3-3 Welded Connections

Welding is the process of joining two steel pieces (the base metal) together by heating them to the point that molten filler material mixes with the base metal to form one continuous piece.

There are many welding processes, however the two most common processes used in structural steel fabrication:

- **Shielded Metal Arc Welding (SMAW):** A manual process that is typically used when welding in the field. It is also used frequently when welding in a fabrication shop.
- **Submerged Arc Welding (SAW):** An automated welding process that frequently used when welding in a fabrication shop.

There are five basic types of welded joints, as depicted in Figure 3-10: Butt Joints, Lap Joints, Tee Joints, Corner Joints, and Edge joints

The basic weld types are groove welds, fillet welds, slot & plug welds.

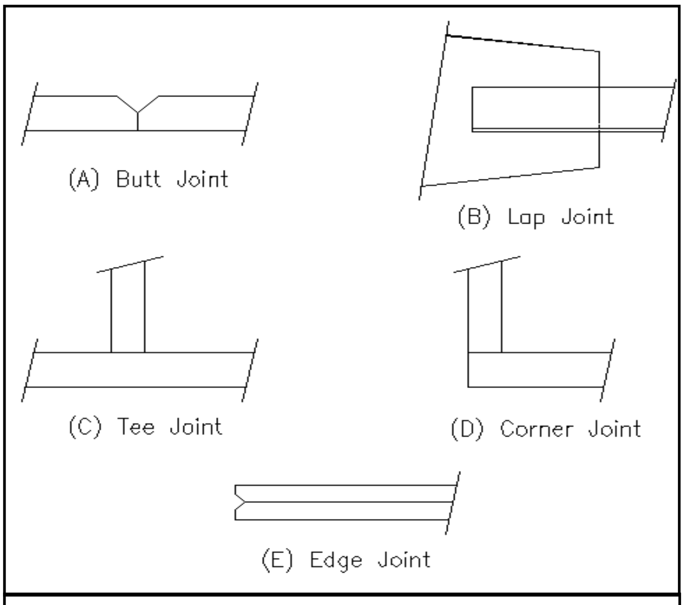


Figure 3-10 Welded Joint Types

Groove Welds: Groove welds are generally used to fill the gap between the two pieces being connected. Groove welds are considered to be either "complete joint penetration" (CJP) or "partial joint penetration" (PJP).

A CJP weld completely fills the gap between the two pieces as shown in Figure 3-11 parts A, B, and C. A PJP weld only fills a portion of the gap as seen in Figure 3-11 parts D, E, F, and G.

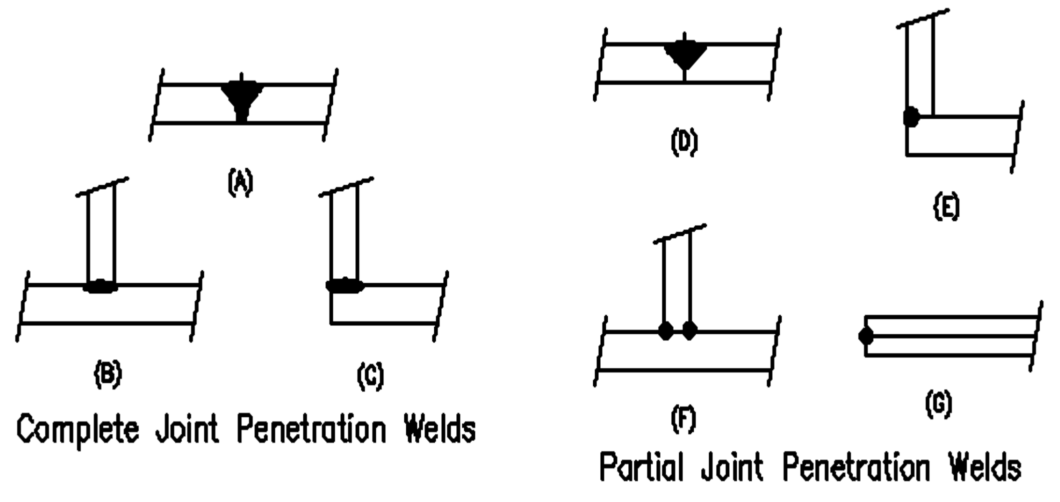


Figure 3-11 Groove Weld Examples

Fillet Welds: Fillet welds do not penetrate the gap between the parts being connected. A fillet weld generally has a triangular cross section with one leg of the triangle being attached to each piece being connected. Fillet welds are very common and are used for a variety of connections. A typical fillet weld is shown in Figure 3-12

