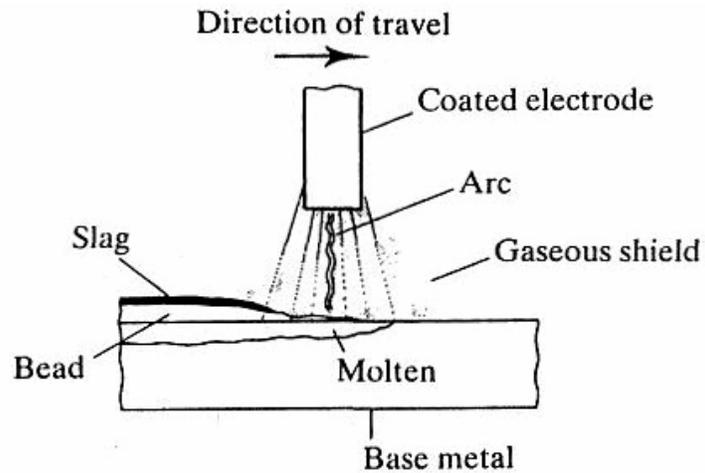
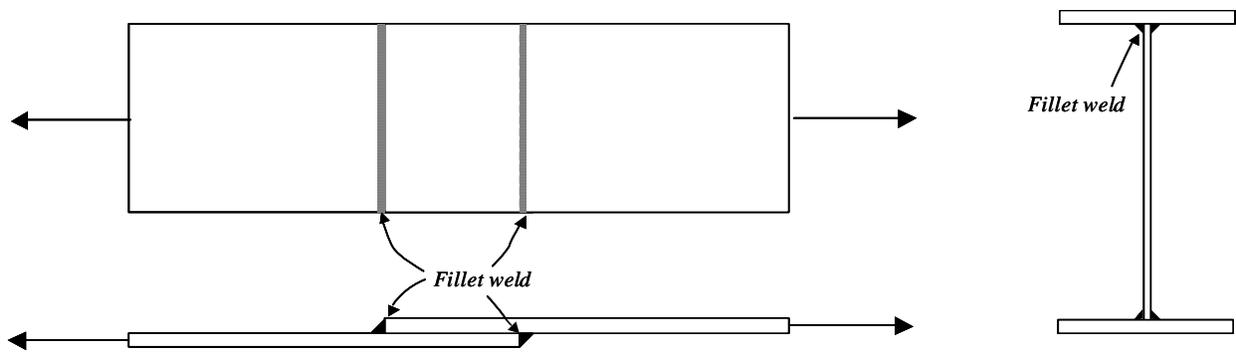


CHAPTER 6. WELDED CONNECTIONS

6.1 INTRODUCTORY CONCEPTS

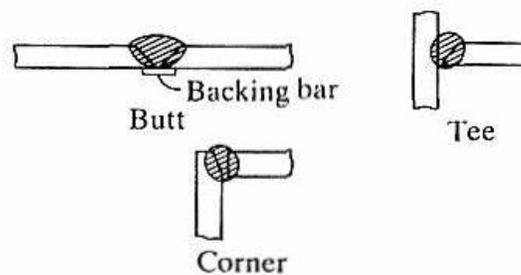
- Structural welding is a process by which the parts that are to be connected are heated and fused, with supplementary molten metal at the joint.
- A relatively small depth of material will become molten, and upon cooling, the structural steel and weld metal will act as one continuous part where they are joined.



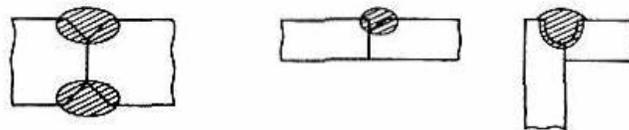
- The additional metal is deposited from a special electrode, which is part of the electric circuit that includes the connected part.
 - In the shielded metal arc welding (SMAW) process, *current* arcs across a gap between the electrode and the base metal, heating the connected parts and depositing part of the electrode into the molten base metal.
 - A special coating on the electrode vaporizes and forms a protective gaseous shield, preventing the molten weld metal from oxidizing before it solidifies.
 - The electrode is moved across the joint, and a weld bead is deposited, its size depending on the rate of travel of the electrode.
 - As the weld cools, impurities rise to the surface, forming a coating called *slag* that must be removed before the member is painted or another pass is made with the electrode.
 - Shielded metal arc welding is usually done manually and is the process universally used for field welds.
- For shop welding, an automatic or semi automatic process is usually used. Foremost among these is the submerged arc welding (SAW),
- In this process, the end of the electrode and the arc are submerged in a granular flux that melts and forms a gaseous shield. There is more penetration into the base metal than with shielded metal arc welding, and higher strength results.
- Other commonly used processes for shop welding are *gas shielded metal arc*, *flux cored arc*, and *electro-slag welding*.
- Quality control of welded connections is particularly difficult, because defects below the surface, or even minor flaws at the surface, will escape visual detection. Welders must be

properly certified, and for critical work, special inspection techniques such as radiography or ultrasonic testing must be used.

