opening.

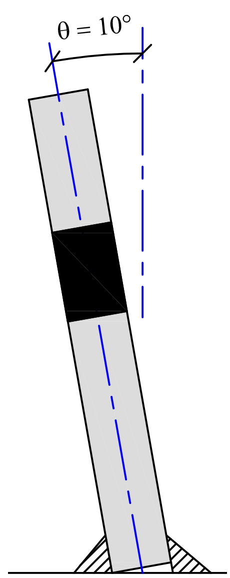

Fig. 1: Skew Angle Definition

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As the skew angle increases, the gap increases and if this dimension becomes too large, beveling may be required, since AWS D1.1 Clause 5.22.1 limits the gap to 3⁄16 in. The square edge usually requires a larger weld size than the beveled edge.

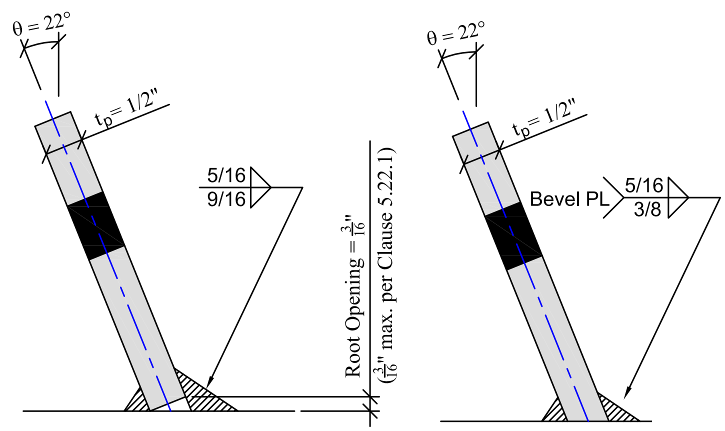


Fig. 2: Square Plate Edge vs. a Beveled Plate Edge

Section J2 of the AISC *Specification* states:

> "All provisions of AWS D1.1/D1.1M apply under this *Specification*, with the exception that the provisions of the listed AISC *Specification* sections apply under this *Specification* in lieu of the cited AWS provisions..."

There are a few options available when sizing fillet welds for a skewed shear tab, and Figure 3 highlights these different paths. Each path is explained in further detail later in this article; partial joint penetration (PJP) and complete joint penetration (CJP) groove welds will also be discussed.

Path 1: Table 10-14C (14th Edition AISC *Manual*). Table 10-14C on page 10-176 of the 14th Edition AISC *Manual* provides the easiest and quickest way to determine the required fillet weld sizes for a skewed shear tab. As long as the plate thickness equals 5⁄16 in., 3⁄8 in. or ½ in. and will have a skew angle of 45° or less, this table will provide a solution. The provided fillet weld leg sizes in the table account for root openings and the Z-loss dimension when it is applicable (see Figure 4). The root opening is the gap at the location of the root of the weld, between the shear tab and the steel to which it is being welded. The Z-loss dimension accounts for the incomplete fusion that is likely in some cases at the root of the joint (on the acute side

