Welding is a process by which heat or pressure is applied to two pieces of structural steel (the *base metal*) to join the pieces of steel together. (This bond can be described as a *solid-liquid-solid molecular bond*.) Molten metal with similar properties to the structural steel may be added to strengthen the joint; this metal is called the *filler metal*. There are many advantages of welding, including a wide range of applications and the elimination of bolts and connection plates. However, welding also requires a higher skill level than bolting and must occur under controlled conditions. Welding is used in the construction of both temporary structures and permanent facilities. Figure 2.10 shows a typical weld.

Welding employs temperatures that produce coalescence of base and filler metals and result in no defined interfaces where jointing is affected by molecular attraction alone. The primary welding processes are arc welding, oxyfuel gas welding, resistance welding, brazing, and soldering. The mechanical properties of an arc weld, oxyfuel gas weld, or resistance weld approach or duplicate the mechanical properties of the base materials at the joint, both those of the materials welded together and those of any filler metals. Other bonding processes, such as soldering, brazing, or adhesive bonding, do not duplicate these mechanical properties.

Standards from the American Welding Society (AWS) govern and guide most structural welding activities. Welding codes assure a safe, reliable weld product, and protect workers and others associated with welding operations from harmful exposure to gases produced during the welding process. AWS publications cover filler materials, qualification and testing, welding processes, welding applications, and safety.

Welds used to join structural steel can transfer loads through tension, shear, bending, and torsion under the required service conditions. They can also avoid stress raisers and obtain an optimum pattern of residual stresses, and they can withstand erosion and corrosion.

There are five basic types of weld joints: butt, tee, lap, corner, and edge. Figure 2.11 illustrates each of these. The five basic weld joints can be made in four different welding positions: flat, horizontal, vertical, and overhead. The six types of welds that are most common include fillet, square, bevel groove, V-groove, J-groove, and U-groove welds. Each of these can be made as a single or double weld. The kind of weld used depends primarily on the thickness of the base material and the strength required of the welded product. Figure 2.12 illustrates the six most common types of welds and the symbols that are used to detail welds on construction shop drawings.

Welding symbols convey how the weld is to be constructed. Figure 2.13 illustrates the most common method used for welding symbols. Other common symbols used to describe welds are shown in Fig. 2.14.

**Welding Estimates**

The key components of a welding estimate are costs for labor, equipment, temporary material, and permanent material. The labor required is determined by the volume of material to be deposited, the deposition rate, and the efficiency of the welder. The equipment is typically
limited to the welding machine. Temporary material is shielding gas, when required by the welding procedure. Permanent materials include the base material and filler material.

To determine the cost of labor, first determine the weight of the metal to be deposited. The time required to perform the weld depends on the deposition rate, which is the weight of the material deposited divided by time. The deposition rate is a function of the welding process, the current used during the weld, and electrode classification.

The arc time is defined as the deposited metal divided by the deposition rate.

\[ t_{\text{arc}} = \frac{W_{\text{filler}}}{\text{deposition rate}} \]  

To increase the accuracy of the estimate, determine operator efficiency, which is the ratio of the arc time to the total time of the welder.

\[ \eta_{\text{operator}} = \frac{t_{\text{arc}}}{t_{\text{welder}}} \]  

**Example 2.10**

A welding process requires a partial penetration weld 28 ft long. The bevel volume of the welded material is 4 in\(^3\)/ft and the density of the filler material is 490 lbf/ft\(^3\). Approximately how many work hours are required to perform the weld if the deposition rate is 5 lbf/hr and the operator efficiency is 65%?

**Solution**

The total weight of the filler material to be deposited is equal to the volume of the weld times the density of the filler material.

\[ W_{\text{filler}} = V \rho = \left( \frac{4 \text{ in}^3}{\text{ft}} \right) (28 \text{ ft}) \left( \frac{490 \text{ lbf}}{\text{ft}^3} \right) \frac{(12 \text{ in})^3}{(12 \text{ in})^3} = 31.76 \text{ lbf} \]

Rearrange Eq. 2.19 to find the total time of the welder.

\[ \eta_{\text{operator}} = \frac{t_{\text{arc}}}{t_{\text{welder}}} \]

\[ t_{\text{welder}} = \frac{t_{\text{arc}}}{\eta_{\text{operator}}} \]

Per Eq. 2.18, substitute filler weight divided by deposition rate for arc time and solve.

\[ t_{\text{welder}} = \frac{W_{\text{filler}}}{\eta_{\text{operator}} (\text{deposition rate})} \]

\[ = \frac{31.76 \text{ lbf}}{(0.65) (5 \text{ lbf/hr})} \]

\[ = 9.77 \text{ hr} \quad (9.8 \text{ hr}) \]

**Electrical Wiring and Conduit**

Electrical wiring connects electrical devices such as light fixtures, outlets, panels, transformers, starters, motors, and motor controls. The most common wire sizes are listed in Table 2.3 with their corresponding diameters and ampacities (the maximum amount of electrical current a conductor or device can carry).

Conductors are typically installed in conduits to protect them from damage and to prevent electrical fires. A conduit and protective covering surround conductors. The most common conduit types are listed in Table 2.4.