- The two most common types of welds are the fillet weld and the groove weld. Fillet weld examples: lap joint – fillet welds placed in the corner formed by two plates
Tee joint – fillet welds placed at the intersection of two plates.
- Groove welds – deposited in a gap or groove between two parts to be connected e.g., butt, tee, and corner joints with beveled (prepared) edges
- Partial penetration groove welds can be made from one or both sides with or without edge preparation.



(a) Complete Penetration Groove Welds

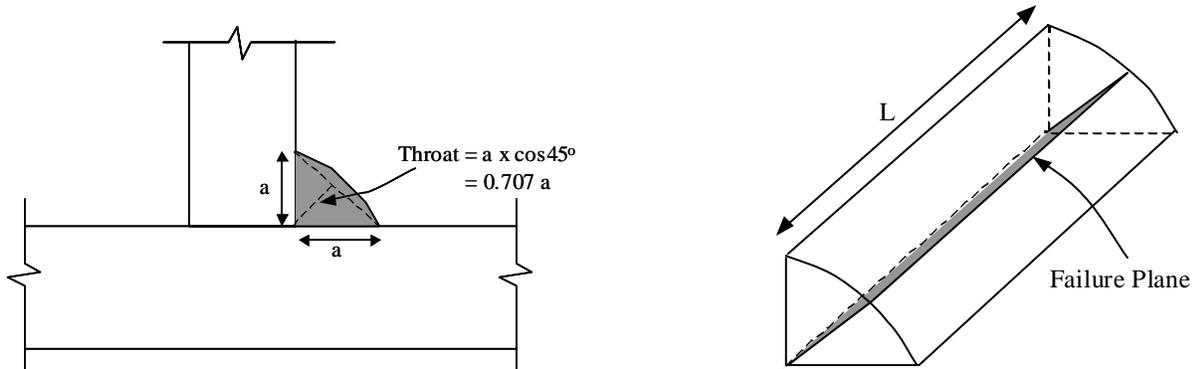


(b) Partial Penetration Groove Welds

6.2 Design of Welded Connections

- Fillet welds are most common and used in all structures.
- Weld sizes are specified in 1/16 in. increments
- A fillet weld can be loaded in any direction in shear, compression, or tension. However, it always **fails in shear**.

- The shear failure of the fillet weld occurs along a plane through the throat of the weld, as shown in the Figure below.



- Shear stress in fillet weld of length L subjected to load $P = f_v = \frac{P}{0.707 a L_w}$
- If the ultimate shear strength of the weld = f_w
 $R_n = f_w \times 0.707 \times a \times L_w$
 $\phi R_n = 0.75 \times f_w \times 0.707 \times a \times L_w$ i.e., ϕ factor = 0.75
- f_w = shear strength of the weld metal is a function of the electrode used in the SMAW process.
 - The tensile strength of the weld electrode can be 60, 70, 80, 90, 100, 110, or 120 ksi.
 - The corresponding electrodes are specified using the nomenclature E60XX, E70XX, E80XX, and so on. This is the standard terminology for weld electrodes.
- The strength of the electrode should match the strength of the *base metal*.
 - If yield stress (σ_y) of the base metal is $\leq 60 - 65$ ksi, use E70XX electrode.
 - If yield stress (σ_y) of the base metal is $\geq 60 - 65$ ksi, use E80XX electrode.
- E70XX is the most popular electrode used for fillet welds made by the SMAW method.
- **Table J2.5** in the AISC Specifications gives the weld design strength