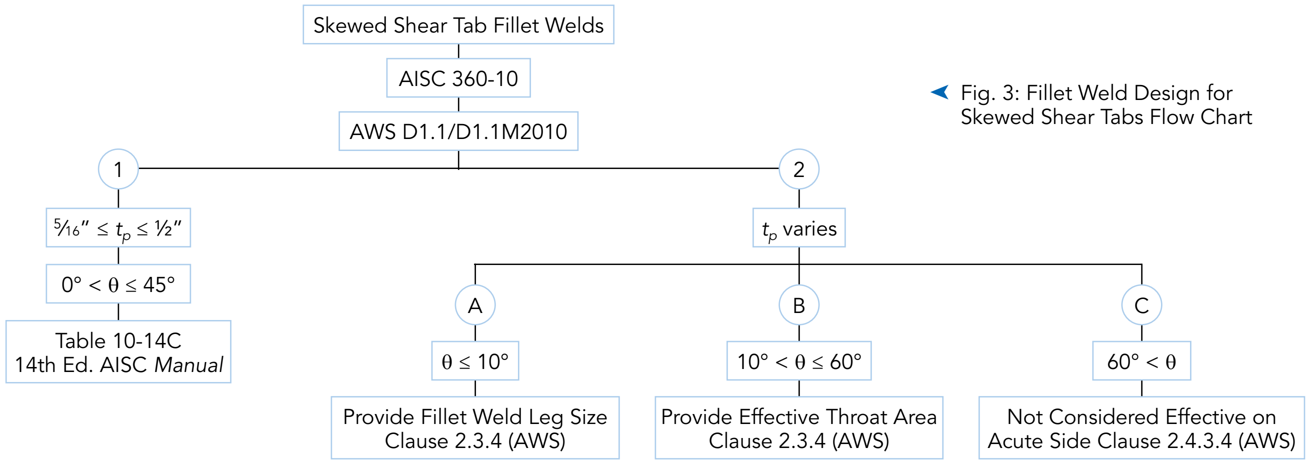


Fig. 3: Fillet Weld Design for Skewed Shear Tabs Flow Chart

of the connection) due to restricted welding access. The Z-loss dimension depends on the acute angle, the welding process and the position of welding.

It is important to point out the note at the bottom of Table 10-14C, which says that the tabular information "satisfies single-plate weld requirements for these thicknesses." This refers to the recommended procedure for sizing welds for single-plate shear connections, which requires fillet welds that are equal to or greater than (5⁄8)t_p (see page 10-102 in the 14th Edition *Manual*). This ensures that the plate will yield in shear or in flexure prior to the rupture of the fillet weld. Essentially, the (5⁄8)t_p weld size requirement will provide a fillet weld size that is strong enough to develop the plate. (This concept is discussed in greater detail in an *Engineering Journal* article "Design of Unstiffened Extended Single-Plate Shear Connections," 2nd Quarter 2009.) The (5⁄8)t_p requirement will be used throughout the remainder of this article to size welds that are large enough to develop the plate.

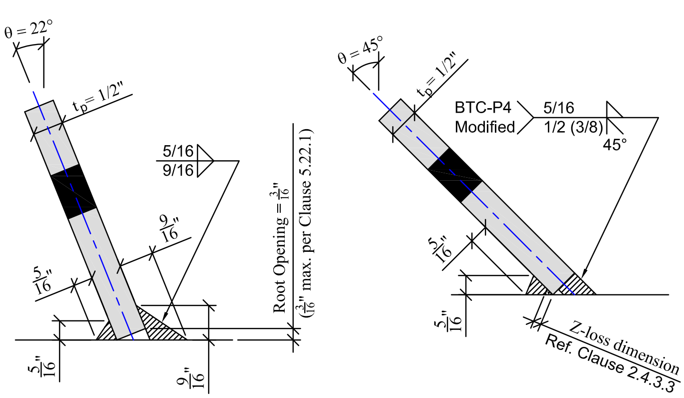
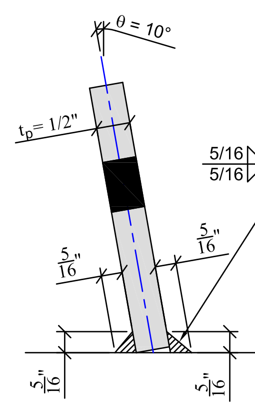


Fig. 4: Using Table 10-14C in the 14th Edition AISC *Manual* for Weld Sizes

Path #2A: Fillet Weld Leg Size. For shear tabs with a skew angle of 10° or less, another quick approach is to use the same fillet weld leg size that would be used for a shear tab that is not skewed (positioned at 90°). (This is discussed in Clause 2.3.4 of AWS D1.1/D1.1M:2010 and in greater detail in the commentary for this section.) For example, a ½-in.-thick shear tab plate that is skewed 10° will have the same fillet weld leg size as a ½-in.-thick shear tab that is not skewed (angle is 90°).

Fig. 5: Skew ≤ 10°



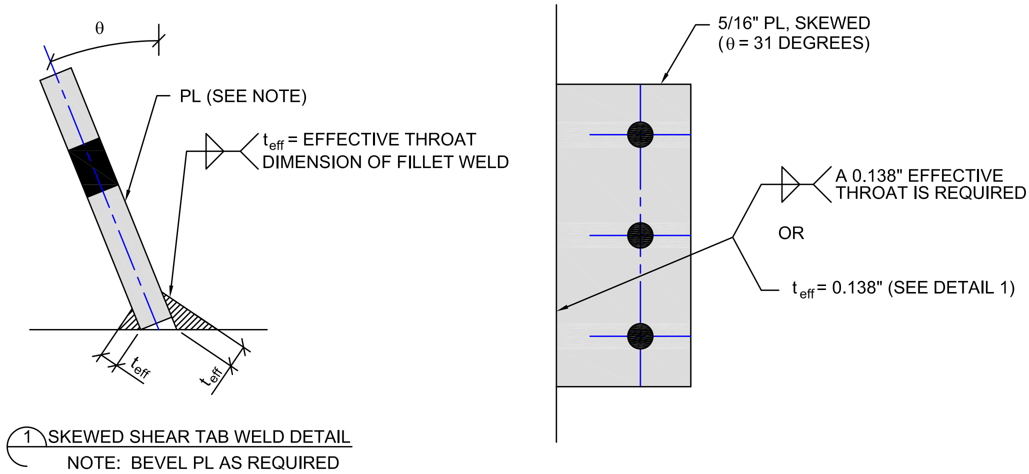
In both cases the fillet weld leg size is equal to (5⁄8)t_p = 5⁄16-in. fillet weld (see Figure 5). While the shear tab that is skewed 10° will have a smaller effective throat thickness on the obtuse side, it will also have a larger effective throat thickness on the acute side. For skew angles that are 10° or less, the net difference in effective thickness is negligible.

