7. AWS 014.3, Specification for Welding Earthmoving and Construction Equipment
8. API 1104 Standard for Welding Pipelines and Related Facilities
9. Marine Engineering Regulations and Material Specifications (CG 115)

These specifications do not provide qualifications of the FCAW process for all applications and service requirements. For applications where AWS or other specifications are not available or do not apply and general criteria for qualification is desired, AWS B2.1, Standard for Welding Procedure and Performance Qualification, is often used. Qualification is obtained differently under the various codes. Qualification under one code will not necessarily qualify a welder to weld under a different code. In most cases, qualification for one employer will not allow the welder to work for another employer. If the welder uses a different process or the welding procedure is altered drastically, requalification is required. In most cases, if the welder is continually; employed, welding requalification is not required, providing the work performed meets the quality requirements.

Responsible manufacturers or contractors may give qualifications tests. On pressure vessel work, the welding procedure must also be qualified and this will be done before the welders are qualified. Under other codes, this is not necessary. To become qualified, the welder must make specified welds using the required process, base metal, base metal thickness, electrode type, position, and joint design. For example, in the AWS Structural Welding Code (D1.1), certain joint designs are considered prequalified for FCAW. Test specimens must be made according to standardized sizes and under the observation of a qualified person. For most government specifications, a government inspector must witness the making of weld specimens. Specimens must be properly identified and prepared for testing. The most common test is a guided bend test. In some cases, radiographic examinations, fracture tests, or other tests are used. Satisfactory completion of test specimens, provided that they meet acceptability standards, will qualify the welder for specific types of welding. Again, the welding that will be allowed depends on the particular code. In general, the code indicates the range of thicknesses that may be welded, the positions that may be used, and the alloys that may be welded.

Qualification of welders is a highly technical subject and cannot be covered fully here. You should obtain and study the actual code prior to taking any tests.

15.1.1 WELDING SAFETY

Safety is an important consideration when welding. Every welding shop should have a safety program and take adequate safety precautions to help protect welders. The welders should also be made aware of safety precautions and procedures. Employees who fail to follow adequate safety precautions can cause physical injury to themselves and others, and damage property. Any of these conditions can result in physical discomfort and loss of property, time, and money. Welding is a safe occupation when safety rules and common sense are followed. A set of safety rules is presented in the American National Standard Z49.1, "Safety in Welding and Cutting," published by the American Welding Society, which should be followed.

There are several types of hazards associated with FCAW. These hazards do not necessarily result in serious injuries. They can also be of a minor nature, which can cause discomforts that irritate and reduce the efficiency of the welders. These hazards are:

1. Electrical shock
2. Arc radiation
3. Air contamination
4. Compressed Gases
5. Fire and explosion
6. Weld cleaning and other hazards

15.1.0 Electrical Shock

There are several precautions that should be taken to prevent an electrical shock hazard. The first item that should be done before welding is to make sure the arc welding equipment is installed properly, grounded, and in good working condition. The electrical equipment should be maintained and installed in accordance with the National Electrical Code and any state and local codes that apply. Power supplies should be connected to an adequate electrical ground, such as an approved building ground, cold water pipe, or ground rod. Power supplies are connected to ground through the cable that connects the power supply to the electrical system ground. Cables with frayed or cracked insulation and faulty or badly worn connections can cause electrical short circuits and shocks. If it is necessary to splice lengths of welding cable together, the electrical connections should be tight and insulated. The proper size welding cables should also be used because constantly overloading a welding cable that is too small can destroy the insulation and create bare spots in the insulation. This occurs because excessive heat builds up in the cable and destroys the insulation. An improperly insulated welding cable is both an electrical shock hazard and a fire hazard.

The welding area should be dry and free of any standing water, which could cause electrical shock. When it is necessary to weld in a damp or wet area, the welder should wear rubber boots and stand on a dry, insulated platform.

15.2.0 Arc Radiation

The welding arc of FCAW emits large amounts of invisible ultraviolet and infrared rays. Skin exposed to the arc, even for a short time, can suffer serious ultraviolet and infrared burns, which are essentially the same as sunburn, but the burn caused by welding can take place in a much shorter time and can be very painful. Because of this, the welder should always wear protective clothing suitable for the welding to be done. These clothes should be fairly heavy and not easily burned. Leather is often used to make jackets, capes and bibs, or other similar arrangements to shield the arms, shoulders, chest, and stomach from the arc radiation and arc spatter. Leather is also used to make gloves and gauntlets for the welder.

The eyes must also be protected from the radiation emitted by the welding arc. Arc-burn can result if the eyes are not protected. Arc-burn of the eye is similar to sunburn of the skin and it is extremely painful for about 24 to 48 hours. Usually, arc-burn does not permanently injure the eyes, but it can cause intense pain as though several grains of sand were in your eyes. There are several commercial solutions available to soothe the skin and eyes during the period of suffering.

Infrared arc rays can cause fatigue of the retina of the eye. The effects of infrared rays are not nearly as noticeable or immediate as the effects of ultraviolet rays. Infrared rays are probably more dangerous in that their effects can be longer lasting and result in impaired vision.

The flux-cored welding arc is a relatively high energy arc that is much brighter than lower current welding arcs. Even though more smoke is given off from the arc area, it does not shield arc rays effectively.

The best protection for the eyes and face is provided by a headshield that has a window set in it with a filter lens in the window. Headshields are generally made of fiberglass or a pressed fiber material that is lightweight. The filter lens is made of a dark glass capable of absorbing infrared rays, ultraviolet rays, and most visible light coming from the arc. The type of lens used varies for different welders but it should be dark enough so the arc can be viewed without discomfort, yet not so dark the welder cannot see what he or she is doing. *Table 11-23* shows the different lenses commonly recommended for use in shielded metal arc welding. The higher the lens numbers, the darker the lens. A clear, replaceable glass should be put on the outside of the welding lens to protect it from spatter and breakage.

Table 11-23— Recommended Filter Lens Shades Used in Shielded Metal Arc Welding (ANSI/AWS Z49.1)

Welding Current	
Range-Amperes	**Lens Shade Number**
75-200	10 to 11
200-400	12 to 13
Above 400	14

15.3.0 Air Contamination

One of the main problems with FCAW is that it gives off more smoke and fumes than processes such as GTAW, GMAW, and SAW. It even tends to produce higher smoke and fume levels than SMAW. A hazard warning for fume is placed on the electrode wire box.

The welding area should be adequately ventilated because fumes and gases, such as ozone, carbon monoxide, and carbon dioxide, are hazardous for the welder to breathe. When welding is done in confined areas, an external air supply is required. This is furnished by the use of a respirator on a special helmet. A second person should stand just outside the confined area to lend assistance to the welder, if necessary. Another method is to use an exhaust system to remove welding fumes. Special fume extractor nozzles attached to the welding gun are popular for use with FCAW to reduce the smoke levels produced. These nozzles are connected to a filter and an exhaust pump, which greatly reduce the smoke level as shown in *Figure 11-117*.

Figure 11-117 — FCAW with fume extractor nozzle.

The shielding gas may displace the air that the welder needs for breathing. Because of this, welding should not be done in an enclosed area or hole, which can cause suffocation without the use of a respirator. Welding should never be done near degreasing and cleaning operations. The fumes from chlorinated solvents used for cleaning form a very toxic gas, called phosgene, when exposed to an arc. A mechanical exhaust system should be used when welding metals with lead, cadmium, and zinc coatings. AWS/ANSI Z49.1 should be consulted for ventilation requirements.

15.4.0 Compressed Gases

The shielding gas used for FCAW is compressed and stored in cylinders. One advantage of self-shielded flux-cored wire is that compressed gas cylinders are not required, so this is primarily a safety consideration when gas-shielded electrodes are used. Improper handling of compressed gas cylinders can create a safety hazard. When in use, gas cylinders should be secured to a wall or other structural support. The valve of the cylinder should be opened slowly and the welder should stand away from the face of the regulator when doing this. The welding arc should never be struck on a compressed gas cylinder. When not in use, gas cylinders should be stored with their caps on. Caps should also be on when they are moved. If the valve would get knocked off, the cylinder acts like a missile because of the escaping gas and can cause injury and damage. When compressed gas cylinders are empty, the valve should be closed and they should be marked as empty. This is done by marking the letters, "MT" or "EMPTY" on the cylinder.

15.5.0 Fires and Explosions

Fires and explosions are hazards that can exist in a welding area if the proper precautions are not taken. The FCAW process produces sparks and spatters which can start a fire or explosion in the welding area if not kept free of flammable, volatile, or explosive materials. Welding should never be done near degreasing and other, similar operations. Welders should wear leather clothing for protection from burns because leather is fireproof. Fires can also be started by an electrical short or by overheated, worn cables. In case of a fire started by a flammable liquid or an electrical fire, a CO_2 or dry chemical type of fire extinguisher is used. Fire extinguishers should be kept at handy spots around the shop and welders should make a mental note of where they are located.

Other precautions that have to do with explosions are also important. A welder should not weld on containers that have held combustibles unless it is absolutely certain there are no fumes or residue left. Welding should not be done on sealed containers without providing vents and taking special precautions. The welding arc should never be struck on a compressed gas cylinder. When the electrode holder is set down or not in use, it should never be allowed to touch a compressed gas cylinder.

15.6.0 Weld Cleaning and Other Hazards

Hazards can also be encountered during the weld cleaning process. Precautions must be taken to protect the skin and eyes from hot slag particles. FCAW produces a moderate slag covering which much be removed. The welding helmet, gloves, and heavy clothing protect the skin from slag chipping and grinding of the weld metal. Safety glasses should also be worn underneath the welding helmet to protect the eyes from particles that could get inside the welding helmet. Screens should be set up if there are other people in the area to protect them from arc burn.

15.7.1 Summary of Safety Precautions

1. Make sure your arc welding equipment is properly installed, grounded, and in good working condition.
2. Always wear protective clothing suitable for the welding to be done.
3. Always wear proper eye protection when welding, grinding, or cutting.
4. Keep your work area clean and free of hazards. Make sure no flammable, volatile, or explosive materials are in or near the work area.
5. Handle all compressed gas cylinders with extreme care. Keep caps on when not in use.
6. When compressed gas cylinders are empty, close the valve, and mark the cylinder “EMPTY”.
7. Do not weld in a confined space without special precautions.
8. Do not weld on containers that have held combustibles without taking special precaution.
9. Do not weld on sealed containers or compartments without providing vents and taking special precautions.
10. Use mechanical exhaust at the point of welding when welding lead, cadmium, chromium, manganese, brass, bronze, zinc, or galvanized steel.
11. When it is necessary to weld in a damp or wet area, wear rubber boots and stand on a dry, insulated platform.
12. Shield others from the light rays produced by your welding arc.
13. Do not weld near degreasing operations.
14. When the welding gun is in use, do not hang it on a compressed gas cylinder.

Summary

This chapter has introduced you to the FCAW process, from the types of power sources, controls, and electrodes to the types of training and qualifications needed. It also described the industries that use the FCAW process and its applications. Welding metallurgy, weld and joint design, and welding procedure variables were also discussed. The chapter finished up with a description of weld defects and how to identify them, then covered welder training and the common safety precautions applicable to all welding processes. As always, use the manufacturer’s operator manuals for the specific setup and safety procedures of the welder you will be using.

Review Questions (Select the Correct Response)

1. What type of current is used in flux cored arc welding?

   A. Constant
   B. Indirect
   C. Unmodulated low frequency
   D. Modulated high frequency

2. What is the main advantage of self shielding flux cored electrodes?

   A. Formation of slag
   B. Prevention of oxidation
   C. Simplified process
   D. All of the above

3. An electrode that has a minimum tensile strength of 80,000 psi for use in all positions for low alloy has what designation?

   A. E118T-1
   B. E802T-2
   C. E801T-2
   D. E7018-1

4. A welding electrode that has an AWS classification of E700T should be used for a metal-arc welding job in what position(s)?

   A. Horizontal position only
   B. Flat position only
   C. Horizontal and flat positions
   D. Vertical and overhead

5. What is the largest diameter electrode that can be used for vertical and overhead welding?

   A. 1/16-inch
   B. 1/8-inch
   C. 3/16-inch
   D. 5/32-inch

6. Which of the following properties is the basic rule for selecting an electrode for a job?

   A. Great tensile strength
   B. Composition similar to the base metal
   C. The melting temperature
   D. The least expensive

7. When the electrode is positive and the workpiece is negative, the electrons flow from the workpiece to the electrode. What polarity is being used?

   A. Straight
   B. Negative
   C. Positive
   D. Reverse

8. Which one of the following steps do you take to correct arc blow?

   A. Change the polarity of the work piece.
   B. Weld toward the edge of the workpiece from the ground clamp.
   C. Reduce the weld current.
   D. All of the above

9. Of the following practices, which one is correct for breaking an arc with an electrode?

   A. It is withdrawn slowly from the crater after the arc has lengthened.
   B. It is held stationary until the crater is filled, then withdrawn slowly.
   C. It is held stationary until the equipment is secured.
   D. It is lowered into the crater until contact is made, then quickly withdrawn.

10. What drag angle is used for flat and horizontal position welding using self shielded electrodes?

   A. 15° to 20°
   B. 20° to 45°
   C. 45° to 60°
   D. 60° to 90°

11. When using gas shielded electrodes, what angle is used for maximum penetration?

   A. 5°
   B. 10°
   C. 15°
   D. 20°

12. For which of the following reasons do you use relatively small electrodes for overhead butt welding?

   A. A long arc is needed to penetrate to the root of the joint.
   B. A short arc is needed to develop penetration at the root of the joint.
   C. Reduced current flow through the small electrode is needed to create a fluid puddle.
   D. Accelerated current flow is needed to control the fluid puddle.

13. Which of the following mistakes can cause undercutting in welds?

   A. Current too high
   B. Current too low
   C. Faulty preheating
   D. Joints too rigid

14. Which of the following mistakes can cause excessive spatter in welds?

   A. Arc too short
   B. Arc too long
   C. Current too low
   D. Rigid joints

15. Which of the following mistakes can cause cracked welds?

   A. Improper welding technique
   B. Improper welder technique
   C. Improper material
   D. All of the above

16. Which of the following mistakes can cause poor penetration?

   A. Current too low
   B. Current too high
   C. Welding speed too slow
   D. Rigid joints

17. Which of the following mistakes can cause brittle welds?

   A. Current too low
   B. Current too high
   C. Rigid joints
   D. Faulty postheating

18. When pipe has _ wall thickness, only the single U-type of butt joint should be used.

   A. 1/4-inch or less
   B. 1/2-inch or less
   C. 1/2-inch or more
   D. 3/4-inch or more

19. You do NOT need to do which of the following procedures when preparing a joint for welding?

   A. Clean the edges of surfaces to be welded
   B. Adjust the joint surfaces so they are smooth and uniform
   C. Remove slag from flame-cut edges
   D. Remove temper color

20. What maximum nominal diameter of electrode should you NOT exceed when making the root pass of a multilayer weld on pipe?

A. 3/32-inch
B. 1/8-inch
C. 3/16-inch
D. 1/4-inch

21. The root of a fillet weld is where the ______.

A. edge of the weld intersects the base metal
B. back of the weld intersects the base metal surfaces
C. face of the weld and the base metal meet
D. face and the toe meet

22. The face of a fillet weld is the ______.

A. exposed surface of the weld
B. edge of the weld that intersects the base metal
C. groove face adjacent to the root joint
D. separation between the members to be joined

23. The toe of a fillet weld is the ______.

A. junction between the face of the weld and the base metal
B. rippled surface of the weld
C. root of the weld to the face
D. edge of the weld that intersects the base metal

24. The leg of the weld is the ______.

A. length of the weld
B. distance from the root of the joint to the toe
C. groove face adjacent to the root joint
D. exposed surface of the weld

25. The throat of a fillet is the shortest distance from the ______.

A. face to the toe
B. root of the weld to the face
C. root to the toe
D. toe to the leg

26. Welding machine installations should be ______.

A. installed according to electrical codes
B. plugged into the nearest receptacle
C. connected to mobile generators only
D. simple with no grounding

27. Welding machine frames should be ______.

A. grounded electrically
B. not grounded electrically
C. rigid and heavy
D. insulated from ground

28. The welding arc gives off ultra-violet rays, which can cause eye injury. Injury can be prevented by ______.

A. wearing the proper lens shade in the helmet
B. using eye drops
C. closing your eyes
D. turning your head away from the arc

29. Ultra-violet rays from the arc ______.

A. do not damage skin
B. can cause skin damage similar to sunburn.
C. are a good source of vitamin C
D. are harmful if inhaled

30. Vaporized metals, such as zinc, cadmium, lead, and beryllium ______.

A. are hazardous
B. can be ignored
C. are used as shielding gases
D. are inert gases

31. After striking an arc, when should the travel angle start?

A. Immediately
B. After drawing back the electrode
C. After the weld puddle is formed
D. Before the formation of slag

32. When welding over a previously deposited bead, ______.

A. hold a long arc to melt the slag on the previous bead
B. use a weaving motion for deep penetration
C. tap the weld bead and electrode several times
D. clean the previous bead thoroughly before depositing the next weld

33. At the completion of the weld, the crater should ______.

A. overlap the workpiece
B. be filled to the height of the bead
C. remain unfilled
D. be twice the size it originally was

34. Horizontal position fillet welding is done from the ______.

A. upper side of the joint
B. lower side of the joint
C. perpendicular to the weld
D. opposite side of the face of the joint

35. In the flat position welding, the face of the weld is approximately ______.

A. perpendicular
B. at a right angle
C. horizontal
D. vertical

36. At what angle should you hold the electrode when making lap joints with metal of differing thickness?

A. 10-20°
B. 20-30°
C. 30-40°
D. 45-90°

37. What determines the direction the arc force applies to the weld pool?

A. Amperage
B. Voltage
C. Electrode angle
D. Electrode diameter

38. When reading current ranges in a welding schedule, fillet welds use the ______.

A. Complete range
B. Middle range
C. Upper range
D. Lower range

39. Tack welds should be ______.

A. cleaned before the full weld is made
B. half the length of the weld joint
C. welded over without cleaning
D. only on opposite corners

40. **(True or False)** You are responsible for performing all checks and procedure steps before, during, and after welding.

A. True
B. False

41. How do you clean the slag form a weld bead?

   A. Hammer
   B. High Pressure air
   C. Mechanical disc
   D. Chemicals

42. **(True or False)** You must be certified under the code that applies to the type of welding you will be doing.

   A. True
   B. False

43. **(True or False)** A sound weld can be made over dirt, paint, and grease if the correct electrode is used.

   A. True
   B. False

44. A destructive test is ______.

   A. a good way to test workmanship
   B. used to test a break fixture
   C. a type of nondestructive testing
   D. only used for small jobs

45. It is necessary to know the position in which welding is to be done ______.

   A. only when selecting iron powder electrodes
   B. when making any electrode selection
   C. when selecting electrodes that end in EXXT only
   D. to select the proper welding machine to use

Trade Terms Introduced in this Chapter

Alloying	An alloy is a compound of one or more metals or other elements. For example, brass is the alloy of copper and zinc.
Austenitic	Consisting mainly of austenite, which is a nonmagnetic solid solution of ferric carbide, or carbon in iron used in making corrosion-resistant steel.
Ferritic	Consisting of the pure iron constituent of ferrous metals, as distinguished from the iron carbides.
Ferrous	An adjective used to indicate the presence of iron. The word is derived from the Latin word *ferrum* ("iron"). Ferrous metals include steel and pig iron (with a carbon content of a few percent) and alloys of iron with other metals (such as stainless steel).
Nonferrous	The term used to indicate metals other than iron and alloys that do not contain an appreciable amount of iron.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

*Principles of Shielded Metal Arc Weldin*g, Miller Electric Manufacturing Company, Appleton, WI.

Safety in Welding, Cutting, and Allied Processes, ANSI/ASC Z49.1:2005 An American National Standard, American Welding Society, Miami FL, 2005.

Shielded Metal Arc Welding, Hobart Institute of Welding Technology , Troy Ohio,1998.

Welding and Allied Processes, S9086-CH-STM-010/CH-074R4, Commander, Naval Sea Systems Command, Washington Navy Yard, Washington D.C.,1999.

Welding Theory and Application, TC 9-237, Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1993.

Welding Theory and Application, TM 9-237, Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1976.

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

Chapter 12

Welding Quality Control

Topics

To hear audio, click on the box.

Overview

To ensure the satisfactory performance of a welded structure, the quality of the welds must be determined by adequate testing procedures. Therefore, they are proof tested under conditions that are the same or more severe than those encountered by the welded structures in the field. These tests reveal weak or defective sections that can be corrected before the materiel is released for use in the field.

This chapter is designed to give you an understanding of what to look for and how to test the finished weld using nondestructive and destructive methods. The weld should be inspected for undercut, overlap, surface checks, cracks, or other defects. Also, the degree of penetration and side wall fusion, extent of reinforcement, and size and position of the welds are important factors in the determination as to whether a welding job should be accepted or rejected, because they all reflect the quality of the weld.

Always refer to the American Welding Society for guidance.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe nondestructive testing.
2. Describe destructive testing.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet-Metal and Fiberglass Duct		
Welding Quality Control		
Flux Core Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 INTRODUCTION

In the fabrication or repair of equipment, tests are used to determine the quality and soundness of the welds. There are many different methods of inspection and testing; the most common methods will be covered in this chapter. The uses of these methods wiIl often depend on the code or specification that covered the welding. Testing of a weldment may be done nondestructively or destructively. The type of test used depends upon the requirements of the welds and the availability of testing equipment.

Nondestructive testing is used to locate defects in the weld and base metal. There are many different nondestructive testing methods. Some of the most widely used methods are visual, magnetic particle, liquid penetrant, ultrasonic, and radiographic. Visual, magnetic particle, and liquid penetrant inspection are used to locate surface defects, where ultrasonic and radiographic inspections are used to locate internal defects.

Destructive testing is used to determine the mechanical properties of the weld, such as the strength, ductility, and toughness. Destructive testing is also done by several methods, depending on the mechanical properties being tested for. Some of the most common types of destructive testing are tensile bar tests, impact tests, and bend tests.

All testing parameters are located in the American Welding Society, American National Standards.

2.0.0 NONDESTRUCTIVE TESTING

Nondestructive testing (NDT) is a method of testing that does not destroy or impair the usefulness of a welded item. These tests disclose all of the common internal and surface defects that can occur when improper welding procedures are used. A large choice of testing devices is available and most of them are easier to use than the destructive methods, especially when working on large and expensive items.

2.1.0 Visual Inspection

Visual inspection is the first method used when inspecting a weld for soundness. It must take place prior to, during, and after welding. Many standards require its use before other methods because there is no point in submitting an obviously bad weld to sophisticated inspection techniques. The ANSI/AWS Structural Welding Code states, "All welds shall be visually inspected…." Visual inspection requires little equipment. Good eyesight and sufficient light, a pocket rule, a weld size gauge, a magnifying glass, and possibly a straight edge and square for checking straightness, alignment and perpendicularity are all that is needed for a sufficient visual inspection.

Before the first welding arc is struck, materials should be examined to see if they meet specifications for quality, type, size, cleanliness, and freedom from defects. Grease, paint, oil, oxide film, or heavy scale should be removed. The pieces to be joined should be checked for flatness, straightness, and dimensional accuracy. Likewise, alignment, fit-up, and joint preparation should be examined. Finally, process and procedure variables should be verified, including electrode size and type, equipment settings, and provisions for preheat or postheat. All of these precautions apply, regardless of the inspection method being used.

During fabrication, visual examination of a weld bead and the end crater may reveal problems such as cracks, inadequate penetration, and gas or slag inclusions. Among the weld detects that can be recognized visually are cracking, surface slag in inclusions, surface porosity, and undercut.

On simple welds, inspecting at the beginning of each operation and periodically as work progresses may be adequate. Where more than one layer of filler metal is being deposited, however, it may be desirable to inspect each layer before depositing the next. The root pass of a multipass weld is the most critical to weld soundness. It is especially susceptible to cracking, and because it solidifies quickly, it may trap gas and slag. On subsequent passes, conditions caused by the shape of the weld bead or changes in the joint configuration can cause further cracking, as well as undercut and slag trapping. Repair costs can be minimized if visual inspection detects these flaws before welding progresses.

Visual inspection at an early stage of production can also prevent underwelding and overwelding. Welds that are smaller than called for in the specifications cannot be tolerated. Beads that are too large increase costs unnecessarily and can cause distortion through added shrinkage stress.

After welding, visual inspection can detect a variety of surface flaws, including cracks, porosity and unfilled craters, regardless of subsequent inspection procedures. Dimensional variances, warpage, and appearance flaws, as well as weld size characteristics, can be evaluated.

Before checking for surface flaws, welds must be cleaned of slag. Shot blasting should not be done before examination because the peening action may seal fine cracks and make them invisible. The AWS *Structural Welding Code*, for example, does not allow peening "on the root or surface layer of the weld or the base metal at the edges of the weld."

Visual inspection can only locate defects in the weld surface. Specifications or applicable codes may require that the internal portion of the weld and adjoining metal zones be examined. Nondestructive examinations may be used to determine the presence of a flaw, but they cannot measure its influence on the serviceability of the product unless they are based on a correlation between the flaw and some characteristic that affects service. Otherwise, destructive tests are the only sure way to determine weld serviceability.

2.2.0 Magnetic Particle Inspection

Magnetic particle inspection is most effective for the detection of surface or near-surface flaws in welds. It is used on ferrous metals or alloys in which you can induce magnetism. While the test piece is magnetized, a liquid containing finely ground iron powder is applied. As long as the magnetic field is not disturbed, the iron particles will form a regular pattern on the surface of the test piece. When the magnetic field is interrupted by a crack or some other defect in the metal, the pattern of the suspended ground metal is also interrupted. The particles cluster around the defect, making it easy to locate.

You can magnetize the test piece by either having an electric current pass through it, as shown in *Figure 12-1*, or by having an

Figure 12-1 — Circular magnetization.

electric current pass through a coil of wire that surrounds the test piece, as shown in *Figure 12-2*. When an electric current flows in a straight line from one contact point to the other, magnetic lines of force are in a circular direction, as shown in *Figure 12-1*. When the current flow is through a coil around the test piece, as shown in *Figure 12-2*, the magnetic lines of force are longitudinal through the test piece.

Figure 12-2 — Longitudinal magnetization.

When a defect is to show up as a disturbance in the pattern of the iron particles, the direction of the magnetic field must be at right angles to the major axis of the defect. A magnetic field having the necessary direction is established when the current flow is parallel to the major axis of the defect. Since the orientation of the defect is unknown, different current directions must be used during the test. As shown in *Figure 12-1*, circular magnetism is induced in the test piece so you can inspect the piece for lengthwise cracks, while longitudinal magnetism, as shown in *Figure 12-2*, is induced so you can inspect the piece for transverse cracks. In general, magnetic particle inspection is satisfactory for detecting surface cracks and subsurface cracks that are not more than 1/4 inch below the surface.

The type of magnetic particle inspection unit commonly used in the Navy is a portable low-voltage unit having a maximum magnetizing output of 1,000 amperes, either alternating or direct current. It is ready to operate when plugged into the voltage supply specified by the manufacturer. The unit consists of a magnetizing current source, controls, metering, three 10-foot lengths of flexible cable, and a prod kit. The prod kit includes an insulated prod grip fitted with an ON-OFF relay or current control switch, a pair of heavy copper contact prods, and two 5-foot lengths of flexible cable. Cable fittings are designed so that either end of the cable can be connected to the unit, to the prods, or to any other cable. The three outlets on the front of the unit make changing from alternating to direct current or vice versa very easy. The outlets are labeled as follows: left is ac, the center is COMMON, and the right is dc. One cable will always be plugged into the COMMON outlet, while the other cable is plugged into either the ac or dc outlet, depending upon what type of current the test requires. For most work, alternating current magnetization effectively locates fatigue cracks and similar defects extending through to the surface. Use direct current when you require a more sensitive inspection to detect defects below the surface.

You can use the unit with alternating or direct current in either of two ways: (1) with prods attached to the flexible cable and used as contacts for the current to pass into and out of a portion of the test piece, setting up circular magnetization in the area between the prods contact points, as shown in *Figure 12-1*; or (2) with the flexible cable wrapped around the work to form a coil that induces longitudinal magnetism in the part of the workpiece that is surrounded by the coiled cable (*Figure 12-2).*

Although you can use either of these two methods, the prod method is probably the easier to apply. In most instances, it effectively serves to detect surface defects. With the prods, however, only a small area of the test piece can be magnetized at any one time. This magnetized area is limited to the distance between prod contact points and a few inches on each side of the current path. To check the entire surface, you must test each adjacent area by changing the location of the prod contact points. Each area of the test piece must be inspected twice— once with the current passing through the metal in one direction, and once with the current passing through the metal in a direction at right angles to the direction of the first test. One of the advantages of the prod method is that the current can be easily passed through the metal in any desired direction. Thus, when a given area is suspect, magnetic fields of different directions can be induced during the test.

The prod method is accomplished by adjusting the unit for a current output suitable for the magnetizing and testing of any particular kind of metal. The current setting required depends on the distance between prod contact points. With the prod kit that is supplied with the unit, the space between prod contact points is 4 to 6 inches. A current setting between 300 and 400 amperes is satisfactory when the material thickness is less than 3/4 inch. When the material thickness is over 3/4 inch, use 400 to 600 amperes. When the prod contact points are closer together, the same magnetic field force can be obtained with less current. With prods constantly at the same spacing, more current will induce greater field strength.

After adjusting the unit, place the prods in position. Hold them in firm contact with the metal and turn on the current. Then apply magnetic particles to the test area with the duster bulb and look for any indicator patterns. With the current still on, remove the excess particles from the test area with a blower bulb and complete the inspection. Do not move the prods until after the current has been turned off. Doing so could cause the current to arc, resulting in a flash similar to that occurring in arc welding.

When you use magnetic particle inspection, hairline cracks that are invisible are readily indicated by an unmistakable outline of the defect. Large voids beneath the surface are easier to detect than small voids, but any defect below the surface is more difficult to detect than one that extends through to the surface. Since false indications frequently occur, you must be able to interpret the particle indications accurately. The factors that help you interpret the test results include the amount of magnetizing current applied, the shape of the indication, the sharpness of the outline, the width of the pattern, and the height or buildup of the particles. Although these characteristics do not determine the seriousness of the fault, they do serve to identify the kind of defect (*Figure 12-3).*

Figure 12-3 — Magnetic particle inspection.

The indication of a crack is a sharp, well-defined pattern of magnetic particles having a definite buildup. This indication is produced by a relatively low-magnetizing current. Seams are revealed by a straight, sharp, fine indication. The buildup of particles is relatively weak, and the magnetizing current must be higher than that required to detect cracks. Small porosity and rounded indentations or similar defects are difficult to detect for inexperienced inspectors. A high-magnetizing current continuously applied is usually required. The particle patterns for these defects are fuzzy in outline and have a medium buildup.

The specifications governing the job determine whether an indicated defect is to be chipped or ground out and repaired by welding. Surface cracks are always removed and repaired. The inspector evaluates indications of subsurface defects detected by magnetic particle inspection. When the indication is positive, the standard policy is to grind or chip down to solid metal and make the repair. Unless the inspector can differentiate accurately between true and false indications, the use of magnetic particle inspection should be restricted to the detection of surface defects, for which this application is almost foolproof.

After the indicated defects have been repaired, you should reinspect the areas to ensure that the repair is sound. The final step in magnetic particle inspection is to demagnetize the workpiece. This is especially important when the workpiece is made of high-carbon steel.

Demagnetization is essential when you use direct current to induce the magnetic field; however, it is not as necessary when alternating current was used in the test. In fact, the usual demagnetization procedure involves placing the workpiece in an ac coil or solenoid and slowly withdrawing it while current passes through the coil. Demagnetization can be accomplished with the portable unit if a special demagnetizer is not available. To demagnetize with the portable unit, form a coil of flexible cable around the workpiece. Ensure that the cable is plugged into the unit for the delivery of alternating current. Set the current regulator to deliver a current identical to that used for the inspection and turn on the unit. Gradually decrease the current until the ammeter indicates zero. On large pieces, it may be necessary to demagnetize a small portion of the work at a time.

A check for the presence of a magnetic field may be made by using a small compass. A deviation of the needle from the normal position when the compass is held near the workpiece is an indication that a magnetic field is present. In addition, you can use an instrument called a field indicator to check for the presence of a magnetic field. This instrument usually comes with the magnetic particle inspection unit.

2.3.1 Liquid Penetrant Inspection

Liquid penetrant inspection is one of the oldest, simplest, least expensive, and most reliable nondestructive examination methods. For welds to perform as intended, they should be free of flaws, or, if any flaws exist, they are evaluated for their significance. Liquid penetrant inspection is used to detect any surface-connected discontinuities, such as cracks from fatigue, quenching, and grinding, as well as fractures, porosity, incomplete fusion, and flaws in joints.

Liquid penetrant inspection is especially suited to weld inspection for the following reasons:

- It can easily be used on small and large surfaces.
- It can be used indoors or outdoors.
- It can be used in most configurations, i.e., on welded surfaces that are upright, sideways, or upside down.
- It can be used in remote locations.
- It can be used on ferrous and nonferrous materials, including plastics and ceramics.
- It will detect a wide variety of discontinuities, ranging in size from those readily visible down to microscopic level.

Liquid penetrant inspection is simple and easy. However, there are several types of penetrant materials, and it is important to match the materials with the application. Liquid penetrant inspections involve using a specific dye penetrant material and two or three related materials. Each one has been formulated to fulfill a specific function in the inspection process.

The liquid penetrant inspection process consists of six steps, each involving a specific penetrant product:

1. Precleaning
2. Penetrant application
3. Penetrant removal
4. Developer application
5. Examination
6. Postcleaning

Penetrant removal and developer application are the most critical steps in the process.

Penetrant materials are qualified, approved, and verified according to *Aerospace Material Specifications 2644, Liquid Penetrants* and are divided into two types.

Type 1 penetrants are fluorescent, and inspections are done under ultraviolet light.

Type 2 penetrants contain visible dyes, normally red, and inspections are conducted under white light.

Type 1, fluorescent penetrants, are available in five sensitivities ranging from ultralow, level ½, to ultrahigh, level 4.

Type 2, visible penetrants, have no sensitivity classifications.

Both fluorescent and visible penetrants are approved for use in four different penetrant inspection methods. These methods relate to how excess penetrant —material that has not entered the flaws —is removed prior to actual inspection.

Method A is water washable, where water is sprayed or wiped on the part.

Method B is post-emulsifiable ***lipophilic***, where a part is dipped in a lipophilic emulsifier and then rinsed with water.

- Lipophilic emulsifiers are capable of being mixed with penetrants in all concentrations. However, if the concentration of penetrant contamination in the emulsifier becomes too great, the mixture will not function effectively as a remover. AMS 2644 requires that lipophilic emulsifiers be capable of 20% penetrant contamination without a reduction in performance. AMS 2647A requires the emulsifier to be replaced when its cleaning action is less than that of new material.

  Since lipophilic emulsifiers are oil based, they have a limited tolerance for water. When the tolerance level is reached, the emulsifier starts to thicken and will eventually form a gel as more water is added. AMS 2644 requires that lipophilic emulsifiers be formulated to function adequately with at least 5% water contamination, and AMS 2647A requires that lipophilic emulsifiers be replaced when the water concentration reaches 5%.

Method C is solvent removable, where a solvent is wiped on the part. This is the process most used in inspecting welds.

Method D is post-emulsifiable ***hydrophilic***, where a part is dipped or sprayed with a hydrophilic emulsifier solution and then rinsed with water.

- Hydrophilic emulsifiers have less tolerance for penetrant contamination. The penetrant tolerance varies with emulsifier concentration and the type of contaminating penetrant. In some cases, as little as 1% (by volume) penetrant contamination can seriously affect the performance of an emulsifier. One penetrant manufacturer reports that 1 to 1.5% penetrant contamination will affect solutions with a 10% concentration of emulsifier. As the emulsifier concentration increases in the solution, the penetrant contamination tolerance also increases, and a solution with a 30% emulsifier concentration can tolerate from 5 to 8.5% penetrant contamination. The percentage of added penetrant required to destroy washability of the emulsifier can be measured. An oil tolerance index is commonly used to compare the tolerance of different emulsifiers to contamination by penetrants. AMS 2647A requires that the emulsification bath be discarded if penetrant is noted floating on the surface or adhering to the sides of the tank.

  Water contamination is not as much of a concern with hydrophilic emulsifiers, since they are miscible with water. However, it is very important that the emulsifier solution be kept at the proper concentration.

  It should also be noted that penetrant dragout and level of possible emulsifier contamination by the penetrant are dependent on the type of material being processed. Tests have shown that on both polished and grit-blasted surfaces, aluminum and stainless steel parts had a greater dragout than titanium parts.

There are six forms of developers, of which the nonaqueous are normally used for inspecting welds. Nonaqueous developers are white powders mixed with a volatile solvent. The following are the six developer forms:

- Dry developer
- Water soluble
- Water suspendable
- Nonaqueous Type 1 Fluorescent (solvent based)
- Nonaqueous Type 2 Visible (solvent based)
- Special application

The first step in liquid penetrant inspection is surface preparation. A clean, relatively smooth surface is needed for successful penetrant inspection. In addition, the surface to be examined and adjacent areas should be free of contaminants such as flux, weld spatter, scale, rust, paint, oil, and grease. Contaminants can prevent or delay the penetrant from entering the flaws, thereby undermining the inspection process.

Organic contaminants, such as oil and grease, can usually be removed with the same solvent used for penetrant removal. Hence, these materials are often called cleaner/removers. Other types of contaminants, such as scale and rust, can trap penetrant, creating false indications, or can prevent penetrant from entering real discontinuities. These contaminants may require using wire brushes or other methods in order to remove them. Precleaning is usually done by the customer and should conform to applicable specifications and codes.

Before the inspection process begins, issues involving ambient and equipment temperatures must be addressed. The normal specified temperature range for liquid penetrant inspection is 40 to 125°F. Do not attempt to use the liquid penetrant when this temperature range cannot be maintained. Do not use an open flame to increase the temperature because some of the liquid penetrant materials are flammable.

After thoroughly cleaning and drying the surface, coat the surface with the liquid penetrant. Spray or brush on the penetrant, or dip the entire piece into the penetrant. In practical terms, under normal ambient conditions, it is hard to let the penetrant stay on the part too long. The dwell time (how long the penetrant stays on the piece) is generally specified in the codes and procedures and may depend on the temperature. At temperatures below 50°F, the dwell times are increased up to 20-30 minutes. At high temperatures, those above 300°F, the dwell times are shortened to as low as 30 seconds. You must also follow any temperature and dwell instructions provided by the penetrant manufacturer.

After keeping the surface wet with the penetrant for the required length of time, remove any excess penetrant from the surface with a clean, dry cloth or absorbent paper towel. Then dampen a clean, lint-free material with penetrant remover and wipe the remaining excess penetrant from the test surface. Next, allow the test surface to dry by normal evaporation or wipe it dry with a clean, lint-free absorbent material. In drying the surface, avoid contaminating it with oil, lint, dust, or other materials that would interfere with the inspection.

After the surface has dried, apply another substance, called a developer. Allow the developer (powder or liquid) to stay on the surface for a minimum of 7 minutes before starting the inspection. Leave it on no longer than 30 minutes, thus allowing a total of 23 minutes to evaluate the results.

The following actions take place when using dye penetrants. First, the penetrant that is applied to the surface of the material will seep into any passageway open to the surface, as shown in *Figure 12-4*, *View A*. The penetrant is normally red in color, and like penetrating oil, it seeps into any crack or crevice that is open to the surface. Next, the excess penetrant is removed from the surface of the metal with the penetrant remover and a lint-free absorbent material. Only the penetrant on top of the metal surface is removed (*Figure 12-4*, *View B*), leaving the penetrant that has seeped into the defect.

Figure 12-4 — Liquid penetrant inspection.

Finally, the white developer is applied to the surface of the metal, as shown in *Figure 12-4*, *View C*. The developer is an absorbing material that actually draws the penetrant from the defect. Therefore, the red penetrant indications in the white developer represent the defective areas. The amount of red penetrant drawn from the defective areas indicates the size and sometimes the type of defect. When you use dye penetrants, the lighting in the test area must be bright enough to enable you to see any indications of defects on the test surface.

The indications you see during a liquid penetrant inspection must be carefully interpreted and evaluated. In almost every inspection, some insignificant indications are present. Most of these are the result of the failure to remove all the excess penetrant from the surface. At least 10 percent of all indications must be removed from the surface to determine whether defects are actually present or whether the indications are the result of excess penetrant. When a second inspection does not reveal indications in the same locations, it is usually safe to assume that the first indications were false.

