Design File

Mixing Welds and Bolts, Part 2

Practical Ideas for the Design Professional by Duane K. Miller, Sc.D., P.E.

In a previous edition of *Welding Innovation* (Volume XVIII, Number 2, 2001), Part 1 of "Mixing Welds and Bolts" was published. That column dealt with snug-tightened and pretensioned mechanical fasteners, including rivets, combined with welds, as well as existing specification requirements for such combinations. Part 1 can be obtained by downloading a PDF file from the *Welding Innovation* web site at www.weldinginnovation.com. Part 2 will address combining welds with slip-critical, high-strength bolted connections, and will also examine existing specification provisions for various combinations of welds and bolts in light of recent research.

Review of Part 1

In Part 1, general information was provided on bolted connections. Snug-tightened, pretensioned, and slip-critical bolted connections were defined. ASTM A325 and A490 bolts were identified, and the capacity of rivets identified as typically about half of the strength of A325 bolts. Slip-critical joints have bolts that have been installed in a manner so that the bolts are under significant tensile load with the plates under compressive load. They have faying surfaces that have been prepared to provide a calculable resistance against slippage. Slip-critical joints work by friction: the pretension forces create clamping forces and the friction between the faying surfaces work together to resist slippage of the joint. The basic design philosophy relies on friction to resist nominal service loads. The provisions for design of slip-critical connections are intended to provide 90–95% reliability against slip at service load levels. In its strength limit state, slip can occur and the bolts will go into bearing. This should not be the case for service loads.

The focus of this Design File series is not upon bolted connections, but rather upon connections that are composed of both welds and bolts. For the snug-tightened and pretensioned bolted connections, it was shown that welds cannot be assumed to be capable of sharing loads with the mechanical fasteners. *AWS D1.1 Structural Welding Code-Steel* and *AISC LRFD Steel Specification* require that the welds be designed to carry the entire load under these conditions. The Canadian standard *CAN/CSA-S16.1-01* provides a more rational criterion by permitting load sharing between welds and bolts for service loads, providing the higher of the two capacities can carry all factored loads alone.

Part 2 focuses on slip-critical joints, combined with welds. As mentioned in Part 1, this topic is the subject of ongoing research and consideration by the various technical committees. Much of this work has been done by Drs. G. Kulak and G. Grondin and their co-workers of the University of Alberta, Canada, and definitive conclusions have not yet been reached as to how these findings should be incorporated into US standards, such as *AWS D1.1* and *AISC LRFD*. However, at least some parts of current standards are likely to be determined to be unconservative, and practicing engineers should review these data and determine how specific projects should be addressed in light of these findings. The same research has drawn into question some of the current specification requirements for snug-tightened connections when welds are added, and these findings will be reviewed.

Code Provisions for Slip-Critical Connections with Welds

The issue of mixing mechanical fasteners and welds is addressed in *AWS D1.1: 2002 Structural Welding Code–Steel*. Provision 2.6.7 states:

> "Connections that are welded to one member and bolted or riveted to the other shall be allowed. However, rivets and bolts used in bearing connections shall not be considered as sharing the load in combination with welds in a common faying surface. Welds in such connections shall be adequate to carry the entire load in the connection. High-strength bolts installed to the requirements for slip-critical connections prior to welding may be considered as sharing the stress in the welds. *(See:*

