Welding WISDOM: Part One

BY DUANE K. MILLER, P.E.

Following the right principles can lead to better welded connections and better projects.

WHAT MAKES FOR a good welded connection?

There are several principles that should be considered that can put you on the path to designing stronger, more efficient and less "stressed out" welds. Part One of this two-part article will illustrate seven of them.

Principle 1: A good welded connection is strong enough to transfer all the applied loads through the connection in an efficient manner.

If the connection is not strong enough, nothing else about it really matters. The weld (or welds) that join the various steel pieces together must be of a size and made with a welding material that will have sufficient strength for the application. Welds are not always required to duplicate the strength of the attached members, but must always be able to transfer the applied loads passed through the connection.

To properly size a weld, it is essential to know what loads are transferred through the connection. For transverse splices, this is a relatively simple task. For longitudinal welds, it's not so simple.

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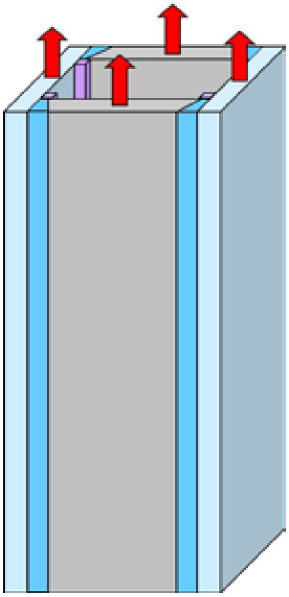


Figure 1

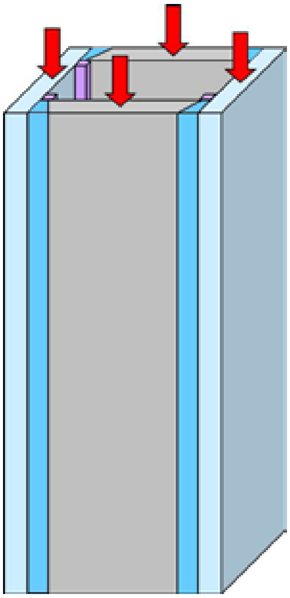


Figure 2

Consider the four illustrations in Figures 1-4, with four longitudinal welds. The welded joints are essentially the same, but the loads transferred through the connections differ significantly. Figure 1 assumes the box assembly functions as a hanger and the tensile forces are uniformly distributed across the whole cross section. The same assembly could be a column and loaded in compression as shown in Figure 2. These are examples of what AISC 360 Table J2.5 calls "tension or compression in parts joined parallel to a weld," which continues with the statement that such welds "need not be considered in design." For Figures 1 and 2, there is essentially

Figure 3

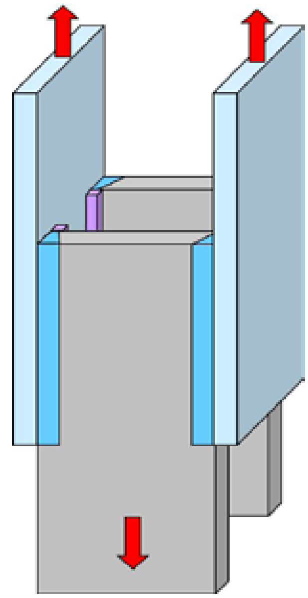


Figure 4

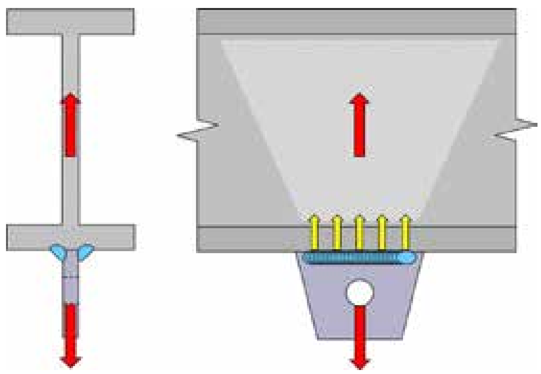


Figure 5

no load transferred across the joint, and thus the weld need only hold the parts together. Shipping and handling loads will likely create the greatest stresses these welds will ever need to transfer, and CJP groove welds are likely unjustified in these situations.