Romex is the most common type of electrical wire used in residential structures. Romex consists of two to three conductors, sizes no. 12 or no. 14, and a ground wire, contained in thermoplastic sheathing. Most residential electrical wiring does not require the use of conduits.
Conductors installed in commercial and industrial structures are sized and installed based on length and the electrical load they must carry. For the most part, all commercial wiring is run in conduits.

To estimate how much electrical wiring is needed for an installation, determine the length of wiring for each wire run as well as the length of each conduit used to encase the wiring. Electrical wiring is typically run vertically within walls and horizontally within the ceiling. Ideally, the wire and conduit are run parallel to walls. To determine the length of wire required between electrical devices, the horizontal distance between electrical devices and the vertical distance within the walls must be taken into account. Additionally, 1 ft is typically added to an electrical wire where it connects to an electrical device. Material and labor costs for wiring and conduit are commonly calculated based on the cost per 100 ft or 1000 ft of conduit or conductor.

Example 2.11

A 30 ft × 30 ft room has a ceiling height of 10 ft. Two light fixtures are placed 15 ft apart and 7.5 ft from the walls. The fixtures must be wired to a switch by the door, 10 ft from the center of the wall and 4 ft above the floor. No. 10 copper will be installed in 3/4 in IMC conduit. Approximately how many lengths of conduit and wiring should be ordered?

![Diagram of a 30 ft × 30 ft room with two light fixtures and a switch]

**Solution**

First, determine the length of conduit required. The conduit will run horizontally along the ceiling (15 ft + 7.5 ft), turn toward the light switch (10 ft), and then down 6 ft to the light switch. This results in a total of 38.5 ft. For purchasing purposes, four 10 ft lengths of IMC conduit must be purchased.

Next, the length of wiring must be calculated. An extra foot must be added at each end of the wiring between the light fixtures, which results in 17 ft (1 ft + 15 ft + 1 ft). A foot must also be added to each end of the section of wire between the light fixture and light switch. The vertical distance of 6 ft must also be added to the 7.5 ft shown in the figure. This results in a total distance of 25.5 ft (1 ft + 7.5 ft + 10 ft + 6 ft + 1 ft). Conduit to power a circuit must be run in threes, so a total of 76.5 ft (25.5 ft × 3) is required.

**Drywall**

Drywall is purchased by the sheet. The most common drywall sheet sizes are 4 ft × 8 ft, 4 ft × 10 ft, and 4 ft × 12 ft. Drywall sheets for walls are generally 1/2 in thick, and sheets for ceilings are generally 5/8 in thick. Different lengths are purchased for different projects to facilitate the drywall layout and installation process and to reduce the need to cut drywall in the field. For example, 4 ft × 10 ft sheets are more economical for an 8 ft wide and 40 ft long ceiling than 8 ft long sheets because no sheets have to be cut to fit the space. The number of drywall sheets required can be estimated using Eq. 2.16, just as with plywood sheathing—the dimensions used are the same, and as with plywood sheathing, partial sheets of drywall cannot be returned.
2. ELEMENTS OF A COST ESTIMATE

When bidding on a project, a construction engineer must assign a unit cost to each work item (major portion of work). To develop an accurate cost estimate, the total cost of each work item is determined based on direct costs such as the material cost, salary and labor costs, labor production rate, and equipment production rate and cost. Then indirect costs, such as profit amount, overhead, and bid costs, are added together to give the total cost of the work item. Once the total cost of a work item is estimated, it is divided by the quantity of work produced to give the unit price for the work item. A breakdown of the costs used to determine unit price is listed in Table 2.5.

Table 2.5 Sample Unit Cost Tabulation

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Components of Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>Material quantity, material price ($/unit)</td>
</tr>
<tr>
<td>Labor</td>
<td>Productivity rate, labor cost rate ($/hr)</td>
</tr>
<tr>
<td>Equipment and tools</td>
<td>Productivity rate, equipment hours (hr), equipment cost rate</td>
</tr>
<tr>
<td>Aggregate cost</td>
<td>Total material cost, total labor cost, total equipment cost</td>
</tr>
<tr>
<td>Total cost (including indirect cost and profit)</td>
<td>Aggregate cost + % of indirect cost + profit</td>
</tr>
<tr>
<td>Unit price</td>
<td>Total cost/quantity</td>
</tr>
</tbody>
</table>

Material quantity is the amount of material needed for a work item. To calculate the total amount of material, use the quantity takeoff method described in Sec. 2.1.

Material price is the cost to purchase each material required, given in dollars per unit. Understanding and anticipating fluctuations in material prices will provide knowledge for an accurate and economical cost estimate. Material prices may be affected by the time of the year, the availability of the material, the size of the order, the time frame required for delivery, physical requirements of delivery location (e.g., distance, road size, site access), payment terms, previous purchases, single-source materials and equipment, and/or currency exchange rates.