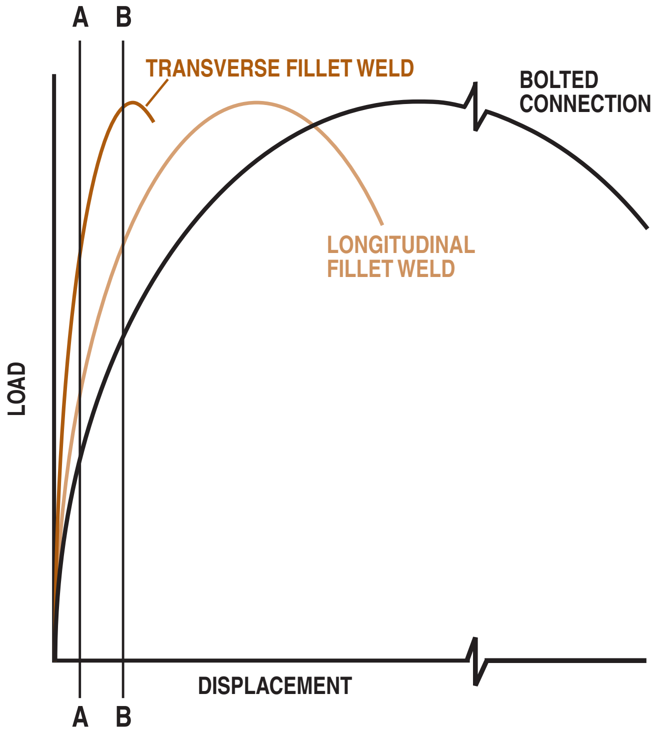

Figure 1.

Specifications for Structural Joints Using ASTM A325 or A490 Bolts of the Research Council on Structural Connections.)"

Note: Part 1 cited the 2000 version of D1.1, in which these provisions were contained in 2.6.3. The latest version is largely unchanged in concept, although the underlined words in 2.6.7 are new for the 2002 edition.

The fourth sentence deals with slip-critical connections. Notice that, in order for sharing to be considered, this provision requires that the high-strength bolts be installed "prior to welding." More will be said on this issue later. *AISC LRFD – 1999*, Provision J 1.9, expresses the same general philosophy when it states:

"In slip-critical connections, high-strength bolts are permitted to be considered as sharing the load with the welds."

The commentary to this provision provides some additional understanding of both the AISC and AWS provisions:

"For high-strength bolts in slip-critical connections to share the load with welds it is advisable to fully tension the bolts before the weld is made. If the weld is placed first, angular distortion from the heat of the weld might prevent the faying action required for the development of the slip-critical force. When bolts are fully tensioned before the weld is made, the slip-critical bolts and the weld may be assumed to share the load on a common-shear plane. The heat of welding near bolts will not alter the mechanical properties of the bolts."

The straightforward reading of these provisions, and indeed the intent of them, is to permit the direct combination of the capacity of the slip-critical connection and the weld. However, recent research indicates that this is not the case, and such an assumption may be unconservative.

The commentary that addresses the angular distortion explains the apparent justification for requiring that the bolts be installed before welding. The basis for such a requirement is suspect, however. Kulak and Grondin point out that "slip resistance of the bolted joint is independent of the amount of area between faying surfaces. As long as there is some area, which is a physical necessity for proper preloading of the bolts…, then the slip resistance will be developed." (Kulak and Grondin, from the minutes of the AISC TC6 Connections Task Committee, June 12-13, 2002.) Thus, the apparent justification for the sequential requirement may be suspect.

Different Deformation Capabilities

In Part 1, the differences in the deformation capabilities between welded connections and those joined with bolts in either a snug-tightened or pretensioned manner was identified as the factor that precluded the simple arithmetic addition of the capacities of the two systems. The welds were identified as being "stiff," whereas the snug-tightened or pretensioned bolted connection could slip to distribute the applied loads on the mechanically fastened joint.

The concept presented in codes with respect to slip-critical connections was presumably based upon the lack of slip in the connection (that is, their "stiffness"), justifying the assumption that the capacities of the two types of joining systems (welds and bolts) can be joined. Ultimately, a slip-critical bolted connection will slip, but if a weld is added, such a connection cannot slip. Thus, the capacities of the two elements cannot be combined in terms of the ultimate strength capacity.

Figure 1 contains a conceptual plot of the load/displacement relationships for welds and bolts. Note that the load/deformation relationships are different for each of the three elements. It should be noted that the two types of welds shown are not equally "stiff." The actual curve for the bolted connection is illustrative only; in fact, there would be various curves for the different types of bolted connections.

