Design File

Consider Direction of Loading When Sizing Fillet Welds

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

The traditional approach used to design a fillet weld assumes that the load is resisted by the weld's throat, regardless of the direction of loading. Experience and experimentation, however, have shown that fillet welds loaded perpendicular to their longitudinal axis have an ultimate strength that is approximately 50% greater than the same weld loaded parallel to the longitudinal axis. The traditional approach, in which direction of loading is not considered, is therefore conservative. Such a philosophy was incorporated into the AWS *D1.1 Structural Welding Code - Steel*, as represented by the following provision from the 1994 edition:

2.3.2 Fillet Welds. The effective area shall be the effective length multiplied by the effective throat. Stress in a fillet weld shall be considered as applied to this effective area, *for any direction of applied load*. (Emphasis added)

The same code defines the effective throat as follows:

2.3.2.4. The effective throat shall be the shortest distance from the joint root to the weld face of the diagrammatic joint.

This definition of effective throat is also conservative. It accurately defines the theoretical failure plane for fillet welds loaded parallel to their length, but underestimates the increased effective throat that results when the failure plane moves from a 45° orientation to a 67.5° orientation, characteristic of fillet welds loaded perpendicular to their longitudinal axis.

Changes incorporated into the 1996 D1.1 Code, and subsequently repeated in the 1998 edition, offer the potential for significant savings. From D1.1 - 98, the following is found:

2.14.4 In-Plane Center of Gravity Loading. The allowable stress in a linear weld group loaded in-plane through the center of gravity is the following:

$$F_V = 0.30\ F_{EXX}\ (1.0 + 0.50 \sin^{1.5} \Theta)$$

where:

F_V = allowable unit stress, ksi
F_{EXX} = electrode classification number, i.e., minimum specified tensile strength, ksi
Θ = angle of loading measured from the weld longitudinal axis, degrees

For parallel loading, $\Theta = 0$, and the parenthetical term in the above equation becomes 1, yielding the same allowable unit stress as has been traditionally permitted. For perpendicular loading, $\Theta = 90°$, and the parenthetical term becomes 1.5, permitting the increased allowable unit stress.

Design Example

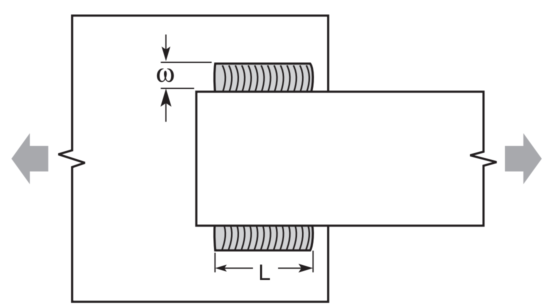

Figure 1. Lap joint with fillet welds loaded in parallel.

Consider the two assemblies shown in Figures 1 and 2. The weld sizes would be computed as follows:

Using an E70 electrode (E48), and with L = 4" (100mm, 0.1m), what weld size is needed to resist the applied load of 40 kips (180 kN)?

$$F_V = 0.30\ F_{EXX}\ (1 + 0.5 \sin^{1.5} \Theta)$$

ENGLISH

$$F_V = 0.30\ (70\text{ ksi})\ (1 + 0.5 \sin^{1.5} 0°) = 21\text{ ksi}$$

$$F = F_V\ (A) = F_V\ (2\text{ welds})\ (L)\ (0.707)\ (\omega)$$

$$\omega = \frac{F}{F_V 2L(0.707)} = \frac{40\text{ kips}}{(21\text{ ksi})(2)(4")(0.707)}$$

$$= 0.337"$$

Use 3/8" fillet

METRIC

$$F_V = 0.30\ (480\text{ MPa})\ (1 + 0.5 \sin^{1.5} 0°) = 144\text{ MPa}$$

$$\omega = \frac{180\text{ kN}}{(144\text{ MPa})(2)(0.1\text{ m})(0.707)}$$

$$= 0.0088\text{ m (8.8mm)}$$

Use 10 mm fillet

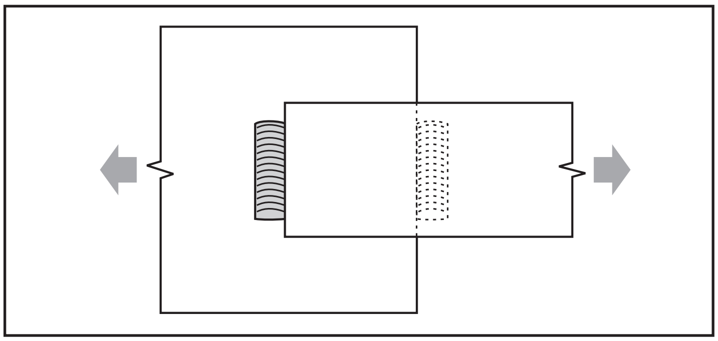

Figure 2. Lap joint with fillet welds loaded perpendicularly.

ENGLISH

$$F_V = 0.30\ (70\text{ ksi})\ (1 + 0.5 \sin^{1.5} 90°) = 31.5\text{ ksi}$$

$$\omega = \frac{40\text{ kips}}{(31.5\text{ ksi})(2)(4")(0.707)} = 0.224"$$

Use 1/4" fillet

METRIC

$$F_V = 0.30\ (480\text{ MPa})\ (1 + 0.5 \sin^{1.5} 90°) = 216\text{ MPa}$$

$$\omega = \frac{180\text{ kN}}{(216\text{ MPa})(2)(0.1\text{ m})(0.707)}$$

$$= 0.00589\text{ m (5.89 mm)}$$

Use 6 mm fillet

Consistent with expectations, the welds in Figure 2 are permitted to be decreased — in this case, by two standard weld sizes. The welds in Figure 2 require 55% less weld metal than the welds in Figure 1.

Decreased Deformation Capacity

Along with the increase in strength of welds loaded perpendicular to their length, the researchers found a decrease in the deformation capacity before failure. If significant post-yielding deformation capacity is desired, the assembly in Figure 1 would be preferred. Most engineered structures are expected to remain elastic under design loads, so consideration of only the strength is generally adequate. However, for structures that may be subject to overload conditions where large amounts of plastic deformation that precede failure are desired, the designer may choose to orient the welds parallel to the major applied load.

Practical Applications

In order to capitalize upon the additional allowable stress capacity, the designer must orient the welds so that they are as nearly perpendicular to the applied load as possible. Notice that the equation permits the use of any value of Θ, even though the examples have shown the extremes of 0° and 90°.

The increased deformation capacity of longitudinally loaded fillet welds may have some design advantages in certain applications. When this is the case, geometries that involve the application of loads perpendicular to the weld's longitudinal axis should be avoided.

The designer has the opportunity to review existing designs and determine whether weld sizes can be reduced. It is imperative, however, that this approach only be employed where previous designs were based upon accurate assumptions and calculations. In many applications, weld sizes have been modified over the years, increasing or decreasing in weld sizes based upon prototype behavior or field experiences. Reduction of weld sizes under these conditions would be inappropriate.

Even though the particular product that is being designed may not fall under the domain of the D1.1 Code, these principles apply and could be used on other types of welded applications other than structures.

Conclusion

The orientation of welds with respect to the primary applied load significantly affects the weld metal allowable stress, as well as the overall deformation capacity. The designer should consider these factors in order to maximize performance while minimizing costs.

References

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