$$f_w = 0.60 F_{EXX}$$

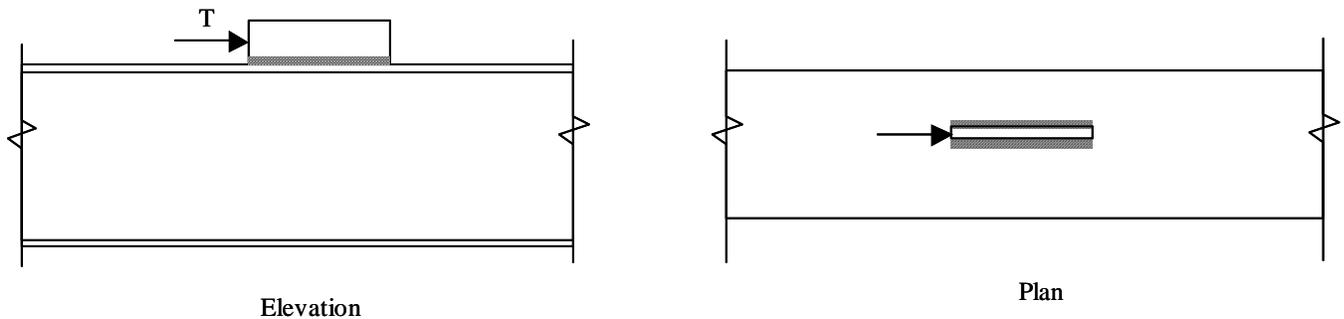
For E70XX, $\phi f_w = 0.75 \times 0.60 \times 70 = 31.5$ ksi

- Additionally, the shear strength of the base metal must also be considered:

$$\phi R_n = 0.9 \times 0.6 F_y \times \text{area of base metal subjected to shear}$$

where, F_y is the yield strength of the base metal.

- For example:



$$\begin{aligned} &\text{Strength of weld in shear} \\ &= 0.75 \times 0.707 \times a \times L_w \times f_w \end{aligned}$$

$$\begin{aligned} &\text{Strength of base metal} \\ &= 0.9 \times 0.6 \times F_y \times t \times L_w \end{aligned}$$

} Smaller governs the strength of the weld

- Always check weld metal and base metal strength. Smaller value governs. In most cases, the weld metal strength will govern.
- In weld design problems it is advantageous to work with strength per unit length of the weld or base metal.

6.2.1 Limitations on weld dimensions (See AISC Spec. J2.2b on page 16.1-54 of manual)

- **Minimum size (a_{\min})**
 - function of the thickness of the thickest connected plate
 - given in Table J2.4 of the AISC specifications
- **Maximum size (a_{\max})**

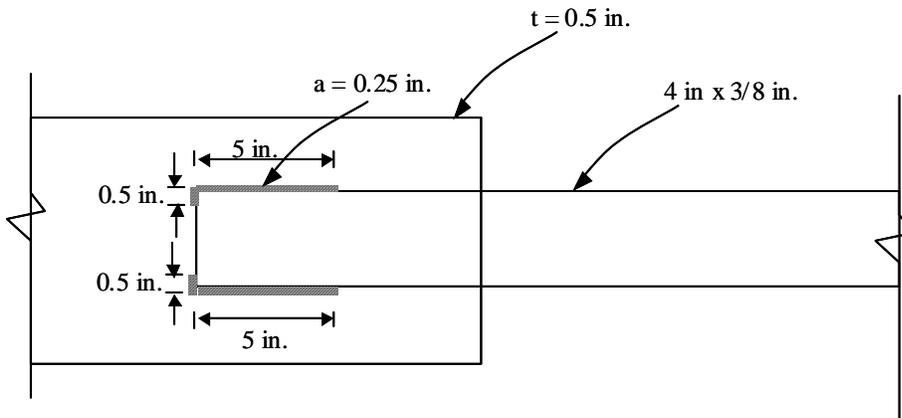
- function of the thickness of the thinnest connected plate:
- for plates with thickness ≤ 0.25 in., $a_{\max} = 0.25$ in.
- for plates with thickness ≥ 0.25 in., $a_{\max} = t - 1/16$ in.

- **Minimum length (L_w)**
 - length (L_w) $\geq 4 a$ otherwise, $a_{\text{eff}} = L_w / 4$
 - Read **J2.2 b**
 - Intermittent fillet welds: $L_{w\text{-min}} = 4 a$ and 1.5 in.

- **Maximum effective length - read AISC J2.2b**
 - If weld length $L_w < 100 a$, then effective weld length ($L_{w\text{-eff}}$) = L_w
 - If $L_w < 300 a$, then effective weld length ($L_{w\text{-eff}}$) = $L_w (1.2 - 0.002 L_w/a)$
 - If $L_w > 300 a$, the effective weld length ($L_{w\text{-eff}}$) = $0.6 L_w$

- **Weld Terminations - read AISC J2.2b**
 - Lap joint – fillet welds terminate at a distance $> a$ from edge.
 - Weld returns around corners must be $> 2 a$

Example 6.1. Determine the design strength of the tension member and connection system shown below. The tension member is a 4 in. x 3/8 in. thick rectangular bar. It is welded to a 1/2 in. thick gusset plate using E70XX electrode. Consider the yielding and fracture of the tension member. Consider the shear strength of the weld metal and the surrounding base metal.