Additionally, while in this illustration the three curves are all shown having the same strength, under most conditions, the capacity of each element will be different. The differences in stiffness preclude simple mathematical additions of the various capacities.

Figure 2 illustrates six possible connection details: a) bolts only, b) longitudinal fillets only, c) transverse fillets only, d) bolts and transverse fillets, e) bolts and longitudinal fillets, and f) bolts with both longitudinal and transverse fillets. In this illustration, it is assumed that the strength of the connections in Figure 2a-2c is equal, as is illustrated in Figure 1. The bolts, for example, offer the same load resistance, as do the transverse fillet welds. All the bolts shown in Figure 2 are assumed to be slip-critical.

If the code provisions cited above were correct, that is, if the capacities of welds and slip-critical bolts could be mathematically combined, then the connections with bolts and welds in Figure 2d and 2e would both be twice the value of the connections in Figure 2a-2c. Further, if these provisions were correct, the capacity of Figure 2f would be three times that of Figure 2a-2c. Loads, however, are not evenly split between the various elements in the mixed connection, because of the differences in the load/deformation curves.

Referring again to Figure 1, the bolted connection in Figure 2a would have a load/deformation curve like the bolt curve. For a unit strength of 1, the deformation experienced would also be a unit of 1. For the longitudinal fillet in Figure 2b, the strength is also normalized to a value of 1, but the deformation capacity is estimated to be 1/6 of the bolted connection. The transverse fillet of Figure 2c also has strength of 1, but with a deformation capacity of about one sixth of the longitudinal fillet weld.

To analyze the combination of welds and bolts and their ultimate load capability, constant displacements for each element must be considered, and the resistances to deformation for each element added to determine the total capacity of the combination. Consider the combination of longitudinal fillet and bolts (Figure 2e). Line A in Figure 1 illustrates a likely deformation level that would contribute to the total connection strength of a level 1. However, rather than a 50-50 split, the weld contributes about 60% of the strength, with 40% coming from the bolts. At line B where the weld is capable of delivering 100% of its strength, the bolts can contribute only about 80% of theirs, and the combination is not 200%, but rather about 180%, or 10% less. Of course, the code provisions would suggest 200%, the direct addition of both members.

The same exercise could be performed with bolts and transverse welds. The reduced deformation capacity of the transverse fillet makes the differences even more

