



## Design File

# Designing Welded Lap Joints

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

Welded connections involve two components that are both under the direct control of the designer: the joint type, and the weld type. Failures in or near the weld may be the result of an improperly designed joint. In this Design File, the principles that should be applied when designing lap joints are presented.

Superficially, a lap joint looks very simple, and it may seem odd that this plain configuration of material would need to be carefully considered. The complication stems from the fact that loads do not instantaneously transfer from one member to another. The three joints in Figure 1—one butt joint, and two lap joints—show the differences in the flow of stress through the two joints. The butt joint includes a groove weld while the lap joints use fillet welds. The difference is, stress flow is more associated with the joint type, as opposed to the weld type. The resultant differences in stress distribution result in the need for rules to proportion the lap connection components.

Forces applied to the ends of lap joints result in eccentric loads in the connection area. This can cause joint rotation, as illustrated in Figure 2. This same eccentricity can cause the root of a fillet weld to tear when only one transverse fillet is applied to a lap joint that is permitted to deflect laterally, as can be seen in Figure 3.

In summary, the simple lap joint inherently offers two broad challenges to the designer:

1. How to deal with the non-uniform stress distribution, and
2. How to deal with the eccentricity.

While many welded applications are not contractually governed by *AWS D1.1 Structural Welding Code—Steel*, the designer of any product can find helpful provisions in that code that address these conditions.