Remove all penetrant inspection materials as soon as possible after the final inspection has been made. Use water or solvents, as appropriate. Since some of the liquid penetrant materials are flammable, do not use them near open flames, and do not apply them to any surface that is at a temperature higher than 100°F. In addition to being flammable, many solvents are poisonous in the vapor form and highly imitating to the skin in the liquid form.

2.4.0 Radiographic Inspection

Radiographic inspection (RT) is a method of inspecting weldments by the use of rays that penetrate through the welds. X and gamma radiation are the two types of waves used for this process. There are also two ways to view the X-ray. The first and oldest method is on film. The rays pass through the weld and onto a sensitized film that is in direct contact with the back of the weld. When the film is developed, gas pockets, slag inclusions, cracks, or poor penetration will be visible on the film. The second method is using a computer. Instead of exposing a film, a computer X-ray digitizes the radiation with the use of sensors. You may have been exposed to this type of X-ray at your dentist. The advantage of digitized images is the computer can analyze the image and help the inspector identify any defects, making the inspection more accurate.

Because of the danger of these rays, only qualified personnel are authorized to perform these tests. As Seabees, you will rarely come in contact with these procedures.

2.5.0 Ultrasonic Inspection

Ultrasonic testing (UT) can be used on ferrous and nonferrous materials and is often suited for testing thicker sections accessible from one side only. In general, it can detect finer linear or planar defects than can RT.

UT makes use of mechanical vibrations similar to sound waves but of higher frequency. A beam of ultrasonic energy is directed into the object to be tested. This beam travels through the object with insignificant energy loss, except when it is intercepted and reflected by a discontinuity.

The ultrasonic contact pulse reflection technique is used in UT. This system uses a transducer, which converts electrical energy into mechanical energy. The transducer is excited by a high-frequency voltage that causes a crystal to vibrate mechanically. The crystal probe becomes the source of ultrasonic mechanical vibration. These vibrations are transmitted into the test piece through a coupling fluid, usually a film of oil, called a couplant.

When the ultrasonic waves pulse strikes a discontinuity in the test piece, it is reflected back to its point of origin. Thus, the energy returns to the transducer. The transducer now serves as a receiver for the reflected energy.

The initial signal, or main bang; the returned echoes from the discontinuities; and the echo of the rear surface of the test piece all are displayed by a trace on the screen of a cathode-ray oscilloscope. The detection, location, and evaluation of discontinuities become possible because the velocity of sound through a material is nearly constant, making distance measurement possible, and the relative amplitude of a reflected pulse is more or less proportional to the size of the reflector.

One of the most useful characteristics of UT is its ability to determine the exact position of a discontinuity in a weld. This testing method requires a high level of operator training and competence and depends on establishing and applying suitable testing procedures.

2.6.0 Eddy Current Testing

Eddy current is another type of testing that uses electromagnetic energy to detect faults in weld deposits and is effective for both ferrous and nonferrous materials. As a Seabee, you will rarely use this type of testing in the field.

In eddy current testing, a sinusoidal AC voltage is applied across the eddy current probe or inspection coil. This coil creates an electromagnetic field, which in turn causes current flow in the surface of the material being inspected. (The circular nature of these currents has been compared to the eddies in a stream or river, hence the term "eddy current.") When the coil or probe is scanned across the material surface, changes in the material's physical properties, i.e., geometry, temperature, conductivity, material type, flaws, etc., affect the current flow generated by the electromagnetic field induced in the material by the probe. These changes reflect back to the probe. If the voltage response of the eddy current probe is monitored, then changes in voltage amplitude and phase angle shift can be used to show changes in material properties. These changes in magnitude and phase angle are displayed on what is known as an impedance plane display.

3.0.0 DESTRUCTIVE TESTING

In destructive testing, sample portions of the welded structures are required. These samples are subjected to loads until they fail. The failed pieces are then studied and compared to known standards to determine the quality of the weld. The most common types of destructive testing are: free bend, guided bend, nick-break, fillet-welded joint, etching, impact, and tensile test. The primary disadvantage of destructive testing is that an actual section of a weldment must be destroyed to evaluate the weld. This type of testing is usually used in the certification process of the welder.

Some of the testing requires elaborate equipment that is not available for use in the field. Three tests that may be performed in the field without elaborate equipment are the free-bend test, the guided-bend test, and the nick-break test.

Details of destructive tests of welded joints and deposited filler metals can be found in AWS B4.0, Standard methods for mechanical testing of welds.

3.1.0 Free-Bend Test

The free-bend test has been developed to measure the ductility of the weld metal deposited in a weld joint. Also, it is used to determine the percentage of elongation of the weld metal. Ductility, you should recall, is that property of a metal that allows it to be drawn out or hammered thin.

The first step in preparing a welded specimen for the free-bend test is to machine the welded reinforcement crown flush with the surface of the test plate. When the weld area of a test plate is machined, as is the case of the guided-bend as well as in the free-bend test, perform the machining operation in the opposite direction that the weld was deposited.

The next step in the free-bend test is to scribe two lines on the face of the filler deposit. Locate these lines 1/16 inch from each edge of the weld metal, as shown in *Figure 12-5,* View B. Measure the distance in inches between the lines to the nearest 0.01 inch and write down the resulting measurement as (x). Then bend the ends of the test specimen until each leg forms an angle of 30 degrees to the original centerline.

Figure 12-5 — Free-bend test.

With the scribed lines on the outside and the piece placed so all the bending occurs in the weld, bend the test piece by using a hydraulic press or similar machine. When the proper precautions are taken, a blacksmith's forging press or hammer can be used to complete the bending operation. If a crack more than 1/16 inch develops during the test, stop the bending because the weld has failed; otherwise, bend the specimen flat. After completing the test, measure the distance between the scribed lines and call that measurement (y). The percentage of elongation is then determined by the formula:

$$\frac{Y - X}{X} \times 100 = \%\ elongation$$

Requirements for a satisfactory test consist of an area with a minimum elongation of 15 percent and no cracks greater than 1/16 inch on the face of the weld.

The free-bend test is being replaced by the guided-bend test where the required testing equipment is available.

3.2.0 Guided-Bend Test

Use the guided-bend test to determine the quality of weld metal at the face and root of a welded joint. This test is made in a specially designed jig. An example of one type of jig is shown in *Figure 12-6*.

Figure 12-6 — Guided-bend test jig.

The test specimen is placed across the supports of the die. A plunger, operated from above by hydraulic pressure, forces the specimen into the die. To fulfill the requirements of this test, bend the specimen 180 degrees—the capacity of the jig. No cracks should appear on the surface greater than 1/8 inch. The facebend tests are made in this jig with the face of the weld in tension (outside), as shown in *Figure 12-7*. The root-bend tests are made with the root of the weld in tension (outside), as shown in *Figure 12-7*

Figure 12-7 — Guided-bend test specimens.

Figure 12-8 shows a machine used for making the guided-bend test. It is used in many welding schools and testing laboratories for the daily testing of specimens. Simple in construction and easy to use, it works by hydraulic pressure and can apply a direct load up to 40,000 pounds, and even more on small specimens. To test the specimen, place it in the machine as previously stated and start to pump the actuator. Keep your eye on the large gauge and watch the load increase. You will know the actual load under which the test piece bends by the position of an auxiliary hand that is carried along by the gauge pointer. The hand remains at the point of maximum load after the pointer returns to zero.

Figure 12-8 — Test machine for making guided-bend tests.

3.3.1 Nick-Break Test

A nick-break test involves breaking the weld joint to examine the fractured surfaces for internal defects such as:

1. Gas pockets
2. Slag inclusions
3. Porosity.

The test also determines weld ductility and the degree of fusion.

The test specimen shall be cut through the welded joint about 1/4 of an inch (6 mm). The excess weld metal and penetration bead shall be left intact.

The specimen is then placed upright on two supports (*Figure 12-9*) and the force on the weld is applied either by a press or by the sharp blows of a hammer until a fracture occurs between the two slots.

Figure 12-9 — Nick-break test of a butt weld.

A visual inspection of the fractured surfaces is carried out in order to find defects (as mentioned earlier), if any. If any defect exceeds 1/16 in. (1.5 mm) in size or the number of gas pockets exceeds six per square inch, the piece has failed the test.

3.4.0 Impact Test

Impact testing relates specifically to the behavior of metal when subjected to a single application of a force resulting in multi-axial stresses associated with a notch, coupled with high rates of loading, and in some cases, being exposed to high or low temperatures. For some materials and temperatures, the results of impact tests on notched specimens, when correlated with service experience, have been found to predict the likelihood of brittle fracture accurately. ASTM E23 is the Standard Test Methods for Notched Bar Impact Testing of Metallic Materials.

Two kinds of tests are used for impact testing. They are *Charpy* and *Izod (Figure 12-10)*. Both tests require notched metal pieces to be broken in an impact testing machine. The differences between the two tests are seen in how they are anchored and which way the notch is facing during the impact.

Figure 12-10 — Test pieces for impact testing.

The Charpy piece is supported horizontally between two anvils and the pendulum strikes opposite the notch, as shown in *Figure 12-11*, View A. The Izod piece is supported as a vertical cantilever beam and is struck on the free end projecting over the holding vise (*Figure 12-11*, View B).

Figure 12-11 — Performing impact test.

3.5.0 Fillet-Welded Joint Test

You use the fillet-welded joint test to check the soundness of a fillet weld. Soundness refers to the degree of freedom a weld has from defects found by visual inspection of any exposed welding surface. These defects include penetrations, gas pockets, and inclusions. Prepare the test specimen, as shown in *Figure 12-12*. Now apply force (*Figure 12-13*) until a break occurs in the joint. This force may be applied by hydraulics or hammer blows. For required thickness and weld sizes, refer to Fillet weld Soundness Tests in AWS American National Standards.

In addition to checking the fractured weld for soundness, now is a good time to etch the weld to check for cracks.

Figure 12-12 — Test plate for fillet weld test.

Figure 12-13 — Rupturing fillet weld test plate.

3.6.0 Etching Test

The etching test is used to determine the soundness of a weld and make the boundary between the base metal and the weld metal visible.

To accomplish the test, you must cut a test piece from the welded joint so it shows a complete transverse section of the weld. You can make the cut by either sawing or flame cutting. File the face of the cut and then polish it with grade 00 abrasive cloth. Then place the test piece in the etching solution.

The etching solutions generally used are hydrochloric acid, ammonium persulfate, iodine and potassium iodide, or nitric acid. Each solution highlights different defects and areas of the weld. The hydrochloric acid dissolves slag inclusions and enlarges gas pockets, while nitric acid is used to show the refined zone as well as the metal zone.

3.7.0 Tensile Strength Test

The term tensile strength may be defined as the resistance to longitudinal stress or pull and is measured in pounds per square inch of cross section. Testing for tensile strength involves placing a weld sample in a tensile testing machine and pulling on the test sample until it breaks.

The essential features of a tensile testing machine are the parts that pull the test specimen and the devices that measure the resistance of the test specimen. Another instrument, known as an extensometer or strain gauge, is also used to measure the strain in the test piece. Some equipment comes with a device that records and plots the stress-strain curve for a permanent record.

The tensile test is classified as a destructive test because the test specimen must be loaded or stressed until it fails. Because of the design of the test machine, weld samples must be machined to specific dimensions. This explains why the test is made on a standard specimen, rather than on the part itself. It is important that the test specimen represents the part. Not only must the specimen be given the same heat treatment as the part, but it also must be heat-treated at the same time.

There are many standard types of tensile test specimens, and *Figure 12-14* shows one standard type of specimen commonly used. The standard test piece is an accurately machined specimen. The diameter and gauge length are critical items, but the overall length is not. The 0.505-inch-diameter (0.2 square inch area) cross section of the reduced portion provides an easy factor to manipulate arithmetically. The 2-inch gauge length is the distance between strain-measuring points. This is the portion of the specimen where you attach the extensometer. In addition, you can use the gauge length to determine percent elongation.

Figure 12-14 — Standard tensile test specimen.

The tensile test involves applying a smooth, steadily increasing load (or pull) on a test specimen and measuring the resistance until it breaks. Even if recording equipment is not available, the test is not difficult to perform. During the test, you observe the behavior of the specimen and record the extensometer and gauge readings at regular intervals. After the specimen breaks and the fracturing load are recorded, you measure the specimen with calipers to determine the percent of elongation and the percent reduction in area. In addition, you should plot a stress-strain curve. From the data obtained, you can determine tensile strength, yield point, elastic limit, modulus of elasticity, and other properties of the material.

Summary

This chapter has introduced you to welding quality control. You should now have an understanding of what to look for and how to test the finished weld using nondestructive and destructive methods. The weld should be inspected for undercut, overlap, surface checks, cracks, or other defects. Also, the degree of penetration and side wall fusion, extent of reinforcement, and size and position of the welds are important factors in the determination as to whether a welding job should be accepted or rejected because they all reflect the quality of the weld. The chapter finished up with a description of possible weld defects and how to identify for them using multiple methods of nondestructive and destructive tests and inspections. As always, use the manufacturer’s operator manuals for the specific setup and safety procedures of the welder you will be using.

Review Questions (Select the Correct Response)

1. How do you know which tests to use on a weld?

   A. Experience
   B. Code
   C. Type of metal
   D. Welding method

2. Which of the following is NOT a nondestructive test?

   A. Ultrasonic
   B. Etching
   C. Magnetic particle
   D. Liquid penetrant

3. In what manual are the testing parameters located?

   A. ANSE
   B. ASTM
   C. AWS
   D. NRTC

4. What test must occur prior to all other tests?

   A. Ultrasonic
   B. Liquid penetrant
   C. Tensile strength
   D. Visual

5. Prior to the first welding arc being struck, what visual checks should be made to the material being welded?

   A. Type, size, and cleanliness
   B. Heat treatment, tensile strength, and ductility
   C. Density, volume, and mass
   D. Temperature, dimensional accuracy, and ductility

6. Prior to checking a work piece for surface defects, what cleaning method is NOT authorized?

   A. Soap and water
   B. Wire brush
   C. Shot peening
   D. Solvents

7. Which nondestructive testing process is most effective for detecting surface and near-surface flaws?

   A. X-rays
   B. Liquid penetrant
   C. Ultrasonic
   D. Magnetic particle

8. What is the visual indication that a flaw exists when using magnetic particle testing?

   A. A fluorescent color is present
   B. Bubbles come from the area of the flaw
   C. Particles cluster at the flaw site
   D. The flaw makes a vibrating sound

9. How do you check the entire surface of the weld using magnetic particle testing?

   A. Move the prods in circular motions.
   B. Increase the current in the prods.
   C. Lightly tap the prods against the weld.
   D. Change the location of the prod contact points.

10. What factors help interpret the test results of a magnetic particle test?

   A. The heat generated at the flaw site
   B. White lights
   C. The shape of the indication
   D. The color of the flaw site

11. How do you check for the presence of a magnetic field in the work piece?

   A. Touch it with a like piece of material
   B. Use a magnetron
   C. Wave a compass over it
   D. See if the work piece sticks to the work bench

12. How many steps are needed to complete the liquid penetration process?

   A. 3
   B. 4
   C. 5
   D. 6

13. How many different penetrant inspection methods are there?

   A. 4
   B. 3
   C. 2
   D. 1

14. Method A liquid penetrant is applied to the work piece by what action?

  A. Dipping
  B. Spraying
  C. Rolling
  D. Immersing

15. What is the normal temperature range for using liquid penetrant?

  A. 32° F to 400°F
  B. 0 to° F 250°F
  C. 40° F to 125°F
  D. 98° F to 300°F

16. How many minutes should the developer stay on a work piece?

  A. 5
  B. 10
  C. 15
  D. 30

17. How have computers helped with radiographic inspections?

  A. By Increasing accuracy of defect identification
  B. By using less paper
  C. By increasing portability
  D. By lowering the cost of the process

18. How are the vibrations from an ultrasonic transducer imparted to the base metal being tested?

  A. Through the air
  B. With a clamp
  C. With a couplant material
  D. With a test fixture

19. Which of the following tests can be used in the field without elaborate equipment?

  A. Fillet-welded joint
  B. Etching
  C. Impact
  D. Free-bend

20. What is the definition of ductility?

  A. The ability to withstand impact
  B. The ability to be drawn out or hammered thin
  C. The ability to withstand extremely high temperatures
  D. The ability to be stretched by pulling

21. What is the maximum surface crack allowable when performing a guided-bend test on a weld?

    A. 1/32
    B. 1/16
    C. 1/8
    D. 1/4

22. When performing a nick-break test, how many inches deep should the end cuts be on the weld?

    A. 1/4
    B. 1/2
    C. 1
    D. No more than half the thickness of the weld

23. Which impact test is performed in a horizontal test fixture?

    A. Charpy
    B. Nike
    C. Izod
    D. Franklin

24. Which destructive test method does NOT use the actual welded material when testing?

    A. Etching
    B. Tensile strength
    C. Fillet-welded joint
    D. Impact

Trade Terms Introduced in this Chapter

Hydrophilic	Having an affinity for water; readily absorbing or dissolving in water
Lipophilic	Having an affinity for, tending to combine with, or capable of dissolving in lipids (fats)

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

American Welding Society, *AWS B2.1 Specification For welding Procedure and Performance Qualification, An American National Standard*, American Welding Society, Miami Florida 2009.

American Welding Society, *AWS D1.1 Structural Welding Code – Steel, An American National Standard*, American Welding Society, Miami Florida 2009.

American Welding Society, *Welding Inspection Handbook*, American Welding Society, Miami , Florida 2009.

Welding Theory and Application, TM 9-237, Department of the Army Technical Manual, Headquarters, Department of the Army, Washington D.C., 1976.

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate__ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

Chapter 13

Layout and Fabrication of Sheet Metal and Fiberglass Duct

Topics

To hear audio, click on the box.

Overview

As a Seabee, you will use many pre-fabricated ducts and fittings. However, not all situations call for the use off the shelf parts; therefore, you will be called upon to assess the needs of the job and fabricate the appropriate parts to complete the job.

This chapter introduces you to basic sheet metal and fiberglass ductwork fabrication. You will be introduced to the tools needed to work the sheet metal; some of the methods of measuring, marking, cutting; and the correct methods to form parallel, radial, and triangular sheet metal shapes. These techniques are not limited to ductwork, so the processes you learn here can be applied to roofing, flashing, and exterior building siding, to name a few. Remember to keep safety as the main focal point on any jobsite.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the tools and equipment associated with fabrication.
2. Describe procedures utilized in sheet metal development.
3. Identify the procedures associated with joining and installing sheet metal duct.
4. Identify the different types of sheet metal duct systems.
5. Identify the different types of fiberglass duct systems.
6. State the safety regulations associated with sheet metal and fiberglass duct systems.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet Metal and Fiberglass Duct		
Welding Quality Control		
Flux Cored Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 TOOLS and EQUIPMENT

Numerous types of layout tools, cutting tools, and forming equipment are used when working with sheet metal. This section will describe the uses of the layout and cutting tools and the operation of the forming equipment.

1.1.0 Layout Tools

The layout of metal is the procedure of measuring and marking material for cutting, drilling, or welding. Accuracy is essential in layout work. Using incorrect measurements results in a part being fabricated that does not fit the overall job. This is a waste of time and material. In most cases, you should use shop drawings, sketches, and blueprints to obtain the measurements required to fabricate the job being laid out. Your ability to read and work from blueprints and sketches is vital in layout work. For more information on blueprints, go to *Blueprint Reading and Sketching,* NAVEDTRA 14040.

Layout tools are used for drawing fabrication jobs on metal. Some of the more common layout tools are scriber, flat steel square, combination square, protractor, prick punch, dividers, trammel points, and circumference ruler.

1.1.1 Scriber

Lines are drawn on sheet metal with a scribe or scratch awl, coupled with a steel scale or a straightedge. To obtain the best results in scribing, first cover the area to be scribed in a very thin layer of layout dye, then hold the scale or straightedge firmly in place and set the point of the scriber as close to the edge of the scale as possible by angling the top of the scriber outward. Then exert just enough pressure on the point to draw the line, tilting the tool slightly in the direction of movement (*Figure 13-1*). For short lines, use the steel scale as a guide. For longer lines, use a circumference ruler or a straightedge. To draw a line between two points, prick punch each point. Start from one prick punch mark and scribe toward the other mark, then stop before reaching the other point. Complete the line by scribing from the other prick punch mark in the opposite direction.

Figure 13-1 — Scribing a line.

1.1.2 Flat Steel Square

A flat steel square is used for making perpendicular or parallel lines. In the method of layout known as parallel line development, the flat steel square is used to create lines that are parallel to each other as well as perpendicular to the base line. This procedure is shown in *Figure 13-2*. Simply clamp the straightedge firmly to the base line. Slide the body of the square along the straightedge. Using the leading edge of the square, draw perpendicular lines at the desired points.

Figure 13-2 — Scribing parallel and perpendicular lines.

Figure 13-3 — Checking a square for accuracy.

Before each use of your square, check it for accuracy. Never assume it is straight. You can check it for accuracy, as shown in *Figure 13-3*.

1. Place the edge of your carpenter's square against a straight board.
2. Draw a line using a pencil against the blade of the carpenter's square.
3. Flip the carpenter's square over and draw a second line against the first.
4. Remove the carpenter's square from the board and check the two lines. If they appear as one (like they were drawn over each other) then your carpenter's square is accurate. If you see two distinct lines that vary at a given point, then your carpenter's square is bent or curved and needs replacing.

When the square is off, your work will be off correspondingly, no matter how careful you are.

1.1.3 ombination Square

The combination square can be used to draw a similar set of lines, as shown in *Figure 13-4*. An edge of the metal you are working on is used as the base line, as shown in the figure. One edge of the head of the combination square is 90 degrees, and the other edge is 45 degrees. Combination squares are sensitive to mishandling. Store your squares properly when you have finished using them. Keep them clean and in proper working order, and you will be able to construct 90-degree angles, 45-degree angles, and parallel lines can be made without error.

Figure 13-4 — Using a combination square.

1.1.4 Protractor

To construct angles other than 45 degrees or 90 degrees, you will need a protractor. A protractor is a semicircular instrument with degree markings from 0° to 180°. Mark the ***vertex*** of the angle of your base line with a prick punch. Set the base of the protractor on the mark and then scribe a V at the desired angle (assume 70°). Scribe a line between the vertex and the V. The resulting is 70° angle from the base.

1.1.5 Prick Punch

A prick punch is used to mark the beginning or end of a desired line or cut. The tip of a prick punch has a 30°-60° angle. The point is placed on the desired spot, and then it is either pressed or hammered to indent the sheet metal. The prick punch prevents overdrawing or over-scoring the lines.

1.1.6 Dividers

Use dividers to scribe arcs and circles, to transfer measurements from a scale to your layout, and to transfer measurements from one part of the layout to another. Careful setting of the dividers is of utmost importance. When you transfer a measurement from a scale to the work, set one point of the dividers on the mark and carefully adjust the other leg to the required length, as shown in *Figure 13-5*.

Figure 13-5 — Setting the dividers.

Figure 13-6 — Scribing an arc with dividers.

To scribe a circle or an arc, grasp the dividers between the fingers and the thumb, as shown in *Figure 13-6.* Place the point of one leg on the center, and swing the arc. Exert enough pressure to hold the point on center, slightly inclining the dividers in the direction in which they are being rotated.

1.1.7 Trammel Points

To scribe a circle with a radius larger than your dividers, select trammel points. Two types of trammel points are shown in *Figure 13-7*. Both sets are easily adjustable. Once adjusted, the arc or circle is scribed in the same manner as with the dividers.

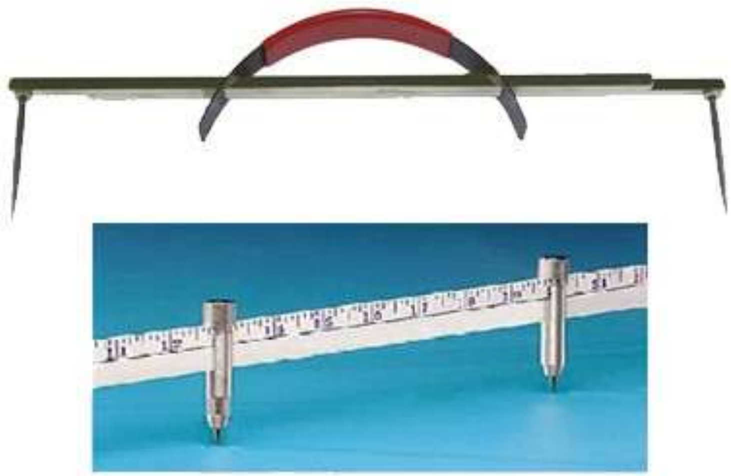


Figure 13-7 — Different types of trammel points.

Now that you have been introduced to dividers and trammel points let us learn how to use them.

Constructing a 90-degree, or right, angle is not difficult if you have a true, steel square. Suppose that you have no square or that your square is off, and you need a right angle for a layout. Using your dividers, a scriber, and a straightedge, draw a base line similar to AB in *Figure 13-8*. Set the dividers for a distance greater than one-half AB; then, with A as a center, scribe arcs like those labeled C and D. Next, without changing the setting of the dividers, use B as a center, and scribe another set of arcs at C and D. Draw a line through the points where the arcs intersect and you have erected perpendiculars to line AB, forming four 90-degree, or right, angles. You have also bisected or divided line AB into two equal parts.

Figure 13-8 — Creating a 90° angle by bisecting a line.

Figure 13-9 — Creating a 90° angle a given point.

Constructing a right angle at a given point with a pair of dividers is a procedure you will find useful when making layouts. *Figure 13-9* shows the method for constructing a right angle at a given point.

Start with line XY, with A as a point to fabricate a perpendicular to form a right angle. Select any convenient point that lies somewhere within the proposed 90-degree angle. In *Figure 13-9,* that point is C. Using C as the center of a circle with a radius equal to CA, scribe a semicircular arc, as shown in *Figure 13-9*. Lay a straightedge along points B and C and draw a line that will intersect the other end of the arc at D. Next, draw a line connecting the points D and A and you have fabricated a 90-degree angle. This procedure may be used to form 90-degree corners in stretch-outs that are square or rectangular, like a drip pan or a box.

Laying out a drip pan with a pair of dividers is no more difficult than drawing a perpendicular line. You will need dividers, a scriber, a straightedge, and a sheet of template paper. Once you have the dimensions of the pan to be fabricated: the length, the width, and the height or depth. Draw a base line (*Figure 13-10*). Select a point on this line for one comer of the drip pan layout. Erect a perpendicular through this point, forming a 90-degree angle. Next, measure off on the base line the required length of the pan. At this point, erect another perpendicular. You now have three sides of the stretch-out. Using the required width of the pan for the other dimensions, draw the fourth side parallel to the base line, connecting the two perpendiculars that you have fabricated.

Set the dividers for marking off the depth of the drip pan. Use a steel scale to measure off the correct radius on the dividers. Using each corner for a point, swing a wide arc, like the one shown in the second step in *Figure 13-10*. Extend the lines as shown in the last step in *Figure 13-10,* and complete the stretch-out by connecting the arcs with a scriber and straightedge.

Figure 13-10 — Laying out a drip pan with dividers.

Bisecting an arc is another geometric construction with which you should be familiar. Angle ABC (*Figure 13-11*) is given. With B as a center, draw an arc, cutting the sides of the angle at D and E. With D and E as centers and with a radius greater than half of arc DE, draw arcs intersecting at F. A line drawn from B through point F bisects angle ABC.

Figure 13-11 — Bisecting an arc.

Two methods used to divide a line into a given number of equal parts are shown in *Figure 13-12*. When the method shown in view A is used, you will need a straightedge and dividers. In using this method, draw line AB to the desired length. With the dividers set at any given radius, use point A as center and scribe an arc above the line. Using the same radius and B as center, scribe an arc below the line as shown. From point A, draw a straight-line tangent to the arc that is below point B. Do the same from point B. With the dividers set at any given distance, start at point A and step off the required number of spaces along line AD using tick marks-in this case, six. Number the tick marks as shown. Do the same from point B along line BC. With the straightedge, draw lines from point 6 to point A, 5 to 1, 4 to 2, 3 to 3, 2 to 4, 1 to 5, and B to 6. You have now divided line AB into six equal parts.

When the method shown in view B of *Figure 13-12* is used to divide a line into a given number of equal parts, you will need a scale. In using this method, draw a line at right angles to one end of the base line. Place the scale at such an angle that the number of spaces required will divide evenly into the space covered by the scale. In the illustration (view B, *Figure 13-12*), the base line is 2 1/2 inches and is to be divided into six spaces. Place the scale so that the 3 inches will cover 2 1/2 inches on the base line. Since 3 inches divided by 6 spaces = 1/2 inch, draw lines from the 1/2-inch spaces on the scale perpendicular to the base line. Incidentally, you may even use a full 6 inches in the scale by increasing its angle of slope from the baseline and dropping perpendiculars from the full-inch graduation to the base line.

Figure 13-12 — Two methods used to divide a line into equal parts.

To divide or step off the circumference of a circle into six equal parts, just set the dividers for the radius of the circle and select a point of the circumference for a beginning point. In *Figure 13-13*, point A is selected for a beginning point. With A as a center, swing an arc through the circumference of the circle, like the one shown at B in the illustration. Use Bas a point and swing an arc through the circumference at C.

Continue to step off in this manner until you have divided the circle into six equal parts. If the points of intersection between the arcs and the circumference are connected as shown in *Figure 13-13*, the lines will intersect at the center of the circle, forming angles of 60 degrees.

To obtain an angle of 30 degrees, bisect one of these 60-degree angles by the method described earlier in this chapter. Bisect the 30-degree angle and you have a 15-degree angle. You can construct a 45-degree angle in the same manner by bisecting a 90-degree angle. In all probability, you will have a protractor to lay out these and other angles. In the event you do not have a steel square or protractor, it is a good idea to know how to construct angles of various sizes and to erect perpendiculars.

Figure 13-13 — Dividing a circle into six equal parts

When laying out or working with circles or arcs, it is often necessary to determine the circumference of a circle or arc. To determine the circumference of a circle, use the formula $C = \pi d$, where C is the circumference, $\pi = 3.14$, and d is the diameter.

1.1.8 Circumference Ruler

Another method of determining circumference is by use of the circumference ruler. The upper edge of the circumference ruler is graduated in inches in the same manner as a regular layout scale, but the lower edge is graduated, as shown in *Figure 13-14*. The lower edge gives you the approximate circumference of any circle within the range of the rule. You will notice in *Figure 13-14* that the reading on the lower edge directly below the 3-inch mark is a little over 9 3/8 inches. This reading is the circumference of a circle with a diameter of 3 inches and is the length of a stretch-out for a cylinder of that diameter. The dimensions for the stretch-out of a cylindrical object, then, are the height of the cylinder and the circumference.

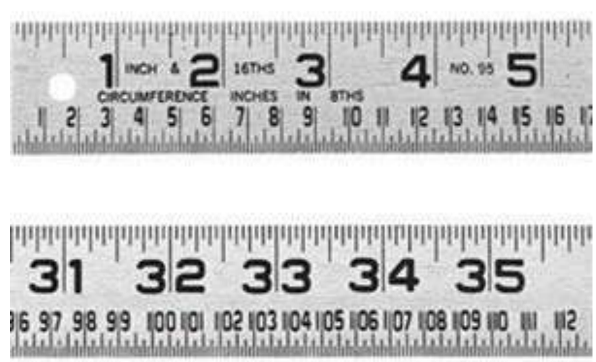


Figure 13-14 — Circumference ruler.

1.2.0 Cutting Tools

Various types of hand snips and hand shears are used for cutting and notching sheet metal. All of the snips, shears, and nibblers are either manual or power operated. Hand snips are necessary because the shape, construction, location, and position of the work to be cut frequently prevent the use of machine-cutting tools.

Hand snips are divided into two groups. Those for straight cuts are straight snips, combination snips, bulldog snips, and compound lever shears. Those for circular cuts are circle, hawk's bill, aviation, and Trojan snips. These snips are shown in *Figure 13-15*. The following is a brief description of each type of snip.

Straight snips (*Figure 13-15*) have straight jaws for straight-line cutting. To ensure strength, they are not pointed. These snips are made in various sizes and the jaws may vary from 2 to 4 1/2 inches. The overall length will also vary from 7 to 15 3/4 inches. The different size snips are made to cut different thicknesses of metal with 18-gauge steel as a minimum for the larger snips. These snips are available for right- or left-hand use.

Combination snips (*Figure 13-15*) have straight jaws for straight cutting, but the inner faces of the jaws are sloped for cutting curves as well as irregular shapes. These snips are available in the same sizes and capacities as straight snips.

Bulldog snips (*Figure 13-15*) are a combination type. They have short .cutting blades with long handles for leverage. The blades are inlaid with special alloy steel for cutting stainless steel. Bulldog snips can cut 16-gauge mild steel. The blades are 2 1/2 inches long and the overall length of the snip varies from 14 to 17 inches.

Compound lever shears (*Figure 13-15*) have levers designed to give additional leverage to ease the cutting of heavy material. The lower blade is bent to allow the shears to be inserted in a hole in the bench or bench plate. This will hold the shear in an upright position and make the cutting easier. The cutting blades are removable and can be replaced. The capacity is 12-gauge mild steel. It has cutting blades that are 4 inches long, with an overall length of 34 1/2 inches.

Circle snips (*Figure 13-15*) have curved blades and are used for making circular cuts, as the name implies. They come in the same sizes and capacities as straight snips and either right- or left-hand types are available.

Hawk's bill snips (*Figure 13-15*) are used to cut a small radius inside and outside a circle. The narrow, curved blades are beveled to allow sharp turns without buckling the sheet metal. These snips are useful for cutting holes in pipe, in furnace hoods, and in close quarters work. These snips are available with a 2 1/2-inch cutting edge, have an overall length of either 11 1/2 or 13 inches, and a 20-gauge mild steel capacity.

Aviation snips (*Figure 13-15*) have compound levers, enabling them to cut with less effort. These snips have hardened blades that enable them to cut hard material. They are also useful for cutting circles, squares, compound curves, and intricate designs in sheet metal. Aviation snips come in three types: right hand, left hand, and straight. On right-hand snips, the blade is on the left and they cut to the left. Left-hand snips are the opposite. They are usually color-coded in keeping with industry standards-green cuts right, red cuts left, yellow cuts straight. Both snips can be used with the right hand. The snips are 10 inches long, have a 2-inch cut, and have a 16-gauge mild steel capacity.

Trojan snips (*Figure 13-15*) are slim-bladed snips that are used for straight or curved cutting. The blades are small enough to allow sharp turning cuts without buckling the metal. These snips can be used to cut outside curves and can also be used in place of circle snips, hawk's bill snips, or aviation snips when cutting inside curves. The blades are forged high-grade steel. These snips come in two sizes: one has a 2 1/2-inch cutting length and a 12-inch overall length and the other has a 3-inch cutting length and a 13-inch overall length. They both have a 20-gauge capacity.

Pipe & Duct snips (Double Cut) (*Figure 13-15*) have a straight cut blade pattern. This style of aviation snip cuts a narrow section equal to the width of the center blade as it cuts. The material on either side of the cut tends to stay flat, as only the narrow section takes a curl as it is cut. This style can be used in stovepipe and downspout work where distortion on either side of the cut is not desirable.

Nibbler (*Figure 13-15*) is for cutting sheet metal with minimal distortion. One type operates much like a punch and die, with a blade that moves in a linear fashion against a fixed die, removing small bits of metal and leaving a kerf approximately 6 mm wide. Another type operates similar to tin snips, but shears the sheet along two parallel tracks 3–6 mm apart, rolling up the waste in a tight spiral as it cuts. Nibblers may be manual (hand operated) or powered.

Figure 13-15 — Cutting tools.

Proper Use and Care of Metal Cutting Snips

It is advisable not to cut exactly on the layout line (to avoid extra finishing work). It is good practice to leave about 1/32-inch of metal beyond the layout line for final dressing and finishing.

As the cut is being made, try not to make the cut the full length of the blades if points of the blades severely overlap. If the points of the blades severely overlap and a cut is made through the points, the material being cut will have a tendency to tear sideways as the cut is completed. If points severely overlap, stop the cut about 1/4-inch before reaching the points of the blades and then take a fresh bite.

When trimming a large sheet of metal, it is best to cut at the left side of the sheet if you are right handed and at the right side of the sheet if you are left handed. This way the waste will be curling up and out of the way while the rest of the sheet will remain flat.

When making a straight cut, place the work over the workbench so that the layout line is slightly beyond the edge of the bench. Hold the snips so that the blades are at a right angle to the material being cut (*Figure 13-16*). The edges of the material will bend or burr if the blades are not at right angles to the work.

Figure 13-16 — Proper cutting technique.

To cut a large circle or disc from sheet metal or other sheet materials, start from the outside of the material and make a cut parallel to the layout line to allow for dressing and finishing. This way you will always be able to see the layout line and still have material left over for final dressing and finishing (*Figure 13-17*).

To cut a large circle or hole in sheet metal or other sheet materials, start by drilling or punching a small entry hole in the center of the circle and proceed to make a spiral cut leading out to the desired circumference. Keep cutting away until all unwanted material is removed (*Figure 13-18*).

Figure 13-17 — Making a circular cut.

Figure 13-18 — Making an internal circular cut.

Keep the blade pivot bolt and nut properly adjusted at all times.

Occasionally oil the pivot bolt.

Before stowing the snips, wipe the cutting edges with a lightly oiled cloth.

The combination ironworker is likely the most valuable and versatile machine in a shop. The combination punch, shear, and **coper** (*Figure 13-19*) is capable of cutting angles, plates, and steel bars, and it can also punch holes. The size of the angles and plates handled by the machine depends upon its capacity. It is made in various sizes and capacities, and each machine has a capacity plate either welded or riveted on it. Strictly adhere to the capacity on the plate. The pressure and power the machine develops demand extreme caution on the part of the operator.

Portable power shears make it possible to do production work. They are designed to make straight or circular cuts (*Figure 13-20*).

Figure 13-19 — Combination iron worker.

Figure 13-20 — Portable power shears.

A solid punch (*Figure 13-21*) or a hollow punch (*Figure 13-22*) makes small diameter openings. Locate the position of the hole, select the correct size punch and hammer, then place the metal section on a lead cake or on the end grain of a block of hard wood (*Figure 13-23*). Strike the punch firmly with the hammer. Turn the punched section over so the burred section is up, and then smooth it with a mallet.

Figure 13-21 — Solid punch.

Figure 13-22 — Hollow punch.

Figure 13-23 — Correct method of backing sheet metal for making a hole with a punch.

Squaring shears are used for cutting and squaring sheet metal. See *Figure 13-24*. They may be foot operated or power operated. Squaring shears consist of a stationary blade attached to a bed and a movable blade attached to a crosshead. To make a cut, place the work in the desired position on the bed of the machine. Then use a downward stroke to move the blade. Foot-powered squaring shears are equipped with a spring that raises the blade when foot pressure is removed from the treadle. A scale graduated in fractions of an inch is scribed on the bed. Two side guides, consisting of thick steel bars, are fixed to the bed, one on the left and one on the right. Each is placed so that its inboard edge creates a right angle with the cutting edge of the bed. These bars are used to align the metal when square corners are desired. When cuts other than right angles are to be made across the width of a piece of metal, the beginning and ending points of the cut must be determined and marked in advance. Then the work is carefully placed into position on the bed with the beginning and ending marks on the cutting edge of the bed.

Figure 13-24 — Squaring shears.

A hold-down mechanism is built into the front of the movable cutting edge in the crosshead. Its purpose is to clamp the work firmly in place while the cut is being made. This action is quick and easily accomplished. The handle is rotated toward the operator and the hold-down lowers into place. A firm downward pressure on the handle at this time should rotate the mechanism over center on its eccentric cam and lock the hold-down in place. You should reverse the action to release the work.

Three distinctly different operations—cutting to a line, squaring, and multiple cutting to a specific size—may be accomplished on the squaring shears. When you are cutting to a line, place the beginning and ending marks on the cutting edge and make the cut. Squaring requires a sequence of several steps. First, square one end of the sheet with one side. Then square the remaining edges, holding one squared end of the sheet against the side guide and making the cut, one edge at a time, until all edges have been squared.

When several pieces are to be cut to the same dimensions, use the adjustable stop gauge. This stop is located behind the bed-cutting edges of the blade and bed. The supporting rods for the stop gauge are graduated in inches and fractions of an inch. The gauge bar is rigged so that it may be set at any point on the rods. With the gauge set at the desired distance from the cutting blade, push each piece to be cut against the stop. This procedure will allow you to cut all pieces to the same dimensions without measuring and marking each one separately.