The labor productivity rate is the rate at which a crew or an individual can complete work, given in units of physical work completed per unit of time (e.g., a crew can place 50 ft of reinforcing steel per hour). The hours of required labor and the expected productivity rate during those hours are determined by crew analysis or by using an established average productivity rate. Pricing based on a quantity of work (e.g., $15 per cubic yard of grade beams set in place) is possible only when data supports this estimation of labor costs. The productivity rate will vary for each work item and from hour to hour, based on the complexity of the project, the time frame, and the available labor. When the total cost of work items is estimated for projects that have planned overtime built into their schedule, the estimator should consider the decreased productivity rate that can result from extended hours. The labor productivity rate is calculated from Eq. 2.20.

\[
labor\ productivity\ rate = \frac{Q_e}{t_w} \tag{2.20}
\]

The labor rate is a craftsman’s cost in dollars per hour. To determine a craftsman’s labor rate, regardless of union status, use Eq. 2.21. The cost to employ a craftsman begins with base wages for the craftsman, the cost of fringe benefits, and the payroll burden. The payroll burden includes FICA (Social Security), FUI (federal unemployment insurance), SUI (state unemployment insurance), WC (workers’ compensation), and other payroll burdens as mandated by legislation. Labor rate is most often calculated based on annual wages and annual billable hours, but the rate can also be calculated on an hourly basis for a mixed construction crew that includes workers trained in a variety of trades.

\[
labor\ rate = \frac{C_w}{t_w} \tag{2.21}
\]

It is also important to consider expected overtime (more than 40 hours in any given Sunday through Saturday period), based on the time frame for completion of the project and/or the companies involved in the project. Overtime is estimated based on the work week. Cost estimates with a 40 hour work week include a modest amount of overtime. Projects with longer work weeks estimate more overtime. The total labor cost, including overtime, can be calculated from Eq. 2.22.

\[
C_{lt} = Q_{worker}t_w(labor\ rate) \tag{2.22}
\]

The equipment cost rate is the total cost for the required equipment expressed in dollars per hour or day. Figure 2.15 shows the considerations included in the total equipment cost. The costs for mobilizing and demobilizing equipment include time for the crew to assemble and transport the equipment, as well as all costs associated with trucking and hauling permits. The labor rate for equipment is the hourly or daily cost of the crew required to operate the equipment. **Cycle time** is the time required to complete the scheduled work for a series of repetitive operations. **Repositioning time** is the time required to move the equipment to different locations on the construction site. The rental rate is the cost of renting the equipment, given in hourly, daily, or weekly amounts. Costs and cost factors will differ depending on whether the equipment is owned or rented by the contractor. Equipment cost rate can be calculated using Eq. 2.23.

\[
equipment\ cost\ rate = \frac{Q_eC_{etw}}{C_{lt}} \tag{2.23}
\]

The equipment productivity rate measures the amount of work a piece of equipment can accomplish in a given period of time. The equipment productivity rate can have a drastic effect on the cost of a project. Accurate
estimation of equipment productivity rates requires knowledge of a project's conditions. A construction engineer must consider what sizes and capacities of equipment will be required to perform the work under the expected conditions and within the allotted time frame.

Indirect costs consist of labor, material, and equipment expenses required to support the overall project but not directly involved in completion of the project's work items. Indirect costs for the owner typically include design fees, permits, land acquisition costs, legal fees, and administration costs. Indirect costs for the general contractor and subcontractor typically include mobilization, staffing, the costs of the on-site job office, temporary construction, temporary heating and cooling, and temporary utilities, equipment, and consumables.

When costs for a project are lower than expected (e.g., labor costs are lowered due to unexpectedly high production capabilities, or a bulk discount results in lower material costs), the project is said to generate profit. How profit from a project is shared will vary depending on the contractual agreements between the involved parties. Some projects may specify a profit amount that must be generated as part of the project; this is considered an indirect cost and must be included in the original bid and all change orders.

Example 2.12

40 ft of formwork is to be constructed, as shown in the following illustration. The cost of materials is as shown. All materials can be purchased from the same manufacturer in a single order, and the manufacturer will transport and unload the nails with the lumber at no extra charge. Lumber waste for this project is expected to be 5%. The project will require all members of the crew for all stages of construction. Ignoring sales tax and bulkheads, estimate the unit cost per square foot for the material and labor needed to construct the formwork.

Solution

First, find the total material costs.

Determine the surface area of the formwork.

\[ A_f = L_f h_f = (40 \text{ ft} + 40 \text{ ft})(8 \text{ ft}) = 640 \text{ ft}^2 \]

Determine the total board feet of studs needed. The actual width of 2 in × 6 in studs is 5.5 in. The total number of members per side is

\[ Q_m = \frac{(40 \text{ ft})(12 \text{ in/ft})}{5.5 \text{ in}} = 87.27 \text{ (88)} \]

Use Eq. 2.4 to find the volume of one stud in board feet.

\[ V_{\text{sheathing, bd-ft}} = \frac{L_{\text{m,in}} A_{\text{m,in}}}{144} = \frac{(8 \text{ ft})(12 \text{ in/ft})(2 \text{ in})(6 \text{ in})}{144 \text{ in}^3/\text{bd-ft}} = 8 \text{ bd-ft} \]