# Welding Considerations for Designers and Fabricators

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## This sneak-peek at AISC's new welding design guide offers insight into common welding concerns.

LATER THIS YEAR, AISC WILL ISSUE A NEW DESIGN GUIDE ON WELDING. The Lincoln Electric Company's Duane Miller, one of the nation's foremost experts on structural welding and the principal author of the design guide, provided a sneak peak at the new publication at this year's NASCC: The Steel Conference. Here are some tidbits gleaned from two chapters of the prepublication draft of the new guide.

What do you do when an anchor rod is set too deep and there is inadequate thread available for proper engagement of the nut (and in extreme conditions, the end of the anchor rod may even be below the top surface of the base plate)? According to section 12.1.2 in the new guide:

Possible solutions that involve welding are often offered, but such approaches are frequently problematic.

Even when weldable anchor rod is involved, several commonly proposed corrective concepts are flawed. For example, if the rod is very short, some may be tempted to use a plug weld in the base plate to weld on to the end of the anchor rod. This is a poor idea; plug welds are intended to be loaded in shear, not in tension. When there is insufficient thread for full nut engagement, some may contemplate welding the nut to the rod. Nuts are always hardened materials, and will have poor weldability, so this is not a viable option.

Before welded options are considered, mechanical fastening options should be exhausted. For example, in some cases it is possible to machine a recess into the top surface of the base plate, allowing the nut to be installed in the normal manner. Where holes in the anchor plate can be enlarged, a coupling nut can be used to mechanically add an extra length of anchor rod.

When an anchor rod must be extended by welding, and when the weldability of the anchor rod has been established, the details of the splice are the next consideration. Welding two small-diameter, solid cylindrical parts to each other with the goal of achieving 100 percent fusion is a significant challenge, simply due to the geometry involved. Compounding this difficulty is the welder's access to the joint; inevitably, the splice location will be only a few inches above the ground, requiring the welder to lie prone when the weld is made.

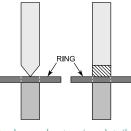
A connection detail has been developed by Lawrence Kloiber of LeJeune Steel to address some of the problematic aspects associated with anchor rod extension. The weld joint is prepared as a horizontal bevel groove weld. Tapering the end of the extension bar to a pencil point is not a good detail. Rather, two bevels should be formed in a chisel-like manner as shown in the figure. A ring or washer has been made from a steel with a known weldability, and with a thickness great enough that welds will not melt through it. The ring acts as a weld tab, allowing the arc starts and stops to be placed outside the width of the anchor rod. As with prequalified double sided welds, the root region of the first weld pass should be backgouged before the second side is welded. When the welding is complete, the ring can be removed and the weld ground flush around the perimeter.

Welding is typically performed with SMAW using electrodes with low hydrogen coatings. The strength of the electrode must be selected to match the strength of the anchor rod used. Depending on the rod composition, preheat may be required.

### Can you weld galvanized steel? According to section 12.2.2 of the new design guide:

When welding on materials with heavy galvanized coatings, particularly for hot-dipped parts, the zinc may enter into the liquid weld metal and lead to segregation cracking. This is more problematic than porosity: the potential consequences of cracking are more serious, and moreover, such cracking is often difficult to detect. Cracking tendencies in fillet welds made in T joints on galvanized steel depend on the following factors:

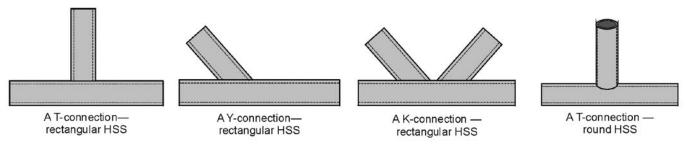
- → The silicon content of the weld metal
- → The degree of penetration of the weld beyond the root
- → The thickness of the base metal (which affects



Anchor rod extension detail.



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Tubular T, K and Y Connections.

#### restraint)

- -> ness)
- The microstructure of the zinc coating, which is related to the base → metal composition, and the silicon content in particular.

The potential influence of the material coating and weld quality depends on the joint and weld type. For example, plate may be primer coated, but then thermally cut and beveled. Thus, in a butt joint, prim- used on the other sides. Depending on the corner radius of the main er coated steel is less likely to cause porosity problems than would the same steel when used in a T joint and joined with fillet welds.

#### (HSS)? According to section 12.5 of the new design guide:

Hollow Structural Shapes (HSS) are an increasingly popular struc- flat side of the HSS chord. tural material, offering many structural and architectural advantages. Connection detailing, fabrication practices, and inspection proce- preferred, and for round HSS, the importance is even greater. The dures for all forms of HSS are quite different from those associated with plate and shape fabrication. The single topic of HSS could justify an entire guide, and most of that volume could be devoted to the topic of welding. Accordingly, this brief section will serve only as an introduction to the overall topic.

Connection methods for HSS fit into two broad categories: directly welded and welded/bolted connections. Unlike structural shapes that can be assembled with purely bolted connections, HSS nearly always involve at least some welding, even if only to attach detailing material that permits bolting.