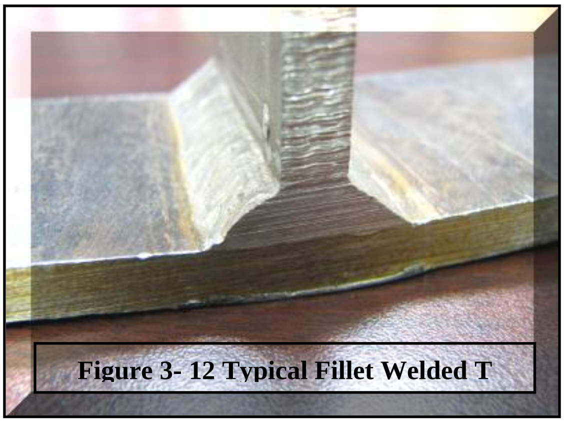


Figure 3- 12 Typical Fillet Welded T

Slot & Plug Welds: Slot & Plug welds are similar to fillet welds in that they do not penetrate the gap between the parts being connected. These welds fill a slot or hole in one of the pieces being connected with the connection being between the edge of the slot or hole on the one piece and the surface of the other piece.

3-4 Size and Effective Area of Fillet Welds

- **Minimum allowed size of fillet welds:** the minimum size of fillet welds shall not be less than size shown in Table J2.4 (LRFDM, pp. 96). This means that the weld needs to be big enough to heat the base material sufficient to create a good bond between the base metal and the weld metal.

- **Maximum allowed size of fillet welds:** The specification limits the weld size (LRFDM, J2.2b, pp. 96):

$$\omega_{,\max} \leq t \ \ldots\ldots\ldots \quad \text{if } t < 1/4''$$
$$\omega_{,\max} \leq t - 1/16'' \ \ldots\ldots\ \text{if } t \geq 1/4''$$

Where t is the thickness of thickest connected member.