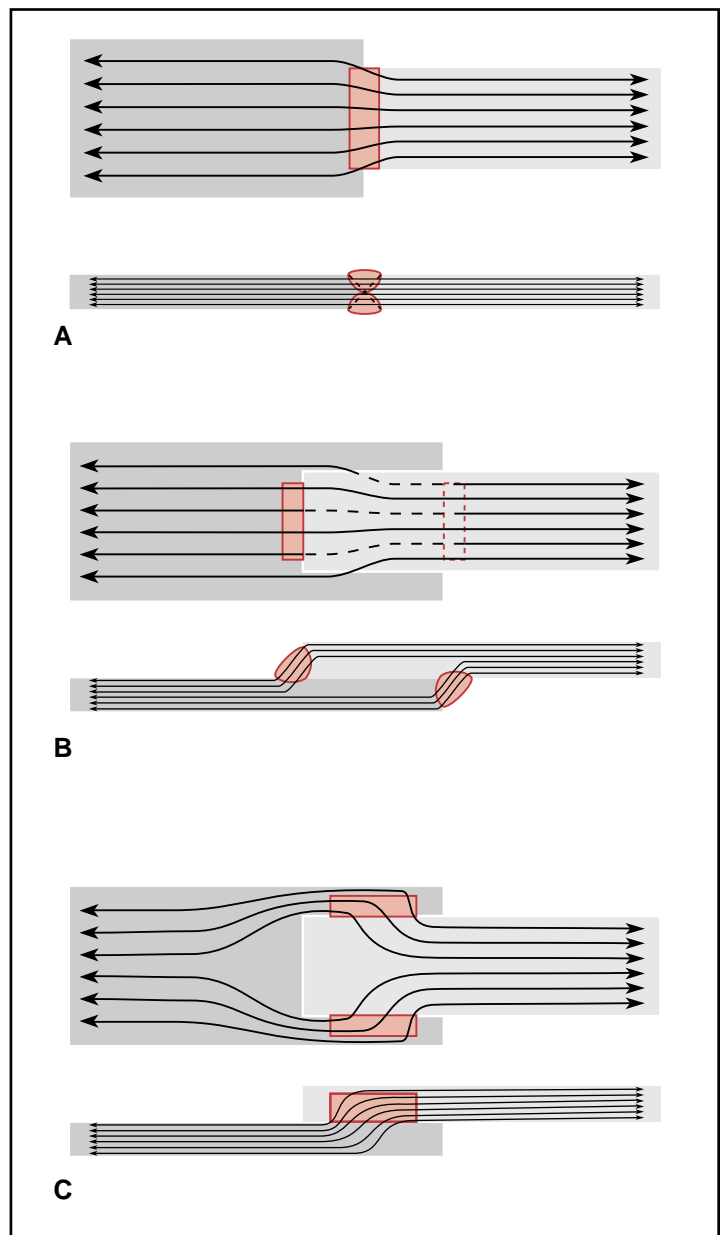


Figure 1

## Non-Uniform Stress Distribution

D1.1 paragraph 2.14.1 requires that, when longitudinal fillet welds are used alone (such as in figure 1c), the length of the fillet weld shall be no less than the perpendicular distance between them. This is illustrated in Figure 4. Even though the weld length “L” may be acceptable for the transfer of force “F,” the complicated stress flow pattern of Figure 4b will generate unacceptable stress concentrations.

The Code goes further in paragraph 2.14.1 and requires that the distance between the welds (shown as “D” in Figure 4) be no greater than 8 in. (200 mm) if only longitudinal welds are used (as shown in Figure 1c). For distances greater than 8 in. (200 mm), transverse welds or intermediate plug or slot welds are permitted to overcome this restriction. While the code does not specifically identify the option, bolts could also be used to accomplish this function.

Paragraph 2.32.1 in Part C for Cyclically Loaded (i.e., susceptible to fatigue failure) Connections additionally requires that this distance not exceed 16 times the thickness of the thinner member, and gives the following reason for the need for the intermediate plug or slot welds: to prevent buckling or separation of the parts. Such separation would strain the root of the longitudinal fillet welds, and could lead to tearing. In cyclic loading, it could lead to fatigue failure, initiating from the weld root.

The role of the 16 times plate thickness would only be applicable for material less than 1/2 in. (12.5 mm); otherwise, the 8 in. (200 mm) requirement from paragraph 2.14.1 would govern.

## Eccentric Loads

D1.1 requires that at least two lines of longitudinal or transverse welds be applied to lap joints (paragraph 2.4.8, 2.4.8.1). This eliminates the concerns shown in Figure 3. There is a caveat: this requirement does not apply when “the joint is sufficiently restrained to prevent it from opening under load” (paragraph 2.4.8.1). Whatever the external restraint, if rotation is prevented, the concerns of eccentric loads are eliminated.

To prevent the condition illustrated in Figure 2, paragraph 2.4.8.2 requires a minimum overlap of five times the thickness of the thinner part, but not less than 1 in. (25 mm). Double fillet welds in lap joints with proper overlap is sufficient to prevent such rotation.

If restrained, the five times overlap provision does not apply. Any sufficient restraint is acceptable, and this is conceptually illustrated in Figure 5.

