15

Steel Construction

15–1 INTRODUCTION

Elements of Steel Construction

Structural steel construction is a specialized task that is usually performed by specialty subcontractors. However, construction managers and inspectors must understand the principles and procedures involved. The process of steel construction can be broken down into the three major elements of advanced planning, steel fabrication and delivery to the job site, and field operations. Each of these elements involves a number of operations which are described in this chapter.

For large or complex projects, advanced planning includes divisioning the steel and planning shipping and erection procedures. *Divisioning* is the process of dividing a structure into units (called *divisions*) which are used to schedule the fabrication and delivery of structural steel members to the job site. Since divisioning is determined by the order in which the structure will be erected, it must be performed as a joint effort of the steel fabricator and the erection manager. When planning shop fabrications procedures, the size and weight of large members must be checked against plant capacity, transportation size and weight limits, and the capacity of erection equipment. In planning erection procedures, the type of equipment to be utilized and the procedures to be followed are determined by the type of structure being erected and the anticipated site conditions. Lifting equipment, alignment requirements, and field connections are described in succeeding sections of this chapter.

Field Operations

Field operations include receiving and unloading, sorting (or "shaking out"), inspecting, storing, and erecting the steel. The process of unloading steel to a temporary storage area and then moving it from storage to the point of erection is called *yarding*. Structural steel members are often carelessly handled during unloading at the job site. They may be thrown off the truck or railcar and stacked up in a manner that will cause distortion in the member

Table 15–1 Fabrication and mill tolerance for steel members

Dimensions	Tolerance
Depth	± ⅛ in. (0.32 cm)
Width	+ ¼ in. (0.64 cm), – 3/16 in. (0.48 cm)
Flanges out-of-square	
Depth 12 in. (30 cm) or less	¼ in. (0.64 cm)
Depth over 12 in. (30 cm)	5/16 in. (0.79 cm)
Area and weight	± 2.5%
Length	
End contact bearing	± 1/32 in. (0.08 cm)
Other members	
Length 30 ft (9.2 m) or less	± 1/16 in. (0.16 cm)
Length over 30 ft (9.2 m)	± ⅛ in. (0.32 cm)
Ends out-of-square	1/64 in./in. (cm/cm) of depth or flange width, whichever is greater
Straightness	
General	⅛ in./10 ft (0.1 cm/m) of length
Compression members	Deviation from straightness of 1/1000 of axial length between points of lateral support

and damage to its paint. Such practices must be avoided. In unloading long flexible members and trusses, double slings should be used to avoid bending the member. If the steel has not been inspected at the fabrication shop, it must be inspected after unloading for conformance to the shop drawings and the tolerances specified in Table 15–1. Camber and sweep of beams are illustrated in Figure 15–1. In any case, members must be checked at the job site for possible shipping and unloading damage.

Shaking out steel is the process of sorting it out by identifying each member, and storing it in such a manner that it can be easily obtained during erection. Code numbers are often painted on the members to facilitate identification during erection. Steel should be stored off the ground on platforms, skids, or other supports, and protected from dirt, grease, and corrosion. Erection, the final element of field operations, is described in Section 15–3.

15–2 STRUCTURAL STEEL

Types of Steel

The type of steel contained in a structural steel member is designated by the letter A followed by the American Society for Testing and Materials (ASTM) designation number. The principal types of structural steel include:

- A36 Carbon Structural Steel.

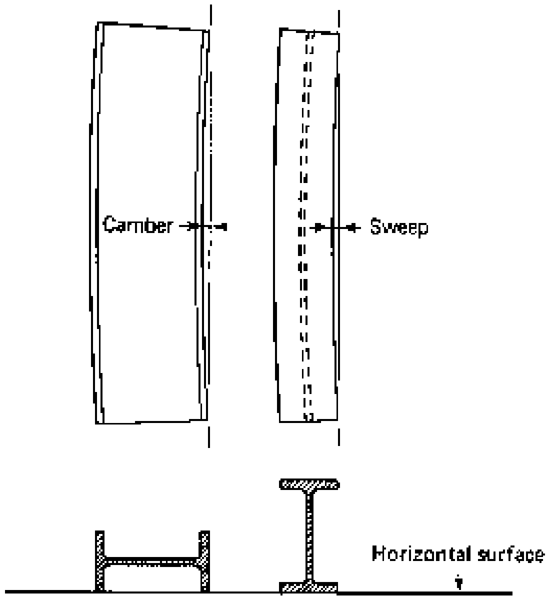

Figure 15–1 Camber and sweep of beams.

- A572 High-Strength Low-Alloy Structural Steel.
- A588 Corrosion-Resistant High-Strength Low-Alloy Structural Steel.

Steel strength is designated by the symbol F_y, which indicates the minimum yield point of the steel expressed in thousands of pounds per square inch (ksi), pounds per square inch (psi), or megapascals (MPa). Type A36 steel has a yield strength of 36 ksi (36,000 lb/sq in. or 248.2 MPa). The high-strength steels (types A572 and A588) are available in yield strengths of 42 ksi (289.6 MPa) to 65 ksi (448.2 MPa).

Weathering steel is a type of steel that develops a protective oxide coat on its surface upon exposure to the elements so that painting is not required for protection against most atmospheric corrosion. That natural brown color that develops with exposure blends well with natural settings. However, care must be taken to prevent staining of structural elements composed of other materials which are located in the vicinity of the weathering steel and thus exposed to the runoff or windblown water from the weathering steel.

Standard Rolled Shapes

There are a number of rolled steel shapes produced for construction which have been standardized by the American Society for Testing and Materials. Figure 15–2 illustrates five major section shapes. A list of standard shapes and their AISC designations is given in Table 15–2. Note that the usual designation code includes a letter symbol (identifying the section shape) followed by two numbers (indicating the section depth in inches and the weight per foot). Designations for angles, bars, and tubes are slightly different, in that

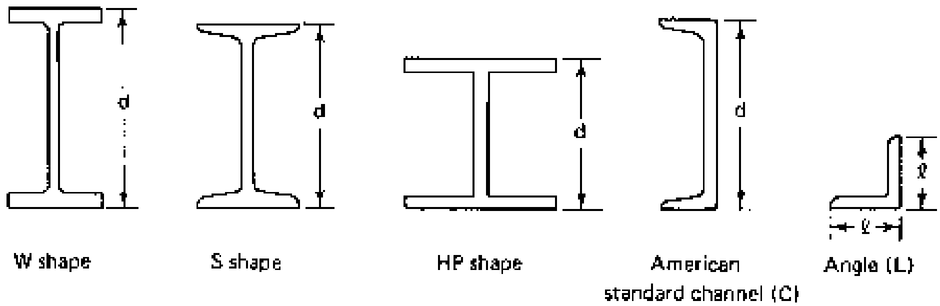

Figure 15–2 Rolled-steel section shapes.