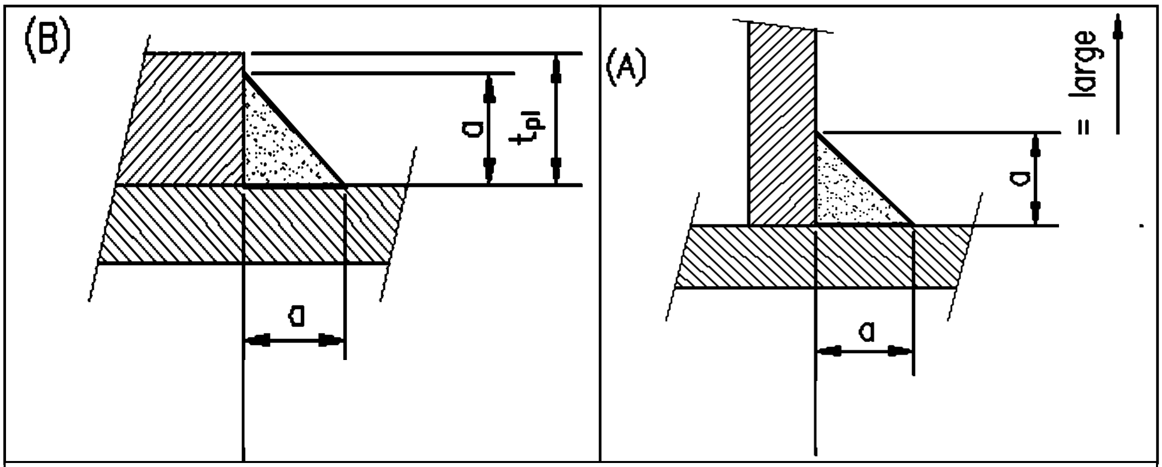


Figure 3-13-1 Maximum Fillet Weld Size

- ***Throat size of fillet weld:*** The effective thickness of throat, $\mathbf{t_e}$, for a fillet weld is taken as the least distance from the root of the weld (i.e. where the two connected pieces meet) to the outer surface of the weld as shown in Figure 3-13-2.

$$t_e = a \sin 45° = 0.707\, \omega$$

Where: t_e = effective throat or effective length of a fillet weld, in.
ω = leg size of a fillet weld, in.

- **Effective Areas:** The effective area of your typical fillet weld equals the effective throat times the length of the weld as shown in Figure 3-13-3.

$$A_w = t_e * L_w$$

Where L_w = gross length of a fillet weld, in.; $L_w \geq L_{w,\min} = 4\,\omega$
t_e = effective length of a fillet weld, in.
A_w = effective area of a fillet weld, in.^{2}

- The actual weld length should be: $L_w/\,\omega \leq 100$
- If $L_w/\,\omega > 100$ multiply by β
- $\beta = 1.2 - 0.002(L_w/a) \leq 1.0$
- If $L_w/\,\omega > 300$ Take $\beta = 0.6$

(LRFDM, J2.2b, pp. 96)

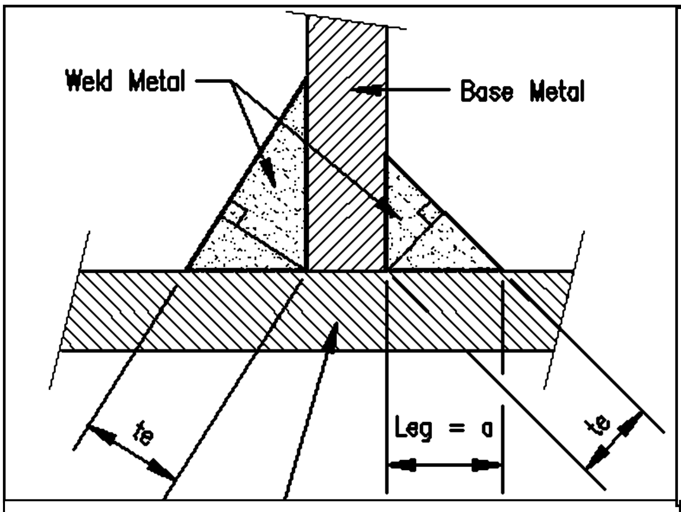


Figure 3-13-2 Fillet Weld Sectional Dimensions

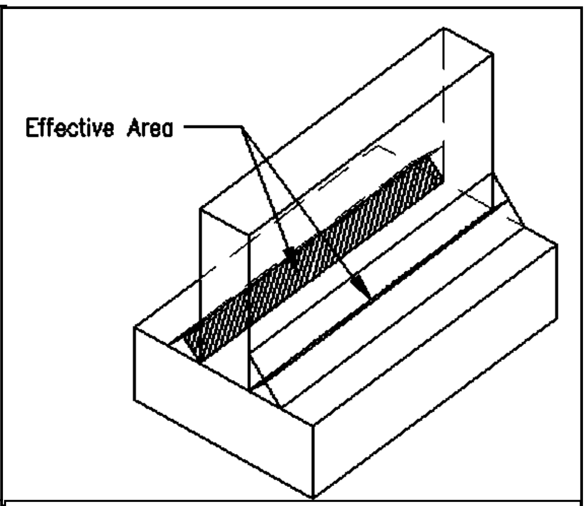


Figure 3-13-3 Effective Area of Fillet Welds

3-5 *Design Strength of Fillet Weld*

In this case two limit state are to be considered; weld metal strength and base metal strength:

- Weld metal design strength
  - Strength based on LRFDS Table J2.5
    $R_{dW} = \varphi F_w A_w = 0.75(0.6F_{EXX})t_e\, L_w = 0.45\, F_{EXX}\, t_e\, L_w$

    Where: A_w = effective area of weld, $in^2 = t_e\, L_w$
    F_w = nominal strength of weld metal, ksi = $0.6F_{EXX}$ (Table J2.5, pp. 100)

    Or $F_w = 0.6F_{EXX}\,[1.0+0.5(\sin\theta)^{1.5}]$ …for linear group loaded in plane through the center of gravity (J2.4, pp. 100)
    θ= angle of loading measured from the weld longitudinal axis, degree

  - Check base metal shear yielding strength
    $\varphi\, R_{BM1} = \varphi(0.6F_y)t_p\, L_w \qquad \varphi=1$
  - Check base metal shear rupture strength
    $\varphi\, R_{BM2} = \varphi(0.6F_u)\, t_p\, L_w \qquad \varphi=0.75$

    $R_d = \min.\,[R_{dW}, \varphi\, R_{BM1}, \varphi\, R_{BM2}]$

Example Problem ***3-5:*** Determine the design shear strength of a 4-in long 5/16 in. fillet weld. Assume SMAW process and E70 electrodes. Assume that the applied load passes through the center of gravity of the weld. The weld is: (a) a longitudinal weld, (b) a transverse load, (c) an oblique weld, with the load inclined at 30^o with axis of the weld. Use: (1) LRFDS Table J2.5; (2) LRFDS Appendix J2.4.

Solution: - Weld size, a = 5/16 in. , Effective length, $L_w = 4.0$ in.
SMAW process: $t_e = a \sin 45° = 0.707\ \omega = 0.707\ (5/16) = 0.221$ in.
E70 electrodes. So, $F_{EXX} = 70.0$ ksi
As no details are given, assume that the base material does not control the design of weld.

1. Strength based on LRFDS Tables J2.5: In this approach, the design strength of the weld is independent of the orientation of the applied load.

$$R_{dw} = 0.45F_{EXX}\ t_e\ L_w = 0.45*70*0.221*4 = 27.85 \text{ kips}$$

2. Strength based on LRFDS Appendix J2.4

a. Longitudinal weld: $\theta = 0.0$, $\sin\theta = 0.0$

$$R_{dw\ (\theta = 0.0)} = 0.45F_{EXX}\ t_e\ L_w\ [1.0 + 0.5\ (\sin\theta)^{1.5}]$$
$$= 0.45*70*\ 0.221*4\ [1.0 + 0.0] = 27.85 \text{ kips}$$

b. Transverse weld: $\theta = 90.0$, $\sin\theta = 1$

$$R_{dw\ (\theta = 90.0)} = 0.45F_{EXX}\ t_e\ L_w\ [1.0 + 0.5\ (\sin\theta)^{1.5}]$$
$$= 0.45*70 * 0.221*4\ [1.0 + 0.5\ (1)^{1.5}] = 41.8 \text{ kips}$$

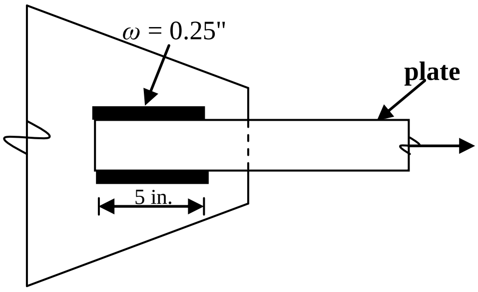
c. Transverse weld: $\theta = 30.0$, $\sin\theta = 0.5$

$$R_{dw\ (\theta = 30.0)} = 0.45F_{EXX}\ t_e\ L_w\ [1.0 + 0.5\ (\sin\theta)^{1.5}]$$

$$= 0.45*70*\ 0.221*4\ [1.0 + 0.5\ (0.5)^{1.5}] = 32.8 \text{ kips}$$

Observe that the transverse weld is 50% stronger than the longitudinal one and the oblique weld 17.7%. the LRFDS Table J5.2 ignores this additional strength.