In Figure 3, the same assembly is now a beam subject to bending. The load transferred between the webs and flanges is horizontal (or longitudinal) shear, and the loading of concern is shear on the effective area of the weld. The shear force transferred from web to flange is typically small, and minimum-sized PJP welds—even intermittent PJP welds—are often adequate to resist the transferred load.

The example shown in Figure 4 uses the same general configuration of material in the joint area, but full tensile loads applied though the hanging brackets are transferred through the connections. This is a much different loading configuration as compared to the situations shown in Figures 1 through 3, yet the groove weld detail is the same. Depending on the magnitude of the load and the length of the joint, a CJP groove weld may be required. A good welded connection is achieved when the load transferred through the connection is considered.

Principle 1 also calls for the welded connection to be "efficient." Welds that are larger than necessary are not efficient. The inefficiency is not just a matter of increased cost; larger-than-necessary welds introduce into the connection additional residual stress and distortion and increase the chances of cracking or tearing. Of the four examples cited, the first three have inefficient connections since a CJP is not justified.

Principle 2: A good welded connection has a clear and direct load path.

Stresses in the member must "flow" from one member, through the welds and into the attached member. With a good welded connection, the load paths are clear and direct. Consider the example shown in Figure 5. The vertical load is transferred to the lug, through the weld, through the flange and directly to the web. The weld is uniformly loaded and the load path is clear and direct.

In contrast, consider the configuration shown in Figure 6. The load in the lug is transferred through the weld to the flange but the flange is flexible. The load eventually flows to the web but the weld is no longer uniformly loaded along the length.

A pair of stiffeners, as shown in Figure 7, corrects for this situation. Here, the load path is clear—from the lug, though the weld, through the stiffened flange, into the stiffeners and ultimately to the parallel member (i.e., the web).

Principle 3: A good welded connection places welds in regions of low stress.

When possible and practical, welds should be placed in regions of low stress. When this is done, welds are less critical.

Figure 6

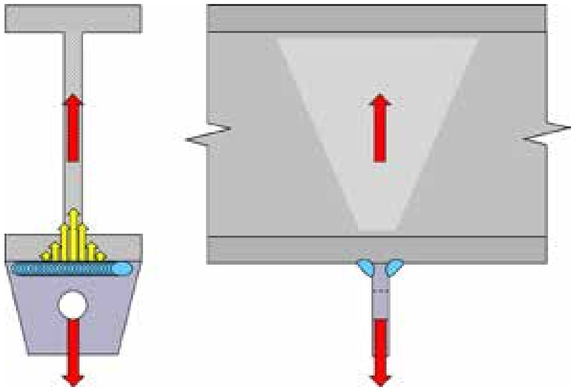
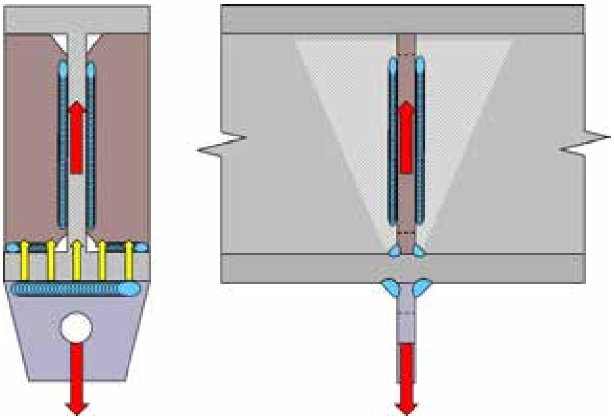