Table 15–2 Rolled-steel shape designations

Type of Shape	Example Designation
W shape	W27 × 114
S shape	S20 × 95
M shape	M8 × 25
American Standard Channel	C12 × 30
Miscellaneous Channel	MC12 × 50
HP (bearing pile) shape	HP14 × 89
Equal leg angle	L6 × 6 × ½
Unequal leg angle	L8 × 4 × ½
Structural tee cut from:	
W shape	WT8 × 18
S shape	ST6 × 25
M shape	MT4 × 16.3
Plate	PL ½ × 12
Square bar	Bar 2 ⏘
Round bar	Bar 2 ϕ
Flat bar	Bar 2 × ½
Pipe	Pipe 6 std.
Structural tubing	
Square	TS6 × 6 × .250
Rectangular	TS6 × 4 × .250
Circular	TS4 OD × .250

the numbers used identify principal section dimensions in inches rather than the section depth and weight. Detailed section properties as well as the weight of pipe, plates, and crane rails are given in reference 3.

Built-Up Members

Girders are used when regular rolled shapes are not deep enough or wide enough to provide the required section properties. Plate girders (Figure 15–3a) normally consist of a web and

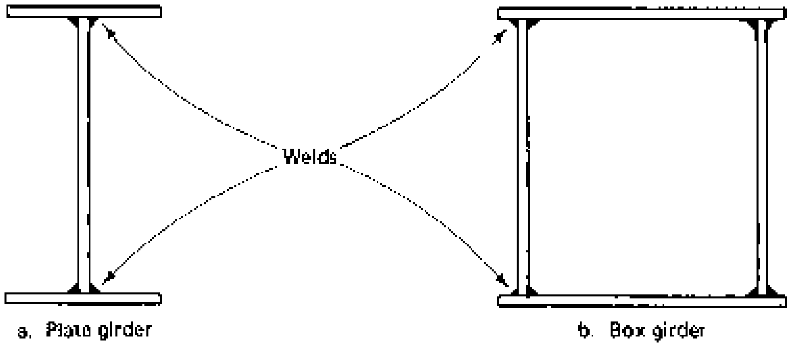

Figure 15–3 Built-up steel members.

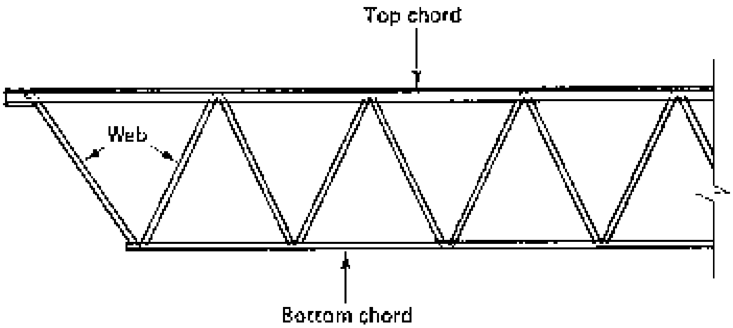

Figure 15–4 Open-web steel joist.

top and bottom flanges. Stiffeners may be added if needed to prevent buckling of the web. Box girders are constructed using two webs as shown in Figure 15–3b.

Open-web steel joists (Figure 15–4) and joist girders are other forms of built-up steel members. These are lightweight open trusses that are strong and economical. They are widely used for supporting floors and roofs of buildings. *Bar joists* are steel joists whose diagonal members consist of steel bars. Standard *open-web steel joist* designations include K, LH, and DLH series. All are designed to support uniform loads. K series are parallel chord joists that span up to 60 ft (18.3 m) with a maximum depth of 30 in. (76 cm). Series K uses steel with a yield strength of 50 ksi (345 MPa) for chords and either 36 ksi (248 MPa) or 50 ksi (345 MPa) for webs. Series LH (longspan joists) and DLH (deep longspan joists) joists are available with parallel chords or with the top chord pitched one way or two ways (Figure 15–5). The standard pitch is ⅛ in./ft (1 cm/m) to provide drainage. Longspan and deep longspan joists are normally cambered to offset the deflection of the joist due to its own weight. They use steel with a yield strength of either 36 or 50 ksi (248 or 345 MPa). Series LH joists span up to 96 ft (29.3 m) with a maximum depth of 48 in. (122 cm). Series DLH joists span up to 144 ft (43.9 m) with depths to 72 in. (183 cm).

Joist girders, Series G, are similar to open-web steel joists except that they are designed to support panel point loads. Series G girders use steel with a yield strength of 36 to

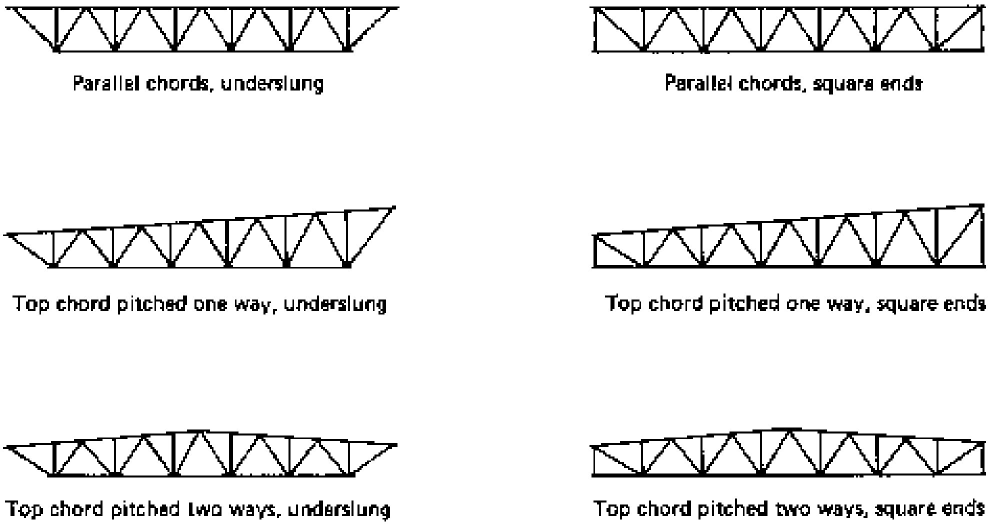

Figure 15–5 Steel joist types.