***Example Problem* 3-6:** Determine the design strength of the tension member and connection system shown below. The tension member is a 4 in. × ⅜ in. thick rectangular bar. It is welded to a ½ in. thick gusset plate of A572 Gr 50 steel, using E70XX electrode. Consider the shear strength of the weld metal and the surrounding base metal.



Solution: -

– Check size limitation of weld

t_{bar}= ⅜ " & t_{plate}= ½ "

$\omega_{,\,max} = t - 1/16"$ ……. t > ¼"

$= ⅜ - 1/16 = 5/16"$

$\omega_{,\,min} = 3/16$ (Table J2.4)

$\omega_{,\,min} = 0.1875" < \omega = 0.25" < \omega_{,\,max} = 0.3125"$ ……. OK

$L_w = 5" > L_{w,\,min} = 4\,\omega = 4*0.25 = 1"$ ………OK

- $L_w/\,\omega = 5/.25 = 20 < 100$ ……… $\beta=1.0$

– Design strength of the weld

$$R_{dW} = \varphi F_w A_w = 0.45F_{EXX}\, t_e\, L_w = 0.45F_{EXX}\,(0.707\,\omega)\, L_w$$
$$= 0.45*70 * (0.707*0.25) * 10 = 55.68 \text{ kips}$$

– Check base metal shear yielding strength

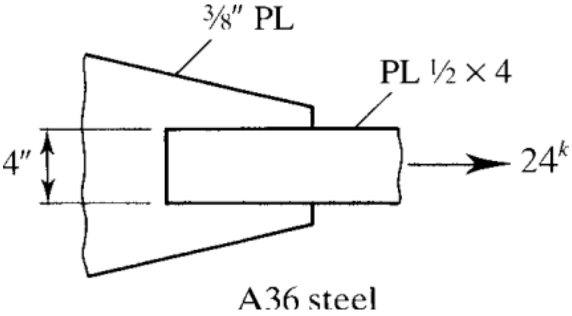
$$\varphi\, R_{BM1} = \varphi(0.6F_y)t_p\, L_w = (1)\,(0.6*36 \text{ ksi})\,(10*3/8 \text{ in}^2) = 80 \text{ kips}$$

– Check base metal shear rupture strength

$$\varphi\, R_{BM2} = \varphi(0.6F_u)t_p\, L_w = (0.75)\,(0.6*58 \text{ ksi})\,(10*3/8 \text{ in}^2) = 97.9 \text{ kips}$$

– Design strength of the system

R_d=55.68 kips



Example 3-7: A plate 1 ⁄2* 4 " of A36 steel is used as a tension member to carry a service dead load of 6 kips and a service live load of 18 kips. It is to be attached to a 3⁄8-inch gusset plate, as shown in Figure. Design a welded connection.

Solution:

The base metal is A36 steel, so E70XX electrodes will be used.

t_{min} = 3/ 8" (gusset plate)

t_{max}=0.5" (Member)

Thus from Table J2.4 of AISC with t_{min} = 3/ 8" thus

$$w_{min} = 3/16 \text{in}$$

For t_{max} = 0.5

$$w_{max} = t - 1/16 = 0.5 - 1/16 = 7/16 \text{in}$$

design w= 3/16 in

Shear strength of the weld

$$F_w = 0.6 F_{EXX} = 0.6 * 70 = 42 \text{ksi}$$

$$\phi R_n = 0.75 * F_w * 0.707 * w * L$$

$$= 0.75 * 42 * 0.707 * 3/16 * L = 4.176 \text{ L}$$

Base Metal Strength

$$\phi R_n = \min \left\{ 1.0 \left(0.6 \text{ } F_y \text{ } t L\right), 0.75 \left(0.6 \text{ } F_u \text{ } t L\right) \right\}$$