Path #2B: Effective Throat Thickness. For shear tabs that are skewed greater than 10°, Clause 2.3.4 of AWS D1.1/D1.1M:2010 states:

> "For welds between parts with the surfaces meeting at an angle less than 80° or greater than 100°, the contract documents shall specify the effective throat."

By specifying the required effective throat, an engineer gets what he or she is most interested in: a weld with the required throat thickness. The "heavy lifting" is left to the fabricator, who must consider the effect of the root opening, any Z-loss factors and the proper weld size for the fillet welds on both the acute and obtuse side. This approach will also allow the fabricator to select the most economical weld detail. Also, since the Z-loss factor is dependent on the welding process and position of welding (variables the engineer will not likely know), the solution can be customized around the contractor's preferences. When this is done the fabricator shows, on the shop drawings, the placement of welds and the required leg dimensions to satisfy the required effective throat, increased by the Z-loss allowance, if required.

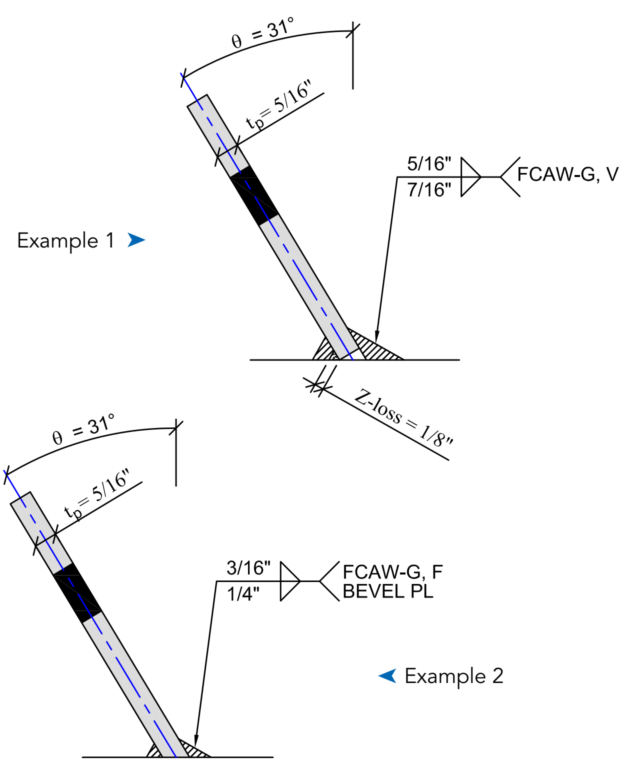
The engineer must properly convey this information on the contract documents. A fillet weld symbol is used to convey the fillet weld leg size, not the effective throat thickness. Instead of providing the leg size, specify the effective throat size. This can be done by using the weld tail, providing specific details or both (see Figure 6).



➤ Fig. 6: Specifying the Effective Throat for Fillet Welds

In specifying a fillet weld with an effective throat thickness of 0.138 in. for a ⁵⁄₁₆-in. shear tab that is skewed 31° (again, see Figure 6), the fabricator would then have the ability to select a weld configuration that works best for that particular situation. Figure 7 provides two examples of how a fabricator may size the fillet welds based on the detail shown in Figure 6. Both options shown in Figure 7 provide an effective weld throat that meets the 0.138-in. design requirement provided in Figure 6. The weld position that the fabricator chooses has an impact on the required fillet weld size. A vertical weld position used in Example 1 would result in a Z-loss dimension, whereas the flat weld position used in Example 2 would not.

