# CHAPTER 3b. WELDED CONNECTIONS

## 3b.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.

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# 3b.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 = *fv* =
* If the ultimate shear strength of the weld = fw

Rn =

**Rn = i.e., ** factor = 0.75

* fw = 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 (y) of the base metal is ≤ 60 - 65 ksi, use E70XX electrode.
* If yield stress (y) of the base metal is ≥ 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

fw = 0.60 FEXX

For E70XX, ** fw = 0.75 x 0.60 x 70 = 31.5 ksi

* Additionally, the shear strength of the base metal must also be considered. The fillet weld is connected to the base metal. The area of the base metal subjected to shear stresses by the fillet weld shall be equal to (tBM x Lw).
* This base metal area can fail by shear yielding or rupture. The smaller of the two strengths will govern. See AISC specification J4.2 on page 16.1-129 for the equations J4-3 and J4-4 that can be used to determine the shear strength of the base metal:

 For shear yielding; **Rn = 1.0 x 0.6 Fy x gross area of base metal subjected to shear

 For shear rupture; **Rn = 0.75 x 0.6 Fu x net area of base metal subjected to shear

where, Fy and Fu are the yield and tensile strength of the base metal.

* For example:

Strength of weld in shear Strength of base metal

= 0.75 x 0.707 x a x Lw x fw  = min {1.0 x 0.6 x Fy x t x Lw

 0.75 x 0.6 x Fu x a x Lw}

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.

**3b.2.1 Limitations on weld dimensions** (See AISC Spec. **J2.2b** on page **16.1-54** of manual)

* **Minimum size (amin)**

**-** function of the thickness of the thinnest connected plate

- given in Table J2.4 of the AISC specifications

* **Maximum size (amax)**

**-** function of the thickness of the thickest connected plate:

- Along edges of plates with thickness ≤ 0.25 in., amax­ = t

- Along edges of plates with thickness ≥ 0.25 in., amax = t - 1/16 in.

* **Minimum length (Lw)**

**-** length (Lw) ≥ 4 a otherwise, aeff = Lw / 4

- Read **J2.2 b**

- Intermittent fillet welds: Lw-min = 4 x a or 1.5 in., whichever is greater

* **Maximum effective length - read AISC J2.2b**
* If weld length Lw < 100 a, then effective weld length (Lw-eff) = Lw
* If Lw < 300 a, then effective weld length (Lw-eff) = Lw (1.2 – 0.002 Lw/a)
* If Lw > 300 a, the effective weld length (Lw-eff) = 180 x a
* **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 (AISC does not require weld returns)

**Example 3b.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

* tmin = 3/8 in. (member)

tmax = 0.5 in. (gusset)

Therefore, amin = 3/16 in. - AISC **Table J2.4**

amax = 3/8 - 1/16 = 5/16 in. - AISC **J2.2b**

 Fillet weld size = a = 1/4 in. - *Therefore, OK!*

* Lw-min = 1.0 in. (4 x a) - OK.
* Lw-min for each length of the weld = 4.0 in. (*transverse distance between welds*, see **J2.2b**)
* Given length = 5.0 in., which is > Lmin. 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 = ** x 0.707 x a x 0.60 x FEXX x Lw

 = 0.75 x 0.707 x 0.25 x 0.60 x 70 x 10 = 55.68 kips

* Base Metal strength = min {** x 0.6 x Fy x Lw x t ; ** x 0.6 x Fu x Lw x a}

 = min {1.0 x 0.6 x 50 x 10 x 3/8 ; 0.75 x 0.6 x 65 x 10 x 1/4}

 = min {112.5 ; 73.125 kips}

 = 73.125 kips

**Step III.** Tension strength of the member

* **Rn = 0.9 x 50 x 4 x 3/8 = 67.5 kips - tension yield
* **Rn = 0.75 x Ae x 65 - tension fracture

Ae = U A

A = Ag = 4 x 3/8 = 1.5 in2 - See Table D3.1

U = 0.75 , since connection length (Lconn) < 1.5 w - See Table D3.1

Therefore, **Rn = 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 3b.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 5-8 on page 5-47 of the AISC manual, select 2*L* 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

* amin = 3/16 in. - **Table J2.4**

amax = 1/2 - 1/16 in. = 7/16 in. - **J2.2b**

*Design*, a = 3/8 in. = 0.375 in.

* Shear strength of weld metal = ** Rn  = 0.75 x 0.60 x FEXX x 0.707 x a x Lw

 = 8.35 Lw kips

* Strength of the base metal in shear = min {1.0 x 0.6 x Fy x t x Lw ; 0.75 x 0.6 x Fu x a x Lw}

 = min {10.8 Lw ; 9.7875 Lw} kips

* Shear strength of weld metal governs,  Rn = 8.35 Lw kips
* Rn > 250 kips

 8.35 Lw > 250 kips

 Lw > 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, L1 will be equal to 7.5 in.
* For option (b), the fillet weld can be returned continuously around the corner for a distance of at least 2 a (1 in.). For this option, L2 can be either 6.5 in. or 7.5 in. However, the value of 7.5 in. is preferred. The end returns are provided to ensure that the weld size is maintained over the full length of the weld. These are not required by AISC Specs.
* For option (c), L3 will be equal to 5.75 in.

**Step V.** Fracture strength of the member

* Ae = U Ag

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

|  |  |
| --- | --- |
| Option | U =  |
| (a) | 1-0.901/7.5 = 0.88 ≤ 0.9 |
| (b) | 1-0.901/6.5 =0.86 ≤ 0.9 |
| (c) | 1-0.901/5.75 = 0.84 ≤ 0.9 |

Assume case (a). Therefore, U =0.88

**Rn = 0.75 x 0.88 x 8.00 x 58 = 306.24 kips > 250 kips - fracture limit state is *ok!*

**Step VI.** Design the gusset plate

**Rn > Tu  - tension yielding limit state

Therefore, 0.9 x Ag x 36 > 250 kips

 Ag > 7.72 in2

**Rn > Tu - tension fracture limit state

Therefore, 0.75 x An x Fu > 250 kips

 An ≤ 0.85 Ag - Spec. **J4.1**

 An > 5.747 in2 Therefore, Ag > 6.76 in2

Design gusset plate thickness = 1.0 in. and width = 8.0 in.