Do not attempt to cut metal heavier than the designed capacity of the shears. The maximum capacity of the machine is stamped on the manufacturer's specification plate on the front of the shears. Check the gauge of the metal against this size with a sheet metal gauge (*Figure 13-25*). This figure shows the gauge used to measure the thickness of metal sheets. The gauge is a disc-shaped piece of metal, having slots of widths that correspond to the U.S. gauge numbers from 0 to 36. Each gauge number is marked on the front and the corresponding decimal equivalent is marked on the back.

Ring and circular shears (*Figure 13-26*) are intended for cutting inside and outside circles in sheet metal. The clamping is positioned for the desired diameter and the blank is inserted. Lower the cutting disc and make the cut.

Figure 13-25 — Sheet metal gauge.

Figure 13-26 — Ring and circular shears.

1.3.0 Sheet Metal Bending and Forming Equipment

Sheet metal is given three-dimensional shape and rigidity by bending. Sheet metal can be formed by hand or with various special tools and machines. Several techniques are described in the following sections.

1.3.1 Stakes

Metal stakes allow the sheet metal artisan to make an assortment of bends by hand. Stakes come in a variety of shapes and sizes. The work is done on the heads or the horns of the stakes. They are machined, polished, and, in some cases, hardened Stakes are used for finishing many types of work; therefore, they should NOT be used to back up work when using a chisel. The following is an assortment of the most common stakes that are used within the NCF and Public Works Departments (*Figure 13-27*):

Square stakes (*Figure 13-27*) have square-shaped heads and are used for general work Three types are used: the coppersmith square stake with one end rounded, the bevel edge square stake that is offset, and the common square stake. Some of the edges are beveled, which allows them to be used for a greater variety of jobs.

The conductor stake (*Figure 13-27*) has cylindrical horns of different diameters and is used when forming, seaming, and riveting pieces and parts of pipes.

The hollow mandrel stake (*Figure 13-27*) has a slot in which a bolt slides, allowing it to be clamped firmly to a bench. Either the rounded or the flat end can be used for forming, seaming, or riveting. There are two sizes available with an overall length of either 40 or 60 inches.

The blow horn stake (*Figure 13-27*) has two horns of different tapers. The apron end is used for shaping blunt tapers and the slender-tapered end is used for slightly tapered jobs.

The beakhorn stake (*Figure 13-27*) is a general-purpose stake. The stake has a round-tapered horn on one end and a square-tapered horn on the other end. This stake is used for riveting and shaping round or square work.

The double seaming stake with four interchangeable heads (*Figure 13-27*) has two shanks and either one can be installed in a bench plate, allowing the stakes to be used vertically or horizontally. This stake is used for double seaming large work of all types and for riveting.

The hand dolly (*Figure 13-27*) is a portable anvil with a handle that is used for backing up rivet heads, double seams, and straightening.

Figure 13-27 — Metal stakes.

1.3.2 Other Forming Tools

Stakes are designed to fit in a bench plate (*Figure 13-28*). The bench plate is a cast-iron plate that is affixed to a bench. It has tapered holes of different sizes that support the various stakes that can be used with the plate. Additionally, there is another type of bench plate that consists of a revolving plate with different size holes that can be clamped in any desired position.

The setting hammer (*Figure 13-29*) has a square, flat face and the peen end is single-tapered. The peen is for setting down an edge. The face is used to flatten seams. Setting hammers vary in size from 4 ounces to 20 ounces, and the gauge of the metal and the accessibility of the work determine their use.

Figure 13-28 — Bench and bench plate.

Figure 13-29 — Setting hammer.

A wood mallet (*Figure 13-30*) provides the necessary force for forming sheet metal without marring the surface of the metal.

Figure 13-30 — Wood mallet.

Narrow sections can be formed with the hand seamer (*Figure 13-31*). Its primary use is for turning a flange, for bending an edge, or for folding a seam. The width of the flange can be set with the knurled knobs on the top of the jaw.

Many forming and bending machines have been designed to perform precise sheet metal bending operations. They include the bar folder, several types of brakes, roll forming machines, and combination rotary machines. These machines are described next.

Figure 13-31 — Hand seamer.

1.3.2.1 Bar Folder

The bar folder (*Figure 13-32*) is designed to bend sheet metal, generally 22 gauge or lighter. Bar folders are used for bending edges of sheets at various angles, for making channel shape (doubleright-angle folds), and for fabricating lock seams and wired edges. Narrow channel shapes can be formed but reverse bends cannot be bent at close distances. The width of the folder edge is determined by the setting of the depth gauge (*Figure 13-33*).

Figure 13-32 — Bar folder.

Figure 13-33 — Depth gauge.

The sharpness of the folded edge, whether it is to be sharp for a hem or seam or rounded to make a wire edge, is determined by the position of the wing (*Figure 13-34*). Right angles (90°) and 45-degree bends can be made by using the 90-degree and 45-degree angle stop.

Figure 13-34 — Wing setting determines the tightness of the fold.

Hemmed edges are made in the following manner (*Figure 13-35*):

1. Adjust the depth gauge for the required size, and position the wing for the desired fold sharpness.
2. Set the metal in place, setting it lightly against the gauge fingers.
3. With the left hand holding the metal, pull the handle as far forward as it will go. Return the handle to its original position.
4. Place the folded section on the beveled section of the blade, as close to the wing as possible. Flatten the fold by pulling the handle forward rapidly.

Figure 13-35 — Making a hemmed edge.

1.3.2.2 Brakes

Large sheet metal sections are formed by using bending brakes. These machines produce more uniform bends than can be made by hand and require significantly less effort. The two most commonly used brakes are the cornice brake and the finger brake.

A cornice brake is shown in *Figure 13-36*. Two adjustments have to be made before using the machine.

First, adjust the upper jaw or clamping bar vertically for the gauge of sheet metal to be bent. The clamping device holds the work solidly in position, provided it is correctly adjusted. For example, if the clamping device is set for 18-gauge sheet metal and you bend 24-gauge sheet metal at that setting, the sheet will slip and the bend will be formed in the wrong position. When you try to bend 18-gauge sheet metal and the machine is set for 24-gauge sheet metal, you can break the clamping bar handle by using too much force. With a little practice you will be able to apply the pressure correctly.

Figure 13-36 — Cornice brake

After you have made the vertical adjustments, you need to adjust the upper jaw horizontally to the correct position for the thickness of the metal and for the radius of the bend to be made.

CAUTION

If the upper jaw is adjusted to the exact thickness of the metal, the bend will be sharp or it will have practically no bend radius. If it is set for more than the thickness of the metal, the bend will have a larger radius; if the jaw is set for less than the thickness of the metal, the jaws of the machine may be sprung out of alignment and the edges of the jaws may be damaged.

After these two adjustments have been made, the machine is operated as follows:

1. Scribe a line on the surface of the sheet metal to show where the bend will be.
2. Raise the upper jaw with the clamping handle and insert the sheet in the brake, bringing the scribed line into position even with the front edge of the upper jaw.
3. Clamp the sheet in position. Ensure that the scribed line is even with the front edge of the upper jaw. The locking motion will occasionally shift the workpiece.
4. Once you are satisfied that the metal is clamped correctly, the next step is to lift the bending leaf to the required angle to form the bend. If you are bending soft and/or ductile metal, such as copper, the bend will be formed to the exact angle you raised the bending leaf. If you are bending metal that has any spring to it, you will have to raise the bending leaf a few degrees more to compensate for the spring in the metal. The exact amount of spring that you will have to allow for depends on the type of metal you are working with.
5. Release the clamping handle and remove the sheet from the brake.

The brake is equipped with a stop gauge, consisting of a rod, a yoke, and a setscrew. You use this to stop the bending leaf at a required angle. This feature is useful when you have to fabricate a large number of pieces with the same angle. After you have made your first bend to the required angle, set the stop gauge so that the bending leaf will not go beyond the required angle. You can now fabricate as many bends as you need.

The cornice brake is extremely useful for making single hems, double hems, lock seams, and various other shapes.

It is impossible to bend all four sides of a box on a conventional brake. The finger brake sometimes referred to as a “box and pan brake” (*Figure 13-37*), has been designed to handle this exact situation. The upper jaw is made up of a number of blocks, referred to as “fingers.” They are various widths and can easily be positioned or removed to allow all four sides of a box to be bent. Other than this feature, it is operated in the same manner as a cornice brake.

Figure 13-37 — Finger brake.

1.3.2.3 Roll Forming Machine

When forming cylinders and conical shapes, no sharp bends are required; instead, a gradual curve is formed in the metal until the ends meet. Roll forming machines were developed to accomplish this task. The simplest method of forming these shapes is on the slip roll-forming machine (*Figure 13-38*). Three rolls do the forming (*Figure 13-39*). The two front rolls are the feed rolls and can be adjusted to accommodate various thicknesses of metal. The rear roll, also adjustable, gives the section the desired curve. The top roll pivots up to permit the cylinder to be removed without danger of distortion. Grooves are machined in the two bottom rolls for accommodating a wired edge when forming a section with this type edge or for rolling wire into a ring.

Figure 13-38 — Slip roll machine.

Figure 13-39 — Forming cylinder.

Figure 13-40 — Combination rotary machine.

1.3.2.4 Combination Rotary Machine

Preparing sheet metal for a wired edge, turning a burr, beading, and crimping are probably the most difficult of sheet metal forming operations to perform. When production dictates, large shops will have a machine for each operation. However, a Combination rotary machine (*Figure 13-40*) with a selection of rolls will prove acceptable for most shop uses.

The wire edge must be applied to tapered shapes after they are formed. This is accomplished by turning the edge on the rotary machine. Gradually, lower the upper roll until the groove is large enough for the wire. The edge is pressed around the wire with the rotary machine (*Figure 13-41*).

Figure 13-41 — Turning a wire edge with a rotary machine.

The wire edge can be finished by hand if a rotary machine is not available. The edge is formed on the bar folder and forced into place around the wire with a setting hammer or pliers (*Figure 13-42*).

Figure 13-42 — Setting an edge.

A burr, in sheet metal language, is a narrow flange turned on the circular section at the end of a cylinder (*Figure 13-43*). Before you cut the section, remember that additional material must be added to the basic dimensions of the object for the burr. *Figure 13-44* shows how to calculate the additional material.

Figure 13-43 — Burrs on a cylindrical section.

Figure 13-44 — Calculating a double seam.

After the rotary machine has been adjusted to turn the proper size burr, the work is placed in position and the upper roll lowered. Make one complete revolution of the piece, scoring the edge lightly. Lower the upper roll a bit more, creating more pressure, and make another turn. Continue this operation, raising the disc slightly after each turn until the burr is turned to the required angle (*Figure 13-45*).

Figure 13-45 — Turning a burred edge.

Figure 13-46 — Fitting burred sections together.

This procedure is also used to turn the burr on the bottom of the cylinder for a double seam (*Figure 13-46*). The two pieces are snapped together, the burr set down, and the seam completed (*Figure 13-47*).

Figure 13-47 — Making a double seam on a cylindrical section.

NOTE

Because turning a burr is a difficult operation, you should turn several practice pieces to develop your skill before turning the burr on the actual piece to be used.

Beading (*Figure 13-48*) is used to give added stiffness to cylindrical sheet metal objects for decorative purposes, or both. It can be a simple bead or an ogee (S-shaped) bead. They are made on the rotary machine using beading rolls.

Crimping (*Figure 13-49*) reduces the diameter of a cylindrical shape, allowing it to be slipped into the next section. This eliminates the need for making each cylinder with a slight taper.

Figure 13-48 — Turning a bead.

Figure 13-49 — Crimped pipe edge.

Test your Knowledge (Select the Correct Response)

1. To obtain the best results from scribing, what step should you perform first?

   A. Insure the work area is quiet
   B. Scribe the lines with firm pressure
   C. Lay a thin layer of layout dye
   D. Make your prick punch points

2. What snips have short cutting blades with long handles?

   A. Bulldog
   B. Hawk's bill
   C. Compound
   D. Aviation

2.0.0 SHEET METAL DEVELOPMENT

Sometimes you will need to layout a one-off project. In this instance, scribe the design directly on the sheet metal. This process is also known as scratching.

When a single part is to be produced in quantity, a different development procedure is used. Instead of laying out directly on the metal, you will develop a pattern, or template, of the piece to be fabricated and then transfer the development to the metal sheet. The template development process is what we are mainly concerned with in this section.

The three procedures commonly used in developing sheet metal patterns are parallel line, radial line, and triangular development. We will also discuss the fabrication of edges, joints, seams, and notches.

2.1.1 Parallel Line Development

Parallel line development is based upon the fact that a line that is parallel to another line is an equal distance from that line at all points. Objects that have opposite lines parallel to each other or that have the same cross-sectional shape throughout their length are developed by this method.

To gain a clear understanding of the parallel line method, we will develop a layout of a truncated cylinder (*Figure 13-50*). Such a piece can be used as one half of a two-piece 0-degree elbow.

Figure 13-50 — Truncated cylinder.

A truncated cylinder is developed in *Figure 13-51*:

Figure 13-51 — Parallel line development.

1. Mark out reference lines using a set square.
2. Identify the diameter measurement and draw a circle. In this example the diameter is 1.5 inches (40 mm).
3. Use the radius of the circle to divide the circumference into 12 equal sectors.
4. Label the marks 1 - 12. Note the numbers begin on the right-hand side and go in a clockwise direction.
5. Identify and mark the height of the cylinder. Here the height is 2.5 inches (60 mm).
6. Determine the angle of the top of the cylinder and use a setsquare. Here the angle is 45 degrees.
7. Mark off the radius on both sides of the reference line to construct the sides of the cylinder. Transfer numbers 1 - 12 from the circle to the base of the cylinder. Project these points to the top of the cylinder.
8. Calculate the circumference of the cylinder to determine the stretch out length of the pattern. Use the formula $r = \pi D$. The diameter here is 1.5 inches (40 mm). Mark out the circumference on the horizontal base line.
9. Divide the length of the circumference into 12. Draw a reference line and mark on it 1/12th of the circumference. Use this to set the dividers. Splitting the circumference into halves and quarters reduces tolerance error.
10. Use the dividers to mark the circumference into 12 equal divisions on the base line. Mark these divisions 1 to 12. The final division is numbered 1. Project these divisions upward at 90°.

11. Now develop the stretch out pattern. Transfer the length of the lines on the side View to the corresponding lines on the stretch out. Draw the top line curve of the pattern by free hand, by using material like packing cord bent to the curve or by using a flexible curve, as used here.
12. This final shape is the stretch out pattern of the cylindrical shape and can be cut to shape to use as a template.

When the development is finished, add necessary allowances for rivets and joints, then cut out your patterns.

2.2.0 Radial Line Development

The radial line method of pattern development is used to develop patterns of objects that have a tapering form with lines converging at a common center.

The radial line method is similar in some respects to the parallel line method. Evenly spaced reference lines are necessary in both of these methods. However, in parallel line development, the reference lines are parallel—like a picket fence. In radial line development, the reference lines radiate from the **apex** of a cone—like the spokes of a wheel.

The reference lines in parallel line development project horizontally. In radial line development, the reference lines are transferred from the front View to the development with the dividers.

Developing a pattern for the **frustum** of a right cone is a typical practice project that will help you get the feel of the radial line method. You are familiar with the shape of a cone. A right cone is one that, if set big side down on a flat surface, would stand straight up. In other words, a centerline drawn from the point, or vertex, to the base line would form right angles with that line. The frustum of a cone is that part that remains after the point, or top, has been removed.

The procedure for developing a frustum of a right cone is given below. Check each step of the procedure against the development shown in *Figure 13-52.*

Figure 13-52 — Radial line development.

1. First establish the apex point (H).
2. Draw reference lines using a set square. Mark out the measurements of the:
   - base (D) – 2.75 in (70 mm)
   - apex (H) – 4 in (100 mm)
   - frustum height (h) – 2 in (50 mm)
3. Draw in the reference lines from the apex (H) to the base (D). Check that the frustum diameter (d) is 1.38 in (35 mm).
4. Develop the half circle representing half the bottom View.
5. Set the dividers at 1.38 in (35 mm) - the radius of the base of the frustum (D). Divide the half circle into 6 equal sectors.
6. Label the marks 1-12 as indicated.
7. Project each of the sectors up to the base line at 90°. Project these lines to the apex.
8. Developing the stretch out pattern of the frustum.
   Place the compass point on the apex. Set the radius to A and seeing an arc as indicated. Repeat with the radius set to B.
9. Draw a line from the apex to the bottom circumference, away from the base of the frustum. The intersection point will be the start for marking out the base circumference into 12 sectors.
10. The frustum circumference is πD = 3.14 x 2.75 in =8.67 inches (220 mm) to the nearest mm. Mark this into 12 equal sectors. Calculate the length of each sector:
    $= \frac{8.67\text{in } (220 \text{ mm})}{12}$
    = .72 in (18.3 mm)
    Draw a reference line and mark out .72 in (18.3 mm). Set the dividers to this distance. Mark off the 12 divisions along the circumference.
11. Project each of these to the apex to form the radial lines. The radial lines will be used in the forming process. The shape shaded in orange is the radial line stretch out pattern for the right cone frustum.

2.3.1 Triangular Development

Triangulation is slower and more difficult than parallel line or radial line development, but it is more practical for many types of figures. Additionally, it is the only method by which the development of warped surfaces may be estimated. In development by triangulation, the piece is divided into a series of triangles, as in radial Line development. However, there is no one single apex for the triangles. The problem becomes one of finding the true lengths of the varying oblique lines. This is usually done by drawing a true, length diagram.

An example of layout using triangulation is the development of a transition piece.

The steps in the triangulation of a warped transition piece joining a large, square duct and a small, round duct are shown in *Figure 13-53*. The steps are as follows:

Figure 13-53 — Triangular development of a transition piece.

1. First establish the reference lines.
2. Develop the top View. With a set square, mark out the measurements for half the base, and label each corner (from the top left-hand corner, moving clockwise) A to D.
3. From the centre of this half base, draw a semicircle with radius 1 in (25 mm). Check that the diameter (D) is 2 in (50 mm).
4. Divide the half circle into six equal spacing by placing the compass point on the three points where the semicircle intersects the reference lines and swinging small arcs (R = 1 in (25 mm)) to intersect the circle.
   Number the points 1 to 7 as shown.
5. Using a set square, draw lines from point D on the base of the shape to points 1 through to 4 on the half circle. Next, draw lines from C on the base of the shape to points 4 through to 7.

   This completes (half) the top View.
6. Draw the side View. First, draw a reference line. Remember, the vertical height is 50 mm, and the diameter of the top is 50 mm.
7. The base is 2.75 in (70 mm) square. Draw lines from the base to the top. Label the base points A and B. Label the top points 1 and 7.

8. Now develop the stretch out pattern for the square to round.
   First establish a reference line (extending to the right from point B on the side View) for the base of the stretch out pattern. Draw the vertical height of the square to round somewhere to the right of the side View, perpendicular to the base line.
   Now place the compass point on D in the top View. Set the radius to point 2 on the half circle. Place the compass point at the intersection of the base line and the vertical height line and swing an arc to mark the base line. Label this point 2D. Note this is the shortest distance from point D to the top of the half circle, the same length as 3D, 5C, and 6C.
   Now place the compass at D and set the radius to point 1 on the half circle. Transfer the compass to the intersection of the base line and the vertical height line and swing an arc to mark the base line. Label it 1D. Note this is the longer distance from point D to the top of the half diameter, the same length as 4D, 4C, and 7C.
   Now draw a line from the top of the vertical height line to point 2D, and then from the top to point 1D.
   This is called the true length diagram.
9. Mark a point on the base line to the right of point 1D.
10. Set the compass at the distance between D and C on the top View (as this is already true length), then transfer the distance D to C to the base line. Label the points D and C.
    Reset the compass to the length of the line 4D. Placing one point on D, draw an arc midway between D and C. Shift the compass to C, draw an arc to bisect the previous one. Label this point 4.
11. Mark out a new short reference line for 1/12th of the circumference of the top of the square to round shape.
    Calculate the circumference of the top of the shape, then divide it by 12.
    $C = \pi D$
    C = 3.14 x 2 in (50 mm)
    = 6.2 in (157 mm)
    1/12th of the circle
    = 6.2 in (157 mm) ÷ 12
    = .5 in (13 mm)
12. Measure and mark out .5 in (13 mm) on the reference line. Set the compass at .5 in (13 mm) (1/12th circumference).
    Place the compass on point 4, and swing arcs to mark to the right, and to the left. Set the compass at the true length of reference line 2D. Place the compass on point D, and swing an arc to intersect the arc on the left.
    Label this point 3. Place the compass on C, and swing an arc to intersect the arc on the right. Label this point 5.
    Reset the compass at .5 in (13 mm), using the measure on the reference line. Place the compass on point 5 and swing an arc to the right hand side. Swing an arc to the left of point 3.
    Reset the compass at the length of the reference line 2D. Place the compass on point D, make a mark intersecting the arc, and Label this point 2. Place the compass on C, make a mark intersecting the arc, and label this point 6.
    Repeat the process, swinging an arc R13 to the left of 2 and right of 6. This time, however, reset the compass to the length of reference line 1D. Place the compass point on D, make a mark intersecting the arc, and label this point 1. Place the compass on C and make a mark intersecting the arc. Label this point 7.

13. Develop the half square base from point D to point A.
    Using the side view diagram, set the compass at the distance between B and 7. Place the compass at point 1 on the stretch out pattern, and draw an arc to the lower left. Repeat the process from point 7 to the lower right.
    Reset the compass to the distance between B and C on the top View diagram. Place the compass on D and make a mark intersecting the arc.
    Label this point A. Place the compass on C, make a mark intersecting the arc, and label this point B.
    Using a set square or ruler, draw lines joining 1 and A; A and D; 7 and B; and B and C. Draw lines from D to 1, 2, 3, and 4. Draw lines from C to 4, 5, 6, and 7.
14. Use a flexible ruler, or freehand to join points 1 to 7.
    This completes the stretch out half pattern for a square to round shape, using the triangulation method.

2.4.0 Fabrication of Edges, Joints, Seams, and Notches

There are numerous types of edges, joints, seams, and notches used to join sheet metal work. We will discuss those that are most often used.

2.4.1 Edges

Edges are formed to enhance the appearance of the work, to strengthen the piece, and to eliminate the cutting hazard of the raw edge. The kind of edge that you use on any job will be determined by the purpose, by the sire, and by the strength of the edge needed.

The single hem edge is shown in *Figure 13-54*. This edge can be made in any width. In general, the heavier the metal, the wider the hem is made. The allowance for the hem is equal to its width (W).

The double hem edge (*Figure 13-55*) is used when added strength is needed and when a smooth edge is required inside as well as outside. The allowance for the double-hem edge is twice the width of the hem.

Figure 13-54 — Single hem edge.

Figure 13-55 — Double hem edge.

A wire edge (*Figure 13-56*) is often specified in the plans. Objects such as funnels, water troughs, and garbage pails are fabricated with wire edges to strengthen and

Figure 13-56 — Development of a wire edge on a cylinder.

stiffen the jobs and to eliminate sharp edges. The allowance for a wire edge is 2 1/2 times the diameter of the wire used. As an example, you are using wire that has a diameter of 1/8 inch. Multiply 1/8 by 2 1/2 and your answer will be 5/16 inch, which you will allow when laying out sheet metal for making the wire edge.

2.4.2 Joints

The grooved seamed joint (*Figure 13-57*) is one of the most widely used methods for joining light- and medium-gauge sheet metal. It consists of two folded edges that are locked together with a hand groover (*Figure 13-58*).

When making a grooved seam on a cylinder, you fit the piece over a stake and lock it with the hand groover (*Figure 13-59*). The hand groover should be approximately 1/16 inch wider than the seam. Lock the seam by making prick punch indentions about 1/2 inch in from each end of the seam.

Figure 13-57 — Development of a grooved seam joint.

Figure 13-58 — Hand groover.

Figure 13-59 —Locking a grooved seam.

The cap strip seam (*Figure 13-60*, *View A*) is often used to assemble air-conditioning and heating ducts. A variation of the joint, the locked corner seam (*Figure 13-60*, *View B*), is widely accepted for the assembly of rectangular shapes.

Figure 13-60 — (A) cap strip seam, (B) locked corner seam.

A drive slip joint is a method of joining two flat sections of metal. *Figure 13-61* is the pattern for the drive slip. End notching and dimensions vary with application and area practice on all locks, seams, and edges.

“S” joints are used to join two flat surfaces of metal. Primarily these are used to join sections of rectangular duct. These are also used to join panels in air housings and columns.

Figure 13-61 — Driveslip pattern connections.

Figure 13-62 — "S" joint slip pattern and connections.

Figure 13-62 shows a flat "S" joint. View A is a pattern for the "S" cleat. View B is a perspective View of the two pieces of metal that form the flat "S" joint. In View C, note the end View of the finished "S" joint.

Figure 13-63 shows a double "S" joint. View B is the pattern for the double "S" cleat. View A is one of two pieces of metal to be joined. Note the cross section of a partially formed cleat and also the cross section of the finished double "S" joint. This is a variation of the simple flat "S" and it does not require an overlap of metals being joined.

Figure 13-63 — Double "S" joint slip pattern.

Figure 13-64 shows a standing “S” joint. View B is the pattern for the standing “S” cleat. View A is one of the two pieces of metal to be joined. Note the cross section of the finished standing “S” cleat and standing “S” joint.

Figure 13-64 — Standing “S” cleat pattern.

2.4.3 Seams

Many kinds of seams are used to join sheet metal sections. Several of the commonly used seams are shown in *Figure 13-65*. When developing the pattern, ensure you add adequate material to the basic dimensions to make the seams. The folds can be made by hand; however, they are made much more easily on a bar folder or brake. The joints can be finished by soldering and/or riveting.

When developing sheet metal patterns, ensure you add sufficient material to the base dimensions to make the seams. Several types of seams used to join sheet metal sections are discussed in this section.

Figure 13-65 — Common sheet-metal seams.

There are three types of lap seams: the plain lap seam, the offset lap seam, and the corner lap seam (*Figure 13-66*). Lap seams can be joined by drilling and riveting, by soldering, or by both riveting and soldering. To figure the allowance for a lap seam, you must first know the diameter of the rivet that you plan to use. The center of the rivet must be set in from the edge a distance of 2 1/2 times its diameter; therefore, the allowance must be five times the diameter of the rivet that you are using. *Figure 13-67* shows the procedure for laying out a plain lap and a comer lap for seaming with rivets (d represents the diameter of the rivets). For comer seams, allow an additional one sixteenth of an inch for clearance.

Figure 13-66 — Lap seams.

Figure 13-67 — Layout of lap seams for riveting.

Grooved seams are useful in the fabrication of cylindrical shapes. There are two types of grooved seams-the outside grooved seam and the inside grooved seam (*Figure 13-68*). The allowance for a grooved seam is three times the width (W) of the lock, one-half of this amount being added to each edge. For example, if you are to have a 1/4-inch grooved seam, 3 x 1/4 = 3/4 inch, or the total allowance; 1/2 of 3/4 inch = 3/8 inch, or the allowance that you are to add to each edge.

Figure 13-68 — Grooved seams.

The Pittsburgh lock seam is a comer lock seam. *Figure 13-69* shows a cross section of the two pieces of metal to be joined and a cross section of the finished seam. This seam is used as a lengthwise seam at comers of square and rectangular pipes and elbows as well as fittings and ducts. This seam can be made in a brake but it has proved to be so universal in use that special forming machines have been designed and are available. It appears to be quite complicated, but like lap and grooved seams, it consists of only two pieces. The two parts are the flanged, or single, edge and the pocket that forms the lock. The pocket is formed when the flanged edge is inserted into the pocket, and the extended edge is turned over the inserted edge to complete the lock.

Figure 13-69 — Pittsburgh lock seam.

The method of assembling and locking a Pittsburgh seam is shown in *Figure 13-70* and *Figure 13-71*.

Figure 13-70 — Assembly of a Pittsburgh lock seam.

Figure 13-71 — Closing a Pittsburgh lock seam.

The allowance for the pocket is W + W + 3/16 inch. W is the width or depth of the pocket. The width of the flanged edge must be less than W. For example, if you are laying out a 1/4-inch Pittsburgh lock seam (*Figure 13-72*), your total allowance should be 1/4 + 1/4 + 3/16 inch, or 11/16 inch for the edge on which you are laying out the pocket and 3/16 inch on the flanged edge.

Standing seams are used for joining metals where extra stiffness is needed, such as roofs, air housing, ducts, and so forth. *Figure 13-73* is a cross section of the finished standing seam. Dimensions and rivet spacing will vary with application.

Figure 13-72 — layout of a 1/4 inch Pittsburgh lock seam.

Figure 13-73 — Cross section of a standing seam.

There are different styles of standing seams. The spreader drive cap, the pocket slip, and the government lock (*Figure 13-74*) are seams frequently used in large duct construction where stiffeners are required.

Figure 13-74 — Miscellaneous seams.

The dovetail seam is used mainly to join a round pipe/fitting to a flat sheet or duct. This seam can be made watertight by soldering. *Figure 13-75* shows the pattern for forming a dovetail seam and an example of its use.

Figure 13-75 — Dovetail lock seam.

2.4.4 Notches

Notching is the last step to be considered when you are getting ready to lay out a job. Before you can mark a notch, you will have to lay out the pattern and add the seams, the laps, or the stiffening edges. If the patterns are not properly notched, you will have trouble when you start forming, assembling, and finishing the job.

No definite rule for selecting a notch for a job can be given. But as soon as you can visualize the assembly of the job, you will be able to determine the shape and size of the notch required for the job. If the notch is made too large, a hole will be left in the finished job. If the notch is too small or not the proper shape, the metal will overlap and bulge at the seam or edge. Do not concern yourself too much if your first notches do not come out as you expected—practice and experience will dictate size and shape.

A square notch (*Figure 13-76*) is likely the first you will make. It is the kind you make in your layout of a box or drip pan and is used to eliminate surplus material. This type of notch will result in butt comers.

Slant notches are cut at a 45-degree angle across the comer when a single hem is to meet at a 90-degree angle. *Figure 13-77* shows the steps in forming a slant notch.

Figure 13-76 — Square notch.

Figure 13-77 — Slant notch.

A V notch is used for seaming ends of boxes. You will also use a full V-notch when you have to construct a bracket with a toed-in flange or for similar construction. The full V is shown in *Figure 13-78*.

When you are making an inside flange on an angle of less than 90 degrees, you will have to use a modification of the full V-notch to get flush joints. The angle of the notch will depend upon the bend angle. A modified V-notch is shown in *Figure 13-79*.

Figure 13-78 — V-notch.

Figure 13-79 — Modified V-notch.

A wire notch is a notch used with a wire edge. Its depth from the edge of the pattern will be one wire diameter more than the depth of the allowance for the wire edge (2 1/2 d), or in other words, 3 1/2 times the diameter of the wire (3 1/2 d). Its width is equal to 1 1/2 times the width of the seam (1 1/2 w). That portion of the notch next to the wire edge will be straight. The shape of the notch on the seam will depend on the type of seam used, which, in *Figure 13-80*, is 45 degrees for a grooved seam.

Most of your work will require more than one type of notch, as shown in *Figure 13-80*, where a wire notch was used in the forming of a cylindrical shape joined by a grooved seam. In such a layout, you will have to notch for the wire edge and seam.

Figure 13-80 — Wire notch in a cylindrical layout.

Test your Knowledge (Select the Correct Response)

3. When preparing a single hem edge, what is the allowance for its width?

   A. Equal to its width
   B. Twice its width
   C. 2 1/2 times its width
   D. 3 1/2 times its width

4. How many times larger than the diameter of the wire should be allowed when fabricating a wire edge?

   A. Equal to its width
   B. Twice its width
   C. 2 1/2 times its width
   D. 3 1/2 times its width

3.0.0 JOINING and INSTALLING SHEET METAL DUCT

After the sheet metal has been cut and formed, it has to be joined together. Most sheet metal seams are locked or riveted but some will be joined by torch brazing or soldering. Primarily the forming processes that have already been given make lock seams. Torch brazing and soldering are discussed in chapter 6. This section deals only with joining sheet metal seams by either metal screws or rivets.

3.1.0 Metal Screws

Different types of metal screws are available for sheet metal work. The most common type in use is the machine screw. Machine screws are normally made of brass or steel. They will have either a flathead or a roundhead and are identified by their number size, threads per inch, and length. For example, a 6 by 32 by 1 inch screw indicates a number 6 screw with 32 threads per inch and 1 inch in length.

Self-tapping sheet metal screws are another common type of screw. Most screws of this type will be galvanized and are identified by their number size and length. These screws form a thread as they are driven (*Figure 13-81*), as the name implies.

Thread cutting screws (*Figure 13-82*) are different from self-tapping screws in that they actually cut threads in the metal. They are hardened and are used to fasten nonferrous metals and join heavy gauge sheet metal.

Drive screws (*Figure 13-83*) are simply hammered into a drilled or punched hole of the proper size to make a permanent fastening.

Figure 13-81 — Self tapping

Figure 13-82 — Thread cutting.

Figure 13-83 — Drive screws.

3.2.1 Rivets

Rivets are available in many different materials, sizes, and types. Rivets, made of steel, copper, brass, and aluminum, are widely used. Rivets should be the same material as the sheet metal that they join. If you use dissimilar metals, corrosion will occur.

Tinners' rivets shown in *Figure 13-84* are used in sheet metal work more than any other type of rivet. Tinners' rivets vary in size, from the 8-ounce rivet to the 16-pound rivet. This size designation signifies the weight of 1,000 rivets. If 1,000 rivets weigh 8 ounces, each rivet is called an 8-ounce rivet. As the weight per 1,000 rivets increases, the diameter and length of the rivets also increase. For example, the 8-ounce rivet has a diameter of 0.089 inch and a length of 5/32 inch, while the 12-pound rivet has a diameter of 0.259 inch and a length of 1/2 inch. For special jobs that require fastening several layers of metal together, special rivets with extra-long shanks are used. *Table 13-1* is a guide for selecting rivets of the proper size for sheet metal work.

Figure 13-84 — TInners' rivets.

Table 13-1 — Guide for selecting rivet size for sheet metal work.

Gauge of Sheet Metal	Rivet Size (weight in pounds per 1,000 rivets)
26	1
24	2
22	2 1/2
20	3
18	3 1/2
16	4

When you are joining sheet metal that is greater than two thicknesses, remember that the shank of the rivet should extend 1 1/2 times the diameter of the rivet. This will give you adequate metal to form the head.

Rivet spacing is given on the blueprint or drawing you are working from. If the spacing is not given, space the rivets according to the service conditions the seam must withstand. For example, if the seam must be watertight, you will need more rivets per inch than is required for a seam that does not have to be watertight. No matter how far apart the rivets are, there must be a distance of 2 1/2 times the rivet diameter between the rivets and the edge of the sheet. This distance is measured from the center of the rivet holes to the edge of the sheet.

After you have determined the size and spacing of the rivets, mark the location of the centers of the rivet holes. Then make the holes by punching or by drilling. If the holes are located near the edge of the sheet, a hand punch, similar to the one shown in *Figure 13-85*, can be used to punch the holes. If the holes are farther away from the edge, you can use a deep-threaded punch (either hand operated or power driven) or you can drill the holes. The hole must be slightly larger than the diameter of the rivet to provide a slight clearance.

Figure 13-85 — Hand punch.

Riveting involves three operations: drawing, upsetting, and heading (*Figure 13-86*). A rivet set and a riveting hammer are used to perform these operations. The method for riveting sheet metal follows:

1. Select a rivet set that has a hole slightly larger than the diameter of the rivet.
2. Insert the rivets in the holes and rest the sheets to be joined on a stake or on a solid bench top with the rivet heads against the stake or bench top.
3. Draw the sheets together by placing the deep hole of the rivet set over the rivet and striking the head of the set with a riveting hammer. Use a light hammer for small rivets, a heavier hammer for larger rivets.
4. When the sheets have been properly drawn together, remove the rivet set. Strike the end of the rivet lightly with the riveting hammer to upset the end of the rivet. Do not strike too hard of a blow, as this can distort the metal around the rivet hole.
5. Place the heading die (dished part) of the rivet set over the upset end of the rivet and form the head. One or two hammer blows on the head of the rivet set will be enough to form the head on the rivet

Figure 13-86 — Drawing, upsetting, and heading a rivet.

A correctly drawn, upset, and headed rivet is shown in the top part of *Figure 13-87*. The lower part of this figure shows the results of incorrect riveting.

Figure 13-87 — Correct and incorrect riveting.

An addition to sheet metal rivets are the pop rivets shown in *Figure 2-88*. These pop rivets are high-strength, precision-made, hollow rivets assembled on a solid mandrel that forms an integral part of the rivet. They are especially useful for blind fastening, where there is limited or no access to the reverse side of the work.

Pop rivets provide simplicity and versatility. They are simple and easy to use in complicated installations. Expensive equipment or skilled operators are not required. Just drill a hole, insert, and set the pop rivet from the same side, and high riveting quality and strength are easily and quickly accomplished.

Figure 13-88 — Pop rivets.

Two basic designs of pop rivets are used: closed end and open end. The closed-end type fills the need for blind rivets that seal as they are set. They are gastight and liquid tight, and like the open-end type, they are installed and set from the same side. As the rivet sets, a high degree of radial expansion is generated in the rivet body, providing effective hole-filing qualities.

The open-end type of pop rivet resembles a hollow rivet from the outside. Because the mandrel head stays in the rivet body, the mandrel stem seals, but it is not liquid tight.

Figure 13-89 shows two of the tools used for setting the pop rivets. These tools are lightweight and very easily used. For example, when using the small hand tool, you need only to insert the mandrel of the rivet in the nosepiece, squeeze the handle (usually three times), and the rivet is set. To operate the scissors type tool, fully extend the lever linkage or gate-like mechanism and insert the rivet mandrel into the nosepiece of the tool. Insert the rivet into the piece being riveted. Apply firm pressure to the tool, ensuring that the nosepiece remains in close contact with the rivet head. Closing the lever linkage retracts the gripping mechanism, which withdraws the mandrel. The rivet is set when the mandrel head breaks.

Figure 13-89 — Pop rivet tools.

Before inserting another rivet in the tool, be sure that the broken mandrel has been ejected from the tool. This can be done by fully extending the lever linkage and allowing the mandrel to fall clear.

The scissors or expandable type of tool is unique because it can reach hard-to-get-at areas and can set the rivets with ease. This tool is particularly useful for installing ventilation ducting.

3.3.0 Riveted Seams

Riveted seams are used for joining metals and have numerous applications.

Figure 13-90 shows the pattern of one of two pieces to be joined by lap and rivet. Note the cross section of the finished seam.

Figure 13-91 shows the patterns for constructing a lapped and riveted comer seam. View A is the pattern for one piece and View B is the other. Note the cross section through the completed seam.

Frequent use is made of lapped and riveted seams in joining round pipe sections.

Figure 13-90 — Lap seam rivet pattern.

Figure 13-91 — Corner seam rivet.

4.0.0 SHEET METAL DUCT SYSTEMS

With the increased use of computers and other specialized electronic equipment, air-conditioning systems are incorporated more than ever into many Naval Construction Force (NCF) construction projects. Many of the structures are designed for long-life usage instead of temporary buildings with a short-time use. There are advanced base functional components (ABFC) that incorporate heating, ventilating, and air-conditioning systems (HVAC) within the facility design.

HVAC systems require close coordination between ratings. A Utilitiesman normally installs air conditioning, air handling, and heating units, and the electrical connections are accomplished by a Construction Electrician. These items must be installed before the ductwork installation phase begins. The Steelworker must also coordinate with the Builder assigned to the project to ensure that all openings in walls and floors are sufficient to accommodate ducts, diffusers, and vents.

Sheet metal HVAC systems require knowledgeable workers to fabricate and install the various ducts and fittings needed in a complete heating, ventilating, and air-conditioning system. The Steelworker must be very versatile because the most difficult part of sheet metal work is the installation of a product that has been built in a shop and is installed on a remote site.

Not all of the variables that occur during the installation process can be covered here; however, this section will cover some of the different hanging and connecting systems used by the sheet metal worker. The type of connecting system used depends upon where the duct system is installed, its size, how many obstructions there are, and what type of structure the system is hanging from or connected to.

4.1.0 Shop Procedures

The small sheet metal shops in the NCF or in a Public Works Department are normally tasked with single fabrication jobs for an NCF project or small repair projects. These shops usually employ a small number of Steelworkers as part of a multi-shop environment. The senior Steelworker assigned to a shop is tasked with the plan development and estimating of materials. The layout Steelworker makes up most of the fittings in the shop and is responsible for stockpiling patterns and tracings on standard fittings used for sheet metal duct systems.