Figure 7



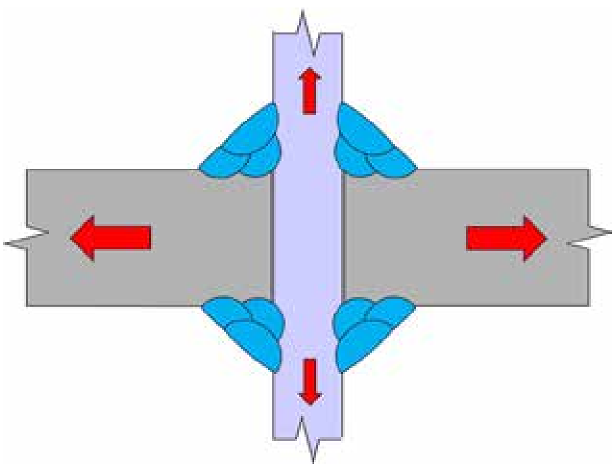


Figure 8

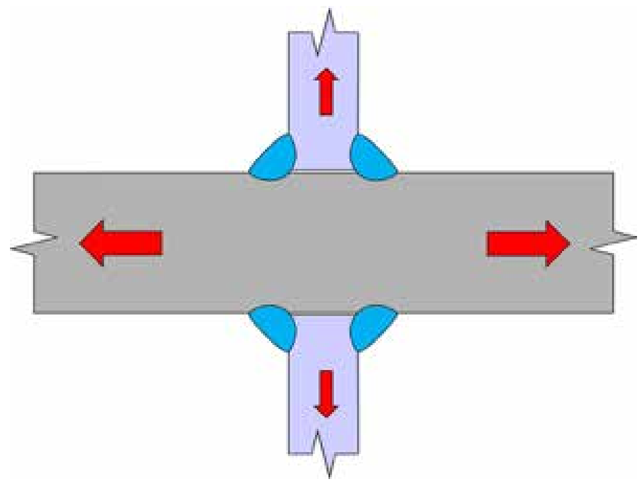


Figure 9

Further, this often leads to economy since the welds are typically smaller in size.

Splices in continuous girders, for example, can be placed at inflection points along the length of the member. For cyclically loaded structures, the termination of coverplates constitutes a low stress range detail; extending the coverplate into a region of lower stress may make the detail acceptable.

Figure 8 illustrates another example: The thicker part (and probably more heavily loaded member) is the discontinuous member, and the resultant welds must be large in size to transfer the loads through the connection. In Figure 9, the thinner member is discontinuous, permitting the use of smaller welds to transfer the load.

Principle 4: A good welded connection does not introduce stress raisers.

Certain welds and welded details may introduce stress raisers into the connection. For example, left-in-place steel backing may introduce a stress raiser. Consider the CJP groove weld in the T-joint shown in Figure 10. The naturally-occurring planar interface between the edge of the steel backing and the face of the vertical member creates a stress raiser. To eliminate this stress raiser, AISC 358 requires the backing to be removed in many of the prequalified seismic connections. However, not all left-in-place steel backing creates a stress raiser. Consider the butt joint shown in Figure 11. There is a naturally occurring lack-of-fusion plane between the back side of the steel and the top surface of the steel backing, but this interface does not create a stress raiser since it is parallel to the direction of applied stress.

Discontinuous steel backing can also introduce problematic stress raisers, as shown in Figure 12. The unfused interface between the segments of backing creates a planar discontinuity. If the box is loaded in bending, tensile stresses at the interface will be locally amplified. To mitigate this problem, the segments of backing can be joined together with CJP welds before being applied to the joint, eliminating the stress raiser. The problem is eliminated if continuous backing is used.

Principle 5: A good welded connection is not constrained.

When joints are welded, the hot, expanded weld metal and hot base metal surrounding the weld are required to shrink when this region cools. As the weld metal cools, the surrounding cooler (and unexpanded) base metal resists the shrinkage stresses imposed by the weld, causing the weld metal to yield. The yielding continues until the shrinkage stresses imposed by the weld are resisted by the surrounding base metal. Equilibrium is achieved when the residual stresses in the weld are at essentially the same level as the resisting stresses in the base metal, resulting in residual stresses that are approximately equal to the yield strength of the materials involved.

