When it comes to a good weld, strength isn't everything.

Clearance is CRITICAL

BY BO DOWSWELL, PE, PHD, AND CURTIS SMITH

WHILE STRENGTH IS the primary consideration for welded joints, it must be coupled with proper joint clearance to ensure a high-quality weld. Inadequate clearance around welded joints can affect weld quality and efficiency, leading to increased costs and delayed schedules. And in extreme cases, obstructions may cause a lack of proper fusion between the base metal and the weld metal, leading to a reduction in strength.

A recent AISC-funded research project was conducted to determine proper clearance requirements for welded joints. We'll discuss the results of the study but first, let's review some general welding advice.

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Making Room

For starters, access is important. The area near the weld must be clear, with enough room for equipment and welder access. For this purpose, R. Shaw, in his 1996 seminar "Structural Welding: Design and Specification," recommended "at least 18 in. of clear space around the joint." This clearance should be maintained until the inspection has been completed. For field welding, erectors can provide project-specific clearance requirements based on the required personnel and equipment.

On a smaller scale, clearance must also be provided for the electrode. For proper fusion and penetration, the welder must be able to direct the arc against the base metal. When an obstruction is present, the electrode is forced into a non-optimal position, potentially causing lower penetration and difficulty achieving the correct weld profile.

The recommended electrode clearance for SMAW welding is shown in Figure 8-11 of the 15th Edition AISC *Steel Construction Manual* (www.aisc.org/manual) shown here as Figure 1. For horizontal welds, the *Manual* recommends a 30° electrode angle, with an absolute minimum angle of 27° (2-to-1 slope). These recommendations were first included in the 1953 AISC publication *Structural Shop Drafting*, with the additional comment that "the root of the weld shall be visible to the operator." Similar clearances were proposed by H.M. Priest in the September 1943 *Journal of the American Welding Society* article "The Practical Design of Welded Steel Structures" and L. Grover in the First Edition *Manual of Design for ARC Welded Steel Structures* more than seven decades ago, when SMAW was the prevalent welding process for steel structures.

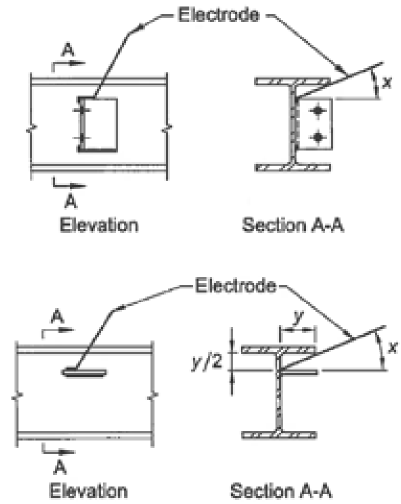


Figure 1. Clearances for SMAW welding.

A special condition is shown in *Manual* Figure 8-12 (shown here as Figure 2), where weld access is available at the member end. In this case, the clearance is independent of the flange width, and the angle between the electrode and the longitudinal weld axis is critical. For further information, see Part 8 of the *Manual*, where a 20° minimum electrode angle is recommended for straight electrodes.

If the proper clearance cannot be attained, the more expensive alternative details shown in Figure 3 can be used. Also, a single-sided fillet weld may be acceptable in some cases. Because these joints result in a crevice, corrosion can cause problems for structures exposed to weather unless measures are taken to prevent moisture accumulation within the joint.

An additional parameter that may affect weld clearance requirements is the "banking" of weld metal to counteract the effect of gravity for welds made in the horizontal position. To obtain equal-leg fillet welds, the welder typically rotates the electrode toward the horizontal surface, so the arc is directed more toward the vertical surface. Based on this, a vertical obstruction may be more critical than a horizontal obstruction in the welding of joints in the horizontal position.

AISC Design Guide 21: *Welded Connections-A Primer for Engineers* (**www.aisc.org/dg**) describes the different processes and where they are commonly used. Flux cored arc welding (FCAW) is the most common process for welding steel structures. Most shops now use gas-shielded flux cored arc welding (FCAW-G) or gas metal arc welding (GMAW) in production, and self-shielded flux-cored arc welding (FCAW-S) is the most-used process for field welding.