50 ksi (248 to 345 MPa), span up to 60 ft (18.3 m), and have a maximum depth of 72 in. (183 cm). Joist girders and open-web steel joists are available with square ends, underslung ends, or extended ends, as shown in Figure 15–6.

Castellated steel beams are created from standard rolled shapes by shearing one side and then joining two sections together to create the shape shown in Figure 15–7. Beams such as these are deeper and have a higher strength/weight ratio than do standard rolled sections. The open portions of the web also facilitate the installation of building utilities.

15–3 STEEL ERECTION

Erection Procedure

The usual steel erection procedure employs three crews (a raising crew, a fitting crew, and a fastening crew) which operate in sequence as erection proceeds. The raising crew lifts the steel member into position and makes temporary bolted connections that will hold the member safely in place until the fitting crew takes over. OSHA safety regulations use the term *structural integrity* to indicate the ability of a structure to safely stand up during erection and has prescribed specific safety measures to ensure structural integrity. For example, the erection deck cannot be more than eight stories above the highest completed permanent floor. Neither can there be more than four floors or 48 ft (14.6 m) of unfinished bolting or welding above the highest permanently secured floor (not necessarily completed floor). The fitting crew brings the member into proper alignment and tightens enough bolts to hold the structure in alignment until final connections are made. The fastening crew makes the final connections (bolted or welded) to meet specification requirements.

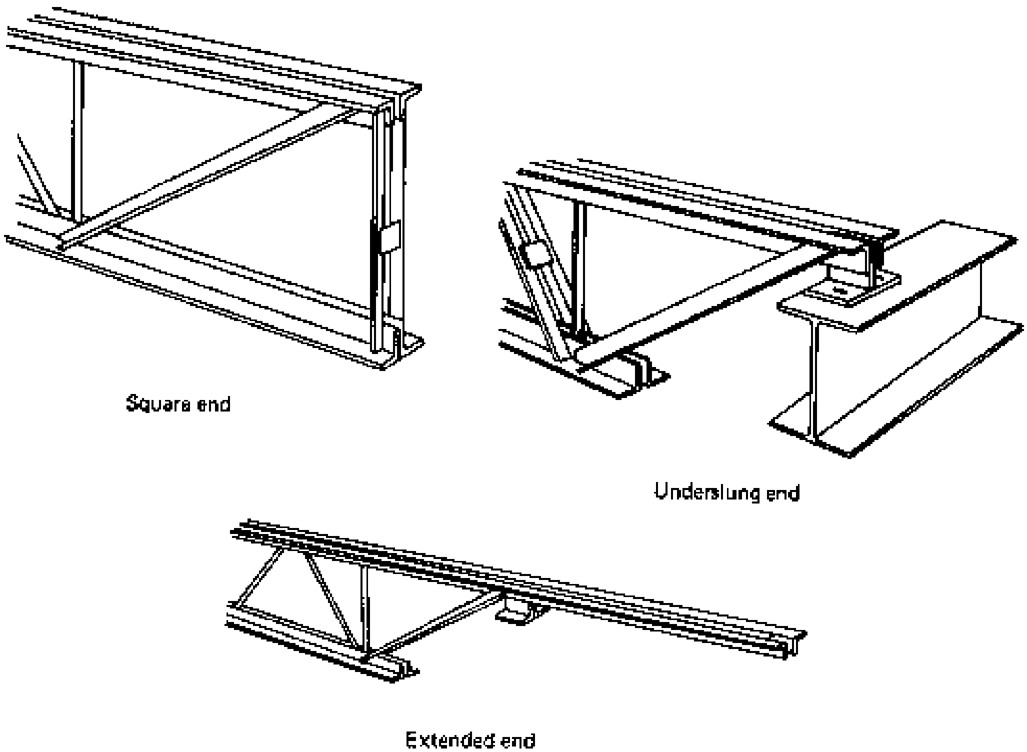

Figure 15–6 Types of joist ends.

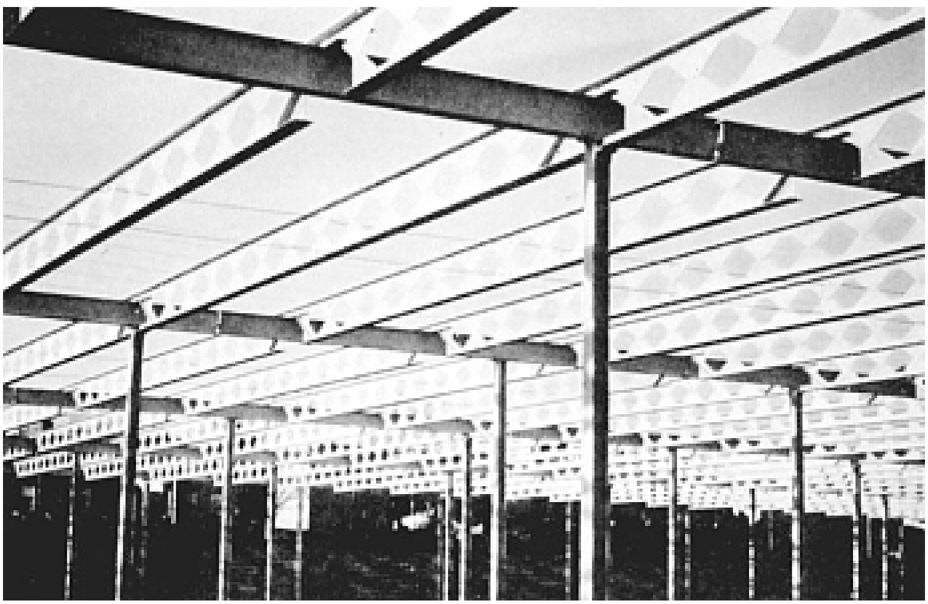

Figure 15–7 Castellated steel beams. (Courtesy of American Institute of Steel Construction)