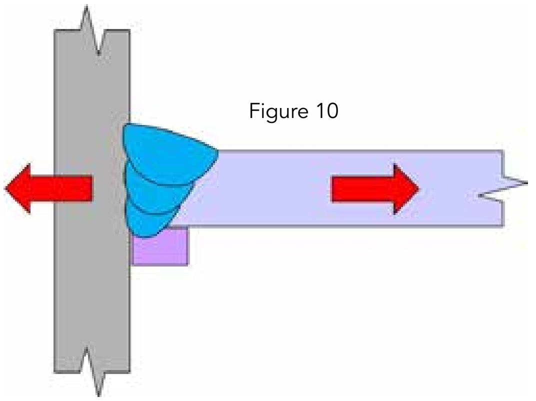


Figure 10

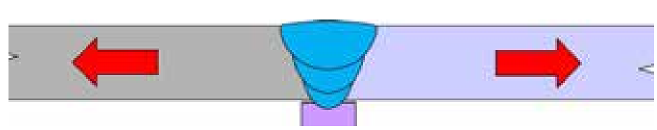


Figure 11

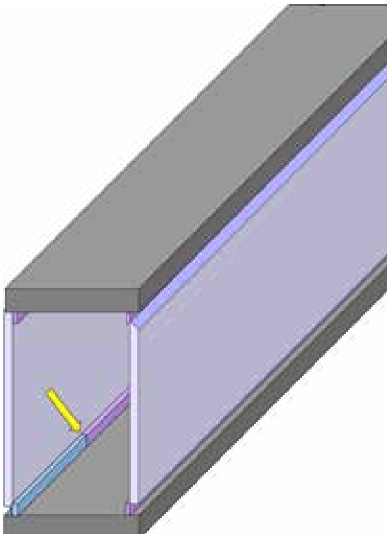


Figure 12

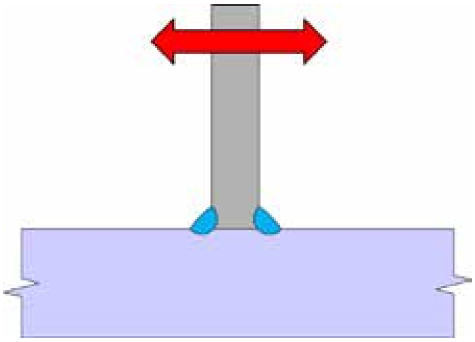
When the members being welded are free to move or flex, the residual stresses are relaxed by the movement. When members are rigid and cannot move, residual stresses increase. Under severe restraint, normally ductile weld metal or base metal may crack instead of yielding.

Tri-axial residual stresses are the most harmful and may cause normally ductile steel and welds to crack. Generously sized weld access holes and large snipes assist in precluding the buildup of residual stresses at the intersection of welds from the different orthogonal directions.

Principle 6: A good welded connection does not subject the weld to bending.

To understand this principle, it is first necessary to understand what it does not mean. It is certainly acceptable to make a plate girder with longitudinal welds and subject the girder to bending. Principle 6 discourages loading that would bend the weld about its longitudinal axis, as shown in Figure 13; such loading concentrates