As shown in Figure 4, the geometry of a FCAW or GMAW welding gun is much different from that of a SMAW "stick" electrode. Additionally, electrode manipulation techniques may be different between the processes. Therefore, the historic values previously recommended for the SWAW process may not apply to FCAW and GMAW.

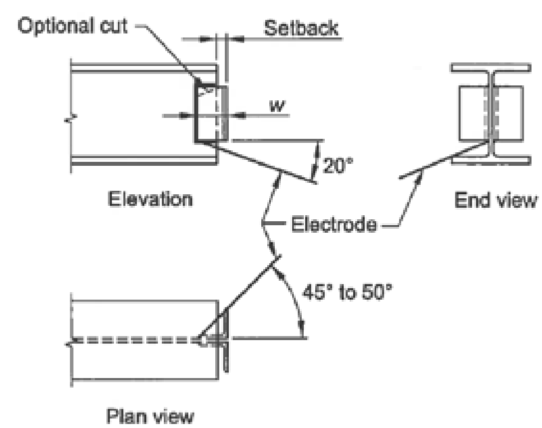
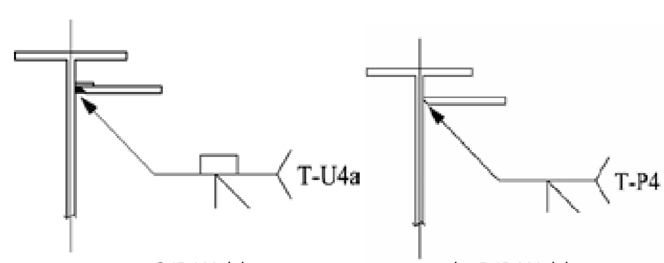


Figure 2. Clearances for welding near the end of members.



a. CJP Weld

b. PJP Weld

Figure 3. Alternative welds for joints with clearance on one side only.

Figure 4. Fillet weld joints using the FCAW-G process.

a. Unobstructed

b. Obstructed

The Study

Now, let's get to the results of the research we mentioned at the beginning of the article. The project studied electrode clearance for the FCAW-G process by sectioning specimens that were welded at various distances from an obstruction plate, as shown in Figure 5. Three AISC member and certified fabricators each welded specimens in three different positions for a total of nine specimens. Because the equipment for GMAW is similar to that of FCAW-G, the clearance requirements are similar. Due to the absence of a gas nozzle, less clearance is required for the FCAW-S process.

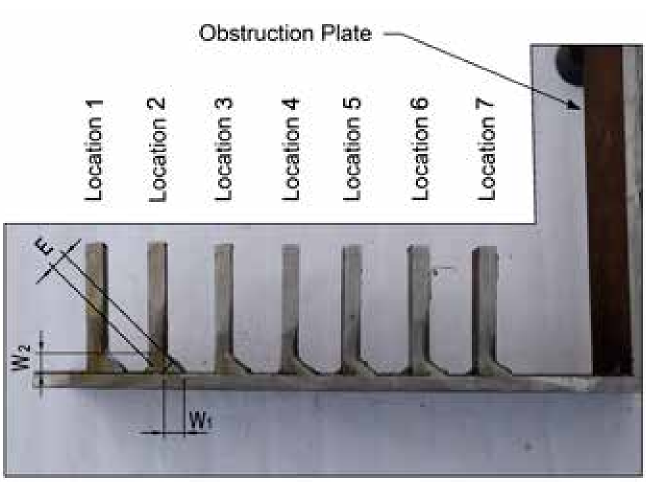


Figure 5. Section of a completed weld clearance specimen.

The cross-sectioned welds showed that, as the distance between the weld and the obstruction plate decreased, both the production efficiency and the penetration into the base metal parallel to the obstruction plate decreased. Another issue at Location 7 (see Figure 5), where the welds are 2 in. from the obstruction plate, is the limited access for measuring the weld size with a standard gage. Although the penetration was generally low at Location 6, where the welds are 3 in. from the obstruction plate, the measured effective throats exceeded the nominal values. This is because the decrease in penetration was compensated by an increase in weld metal. In interviews, welders expressed concerns regarding the potential effects of the obstruction on the weld fusion and penetration at Locations 6 and 7, which may have caused them to increase the weld metal deposited.