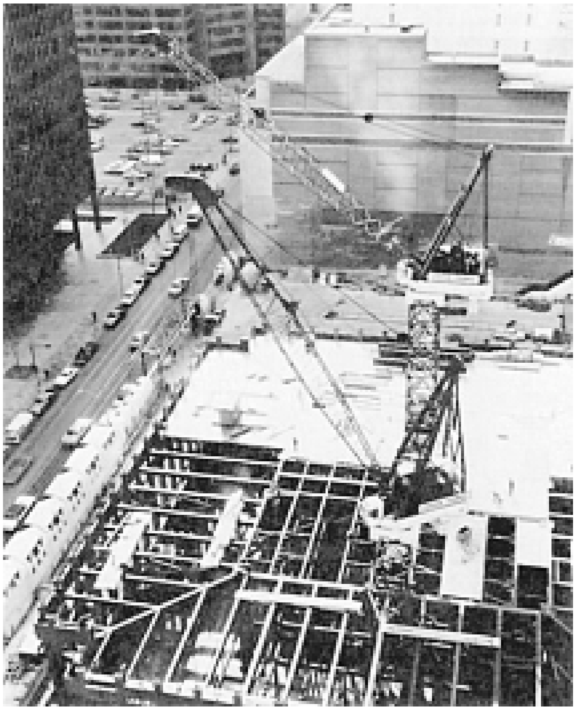

Figure 15–8 Tower crane erecting steel. (Courtesy of FMC Corporation)

Lifting Equipment

The mobile crane and tower crane described in Chapter 3 are often used for handling steel and lifting it into final position. Figure 15–8 shows a tower crane erecting steel. There are also a number of other lifting devices which are often used in steel construction. The *gin pole* shown in Figure 15–9a is one of the simplest types of powered lifting device. Two or more of these may be used together to lift large pieces of equipment such as boilers or tanks. A *guy derrick* is shown in Figure 15–9b. This is probably the most widely used lifting device in high-rise building construction. An advantage of the guy derrick is that it can easily be moved (or jumped) from one floor to the next as construction proceeds. Figure 15–9c illustrates a heavy-duty lifting device called a *stiffleg derrick.* Stiffleg derricks may be mounted on tracks to facilitate movement within a work area.

Alignment of Steel

Alignment of steel members must be accomplished within the tolerances of the AISC Code of Standard Practice (see reference 3). Under AISC standards the vertical (or plumb) error cannot exceed 1 unit in 500 units of height and the centerline of exterior columns cannot be more than 1 in. (2.5 cm) toward or 2 in. (5 cm) away from the building line in 20 stories.

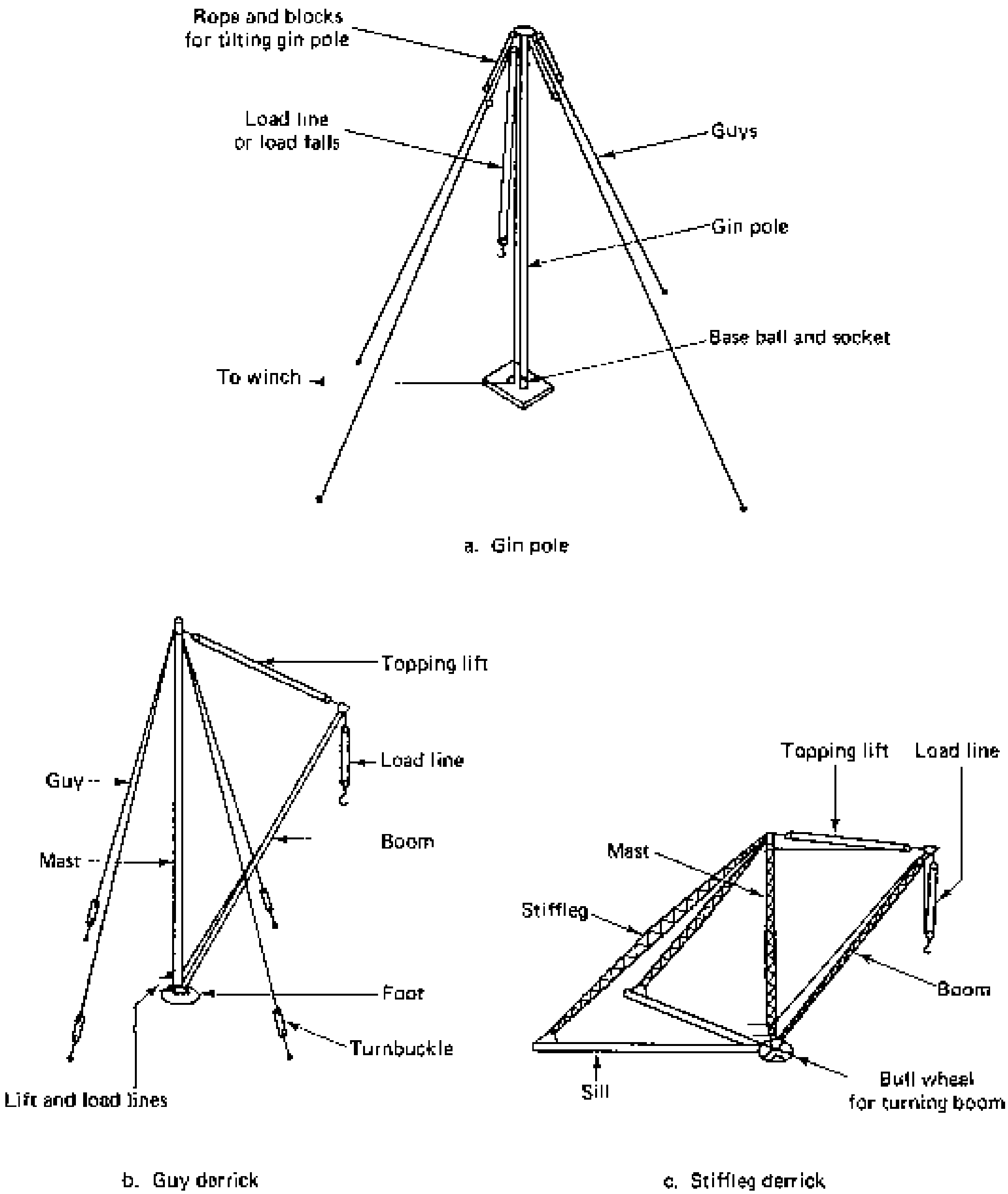

Figure 15–9 Steel-lifting equipment.