Solution

Step I. Check for the limitations on the weld geometry

- $t_{\min} = 3/8$ in. (member)

$t_{\max} = 0.5$ in. (gusset)

Therefore, $a_{\min} = 3/16$ in.

- AISC **Table J2.4**

$a_{\max} = 3/8 - 1/16 = 5/16$ in.

- AISC **J2.2b**

Fillet weld size = $a = 1/4$ in.

- Therefore, *OK!*

- $L_{w-\min} = 1.0$ in.

- *OK.*

- $L_{w-\min}$ for each length of the weld = 4.0 in. (*transverse distance between welds, see J2.2b*)

- Given length = 5.0 in., which is $> L_{\min}$. Therefore, *OK!*

- Length/weld size = $5/0.25 = 20$ - Therefore, maximum effective length **J2.2 b** satisfied.

- End returns at the edge corner size - minimum = $2 a = 0.5$ in.

-Therefore, *OK!*

Step II. Design strength of the weld

- Weld strength = $\phi \times 0.707 \times a \times 0.60 \times F_{EXX} \times L_w$
 $= 0.75 \times 0.707 \times 0.25 \times 0.60 \times 70 \times 10 = 55.67$ kips
- Base Metal strength = $\phi \times 0.6 \times F_y \times L_w \times t$
 $= 0.9 \times 0.6 \times 50 \times 10 \times 3/8 = 101.25$ kips

Step III. Tension strength of the member

- $\phi R_n = 0.9 \times 50 \times 4 \times 3/8 = 67.5$ kips - tension yield
 - $\phi R_n = 0.75 \times A_e \times 65$ - tension fracture
- $A_e = U A$
- $A = A_g = 4 \times 3/8 = 1.5$ in² - See Spec. B3
- $U = 0.75$, since connection length (L_{conn}) < 1.5 w - See Spec. B3

Therefore, $\phi R_n = 54.8$ kips

The design strength of the member-connection system = 54.8 kips. Tension fracture of the member governs. The end returns at the corners were not included in the calculations.

Example 6.2 Design a double angle tension member and connection system to carry a factored load of 250 kips.

Solution

Step I. Assume material properties

- Assume 36 ksi steel for designing the member and the gusset plates.
- Assume E70XX electrode for the fillet welds.