Figure 13



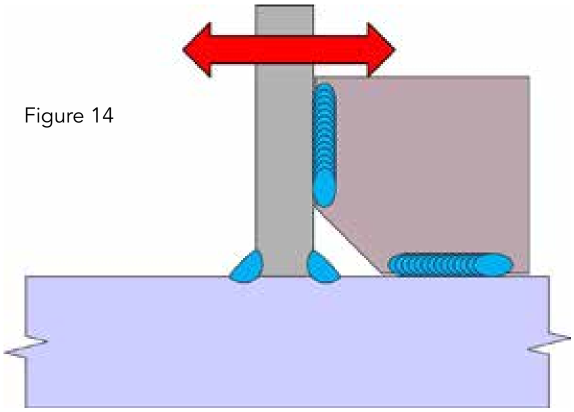


Figure 14

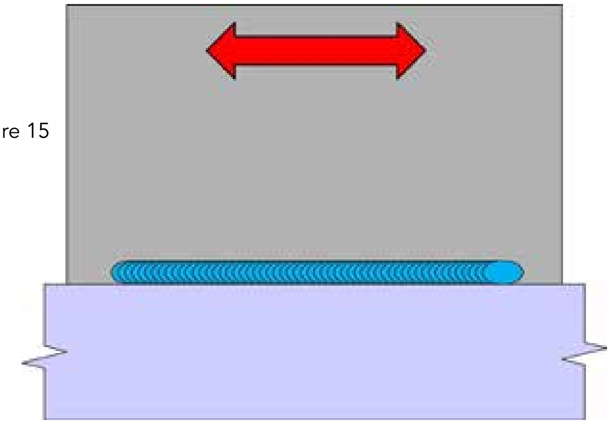


Figure 15

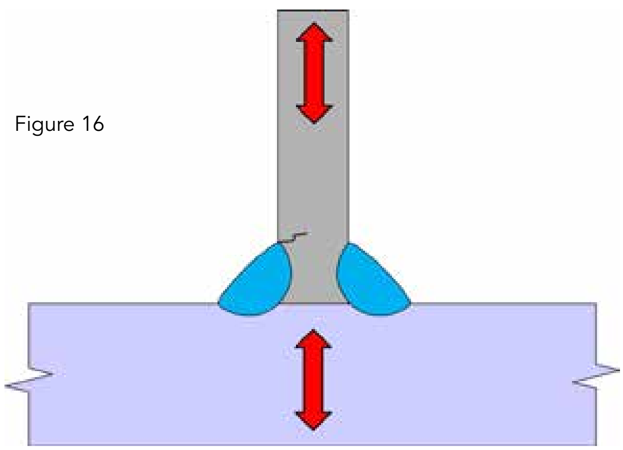


Figure 16

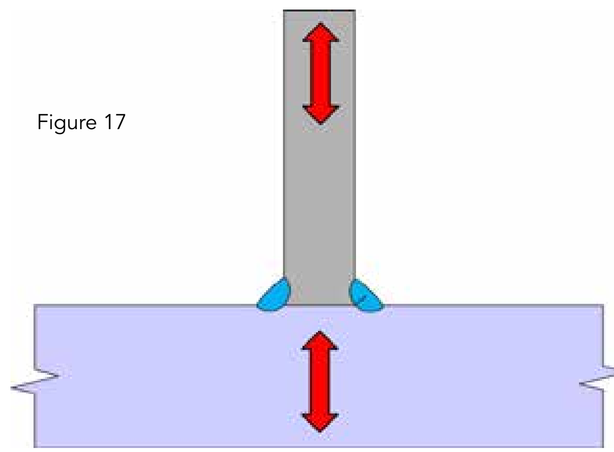


Figure 17

strains at weld toes and roots. Stiffeners can be applied to eliminate this bending (Figure 14) and in some cases, the orientation of the member can be changed so the weld is loaded in shear (Figure 15).

Principle 7: A good welded connection protects the toes and roots of the welds.

Weld toes and roots can create stress concentrations and a good welded connection protects these vulnerable regions. The root of a single-sided PJP groove weld is left unprotected when loaded in tension, as shown in Figure 18. A double-sided PJP (as shown in Figure 19) groove weld provides adequate protection of the root in many static applications. For cyclically loaded connections, failure of the double-sided joint will eventually initiate at the root.

In addition to the stress concentration created by weld roots, weld toes can similarly create stress raisers—albeit typically to a lesser level than severe root problems. In fatigue sensitive applications, removal of the reinforcement on transverse CJP groove welds improves the fatigue resistance from Category C to Category B. It is at the toe of transverse fillet welds at the ends of coverplates that fatigue cracks will initiate. Also, various weld discontinuities are concentrated at weld toes, such as undercut, overlap and underbead cracking.

For these reasons, it is wise to "watch your toes and remember your roots." Welded connection details should be examined to make sure that neither the toes nor roots will be problematic. Principle 7 is directly related to principle 4 and it is important to remember that stress raisers are only important when there is a perpendicular force (or component of force) to the geometric feature. The roots and toes of longitudinal fillet welds on plate girders subject to bending loads do not have stresses that are concentrated at these geometric discontinuities. ■

Part Two of this article will appear in the November issue and will list an additional seven welding principles. Both parts are based on the 2015 NASCC: The Steel Conference presentation N1 "Welded Connections: The Good, the Bad and the Ugly," available at ***www.aisc.org/2015nascconline****.*

Figure 18

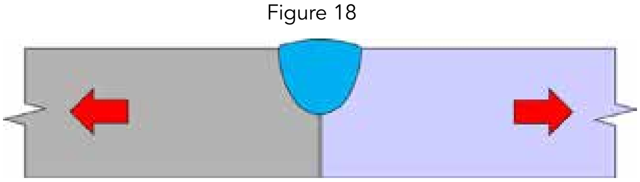


Figure 19