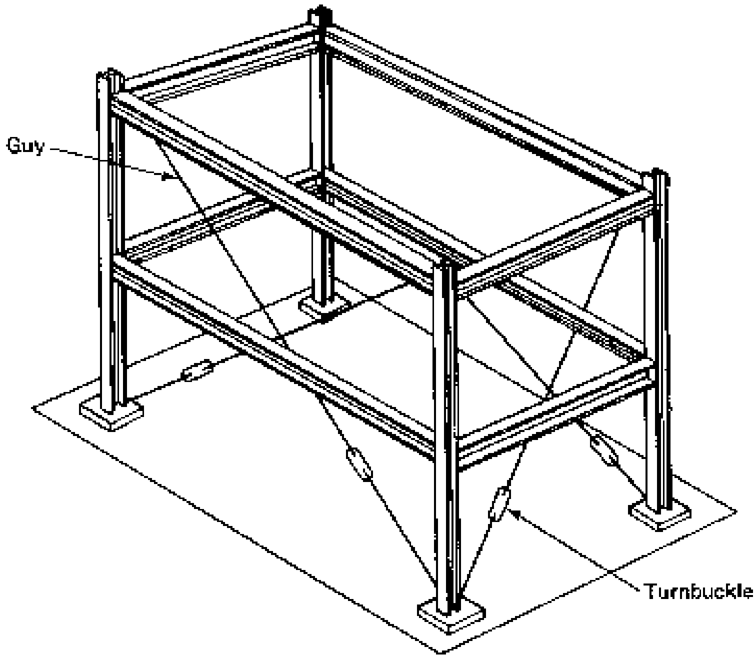

Figure 15–10 Plumbing a steel structure.

The minimum clearance between steel members is also specified in reference 3. *Coping* or *blocking* is the name applied to notching beams to provide the necessary clearance when beams connect to columns or other beams. Electrical, plumbing, and other trades often find it convenient to make attachments to steel or to cut openings (inserts) in the steel to facilitate installation of their equipment. No attachments or inserting, including blocking and coping, should be permitted without the approval of the structural designer.

Guy ropes and supports are often used in the process of bringing steel into alignment, as illustrated in Figure 15–10. Erection planning should include the number, type, and location of all guys and supports to be used. Guys should be placed so as to minimize interference with travel ways and erection equipment, and must be kept taut. Care must be taken not to overstress guys during alignment.

Erection of Steel Joists

The requirements for the lateral bracing of steel joists by bridging have been established by the Steel Joist Institute (SJI) (reference 5). The lateral bracing of longspan and deep longspan joists during erection is especially critical. For these joists the SJI requires that hoisting cables not be released until a minimum number of lines of bridging have been installed: one line for spans to 60 ft (18.3 m), two lines for spans of 60 to 100 ft (18.3 to 30.5 m), and all lines for spans over 100 ft (30.5 m). Joists should be completely braced before any loads are applied.

15–4 FIELD CONNECTIONS

Fastening Systems

The three principal systems used for connecting steel members are bolting, riveting, and welding. Riveting is now seldom used for making field connections or for shop fabrications. Riveting procedures will not be described here.

Bolted Connections

While unfinished (ASTM A307) bolts are still available for low stress applications, high-strength bolts are used in most of today's steel construction. To prevent confusion in identification, ASTM has prescribed special markings for high-strength bolts, which are illustrated in Figure 15–11. Bolts that are driven into place and use oversize shanks to prevent turning during tightening are referred to as *interference-body* or *interference-fit bolts.* Bolts that incorporate a torque control groove so that the stem breaks off under a specified torque are referred to as *tension control bolts* or *tension set bolts.*

The Specifications for Structural Joists Using ASTM A325 or A490 Bolts, approved by the Research Council on Riveted and Bolted Structural Joints and endorsed by the AISC, has prescribed acceptable procedures for assembling steel using high-strength bolts (reference 3). These procedures are described briefly in the remainder of this section. Two of the methods used for tightening standard high-strength bolts to the specified tension are the turn-of-nut method and the calibrated wrench method.

Quality control procedures may require the use of a torque wrench to verify that the required bolt tension is being obtained. When used, torque wrenches should be calibrated with a bolt-tension calibrator at least once a day by tightening at least three bolts of each diameter being used. A *bolt-tension calibrator* is a device that can be used to calibrate both impact wrenches (used for bolt tightening) and hand-indicator torque wrenches (used by inspectors for checking the tension of bolts that have been tightened by either method). Torque-control devices on impact wrenches should be set to produce a bolt tension 5 to 10% greater than the specified minimum bolt tension. Air pressure at the impact wrench used for bolt tightening should be at least 100 lb/sq in. (690 kPa), and the wrench should be capable of producing the required bolt tightening in about 10 s.