▼ Fig. 7: Possible Weld Configurations to be Determined by the Fabricator



Checking Shop Drawings

Clauses 2.4.3.2 and 2.4.3.3 of AWS D1.1/D1.1M:2010 state that the contract documents shall specify the required effective throat and that the shop drawings shall show the required leg dimensions to satisfy the required effective throat. How can the fillet weld leg sizes provided on the shop drawings be checked to make sure that the effective throat requirement has been met? AWS D1.1/D1.1M:2010 provides a simple procedure in Annex B.

For example, if an engineer is checking the fillet weld leg size for a ½-in. shear tab that's skewed 22°, a good place to start is with the required effective throat thickness that the engineer specified in the contract documents. The engineer can then use this value along with the angle and root opening to determine the required fillet weld leg size.

Required effective throat size, $t = (5/8)t_p \times 0.707$

$t = (5/8)½ \text{ in.} \times 0.707 = 0.221 \text{ in.}$

$$w = [2 \times t \times \sin(\Psi/2)] + R$$

where:

R = root opening, inches
(> ¹⁄₁₆ in. and ≤ ³⁄₁₆ in. per AWS Clause 5.22.1)
w = fillet weld leg size, inches
Ψ = dihedral angle

$$w_2 = [2\times0.221 \text{ in.} \times \sin(112°/2)] + 3/16 \text{ in.} = 0.554 \text{ in.} \rightarrow 9/16 \text{ in. Fillet Weld}$$

Following the same procedure, the following expression can be used to calculate the required fillet weld size for the far side weld.

$$w_1 = [2\times0.221 \text{ in.} \times \sin(68°/2)] + 0 = 0.247 \text{ in.} = 1/4\text{-in. Fillet Weld}$$

The required fillet welds are shown in Figure 8. Notice that the far side weld is less than the ⁵⁄₁₆-in. fillet weld size shown in Table 10-14C on page 10-177. The ⁵⁄₁₆-in. fillet weld that is shown in Table 10-14C is based on an angle range between 17° and 22°, and the controlling fillet weld size on the acute angle side would occur at the smallest angle in that range. By allowing the fabricator to determine the required fillet weld leg size from the required effective throat thickness, there is an opportunity to reduce weld costs. Another example where a calculated fillet weld leg size is smaller than what is shown in Table 10-14C is for the 22° to 45° weld detail for the ½-in. plate. At a 23° angle, a ⅜-in. fillet weld would be required for the near-side weld. But if Table 10-14C is used, a ½-in. fillet weld would be specified. This example is looking at the extreme end of any potential difference between what is provided in Table 10-14C versus what could be calculated. For most projects, the use of Table 10-14C is economical with the added benefits of being easy and fast to use. If a project will require a substantial amount of skewed shear tab connections, there may be an opportunity to reduce weld costs by calculating the required fillet weld leg sizes.

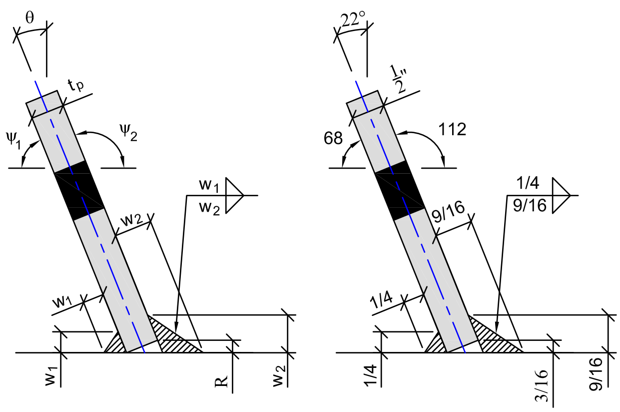


Fig. 8: Using Annex B to Check the Required Fillet Weld Leg Size

Z-loss Dimension

Per AWS D1.1 Clause 2.4.3.3, for welds in angles greater than 30° and less than or equal to 60°, the effective throat shall be increased by the Z-loss allowance, which is provided in Table 2.2 of AWS D1.1/D1.1M:2010. The Z-loss dimension was described earlier as a way to account for the incomplete fusion that could occur at the root of a weld when the acute angle is narrow. When this is the case, fusion to the root is unlikely, which is why an adjustment of the fillet weld leg sizes is required. The required fillet weld leg can be calculated using the same method (Annex B) described earlier. The only difference here is that the Z-loss value that is provided in Table 2.2 needs to be added to the required effective throat. The following example demonstrates this additional step (see Figure 9).