NOTE

You should fabricate an entire job at the shop, rather than deliver an incomplete system to the jobsite.

4.2.0 Shop Drawings

A shop drawing is a plan View or an elevation View of a fitting, duct, or other object that is drawn either by the freehand sketch method or by using drafting instruments. It may be useful to get assistance from an Engineering Aid for complex duct systems or fittings. One of the better methods is to draw a complete set of standard fittings and then add the required dimensions to fit the job.

The dimensions shown on the Views of a shop drawing are finished dimensions. Once the finished dimensions have been determined, one-half inch must be added to each end to obtain the raw size of the pattern. This dimension produces a cut size dimension. The type of material, gauge number, and type of seam may be added to the shop drawing, if desired. Usually these are specified on the drawings and on the pattern sheets.

4.3.0 Duct Material

Metal sheets, wire, band iron, and angle iron are the most widely used materials in sheet metal fabrication. The types of metal sheets are plain, flat sheets and ribbed, corrugated sheets. The sheets are made of such materials as black iron, galvanized iron, tin plate, copper, aluminum, stainless steel, or ***Monel***. Galvanized and black iron sheets are the most commonly used material in sheet metal work.

The thickness of a sheet is designated by a series of numbers called gauges. Iron and steel sheets are designated by the U.S. standard gauge that is the accepted standard in the United States.

4.4.0 Reinforcement and Support

The recommended gauge thicknesses of sheet metal used in a standard ventilating and air-conditioning system with normal pressure and velocities are shown in table 2-2.

Table 13-2 — Recommended gauges for sheet metal duct construction.

Aluminum B.& S. gauge	Steel U.S. std. gauge	Maximum side, inches	Type of transverse joint connections	Bracing
24	26	Up to 12	S-drive, pocket, or bar slips, on 7 ft. 10 in. centers	None
		13 to 24	S-drive, pocket, or bar slips, on 7 ft. 10 in. centers	None
22	24	25 to 30	S-drive, 1 in. pocket or 1 in. bar slips, on 7 ft. 10 in. centers	1 x 1 x 1/8 in. angles 4 ft. from the joint
		31 to 40	Drive, 1 in. pocket or 1 in. bar slips, on 7 ft. 10 in. centers	1 x 1 x 1/8 in. angles 4 ft. from the joint
20	22	41 to 60	1 1/2 in. angle connections, or 1 1/2 in. bar slips with 1 3/8 x 1/8 in. bar reinforcing on 7 ft. 10 in. centers	1 1/2 x 1 1/2 x 1/8 in. angles 4 ft. from the joint
18	20	61 to 90	1 1/2 in. angle connections, or 1 1/2 in. bar slips with 3 ft. 9 in. maximum centers with 1 3/8 x 1/8 in. bar reinforcing.	1 1/2 x 1 1/2 x 1/8 in. diagonal angles, or 1 1/2 x 1 1/2 x 1/8 in. 2 ft. from the joint
16	18	91 and up	2 in. angle connections or 1 1/2 in. bar slips 3 ft. 9 in. maximum centers with 1 3/8 x 1/8 in. bar reinforcing	1 1/2 x 1 1/2 x 1/8 in. diagonal angles, or 1 1/2 x 1 1/2 x 1/8 in. 2 ft. from the joint

Where special rigidity or stiffness is required, ducts should be constructed of metal two gauges heavier than those given in the table. All insulated ducts 18 inches or greater on any flat side should be cross broken, as shown in *Figure 13-92*. Cross breaking maybe omitted if the duct is insulated with approved rigid type of insulation and sheet metal two gauges heavier is used.

The maximum length of any section of ductwork will not exceed 7 feet 10 inches; this measurement allows individual sections to be fabricated from an 8-foot sheet of metal with a 2-inch allowance for connection tabs. If lengths of 7 feet 10 inches are considered too long for a specific job, it is recommended that the duct system be constructed with sections of 3-foot 9-inch multiples.

Many duct systems run into unplanned obstructions, particularly in renovation work, such as electrical connections and wiring, structural members, and piping systems. These obstructions must be avoided by fabricating the duct system to go around the obstacles. Do NOT run obstructions through duct systems because it creates turbulence that reduces the efficiency of the system. When the obstruction is an electrical obstruction, you should ensure all power is off and safety checked. When running the duct through an obstruction is unavoidable, the turbulence can be reduced by enclosing the obstruction in a streamlined collar (*Figure 13-93*).

Figure 13-92 — Cross-broken flat surfaces.

Figure 13-93 — Easement around an obstruction in ducts.

4.5.0 Flexible Connections

Most duct systems are connected to either a heating or a cooling system. These systems are generally electric motor driven to move air through the duct system. Therefore, all inlet and outlet duct connections to all fans or other equipment that may create vibration should be made with heavy canvas, as shown in *Figure 13-94.*

The most common method of making connections between duct sections and fittings is the method of combining two S-slips and two drive slips (*Figure 13-95*). S-slips are first placed on two opposite edges of one of the sections or fittings to be joined. These S-slips are applied to the widest dimension of the duct (*Figure 13-96*). The second section or fitting is then inserted into the slips, and the two sections are held together by inserting drive slips along the opposite sides (*Figure 13-97*). After the drive slips are driven home, they are locked in place by bending the ends of the drive slip over the comer of the S-slips to close the corner and lock the drive slips in place (*Figure 13-98*), completing the joint shown in *Figure 13-99*.

Figure 13-94 — Flexible duct connection.

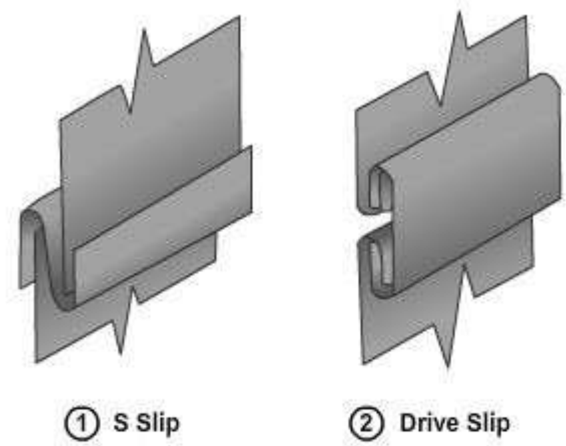


Figure 13-95 — Methods of connecting ducts.

Figure 13-96 — Placing S-clips for S- and drive connection.

Figure 13-97 — Inserting drive slips.

Figure 13-98 — Bending drive slips to complete the joint.

Figure 13-99 — Completed S and drive connection.

4.6.0 Hanging Duct

Most of the ductwork Steelworkers install, modify, or repair is in pre-engineered buildings or repairs to more permanent types of ducting in buildings, such as barracks and base housing.

The most common installation method is hanging the duct from purlins or beams in the hidden area of a roof or below a ceiling. *Figure 13-100* shows one such system when the duct is running parallel to the structural member. These systems require that angle be installed between the beams so that the hanger straps can be installed on both sides of the duct. Normally, 2-inch by 2-inch by 1/8-inch angle is sufficient. However, if the duct is a very large size, a larger angle may be required.

Figure 13-100 — Duct running parallel to purlins or beams.

The straps that are used as hangers may be fabricated from 1/8-inch plate. In a normal installation, a 1-inch by 1/8-inch strap will suffice. All straps must be connected to the ductwork with sheet metal screws. On all government work, it is required that the screws be placed 1 1/4 inches from all edges, as illustrated in *Figure 13-100*, which shows the duct system hanging from angle rails. All angles should be either bolted or tack-welded to purlins or beams.

Strap hangers may be hung directly on purlins or beams when the duct is running transversely or across the purlins or beams, as shown in *Figure 13-101*. However, the strap hangers must be twisted to turn 90 degrees onto the flange of the beam or purlin. Again, the standard 7 feet 10 inches maximum span is required between hangers applies. Also, the hanger screws standard will apply. The hanger span may be shortened to fit the job requirements.

Figure 13-101 — Strap hangers from purlins.

For heavier or larger systems, an installation similar to that shown in *Figure 13-102* may be required. This system is hung entirely on angle rails and the straps are fabricated into one-piece units. This system is by far the neatest looking and is normally used when the duct system is exposed.

Figure 13-102 — Duct system with strap hangers from angle rails transverse to purlin.

Installing a duct system under a built-up steel roof (*Figure 13-103*) is accomplished by hanging the duct system with all-thread bolts and 2-inch by 2-inch by 1/8-inch angles. The all-thread bolt protrudes through the steel decking and is bolted from the top with a large washer and bolt. The bolts extend down alongside the duct into the 2-inch by 2-inch angles which is bolted from under the angle. This system allows for adjustment of height. Also notice that the all-thread bolt extends into the top flat of the apex of the steel roof decking. This is required because connecting the all-thread bolt to the bottom valley of the steel deck will reduce the structural strength of the decking and may also cause water leaks.

Figure 13-103 — Duct installed to a built up steel roof.

5.0.0 FIBERGLASS DUCT SYSTEMS

Throughout the Naval Construction Force (NCF), fiberglass duct is becoming common on jobsites. It has the advantage of added insulating value and ease of fabrication, handling, and installation, making it useful where traffic and handling/abuse are restricted.

5.1.0 Characteristics

Fiberglass ducts are manufactured of molded fiberglass sheets covered with a thin film coating of aluminum, although thin vinyl or plastic coatings are sometimes used. In the NCF, we are primarily concerned with aluminum-coated duct. Because it is fabricated of glass fibers, it is inherently insulated; therefore, it is used where insulation is a requirement.

Fiberglass ducts can be molded into various shapes for special applications. The desired shapes can be ordered from the manufacturer’s stock. In the NCF, for all but special purposes, the duct is supplied in the flat form of a board that has Vgrooves cut into the inner surfaces to allow folding to fabricate rectangular sections (*Figure 13-104, View A*). The ends of the board are molded so when a rectangular/square duct is formed, two sections of the same size will fit together in a shiplap joint (*Figure 13-104, View C*). This joint ensures a tight connection coupled with a positive alignment.

Of extreme importance is the selection of the proper board size to fabricate the duct before cutting and grooving. In all applications, the inside diameter of the duct is the determining factor of the board size. Use *Table 13-3* to determine board size.

Figure 13-104 — Fabricating rectangular/square fiberglass duct from duct board.

Table 13-3 — Duct board length selection chart.

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
6	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76
7	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78
8	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80
9	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82
10	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84
11	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86
12	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88
13	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90
14	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92
15	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94
16	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96
17	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98
18	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
19	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102
20	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104
21	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106
22	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108
23	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
24	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112
25	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114
26	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116
27	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118
28	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120
29	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	
30	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120		
31	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120			
32	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120				
33	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120					
34	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120						
35	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120							
36	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120								
37	94	96	98	100	102	104	106	108	110	112	114	116	118	120									
38	96	98	100	102	104	106	108	110	112	114	116	118	120										
39	98	100	102	104	106	108	110	112	114	116	118	120											
40	100	102	104	106	108	110	112	114	116	118	120												
41	102	104	106	108	110	112	114	116	118	120													
42	104	106	108	110	112	114	116	118	120														
43	106	108	110	112	114	116	118	120															
44	108	110	112	114	116	118	120																
45	110	112	114	116	118	120																	
46	112	114	116	118	120																		
47	114	116	118	120																			
48	116	118	120																				
49	118	120																					
50	120																						

* For 1 1/2 inch board - add 4 inches to these dimensions
* For 2 inch board - add 8 inches to these dimensions

NOTE

Within a heating system, the adhesive used to affix the protective outer coating to the fiberglass restricts the use of fiberglass duct. Check the specifications and ensure that it will not fail when exposed to heat over 250 degrees.

5.2.0 Fabrication

To fabricate a rectangular/square duct, you must first measure the duct board accurately. Next, the grooves must be cut. Ensure they are at the proper locations and cut straight because this allows the board to be folded to create the desired rectangular/square shape. When cutting the board, you will need to leave an overlapping tab that is pulled tight and stapled (*Figure 13-104*, View A). Tape is then applied and the joint is heat-sealed (*Figure 13-104*, View B). Joints between sections are fabricated by pulling the shiplap end sections together and finished by stapling, taping, and heat sealing the joint (*Figure 13104*, View C).

5.3.0 Installation

The very nature of fiberglass duct requires that it be supported with 1-inch by 1/16-inch galvanized steel strap hangers. These must be supplied or fabricated to fit the duct precisely whether the duct is rectangular/square or round. Rectangular/square ducts up to 24 inches (span) can be supported on 8-foot centers. Ducts larger than 24 inches must be supported on 4-foot centers. For round ducts, the supports must not be less than 6-foot centers.

Test your Knowledge (Select the Correct Response)

5. When using rivets to join sheet metal, what characteristic should the rivets have?

   A. Softer than the metal being riveted
   B. The same material as being riveted
   C. Harder than the material being riveted
   D. Different material as being riveted

6. What must be the distance between the rivets being used and the edge of the sheet metal?

   A. 2 1/2 inches
   B. 2 1/2 times the diameter of the rivet
   C. 2 1/2 times the thickness of the completed joint
   D. 2 1/2 times the distance to the next rivet

6.1.1 SAFETY

Some of the safety precautions applicable to sheet metal tools and equipment have been mentioned throughout this chapter. Here are a few additional precautions that should be carefully observed when you are working with sheet metal.

1. Sheet metal can cause serious cuts. Handle it with care. Wear steel-reinforced gloves whenever feasible.
2. Treat every cut immediately, no matter how minor.
3. Remove all burrs from the metal sheet before attempting to work on it further.
4. Use a brush to clean the work area. NEVER brush metal with your hands.

5. Use tools that are sharp.
6. Keep your hands clear squaring shears.
7. A serious and painful foot injury will result if your foot is under the foot pedal of the squaring shears when a cut is made.
8. Do not run your hands over the surface of sheet metal that has just been cut or drilled. Painful cuts can be received from the burrs.
9. Get help when large pieces of sheet metal are being cut. Keep your helper well clear of the shears when you are making the cut.
10. Keep your hands and fingers clear of the rotating parts on forming machines.
11. Place scrap pieces of sheet metal in the scrap box.
12. Always remember to keep a clean shop. Good housekeeping is the key to a safe shop.
13. Do not use tools that are not in proper working condition: hammer heads loose on the handle, chisels with mushroomed heads, power tools with guards removed, and so forth.
14. Wear goggles when in the shop.

Summary

This chapter introduced you to basic sheet metal and fiberglass ductwork fabrication. You were introduced to the tools needed to work the sheet metal, some of the methods of measuring, marking, cutting, and the correct methods to form parallel, radial, and triangular sheet metal shapes. Different types of joints and edges as well as how to connect the duct work were also discussed.

Always remember to keep your tools and work space clean and in good working order. Sheet metal is very dangerous to work with so always following prescribed safety precautions and wearing the proper personal protective equipment is a must.

Review Questions (Select the Correct Response)

1. **(True or False)** The procedure for measuring and marking material for the cutting, drilling, and/or welding of metal is known by the term "layout."

   A. True
   B. False

2. What type of tool is most frequently used to scribe lines on sheet metal?

   A. Prick punches
   B. Trammel points
   C. Scratch awls
   D. Dividers

3. In a simple drip pan layout, the radius of a corner arc is equal to what dimension of the pan?

   A. Its depth
   B. Its length
   C. Its width
   D. Its diagonal cross section

4. You set dividers for the radius of a circle and strike off this distance on the entire circumference. Into how many equal arcs have you divided the circumference?

   A. Six
   B. Two
   C. Three
   D. Nine

5. Into how many equal parts is the circumference of a circle divided if the lines intersecting at the center of the circle form angles of 30 degrees?

   A. 4
   B. 6
   C. 12
   D. 18

6. What is the approximate circumference of a circle that has a diameter of 18 inches?

   A. 45.5 inches
   B. 56.5 inches
   C. 133.0 inches
   D. 365.0 inches

7. What is the mathematical formula for determining the area of the stretch-out of a cylinder?

   A. $A = \pi r$
   B. $A = \pi rd$
   C. $A = 2\pi r$
   D. $A = (\pi d)\ h$

8. **(True or False)** Metal stakes are used to make an assortment of bends by hand and to finish many types of work.

   A. True
   B. False

9. What part of the bar-folding machine is used to make right angles and 45-degree bends?

   A. The depth gauge
   B. The bar handle
   C. The wing
   D. The angle stop

10. A total of how many adjustments must be made on a cornice brake before you can use the machine to bend sheet metal?

   A. One
   B. Two
   C. Three
   D. Four

11. What feature on the cornice brake enables you to make as many duplicate bends as required?

   A. The clamping device
   B. The balancing weight
   C. The stop gauge
   D. The mold clamps

12. **(True or False)** The box and pan brake is often referred to as a finger brake.

   A. True
   B. False

13. When forming a curved shape, you can fabricate the most accurate bend by using what piece of equipment?

   A. A stake
   B. A mandrel
   C. A pipe
   D. A slip-roll forming machine

14. The slip-roll forming machine is designed to allow one end of the top front roll to be released quickly so you can perform what task easily?

    A. Removal of the work
    B. Cleaning operations
    C. Repairs on the machine
    D. Adjustments to the machine

15. What operation of the combination rotary machine is used to reduce the size of the end of a cylinder?

    A. The beading
    B. The burring
    C. The crimping
    D. The clamping

16. **(True or False)** Instead of scribing directly on the metal when a single piece is being made in quantity, you can make a pattern or template and transfer it to the metal.

    A. True
    B. False

17. A patternmaker decides to divide a half plan or top View into 12 equal parts. What number of divisions will be required for the stretch-out line?

    A. 6
    B. 12
    C. 24
    D. 48

18. What method of pattern development should you use to develop a pattern for an object that has a tapering form with lines converging at a common center?

    A. Radial line
    B. Parallel line
    C. Triangulation
    D. Scratching

19. When fabricating a wired edge to a cylinder, you must add how much edging to a pattern?

    A. 1 1/2 times the thickness of the metal
    B. 2 1/2 times the diameter of the wire to be used
    C. Twice the diameter of the upper burring roller
    D. One half of the diameter of the wire to be used

20. In the fabrication of rectangular duct, what seam is used most often?

A. Grooved
B. Pittsburgh lock
C. Lap
D. Standing

21. When laying out a pattern, you consider what feature last?

A. Seams
B. Laps
C. Notches
D. Edges

22. What type of notch is used on a corner when a single-hemmed edge is to meet a 90-degree angle?

A. Square
B. Slant
C.V
D. Wire

23. What type of connection is used to join a flat sheet and a round pipe/fitting?

A. Dovetail seam
B. Drive slip
C. Pocket slip
D. Standing seam

24. What type of screw is most often used in sheet metal work?

A. Self-tapping
B. Machine
C. Thread-cutting
D. Drive

25. **(True or False)** Drive screws are simply driven into sheet metal.

A. True
B. False

26. **(True or False)** Tinners' are designated by weight per 1,000 rivets.

A. True
B. False

27. The distance from the center of the rivet to the edge of the sheet must equal how many rivet diameters?

A. 1
B. 1 1/2
C. 2
D. 2 1/2

28. **(True or False)** The correct method for riveting using Tinners' rivets is to draw, upset, and head the rivet.

A. True
B. False

29. What gauge of aluminum sheet metal is required to construct a duct 62 inches wide at the top and 28 inches high on the sides?

A. 26
B. 22
C. 18
D. 16

30. You are to construct a duct of 24-gauge sheet metal. Each section is 7 feet 10 inches long. If the total system length is 60 feet, you should place the bracing angles at what location?

A. 2 feet on center along the length of the duct
B. 4 feet on center along the length of the duct
C. 2 feet from each joint
D. 4 feet from each joint

31. The cross breaking of a duct having a flat side of 18 inches or greater can be omitted under which of the following conditions?

A. The duct is installed in the vertical position.
B. The material used is at least reinforced at the edges of each duct segment.
C. The duct is insulated with approved materials.
D. The duct is insulated with rigid insulation and the sheet metal used is 2 gauges heavier.

32. When securing duct systems to heating and cooling units, you should use what material to fabricate the flexible connections?

A. Light-gauge sheet metal
B. Asbestos
C. Heavy canvas
D. Aluminum

33. When S-slips and drive slips are used on a duct system, you lock the joint into position in what way?

A. By bending the S-slip over the drive slip
B. By bending the drive slip over S-slip
C. By cutting off the drive slip even with the S-slip and welding each corner
D. By center punching the S-slip

34. Fiberglass duct has which of the following advantages?

A. Added insulating value
B. Ease of fabrication and handling
C. Ease of installation
D. Each of the above

35. **(True or False)** In all fiberglass duct applications, the inside diameter is the determining factor of the duct size.

A. True
B. False

36. Fiberglass duct must not be used in a heating system in which the heat generated exceeds what temperature?

A. 150°F
B. 200°F
C. 250°F
D. 300°F

37. What are the dimensions of the galvanized steel straps used to support fiberglass duct?

A. 3/4-inch diameter by 1/8-inch thick
B. 1-inch diameter by 1/8-inch thick
C. 1-inch diameter by 1/16-inch thick
D. 1 1/8-inch diameter by 1/16 inch thick

38. You have fabricated a fiberglass duct system that has a 30-inch diameter. At what distance should the supports be placed?

A. 8-foot centers
B. 6-foot centers
C. 4-foot centers
D. 2-foot centers

Trade Terms Introduced in this Chapter

Apex	The highest point or peak.
Frustum	A truncated cone or pyramid in which the plane cutting off the apex is parallel to the base. 
Monel	Monel is a trademark of Special Metals Corporation for a series of nickel alloys, primarily composed of nickel (up to 67%) and copper, with some iron and other trace elements.
Vertex	A corner or a point where lines meet.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Blueprint Reading and Sketching, NAVEDTRA 14040, Naval Education Training Program Management Support Activity, Pensacola FL, 2003.

Budzik Richard, S., 'Fittings Used Today that Require Triangulation Including the 'Theory of Triangulation" *Practical Sheetmetal Layout, Practical* Publications,Chicago, IL, 1971.

Budzik, Richard, S., "Round Fittings Used Today including Methods and Techniques of Fabricating Round Work" *Practical Sheetmetal Layout,* Practical Publications, Chicago, IL, 1971.

Budzik, Richard, S., "Today's 40 Most Frequently-Used Fittings, " *Practical Sheetmetal Layout,* Practical Publications, Chicago, IL, 1971.

Heating, Ventilation, Air Conditioning and Sheetmetal Work, TM 5-745, Headquarters Department of the Army, Washington, DC, 1968.

Johnston, Philip, M., *Sheet Metal,* Volumes 1-4, Delmar Publishers Inc., Albany, NY, 1966.

Tools and Their Uses, NAVEDTRA 14256, Naval Education and Training Program Management Support Activity, Pensacola, FL, 1992.

Walker, John, R., Modern Metalworking, Goodheart-Wilcox Company Inc., South Holland, IL, 1993.

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical ReView Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

Chapter 14

Fiber Line

Topics

To hear audio, click on the box.

Overview

Steelworkers need tools to hoist and move steel into place to erect a structure of any scale. This hoisting gear ranges from uncomplicated devices, such as tripods and gin poles, to complex mechanisms, such as cranes and motor-powered derricks. Whatever the case, one of the most important components of these hoisting machines is the fiber line or wire rope that must be attached to and hold the load to be moved. Before you, as a Steelworker, can become skilled in the supervision of hoisting devices, you must first understand the use and maintenance of fiber line.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe Fiber line fabrication and use.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	S T E E L W O R K E R B A S I C
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet metal and Fiberglass Duct		
Welding Quality Control		
Flux Cored Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 FIBER LINE

Fiber line is made from either natural or synthetic fiber. Natural fibers, which come from plants, include manila, sisal, hemp, coir, and cotton. The synthetic fibers include nylon, polyester, and polypropylene.

1.1.0 Types of Natural Fiber Line

The principal vegetable fibers are abaca (ab-*uh*-**kah)** (known as Manila), agave sisalana and henequen (**hen**-*uh*-kin) (both known as sisal), hemp, sometimes coir, and cotton. The last two are relatively unimportant in the heavy ***cordage*** field. Abaca, agave sisalana, and henequen are classified as hard fibers. The comparative strengths of the vegetable fibers, considering abaca as 100, are as follows:

- Sisalana 80
- Henequen 65
- Hemp 100

1.1.1 Manila

This is a strong fiber that comes from the leaf stems of the stalk of the abaca plant, which belongs to the banana family. The fibers vary in length from 5 to 11½ feet (1.5 to 3.5 meters) in the natural states. The quality of the fiber and its length give Manila rope relatively high elasticity, strength, and resistance to wear and deterioration. The manufacturer treats the rope with chemicals to make it more mildew resistant, which increases the rope's quality. It is very popular for public utility construction and repair because it will not melt on contact with hot wires or equipment like synthetics do. It will burn, however, if the temperature is very high or if the rope is in contact with the wires/equipment for an extended period of time. A good grade of manila is cream in color, smooth, clean, and pliable. Poorer grades of manila are characterized by varying shades of brown. Manila rope is generally the standard item of issue because of its quality and relative strength.

1.1.2 Sisal

Sisal (the next best line-making fiber) rope is made from two tropical plants, sisalana and henequen, that produce fibers 26 to 40 inches (65cm to 1 m) long. Sisalana produces the stronger fibers yarn. Sisal rope is about 80 percent as strong as high quality Manila rope and can be easily obtained. The fiber is similar to manila, but lighter in color. It withstands exposure to seawater very well and is often used for this purpose.

1.1.3 Hemp

This tall plant is cultivated in many parts of the world and provides useful fibers for making rope and cloth. Hemp was used extensively before the introduction of Manila, and the term *small stuff* is used to describe small cordage that a layman may call string, yarn, or cords, but its principal use today is in fittings, such as ratline, ***marline*** (**mahr**-lin), and spun yarn. Since hemp absorbs tar much better than the hard fibers, these fittings are invariably tarred to make them more water-resistant. Tarred hemp has about 80 percent of the strength of hemp. Of these tarred fittings, marline is the standard item of issue.

1.1.4 Coir

Coir line is made from the fiber of coconut husks. It is a very elastic, rough line, light enough to float on water, but at about one-fourth the strength of hemp, coir usage is restricted to small lines.

1.1.5 Cotton

Cotton makes a very smooth, white line that withstands much bending and running. However, cotton is very susceptible to the elements and deteriorates very quickly compared to the other materials used to make rope. Therefore, cotton is only used in some cases for very small lines.

1.2.0 Types of Synthetic Fiber Lines

Synthetic fiber rope, such as nylon and polyester, has rapidly gained wide use by the Navy. It is lighter in weight, more flexible, less bulky, and easier to handle and store than manila line. It is also highly resistant to mildew, rot, and fungus. Synthetic rope is stronger than natural fiber rope. For example, nylon is about three times stronger than manila. When nylon line is wet or frozen, the loss of strength is relatively small. Nylon rope will hold a load even though several strands may be frayed. Ordinarily, the line can be made reusable by cutting away the chafed or frayed section and splicing the good line together.

1.3.0 Fabrication of Line

The fabrication of line consists essentially of three progressive twisting operations, each in the opposite direction of each other.

1.3.1 Fibers

Fibers are a class of materials that are continuous filaments or are in discrete, elongated pieces, similar to lengths of thread. Fibers are the smallest component of a rope. The fibers are twisted or spun together. The fibers are twisted to the right.

1.3.2 Yarns

Yarn is produced by the twisting of the fibers. Two or more yarns are twisted in the opposite direction (left) of the fibers, increasing its resilience.

1.3.3 Strands

The result of twisting the yarns is strands. The strands are twisted in the opposite direction to the yarns (right) to form the line. Usually three strands are twisted together to form a line; however, more can be used as needed.

1.3.4 Lines

Figure 14-1 shows how the fibers are grouped to form a three-strand line.

Figure 14-1 — Fabrication of line.

The operation just described is the typical line-making procedure, and the resulting product is known as a right-laid line. When the process is reversed, the result is a left-laid line. In either instance, the principle of opposite twists must always be observed. The two main reasons for the principle of opposite twists are to keep the line tight to prevent the fibers from ***unlaying*** with a load suspended on it and to prevent moisture penetration.

1.4.0 Types of Lays of Line

You need to be familiar with three types of fiber line lays: hawser-laid, shroud-laid, and cable-laid lines. Each type is illustrated in *Figure 14-2*.

Figure 14-2 — Lays of line.

1.4.1 Hawser-Laid

Hawser-laid line (common/plain rope) generally consists of three strands twisted together, usually in a right-hand direction.

1.4.2 Shroud-Laid

A shroud-laid line ordinarily is composed of four strands twisted together, usually in a right-hand direction around a center strand, or core, which is usually of the same material, but smaller in diameter than the four strands. Shroud-laid line is more pliable and stronger than hawser-laid line, but it has a strong tendency toward kinking. In most instances, it is used on ***sheaves*** and drums. This not only prevents kinking, but also makes use of its pliability and strength.

1.4.3 Cable-Laid

Cable-laid line usually consists of three right-hand, hawser-laid lines twisted together in a left-hand direction. It is especially safe to use in heavy construction work; if cable-laid line untwists, it will tend to tighten any regular right-hand screw connection to which it is attached.

1.5.0 Size Designation

Line 1 3/4 inches (44.5 mm) or less in circumference is called small stuff. The number of threads, or yarns, that make up each strand, usually designates the size. You may use from 6 to 24 thread strands, but the most commonly used are 9 to 21 thread strands, as shown in *Figure 14-3*. You may hear some small stuff designated by name without reference to size. One such type is marline, a tarred, two-strand, left-laid hemp. Marline is the small stuff you will use most for seizing. When you need something stronger than marline, use a tarred, three-strand, left-laid hemp called houseline.

Figure 14-3 — Size designation of a line.

Line larger than 1 3/4 inches in circumference is generally size designated by its circumference in inches. A six-inch manila line, for instance, is constructed of manila fibers and measures six inches in circumference. Twelve inches is about the largest manila carried in stock. Anything larger is used only on special jobs.

If you have occasion to order line, you may find that the catalogs designate it by diameter rather than circumference, and you order it by diameter. The catalogs may also use the term rope rather than line.

You can pull rope yarns for temporary seizing, whippings, and lashings from large strands of old line that have outlived their usefulness. Pull your yarn from the middle, away from the ends, or it will get fouled.

1.6.0 Handling and Care of Fiber Line

If you expect the fiber line you work with to give safe and dependable service, make sure it is handled and cared for properly. Study the precautions and procedures given here and carry them out properly.

Cleanliness is part of the care of fiber line. Never drag a line over the deck or ground, or over rough or dirty surfaces. The line can easily pick up sand and grit, which will work into the strands and wear the fibers. If a line does get dirty, use only water to clean it. Do not use soap because it will remove oil from the line, which weakens it.

When nylon line is properly handled and maintained, it should last more than five times longer than manila line subjected to the same use. Nylon line is also lighter, more flexible, less bulky, and easier to handle and store than manila line. When nylon line is wet or frozen, it loses little strength. Additionally, nylon line is resistant to mildew, rotting, and attack by marine borers. If a nylon line becomes slippery because of grease, it should be cleaned with light oils, such as kerosene or diesel oil.

Avoid pulling line over sharp edges because the strands may break. When you encounter a sharp edge, place chafing gear, such as a board, folded cardboard, canvas, or part of a rubber tire between the line and the sharp edge to prevent damaging the line.

Never cut a line unless you have to. When possible, use knots that you can easily untie.

Fiber line contracts, or shrinks, when it gets wet. If there is not enough slack in a wet line to permit shrinkage, the line is likely to become overstrained and weakened. If a taut line is exposed to rain or dampness, make sure the line, while still dry, is slacked to allow for shrinkage.

Inspect line carefully at regular intervals to determine whether it is safe.

1.6.1 Uncoiling

New line is coiled, bound, and wrapped in burlap. This protective covering should not be removed until the line is to be used because it protects the line during storage and prevents tangling. To open, remove the burlap wrapping and look inside the coil for the end of the line. This should be at the bottom of the coil. If it is not, turn the coil over so that the end will be at the bottom. Pull the end of the line up through the center of the coil (*Figure 14-4*). As the line comes up through the coil, it will unwind in a counterclockwise direction.

1.6.2 ncoiling Nylon

Never uncoil new nylon line by pulling the ends up through the eye of the coil. Avoid repeatedly coiling nylon in the same direction or you will unbalance the lay.

Figure 14-4 — Uncoiling line.

1.6.3 Making Up

After the line has been removed from the manufacturer’s coil, it may be made up (prepared for storage or use) by winding on a reel. It may also be made up by cooling down, faking down, or blemishing down. To coil down a line simply means to lay it in circles, roughly one on top of the other (*Figure 14-5*). Line should always be coiled in the same direction as the lay—clockwise for right lay and counterclockwise for left lay. When a line has been coiled down, one end is ready to run off. This is the end that went down last and is now on top. If, for some reason, the bottom end must go out first, you will have to turn your coil over to free it for running.

Figure 14-5 — Coiling down line after use.

1.6.4 Whipping

The term whipping refers to the process of securing the ends of a line to prevent the strands from unlaying and the yarns from separating or fraying. It will not increase the size of the line enough to prevent the fitting of the blocks or openings through which it must pass. Whippings are made with fine twine.

Figure 14-6 shows the steps to follow in applying a whipping:

1. Make a loop in the end of the twine and place the loop at the end of the line, as shown in the figure.
2. Wind the standing part around the line covering the loop of the whipping. Leave the small loop uncovered, as shown.
3. Pass the remainder of the standing end up through the small loop and pull the dead end of the twine, thus pulling the small loop and the standing end back toward the end of the line underneath the whipping.
4. Pull the dead end of the twine until the loop with the standing end through it reaches a point midway underneath the whipping.
5. Trim both ends of the twine close up against the loops of the whipping.

Figure 14-6 — Whipping a line.

Before cutting a line, place two whippings on the line 1 or 2 inches apart and make the cut between the whippings, as shown in *Figure 14-7*. This procedure prevents the ends from untwisting after they are cut.

Figure 14-7 — Cutting a line between whipping.

1.6.5 Inspecting

The exterior appearance of fiber line is not always a good indication of its internal condition. Line softens with use, and dampness, heavy loads, fraying, breaking strands, and dragging over rough surfaces all contribute to line weakening and failure. Also, overloading a line can cause it to part, resulting in heavy damage to material, equipment, and/or serious injury to personnel. For these reasons, line should be inspected carefully at regular intervals to determine whether it is safe for use.

The interior of a line can be checked by untwisting the strands slightly. Again, line that is mildewed gives off a musty odor. A trained observer usually can spot broken strands or yams immediately. Look carefully to ensure there is no dirt or sawdust-like material inside the line; the presence of dirt or other foreign matter indicates possible damage to the internal structure of the line. In line having a central core, the core should not break away in small pieces upon examination. If this occurs, it indicates that the line has been overloaded. Additionally, a decrease in line circumference is usually a sure sign that an excessive strain has been applied to the line.

For a thorough inspection, a line should be examined at several places.

CAUTION

Only one weak spot anywhere in a line makes the entire line weak.

As a final check, if the line appears to be satisfactory in all aspects, pull out a couple of fibers from the line and try to break them. Sound fibers show a strong resistance to breakage.

If an inspection discloses any unsatisfactory conditions in a line, destroy it or cut it into small pieces as soon as possible, but save the small pieces for miscellaneous uses on the jobsite. This precaution will prevent the possibility of the defective line being used for hoisting purposes.

As with manila, nylon line is measured by circumference. Nylon, as manila, usually comes on a reel of 600 to 1,200 feet, depending upon the size.

1.6.6 Storing

When fiber line is to be stored, certain precautions must be taken to safeguard the line against deterioration. A line should never be stored when wet. Always dry the line well before placing it in storage.

After being used, a line should be coiled down in a clockwise direction (assuming it is a right-hand lay). Should the line be kinked from excessive turns, remove them by the procedure known as “thorough footing.” This is accomplished by coiling the line down counterclockwise (again assuming it is a right-hand lay) and then pulling the bottom end of the coil up and out the middle of the coil. If the line is free of kinks as it leaves the coil, make it up in the correct manner. If the line is still kinked, repeat the process before making up the line for storage.

Carefully consider where you store line. Line deteriorates rapidly if exposed to prolonged dampness; therefore, it is important that the storage area is dry, unheated, and well ventilated. To permit proper air circulation, place the line in loose coils on a wood grating platform about 6 inches (15 cm) above the floor. You can also hang the line in loose coils on a wooden peg. Avoid continuous exposure of line to sunlight; excessive sunlight can damage the line. Do not store nylon line in strong sunlight. Cover it with tarpaulins.

As a final precaution, do not expose line to lime, acids, or other chemicals, or even store line in a room containing chemicals. Even the fumes may severely damage the line.

1.7.0 Strength of Fiber Line

Overloading a line poses a serious threat to the safety of personnel, not to mention the heavy losses likely to result through damage to material. To avoid overloading, you must know the strength of the line with which you are working. This involves three factors: breaking strength, safe working load (SWL), and safety factor.

1.7.1 Breaking Strength

Breaking strength refers to the tension at which the line will part when a load is applied. Rope manufacturers determine breaking strength through tests and provide tables with this information. In the absence of manufacturers' tables, a rule of thumb for finding the breaking strength of manila line is the formula:

$$BS = C^2 \times 900$$

BS equals the breaking strength in pounds and *C* equals the circumference in inches. To find *BS*, first square the circumference, then multiply the value obtained by 900. For example, with a three-inch line you will get a *BS* of 8,100 pounds as follows:

$$BS = 3 \times 3 \times 900 = 8{,}100$$

If you are OUTCONUS and the supplier uses the metric system, the line is measured in centimeters, so you can figure breaking strength in kilograms. The same equation is used with only the constant being changed to 64.8 (vice 900). The breaking strength in kilograms is figured as follows:

7.5 cm x 7.5 cm x 64.8 = 3,645 kg

The breaking strength of manila line is higher than that of sisal line because of the difference in the two fibers. The fiber from which a particular line is constructed has a definite bearing on its breaking strength.

1.7.2 Safe Working Load

Briefly defined, the safe working load of a line is the load that can be applied without damaging the line. Note that the safe working load is considerably less than the breaking strength. A wide margin of difference between breaking strength and safe working load is necessary. This difference allows for such factors as additional strain imposed on the line by jerky movements in hoisting or bending over sheaves in a pulley block.

You may not always have a chart available to tell you the safe working load for a particular line. Here is a rule of thumb that will adequately serve your needs on such an occasion:

$$SWL = C^2 \times 150$$

In this equation, *SWL* equals the safe working load in pounds, and *C* equals the circumference of the line in inches. Simply take the circumference of the line, square it, and then multiply by 150. For a 3-inch line:

$$SWL = 3 \times 3 \times 150 = 1{,}350 \text{ pounds}$$

The safe working load of a three-inch line is equal to 1,350 pounds.

If you are OUTCONUS using the metric system, use the same formula with a constant figure of 10.8, the metric constant equivalent to 150 in the decimal system.

In the metric system, the rule is as follows:

$SWL = C^2 \times 10.8$

SWL equals the safe working load in kilograms, and *C* equals the circumference of the line in centimeters.

Substituting the centimeter equivalent of 3 inches (3 inches = 7.5 cm), the formula becomes the following:

SWL = 7.5 cm x 7.5 cm x 10.8 = 607.5 kg

Thus, the safe working load of a line 7.5 cm in circumference is equal to 607.5 kg.

If a line is in good shape, add 30 percent to the SWL derived by means of the preceding rule; if it is in bad shape, subtract 30 percent from the SWL. In the example given above for the three-inch line, adding 30 percent to the 1,350 pounds gives you a safe working load of 1,755 pounds. On the other hand, subtracting 30 percent from 1,350 pounds leaves you with a safe working load of 945 pounds.

Remember, the strength of a line decreases with age; use; and exposure to excessive heat, boiling water, or sharp bends. Especially with used line, give these and other factors affecting strength careful consideration and make proper adjustments in determining the breaking strength and safe working load capacity of the line. Manufacturers of line provide tables that show the breaking strength and safe working load capacity of line. Those tables are very useful in your work, but you must remember that the values given in manufacturers' tables apply only to new line used under favorable conditions. Therefore, you must progressively reduce the values given in manufacturers' tables as the line ages or deteriorates with use.

Keep in mind that a strong strain on a kinked or twisted line can put a permanent distortion in the line. The kink that could and should have been worked out may now be permanent, and the line ruined.