When tightening a high-strength bolt by either the turn-of-nut method or the calibrated wrench method, the bolt is first brought to a snug condition. (The snug condition is reached when an impact wrench begins to impact solidly or when a worker uses his full strength on an ordinary spud wrench.) Except for interference-body bolts, final bolt tightening may be accomplished by turning either the nut or the bolt head. Residual preservative oil on bolts may be left in place during tightening. When the surface to be bolted is inclined at a slope greater than 1 in 20 to an axis perpendicular to the bolt, a beveled washer must be used to provide full bearing for the nut or head. Both A325 and A490 bolts tightened by the calibrated wrench tightening method and A490 bolts installed by the turn-of-nut method must have a hardened washer under the element being turned (head or nut). Hardened washers must be used under both the head and the nut of A490 bolts used to connect material having a yield strength of less than 40 ksi (276 MPa). For final tightening by the calibrated wrench method, the bolt is impacted until the

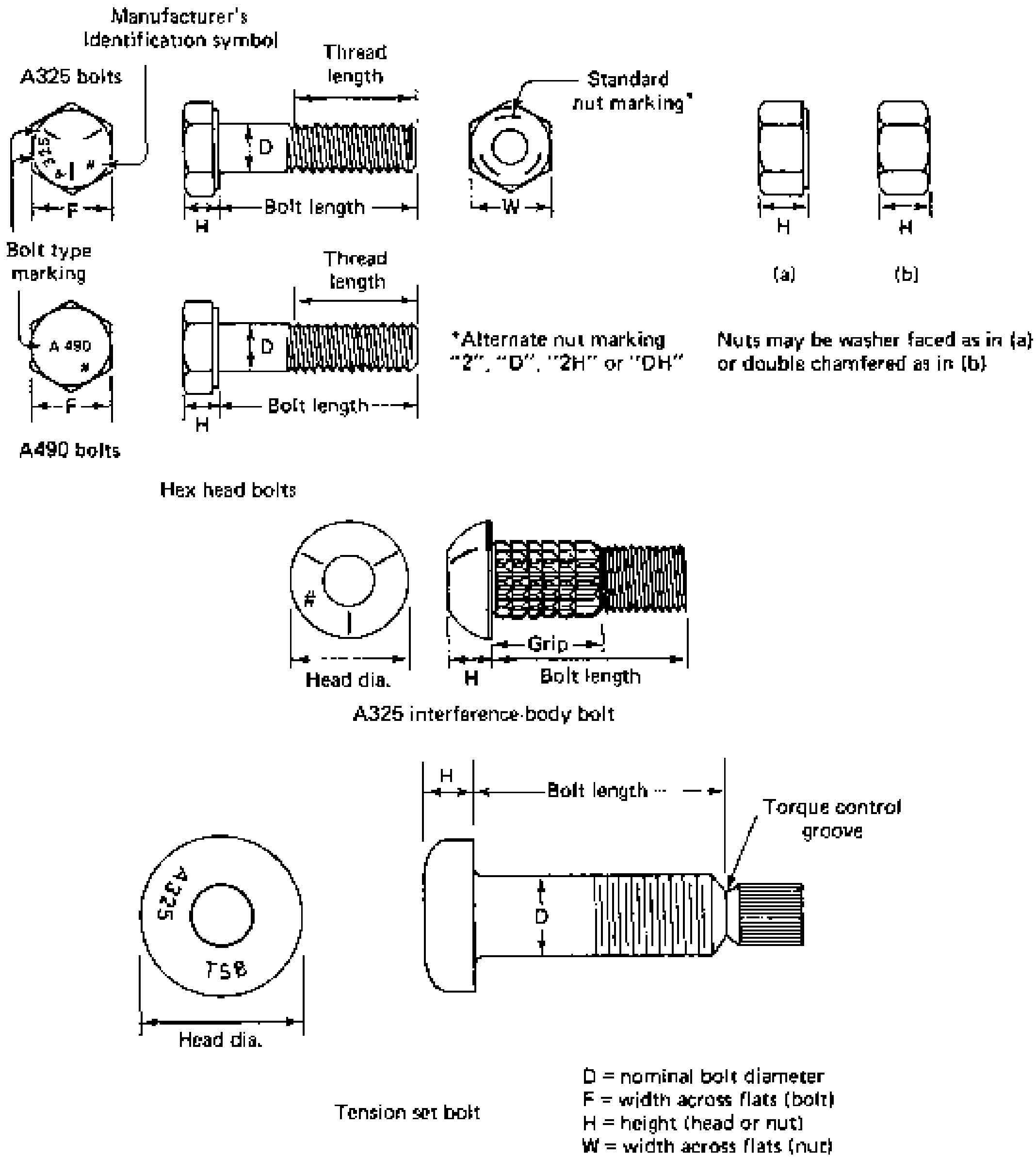

Figure 15–11 High-strength steel bolts.

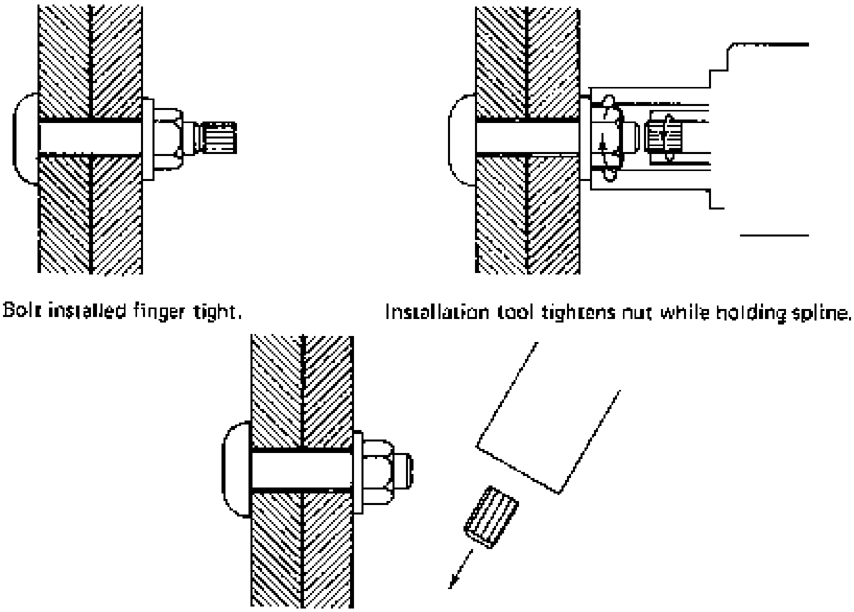

Figure 15–12 Installation of tension control bolts.

torque-control device cuts off. Using the turn-of-nut method, the specified rotation must be obtained from the snug condition while the stationary end (bolt head or nut) is held by hand wrench to prevent rotation. The tightening requirement for a bolt not more than 8 diameters or 8 in. (20 cm) in length, having both faces perpendicular to the bolt axis, is one-half turn from the snug condition.