$$\phi R_n = \min \begin{Bmatrix} 1.0 \left(0.6 * 36 * 3/8 * L\right), \\ 0.75 \left(0.6 * 58 * 3/8 * L\right) \end{Bmatrix}$$

$$\phi R_n = \min \left\{ 8.1 L, 9.79 L \right\} = 8.1 \text{ L}$$

Thus weld strength control and the connection strength = 4.176L

$$P_u = 1.2 P_D + 1.6 P_L = 1.2 * 6 + 1.6 * 18 = 36 \text{kips}$$

$$\phi R_n = 4.176 L = P_u$$

$$\text{Required length}, L = \frac{36}{4.176} = 8.62 \text{in}$$

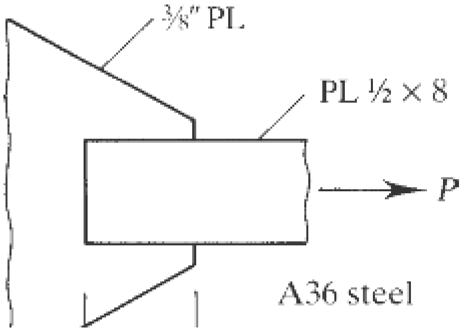
L=8.62>L_{min}=4w=4*3/16=0.75 in OK

Use two 4.5 in side weld

Total length=2*4.5=9 > 8.62

Length of side weld = 4.5 > transverse distance between welds = 4 " OK

Example 3-8: A plate 1⁄2*8 of A36 steel is used as a tension member and is to be connected to a 3⁄8- inch-thick gusset plate, as shown in Figure.. Design a weld to develop the full tensile capacity of the member. Use U=1.0.



Solution

Find design tensile strength of member.

- Yielding of gross area

$$\phi P_n = 0.9\ F_y\ A_g = 0.9 * 36 * (0.5 * 8) = 129.6 \text{kips}$$

Fracture of net area

$$A_e = UA_g = 1.0 * 0.5 * 8 = 4\ \text{in}^2$$

$$\phi P_n = 0.75\ F_u\ A_e = 0.75 * 58 * (0.5 * 8) = 174.0 \text{kips}$$

Thus design tensile strength = P_u = 129.6 kips

The base metal is A36 steel, so E70XX electrodes will be used.

t_{min} = 3/ 8" (gusset plate)
t_{max}=0.5" (Member)
Thus from Table J2.4 of AISC with t_{min} = 3/ 8" thus

$$w_{min} = 3/16 \text{in}$$

For t_{max} = 0.5

$$w_{max} = t - 1/16 = 0.5 - 1/16 = 7/16 \text{in}$$

design w= 3/16 in

Shear strength of the weld

$$F_w = 0.6 F_{EXX} = 0.6 * 70 = 42 \text{ksi}$$

$$\phi R_n = 0.75 * F_w * 0.707 * w * L$$

$$= 0.75 * 42 * 0.707 * 3/16 * L = 4.176\ L$$

Base Metal Strength

$$\phi R_n = \min \left\{ 1.0\ (0.6\ F_y\ t\,L), 0.75\ (0.6\ F_u\ t\,L) \right\}$$

$$\phi R_n = \min \left\{ \begin{matrix} 1.0\ (0.6 * 36 * 3/8 * L), \\ 0.75\ (0.6 * 58 * 3/8 * L) \end{matrix} \right\}$$

$$\phi R_n = \min \{ 8.1 L, 9.79 L \} = 8.1\ L$$

Thus weld strength control and the connection strength = 4.176L

$$P_u = 1.2P_D + 1.6P_L = 1.2*6 + 1.6*18 = 36\,\text{kips}$$

$$\phi R_n = 4.176L = P_u$$

$$\text{Required length}, L = \frac{129.6}{4.176} = 31.03\,\text{in}$$

$L=31.03>L_{min}=4w=4*3/16=0.75$ in OK

Use two 16 in side weld

Total length=2*16=32 > 31.03

Length of side weld = 16 > transverse distance between welds = 8 " OK