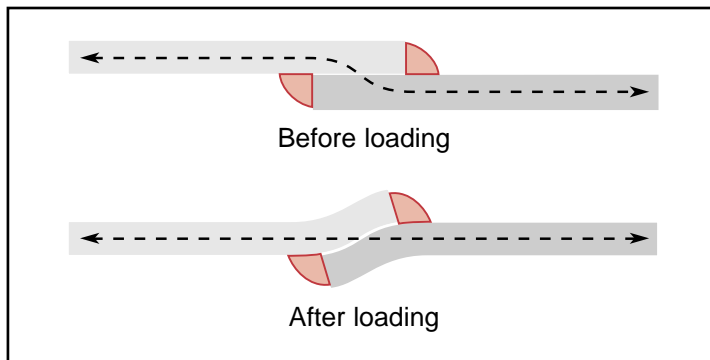


Figure 2

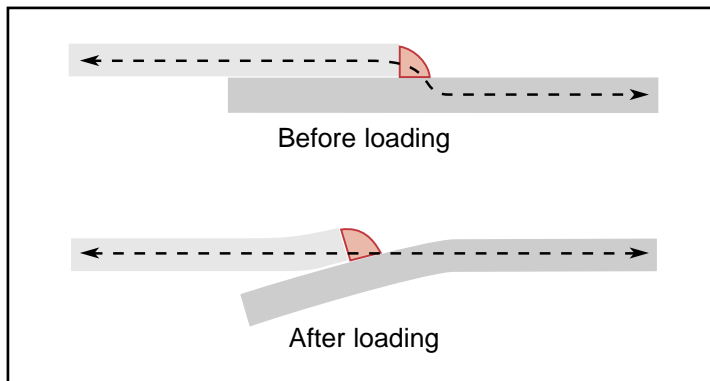


Figure 3

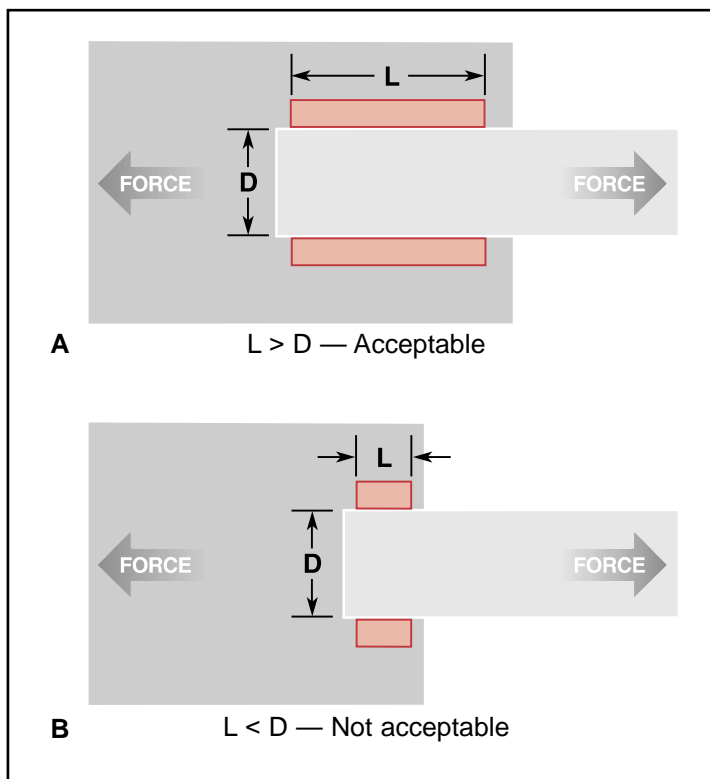


Figure 4

## Other Issues

The code also provides requirements for the details of the fillet welds that are typically used in these connections. For example, the fillet welds are to terminate “not less than the size of the weld from the start of the extension” (paragraph 2.4.7.2). See Figure 6. This is primarily a workmanship concern. Carrying the weld out to the end of the part (where there is little material to conduct away the heat of the weld) often leads to undercut, or melting away of the edges, creating a weak spot in the lapped attachment.

Often, the lap joint lends itself to welds being applied on either side of the joint. Illustrated in Figure 6, the code describes this as welding on “opposite sides of a common plane,” and in paragraph 2.4.7.5, requires that the welds be interrupted at the corners. Again, this is to avoid undercut and unacceptable melting of the edges.

The provisions of paragraph 2.4.5 also apply to lap joints. This provision restricts the maximum fillet weld size to the thickness of the base metal for material less than 1/4 in. (6 mm) thick, and for heavier material, to the thickness of the part less 1/16 in. (2 mm), “unless the weld is designated on the drawings to be built out to obtain full throat thickness.” See figure 7. This is to avoid the situation where a “nothin’ ” weld can be generated—that is, a weld that appears to be full size, but in fact lacks the required weld throat. (See Design File, *Welding Innovation* Vol. XVI, Number 1, 1999.)

The selection criteria for longitudinal versus transverse fillet welds could consider the increased allowable strength associated with the transverse option, reducing the required size (see “Consider Direction of Loading When Sizing Fillet Welds,” Vol. XV, No. 2, 1998). While this option will result in a higher allowable strength, it comes at the cost of reduced ductility *in the weld*. The ductility of the connected material, typically the point where inelastic strains are designed to be concentrated, would be unchanged with either weld orientation.