Recommended clearances for FCAW and GMAW welding, based on the research, are shown in Figure 6. Two joint geometries are considered: Case 1, where the welded element is parallel to the obstruction and Case 2, where the welded element is perpendicular to the obstruction.

- Case 1: When welding near wide obstructions, (large b-dimension), the welder's hand and the welding gun must fit into the opening while allowing enough room for proper electrode manipulation. For this geometry, the required clearance, c_{min}, is the minimum of $b/2$ and 4 in. This should be considered the absolute minimum clearance. As with the SMAW process, a 30° electrode angle is recommended for optimum production efficiency, resulting in the 0.6b clearance recommendation.
- Case 2: This configuration does not require the entire welding gun to fit within the clearance dimension, allowing less restrictive clearances. Due to the high heat input with the FCAW and GMAW processes and the increased access between the gas nozzle and the weld surface, c_{min} is dependent on the plate thickness, t. If these requirements cannot be met, the welded edge can be beveled as shown in Figure 10 (page 52).

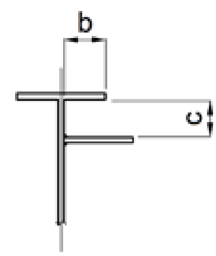
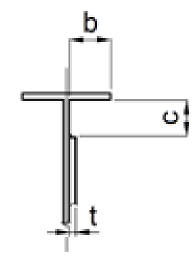
	
Recommended: c_{min} = min(0.6b, 5 in.) Minimum: c_{min} = min(b/2, 4 in.)	$t \le 5/16$ in.: c_{min} = ¾ in. 5/16 in. < $t \le 5/8$ in.: c_{min} = min(b/2, 2 in.) 5/8 in. < t: Recommended: c_{min} = min(b/2, 3½ in.) Minimum: c_{min} = min(b/2, 2½ in.)
a. Case 1	b. Case 2

Figure 6. Recommended clearances for FCAW and GMAW welding.

Weld Preparation

Let's step back and take a look at common practices for groove welds and doubler plate welds. The main function of weld preparation is to facilitate the required weld metal penetration. The preparation must provide adequate access so the arc can be directed against the base metal. Figure 7a (following page) shows a tee joint with a square groove preparation that is not prequalified because the arc cannot be directed against the base metal. A similar detail is shown for a corner joint in Figure 7b. For relatively thin materials, the corner joint is prequalified because arc access is not obstructed as it is for the tee joint. A prequalified tee joint with a single-bevel weld preparation is shown in Figure 7c, where the arc can be easily directed against the beveled surface.

A potential access problem for groove-welded joints is shown in Figure 8 (following page), where a plate is welded to the web of an I-shape member. In many cases, the arc cannot be

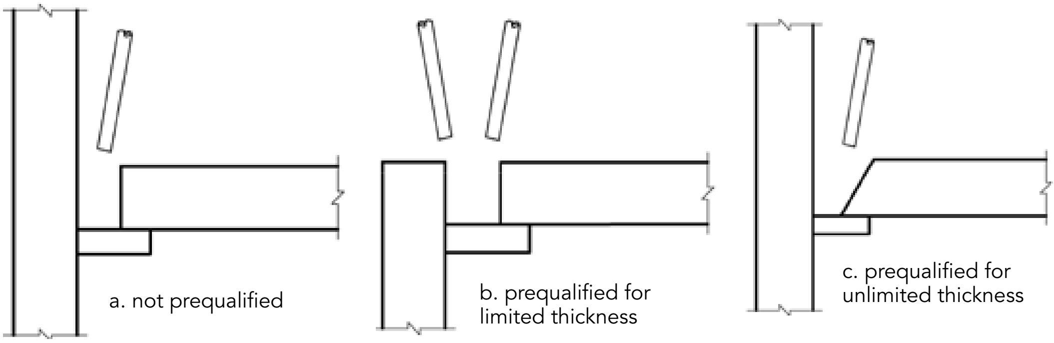
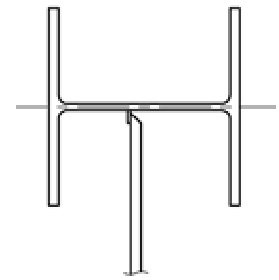


Figure 7. Arc access.