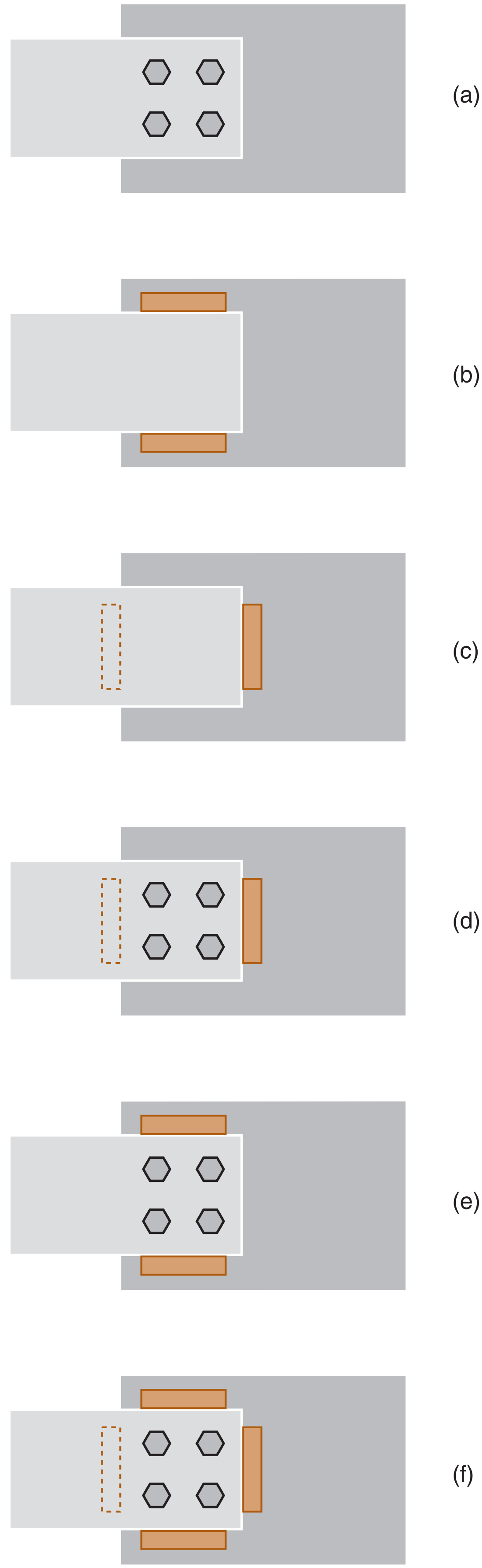

Figure 2.

pronounced. Thus, the significance of these differences in displacement is more pronounced for the connections composed of bolts and transverse welds.

A Proposed Model

Kulak and Grondin propose a model whereby the ultimate load resistance of the joint can be computed from the following relationship:

$R_{utl\ joint} = R_{friction} + R_{bolts} + R_{trans} + R_{long}$

Where $R_{friction}$ is the frictional resistance
R_{bolts} is the bolt shear resistance
R_{trans} is the transverse weld shear resistance
R_{long} is the longitudinal weld shear resistance

$R_{friction}$ is estimated to be 0.25 times the slip resistance of the slip-critical bolted joint. For slip-critical connections in conjunction with welds, this factor is always present, but is accounted for differently, depending on the orientation of the weld (longitudinal versus transverse). This factor, of course, would be zero for bearing-type bolted connections.

R_{bolts} depends on the type of weld (transverse or longitudinal) and the condition of bearing, whether already in bearing (positive) or unknown (indeterminate).

For transverse welds along with slip-critical bolted joints, the ultimate joint resistance is the strength of the transverse weld plus the frictional resistance, or the bolt shear, whichever is greater.

For longitudinal welds along with slip-critical bolted joints, the ultimate joint resistance is a percentage of the bolt shear plus the shear resistance of the longitudinal weld plus the frictional resistance, or the bolt shear, whichever is greater. Under positive bearing conditions, 75% of the ultimate bolt shear strength is used, and for indeterminate bearing conditions, 50% is used.

The work of Kulak and Grondin indicates that for slip-critical connections, the code provisions are unconservative. For example, the capacity of a combined longitudinal weld and bolts is equal to the weld capacity plus 50% of the bolt capacity. For this condition AWS and AISC would indicate the weld capacity plus 100% of the bolts capacity, thus overestimating the capacity of the connections.

Recall from Part 1 that in the general case, AWS and AISC require that combinations of welds and bolts of the bearing type be designed such that the entire load is transferred through the weld. Thus, regardless of the capacity of the bolts, any small weld addition effectively eliminates the capacity of the bolts. The preceding model could be used to address these snug-tightened connections. In such cases, $R_{friction}$ is zero. The greater capacity of the bolts and welds could then be used, as is the case in the Canadian standard *CAN/CSA-S16.1-01*. The Kulak work would indicate that this approach is correct and conservative.

The Kulak work has also revealed new information regarding the combination of longitudinal and transverse fillet welds, which are subject to some of the same deformation capacity differences. This will be addressed in a future edition of Design File.

Conclusion

The responsible technical committees are evaluating these research findings, and changes to specifications will no doubt result. Currently, the data suggest that while a portion of the slip-critical bolt capacities can be directly added to the capacities of longitudinal welds, the same is not the case for slip-critical bolts and transverse welds. In the case of the latter, the greater capacity of the two elements is a conservative assumption.

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