## Conclusion

Superficially, detailing a lap joint and the corresponding welds may seem simple, but a variety of important details need to be considered. The following checklist may be helpful:

- Are the parts sufficiently restrained to prevent joint rotation? If not, use at least two rows of welds.
- Is the overlap at least five times the thickness of the thinner part? And, is it at least 1 in. (25 mm)?
- For longitudinal welds, are they at least as long as the distance between them?
- For lap joints with only longitudinal welds, is the distance between the welds less than 8 in. (200 mm)? For cyclically loaded members, is this distance also less than 16 times the thinner member?

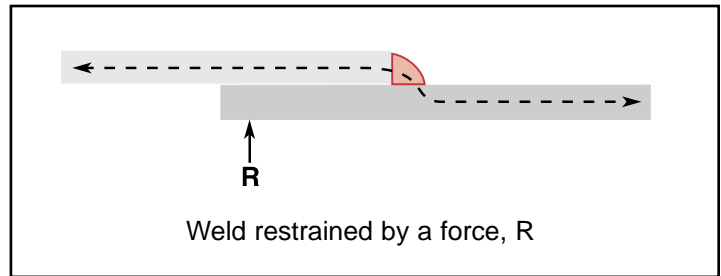


Figure 5

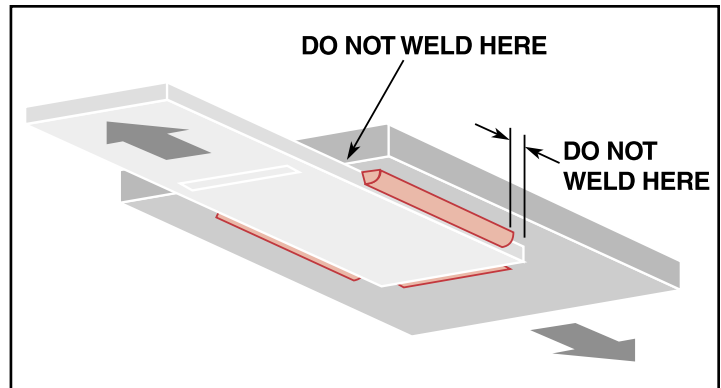


Figure 6

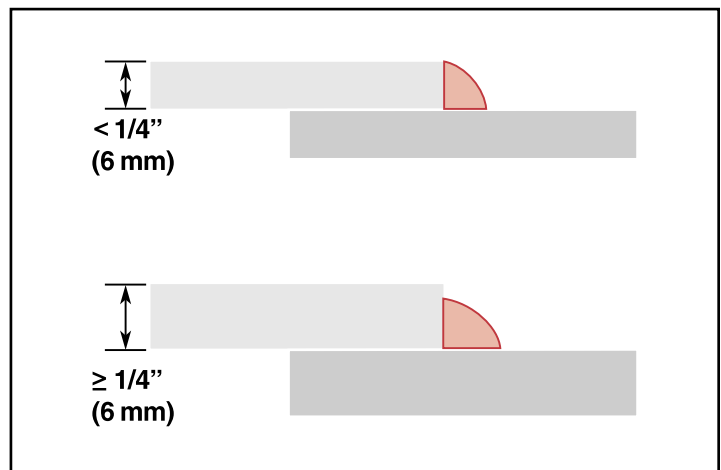


Figure 7

For material thicknesses of 1/4 in. (6 mm) or more, has the fillet weld leg size been reduced by 1/16 in. (2 mm)? Have the fillet welds been detailed to terminate at least one weld size from the end of the piece? Are they detailed to avoid tying the welds together on opposite sides of the common plane of contact?

One final note: these provisions are intended to be applied to lap joints designed to transfer stresses between members. For situations involving lap joints but where the joint is more associated with the assembly of a member, and not with transfer of calculated forces, the principles presented above are not necessarily applicable. 