1.7.3 Safety Factor

The safety factor of a line is the ratio between the breaking strength and the safe working load. Usually, a safety factor of four is acceptable, but this is not always the case. The safety factor will vary, depending on such things as the condition of the line and circumstances under which it is to be used, but the safety factor should never be less than three, and often must be well above four, possibly as high as eight or ten. For the best, average, or unfavorable conditions, the following safety factors may often be suitable:

- Best conditions (new line): four
- Average conditions (line used, but in good condition): six
- Unfavorable conditions (frequently used line, such as running rigging): eight

1.7.4 Breaking Strength of Nylon Line

The breaking strength of nylon line is almost three times that of manila line of the same size. The rule of thumb for the breaking strength of nylon line is as follows:

$BS = C^2 \times 2{,}400$

NOTE

The symbols in this rule are the same as those for fiber line in both the English and metric systems, while the constant for the metric system is 172.8.

Application of the formula: determine the *BS* for a 2 1/2-inch nylon line in both pounds and kilograms:

Solution: $BS = 2.5 \times 2.5 \times 2{,}400 = 15{,}000$ pounds

or

$BS = 6.35\text{ cm} \times 6.35\text{ cm} \times 172.8 = 6{,}967$ kilograms

Nylon line can withstand repeated stretching to this point with no serious effects. When nylon line is under load, it thins out. Under normal safe working loads, nylon line will stretch about one third of its length. When free of tension, it returns to its normal size.

However, when nylon line is stretched more than 40 percent, it is likely to part, and the stretch is immediately recovered with a snapback that sounds like a pistol shot.

WARNING

The snapback of a nylon line can be as deadly as a bullet. This feature is also true for other types of lines, but overconfidence in the strength of nylon may lead one to underestimate its backlash; therefore, ensure that no one stands in the direct line of pull when a heavy strain is applied to a line.

The critical point of loading is 40-percent extension of length; for example, a 10-foot length of nylon line would stretch to 14 feet when under load. Should the stretch exceed 40 percent, the line will be in danger of parting.

Nylon line will hold a load even though a considerable number of strands are ***abraded***. Ordinarily, when abrasion is localized the line may be made satisfactory for reuse by cutting away the chafed section and splicing the ends.

1.8.0 Knots, Bends, and Hitches

The term *knot* is usually applied to any tie or fastening formed with a cord, rope, or line. In a general sense, it includes the words *bends* and *hitches.*

1.8.1 Line Parts

A *bend* is used to fasten two lines together or to fasten a line to a ring or loop. A *hitch* is used to fasten a line around a timber or spar, so it will hold temporarily but can be readily untied. Many ties, which are strictly bends, have come to be known as knots; for this reason, we will refer to them as knots in this discussion.

Knots, bends, and hitches are made from three fundamental elements: a ***bight***, a loop, and a round turn. Observe *Figure 14-8* closely and you should experience no difficulty in making these three elements. Note: the free or working end of a line is known as the *running end*, the remainder of the line is called the *standing part*.

Figure 14-8 — Elements of knots, bends, and hitches.

NOTE

A good knot is one that is tied rapidly, holds fast when pulled tightly, and is untied easily. In addition to the knots, bends, and hitches described in the following paragraphs, you may need others in steel working. When you understand how to make those covered in this chapter, you should find it fairly easy to learn the procedure for other types.

1.8.2 Overhand Knot

The overhand knot is considered the simplest of all knots to make (*Figure 14-9*):

1. Hold a rope or string in your left hand, about 12 inches from the end.
2. Make a loop (called an eye) in the rope with your right hand. You will make an X at the top of the loop where the rope crosses itself. The section of rope closest to the end should pass under the other section, from the top left to the lower right of the X.
3. Hold the X with your left hand.
4. Use your right hand to push the end of the rope into the loop and then pull on both ends.

Figure 14-9 — Overhand knot.

The overhand knot is often used as a part of another knot. At times, it may also be used to keep the end of a line from untwisting or to form a knob at the end of a line.

1.8.3 Figure-Eight Knot

The figure-eight knot is used to form a larger knot than would be formed by an overhand knot in the end of a line (*Figure 14-10*). A figure-eight knot is used in the end of a line to prevent the end from slipping through a fastening or loop in another line. To make the figure-eight knot:

1. Make a loop in the standing part.
2. Pass the running end around the standing part, back over one side of the loop and down through the loop.
3. Pull tightly.

Figure 14-10 — Figure-eight knot.

1.8.4 Square Knot

The square knot, also called the reef knot, is an ideal selection for tying two lines of the same size together so they will not slip. To tie a square knot:

1. Bring the two ends of the line together and make an overhand knot.
2. Form another overhand knot in the opposite direction, as shown in *Figure 14-11*.

NOTE

A good rule to follow for a square knot is left over right and right over left.

When tying a square knot, make sure the two overhand knots are parallel. This means that each running end must come out parallel to the standing part of its own line. If your knot fails to meet this test, you have tied what is known as a “granny.” A granny knot should never be used; it is unsafe because it will slip under strain. A true square knot, instead of slipping under strain, will only draw tighter.

Figure 14-11 — Square knot.

1.8.5 Sheepshank

The Sheepshank is generally thought of as merely a means to shorten a line, but in an emergency, it can also be used to take the load off a weak spot in the line. To make a sheepshank:

1. Form two bights (*Figure 14-12*, *View 1*).
2. Take a half hitch around each bight (*Figure 14-12, Views 2 and 3*).

In case you are using the sheepshank to take the load off a weak spot, make sure the spot is in the part of the line indicated by the arrow in *Figure 14-12, View 2*.

Figure 14-12 — Sheepshank.

1.8.6 Bowline

Use the bowline to tie a temporary eye in the end of a line. A bowline neither slips nor jams and unties easily. An example of a temporary use is that of tying a heaving line or messenger to a hawser and throwing it to a pier, where line handlers can pull the hawser to the pier, using the heaving line or messenger.

To tie a bowline (*Figure 14-13*):

1. Hold the standing part with your left hand and the running end with your right.
2. Flip an overhand loop in the standing part, and hold the standing part and loop with the thumb and fingers of your left hand.
3. Using your right hand, pass the running end up through the loop, under the standing part, and down through the loop. Its strength is 60 percent.

Figure 14-13 — Bowline.

1.8.7 French Bowline

Use a French bowline as a sling for lifting an injured person. For this purpose, one loop is used as a seat and the other loop is put around the body under the arms, then the knot is drawn tightly at the chest. Even an unconscious person can ride up safely in a properly secured French bowline because his or her weight keeps the two loops tight so that he or she will not fall out. It follows, though, that it is necessary to take care not to allow the loop under the arms to catch on any projections. Also, use the French bowline where a person is working alone and needs both hands free. The two loops of the knot can be adjusted to the required size. *Figure 14-14* shows the step-by-step procedure for tying the French bowline.

Figure 14-14 — French bowline.

1.8.8 Spanish Bowline

The Spanish bowline is useful in rescue work, especially as a substitute for the boatswain's chair. It may also be used to give a twofold grip for lifting a pipe or other round object in a sling. Many people prefer the Spanish bowline to the French bowline because the bights are set and will not slip back and forth (as in the French bowline) when the weight is shifted. To tie a Spanish bowline:

1. Take a bight and bend it back away from you (*Figure 14-15*, *View 1*), forming two bights.
2. Lap one bight over the other (*View 2*).

Figure 14-15 — Spanish bowline.

3. Grasp the two bights where they cross at (a) in *View 2*.
4. Fold this part down toward you, forming four bights (*View 3*).
5. Pass bight (c) through bight (e) and bight (d) through bight (f) (*View 4*).

The complete knot is shown in *View 5*.

1.8.9 unning Bowline

The running bowline forms a strong running loop (*Figure 14-16).* It is a convenient form of running an eye. The running bowline provides a sling of the choker type at the end of a single line. Use it when tying a hand line around an object at a point that you cannot safely reach, such as the end of a limb. The weight of the object determines the tension necessary for the knot to grip. To make a running bowline:

1. Make an overhand loop with the end of the rope held toward you.
2. Hold the loop with your thumb and fingers and bring the standing part of the rope back so that it lies behind the loop.
3. Take the end of the rope in behind the standing part, bring it up, and feed it through the loop.
4. Pass it behind the standing part at the top of the loop and bring it back down through the loop.

Figure 14-16 — Running bowline.

1.8.10 Becket Bend

Use a becket bend to tie two lines of unequal size together or to tie a line to an eye. The becket bend will draw tightly, but will loosen when the line is slackened. The becket bend is stronger than the square knot, and is more easily untied than the square knot.

To tie a becket bend (*Figure 14-17*):

1. Take a bight in the larger of the two lines.
2. Using the smaller of the two lines, put its end up through the bight. Then put it around the standing part of the larger line first because it will have the strain on it and then around the running end of the larger line.
3. Put the end of the smaller line under its standing part. The strain on the standing part will hold the end.

Figure 14-17 — Becket bend.

Notice in the double sheet or becket bend that the end of the smaller line goes under its standing part both times.

1.8.11 Clove Hitch

The clove hitch is one of the most widely used knots (*Figure 14-18).* You can use it to fasten a rope to a timber, pipe, or post. You can also use it to make other knots. This knot puts very little strain on the fibers when the rope is put around an object in one continuous direction. You can tie a clove hitch at any point in a rope. A clove hitch will not jam or pull out; however, if a clove hitch is slack, it might work itself out, and for that

Figure 14-18 — Clove hitch.

reason, it is a good idea to make a half hitch in the end, as shown in *Figure 14-19*, *View 1*. A half hitch never becomes a whole hitch. Add a second one and all you have is two half hitches, or double half-hitches, as shown in *Figure 4-19*, *View 2*.

Figure 14-19 — Half hitch.

1.8.12 Scaffold Hitch

The scaffold hitch is used to support the end of a scaffold plank with a single line. To make the scaffold hitch:

1. Lay the running end across the top and around the plank, then up and over the standing part (*Figure 14-20*, *View 1*).
2. Bring a doubled portion of the running end back under the plank to form a bight at the opposite side of the plank (*View 2*).
3. The running end is taken back across the top of the plank until it can be passed through the bight (*View 3*).
4. Make a loop in the standing part above the plank (*View 4*).
5. Pass the running end through the loop and around the standing part and back through the loop (*View 5*).

Figure 14-20 — Scaffold hitch.

1.8.13 Barrel Hitch

A Barrel hitch can be used to lift a barrel or other rounded object, either in a horizontal or vertical position.

To sling a barrel horizontally (*Figure 14-21*):

1. Start by making a bowline with a long bight.
2. Bring the line at the bottom of the bight up over the sides of the bight.
3. Place the two “ears” thus formed over the end of the barrel.

Figure 14-21 — Barrel hitch.

To sling a barrel vertically (*Figure 14-22)*:

1. Pass the line under the bottom of the barrel, bring it up to the top, and then form an overhand knot, (*View 1*).
2. While maintaining slight tension on the line, grasp the two parts of the overhand knot and pull them down over the sides of the barrel (*View 2*).
3. Pull the line snug and make a bowline over the top of the barrel (V*iew 3*).

1.9.0 Splicing Fiber Line

When it is necessary to join lengths of line, a splice should be used, rather than a knot.

Figure 14-22 — Vertical barrel hitch.

A properly made short splice will retain up to 100 percent of the strength of the line, while a knot will retain only 50 percent. “Splicing” means the joining of two separate lines. It also means the retracing of the unlaid strand of the line back through its own strands in the standing part of the line. The four general types of splices in fiber line commonly used in rigging work are: eye, short, long, and back splices. Once you learn how to make one type, the others should not be difficult.

1.9.1 Eye Splice

The principal use of an eye splice is to make an eye in the end of a line. The eye is useful in fastening the line to a ring or hook. It can also be made up with a thimble. A thimble is a grooved ring that may be set in the eye of a line to prevent chafing. The eye splice is estimated as being 90 percent as strong as the line itself.

To make an eye splice, you unlay (untwist) the strands in the end of your line about five turns, and splice them into the standing part of the line by tucking the unlaid strands from the end into the standing part. An original round of tucks plus two additional complete rounds is enough for an ordinary eye splice.

With large lines, you must whip the ends of your strands before you start; otherwise, they will

Figure 14-23 — Working the fid.

frazzle out and cause you trouble. Large lines must also be seized at the point where unlaying stops or you will have trouble working them. With any lineup to about 2 inches (50 mm), you can open the strands in the standing part with your fingers.

With larger lines, you use the fid. A fid is a tapered and pointed tool made from maple, hickory, or other hardwood. *Figure 14-23* shows you the knack of working the fid in making an eye splice.

Lay your line out along the deck with the end to your right. Bend it back until your eye is the size you want it, and shove the fid through the standing part at the right spot to raise the top strand. Shove the fid through the rope away from you with your right hand as you hold the line with your left. Take the raised strand with your left finger and thumb, and hold it up while you pull out the fid. Drop the fid, pick up the proper strand in the end, and tuck it through the raised strand from outboard toward you, as shown in *Figure 14-23*.

Your first round of tucks must be taken in proper order or you will come out all fouled up. Separate the strands in the end and hold them up, as shown in *Figure 14-24*, *View 1*. The middle strand facing you always tucks first. Be sure you keep the right-hand strand (*View 2*) on the side of the line that is toward you. You tuck that one next, over the strand you just tucked the other one under, and under the strand just below it (View 3).

Now turn the whole thing over. You can see (*View 4*) that you now have only one strand from the end left untucked, and only one strand in the standing part that does not already have a strand under it. Be sure you tuck your last strand also from outboard toward you, as shown in *View 5*.

The first round of tucks is the big secret. The rest is easy. Simply tuck each strand from the end over the strand of the standing part, which it is now above, and under the next strand below that one, until you have tucked each strand twice more besides the original tuck. Three tucks to each strand in all is enough.

Figure 14-24 — Making an eye splice.

1.9.2 Short Splice

In a short splice, the ends of a line are joined together or the ends of two different lines are joined, causing an increase in the diameter of the line for a short distance. This splice should NOT be used where the increase in the diameter of the line would affect operation. One purpose for which you may find the short splice especially useful is in making endless slings. It is also used for making straps. Slings and straps are made of pieces of line with their own ends short-spliced together. Where possible, use a short splice, rather than a long splice; the short splice requires less line and can be fashioned more quickly than the long splice.

In making a short splice:

1. Unlay both ends of the lines about seven turns (*Figure 14-25*, *View 1*) and put a temporary whipping on each of the loose strands.
2. "Marry" the ends together. In marrying, the technique is to interlace the loose strands of one line with the loose strands of the other line. When this is completed properly, each loose strand should be between the two loose strands of the other line. With the strands in this manner, start making the tucks, following the principle of "over one and under one" (*View 2*).
3. One side of the splice can be made with three tucks, and then the other side will be made identically. Three complete tucks of each strand should be sufficient to

ensure a safe splice (*View 3*).

4. As a finishing touch, cut off all loose ends and roll and pound the splice on a hard surface (*View 4*).

Figure 14-25 — Making a short splice.

1.9.3 Long Splice

In a long splice, either the ends of a line are joined together or the ends of two different lines are joined without increasing the diameter of the line. The strength of a properly made long splice will be equal to that of the line itself. The long splice is ideal for joining two lines where the line will be run over pulleys in a block. A short-spliced line would not serve this purpose since the diameter of the line at the point of splicing is larger than that of the remaining portion and may not pass over the pulleys in the block properly. The long splice also has a neater appearance than the short splice.

To make a long splice:

1. Unlay the ends about 15 turns and arrange the strands as shown in *Figure 14-26*, *View 1*.
2. Using two opposing strands, begin unlaying one and follow immediately laying its opposing strand tightly into the left groove (*Figure 14-26*, *View 2*). Be sure you choose the correct pairs of strands for opposites. This is important. To determine the correct pair, try laying one of the tucking ends into the opposite standing line. The strand that this tucking end tends to push out and replace will be the correct opposing strand. In the process of replacing one strand with its opposing tucking end, keep a close watch on the marriage back at the starting place. If the other loose tucking ends are allowed too much freedom, they will divorce themselves from the original marriage. This creates quite a puzzle for the splicer because the lines do not fit up correctly, and no matter which two strands are chosen, the splicer seems to end up with a stranger between them, or else the last tucking ends have two strands between them. Therefore, it is important to keep the marriage intact when replacing one strand with another. Cut off all the remainders of the ends close up, then roll and pound the line so the tucks will settle in tightly. As soon as you have gone far enough with the first tucking end to have its end left to make an overhand knot and two tucks, stop and tie the ends together. This procedure must be done in the correct direction; the ends must stand out away from the standing part, not alongside.
3. Now, select two more opposing strands from the marriage in the same manner

as before. Be careful to pick the correct two strands. Proceed to unlay and replace (down tight) as you did the first pair-this time in the opposite direction. When the proper place is reached, tie a knot (*View 3*).

4. You now have two opposing strands with which you have nothing to do but make an overhand knot. If at this point there happens to be a standing strand running between them, a wrong choice has been made in choosing opposing strands (pairs) during one of the first two steps. The solution is to bring one or the other of these first two back and redo it with the correct pair. When completed, the splice should look similar to the example shown in *View 4*.
5. After all three overhand knots have been correctly tied, start tucking all the loose ends over one and under one, twice each.
6. Cut off all the remainders of the ends close up, then roll and pound the line so the tucks will settle in tightly. When completed, the splice will look like *View 4*.

Figure 14-26 — Making a long splice.

1.9.4 Back Splice

In a back splice, the strands at the end of a line are spliced back into its own strands. This splice is used to prevent a line from unlaying or unraveling when an enlargement at the end of the line is not objectionable.

The back splice starts from a crown knot. The procedure for making a back splice is shown in *Figure 14-27*.

After you have hauled the crown down tight by heaving on each of the three strands, proceed to lay up the back splice. This merely requires splicing the three loose strands back into the line, following the same principle as with the eye and short

Figure 14-27 — Making a back splice.

splice—over one and under one.

Because the back splice leaves a lump in the line, it should not be used where there is a possibility of the enlarged end hanging up, as might be the case if it were run through hoisting blocks.

1.10.0 Splicing Nylon Line

Nylon line can hold a load even when many strands are abraded. Normally, when abrasion is local, the line may be restored for use by cutting away the chafed section and splicing the ends. Chafing and stretching do not necessarily affect the load-carrying ability of nylon line.

Splicing nylon line is similar to splicing manila; however, friction tape is used instead of seizing stuff for whipping the strands and line, and because it is smooth and elastic, nylon line requires at least one tuck more than does manila. For heavy loads, a back tuck should be taken with each strand.

Summary

This chapter introduced you to the basics of fiber line. You learned the materials and characteristics of natural fiber line as well as some calculations to measure the strength of those lines. You learned some important knots, hitches, and bends that will help you when you need to move materials. You were introduced to some splices that will help you mend deteriorated line. These techniques and your ability to assess the material conditions of the fiber line will help insure a safe and effective project.

Always remember to keep your line clean and in good working order. Poorly maintained fiber line can be very dangerous to work with, so always follow prescribed safety precautions.

Review Questions (Select the Correct Response)

1. What is the primary reason manila line is preferred for use as standard issue line?

   A. It is resistant to wear.
   B. It is waterproof.
   C. It doesn't melt.
   D. It is easy to handle.

2. The primary reason for the use of nylon line is that it ________.

   A. is waterproof
   B. is resistant to abrasion
   C. resumes normal length after being stretched
   D. has a breaking strength that is nearly 3 times greater than that of manila line

3. **(True or False)** Fiber line is fabricated in three twisting operations.

   A. True
   B. False

4. Which, if any, of the following types of line is formed from three twisting operations in a right-hand direction?

   A. Hawser-laid
   B. Shroud-laid
   C. Cable-laid
   D. None of the above

5. **(True or False)** You may have to order line by diameter rather than circumference, and refer to it as rope.

   A. True
   B. False

6. Soap is not used to clean fiber line because ________.

   A. it shrinks the line
   B. it creates abrasion
   C. it causes deterioration of fibers
   D. it takes the oil out of the line

7. When nylon line becomes slippery with grease or oil, it should be cleaned with what solvent(s)?

   A. Acetone only
   B. Either kerosene or diesel fuel
   C. Alcohol or gasoline
   D. Gasoline only

8. Which of the following fabrics should you use to apply whippings to a line?

A. Rope yarn
B. Marline
C. Houseline
D. Twine

9. **(True or False)** When nylon line is properly handled and maintained, it should last five times longer than manila line subjected to the same use.

A. True
B. False

10. Which of the following agents can cause damage to a line that is hard to detect by visual examination?

A. Storage room containing chemicals
B. Lime
C. Direct sunlight
D. Each of the above

11. What does breaking strength refer to when a load is applied to a line?

A. Maximum tension prior to parting
B. Minimum tension prior to parting
C. Maximum shear prior to parting
D. Minimum shear prior to parting

12. Why is manila line stronger than sisal line?

A. Line direction of fiber
B. Type of fiber
C. Length of fiber
D. Diameter of fiber

13. The breaking strength of a line is considerably higher than its safe working load to account for what factor?

A. The different applications of pressure due to load sizes
B. The strain imposed by bending over sheaves in a block
C. Excessive vibration
D. Exposure to moisture

14. You are going to use a new 2-inch manila line to hoist a load, and you do not have tables to use to determine the safe working load (SWL) of the line. This situation requires you to use the “rule of thumb” formula to calculate the SWL for the 2-inch line. By doing so, you determine the SWL for the line is_ .

A. 400 pounds
B. 600 pounds
C. 800 pounds
D. 900 pounds

15. What is the breaking strength of a 2 1/2-inch fiber line?

A. 4625 pounds
B. 4825 pounds
C. 5225 pounds
D. 5625 pounds

16. **(True or False)** The safety factor of a line is the ratio between the breaking strength and the safe working load.

A. True
B. False

17. Nylon has a breaking strength approximately three times greater than that of manila line. What is the breaking strength of a 2–inch nylon line?

A. 7,600 pounds
B. 8,600 pounds
C. 9,600 pounds
D. 10,600 pounds

18. Nylon line can be stretched what percentage of its length before it will part?

A. 20%
B. 30%
C. 40%
D. 50%

19. Although nylon line is superior in many ways to manila line, what characteristic can cause it to be hazardous?

A. It is very smooth and slips through the hands easily.
B. It may part when stretched more than 30%.
C. The snapback is severe when a heavy strain is released.
D. Freezing produces a slight loss of stretch.

20. The free or working end of a line is known as the ________.

A. bight
B. running end
C. tag end
D. open end

21. What type of knot is best used to tie two lines of the same size together so they will not slip?

A. Reef
B. Figure eight
C. Overhand
D. Sheepshank

22. Which of the following types of knots is used to take a load off a weak section out of line and can also be used to shorten a line?

    A. Reef
    B. Figure eight
    C. Overhand
    D. Sheepshank

23. When tying lines together that are unequal in size, you should use what type of knot?

    A. Becket bend
    B. Bowline
    C. Running bowline
    D. Half hitch

24. A free-running lasso that will not tighten up on the standing part of the line is provided by what knot?

    A. Bowline
    B. Running bowline
    C. Spanish bowline
    D. French bowline

25. When tying up timber or anything that is round or nearly round, you should use what type of hitch?

    A. Barrel
    B. Clove
    C. Half
    D. Scaffold

26. **(True or False)** A properly made short splice will retain up to 50% of the strength of the line, while a properly tied knot will retain 100% of its strength.

    A. True
    B. False

27. What type of tape is used for whipping the strands and lines in nylon line instead of seizing stuff as in manila line?

    A. Duct
    B. Aluminum
    C. Friction
    D. Strapping

28. Because nylon line is smooth and elastic, at least how many extra tucks are required when splicing it?

A. One
B. Two
C. Three
D. Four

29. What type of splice should be used to run freely through a block?

A. Back
B. Long
C. Short
D. Eye

30. When there is not much overlap for splicing, you should use what type of splice?

A. Back
B. Long
C. Short
D. Eye

31. **(True or False)** A back splice should be used to prevent a line from unlaying or unraveling at the end of a line.

A. True
B. False

Trade Terms Introduced in this Chapter

Abraded	To wear down or rub away by friction
Bight	A curved section or slack part in a rope
Cordage	Collective name for rope and other flexible lines used for such purposes as wrapping, hauling, and lifting
Marline	A light rope (small stuff) made of two of loosely twisted fiber strands, sometimes tarred, laid up left-handed
Sheaves	A wheel or disk with a grooved rim used as a pulley
Unlaying	To untwist a rope; to separate its strands

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Cargo Specialist Handbook, Department of the Army, Washington DC, 1999

Hoisting and Rigging Safety Manual, Construction Safety Association of Ontario*, Etobicoke, Ontario Canada, 2007*

Rigging Techniques, Procedures, and Applications, FM 5-125, Department of the Army, Washington DC, 2001

Wire and Fiber Rope and Rigging, S9086-UU-STM-010/CH-613R3, Naval Ship's Technical Manual, Commander, Naval Sea Systems Command, Washington DC, 1999

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

___

___

___

(Optional) Correction

___

___

___

(Optional) Your Name and Address

___

___

___

Chapter 15

Wire Rope

Topics

To hear audio, click on the box.

Overview

As a Seabee Steelworker, you will be tasked, from time to time, with an important construction task: setting up rigging to hoist loads. You will be expected to perform these tasks safely. Safety is paramount while doing any job, but it is especially important when hoisting heavy loads.

This chapter presents information on how to set up and handle wire rope for rigging, and in addition, it will give you formulas for determining the safe working loads.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe wire rope fabrication and use.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	S T E E L W O R K E R B A S I C
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet metal and Fiberglass Duct		
Welding Quality Control		
Flux Cored Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 WIRE ROPE

During the course of a project, Seabees often need to hoist or move heavy objects. Wire rope is used for heavy-duty work.

Wire rope is stronger, lasts longer, and is much more resistant to abrasion than fiber line, so wire rope is used for hoisting tasks too heavy for fiber line to handle. Also, many of the movable components on the hoisting devices and attachments are moved by wire rope.

Wire rope is an intricate device made up of a number of precise moving parts designed and manufactured to maintain a definite relationship with one another. This relationship ensures that the wire rope has the flexibility and strength crucial to professional and safe hoisting operations.

The following paragraphs discuss the characteristics, construction, and use of many types of wire rope. We will also discuss the safe working load, use of attachments and fittings, and procedures for the care and handling of wire rope. You can obtain further information about wire ropes from *Naval Ships' Technical Manual NSTM Chapter 613, Wire and Fiber Rope and Rigging.*

1.1.0 Construction

Wire rope consists of three parts: wires, strands, and core, as shown in *Figure 15-1*. In the manufacture of rope, a predetermined number of wires are laid together to form a strand. Then a specific number of strands are laid together around a core to form the wire rope.

Figure 15-1 — Fabrication of wire rope.

1.1.1 Wires

The basic unit of wire rope construction is the individual wire, which may be made of steel, iron, or other metal, in various sizes. The number of wires to a strand varies, depending on the purpose for which the rope is intended. The number of strands per rope and the number of wires per strand designate wire rope. Thus, a 1/2 inch 6 X 19 rope will have 6 strands with 19 wires per strand; but will have the same outside diameter as a 1/2 inch 6 X 37 wire rope, which will have 6 strands with 37 wires of much smaller size per strand. Wire rope made of a small number of large wires is more resistant to external abrasion and breaking, but is less flexible than a similar size wire rope made of a large number of small wires.

1.1.2 Strands

The design arrangement of a strand is called the construction. The wires in the strand may be all the same size or a mixture of sizes. The most common strand constructions are Ordinary, Seale, Warrington, and Filler (*Figure 15-2*).

Ordinary strand construction is made of wires all the same size.

Seale construction uses larger diameter wires on the outside of the strand to resist abrasion, and smaller wires on the inside to provide flexibility.

Warrington construction alternates large and small wires to combine great flexibility with resistance to abrasion.

Filler construction uses small wires to fill in the valleys between the outer and inner rows of wires to provide good abrasion and fatigue resistance.

Figure 15-2 — Common strand construction.

1.1.3 Core

The core is the element around which the strands are laid to form the rope. It may be a hard fiber, such as manila, hemp, plastic, paper, or sisal; a wire strand; or an independent wire rope. Each type of core serves the same purpose: to support the strands laid around it (*Figure 15-3*).

A fiber core offers the advantage of increased flexibility. Also, it serves as a cushion to reduce the effects of sudden strain and acts as a reservoir for the oil to lubricate the wires and strands to reduce friction between them. Wire rope with a fiber core is used in places where flexibility is important.

A wire strand core not only resists heat more than a fiber core, but it also adds about 15 percent to the strength of the rope. On the other hand, the wire strand core makes the rope less flexible than a fiber core.

An independent wire rope is a separate wire rope over which the main strands of the rope are laid. It usually consists of six seven-wire strands laid around either a fiber core or a wire strand core. This core strengthens the rope more, provides support against crushing, and supplies maximum resistance to heat.

Wire rope may be made by either of two methods. If the strands or wires are shaped to conform to the curvature of the finished rope before laying up, the rope is called preformed. If they are not shaped before fabrication, the rope is called non-preformed.

Figure 15-3 — Core construction.

The most common type of manufactured wire rope is preformed. When cut, preformed wire rope tends not to unlay, and it is more flexible than non-preformed wire rope. With non-preformed wire rope, twisting produces a stress in the wires; and when it is cut or broken, the stress causes the strands to unlay.

WARNING

When non-preformed wire rope is cut or broken, the almost instantaneous unlaying of the wires and strands can cause serious injury to someone careless or unfamiliar with this characteristic of non-preformed wire rope.

1.2.0 Grades

Wire rope is made in a number of different grades. Three of the most common are mild ***plow steel***, plow steel, and improved plow steel.

1.2.1 Mild Plow Steel

Mild plow steel wire rope is tough and pliable. It can stand up under repeated strain and stress and has a tensile strength, or resistance to lengthwise stress, of from 200,000 to 220,000 pounds per square inch (psi). These characteristics make it desirable for cable tool drilling and other purposes where abrasion is encountered.

1.2.2 Plow Steel

Plow steel wire rope is unusually tough and strong. It has a tensile strength of 220,000 to 240,000 psi. This wire rope is suitable for hauling, hoisting, and logging.

1.2.3 Improved Plow Steel

Improved plow steel wire rope is one of the best grades of rope available, and most, if not all, of the wire rope in your work in the NCF will probably be made of this material. It is stronger, tougher, and more resistant to wear than either plow steel or mild plow steel. Each square inch of improved plow steel can withstand a strain of 240,000 to 260,000 psi. This wire rope is especially useful for heavy-duty service, such as cranes with excavating and weight-handling attachments.

1.3.1 Lays

The term lay refers to the direction of the twist of the wires in a strand and the direction that the strands are laid in the rope. Depending on the intended use of the rope, in some instances, both the wires in the strand and the strands in the rope are laid in the same direction; in other instances, the wires are laid in one direction and the strands are laid in the opposite direction. Most equipment manufacturers specify the types and lays of wire rope to be used on a specific piece of equipment. Be sure and consult the operator's manual for proper application.

The five types of lays used in wire rope are as follows:

1. Right Regular Lay: In right regular lay rope, the wires in the strands are laid to the left, while the strands are laid to the right.
2. Left Regular Lay: In left regular lay rope, the wires in the strands are laid to the right, while the strands are laid to the left. In this lay, each step of fabrication is exactly opposite from the right regular lay.
3. Right Lang Lay: In right lang lay rope, the wires in the strands and the strands in the rope are laid in the same direction; in this instance, the lay is to the right.
4. Left Lang Lay: In left lang lay rope, the wires in the strands and the strands in the rope are also laid in the same direction; in this instance, the lay is to the left (rather than to the right as in the right Lang lay).
5. Reverse Lay: In reverse lay rope, the wires in one strand are laid to the right, the wires in the nearby strand are laid to the left, the wires in the next strand are laid to the right, and so forth, with alternate directions from one strand to the other. Then all strands are laid to the right.

The five different lays of wire rope are shown in *Figure 15-4*.

Figure 15-4 — Lays of wire rope.

1.4.0 Lay Length

The length of a wire rope lay is the distance measured parallel to the center line of a wire rope in that a strand makes one complete spiral or turn around the rope.

The length of a strand lay is the distance measured parallel to the centerline of the strand in that one wire makes one complete spiral or turnaround the strand. A wire rope lay length measurement is shown in *Figure 15-5*.

Figure 15-5 — Lay length of wire rope.

1.5.0 Classification

The main types of wire rope used by the NCF consist of 6, 7, 12, 19, 24, or 37 wires in each strand. Usually, the rope has six strands laid around a fiber or steel center.

The two most common types of wire rope, 6x19 and 6x37 ropes, are illustrated in views A and B of *Figure 15-6*, respectively. The 6x19 type of rope, having six strands with 19 wires in each strand, is commonly used for rough hoisting and skidding work where abrasion is likely to occur.

The 6x37 wire rope, having six strands with 37 wires in each strand, is the most flexible of the standard six-strand ropes. It is particularly suitable when small sheaves and drums are to be used, such as on cranes and similar machinery, but will not stand abrasive wear as well as the 6x19 wire rope.

Figure 15-6 — (A) 6x19 wire rope, (B) 6x37 wire rope.

1.6.0 Selection

You must consider several factors when you select a wire rope for use in a particular type of operation. It is impossible to manufacture a wire rope that can withstand all of the different types of wear and stresses. Therefore, selecting a rope is often a matter of compromise. You must sacrifice one quality to have some other, more urgently needed characteristic.

1.6.1 Tensile Strength

Tensile strength is the strength necessary to withstand a certain maximum load applied to the rope. Tensile strength is the average strength of new rope under laboratory conditions. This is determined by wrapping the rope around two large-diameter capstans and slowly tensioning the line until it breaks. The manufacturer's recommended working load is determined by taking the tensile strength and dividing it by a factor that more accurately reflects the maximum load that should be applied to a given rope. It includes a reserve of strength measured in a so-called factor of safety.

1.6.2 Crushing Strength

Crushing strength is the strength necessary to resist the compressive and squeezing forces that distort the cross section of a wire rope as it runs over sheaves, rollers, and hoist drums when under a heavy load. Regular lay rope distorts less in these situations than lang lay.

1.6.3 Fatigue Resistance

Fatigue resistance is the ability to withstand the constant bending and flexing, such as wire rope running continuously on sheaves and hoist drums. Fatigue resistance is particularly important when the wire rope must be run at high speeds. Such constant and rapid bending of the rope can break individual wires in the strands. Lang lay ropes are best for service requiring high fatigue resistance. Ropes with smaller wires around the outside of their strands also have greater fatigue resistance since these strands are more flexible.

1.6.4 Abrasion Resistance

Abrasion resistance is the ability to withstand the gradual wearing away of the outer metal as the rope runs across sheaves and hoist drums. The rate of abrasion depends mainly on the load carried by the rope and the running speed. Generally, abrasion resistance in a rope depends on the type of metal the rope is made of, and the size of the individual outer wires. Wire rope made of the harder steels, such as improved plow steel, has considerable resistance to abrasion. Ropes that have larger wires forming the outside of their strands are more resistant to wear than ropes having smaller wires that wear away more quickly.

1.6.5 Corrosion Resistance

Corrosion resistance is the ability to withstand the dissolution of the wire metal that results from chemical attack by moisture in the atmosphere or elsewhere in the working environment. Ropes put to static work, such as guy wires, may be protected from corrosive elements by paint or other special dressings. Wire rope may also be galvanized for corrosion protection. Most wire ropes used in crane operations rely on their lubricating dressing to double as a corrosion preventive.

1.7.0 Measuring

The size of wire rope is designated by its diameter. The true diameter of a wire rope is the diameter of a circle that will just enclose all of its strands. Correct and incorrect methods of measuring wire rope are illustrated in *Figure 15-7*. In particular, the correct way is to measure from the top of one strand to the top of the strand directly opposite it; the wrong way is to measure across two strands side-by-side. Use calipers to take the measurement, or if calipers are not available, use an adjustable wrench and a rule.

To ensure an accurate measurement of the diameter, always measure the wire rope at three places, at least 5 feet apart. Use the average of the three measurements as the diameter of the rope.

Figure 15-7 — Correct and incorrect methods of measuring wire rope.

1.8.0 Safe Working Load

The term safe working load (SWL), in reference to wire rope, defines the load you can apply and still obtain the most efficient service from and still prolong the life of the rope. Most manufacturers provide tables that show the safe working load for their rope under various conditions. In the absence of these tables, you must apply a formula to obtain the SWL. There are rules of thumb you can use to compute the strength of wire rope. The one recommended by the Naval Facilities Engineering Command (NAVFAC) is:

$$SWL = D^2 \times 8$$

D represents the diameter of the rope in inches, and *SWL* represents the safe working load in tons. This particular formula provides an ample safety margin to account for such variables as the number, size, and location of the sheaves and drums on which the rope runs. It also includes dynamic stresses, such as the speed of operation and the acceleration and deceleration of the load. All can affect the endurance and breaking strength of the rope. Let us work an example. Suppose you want to find the SWL of a 1/2-inch wire rope. Using the formula above and converting the fraction to a decimal, your figures would be:

$$SWL = .5^2 \times 8 = .25 \times 8 = 2$$

The answer is 2, meaning that the rope has an SWL of 2 tons.

CAUTION

Do **NOT** downgrade the SWL of wire rope because it is old, worn, or in poor condition. Cut up and discarded wire rope in these conditions.

Use the manufacturer’s data concerning the breaking strength (BS) of wire rope if available. However, if you do not have that information, one rule of thumb recommended is:

$BS = C^2 \times 4$

Wire rope is measured by the diameter (*D*). To obtain the circumference (*C*) required in the formula, multiply *D* by *pi* (π), which is approximately 3.1416. Thus, the formula to find the circumference is:

$C = D \times \pi$

so the rule of thumb calculation for the breaking strength of our example is:

$BS = (.5 \times 3.1416)^2 \times 4$

The answer is 9.87, meaning the wire rope has a *BS* of 9.87 tons

1.9.1 Failure

The following is a list of conditions that indicate a wire rope should be removed from service:

1. Nominal rope diameter reduced by more than the amount shown in *Table 15-1* for the applicable size rope, or unexpected increase in lay length, as compared to previous lay length measurements

Table 15-1 — Wire rope allowable diameter reduction.

Rope Diameter (Inches)	Maximum Allowable Nominal Diameter Reduction (Inches)
5/16 and smaller	1/64
3-8 to 1/2	1/32
9/16 to 3/4	3/64
7/8 to 1 1/8	1/16
1 1/4 to 1 1/2	3/32
1 9/16 to 2	1/8
2 1/8 to 2 1/2	5/32

2. Six broken wires in one rope lay length, or three broken wires in one strand lay length
3. One broken wire within one rope lay length of any end fitting
4. Wear of 1/3 the original diameter of outside individual wires, evidenced by flat spots almost the full width of the individual wire, extending one lay length or more
5. Pitting due to corrosion, or nicks, extending one lay length or more
6. Severe kinking, crushing, or any other damage resulting in distortion of the rope structure
7. Evidence of internal corrosion, broken wires on the underside of strands or in the core

Wire can fail due to any number of causes. Here is a list of some of the common causes of wire rope failure:

- Using the incorrect size, construction, or grade of wire rope
- Dragging rope over obstacles
- Applying improper lubrication
- Operating over sheaves and drums of inadequate size
- Overriding or cross winding on drums
- Operating over sheaves and drums with improperly fitted grooves or broken flanges
- Jumping off sheaves
- Subjecting it to acid fumes
- Attaching and using fittings improperly
- Promoting internal wear by allowing grit to penetrate between the strands
- Subjecting rope to severe or continued overload

1.10.0 Attachments

Many attachments can be fitted to the ends of wire rope to connect it to other wire ropes, pad eyes, chains, or equipment.

1.11.0 End Fittings

Some quick and easy-to-change end fittings include wire rope clips, clamps, thimbles, wedge sockets, and basket sockets. Generally, these attachments permit the wire rope to have greater flexibility than a more permanent splice would allow. These attachments allow you to use the same wire rope for multiple purposes in numerous different arrangements.

1.11.1 Clips

To make an eye in the end of a wire rope, use wire rope clips, such as those shown in *Figure 15-8*. The U-shaped part of the clip with the threaded ends is the U-bolt; the other part is the saddle. The saddle is stamped with the diameter of the wire rope that the clip will fit. Always place a clip with the U-bolt on the bitter end, not on the standing part of the wire rope. If you place the clips incorrectly, you will distort or have mashed spots in the standing part or live end of the wire rope. An easy way to remember this is “Never saddle a dead horse.”

You also need to determine the correct number of clips to use and the correct spacing. Here are two simple formulas:

Remember, *D* represents the diameter of the wire rope:

Figure 15-8 — Wire rope clips.