HSS can be joined to plates, or to shapes, or to other HSS. HSSto-plate examples include HSS columns to base plates and shear tabs to tubular columns, as well as HSS braces in EBF and CBF systems to gussets. Shapes may be directly connected to HSS columns in moment connections, or tube columns to supporting beams. These are relatively easily designed and fabricated connections, although the limit states that must be considered in the design of such connections are somewhat different.

A popular application of HSS is for trusses, or truss-like assemblies, where tube-to-tube connections are made. Such assemblies may have the various HSS members intersecting each other, forming Ts, Ks, and Ys. The details associated with such connections are quite different from shapes and plates and require special thought and planning.

HSS fits into two distinct categories: round and rectangular, with square HSS a subset of rectangular HSS. Round HSS must be approached differently than rectangular HSS.

With HSS, the capacity of the connection is rarely controlled by the weld size. In many situations, a larger weld size will not increase the capacity of the connection. This is simply because other limit states typically control. As a result, however, HSS member sizes may be determined based upon connection demand. Several limit states exist as shown in the figure at right, and the chord member is often the controlling element.

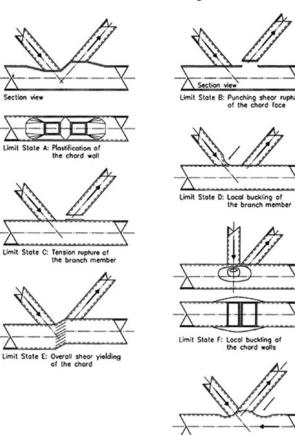
Given the geometry of the connected elements and their different

relative flexibility, the loading on the weld is often non-uniform. As The coating weight of the zinc (a function of the coating thick- a result, the welds may "unzip" if such non-uniformity is not considered

HSS branch members should preferably be made of narrower members than chords, to avoid the difficulty of welding on the rounded edge of the chord. In the case of the matched connection, a fillet weld can be used on two sides, but a flare bevel groove must be member, a gap may exist at the root, requiring the use of backing or more careful profile cutting of the branch member. These problems go away, however, when the branch member is narrower. Simple fil-Is welding an issue when specifying Hollow Structural Sections let welds can then be used. Preferably, the branch member is narrow enough to permit at least some of the fillet weld to be placed on the

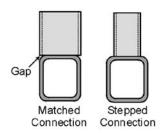
> For K-connections, gapped versus overlapped connections are gapped connections are easier to fabricate, but the overlapped connections often have greater strength and stiffness.

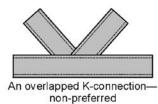
For K- and Y-connections, the acute angle should not be less

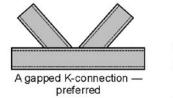


Limit State G: Local buckling of

Limit states for K-connections in rectangular HSS.







Access becomes difficult when the orientation of the branch member is less than 30 degrees.

HSS details.

than 30 degrees to keep welding and inspection of the weld in this area from becoming too difficult.

Square and rectangular HSS are cut with methods similar to those used for structural shapes: saws and thermal cutting methods. Sawing is particularly effective with HSS, as the cut edges are often on one plane. Complex intersections, however, may necessitate careful thermal cutting. For the thicknesses of materials that are typically involved, plasma and laser cutting are particularly effective.

Round HSS provide a particular challenge with respect to fabricating the tubes for directly welded connections in that the ends of the tubes must be "saddle cut" for T-K-Y connections. For Ts, the cut is relatively easy to make, but when other than a 90 degree intersection is used, the cut profile becomes complicated, and the situation is compounded further by an ever-changing bevel angle on the edge. Fortunately, a computer controlled plasma and laser cutting apparatus is available to cut such profiles, greatly simplifying the process while increasing fit-up quality.

When round HSS are used in a truss-like assembly, special attention must be paid to the assembly sequence. For example, if the chords are fixed relative to each other, a cut-to-length vertical member cannot be inserted into the space (see figure next page), a problem that does not happen with box HSS. Special techniques can be used to overcome this problem, typically involving cutting the tube and making an extra splice in it. A planned out sequence can overcome this problem; an "E" configuration is made first, and the final chord added later.

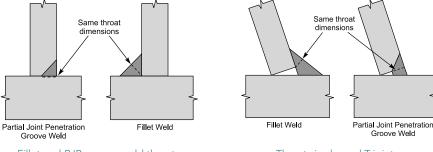
HSS routinely requires all-position welding, and in the case of round HSS, the orientation of the joint continually changes. Thus, the welding process and position of welding necessitate all-position capability. HSS are typically very clean and free of heavy mill scale and oxides, and therefore the welding process does not need the deoxidizing capability that might be necessary for welding on hot rolled material. HSS are often painted with glossy paint, and processes that generate low levels of spatter and less welding smoke are desirable since they minimize after-welding clean up efforts. All of these factors and others will drive welding process selection and will determine the suitability of the welding procedures. A key process requirement, particularly for T-K-Y connections, is to have easy access to the joint. SMAW provides for easy access in terms of getting into the root of the joint, although the length of the electrode may be restrictive in some situations. Gas shielded processes require shielding gas nozzles that often restrict access and visibility, particularly on members that intersect at acute angles. FCAW-S overcomes this restriction and is often used for this singular purpose in T-K-Y connection fabrication.