Required effective throat size,

$$t = (5/8)t_p \times 0.707 + \text{Z-loss Dimension}$$

$$t = [(5/8)\tfrac{1}{2}\text{ in.} \times 0.707] + \tfrac{1}{8}\text{ in.} = 0.346\text{ in.}$$

$$w = [2 \times 0.346\text{ in.} \times \sin(45°/2)] + 0\text{ in.} = 0.265\text{ in.} \rightarrow \tfrac{5}{16}\text{ in. Fillet Weld}$$

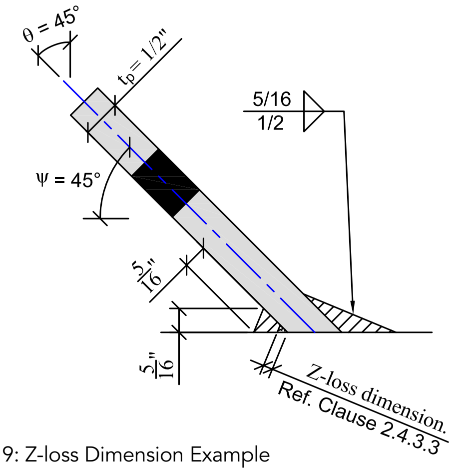


Fig. 9: Z-loss Dimension Example

PJP Groove Welds

PJP groove welds can be used for skewed shear tab connections, usually in combination with a fillet weld (see Figure 10). Depending on the connection layout, a PJP groove weld can be used to help reduce weld costs by reducing the amount of weld material required. Figure 10 provides two weld details taken from Table 10-14C. The ½-in. fillet weld not only requires more weld material than the PJP groove weld, but there is also an additional cost in having to bevel the plate. This is one of those exceptions to the usual advice that fillet welds are more economical than groove welds.

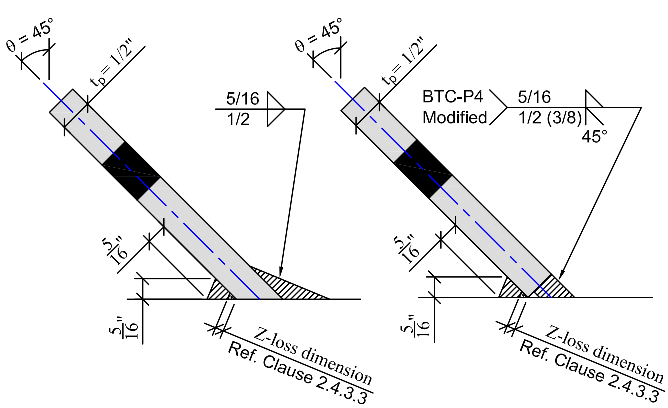


Fig. 10: PJP Groove vs. Fillet Weld Comparison

CJP Groove Welds

When dealing with large skew angles, access to the acute side is limited and double-sided joints should be avoided. Clause 2.4.3.4 of AWS D1.1 states that for prequalified welds:

"Welds deposited in acute angles less than 30° shall not be considered as effective in transmitting applied forces except as modified for tubular structures in 4.13.4.2."

A single-sided PJP groove or fillet weld detail should not be used for shear tabs either. For a skewed shear tab that has a skew angle greater than 60°, the best option is typically to use a CJP groove weld (see Figure 11).

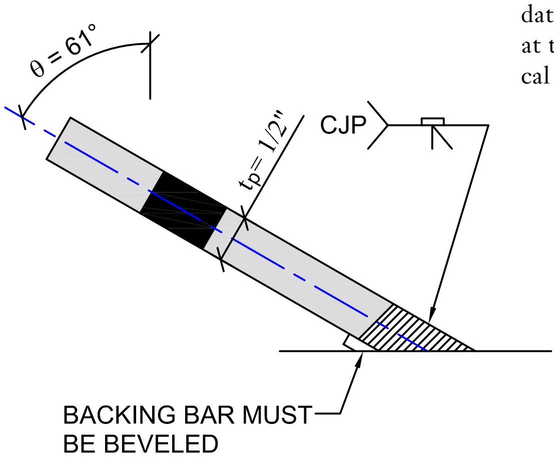


Fig. 11: CJP Groove Weld Option for Shear Tab with a Large Skew Angle

You Have Options

There are a lot of options when designing welds for skewed shear tabs. Having a lot of choices, though, can make it difficult for the engineer to pick the best one. The following recommendations will help you avoid mistakes and at the same time, achieve more economical weld designs:

1. For skews that are less than or equal to 10°, provide the same fillet weld leg size as for a 90° angle.
2. For skews that are larger than 10°, state the required effective throat in the design drawing and let the fabricator determine the best weld type and process to use.
3. Aside from making changes to the framing layout, when the skew angle exceeds 60°, a CJP groove weld is typically the best option.
4. Avoid single-sided fillet and PJP groove welds for shear tabs. MSC