- Number of clips = 3 x *D* + 1
- Spacing between clips = 6 x *D*

So, for the ½-inch wire rope previously used for the examples, the calculations would be:

- Number of clips = 3 x ½ = 1 ½ + 1, or 2 ½ clips. However, always round up for safety, so 3 clips is correct. Note: 2 clips is the minimum for any of the smaller sized wire ropes.
- Spacing between clips = 6 x ½ = 3-inch spacing between clips.

Another easy to remember rule of thumb is “One clip for every ¼ inch plus one.”

In addition to quantity and spacing, you must ensure that the nuts on the cable clips are tightened correctly with sufficient torque. *Table 15-2* shows the required cable clip torque for wire rope up to 1-inch diameter.

Table 15-2 — Torque for cable clips.

Clip Size (in.)	Rope Size (in.)	Minimum No. of Clips	Amount of Rope to Turn Back in Inches	* Torque in Ft.Lbs.
1/8	1/8	2	3 1/4	4.5
3/16	3/16	2	3 3/4	7.5
1/4	1/4	2	4 3/4	15
5/16	5/16	2	5 1/4	30
3/8	3/8	2	6 1/2	45
7/16	7/16	2	7	65
1/2	1/2	3	11 1/2	65
9/16	9/16	3	12	95
5/8	5/8	3	12	95
3/4	3/4	4	18	130
7/8	7/8	4	19	225
1	1	5	26	225
If a pulley (sheave) is used for turning back the wire rope, add one additional clip.				
If a greater number of clips are used than shown in the table, the amount of turnback should be increased proportionately.				
*The tightening torque values shown are based upon the threads being clean, dry, and free of lubrication.				

Another type of wire rope clip is the twin-base wire clip, sometimes referred to as the universal or two-clamp, shown in *Figure 15-9*. Since both parts of this clip are shaped to fit the wire rope, correct installation is almost certain. This considerably reduces potential damage to the rope. The twin-base clip also allows for a clean 360° swing with the wrench when the nuts are being tightened.

Figure 15-9 — Twin-base wire rope clip.

1.11.2 Clamps

Wire rope clamps (*Figure 15-10*) are used to make an eye in the rope with or without a thimble; however, a clamp is normally used without a thimble. The eye will have approximately 90 percent of the strength of the rope. The two end collars should be tightened with wrenches to force the wire rope clamp to a good, snug fit. This squeezes the rope securely against each other.

Figure 15-10 — Wire rope clamp.

1.11.3 Thimble

When the wire rope is terminated with a loop, there is a risk that it will bend too tightly, especially when the loop is connected to a device that spreads the load over a relatively small area. A thimble can be installed inside the loop to preserve the natural shape of the loop, and protect the cable from pinching and abrading on the inside of the loop (*Figure 15-8*).

Wire rope eyes with thimbles and wire rope clips can hold approximately 80 percent of the wire rope strength. After the eye made with clips has been strained, the nuts on the clips must be retightened, and periodic checks should be made for tightness or damage to the rope cause by the clips.The use of thimbles in loops is industry best practice. The thimble prevents the load from coming into direct contact with the wires.

1.11.4 Wedge Socket

The attachment used most often to attach dead ends of wire ropes to pad eyes or like fittings on earthmoving rigs is the wedge socket, shown in *Figure 15-11*. Apply the socket to the bitter end of the wire rope, as shown in the figure.

To configure a wedge socket and attach to wire rope, follow the steps listed below:

1. Remove the pin and knock out the wedge.
2. Pass the wire rope up through the socket and lead enough of it back through the socket to allow a minimum of six to nine inches of the bitter end to extend below the socket.
3. Replace the wedge and haul on the bitter end of the wire rope until the bight closes around the wedge, as shown in *Figure 15-11*. A strain of the standing part will tighten the wedge. You need at least six to nine inches on the dead end, the end of the line that does not carry the load.
4. Place one wire rope clip on the dead end to keep it from accidentally slipping back through the wedge socket. The clip should be approximately three inches from the socket. Use a clip one size smaller than normal so that the threads on the U-bolt are only long enough to clamp tightly on one strand of wire rope. The other alternative is to use the normal size clip and hop the dead end back, as shown in *Figure 15-11*. Never attach the clip to the live end of the wire rope.

Figure 15-11 — (A) Wedge socket types, (B) Parts of a wedge socket.

The advantage of the wedge socket is that it is easy to remove; just take off the wire clip and drive out the wedge. The disadvantage of the wedge socket is that it reduces the strength of wire rope by about 33 percent due to the crushing action of the wedge. Of course, reduced strength means a lower safe working load calculation.

1.11.5 Basket Socket

A basket socket is normally attached to the end of the rope with either molten zinc or ***babbitt metal***; therefore, it is a permanent end fitting. In all circumstances, dry or poured, the wire rope should lead from the socket in line with the axis of the socket.

1.11.5.1 Dry Method

The basket socket can be fabricated by the dry method (*Figure 15-12*) when facilities are not available to make a poured fitting; however, its strength will be reduced to approximately one sixth of that of a poured zinc connection.

1.11.5.2 Poured Method

The poured method or speltering is the best way to attach a closed or open socket in the field (*Figure 15-13*). "Speltering" means to attach the socket to the wire rope by pouring hot zinc around it. Speltering should be done by qualified personnel. Properly fabricated, it is as strong as the rope itself, and when tested to destruction, a wire rope will break before it will pull out of the socket. When molten lead is used vice zinc, the strength of the connection is approximately three-fourths the strength of a zinc connection.

Figure 15-12 — Attaching a basket socket by the dry method.

Figure 15-13 — Attaching a basket socket by the pouring method.

1.11.6 Splices

Permanent eyes in wire rope slings can also be made in 3/8- to 5/8-inch (9.5 to 15.9-mm) wire rope by using the nicopress portable hydraulic splicing tool and oval sleeves. The nicopress portable splicing tool (*Figure 5-14*) consists of a hand-operated hydraulic pump connected to a ram head assembly.

Included as a part of the tool kit are interchangeable compression dies for wire sizes 3/8, 7/16, 1/2, 9/16, and 5/8 inch (9.5, 11.1, 12.7, 14.3, and 15.9 mm). The dies are in machined halves with a groove size to match the oval sleeve and the wire rope being spliced. The oval sleeves (*Figure 5-15)* are available in plain copper or zinc-plated copper. To make an eye splice:

Figure 15-14 — Nicopress portable hydraulic splicing tool.

Figure 15-15 — Oval sleeve.

1. Pick an oval sleeve equal to the size of the wire rope being spliced.
2. Slide the sleeve over the bitter end of the length of rope, then form an eye and pass the bitter end through the end again (*Figure 5-16*).
3. Place the lower half of the compression die in the ram head assembly.
4. Place the oval sleeve in this lower half and drop in the upper half of the die.
5. Fully insert the thrust pin that is used to hold the dies in place when making the swage.
6. Start pumping the handle and continue to do so until the dies meet. At this time the overload valve will pop off, and a 100-percent efficient splice is formed (*Figure 5-17*).
7. Retract the plunger and remove the swaged splice.
8. Check the swage with the gauge supplied in each die set (*Figure5-18*).

This process represents a savings in time over the eye formed by using wire rope clips.

Additionally, lap splices can be made with nicopress oval sleeves (*Figure5-19*). Usually, two sleeves are needed to create a full-strength splice. A short space should be maintained between the two sleeves, as shown. Test the lap splice before placing it in operational use.

Figure 15-16 — Starting an eye splice.

Figure 15-17 — Completed eye splice.

Figure 15-18 — Swage gauge.

Figure 15-19 — Lap splice using a nicopress oval sleeve.

1.12.0 Handling and Care

To render safe, dependable service over a maximum period, wire rope must have the care and upkeep necessary to keep it in good condition. In this section, we will discuss various ways of caring for and handling wire rope. Not only should you study these procedures carefully, you should also practice them on your job to help you do a better job now. In the end, the life of the wire rope will be longer and more useful.

1.12.1 Coiling and Uncoiling

Once a new reel has been opened, to lay in back down, you can either coil it or ***fake*** it down like line. The proper direction of coiling is counterclockwise for left lay wire rope and clockwise for right lay wire rope. However, because of the general toughness and resilience of wire, it occasionally tends to resist being coiled down. When this occurs, it is useless to fight the wire by forcing down a stubborn turn; it will only spring up again. In these instances, you can throw in a back turn, as shown in *Figure 15-20*, and it will lie down properly. A wire rope when faked down will run right off as line; however, when wound in a coil, it must always be unwound.

Figure 15-20 — Throwing a back turn.

Wire rope tends to kink during uncoiling or unreeling, especially if it has been in service for a long time. A kink can cause a weak spot in the rope, which will wear out more quickly than the rest of the rope.

A good method for unreeling wire rope is to run a pipe or rod through the center and mount the reel on drum jacks or other supports so the reel is off the ground or deck, as shown in *Figure 15-21*. In this way, the reel will turn as you unwind the rope, and the rotation of the reel will help keep the rope straight. During unreeling, pull the rope straightforward, as shown in *Figure 15-21*, and try to avoid hurrying the operation; you do not want the drum to gain spinning momentum as you pull off the wire rope — it may be hard to stop. As a safeguard against kinking, never remove wire rope from a stationary reel.

To uncoil a small coil of wire rope, simply stand the coil on edge and roll it along the ground or deck as with a wheel or hoop, as illustrated in *Figure 15-21*. Never lay the coil flat on the deck or ground and uncoil it by pulling on the end; that practice can kink or twist the rope.

To rewind wire rope back onto a reel or a drum, you may have difficulty unless you remember that it tends to roll in the direction opposite the lay. For example, a right-laid wire rope tends to roll to the left.

Figure 15-21 — (A) unreeling a wire drum, (B) uncoiling wire rope.

1.12.2 Kinks

One of the most common forms of damage resulting from improperly handled wire rope is the development of a kink. If any of the improper practices in uncoiling and unreeling are used, a spiral condition is produced in the rope that is very difficult to remove. Usually this condition leads to kinking, which, if tightened under a strain, is almost certain to result in the destruction of the wire rope at that location. It is important to note that once a kink has been tightened in a wire rope, permanent and irreparable damage is done.

A loop may also be formed if an attempt is made to either lengthen or shorten the rope lay from its natural position when, at the same time, sufficient slack is present in the rope (*Figure 15-22*). Kinking can be prevented by proper uncoiling and unreeling methods and by the correct handling of the wire rope throughout its installation.

Figure 15-22 — Wire rope loop.

A loop that has not been pulled tight enough to set the wires or strands into a kink can be removed by turning the rope at either end in the proper direction to restore the lay. If a wire rope should form a loop, never try to pull it out by putting strain on either part. As soon as you notice a loop:

1. Uncross the ends by pushing them apart. See steps 1 and 2 in *Figure 15-23*. This reverses the process that started the loop.
2. Turn the bent portion over and place it on your knee or some firm object and push downward until the loop straightens out somewhat. See step 3 in *Figure 15-23*.
3. Lay the bent portion on a flat surface and pound it until smooth with a wooden mallet. See step 4 in *Figure 15-23*.

If a heavy strain has been put on a wire rope with a kink in it (*Figure 15-24*), the rope can no longer be used. *Figure 15-25* shows a permanently damaged rope that should be replaced.

Figure 15-24 — Wire rope kink.

Figure 15-23 — The correct way to remove a loop in a wire rope.

Figure 15-25 — Kink damage.

1.12.3 Reverse Bends

Whenever possible, drums, sheaves, and blocks used with wire rope should be placed to avoid reverse or S-shaped bends. Reverse bends cause the individual wires or strands to shift too much and increase wear and fatigue. For a reverse bend, the drums and blocks affecting the reversal should have a larger diameter than normal and should be spaced as far apart as possible.

1.12.4 Sizes of Sheaves

The diameter of a sheave should never be less than 20 times the diameter of the wire rope. An exception is 6x37 wire rope; it can be used with a smaller sheave because this wire rope is more flexible.

The chart shown in *Table 15-3* can be used to determine the minimum sheave diameter for wire rope of various diameters and construction.

Table 15-3 — Suggested minimum tread diameter of sheaves and drums.

Rope diameter in inches	Minimum tread diameter in inches for a given rope construction*			
	6x7	6x19	6x37	8x19
1/4	10 1/2	8 1/2		6 1/2
3/8	15 3/4	12 3/4	6 3/4	9 3/4
1/2	21	17	9	13
5/8	26 1/4	21 1/4	11 1/4	16 1/4
3/4	31 1/2	25 1/2	13 1/2	19 1/2
7/8	36 3/4	29 3/4	15 3/4	22 3/4
1	42	34	18	26
1 1/8	47 1/4	38 1/4	20 1/2	29 1/4
1 1/4	52 1/2	42 1/2	22 1/2	32 1/2
1 1/2	63	51	27	39
* Rope construction is in strands times wire per strand.				

1.12.5 Seizing and Cutting

The makers of wire rope are careful to lay each wire in the strand and each strand in the rope under uniform tension. When the ends of the rope are not secured properly, the original balance of tension is disturbed and maximum service cannot be obtained because some strands can carry a greater portion of the load than others. Before cutting wire rope, place seizing on each side of the point where you will cut the rope, as shown in *Figure 15-26*. A rule of thumb for determining the size, number, and distance between seizing is as follows:

1. The number of seizing to be applied equals approximately three times the diameter of the rope.

Example: 3- x 3/4-inch-diameter rope = 2 1/4 inches. Round up to the next higher whole number and use three seizings.

2. The width of each seizing should be 1 to 1 1/2 times as long as the diameter of the rope.

Example: 1- x 3/4-inch-diameter rope= 3/4 inch. Use a 1-inch width of seizing.

3. The seizing should be spaced a distance equal to twice the diameter of the wire rope.

Example: 2- x 3/4-inch-diameter rope = 1 1/2 inches. Space the seizing 2 inches apart.

A common method used to make a temporary wire rope seizing is as follows:

1. Wind on the seizing wire uniformly, using tension on the wire *(Figure 15-26* step 1).
2. After taking the required number of turns, twist the ends of the wires counterclockwise by hand, so the twisted portion of the wires is near the middle of the seizing *(Figure 15-26* step 2).
3. Grasp the ends with end-cutting nippers and twist up the slack *(Figure 15-26* step 3).
4. Do not try to tighten the seizing by twisting; instead, draw up on the seizing *(Figure 15-26* step 4).
5. Twist up the slack again, using nippers *(Figure 15-26* step 5). Repeat steps 4 and 5 if necessary.
6. Cut the ends and pound them down on the rope *(Figure 15-26* step 6).

Figure 15-26 — Seizing wire rope.

When the seizing is to be permanent or when the rope is 1 5/8 inches or more in diameter, use a serving bar, or iron, to increase tension on the seizing wire when putting on the turns.

A number of methods can cut wire rope successfully. One effective and simple method is to use a hydraulic type of wire rope cutter, as shown in *Figure 15-27, View A*.

Remember to seize all wire rope before you cut it. For best results in using this method, place the rope in the cutter so the blade comes between the two central seizings. With the release valve closed, jack the blade against the rope at the location of the cut and continue to operate the cutter until the

Figure 15-27 — Types of wire cutters: (A) hydraulic, (B) hammer.

blade completely severs the rope.

A second common field method is to use the hammer style cutter (*Figure 15-27, View B),* which only requires a large sledgehammer and a solid surface to make the cut.

1.13.0 Inspection

Inspect wire rope at regular intervals, the same as fiber line. In determining the frequency of inspection, carefully consider the amount of use of the rope and the conditions under which it is used.

During an inspection, examine the rope carefully for fishhooks, kinks, and worn, corroded spots. Usually, breaks in individual wires are concentrated in those portions of the rope that consistently run over the sheaves or bend onto the drum. Abrasion or reverse and sharp bends cause individual wires to break and bend back. These breaks are known as fishhooks. When wires are only slightly worn, but have broken off squarely and stick out all over the rope, the condition is usually caused by overloading or rough handling. Even if the breaks are confined to only one or two strands, the strength of the rope may be seriously reduced. When 4 percent of the total number of wires in the rope have breaks within the length of one lay of the rope, the wire rope is unsafe. Consider a rope unsafe when three broken wires are found in one strand of 6x7 rope, six broken wires in one strand of 6x19 rope, or nine broken wires in one strand of 6x37 rope.

Overloading a rope also reduces its diameter. Failure to lubricate the rope is another cause of reduced diameter since the fiber core will dry out and eventually collapse or shrink. The surrounding strands are thus deprived of support, and the rope’s strength and dependability are correspondingly reduced. Rope with a diameter reduced to less than 75 percent of its original diameter should be removed from service.

A wire rope should also be removed from service when an inspection reveals widespread corrosion and pitting of the wires. Pay particular attention to signs of corrosion and rust in the valleys, the small spaces between the strands. Since such corrosion is usually the result of improper or infrequent lubrication, the internal wires of the rope are then subject to extreme friction and wear. This form of internal, and often invisible, destruction of the wire is one of the most frequent causes of unexpected and sudden failure of wire rope. The best safeguard is to keep the rope well lubricated and to handle and store it properly.

1.14.1 Cleaning and Lubricating

Wire rope should always be cleaned carefully before lubrication. Scraping or steaming removes most of the dirt and grit that has accumulated on used wire rope. Rust should be removed at regular intervals by wire brushing. The objective of cleaning is to remove all foreign material and old lubricant from the valleys between the strands as well as the spaces between the outer wires. This allows the new lubricant to flow into the rope.

Periodic lubrication is required because wire rope is really a mechanical device with many moving parts. Each time a rope bends or straightens, the wires in the strands and the strands in the rope slide upon each other. A film of lubricant is needed on each moving part. Another important reason for lubricating iron and steel wire ropes is to prevent corrosion of the wires and deterioration of the hemp, synthetic, or steel core. There is no known method to determine the strength of a corroded rope. A rusty rope is a liability.

Deterioration from corrosion is more dangerous than deterioration from wear; corrosion ruins the inside wires —a process hard to detect by inspection. Deterioration caused by wear can be detected by examining the outside wires of the wire rope; these wires become flattened and reduced in diameter as the wire rope wears.

Both internal and external lubrication protect a wire rope against wear and corrosion. Internal lubrication can be properly applied only when the wire rope is being manufactured, and manufacturers customarily coat every wire with a rust-inhibiting lubricant and lay it into the strand. The core is also lubricated in manufacturing.

Lubrication applied in the field is designed not only to maintain surface lubrication but also to prevent the loss of the internal lubrication provided by the manufacturer. The Navy issues asphaltic petroleum oil that must be heated before using. This lubricant is known as *Lubricating Oil for Chain, Wire Rope, and Exposed Gear* and comes in two types:

- Type I, Regular: This type of lubricant does not prevent rust and is used where rust prevention is unnecessary. For example, elevator wires used inside structures that are not exposed to the weather, but still require lubrication.
- Type II, Protective: A lubricant and an anti-corrosive, it comes in three grades:
    - Grade A: For cold weather (60°F and below)
    - Grade B: For warm weather (between 60°F and 80°F)
    - Grade C: For hot weather (80°F and above)

Apply the oil (issued in 25-pound or 35-pound buckets, and 100-pound drums) with a stiff brush, or draw the wire rope through a trough of hot lubricant (*Figure 15-28*). The frequency of application depends upon service conditions; as soon as the last coating has appreciably deteriorated, renew it.

CAUTION

Avoid prolonged skin contact with oils and lubricants. Consult the Materials Safety Data Sheet (MSDS) on each item before use for precautions and hazards.

A good lubricant to use when working in the field, as recommended by *Naval Ships Technical Manual Chapter 613*, is Mil-Spec lubricant (MIL-G-18458). The NAVFAC P-404 contains added information on additional lubricants that can be used.

Do not lubricate wire rope that works a dragline or other attachments that normally bring the wire rope in contact with soils. The lubricant will pick up fine particles of material, and the resulting abrasive action will be detrimental to both the wire rope and sheave.

As a safety precaution, always wipe off any excess oil when lubricating wire rope, especially with hoisting equipment. Too much lubricant can get into brakes or clutches and cause them to fail. When

Figure 15-28 — Trough method of lubricating wire rope.

machinery is in use, its motion may sling excess oil around, over crane cabs and onto catwalks, making them unsafe.

NOTE

Properly dispose of wiping rags and used or excess lubricant as hazardous waste. See your supervisor for details on local disposal requirements.

1.15.0 Storage

Wire rope should never be stored in places where acid is or has been kept. The slightest trace of acid coming in contact with wire rope damages it at that particular spot. Many times, wire rope that has failed has been found to be acid damaged. The importance of keeping acid or acid fumes away from wire rope must be stressed to all hands.

It is especially important that wire rope be cleaned and lubricated properly before it is placed in storage. Corrosion of wire rope during storage can be virtually eliminated if the lubricant film is applied properly beforehand and if adequate protection is provided from the weather. Bear in mind that rust, corrosion of wires, and deterioration of the fiber core greatly reduce the strength of wire rope. It is not possible to state exactly the loss of strength that results from these effects, but it is certainly great enough to require close observance of precautions prescribed for protection against such effects.

Summary

This chapter discussed the characteristics, construction, and use of many types of wire rope. We also discussed the safe working load, use of attachments and fittings, and procedures for the care and handling of wire rope. Further information about wire ropes can be obtained in NSTM Chapter 613, *Wire and Fiber Rope and Rigging*.

Always remember to keep your tools and work space clean and in good working order. Wire rope is very dangerous to work with, so always follow the prescribed safety precautions and wear the proper personal protective equipment.

Review Questions (Select the Correct Response)

1. The most common strand constructions are Ordinary, Seale, Warrington, and _______.

   A. Babbitt
   B. Plow
   C. Filler
   D. Manila

2. Which of the following wire rope sizes is the most flexible?

   A. 6 x 14
   B. 6 x 19
   C. 6 x 21
   D. 6 x 37

3. The size of wire rope is designated by what characteristic?

   A. Circumference
   B. Diameter
   C. Weight per running foot
   D. Number of wires per strand

4. To measure the diameter of a wire rope, you should use which of the following methods?

   A. Measure in one place near the middle.
   B. Measure in two places near the middle, 10 feet apart; then average the results.
   C. Measure in three places, 3 feet apart; then average the results.
   D. Measure in three places, 5 feet apart; then average the results.

5. The bitter end of a wire rope should extend what minimum distance below a wedge socket?

   A. Six inches
   B. Four inches
   C. Three inches
   D. Two inches

6. Which of the following strand constructions has alternating large and small wires that provide a combination of great flexibility with a strong resistance to abrasion?

   A. Ordinary
   B. Seale
   C. Warrington
   D. Filler

7. Each square inch of improved plow steel can withstand a strain that is within what range, in pounds, of pressure?

   A. Between 100,000 and 140,000
   B. Between 240,000 and 260,000
   C. Between 300,000 and 340,000
   D. Between 440,000 and 440,000

8. What type of wire rope damage starts with the formation of a loop?

   A. Crush spots
   B. Wear spots
   C. Kinks
   D. Broken wires

9. In wire rope rigging, the diameter of the sheave should never be less than how many times the diameter of the wire rope?

   A. 10
   B. 20
   C. 30
   D. 40

10. Type II, Protective A lubricant comes in three grades. Which grade would be used in temperatures of between 80°F and 110°F?

   A. Grade A
   B. Grade B
   C. Grade C
   D. Grade D

11. What term is used to describe the technique of attaching a socket to a wire rope by pouring hot zinc around it?

   A. Seizing
   B. Speltering
   C. Wedging
   D. Swaging

12. Which of the following formulas is used to obtain the number of wire clips required for a wire rope?

   A. 6 x wire rope diameter
   B. 3 x wire rope diameter
   C. 6 x wire rope diameter + 1
   D. 3 x wire rope diameter + 1

13. Wire rope eyes with thimbles and wire rope clips can hold approximately what percentage of strength of a wire rope?

    A. 60
    B. 70
    C. 80
    D. 90

14. Why is deterioration from corrosion more dangerous than that from wear?

    A. It is quick acting.
    B. It is hard to detect.
    C. It produces toxic gases.
    D. It absorbs into your skin.

15. Which lay of wire rope has the wires in the strands laid to the left, while the strands are laid to the right?

    A. Right regular lay
    B. Left regular lay
    C. Right lang lay
    D. Left lang lay

Trade Terms Introduced in this Chapter

Babbitt metal	Any of various alloys of tin with smaller amounts of antimony and copper, used as an antifriction lining for bearings
Fake	Faking down. Line is laid out in long, flat bights, one alongside of the other instead of in a round coil
Plow steel	A high-strength steel having a carbon content of 0.5 to 0.95 percent and used primarily to make wire rope

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Cargo Specialist Handbook, Department of the Army, Washington DC, 1999

Hoisting and Rigging Safety Manual, Construction Safety Association of Ontario*, Etobicoke, Ontario Canada, 2007*

Rigging Techniques, Procedures, and Applications, FM 5-125, Department of the Army, Washington DC, 2001

Wire and Fiber Rope and Rigging, S9086-UU-STM-010/CH-613R3, Naval Ship's Technical Manual, Commander, Naval Sea Systems Command, Washington DC, 1999

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

Chapter 16

Rigging

Topics

To hear audio, click on the box.

Overview

Rigging is the method of handling materials using fiber line, wire rope, and associated equipment. Fiber line and wire rope were discussed in Chapters 14 and 15. This chapter will present information on how you can use these materials with additional equipment in various tackle and lever arrangements to form the fundamental rigging necessary to move heavy loads. Additionally, it will describe the makeup of block and tackle, reeving procedures, and common types of tackle arrangements. It also provides information on other common types of weight-handling equipment, such as slings, spreaders, pallets, jacks, planks and rollers, blocking and cribbing, and scaffolds.

Safety is paramount in importance. You will be briefed throughout this chapter on safety measures to be observed as they pertain to the various operations or particular equipment. In addition, formulas are given for your use in calculating the working loads of various weight-moving devices, such as hooks, shackles, chains, and so on. SAFE rigging is the critical link in the weight-handling process. Whenever you are making a heavy lift, keep the ORM process in mind and use the five step deliberate process:

1. Identify hazards.
2. Assess hazards.
3. Make risk decisions.
4. Implement controls.
5. Supervise (watch for change).

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the purpose, types, and maintenance of block and tackle.
2. Describe the purpose, types, and maintenance of slings.
3. Describe the purpose, types, and maintenance of chains.
4. Describe the purpose, types, and maintenance of additional lifting equipment.
5. Describe the purpose, types, and maintenance of other lifting equipment.
6. Describe the purpose, types, and maintenance of field-erected hoisting devices.
7. State the safety operating procedures for rigging evolutions.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet metal and Fiberglass Duct		
Welding Quality Control		
Flux Cored Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 BLOCK and TACKLE

A block consists of one or more sheaves fitted in a wood or metal frame supported by a shackle inserted in the strap of the block (*Figure 16-1*). A tackle is an assembly of blocks and lines used to gain a ***mechanical advantage*** in lifting and pulling (*Figure 16-2*).

A machine's mechanical advantage is the amount the machine can multiply the force used to lift or move a load. A person's strength determines the weight he or she can push or pull; this is referred to as the amount of force the individual can exert.

To move any load heavier than the force a person can exert requires the use of a machine to provide a mechanical advantage. If you use a machine that can produce a force (push or pull) on an object that is 10 times greater than the force you apply, the machine has a mechanical advantage of 10. For example, if the downward pull on a block-and-tackle assembly requires 10 pounds of force to raise 100 pounds, the assembly has a mechanical advantage of 10.

In a tackle assembly, the line is ***reeved*** over the sheave(s) of blocks. The two types of tackle systems are simple and compound. A simple tackle system is an assembly of blocks in which a single line is used (*Figure 16-2, View A*). A compound tackle system is an assembly of blocks in which more than one line is used (*Figure 16-2, View B*).

Figure 16-1 — Fiber line block.

Figure 16-2 — Tackles: (A) simple tackle, (B) compound tackle.

1.1.1 Terminology

To help avoid confusion in working with tackle, you need a working knowledge of tackle vocabulary. *Figure 16-3* will help you organize the various terms and use a common language when participating in a rigging operation.

- The block(s) in a tackle assembly change(s) the direction of pull, provide(s) mechanical advantage, or both.
- The fall is either a wire rope or fiber line reeved through a pair of blocks to form a tackle.
- The hauling part of the fall leads from the block upon which the power is exerted.
- The fixed (or standing) block is the end that is attached to a ***becket***.

- The movable (or running) block of a tackle is the block attached to the object or support being moved or hoisted. When a tackle is being used, the movable block moves and the fixed block remains stationary.
- The frame (or shell), made of wood or metal, houses the sheaves.
- The sheave is a round, grooved wheel over which the line runs. Usually the blocks have one, two, three, or four sheaves, but some blocks have up to eleven sheaves.
- The cheeks are the solid sides of the frame or shell.
- The pin is a metal axle that the sheave turns on. It runs from cheek to cheek through the middle of the sheave.
- The becket is a metal loop formed at one or both ends of a block; the standing part of the line is fastened to the becket.
- The straps (inner and outer) hold the block together and support the pin on which the sheaves rotate.
- The shallow is the opening in the block through which the line passes.
- The breech is the part of the block opposite the swallow.
- To "overhaul" means to lengthen a tackle by pulling the two blocks apart (without a load).

Figure 16-3 — Tackle nomenclature.

- To "round in" means to bring the blocks of a tackle toward each other, usually without a load on the tackle (opposite of overhaul).
- The term "two blocked" means that both blocks of a tackle are as close together as they can go. You may also hear this term called "block and block."

1.2.0 Block Construction

Blocks are constructed for use with fiber line or wire rope. Wire rope blocks are heavily constructed and have a large sheave with a deep groove. Fiber line blocks are generally not as heavily constructed as wire rope blocks and have smaller sheaves with shallower wide grooves. Wire rope requires a large sheave to prevent sharp bending. Since fiber line is more flexible and pliable than wire rope, it does not require a sheave as large as the same size of wire rope.

Figure 16-4 — Heavy duty blocks.

Blocks fitted with one, two, three, or four sheaves are often referred to as single, double, triple, and quadruple blocks, respectively. Blocks are fitted with a number of attachments, the number depending upon their use. Some of the most commonly used fittings are hooks, shackles, eyes, and rings. *Figure 16-4* shows two metal frame, heavy-duty blocks; block A is designed for manila line, and block B is for wire rope.

1.3.0 Block to Line Ratio

The size of fiber line blocks is designated by the length in inches of the shell or cheek. The size of standard wire rope blocks is controlled by the diameter of the rope. The size of nonstandard and special purpose wire rope blocks is found by measuring the diameter of one of its sheaves in inches.

Use care in selecting the proper size line or wire for the block you are using. If you reeve a fiber line onto tackle whose sheaves are below a minimum diameter, you will distort the line, and it will soon wear badly.

If you reeve a wire rope too large for a sheave, it will pinch and damage the sheave. The wire will also be damaged because of too short a radius of the bend. In addition, a wire rope too small for a sheave lacks the necessary bearing surface, puts the strain on only a few strands, and shortens the life of the wire.

With fiber line, the length of the block should be about three times the circumference of the line, but an inch or so either way does not matter too much; for example, a three-inch line may be reeved onto an eight-inch block with no ill effects. As a rule, you are more likely to know the block size than the sheave diameter, although the sheave diameter should be about twice the size of the circumference of the line used.

Remember, with wire rope, the diameter of the sheave rather than the size of the block is what matters. Wire rope manufacturers issue tables that give the proper sheave diameters used with the various types and sizes of wire rope they manufacture. In the absence of these, a rough rule of thumb is that the sheave diameter should be about 20 times the diameter of the wire. Also, remember that with wire rope, diameter is the important dimension, rather than circumference as with line.

1.4.0 Types of Blocks

There are several different types of blocks, each with a particular use. Wooden and metal blocks are of the same design except for the head or heel block, which is only metal.

1.4.1 Standing

A standing block is a block that is connected to a fixed object.

1.4.2 Traveling

A traveling (movable/running) block is a block that is connected to the load that is being lifted. It also moves with the load as the load is moved.

1.4.3 Snatch

A snatch block is a single sheave block made so that the shell opens on one side at the base of the hook to permit a rope or line to be slipped over a sheave without threading the end of it through the block (*Figure 16-5*). Snatch blocks are ordinarily used where it is necessary to change the direction of the pull on a line.

Figure 16-5 — Snatch blocks.

Figure 16-6 shows a system for moving a heavy object horizontally away from the power source using snatch blocks. This is an ideal way to move objects in limited spaces. Note that the weight is pulled by a single luff tackle, which has a mechanical advantage of three. Adding snatch blocks to rigging changes the direction of pull but does not affect the mechanical advantage. It is, therefore, wise to select the proper rigging system to use based upon the weight of the object and the type and capacity of the available power.

The snatch block used as the last block in the direction of pull to the power source is called the leading block. This block can be placed in any convenient location provided it is within 20 drum widths of the power source. This is required because the ***fairlead angle***, or ***fleet angle***, cannot exceed 2° from the center line of the drum; therefore, the 20-drum width distance from the power source to the leading block will assure the fairlead angle. If the fairlead angle is not maintained, the line could jump the sheave of the leading block and cause the line on the reel to jump a riding turn.

Figure 16-6 — Moving a heavy object horizontally along the ground with limited access using snatch blocks and fairleads.

1.5.0 Reeving Blocks

In reeving a simple tackle, lay the blocks a few feet apart. Place the blocks down with the sheaves at right angles to each other and the becket ends (if two) pointing toward each other.

To begin reeving, lead the standing part of the falls through one sheave of the block that has the greatest number of sheaves. If both blocks have the same number of sheaves, begin at the block fitted with the becket. Then pass the standing part around the sheaves from one block to the other, making sure no lines are crossed, until all sheaves have a line passing over them. Now, secure the standing part of the falls at the becket of the block containing the least number of sheaves, using a becket hitch for a temporary securing or an eye splice for a permanent securing.

With blocks of more than two sheaves, lead the standing part of the falls through the sheave nearest the center of the block. This method places the strain on the center of the block and prevents the block from toppling and the lines from being cut by rubbing against the edges of the block.

Falls are generally reeved through eight- or ten-inch wood or metal blocks in such a manner as to have the lower block at right angles to the upper block. Two 3-sheave blocks are the usual arrangement, and the method of reeving these is shown in *Figure*

16-7. The hauling part must go through the middle sheave of the upper block, or the block will tilt to the side and the falls jam when you take a strain.

If you are rigging a 3-sheave and 2-sheave block, use the method of reeving as in *Figure 16-7*, but for the deadman, use the becket on the lower instead of the upper block.

1.6.0 Types of Tackle

A block with a line led over the sheave makes applying power by changing the direction of the pull easier. Used with line and another block, it becomes a tackle and increases the power applied on the hauling part. Tackles are designated according to their uses and the number of sheaves in the blocks that are used to make the tackle. There are various types of tackle with different size blocks and all have a limited lifting capacity depending on the number of sheaves, the size blocks, and the size line used. The tackles are named for their use or from their makeup.

Figure 16-7 — Reeving two three-sheave blocks.

This section will introduce you to some of the different types of tackle in common use: single whip, runner, gun tackle, single luff, twofold purchase, double luff, and threefold purchase. The purpose of the letters and arrows in *Figures 16-8* through *16-14* is to indicate the sequence and direction in which the standing part of the fall is led in reeving the blocks. You should refer to these illustrations when you review how to reeve blocks in the next sections.

1.6.1 Single-whip

A single whip tackle consists of one single sheave (tail) block fixed to a support with a rope passing over the sheave as shown in *Figure 16-8*. It has a mechanical advantage of 1. Lifting a 100-pound load requires a pull of 100 pounds plus an allowance for friction.

1.6.2 Runner

A runner is a single-sheave movable block that is free to move along the line on which it is reeved (*Figure 16-8*). It has a mechanical advantage of 2.

Figure 16-8 — Single whip, runner.

1.6.3 Gun Tackle

The gun tackle is made up of two single-sheave blocks (*Figure 16-9*). This tackle got its name in the old days because it was used to haul muzzle-loading guns back into the battery after they had been fired and reloaded. A gun tackle has a mechanical advantage of 2. To lift a 200 pound load with a gun tackle requires 100 pounds of power, disregarding friction.

By inverting any tackle, you always gain an additional mechanical advantage of 1 because the number of parts at the "*movable block"* increases. By inverting a gun tackle, for example, you gain a mechanical advantage of 3, as shown in *Figure 16-10*.

When a tackle is inverted, the direction of pull is difficult. You can easily overcome this by adding a snatch block, which changes the direction of the pull but does not increase the mechanical advantage.

Figure 16-9 — Gun tackle.

Figure 16-10 — Inverted gun tackle.

1.6.4 Single-luff Tackle

Position one single- and one double-sheave block in the same manner as with the gun tackle. Run the line through one of the sheaves of the double-sheave block first and then to the sheave of the single-sheave block. Next, run the line through the other sheave of the double-sheave block and splice the line to the becket of the single-sheave block (*Figure 16-11*). This tackle offers a 3 to 1 mechanical advantage.

Figure 16-11 — Single luff tackle.

1.6.5 Twofold Purchase

A twofold purchase tackle consists of two double blocks (*Figure 16-12*). It has a mechanical advantage of 4.

1.6.6 Double-Luff

A double-luff tackle consists of a triple block and a double block (*Figure 16-13*). It has a mechanical advantage of 5.

Figure 16-12 — Twofold Purchase.

Figure 16-13 — Double luff tackle.

1.6.7 Three-fold Purchase

Place two triple-sheave blocks 3 feet apart with the hooks or straps facing outboard, positioning the blocks so one is face down and the other is cheek down. Start reeving in the center sheave of one block and finish in the center sheave on the other. Then splice the standing part to the becket. This tackle offers a 6 to 1 mechanical advantage (*Figure 6-14*).

Figure 16-14 — Threefold purchase.

1.6.8 Compound Tackle

A compound tackle is a rigging system using more than one line with two or more blocks. Compound systems are made up of two or more simple systems. The fall line from one simple system is secured to the hook on the traveling block of another simple system, which may have one or more blocks.

To determine the mechanical advantage of a compound tackle system, you must determine the mechanical advantage of each simple system in the compound system. Next, multiply the individual advantages to get the overall mechanical advantage. As an example, if there are two inverted luff tackles, each with a mechanical advantage of 4 (luff tackle=3 plus 1 for inverting and increasing the parts at the "*movable block*"), the mechanical advantage of this particular compound system is 4 x 4 = 16.

1.7.0 Allowance for Friction

Because of friction, some of the force applied to tackle is lost. Friction develops in tackle by the lines rubbing against each other or the shell of the block. It is also caused by the line passing over the sheaves or by the rubbing of the pin against the sheaves. Each sheave in the tackle system is expected to create a resistance equal to 10 percent of the weight of the load. Because of fiction, a sufficient allowance for loss must be added to the weight being moved in determining the power required to move the load.

As an example, you have to lift a 1,000-pound load with a twofold purchase with a mechanical advantage of 4. To determine the total force needed to lift the load, you take 10 percent of 1,000 pounds, which is 100 pounds. Multiply this figure by 4 (the number of sheaves), which gives you 400 pounds. Add this value to the load, making the total load 1,400 pounds. Once you calculate the total payload, you can then divide the total weight by the mechanical advantage of the tackle, 4 in this case. Divide 1400 by 4, resulting in 350 pounds being the force required to move the load. This is a substantial increase over the calculation you would arrive at without allowing for friction, 250 pounds of force. Always include friction in your calculations, especially if you are using human power or limited mechanical means as your power source. It will help you save setup time, keep on schedule, minimize the risk of rigging failure, and maximize rigging safety.

1.8.1 Block Safety

Safety rules you should follow when using blocks and tackle include the following:

- Always stress safety when hoisting and moving heavy objects around personnel.
- Always check the condition of blocks and sheaves before using them to make sure they are in safe working order. See that the blocks are properly greased. Make sure the line and sheave are the right size for the job.
- Remember that sheaves or drums that have become worn, chipped, or corrugated, must not be used because they will injure the line. Always find out whether you have enough mechanical advantage with the number of blocks and calculated friction allowance to make the load as easy to handle as possible.
- Do NOT use wire rope in sheaves and blocks designed for fiber line. They are not strong enough for that type of service, and the wire rope will not properly fit the sheaves grooves. Likewise, sheaves and blocks built for wire rope should never be used for fiber line.

2.0.0 SLINGS

The term “sling” covers a wide variety of configurations for fiber ropes, wire ropes, chains, and webs. Correct application of slings commonly used in construction will be explained here.

WARNING

Improper use, maintenance, or application of slings or chokers can be dangerous.