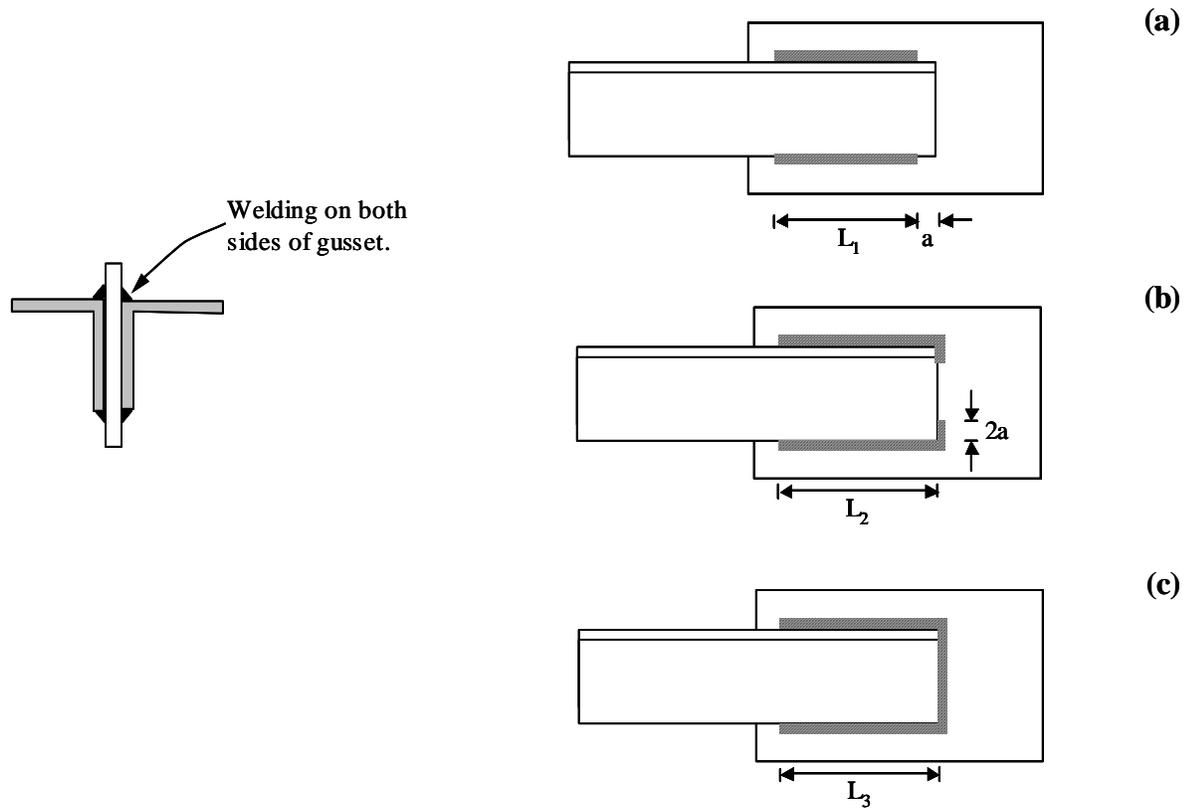
Step II. Design the tension member

- From Table 3-7 on page 3-32 of the AISC manual, select 2L 5 x 3½ x 1/2 made from 36 ksi steel with yield strength = 259 kips and fracture strength = 261 kips.

Step III. Design the welded connection

- $a_{\min} = 3/16$ in. **- Table J2.4**
 $a_{\max} = 1/2 - 1/16$ in. = $7/16$ in. **- J2.2b**
Design, $a = 3/8$ in. = 0.375 in.
- Shear strength of weld metal = $\phi R_n = 0.75 \times 0.60 \times F_{EXX} \times 0.707 \times a \times L_w$
 $= 8.35 L_w$ kips
- Strength of the base metal in shear = $\phi R_n = 0.9 \times 0.6 \times F_y \times t \times L_w$
 $= 9.72 L_w$ kips
- Shear strength of weld metal governs, $\phi R_n = 8.35 L_w$ kips
- $\phi R_n > 250$ kips
 $\therefore 8.35 L_w > 250$ kips
 $\therefore L_w > 29.94$ in.
Design, length of 1/2 in. E70XX fillet weld = 30.0 in.
- *Shear strength of fillet weld = 250.5 kips*

Step IV. Layout of Connection



- Length of weld required = 30 in.

Since there are two angles to be welded to the gusset plate, assume that total weld length for each angle will be 15.0 in.

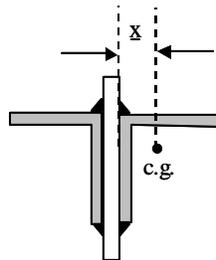
- As shown in the Figure above, 15 in. of 1/2 in. E70XX fillet weld can be placed in three ways (a), (b), and (c).
 - For option (a), the AISC Spec. **J2.2b** requires that the fillet weld terminate at a distance greater than the size (1/2 in.) of the weld. For this option, L_1 will be equal to 7.5 in.
 - For option (b), the AISC Spec. **J2.2b** requires that the fillet weld be returned continuously around the corner for a distance of at least $2a$ (1 in.). For this option, L_2 can be either 6.5 in. or 7.5 in. However, the value of 7.5 in. is preferred.
 - For option (c), L_3 will be equal to 5.75 in.

Step V. Fracture strength of the member

- $A_e = U A_g$

For the double angle section, use the value of \bar{x} from Table 1-7 on page 1-37 of manual.

Option	$U = 1 - \frac{\bar{x}}{L}$
(a)	$1 - 0.901/7.5 = 0.88 \leq 0.9$
(b)	$1 - 0.901/6.5 = 0.86 \leq 0.9$
(c)	$1 - 0.901/5.75 = 0.84 \leq 0.9$



Assume case (a). Therefore, $U = 0.88$

$\phi R_n = 0.75 \times 0.88 \times 8.00 \times 58 = 306.24 \text{ kips} > 250 \text{ kips}$ - fracture limit state is *ok!*

Step VI. Design the gusset plate

$\phi R_n > T_u$ - tension yielding limit state

Therefore, $0.9 \times A_g \times 36 > 250 \text{ kips}$
 $A_g > 7.71 \text{ in}^2$

$\phi R_n > T_u$ - tension fracture limit state

Therefore, $0.75 \times A_n \times F_u > 250 \text{ kips}$
 $A_n \leq 0.85 A_g$ - Spec. J5
 $A_n > 5.747 \text{ in}^2$ Therefore, $A_g > 6.76 \text{ in}^2$

Design gusset plate thickness

= 1.0 in. and width = 8.0 in.