Figure 8. Complete-joint-penetration weld with access problems.



properly directed against the base metal due to an obstruction caused by the flange. Also, there is not a direct line of sight for the welder or the inspector to view the beveled weld preparation surface. Although it may seem obvious, the decades-old advice of Priest (1943) can be used to determine the proper geometry: "The welder must be able to see his work clearly." For this type of joint, a fillet-welded joint may be more appropriate.

AISC Design Guide 13: *Wide-Flange Column Stiffening at Moment Connections: Wind and Seismic Applications* discusses several different weld configurations for web doubler plates (see Figure 9 for an example) including both fillet- and groove-welded joints. For the groove-welded option, a typical weld detail is shown in Figure 10, which is similar to Figures 7a and 7c. Doubler plates for structures designed in accordance with the AISC *Seismic Provisions for Structural Steel Buildings* (ANSI/AISC 341-16, www.aisc.org/specifications) must be welded according to Section 4.3 of AWS D1.8: *Structural Welding Code-Seismic Supplement*. In this case, only groove welding is allowed, and the variables defined in D1.8 must be followed.

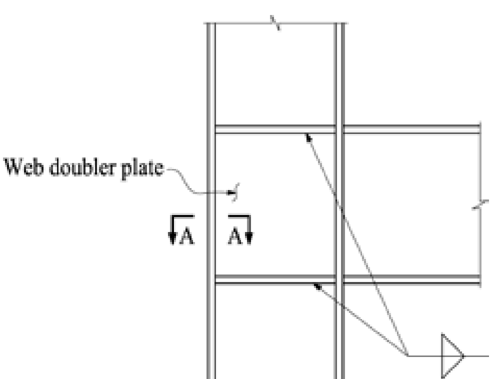
For non-seismic design, the plate edge is often located at the tangent point of the column fillet ($R = 0$). However, detailing the joint with an encroachment onto the fillet ($R < 0$), as shown in *Manual* Figure 10-3, can reduce the weld metal. In addition to the cost savings and increased productivity, reductions in weld metal can decrease flange rotations caused by weld shrinkage.

For thick doubler plates, a groove angle, α, of 30° is common, but angles as low as 15° have been used successfully. For thin doubler plates, square-cut plates ($\alpha = 0°$) are often used to eliminate the weld preparation and reduce the weld metal. Square-cut preparations must be limited to thin plates because proper fusion between the weld metal and the doubler plate is attained by weld penetration into the doubler plate, essentially melting the plate corner and creating a groove angle as the weld progresses.

Fabrication practices vary, but generally, plates less than ⅜ in. thick are cut square and plates that are ⅜ in. thick and thicker are beveled. The AISC project, which studied eight doubler plate specimens with various plate thicknesses, confirmed the validity of this practice. The specimens with a ¼-in. doubler plate showed good fusion and penetration at both the column and the plate. In this case, the root opening, R, had no observable effect on the weld quality; therefore, $R \le 0$ is recommended for thin plates. Portions of the weld at some of the thicker plates showed a lack of root penetration. For ⅜-in.-thick and thicker doubler plates, a groove angle, α, of 15° to 30° may be required to ensure consistent weld quality. Based on the results of the ¼-in. doubler plate specimens, it is expected that a ¼-in. land could be used for these joints to reduce the weld metal while still maintaining quality.

We are grateful to the following AISC member fabricators for providing partial funding of the weld clearance project through specimen donations, shipping costs and practical recommendations: Bell Steel Company, Pensacola, Fla., North Alabama Fabricating Company, Inc., Birmingham, Ala., and Structural Steel Services, Inc., Meridian, Miss.

Figure 9. Doubler plate.



Welding in a fabrication shop, using the FCAW-G process.

Figure 10. Doubler plate groove weld.