How do you select the proper weld type? Chapter 14 of the new guide deals with economy in welding and offers a number of suggestions as to the relative economy of different weld types and when each is most appropriate. Here a just a few of the suggestions contained in the guide:

The number one cost in welding is that of the skilled labor required to make a weld. In general terms, labor will account for 75 percent to 95 percent of the cost of a weld made manually or semiautomatically. Energy costs, filler metals, and shielding materials make up the remaining 5 percent to 25 percent. For a given weld size, economical welding is typically achieved when welding procedures are used that deposit the required metal in the least amount of time. Quality and safety should never be compromised for the sake of productivity. It is not unusual, however, to make quality welds in a safe manner with procedures that are twice as productive as another otherwise acceptable alternative. In general terms, the higher productivity procedures will reduce the welding cost by 50 percent.

Most of the principles below are presented in terms of reduced weld metal volumes, assuming that as the required amount of welding goes down, so will the required time to make the weld. One caveat: presenting the concepts in such terms runs the risk of implying that the major cost of welding is filler metal when in fact, with North American labor rates, labor is invariably the largest single cost factor in welding.

The lowest cost weld will always be the one that is made only once. The cost of a weld repair is estimated to be ten times as great as the initial welding cost. If a particular weld design or welding



Fillet and PJP groove weld throats.



procedure is marginal in its ability to achieve the required quality criteria, necessitating ongoing weld repairs, economy can surely be achieved by adopting practices to eliminate the rework.

Complete joint penetration (CJP) groove welds are typically the most expensive type of weld, and, in general, are reserved for situations in which they are the only viable option. In butt joints where the full tensile capacity of the surrounding steel must be developed, CJP groove welds are the only option and should be used. It is possible to replace the direct butt joint with lapped plates joined with fillet weld and/or plug/slot welds, but such a configuration is generally much more expensive.

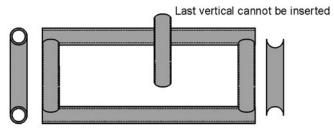
In corner joints, the capacity of a CJP groove weld is seldom required because the welds in such joints are normally subject to shear. If the capacity of a CJP is needed, and if access to both sides of the joint is possible, partial joint penetration (PJP) groove welds with fillet welds on the opposite side are typically more economical.

Like corner joints, T-joints rarely are loaded in a manner that would necessitate the use of CJP groove welds. If such loading is required, however, PJP or fillet welds, or combinations of the two, are usually more economical than the use of CJPs.

Fillet welds and PJP groove welds can both be used in T-joints and inside corner joints, and thus, it is important to know which option is more economical. For welds with equal throat dimensions, a PJP groove weld in a 90 degree T-joint requires one half the volume of weld metal as does a fillet weld—see figure above, left. This assumes that the PJP groove uses a 45 degree included angle, and that the effective throat "E" is equal to the depth of groove preparation "S", which will not always be the case. However, with these assumptions in place, a 2:1 ratio in the volume of weld metal for the same strength exists, with the PJP groove weld being more efficient.

However, PJP groove welds require that a bevel be applied to create the groove. One method of estimating time for beveling is to assume that it will take the same amount of time as making a single weld pass. This would suggest that single pass fillet welds are always more economical than PJP groove welds, and that so long as a fillet weld requires no more than one additional pass over that required for the PJP, the fillet weld will be the more economical choice.

A simple rule-of-thumb is this: Use fillet welds whenever the required weld leg size is 1" or less, and use PJP groove welds when larger sizes are required. In that most structural steel fillet welds are not required to have leg sizes greater than 1", fillets will be the most economical choice.



Assembly problems with round HSS.

An exception to this trend exists when the T-joints are skewed, as shown in the figure above, right. On the obtuse side, the throat of the fillet weld becomes disproportionately small as the angle increases, whereas the PJP option does not suffer from this trend. The naturally occurring gap is another factor that must be considered, and the effect with the fillet weld is greater than with the PJP. Many factors are involved in determining the best detail for this situation, and this is best examined on a case-by-case basis.

When the required weld size justifies a PJP groove weld rather than a fillet, a PJP/fillet weld combination may be the most economical option. When a 45 degree included angle is used for the PJP portion of the weld, and when the fillet weld leg size is equal to the depth of groove weld preparation ("S"), then a combination PJP/fillet weld requires no more weld metal than does a PJP alone. This will be one-half as much as would be required for a fillet weld of equal strength.

The combination offers some additional advantages: first, in a T-joint, it is hard to make an absolutely flat-faced PJP groove weld, and it is natural to find that a fillet weld of some sort is often applied, even though not specified. When made in the horizontal position, the extra weld applied in this manner is often extensive. Secondly, and particularly for cyclically loaded structures, it may be desirable to have a fillet weld on top of the PJP groove weld to provide for a better contour at the intersection.

When PJPs offer advantages over fillets, then the PJP/fillet weld combination should be considered as well, and the combination is typically preferred over the PJP-only option.

The complete paper will be available free online to AISC members and ePubs subscribers at www.aisc.org/ePubs after February 15, 2006.