The procedure for tightening tension control or tension set bolts is illustrated in Figure 15–12. After bolts have been installed finger-tight, the installation tool is placed over the bolt end so that it engages both the bolt spline and nut. The installation tool holds the bolt spline to prevent the bolt from rotating while torque is applied to the nut. When the torque on the nut reaches the required value, the bolt spline will shear off at the torque control groove. Visual inspection will indicate whether bolts have been properly tightened by determining that the spline end of the bolt has sheared off. If desired, bolt tension may be verified by the use of a calibrated torque wrench, as described in the previous paragraph.

Welded Connections

Welding (Figure 15–13) is another specialized procedure that must be accomplished properly if adequate connection strength is to be provided. Welding requirements for steel construction are contained in reference 3 and the publications of the American Welding Society (AWS). A few of the principal welding requirements are described in this section. In the United States, all welders responsible for making connections in steel construction should

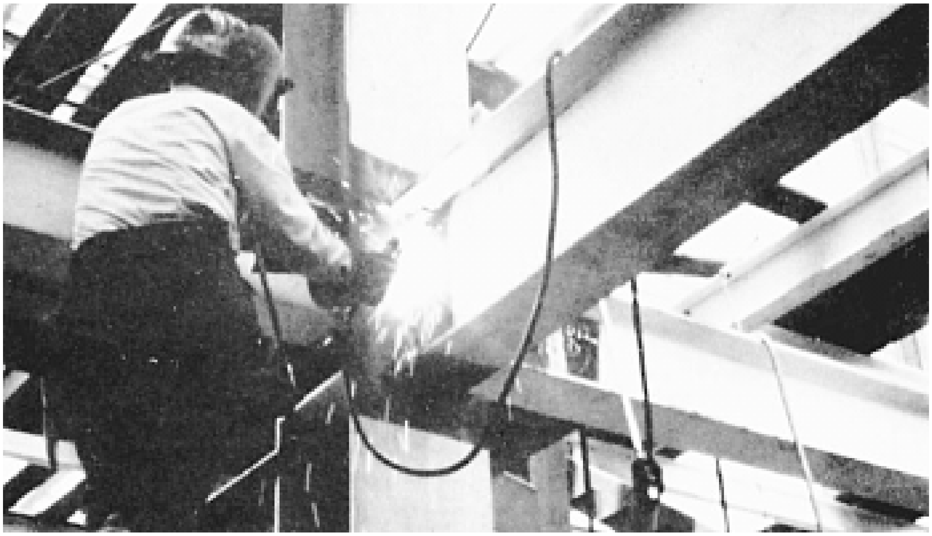

Figure 15–13 Welded steel construction. (Courtesy of American Institute of Steel Construction)

be certified by the American Welding Society. All supervisors and inspectors must be able to interpret the standard welding symbols shown in Figure 15–14. The major types of structural welds include fillet welds, groove (or butt or vee) welds, and plug or rivet welds. These are illustrated in Figure 15–15.

In addition to the use of qualified welders, requirements for producing satisfactory electric welds include the proper preparation of the base metal, the use of proper electrodes, and the use of the correct current, voltage, and polarity settings.

There are a number of inspection methods available for determining the quality of welds. Test methods include visual inspection, destructive testing, radiographic inspection, ultrasonic inspection, magnetic-particle inspection, and liquid-penetrant inspection. Visual inspection is the quickest, easiest, and most widely used method of inspection. However, to be effective it requires the use of highly trained and experienced inspection personnel. It is also the least reliable method for ensuring adequate weld strength. Destructive testing is used primarily in welder qualification procedures. Its use may also be necessary to determine the actual strength of welds when nondestructive test methods indicate questionable weld quality. Radiographic inspection involves producing an X-ray picture of the weld. When properly employed, it can detect defects as small as 2% of the joint thickness. Ultrasonic inspection uses high-frequency vibration to detect defects. The nature of the signals that are reflected back from the weld gives an indication of the type, size, and location of any defect. Magnetic-particle inspection utilizes magnetic particles spread on a weld to indicate defects on or near the weld surface. However, it cannot be used on nonmagnetic metals such as aluminum. Liquid-penetrant inspection involves spraying the weld with a liquid penetrant, drying the surface, and then applying a developing fluid which shows the location where penetrant has entered the weld. The method is inexpensive and easy to use but can detect only those flaws that are open to the surface.