2.1.0 Slings and Rigging Gear Kits

The NCF has slings and rigging gear in the battalion Table of Allowance to support the rigging operations and lifting of Civil Engineer Support Equipment (CESE). The rigging kits 80104, 84003, and 84004 must be stored under cover and remain in the custody of the supply officer in the central tool room (CTR). The designated embarkation staff and the crane test director monitor the condition of the rigging gear.

2.2.0 Wire Rope Slings

Using wire rope slings to lift materials provides several advantages over other types of sling; they have good flexibility with minimum weight. Breaking outer wires warn of failure and allow time to react. Properly fabricated wire rope slings are very safe for general construction use.

On smooth surfaces, the basket hitch should be snubbed against a step or change of contour to prevent the rope from slipping as load is applied. The angle between the load and the sling should be approximately 60 degrees or greater to avoid slippage.

On wooden boxes or crates, the rope will dig into the wood sufficiently to prevent slippage. On other rectangular loads, the rope should be protected by guards or load protectors at the edges to prevent kinking.

Loads should not be allowed to turn or slide along the rope during a lift. The sling or the load may become scuffed or damaged.

2.3.0 Fiber Line Sling

Fiber line slings are preferred for some applications because they are pliant, grip the load well, and do not mar the load’s surface. They should be used only on light loads, however, and must never be used on objects that have sharp edges capable of cutting the line, or in applications where the sling will be exposed to high temperatures, severe abrasion, or acids.

The choice of line type and size will depend on the application, the weight to be lifted, and the sling angle. Before lifting any load with a fiber line sling, be sure to inspect the sling carefully. Fiber slings, especially manila, deteriorate far more rapidly than wire rope slings and their actual strength is very difficult to estimate.

Like other slings, fiber line slings should be inspected regularly. Look for external wear and cutting, internal wear between strands, and deterioration of fibers.

Open up the line for inspection along the length of the line by untwisting the strands, but take care not to kink them. The inside of the line should be as bright and clean as when it was new. Check for broken or loose yarns and strands. An accumulation of powder-like dust indicates excessive internal wear between strands as the line is flexed back and forth during use.

2.3.1 Synthetic Web Slings

Web slings are available in two materials – nylon and polyester (Dacron). Nylon is resistant to many alkalis, whereas polyester is resistant to many acids. Consult the manufacturer before using web slings in a chemical environment. Nylon slings are more common, but polyester slings are often recommended where headroom is limited since they stretch only half as much as nylon slings.

Synthetic web slings offer a number of advantages for rigging purposes.

- Their relative softness and width create much less tendency to mar or scratch finely machined, highly polished, or painted surfaces, and exhibit less tendency to crush fragile objects than either fiber rope, wire rope, or chain slings.
- Because of their flexibility, they tend to mold themselves to the shape of the load.
- They do not rust and thus will not stain ornamental precast concrete or stone.
- They are non-sparking and can be used safely in explosive atmospheres.
- They minimize twisting and spinning during lifting.
- Their light weight permits ease of rigging, their softness precludes hand cuts, and the danger of harm from a free-swinging sling is minimal.
- They are elastic and stretch under load more than either wire rope or chain, so they help absorb heavy shocks and cushion loads. In cases where sling stretching must be minimized, a sling of larger load capacity or a polyester sling should be used.

Synthetic web slings are available in a number of configurations useful in construction.

In place of sewn eyes, web slings are available with metal end fittings. The most common are triangle and choker hardware. Combination hardware consists of a triangle for one end of the sling and a triangle/rectangle (choker attachment) for the other end. With this arrangement, choker and basket as well as straight hitches may be rigged. Such attachments help reduce wear in the sling eyes and thus lengthen sling life (*Figure 16-15, View A*).

Figure 16-15 — Synthetic slings.

Despite their inherent toughness, synthetic web slings can be cut by repeated use around sharp-cornered objects and ***abraded*** by continually hoisting rough-surfaced loads.

Protective devices offered by most sling manufacturers can minimize these effects (*Figure 16-15, View B*).

Buffer strips of leather, nylon, or other materials sewn on the body of the sling protect against wear. Leather pads are most resistant to wear and cutting, but are subject to weathering and deterioration. They are not recommended in lengths over six feet because their stretch characteristics differ from those of webbing. On the other hand, nylon-web wear pads are more resistant to weathering, oils, grease, and most alkalis. Moreover, they stretch in the same ratio as the sling body.

Edge guards consist of strips of webbing or leather sewn around each edge of the sling. This is necessary whenever sling edges are subject to damage.

Sleeve or sliding tube wear pads are available for slings used to handle material with sharp edges. The pads are positioned on the sling where required, will not move when the sling stretches, adjust to the load, and cover both sides of the sling.

Reinforcing strips sewn into the sling eyes double or triple the eye thickness and greatly increase sling life and safety.

Coatings provide added resistance to abrasion and chemicals as well as a better grip on slippery loads. Coatings can be brightly colored for safety or load rating.

Cotton-faced nylon webbing affords protection for hoisting granite and other rough-surfaced material.

The rated capacity of synthetic web slings is based on the tensile strength of the webbing, a design factor of 5, and the fabrication efficiency. Fabrication efficiency accounts for loss of strength in the webbing after it is stitched and otherwise modified during manufacture. Fabrication efficiency is typically 80 to 85% for single-ply slings but will be lower for multi-ply slings and very wide slings.

Although manufacturers provide tables for bridle and basket configurations, these should be used with extreme caution. At low sling angles, one edge of the web will be overloaded and the sling will tend to tear.

Slings with aluminum fittings should never be used in acid or alkali environments. Nylon and polyester slings must not be used at temperatures above 194°F (90°C).

Inspect synthetic web slings regularly. Damage is usually easy to detect. Cuts, holes, tears, frays, broken stitching, worn eyes and worn or distorted fittings, and burns from acid, caustics, or heat are immediately evident and signal the need for replacement. Do not attempt repairs yourself.

2.4.0 Chain Slings

Chain slings are suited to applications requiring flexibility and resistance to abrasion, cutting, and high temperatures. However, their use should be limited to specific lifts to meet a particular requirement. This guidance will be repeated in Topic 3.0.0 which provides additional guidance concerning chains: “In the NCF, never use a chain when it is possible to use wire rope.”

Alloy steel chain grade 80 is marked with an 8, 80, or 800; grade 100 is marked with a 10, 100, or 1000. Alloy steel chain is the only type that can be used for overhead lifting.

As with all slings and associated hardware, chain slings must have a design factor of 5. In North America, chain manufacturers usually give working load limits based on a design factor of 3.5 or 4. Always check with manufacturers to determine the design factor on which their working load limits are based.

If the design factor is less than 5, calculate the working load limit of the chain by multiplying the catalog working load limit by the manufacturer's design factor and dividing by 5.

$$\frac{Catalog\ WLL}{5} \text{ x Manufacturer's D.F.} = \text{WLL (based on design factor of 5)}$$

Example – 1/2" Alloy Steel Chain

Catalog WLL = 13,000 Ibs.

Design Factor = 3.5

$$\frac{13{,}000}{5} \text{x } 3.5 = 9{,}100$$

This chain sling must be de-rated to 9,100 Ibs. for construction applications.

Wherever they bear on sharp edges, chain slings should be padded to prevent links from being bent and to protect the load. Never tie a knot in a chain sling to shorten the reach. Slings can be supplied with grab hooks or shortening clutches for such applications.

Inspect chain slings for inner link wear, and wear on the outside of the link barrels. Manufacturers publish tables of allowable wear for various link sizes. Many companies will also supply wear gauges to indicate when a sling must be retired or links replaced. Gauges or tables from a particular manufacturer should be used only on that brand of chain since exact dimensions of a given nominal size can vary from one manufacturer to another.

A competent worker should check chain slings for nicks and gouges that may cause stress concentrations and weaken links. If nicks or gouges are deep or large in area, or reduce link size below allowable wear, remove the chain from service. Any repairs must be done according to manufacturers' specifications.

Never use repair links or mechanical coupling links to splice broken lengths of alloy steel chain. They are much weaker than the chain links. Never use a chain if the links are stretched or do not move freely.

2.4.1 Metal Mesh Slings

Metal mesh slings, also known as wire or chain mesh slings, are well adapted for use where loads are abrasive or hot, or tend to cut fabric slings and wire ropes. They resist abrasion and cutting, grip the load firmly without stretching, and can withstand temperatures up to 550° (288°C). They have smooth, flat bearing surfaces, conform to

Figure 16-16 — Metal mesh sling.

irregular shapes, do not kink or tangle, and resist corrosion.

For handling loads that would damage the mesh, or for handling loads that the mesh would damage, the slings can be coated with rubber or plastic. *Figure 16-16* shows different mesh configurations.

2.5.0 Using Wire Rope and Fiber Slings

Three types of fiber line and wire rope slings commonly used for lifting a load are the endless, the single leg, and the bridle slings.

2.5.1 Endless

Endless slings are useful for a variety of applications. Endless chain slings are manufactured by attaching the ends of a length of chain with a welded or mechanical link. Endless web slings are sewn. An endless wire rope sling is made from one continuous strand wrapped onto itself to form a six-strand rope with a strand core. The end is tucked into the body at the point where the strand was first laid onto itself. These slings can be used in a number of configurations, as vertical hitches, basket hitches, choker hitches, and combinations of these basic arrangements. They are very flexible but tend to wear more rapidly than other slings because they are not normally equipped with fittings and thus are deformed when bent over hooks or choked. An endless sling is easy to handle and can be used as a choker hitch (*Figure 16-17*).

Figure 16-17 — Endless sling.

2.5.2 Single Leg

A single-leg sling, also known as an eye-and-eye sling or just commonly referred to as a strap or choker, can be made by forming a spliced eye in each end of a piece of fiber line or wire rope or any of the synthetic webs. Sometimes the ends of a piece of wire rope are spliced into eyes around thimbles, and one eye is fastened to a hook with a shackle. With this arrangement, the shackle and hook are removable.

The single-leg sling may be used as a choker hitch in hoisting by passing one eye through the other eye and over the hoisting hook (*Figure 16-18*, *View A*). The single-leg sling is also useful as a double-anchor hitch (*Figure 16-18*, *View C*). The double-anchor hitch works well for hoisting drums or other cylindrical objects where a sling must tighten itself under strain and lift by friction against the sides of the object.

Single-leg slings can be used to make up various types of bridles, also commonly called spreaders**.** Two common uses of bridles are shown in *Figure 16-19*. Either two or more single slings may be used for a given combination.

Figure 16-18 — Uses of a single leg sling.

Figure 16-19 — Multi-legged bridle slings.

2.5.3 Bridle

Two, three, or more single-leg slings with the necessary lifting lugs or attachments can be used together to form a bridle hitch (spreader) for hoisting an object. Used with a wide assortment of end fittings, bridle hitches provide excellent load stability when the load is distributed equally among the legs, the hook is directly over the load's center of gravity, and the load is raised level. Proper use of a bridle hitch requires that sling angles be carefully measured to ensure that individual legs are not overloaded.

NOTE

It is wrong to conclude that a three- or four-leg bridle will safely lift a load equal to the safe load on one leg multiplied by the number of legs. This is because there is no way of knowing that each leg is carrying its share of the load.

With a four-legged bride sling lifting a rigid load, it is possible for two of the legs to support practically the full load while the other two legs only balance it. COMFIRSTNCD strongly recommends that the rated capacity for two-leg bridle slings listed in the NSTM Chapter 613, *Wire and Fiber Rope and Rigging* be used also as the safe working load for three- or four-leg bridle hitches.

2.6.1 Sling Inspection

All slings must be visually inspected for obvious unsafe conditions before each use. A determination to remove slings from service requires experience and good judgment, especially when evaluating the remaining strength in a sling after allowing for normal wear. The safety of the sling depends primarily upon the remaining strength.

The American Society of Mechanical Engineers (ASME) provides their recommended guidance for a sling inspection program in ASME B30.9—2006, provided here in Topics 2-6-1 through 2-6-5.

The inspection process for slings is one requiring ongoing effort from the time a product arrives until it has been deemed unfit for use. The following is a breakdown for the types of inspection required.

Types of Inspection:

- **Initial Inspection**. Before using any new or repaired sling, it should be inspected to ensure that the correct sling is being used, as well as to determine that the sling meets ASME standards.
- **Frequent Inspection**. This inspection should be made by the person handling the sling each day the sling is used.
- **Periodic Inspection**. This inspection should be conducted by designated personnel, with the frequency of inspection based on the following:
  - Frequency of sling use
  - Severity of service conditions
  - Experience gained from the service life of slings used in similar applications

Periodic inspections should be conducted at least annually with a written record of each sling's condition, utilizing the identification for each sling as established by the user.

Initial and frequent inspections are relatively straightforward in terms of how often they are done. Periodic inspection is required a minimum of once a year. You may want to perform written inspections more frequently, and track rejection rates until a baseline can be established and goals can be set. If a good job is done on the frequent inspections, you may find that an annual periodic is sufficient.

ASME B30.9 requires tagging of all slings. The inspection process should begin with making sure that each sling has proper identification. The criteria for inspection can be found in the following:

2.6.1 Synthetic Web Slings

Inspection: Each day before and during use where service conditions warrant, the sling and all attachments should be inspected by a competent person and removed from service if damage or defects such as the following are visible:

1. Missing or illegible rated capacity tag
2. Cuts, snags, holes, punctures, or tears in any part of the webbing
3. Excessive abrasive wear
4. Broken or worn threads in the stitching
5. Melting or charring in any part of the sling
6. Acid or caustic burns
7. Broken, cracked, distorted, pitted, or corroded fittings
8. Any modification or alteration such as knots or tying slings together
9. Other conditions, including visual damage, that cause doubt as to the continued use of the sling

2.6.2 Synthetic Round Slings

Inspection: Before each lift, inspect the sling for the following signs of damage. If any are present, remove the sling from service.

1. Missing or illegible identification tag
2. Melting, charring, or weld splatter on any part of the sling
3. Holes, tears, cuts, abrasive wear, or snags that expose the core yarns
4. Knotting
5. Acid or alkali burns
6. Other conditions, including visual damage, that cause doubt as to the continued use of the sling

2.6.3 Wire Rope Slings

Inspection: No precise rules can be given for the determination of the exact time for replacement of a wire rope sling since many variable factors are involved. Safety in this respect depends largely upon the use of good judgment of an appointed person in evaluating remaining strength in a used sling after allowance for deterioration disclosed by inspection. Safety of sling operation depends on this remaining strength. Conditions such as the following should be sufficient for questioning sling safety and for consideration of replacement:

1. Ten randomly distributed broken wires in one rope lay, or five broken wires in one strand in one rope lay
2. Wear or scraping of one-third the original diameter of outside individual wires
3. Kinking, crushing, bird caging, or any other damage resulting in distortion of the rope structure
4. Evidence of heat damage
5. End attachments that are cracked, deformed, or worn
6. For hooks, removal criteria as stated in ASME B30.10
7. Corrosion of the rope or end attachments
8. Missing or illegible tag
9. Other conditions, including visual damage, that cause doubt as to the continued use of the sling

2.6.4 Wire Mesh Slings

Inspection: Remove the sling from service if any of the following is visible:

1. A broken weld or brazed joint along the sling edge
2. A broken wire in any part of the mesh
3. Reduction in wire diameter of 25% due to abrasion or 15% due to corrosion
4. Lack of flexibility due to deterioration of the mesh
5. Visible distortion or wear of either end fitting
6. Cracked end fitting
7. Other conditions, including visual damage, that cause doubt as to the continued use of the sling

2.6.5 Alloy Chain Slings

Inspection: It is important to inspect slings regularly. Clean slings so that marks, nicks, wear, and other conditions can be seen. Each chain link and component should be individually inspected for the following conditions:

1. Missing or illegible tag
2. Twists or bends
3. Nicks or gouges
4. Excessive wear at bearing points (refer to wear allowance chart)
5. Cracks
6. Stretch
7. Evidence of heat damage
8. Distorted, worn, or damaged master links, coupling links, or attachments, especially spread in throat opening of hooks
9. Other conditions, including visual damage, that cause doubt as to the continued use of the sling

Each link or component having any condition listed above should be marked with paint to plainly indicate rejection, and removed from service until properly repaired.

To avoid confusion and to eliminate doubt, you must **NOT** downgrade slings to a lower rated capacity. A sling must be removed from service if it cannot safely lift the load capacity for which it is rated. Slings and hooks removed from service must be destroyed by cutting before disposal. This ensures inadvertent use by another unit.

When a leg on a multi-legged bridle sling is unsafe, you have to destroy only the damaged or unsafe leg(s). Units that have the capability may fabricate replacement legs in the field, provided the wire rope replacement complies with specifications. The NCF has a hydraulic swaging and splicing kit in the battalion Table of Allowance (TOA). Kit 80092 contains the tools and equipment necessary to fabricate 3/8- through 5/8-inch sizes of wire rope slings. Before use, all fabricated slings must be proof-tested as outlined in the NSTM Chapter 613, *Wire and Fiber Rope and Rigging.*

2.7.0 Proof Testing Slings

All field-fabricated slings terminated by mechanical splices, sockets, and pressed and swaged terminals must be proof-tested before placing the sling in initial service.

The NSTM Chapter 613 has rated capacity charts enclosed for numerous wire rope classifications. You must know the diameter, rope construction, type core, grade, and splice on the wire rope sling before referring to the charts. The charts provide the vertical-rated capacity for the sling. The test weight for single-leg bridle slings and endless slings is the vertical-rated capacity (V. R. C.) multiplied by two, or (V.R.C. x 2 = sling test weight).

The test load for multi-legged bridle slings must be applied to the individual legs and must be two times the vertical-rated capacity of a single-leg sling of the same size, grade, and wire rope construction. When slings and rigging are broken out of the TOA for field use, they must be proof-tested and tagged before being returned to CTR for storage.

Check fiber line slings for signs of deterioration caused by exposure to the weather. Ensure none of the fibers have been broken or cut by sharp-edged objects.

2.8.0 Safe Working Loads of Slings

There are formulas for estimating the loads in most sling configurations. These formulas are based on the safe working load of the single-vertical hitch of a particular sling. The efficiencies of the end fittings used also have to be considered when determining the capacity of the combination.

The formula used to compute the safe working load (SWL) for a bridle hitch with two, three, or four legs (*Figure 16-20*) is:

$$SWL\,(Bridle\,Hitch) = SWL\,(Single\ Vert\ Hitch)\ x\ \frac{H}{L}\,x\ 2$$

Where:

H (Height) = the vertical height to the bridle

L (Length) = the angled length of the single vertical hitch to the bridle

Figure 16-20 — Determining bridle hitch sling capacity.

When the sling legs are not of equal length, use the smallest H/L measurement. This formula is for a two-leg bridle hitch, but it is strongly recommended it also be used for the three- and four-leg hitches.

NOTE

Do **NOT** forget it is wrong to assume that a three- or four-leg hitch can safely lift a load equal to the safe load on one leg multiplied by the number of legs.

Other formulas are as follows: **Single-basket hitch** (*Figure 16-21*): For vertical legs:

SWL = SWL (of single-vertical hitch) x 2.

For inclined legs:

SWL = SWL (of single-vertical hitch) x H divided by L x 4.

Double-basket hitch (*Figure 16-22*):

For vertical legs:

SWL = SWL (of single-vertical hitch) x 4.

For inclined legs:

SWL = SWL (of single-vertical hitch) x H divided by L x 4.

Single-choker hitch (*Figure 16-23*):

For sling angles of 45 degrees or more:

SWL = SWL (of single-vertical hitch) x 3/4 (or .75).

Sling angles of less than 45 degrees are not recommended; however, if they are used, the formula is as follows:

SWL = SWL (of single-vertical hitch) x A/B.

Figure 16-21 — Determining single basket hitch sling capacity.

Figure 16-22 — Determining double basket hitch sling capacity.

Figure 16-23 — Determining single choker hitch sling capacity.

Double-choker hitch (*Figure 16-24*):

For sling angle of 45 degrees or more:

SWL = SWL (of single-vertical hitch) x 3 divided by 4 x H divided by L x 2.

Sling angles of less than 45 degrees:

SWL = SWL (of single-vertical hitch) x A divided by B x H divided by L x 2.

Figure 16-24 — Determining double choker hitch sling capacity.

When lifting heavy loads, you should ensure that the bottoms of the sling legs are fastened to the load to prevent damage to the load. Many pieces of equipment have eyes fastened to them during the process of manufacture to aid in lifting. With some loads, though, fastening a hook to the eye on one end of each sling leg suffices to secure the sling to the load.

Use a protective pad when a fiber line or wire rope sling is exposed to sharp edges at the comers of a load. Pieces of wood or old rubber tires are fine for padding.

2.9.0 Sling Angle

When you use slings, remember that the greater the angle from vertical, the greater the stress on the sling legs. This factor is shown in *Figure 16-25*.

The rated capacity of any sling depends on the size, configuration, and angles formed by the legs of the sling relative to horizontal. A sling with two legs used to lift a 1,000-pound object will have 500 pounds of the load on each leg when the sling angle is 90 degrees. The load stress on each leg increases as the angle decreases. For example, if the sling angle is 30 degrees when lifting the same 1,000-pound object, the load is 1,000 pounds on each leg. Try to keep all sling angles greater than 45 degrees; sling angles approaching 30 degrees are considered extremely hazardous and must be avoided.

Figure 16-25 – Stress on slings at various vertical angles.

2.10.0 Storage

Wire rope slings and associated hardware must be stored either in coils or on reels, hung in the rigging loft, or laid on racks indoors to protect them from corrosive weather and other types of damage, such as kinking or being backed over. Slings are not to be left out at the end of the workday.

3.0.0 CHAINS

Chains are made up of links fastened through each other. Each link is fabricated of wire bent into an oval and welded together. The weld usually causes a slight bulge on the side or end of the link. Chain size refers to the diameter, in inches, of the wire used to fabricate the chain.

In the NCF, never use a chain when it is possible to use wire rope. Chain does not give any warning that it is about to fail. Wire rope, on the other hand, fails a strand at a time, giving you warning before failure actually occurs.

NOTE

Although chain gives no warning of failure, it is better suited than wire rope for some jobs. Chain is more resistant to abrasion, corrosion, and heat. Additionally, use chains to lift heavy objects that are hot or have sharp edges that could cut wire. When chain is used as a sling, it has little flexibility but grips the load well.

3.1.0 Inspection

First, you must be aware that chains normally stretch under excessive loading and individual links will be bent slightly. Therefore, bent links are a warning that the chain has been overloaded and may fail suddenly under load. Before lifting with a chain, make sure the chain is free from twists and kinks. A twisted or kinked chain placed under stress could fail even when handling a light load. Additionally, ensure that the load is properly seated in the hook (not on the point) and that the chain is free from nicks or other damage. Avoid sudden jerks in lifting and lowering the load, and always consider the angle of lift with a sling chain bridle.

The strength of any chain is negatively affected when it has been knotted, overloaded, or heated to temperatures above 500°F.

3.2.0 Safe Working Loads

To determine the safe working load on a chain, apply a factor of safety to the breaking strength. The safe working load is ordinarily one-sixth of the breaking strength, giving a safety factor of 6 (*Table 16-1*).

Table 16-1 — Chain Safe Working Loads.

Size*	Approximate weight per linear foot in pounds	Safe working load in pounds			
		Common iron	High grade iron	Soft steel	Special steel
1/4	0.8	512	563	619	1240
3/8	1.7	1350	1490	1650	3200
1/2	2.5	2250	2480	2630	5250
5/8	4.3	3470	3810	4230	7600
3/4	5.8	5070	5580	6000	10500
7/8	8.0	7000	7700	8250	14330
1	10.7	9300	10230	10600	18200
1 1/8	12.5	9871	10858	11944	21500
1 1/4	16.0	12186	13304	14634	26300
1 3/8	18.3	14717	16188	17807	32051

* Size listed is the diameter in inches of one side of a link.

The capacity of an open link chain can be approximated by using the following rule of thumb:

$$SWL = 8D^2 \times 1 \text{ ton}$$

Where:

D = Smallest diameter measured in inches

SWL = Safe working load in tons

Example:

Using the rule of thumb, the safe working capacity of a chain with a diameter of 3/4 inch is as follows:

Converting the fraction to a decimal, $SWL = 8D^2 = 8\ (.75)^2 = 4.5$ tons (or 9,000 lbs)

These figures assume the load is being applied in a straight pull, rather than an impact. An impact load is when an object is suddenly dropped for a distance and stopped. The impact load is several times the weight of the load.

3.3.0 Handling and Care

When hoisting heavy metal objects using chain for slings, you should insert padding around the sharp comers of the load to protect the chain links from being cut.

Store chains in a clean, dry place where they will not be exposed to the weather. Before storage, apply a light coat of lubricant to prevent rust.

Do NOT perform makeshift repairs, such as fastening links of a chain together with bolts or wire. When links become worn or damaged, cut them out of the chain, then fasten the two nearby links together with a connecting link. After the connecting link is closed, welding makes it as strong as the other links, but the welder must be fully qualified to perform the weld on the link with the available equipment. The safety of all other personnel within the area of any of the chain's future hoisting will depend on it. For cutting small-sized chain links, use bolt cutters. To cut large-sized links, use a hacksaw.

Inspect the chain to ensure it is maintained in a safe, operating condition. A chain used continuously for heavy loading should be inspected frequently. Chain is less reliable than manila or wire rope slings because the links may crystallize and snap without warning.

Examine the chain closely link by link and look for stretch, wear, distortion, cracks, nicks, and gouges. Wear is usually found at the ends of the links where joining links rub together. If you find wear, lift each link and measure its cross section.

NOTE

Remove chains from service when any link shows wear more than 25 percent of the thickness of the metal.

Replace any link that shows cracks, distortion, nicks, or cuts. However, if a chain shows stretching or distortion of more than 5 percent in a five-link section, discard and destroy the entire chain.

Remove chains from service when any link shows signs of binding at juncture points. This binding condition indicates that the sides of the links have collapsed as a result of stretching.

Before lifting with a chain, first place dunnage between the chain and the load to provide a gripping surface. For hoisting heavy metal objects with a chain, always use chaffing gear around the sharp comers on the load to protect the chain links from being cut. As chafing gear, use either planks or heavy fabric. In handling rails or a number of lengths of pipe, make a round turn and place the hook around the chain as shown in *Figure 6-26*.

4.0.0 ADDITIONAL LIFTING EQUIPMENT

In addition to block and tackle, slings, and chains, to lift objects and material, you will also use hooks, shackles, and beam clamps.

Figure 16-26 — Chain sling.

4.1.0 Hooks

The two general types of hooks available are the slip hook and the grab hook (*Figure 16-27*).

4.1.1 Slip Hooks

Slip hooks are made so the inside curve of the hook is an arc of a circle. They are used with wire rope, chains, and fiber line. Chain links can slip through a slip hook so that the loop formed in the chain can tighten under a load.

4.1.2 Grab Hooks

Grab hooks have an inside curve that is almost U-shaped so the hook will slip over a link edgeways and not allow the next chain link to slip past. Grab hooks have a much more limited range of use than slip hooks. They are used exclusively when the loop formed in the chain is not intended to close around the load.

Figure 16-27 — (A) slip, (B) grab.

4.1.3 Mousing a Hook

As a rule, a hook should always be moused as a safety measure to prevent slings or line from coming off. Mousing also helps prevent the straightening of a hook but does not add to the strength of the hook. To mouse a hook after the sling is on the hook, wrap wire or small stuff 8 or 10 turns around the two sides of the hook, then wind several turns around the wire or small stuff, and tie the ends securely (*Figure 16-28*).

Figure 16-28 — Mousing a hook.

4.1.4 Inspection

Hooks should be inspected at least once a month, but those used for heavy and continuous loading should be inspected more frequently. Pay particular attention to the small radius fillets at the neck of the hooks for any deviation from the original inner arc. Additionally, examine each hook for small dents, cracks, sharp nicks, worn surfaces, or distortions. If any of these defects are present, you must discard the hook.

4.1.5 Hook Strength

Hooks normally fail by straightening. If any deviation of the inner arc of a hook is evident, it indicates that the hook has been overloaded. Evidence of overloading a hook is easy to detect, so it is customary to use a hook that is weaker than the chain to which it is attached. Using this system, distortion of the hook will occur before the hook is overloaded. Any distorted, cracked, or badly worn hook is dangerous and should be discarded immediately.

The safe working load of a hook can be formulated by using the following rule of thumb:

SWL = 2/3 x D^2 x 1 ton.

Where:

D is the diameter (in inches) of the hook where the inside of the hook starts to arc (*Figure 16-29*).

Below is an example of the safe working capacity of a hook with a diameter of 5/8 inch:

Converting the fractions to a decimals, D^2 = .625 X .625 = .390

SWL = .666 x .390 x 2,000 lbs.= 519 pounds

In the metric system, the formula for the safe working load for hooks is as follows:

SWL = .46 x D^2 x 1 tonne

Figure 16-29 — Hook diameter.

Below is an example of the safe working

capacity of a hook having a diameter of 1.59 cm.

D = 1.59 cm

$D^2 = 2.52\ cm^2$

SWL= .046 x 2.52 cm^2 x 1 tonne = .116 tonne

4.2.0 Shackles

Shackles should be used for loads too heavy for hooks to handle (*Figure 16-30*). They provide a useful way of attaching, hauling, and lifting a load without tying directly to the object with a line, wire rope, or chain. Additionally, they can be attached to wire rope, line, or chain.

4.2.1 Safe Working Load

The formula for computing the safe working load for a shackle is as follows:

SWL = $3D^2$ x 1 ton

Below is an example of the safe working capacity of a shackle with a diameter of 5/8 inch. (See *Figure 16-31.*)

Converting the fractions to a decimals,

D^2 = .625 X .625 = .390

SWL = 3 X .390 x 2,000 lbs. = 2340 pounds

In the metric system, the formula for the safe working load for shackles is as follows:

SWL = .417 X D2 X 1 tonne

Example:

D= 1.59cm

D^2= 1.59 X 1.59 = 2.52

SWL = .417 x 2.52 x 1 tonne

SWL = 1.05 tonnes

NOTE

A hook or a shackle can actually lift more than these formulas allow, but these formulas give you the safe working load under any conditions**.**

Figure 16-30 — Two types of shackles :(A) anchor, (B) chain.

Figure 16-31 — Shackle diameter.

4.2.2 Mousing a Shackle

Mouse shackles whenever there is danger of the shackle's pin working loose or coming out due to vibration. To mouse a shackle properly, take several turns with seizing wire through the eye of the pin and around the bow of the shackle. *Figure 16-32* shows what a properly moused shackle looks like.

Figure 16-32 — Mousing a shackle.

4.3.0 Beam Clamps

Steelworkers are required to move and handle many steel beams and steel shapes. For off-loading steel from vehicles and storing for further use or staging for erection, beam clamps are much more practical than using slings or chokers, especially when the flanges are the only available parts of the load. *Figure 16-33* shows three different types of beam clamps. *View A* shows a clamp designed for use on a beam with a flat flange, either an I or an H. The clamp in *View B* may be used on beams with a circular cross-sectional area or where only one side of the flange is accessible. *View C* shows a clamp that is useful for connection to a column with a snatch block attached. The clamps shown can all be fabricated in the shop or field.

Hooks, shackles, and beam clamps must have the rated capacities and SWL permanently stenciled or stamped on them. OSHA identification tags can be acquired at no cost from Naval Facilities Expeditionary Logistics Center. Metal dog tags are authorized providing the required information is stamped onto the tags

Figure 16-33 — Types of beam clamps.

5.0.0 OTHER LIFTING EQUIPMENT

Other devices used for moving equipment include spreader bars, pallets, jacks, planks and rollers, blocks and cribbing, and scaffolds.

5.1.0 Spreader Bars

In hoisting with slings, spreader bars are used to prevent crushing and damaging the load. Spreader bars are short bars, or pipes, with eyes fastened to each end. By setting spreader bars in the sling legs above the top of the load, you change the angle of the sling leg and avoid crushing the load, particularly in the upper portion (*Figure 16-34*).

Spreader bars are also used in lifting long or oversized objects to control the sling angle (*Figure 16-35*). When spreader bars are used, make sure you do not overload the end connection. A spreader bar has a rated capacity that is the same as hooks and shackles. A good rule of thumb is the thickness of the spreaders end connection should be the same as the thickness of the shackle pin.

Figure 16-34 — Using spreader bars.

Figure 16-35 — Spreader bar used with an oversized load.

5.2.1 Pallets

Cargo pallets coupled with slings are an immense advantage on jobs that involve moving many small items staged on pallets. Spreader bars can be used often to avoid damaging the pallet and the load (*Figure 16-36*). The pallet supplies a small platform on which a number of items can be placed and then moved as a whole instead of piece-by-piece. Palletizing is clearly easier and faster than moving each item by itself.

The four basic types of pallets used in military cargo handling are the stevedore, general-purpose, sled, and warehouse pallets.

1. A stevedore pallet, which is reversible, is used to handle loose cargo at water terminals. The standard stevedore pallet is 4 feet wide, 6 feet long and 8 inches high.

   The stringers are made of 3- or 4- by 4-inch lumber. The deck boards are made of lumber 2 inches thick. The outside boards may be random widths. The outside stringers are set in 4 to 6 inches from the ends so that a pallet bridle may be inserted. The

Figure 16-36 — Cargo pallet.

inside stringers are arranged to permit easy entrance of forks for movement by forklift trucks.

2. A general-purpose pallet is a four-way-entry wood pallet, 48 inches long, 40 inches wide, and approximately 5 1/2 inches high. This pallet is used mainly for the shipment of palletized cargo and often accompanies the cargo from shipper to consignee.
3. The sled pallet is a heavy timbered platform with runners. Supplies and equipment are normally banded to the pallet.
4. A warehouse pallet is used to handle cargo in warehouses. It is much lighter than the stevedore pallet. The most common size of warehouse pallet is 48 by 48 inches, but a 40 by 48-inch size is also made. The warehouse pallet can be the open-end type that is moved by a forklift or hoisted by a pallet bridle, or the closed end type that is moved by forklift only.

When items of cargo are palletized, the tiers are laid so that one tier ties together with another to give stability to the unitized load and to keep the cargo from falling off the pallet while it is being moved. Cargo handlers can obtain greater use of the pallet area by building the load in a definite pattern whenever possible.

Commonly, packages of the same size are palletized together, and when shipped, remain on the pallet until they are used up. You may not have the luxury of having excess pallets at your job site; however, you need to have several to work efficiently. One can be loaded as the prior loaded one is being lifted, and the landed pallet is being unloaded (if necessary). After each pallet is unloaded, the hoist will return with the empty pallet for reloading. With two (or three) pallets, you are able to maintain a steady flow of material. One set of slings will be able to handle any number of pallets.

5.3.1 Jacks

To be able to place cribbing, skids, and rollers, you need to be able lift a load a short distance. Jacks are designed and built for this purpose. Jacks are also used for precise placement of heavy loads, such as beams, or for raising and lowering heavy loads a short distance. There are a number of different styles of jacks available; however, you should use only heavy-duty hydraulic jacks or screw jacks. The number of jacks you use is determined by the weight of the load and the rated capacity of the jacks. Ensure the jacks have a solid footing and are not susceptible to slipping.

Jacks are available in capacities from 5 to 100 tons. Small capacity jacks are normally operated through a rack bar or screw, and large capacity jacks are usually operated hydraulically (*Figure 16-37*).

The types of jacks typically used by Steelworkers are the following:

1. Ratchet lever jacks are rack bar jacks with a rated capacity of 15 tons. These jacks have a foot lift by which loads close to the base of the jack can be engaged (*Figure 16-37*, *View A*).
2. Steamboat ratchets (often referred to as pushing and pulling jacks) are ratchet screw jacks of 10-ton-rated capacity with end fittings that permit pulling parts together or pulling them apart. They are primarily used for tightening lines or lashings and for spreading or bracing parts in bridge construction (*Figure 16-37*, *View B*).

3. Screw jacks have a rated capacity of 12 tons. They are approximately 13 inches high when closed and have a safe rise of 7 inches. These jacks are used for general purposes, including steel erection (*Figure 16-37*, *View C).*
4. Hydraulic jacks are available in many different capacities and are used for general purposes (*Figure 16-37*, V*iew D*).

Figure 16-37 — Jacks.

5.4.0 Planks and Rollers

Planks and rollers provide you with an excellent means of moving heavy loads across the ground on a jobsite or the floor of a shop (*Figure 16-38*).

Oak planks are appropriate for most operations involving plank skids. Planks 15 feet long and 2 to 3 inches thick should be suitable. They distribute the weight of a load and provide a smooth runway surface on which to skid the load along, or on which to use rollers to ease the effort required to move the load.

Timber skids (planks) are placed longitudinally under heavy loads to distribute the weight over a greater area. (Refer again to *Figure 16-38*.) The angle of the skids must be kept low to prevent the load from drifting or getting out of control.

Skids can be greased only when horizontal movement is involved. Exercise extreme care if using grease. In most circumstances, greasing is inherently dangerous; it can cause the load to drift sideways suddenly, causing injuries to personnel, damage to equipment, and loss of the load.

Hardwood or pipe rollers can be used in conjunction with plank skids for moving heavy loads into position. Planks are placed under the rollers to provide a smooth continuous surface to enable them to roll easily. The rollers must be smooth and round to aid in the ease of movement, and long enough to pass completely under the load. The load should be supported by longitudinal wooden members to provide a smooth upper surface for the rollers to roll on. The skids placed underneath must form continuous support.

Normal practice is to place four to six rollers under the load to be moved. Place several rollers in front of the load and then slowly roll the load onto these rollers. As the load passes, pick up the rollers that are left behind the load and move them in front of the load, creating a continuous path of rollers. Turns can be made using rollers, but you must incline the front rollers slightly in the direction of the turn and incline the rear of the rollers in the opposite direction. You can make this inclination by striking them sharply with a sledgehammer. In addition, rollers can be fabricated and set on axles in side beams as a semi-permanent conveyor for lighter loads. Permanent metal roller conveyors are available and are normally fabricated in sections that can be joined together (*Figure 16-39*).

Figure 16-38 — Use of planks and rollers.

Figure 16-39 — Permanent metal roller conveyor.

5.5.0 Blocking and Cribbing

Block timbers are commonly used to provide a foundation for heavy loads or jacks. Cribbing must be used when a heavy weight must be supported at a height greater than blocking can provide. Cribbing is made up by aligning timber in tiers that run in alternate directions (*Figure 16-40*). Blocking and cribbing are often necessary as a safety measure to keep an object stationary to prevent accidents and injury to personnel working near these heavy objects.

When selecting blocking as a foundation for jacks, ensure it is sound and large enough to support the load safely. It **must** be thoroughly dry and free from grease. Additionally, it **must** be placed firmly on the ground with the load (pressure) distributed evenly.

A firm and level foundation is a paramount requirement where cribbing is used. Equally as critical, the bottom timbers **must** be placed so they rest evenly and firmly on the firm and level foundation.

Cribbing is desirable when lifting loads by jacking stages. This procedure requires blocking to be placed under the jacks, lifting the load to the maximum height the jacks can accommodate safely, placing the cribbing under the load in alternating tiers, **with no personnel under the load***,* and then lowering the load onto the cribbing.

When cribbing is not high enough or at the correct height, build up the blocking under the jacks until the jacks can bear against the load while in their lowered position. Raise the jacks again to their maximum safe height and lower onto the added cribbing. This procedure can be repeated as many times as necessary to build up the cribbing to the desired height.

Figure 16-40 — Examples of the use of cribbing.

5.6.0 Scaffolds

The term *scaffold* refers to a temporary elevated platform used to support personnel and materials, for immediate usage or for a particular phase of construction throughout the course of the work. You will use scaffolds in performing various jobs that cannot be done safely from securely placed ladders. Take a look at a few of the different types of scaffolds that you may need from time to time on the job.

5.6.1 Planking and Runway Scaffold

A planking and runway scaffold consists of single scaffold planks laid across beams of upper floors or roofs (*Figure 16-41*). It is frequently used to provide working areas or runways. Each plank should extend from

Figure 16-41 — Planking and runway scaffold.

beam to beam, with not more than a few inches of the planks extending beyond the end-supporting beam. The short overhang is essential to safe practice to prevent personnel from stepping on an unsupported plank end and falling from the scaffold.
Planks should be thick enough to support the load safely and applied without excessive sagging. When the planking is laid continuously, as in a runway, make sure the planks are laid so their ends overlap. Single plank runs may be staggered, with each plank being offset with reference to the next plank in the run.

5.6.2 Swinging Platform Scaffold

The most commonly used type of swinging scaffolding is the platform scaffold (*Figure 16-42*). The swinging platform scaffold consists of a frame with a deck of wood slats. The platform is supported near each end by iron rods, called stirrups, which have the lower blocks of fiber line fall attached to them. This tackle arrangement permits the platform to be raised or lowered as required. The tackle and platform are supported by hooks and anchors on the roof of the structure. The fall line of the tackle must be secured to a part of the platform when in final position to prevent it from falling.