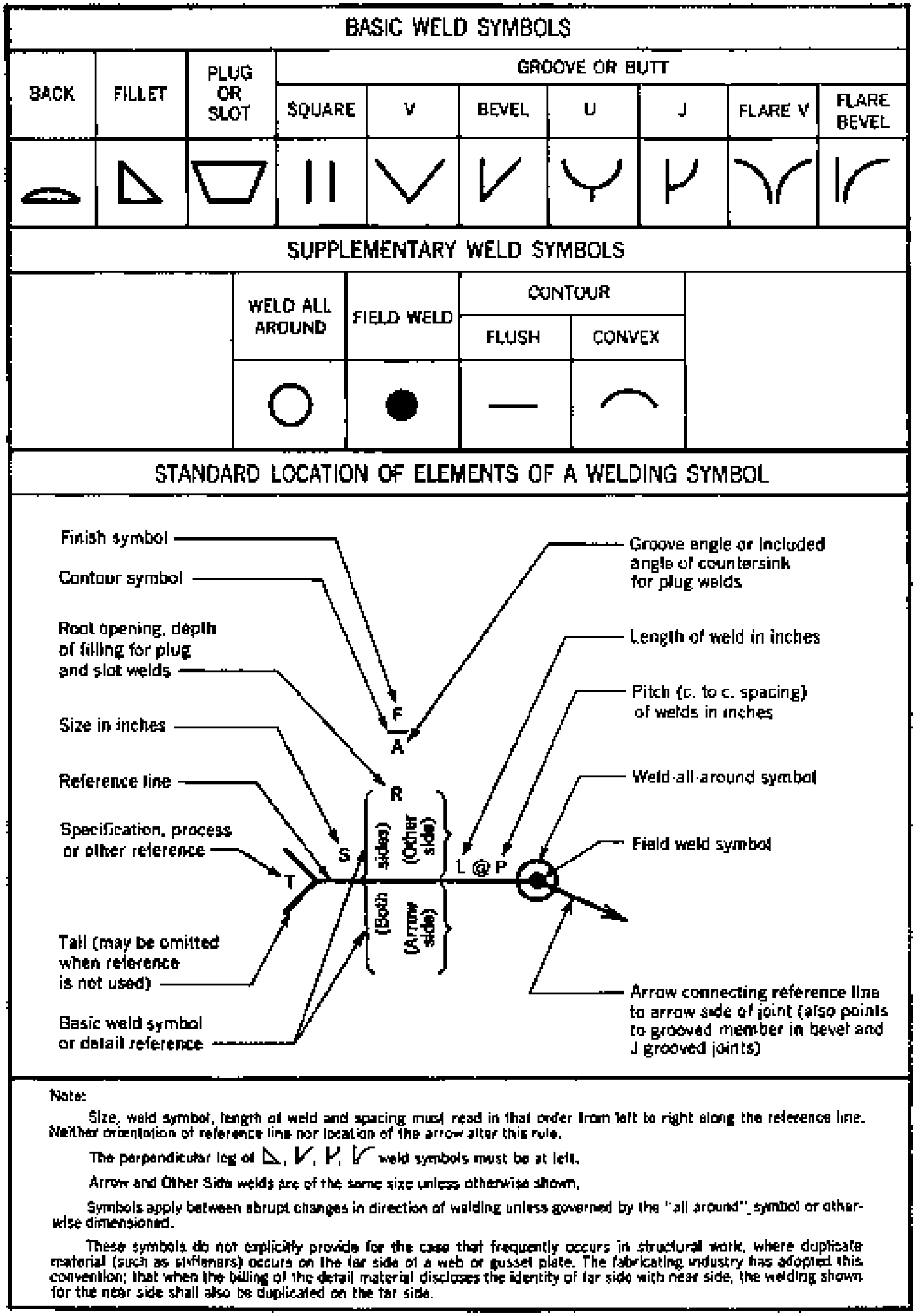

Figure 15–14 Standard welding symbols. (Courtesy of American Institute of Steel Construction)

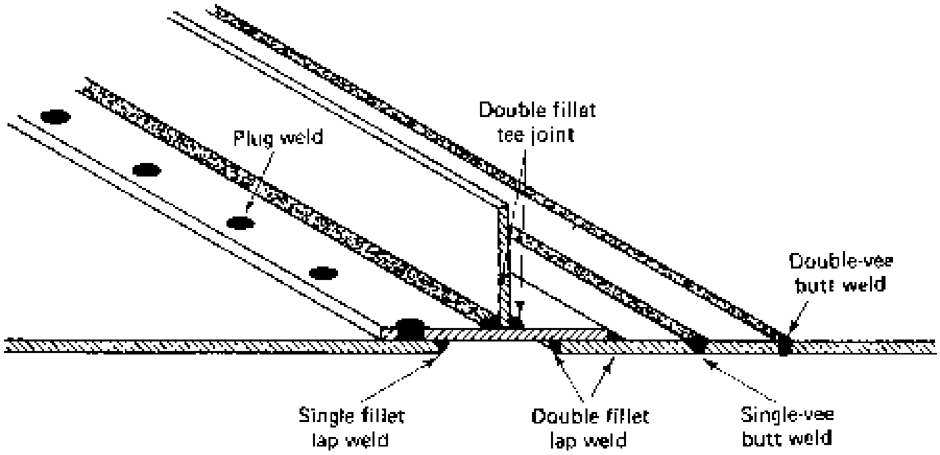

Figure 15–15 Weld types.

15–5 SAFETY

As stated earlier, steel erection is a very hazardous construction task. As a result, a number of safety requirements have been developed and many of these are contained in OSHA safety regulations (reference 2). Some of these requirements have been described earlier in the chapter. Two additional safety areas that deserve comment are the use of protective equipment and the hazards presented by site conditions.

Protective Equipment

OSHA regulations contain a number of requirements for the use of personal protective equipment. Hardhats and gloves are standard requirements for steel erection. Eye protection must be provided for workers engaged in welding, cutting, and chipping operations, as well as for those working nearby. Employees working above ground level require protective measures against falls. Temporary floors and scaffolds with guard rails should be provided whenever possible. If these are not feasible, lifelines and safety belts must be used. Where the potential fall exceeds 25 ft (7.6 m) or two stories, safety nets should also be used. When used, safety nets should be placed as close under the work surface as practical and extend at least 8 ft (2.4 m) beyond the sides of the work surface.

Site Hazards

Weather is responsible for many of the hazards at the steel erection site. High and gusty winds may throw workers off balance and cause steel being lifted to swing dangerously. Tag lines must be used for all hoisting operations. Since steel workers will be walking on members shortly after they are lifted, care must be taken to prevent the surfaces of members from becoming slippery. Wet and icy surfaces are obvious hazards. Structural members should be checked to ensure that they are free of hazards such as dirt, oil, loose debris, ice, and wet paint before being hoisted into place.

PROBLEMS

1. Explain the meaning of the term *blocking* as used in steel construction.
2. Identify the maximum fabrication tolerance of a steel column in terms of depth, width, length and squareness.
3. Identify the following steel sections:
   a. W20 × 124
   b. C10 × 25
   c. S24 × 100
   d. L6 × 6 × ⅝
4. When erecting a steel building structure, what is the maximum height that the erection deck can be above the highest completed permanent floor?
5. What advantages do tension control bolts have over conventional steel bolts in making bolted steel connections?
6. Briefly describe five methods for determining the quality of welds in structural steel connections.
7. What is the yield strength of type A36 steel?
8. Describe the principal characteristics of of Series LH open-web steel joists.
9. Describe how high-strength steel bolts may be identified.
10. Develop a computer program to provide an inventory of structural steel required for a building project. Provide for all shapes listed in Table 15–2. Input should include shape and size, length, quantity, and unit weight. Output should include a summary by steel shape, as well as the total weight of steel for the project. Using your program, provide an inventory example.

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