Figure 16-42 — Platform scaffold.

5.6.3 Needle-Beam Scaffold

A needle-beam scaffold consists of a plank platform resting on two parallel horizontal beams, called needle beams, which are supported by lines from overhead. (*Figure 16-43.*)

Needle-beam scaffolds should be used only for the support of personnel doing light work. They are suitable for use by riveting gangs working on steel structures because of the necessity of frequent changes of location and the adaptability of this type of scaffold to different situations.

Several types of patent and independent scaffolding are available for simple and rapid assembly (*Figure 6-44*). The scaffold uprights are braced with diagonal members, and the working level is covered with a platform of planks. All bracing must form triangles, and the base of each column requires adequate footing plates for bearing area on the ground. The patented steel scaffolding is usually erected by placing the two uprights on the ground and inserting the diagonal members. The diagonal members have end fittings, which permit easy assembly.

Figure 16-43 — Needle-barn scaffold.

Figure 16-44 — Assembling prefabricated independent scaffolding.

The first tier is set on steel bases on the ground, and a second tier is placed in the same manner on the first tier with the bottom of each upright locked to the top of the lower tier. A third and fourth upright can be placed on the ground level and locked to the first set with diagonal bracing. The scaffolding can be built as high as desired, but high scaffolding should be tied into the main structure. As with blocking and cribbing, the steel bases used for the foundation to set up independent scaffolding must be set either on a flat, horizontal surface, or be sufficiently close so adjustable threaded bases can level the platform.

5.6.4 Boatswain's Chair

The boatswain's chair also comes under the heading of scaffolding (*Figure 16-45*). It is sometimes used to provide a seat for a person working above the ground.

The seat of the boatswain's chair should be at least 2 feet long, 1 foot wide, and 1 1/4 inches thick (60 cm long, 30 cm wide, and 3.1 cm thick). Make sure you always wear a safety belt when using a boatswain's chair. The safety belt should be attached to a lifeline secured to a fixed object overhead. Use a bowline to secure the lifeline to the person in the chair.

NOTE

Use a boatswain's chair only if other means are not available.

Figure 16-45 — Boatswain's chair.

5.6.5 Safety

When you are using scaffolds, safety is your number 1 priority. Failure to observe safety precautions can result in serious injury to yourself or coworkers. Some essential safety measures applicable to scaffolds are given here. Use each of them habitually.

Structural members, support ropes, and scaffold equipment must be inspected carefully each workday before using them on the job. The use of makeshift scaffolds is strictly prohibited.

When personnel are working on a scaffold with other personnel engaged directly above, either the scaffold must have an overhead protective covering or the workers on the lower scaffold must wear Navy-approved, protective hard hats to provide protection against falling material. Where the upper working level is no more than 12 feet (3.6 m) above the lower, hard hats worn by workers on the lower level will satisfy this requirement.

An overhead protective covering consists of a roof of lumber, heavy wire screen, or heavy canvas, depending upon the hazard involved. The covering should extend a sufficient distance beyond the edge of the scaffold to catch any material that may fall over the edge. A netting of screen should not be less than No. 18 gauge, U.S. standard wire, with a mesh not to exceed 1/2 inch. Screens of heavier wire or smaller mesh should be used where conditions are such that the No. 18 gauge wire or 1/2-inch mesh will not supply adequate protection. Personnel should **NOT** be required to work underneath a scaffold.

Scaffolds erected over passageways, thoroughfares, or locations where persons are working should be provided with side screens and a protective covering. A side screen is a screen paneling from the platform to an intermediate railing or from the platform to the top railing. Screening is formed of No. 16 U.S. gauge wire with 1/2-inch mesh. Screen is used to prevent materials, loose or piled, from falling off the scaffolds.

A safe means of access should be provided to all scaffolds by means of standard stairs or fixed ladders. Additionally, ensure that a scaffold is properly secured against swaying.

Personnel should not be permitted on scaffolds covered with ice or snow. In such instances, clinging ice must be removed from all guardrails, then the planking sanded or otherwise protected against slipping. Workers should not be permitted on scaffolds during a storm or high wind.

No scaffold should be used for storing materials, except those required for the immediate needs of the job. Place tools in containers to prevent their being knocked off, and secure the containers to the scaffold by line. Always make a special effort to ensure that tools, equipment, material, and rubbish do not accumulate on a scaffold to the point where safe movement is jeopardized.

Never throw or drop objects or tools from scaffolds. Hand lines should be used for raising or lowering objects when they cannot be reached easily and safely by hand. Such things as jumping or throwing material upon a scaffold platform are to be avoided at all times.

Never overload a scaffold. Furthermore, whenever possible, see that the scaffold load is uniformly distributed and not concentrated at the center of the platform.

Wire ropes and fiber lines used on suspension and swinging scaffolds should be of the best quality steel, manila, or sisal. Manila or sisal line used as lifelines should be 1 7/8 inches (51.2 mm) in circumference.

Lifelines and safety belts must be used when working on unguarded scaffolds at heights of 10 feet (3 m) and above (as well as on boatswain's chairs, as explained earlier). If working over water, personnel must wear life jackets.

Maintain all scaffolds and scaffold equipment in safe condition. Avoid making repairs or alterations to a scaffold or scaffold equipment while in use. Rather than take a chance, **NEVER** permit personnel to use damaged or weakened scaffolds.

6.0.0 FIELD-ERECTED HOISTING DEVICES

At times, due to the very nature of heavy construction, such as when constructing pre-engineered buildings, piers, bridges, and many other components related to Advanced Base Functional Components (ABFC), Steelworkers must erect heavy structural members. Usually you will hoist these members into position using cranes, forklifts, or other construction equipment. In contingency/ combat operations, however, this equipment may not be available because of operational commitments, and structural members must be hoisted without the heavy equipment. This section will present some of the methods you can use for the erection process when heavy equipment is unavailable.

The term *field-erected hoisting device* refers to a device constructed in the field using locally available material to hoist and move heavy loads. Essentially, it consists of a block-and-tackle system arranged on a skeleton structure of wooden poles or steel beams. The tackle system requires some form of machine power or work force power to do the actual hoisting. The three most commonly used types of field-erected hoisting devices are *gin poles, tripods, and shears.* The skeleton structures these devices are anchored to are called *holdfasts*.

6.1.0 Holdfasts

Gin poles, shear legs, and other rigging devices are held in place by means of ***guy lines*** anchored to holdfasts. In fieldwork, the most desirable and economical types of holdfasts are natural objects, such as trees, stumps, and rocks. When natural holdfasts of sufficient strength are not available, you will need to field manufacture the holdfasts for proper anchorage. These include single picket holdfasts, combination picket holdfasts, combination log picket holdfasts, log deadman, and steel picket holdfasts.

6.1.1 Natural Types

When using trees, stumps, or boulders as holdfasts, always attach the guys near ground level (*Figure 16-46*). The strength of the tree, stump, or boulder size is also an important factor in determining its suitability as a holdfast. With this in mind, **NEVER** use a dead tree, a rotten stump, or loose boulders and rocks. Such holdfasts are unsafe; they are likely to suddenly snap or slip when a strain is placed on the guy. Whenever possible, make it a practice to lash the first tree or stump to a second one; this will provide added support for the guy.

Figure 16-46 — Using trees as a holdfast.

You can make rock holdfasts by inserting pipes, crowbars, or steel pickets into holes drilled in solid rock. Keeping them in line with the guy, use a star drill to drill holes in the rock 1 1/2 to 3 feet apart. Remember to drill the holes at a slight angle so the pickets lean away from the direction of pull. Make the front hole about 1 1/2 to 3 feet deep and the rear hole 2 feet deep (*Figure 16-47*). After driving pickets into the holes, secure the guy to the front picket, then lash the pickets together with a chain or wire rope to transmit the load.

Figure 16-47 — Rock holdfast.

6.1.2 Single-Picket

The pickets for picket holdfasts may be either wood or steel. A wood picket should be at least 3 inches in diameter and 5 feet long. A single picket holdfast can be provided by driving a picket 3 to 4 feet into the ground, and slanting it at an angle of 15 degrees opposite the pull. In securing a single guy line to a picket, take two turns around the picket and then have part of the crew haul in on the guy as you take up the slack. When you have the guy taut, secure it with two half hitches. In undisturbed loam soil, the single picket is strong enough to stand a pull of about 700 pounds.

6.1.3 Combination-Picket

A combination picket holdfast consists of two or more pickets. *Figure 16-48* gives you an idea of how to arrange pickets in constructing a 1-1-1 and a 3-2-1 combination picket holdfast.

Figure 16-48 — Combination pickets.

In constructing the 1-1-1 combination (*Figure 16-49*), drive three single pickets about 3 feet into the ground, 3 to 6 feet apart, and in line with the guy. For a 3-2-1 combination, drive a group of three pickets into the ground, lashing them together before you secure the guy to them. Follow this with a group of two lashed pickets 3 to 6 feet from the first group and in line, and finish with a single picket, again 3 to 6 feet away and on line. The 1-1-1 combination can stand a pull of about 1,800 pounds, while the 3-2-1 combination can stand as much as 4,000 pounds.

The pickets grouped and lashed together, plus the use of small stuff secured onto every pair of pickets, are what make the combination picket holdfasts much stronger than the single holdfasts.

The reason for grouping and lashing the first cluster of pickets together is to reinforce the point where the pull is the greatest. The way small stuff links each picket to the next is what divides the force of pull, so the first picket does not have to withstand all of the strain.

Using 12- to 15-thread small stuff, clove hitch it to the top of the first picket. Then take about four to six turns around the first and second pickets, going from the bottom of the second to the top of the first picket. Repeat this with more small stuff from the second to the third picket, and so on, until the last picket has been secured.

Then pass a stake between the turns of small stuff between each pair of pickets and make the small stuff taut by twisting it with the stake. Now drive the stake into the ground.

If you are going to use a picket holdfast for several days, it is best to use galvanized guy wire in place of the small stuff. Rain will not affect galvanized guy wire, but it will cause small stuff to shrink. If the small stuff is already taut, it could break from overstrain. Still, if you must use small stuff, be sure to slack it off before leaving it overnight. You do this by pulling the stake up, untwisting the small stuff once, and then replacing the stake.

Figure 16-49 — Preparing a 1-1-1 picket holdfast.

6.1.4 Combination Log Picket

For heavy loads or in soft- or wet-earth areas, you can use a combination log-picket holdfast. With this type, the guys are anchored to a log or timber supported against four or six combination picket holdfasts (*Figure 16-50*). The timber serves as beam, and must be placed so it bears evenly against the front rope of the pickets. Since the holding power of this setup depends on the strength of the timber and anchor line, as well as the holdfast, you must use a timber big enough and an anchor line strong enough to withstand the pull.

Figure 16-50 — Combination log picket.

6.1.5 Deadman

A deadman provides the best form of anchorage for heavy loads. It consists of a log, steel beam, steel pipe, or similar object buried in the ground with the guy connected at its center (*Figure16-51*). The deadman is suitable as a permanent anchorage because it is buried, and when you install a permanent deadman anchorage, it is a good idea to put a turnbuckle in the guy near the ground to permit slackening or tightening when necessary.

Figure 16-51 — Deadman anchorage for a heavy load.

When you dig the hole to bury the deadman, make sure it is deep enough for good bearing on solid ground, but the less earth you disturb on the bearing face when digging, the better the bearing will be. Undercut the bank in the direction toward the guy at an angle of about 15 degrees from the vertical, and to increase the bearing surface, you can drive stakes into the bank at several points over the deadman.

Cut a narrow, inclined trench for the guy through the bank and leading to the center of the deadman. At the outlet of the trench, place a short beam or log on the ground under the guy. In securing the guy to the center of the deadman, see that the standing part (that is, the part on which the pull occurs) leads from the bottom of the log deadman. Thus, if the wire rope clips slip under strain, the standing part will rotate the log in a counterclockwise direction, causing the log to dig into the trench, rather than roll up and out. However, to prevent the clips from slipping in the first place, make sure the running end of the guy is secured properly to the standing part.

6.1.6 Steel Picket

The steel picket holdfast consists of a steel box plate with nine holes, and a steel eye welded on the end for attaching the guy (*Figure 16-52*). When you install this holdfast, it is important to drive the steel pickets through the holes in such a manner that it causes them to clinch in the ground. The steel picket holdfast is especially useful for anchoring horizontal lines, such as the anchor cable on a pontoon bridge. Using two or more of the units in combination provides a stronger anchorage than a single unit.

Figure 16-52 — Steel picket holdfast.

6.2.1 Gin Poles

A gin pole consists of an upright mast equipped with suitable hoisting tackle that is guyed at the top to maintain it in a vertical or nearly vertical position. The vertical mast can be a timber, wide-flange steel beam section, railroad rail, or similar member of sufficient strength to support the load being lifted. The load can be hoisted by hand tackle, or by hand- or engine-driven hoists. The gin pole is predominately used in erection work because of the ease with which it can be rigged, moved, and operated. It is suitable for raising loads of medium weight to heights of 10 to 50 feet where only a vertical lift is required, and it can be used to drag loads horizontally toward the base of the pole in preparation for a vertical lift. However, it cannot be drifted (inclined) more than 45 degrees from the vertical or seven-tenths the height of the pole, nor is it suitable for swinging a load horizontally.

The length and thickness of the member selected for use as a gin pole will depend on the purpose for which it is installed. It should not be longer than 60 times its minimum thickness because of the tendency to buckle under compression. A usable rule is to allow 5 feet of pole for each inch of minimum thickness. *Table 16-2* lists values for using spruce timbers as gin poles with allowance for normal stresses in hoisting operations.

Table 16-2 — Safe Capacity of Spruce Timbers as Gin Poles in Normal Operations.

Size of timber in inches	Safe capacity in pounds for given length of timber					
	20 feet	25 feet	30 feet	40 feet	50 feet	60 feet
6 dia	5000	3000	2000			
8 dia		11000	8000	5000	3000	
10 dia	31000	24000	16000	9000	6000	
12 dia			31000	19000	12000	9000
6x6	6000	4000	3000			
8x8		14000	10000	6000	4000	
10x10	40000	30000	20000	12000	8000	
12x12			40000	24000	16000	12000

NOTE

For the following text about gin poles, tripods, and shears: The safe capacity of each length tripod or shears is seven-eighths of the value given for a gin pole.

Use the following guidance when rigging, erecting, and operating a gin pole.

1. *Rigging* — Lay out the pole with the base at the exact spot where it is to be erected. Place the gin pole on cribbing for ease of lashing, and to make provisions for the guy lines and tackle blocks. *Figure 16-53* shows the lashing on top of a gin pole and the method of attaching guys. The procedure is as follows:

   a. Make a tight lashing of eight turns of fiber rope about 1 foot from the top of the pole, with two of the center turns engaging the hook of the upper block of the tackle. Secure the ends of the lashing with a square knot. Nail wooden cleats (boards) to the pole flush with the lower and upper sides of the lashing to prevent the lashing from slipping.

   b. Lay out guy ropes, each one four times the length of the gin pole. In the center of each guy rope, form a clove hitch over the top of the pole next to the tackle lashing, and be sure the guy lines are aligned in the direction of their anchors.

c. Lash a block to the gin pole about 2 feet from the base of the pole, the same as was done for the tackle lashing at the top, and place a cleat above the lashing to prevent slipping. This block serves as a leading block on the fall line, which allows a directional change of pull from the vertical to the horizontal. A snatch block is the most convenient type to use for this purpose.

d. Reeve the hoisting tackle and use the block lashed to the top of the pole so that the fall line can be passed through the leading block at the base of the gin pole.

e. Drive a stake about 3 feet from the base of the gin pole. Tie a rope from the stake to the base of the pole below the lashing on the leading block and near the bottom of the pole. This is to prevent the pole from skidding while it is being erected.

f. Check all lines to be sure that they are not tangled. Check all lashings to ensure they are made up properly, and see that all knots are tight. Check the hooks on the blocks to see that they are moused properly. The gin pole is now ready to be erected.

Figure 16-53 — Lashing for a gin pole.

2. *Erecting* — A gin pole 40 feet long can be raised easily by hand, but longer poles must be raised by supplementary rigging or power equipment. *Figure 16-54* shows such a gin pole being erected. The number of personnel needed depends on the weight of the pole. The procedure is as follows:

   a. Dig a hole about 2 feet deep for the base of the gin pole.

b. Run out the guys to their respective anchorages and assign a person to each anchorage to control the slack in the guy line with a round turn around the anchorage as the pole is raised. If it has not been done already, install an anchorage for the base of the pole.

Figure 16-54 — Erecting a gin pole.

c. If necessary, the tackle system used to raise and lower the load under normal operations can be used to assist in raising the gin pole, but attaching an additional tackle system to the rear guy line is preferable when raising the gin pole. Attach the running block of the rear guy line tackle system to the rear guy line end, which at this point is near the base of the gin pole. The fixed or stationary block is then secured to the rear anchor. The fall line should come out of the running block to give greater mechanical advantage to the tackle system. The tackle system is stretched to the base of the pole before it is erected to prevent the chocking of the tackle blocks during the erection of the gin pole.

d. Keeping a slight tension on the rear guy line, and *on each of the side guy lines,* haul in on the fall line of the tackle system while eight personnel (more for larger poles) raise the top of the pole by hand until the tackle system can take control.

e. The rear guy line must be kept under tension to prevent the pole from swinging and throwing all of its weight on one of the side guys.

f. When the pole is in its final position, approximately vertical or inclined as desired, make all guys fast to their anchorages with the round turn and two half hitches. It is often advantageous to double the portion of rope used for the half hitches.

g. Open the leading block at the base of the gin pole and place the fall line from the tackle system through it. When the leading block is closed, the gin pole is ready for use. If it is necessary to move (drift) the top of the pole without moving the base, it should be done when there is no load on the pole unless the guys are equipped with tackle.

3. *Operating* — The gin pole is perfectly suited to vertical lifts. It also is used under some circumstances for lifting and pulling at the same time so the load being moved travels toward the gin pole just off the ground. When used in this manner, you must attach a snubbing line of some kind to the other end of the load being

dragged and keep it under tension at all times. Use tag lines to control loads being lifted vertically. A tag line is a light line fastened to one end of the load and kept under slight tension during hoisting (*Figure 16-55*).

Figure 16-55 — Hoisting with a gin pole.

6.3.1 Tripods

A tripod consists of three legs lashed or secured at the top. The advantage of the tripod over other rigging installations is its stability, and it requires no guy lines to hold it in place. The disadvantage of a tripod is that the load can be moved only up and down. The load capacity of a tripod is approximately 1 1/2 times that of shears made of the same-size material.

Use the following guidance when rigging and erecting a tripod.

1. *Rigging* — There are two methods of lashing a tripod, either of which is suitable provided the lashing material is strong enough. The material used for lashing can be fiber rope, wire rope, or chain. Metal rings joined with short chain sections and large enough to slip over the top of the tripod legs can be used as well. The method described below is for fiber rope 1 inch in diameter or smaller. Since the strength of the tripod is affected directly by the strength of the rope and the lashing used, more turns than described below should be used for extra heavy loads, and fewer turns can be used for light loads.

- *Procedure —*
  a. Select three masts of approximately equal size and place a mark near the top of each mast to indicate the center of the lashing.
  b. Lay two of the masts parallel with their tops resting on a skid or block and a third mast between the first two, with the lashing marks on all three in line, but with the butt in the opposite direction. The spacing between masts should be about one half of the diameter of the spars. Leave the space between the spars so that the lashing will not be drawn too tight when the tripod is erected.
  c. With a 1-inch rope, make a clove hitch around one of the outside masts about 4 inches above the lashing mark, and take eight turns of the line around the three masts (*Figure 16-56*). Be sure to maintain the space between the masts while making the turns.
  d. Finish the lashing by taking two close frapping turns around the lashing between each pair of masts. Secure the end of the rope with a clove hitch on the center mast just above the lashing. Frapping turns should not be drawn too tight.

Figure 16-56 — Lashing for a tripod.

- *Alternate procedure —*
  a. An alternate procedure can be used when slender poles not more than 20 feet long are being used or when some means other than hand power is available for erection (*Figure 16-57*).
  b. Lay the three masts parallel to each other with an interval between them slightly greater than twice the diameter of the rope to be used. Rest the tops of the poles on a skid so the ends project over the skid approximately 2 feet and the butts of the three masts are in line.
  c. Put a clove hitch on one outside leg at the bottom of the position the lashing will occupy, which should be approximately 2 feet

Figure 16-57 — Alternate lashing for a tripod.

from the end. Weave the line over the middle leg, under and around the outer leg, under the middle leg, over and around the first leg, and continue this weaving for eight turns. Finish with a clove hitch on the outer leg.

2. *Erecting* — The legs of a tripod in its final position should be spread so each leg is equidistant from the others (*Figure 16-58*). This spread should not be less than one half or more than two thirds of the length of the legs. Use chain, rope, or boards to hold the legs in this position. Lash a leading block for the fall line of the tackle to one of the legs. The procedure is as follows:

    a. Raise the tops of the masts about 4 feet, keeping the base of the legs on the ground.

    b. Cross the two outer legs. The third or center leg then rests on top of the cross. With the legs in this position, pass a sling over the cross so that it passes over the top or center leg and around the other two.

    c. Hook the upper block of a tackle to the sling and mouse the hook.

    d. Continue raising the tripod by pushing in on the legs as they are lifted at the center. Eight personnel should be able to raise an ordinary tripod into position.

    e. When the legs are in their final position, place a rope or chain lashing between them to keep them from shifting.

Figure 16-58 — Tripod assembled for use.

- *Erecting Large Tripods.* For larger tripod installations, it may be necessary to erect a small gin pole to raise the tripod into position. Tripods, lashed with the three legs laid together, must be erected by raising the tops of the legs until the legs clear the ground so they can be spread apart. Use guy lines or tag lines to assist in steadying the legs while they are being raised. Cross the outer legs so the center leg is on the top of the cross, and pass the sling for the hoisting tackle over the center leg and around the two outer legs at the cross.

6.4.1 Shears

Shears, made by lashing two legs together with a rope, are well adapted for lifting heavy machinery or other bulky loads. They are formed by two members crossed at their tops with the hoisting tackle suspended from the intersection. The shears must be guyed to hold them in position. The shears are quickly assembled and erected. They require only two guys and are adapted to working at an inclination from the vertical. The shear legs can be round poles, timbers, heavy planks, or steel bars, depending on the material at hand and the purpose of the shears.

For determining the size of the members to be used, the determining factors you need to consider are the load to be lifted, and the ratio of the length and diameter of the legs of the members. For heavy loads, the length-diameter *(L/D)* ratio should not exceed 60 because of the tendency of the legs to bend rather than act as columns. For light work, shears can be improvised from two planks or light poles bolted together and reinforced by a small lashing at the intersection of the legs.

Use the following guidance when rigging, erecting, and operating shears.

1. *Rigging* — Once erected, the spread of the legs should equal about one-half the height of the shears, with the maximum allowable drift (inclination) of 45 degrees. Tackle blocks and guys for shears are essential. The guy ropes can be secured to firm posts or trees with a turn of the rope so the length of the guys can be adjusted easily. The procedure is as follows:
    a. Lay two timbers together on the ground in line with the guys, with the butt ends pointing toward the back guy and close to the point of erection.
    b. Place a large block under the tops of the legs just below the point of lashing (*Figure 16-59*), and insert a small spacer block between the tops at the same point. The separation between the legs at this point should be equal to one third of the diameter of one leg to make handling of the lashing easier.
    c. With sufficient 1-inch rope for 14 turns around both legs, make a clove hitch around one mast, and take 8 turns around both legs above the clove hitch. Wrap the turns tightly so that the lashings are made smooth and without kinks.

Figure 16-59 — Lashing for shears.

d. Finish the lashing by taking two frapping turns around the lashing between the legs and securing the end of the rope to the other leg just below the lashing. For handling heavy loads, increase the number of lashing turns.

2. *Erecting* — Dig holes at the points where the legs of the shears are to stand. In case of placement on rocky ground, the base for the shears should be level. The legs of the shears should be crossed and the butts placed at the edges of the holes. With a short length of rope, make two turns over the cross at the top of the shears and tie the rope together to form a sling. Be sure to have the sling bearing against the masts and *not* on the shears lashing entirely. The procedure is as follows:

   a. Reeve a set of blocks and place the hook of the upper block through the sling. Secure the sling in the hook by mousing. Fasten the lower block to one of the legs near the butt so it will be in a convenient position when the shears have been raised, but will be out of the way during erection.

   b. If the shears are to be used on heavy lifts, rig another tackle in the base guy near its anchorage. Secure the two guys to the top of the shears with clove hitches to legs opposite their anchorages above the lashing.

   c. Several personnel (depending on the size of the shears) should lift the top end of the shear legs and "walk" them up by hand until the tackle on the rear guy line can take effect. After this, the shear legs can be raised into final position by hauling in on the tackle. Secure the front guy line to its anchorage before raising the shear legs, and keep a slight tension on this line to control movement (*Figure 16-60*).

   d. Keep the legs from spreading by connecting them with rope chain or bards. It can be necessary, under some conditions, to anchor each leg of the shears during erection to keep them from sliding in the wrong direction.

Figure 16-60 — Erecting shears.

3. *Operating* — The rear guy is a very important part of the shears rigging, as it is under a considerable strain when hoisting. The front guy has very little strain on it and is used mainly to aid in adjusting the drift and to steady the top of the shears when hoisting or placing the load. It may be necessary to rig a tackle in the rear guy for handling heavy loads.

   In operation, the drift (inclination of the shears) desired is set by adjustment of the rear guy, but this should not be done while a load is on the shears. For handling light loads, the fall line of the tackle of the shears can be led straight out of the upper block. When heavy loads are handled, you should lash a snatch block near the base of one of the shear legs to act as a leading block (*Figure 16-61*). The fall line should be run through the leading block to a hand- or power-operated winch for heavy loads.

Figure 16-61 — Hoisting with shears.

7.1.1 SAFE RIGGING OPERATING PROCEDURES

All personnel involved with the use of rigging gear should be thoroughly instructed and trained to comply with the following practices:

1. Wire rope slings must not be used with loads that exceed the rated capacities outlined in enclosure (2) of the NSTM Chapter 613, *Wire and Fiber Rope and Rigging*. Slings not included in the enclosure must be used only according to the manufacturer's recommendation.
2. Determine the weight of a load before attempting any lift.
3. Select a sling with sufficient capacity rating.
4. Examine all hardware, equipment, tackle, and slings before using them and destroy all defective components.
5. Use the proper hitch.

6. Guide loads with a tag line when practical.
7. When using multiple-leg slings, select the longest sling practical to reduce the stress on the individual sling legs.
8. Attach the sling securely to the load.
9. To prevent chaffing, pad or protect any sharp comers or edges the sling may come in contact with.
10. Keep slings free of kinks, loops, or twists.
11. Keep hands and fingers from between the sling and the load.
12. Start the lift slowly to avoid shock-loading slings.
13. Keep slings well lubricated to prevent corrosion.
14. Do not pull slings from under a load when the load is resting on the slings; block the load up to remove slings.
15. Do not shorten a sling by knotting or using wire rope clips.
16. Do not inspect wire rope slings by passing bare hands over the rope. Broken wires, if present, can cause serious injuries. When practical, wear leather palm gloves when working with wire rope slings.
17. Establish the center of balance. It is very important in the rigging process that the load is stable. A stable load is a load in which the center of balance of the load is directly below the hook. When a load is suspended, it will always shift to that position below the hook, as shown in *Figure 16-62*. To rig a stable load, establish the center of balance (C/B). Once you have done this, simply swing the hook over the C/B and select the length of slings needed from the hook to the lifting point of the load.
18. When using a multi-legged bridle sling, do not forget it is wrong to assume that a three- or four-leg hitch will safely lift a load equal to the safe load on one leg multiplied by the number of legs. With a four-legged bridle sling lifting a rigid load, it is possible for two of the legs to support practically the full load while the other two only balance it (*Figure 16-63*).

Figure 16-62 — Example of a load shifting when lifted.

NOTE

If all the legs of a multi-legged sling are not required, secure the remaining legs out of the way, as shown in *Figure 16-64*.

Figure 16-63 — Multi-legged bridle sling lifting a load.

Figure 16-64 — Secure sling legs not being used.

Summary

This chapter discussed the characteristics, construction, and use of many types of wire rope. It also discussed the safe working load, use of attachments and fittings, and procedures for the care and handling of wire rope. You can obtain further information about wire ropes in NSTM Chapter 613, *Wire and Fiber Rope and Rigging.*

Rigging and hoisting are inherently dangerous elements of construction work, so always follow the prescribed safety precautions and wear the proper personal protective equipment.

Review Questions (Select the Correct Response)

1. **(True or False)** The most important operation in rigging is safety.

   A. True
   B. False

2. **(True or False)** The mechanical advantage of a machine is the amount a machine can multiply the force used to lift or move a load.

   A. True
   B. False

3. What term is used when blocks of a tackle are as close together as they can go?

   A. Two-blocked
   B. Fall
   C. Running block
   D. Standing block

4. What is a block called when it is attached to an object to be moved?

   A. Two-block
   B. Fall
   C. Running block
   D. Standing block

5. **(True or False)** The becket holds the block together and supports the pins.

   A. True
   B. False

6. **(True or False)** The cheeks are the solid sides of the frame or shell.

   A. True
   B. False

7. **(True or False)** A sheave is a round grooved wheel over which the line runs.

   A. True
   B. False

8. **(True or False)** The breech is the opening through which the line passes.

   A. True
   B. False

9. When rigging a tackle using 1/2-inch wire rope, what diameter sheave should you use, in inches?

   A. 10
   B. 14
   C. 18
   D. 20

10. What type of block should you use to change the direction of pull on a line?

   A. Snatch
   B. Standard
   C. Leading
   D. Double

11. **(True or False)** Adding a snatch block does NOT increase the mechanical advantage of a tackle system.

   A. True
   B. False

12. What is the added mechanical advantage of gun tackle when it is inverted?

   A. 1
   B. 2
   C. 3
   D. 4

13. A threefold purchase is made of two triple sheave blocks and provides a mechanical advantage of what value?

   A. 4
   B. 6
   C. 8
   D. 10

14. Determine the mechanical advantage of a compound tackle using two inverted luff tackles.

   A. 8
   B. 12
   C. 16
   D. 20

15. What are the primary advantages of wire rope slings?

   A. Resiliency and strength
   B. Strength and hardness
   C. Flexibility and weight
   D. Flexibility and strength

16. **(True or False)** When compared to wire rope slings, fiber line slings offer the advantage of protecting the finished material; however, they are not as strong as wire rope and are easily damaged by sharp edges on material.

A. True
B. False

17. Chain slings offer which advantage?

A. Best for resisting abrasion
B. Best for slinging hot loads
C. Best for handling loads with sharp edges
D. All of the above

18. “Strap” is the term commonly used when referring to what type of sling?

A. Single leg
B. Endless
C. Fiber line
D. Wire rope

19. When the weight is evenly distributed among the slings, how many 1/2-inch chain slings will you need to hoist a 5-ton load safely?

A. 1
B. 2
C. 3
D. 4

20. Why are chain slings less reliable than fiber line or wire rope slings?

A. They have less resistance to stress and strain.
B. They have welded links.
C. Their links may crystallize and snap without warning.
D. They cannot be protected from rust.

21. How many wraps should you make when using rope yarn or wire to mouse a hook?

A. 10 to 14
B. 8 to 10
C. 5 to 7
D. 3 to 5

22. What is the safe working load (SWL), in pounds, of a 3/4-inch-diameter hook?

A. 500
B. 750
C. 1,000
D. 1,250

23. What term refers to the small platform that is used to store small lot items that can then be moved as one large item instead of piece by piece?

    A. Sling
    B. Spreader bar
    C. Bridle
    D. Pallet

24. What jack is used for tightening lines and bracing parts on bridge construction?

    A. Ratchet
    B. Screw
    C. Steamboat
    D. Hydraulic

25. When making a turn with a load on rollers, you should point the front and rear rollers in what direction?

    A. Slightly opposite to the direction of the turn
    B. Front rollers slightly opposite to the direction of the turn and rear rollers pointing slightly in the direction of the turn
    C. Both slightly in the direction of the turn
    D. Front rollers slightly inclined in the direction of the turn and rear rollers in the opposite direction

26. **(True or False)** Blocking and cribbing are often necessary as a safety measure to keep an object stationary in position; this action can prevent accidental injury to personnel who must work near these heavy objects.

    A. True
    B. False

27. What is the maximum length of a swinging platform equipped with reinforcing under the rails?

    A. 14 feet
    B. 18 feet 6 inches
    C. 22 feet
    D. 24 feet 6 inches

28. **(True or False)** A boatswain’s chair should be used only if no other scaffolding means is available.

    A. True
    B. False

29. **(True or False)** If secured properly, the material used by a crew working on a scaffold can be stored on another scaffold.

    A. True
    B. False

30. **(True or False)** Hand lines should be used to raise and lower objects from scaffolding when they cannot be reached easily by hand.

A. True
B. False

31. What is the maximum height limit, in feet, for an 8-inch-diameter gin pole?

A. 20
B. 30
C. 40
D. 50

32. What is the safe capacity, in pounds, of a 40-foot spruce timber gin pole that has a 10-inch diameter?

A. 6,000
B. 7,000
C. 8,000
D. 9,000

33. How many feet long should the guy ropes for a 15-foot gin pole be?

A. 30
B. 45
C. 60
D. 75

34. How many feet deep should you dig the hole for the base of a gin pole?

A. 2
B. 3
C. 4
D. 6

35. **(True or False)** When a gin pole is being erected, the rear guy line must be kept under tension to prevent the pole from swinging and throwing all its weight on one of the side guys.

A. True
B. False

36. What are the primary advantages of using the tripod over other rigging installations?

A. Load capacity and stability
B. Load capacity and cost
C. Load capacity and no requirement for guy lines
D. Stability and no requirement for guy lines

37. **(True or False)** The strength of a tripod is directly affected by the strength of the rope and the lashings used.

A. True
B. False

38. When shears are used to lift heavy loads, the length to diameter (L/D) ratio should not exceed what number?

A. 40
B. 50
C. 60
D. 70

39. What is the maximum allowable drift (inclination), in degrees, for shears?

A. 30
B. 35
C. 40
D. 45

40. When shears are erected, the spread of the legs should equal what proportion of the length of the legs?

A. 1/5
B. 1/4
C. 1/3
D. 1/2

Trade Terms Introduced in this Chapter

Abraded	To wear down or rub away by friction.
Becket	(Nautical)--a grommet or eye on a block to which the standing end of a fall can be secured.
Fairlead angle or Fleet Angle	The drum of the winch is placed so that a line from the last block passing through the center of the drum is at right angles to the axis of the drum. The angle between this line and the hoisting line as it winds on the drum is called the fairlead or fleet angle
Guy lines	A **guy-wire** or **guy rope** is a tensioned cable designed to add stability to structures (frequently ship masts, radio masts, wind turbines, and tents). One end of the cable is attached to the structure, and the other is anchored to the ground at a distance from the structure's base. They are often configured radially (equally spaced about the structure) in trios, quads (pairs of pairs) or other sets. This allows the tension of each guy-wire to offset the others.
Mechanical Advantage	(Mechanics)--the ratio of output force to the input force applied to a mechanism.
Reeved	To pass (a rope or the like) through a hole, ring, pulley, block, or the like.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Cargo Specialist Handbook, Department of the Army, Washington DC, 1999

Hoisting and Rigging Safety Manual, Construction Safety Association of Ontario*, Etobicoke, Ontario Canada, 2007*

Rigging Techniques, Procedures, and Applications, FM 5-125, Department of the Army, Washington DC, 2001

Wire and Fiber Rope and Rigging, S9086-UU-STM-010/CH-613R3, Naval Ship's Technical Manual, Commander, Naval Sea Systems Command, Washington DC, 1999

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

Chapter 17

Pre-Engineered Structures

Topics

To hear audio, click on the box.

Overview

The primary mission tasking of the Seabees is the construction of advanced bases during the early phases of crises and other emergencies. It is our job to move swiftly to build temporary facilities and structures to support U.S. military and humanitarian operations. The most widely used structure is the pre-engineered building. This chapter covers the process involved with the erection of such buildings, as well as k-spans and towers.

In this chapter, we will examine the materials and methods used in building and disassembling pre-engineered structures. We will also discuss the methods and techniques of using ***guy lines*** and anchors for securing towers and antennas.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the purpose, types, and procedures of pre-fabricated buildings.
2. Describe the purpose, types, and procedures of k-span buildings.
3. Describe the purpose, types, and procedures of steel towers.
4. Describe the purpose, types, and procedures of antenna towers.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet metal and Fiberglass Duct		
Welding Quality Control		
Flux Cored Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 PRE-ENGINEERED BUILDINGS

The pre-engineered building (PEB) discussed here is a commercially designed structure fabricated by the civilian industry to conform to armed forces specifications. The advantage of a pre-engineered structure is that it is designed for erection in the shortest possible time. Each PEB is shipped as a complete building kit, including all necessary materials and instructions for erection.

Various types of pre-engineered structures are available from numerous manufacturers, and all are similar because each is built to military specifications. However, it would be impractical to try and include all of the structures that each company fabricates, so this manual will use a description of the basic procedures for erecting and dismantling only a 40-foot by 100-foot building as an example.

The typical PEB is a 40 by 100 foot structure, but a smaller 20 by 48 foot version PEB uses the same erection principles. Layout and erection of either size PEB is normally assigned to Builders, working in conjunction with Steelworkers.

The basic pre-engineered metal building shown in *Figure 17-1* is 40 feet wide by 100 feet long. Although the unit length of the building is 100 feet, the length can be increased or decreased in multiples of 20 feet, which are called 20-foot bays. The true building length will be equal to the number of 20-foot bays plus 6 inches, since each end bay is 20 feet 3 inches. The building is 14 feet high at the eave and 20 feet 8 inches at the ridge.

Figure 17-1 — Completed pre-engineered building.

Pre-engineered buildings are ideal for use as repair shops or warehouses because they have a large, clear floor area without columns or other obstructions, as well as straight sidewalls. This design allows floor-to-ceiling storage of material and wall-to-wall placement of machinery. The column-free interior also permits efficient shop layout and unhindered production flow.

After a building is up, it can be enlarged while in use by 20-foot bays, providing additional space under one roof. If desired, PEBs can be erected side by side in multiples, and when a building is no longer needed it can be disassembled, stored, or moved to another location and re-erected because only bolted connections are used, with no welding or riveting. The rigid frame is strong, designed for working loads of 20 pounds per square foot load, plus the dead load and the load from a 70-mph wind.

The building can be easily modified to varying lengths and purposes by taking out or adding bays, or by substituting various foundation and wall sections. A bay is the distance between two column centers or between the end wall and the first column center in from the end wall.

Formulas used to determine the number of bays, frames, and intermediate frames in a building are as follows:

Length divided by 20 = number of bays

Bays + 1 = total number of frames

Total number of frames - 2 = number of intermediate frames

1.1.0 Pre-Erection Work

Extensive pre-erection work is required before you start the actual erection of a building, and this often includes almost all of the Seabee ratings. After the building site is located and laid out by the Engineering Aids, it will be cleared and leveled by Equipment Operators. Batter boards are set up in pairs where each comer of the foundation is located. Builders fabricate the forms for concrete while Steelworkers are cutting, bending, tying, and placing reinforcing steel. If this particular building requires under slab utilities such as plumbing and electrical service, the Utilitiesman and Construction Electricians will also be on the jobsite. Last, all under slab work must be completed and pass all Quality Control inspections before concrete is placed and finished.

Most importantly, as far as ease of erection is concerned, before the concrete is placed, templates for the anchor bolts are attached to the forms, and the anchor bolts are inserted through the holes in each. Then the anchor bolts and template forms are tied as necessary to make sure the bolts remain vertical. You will have only a tolerance of plus or minus one eighth of an inch to work with.

CAUTION

Proper anchor bolt placement is absolutely critical when erecting a PEB.

The threads of the bolts are greased and the nuts placed on them to protect the threads. Concrete is then poured into the formwork and worked carefully into place around these bolts, so they remain vertical and in place. Finally, according to the plans and specifications, the slab is poured.

While the foundation is being prepared, the crew leader will assign personnel/crews to perform various types of preliminary work, such as uncrating and inventorying all material on the shipping list, bolting up rigid-frame assemblies, assembling door eaves, and glazing windows. Box 1 contains the erection manual, the drawings, and an inventory list; it should be opened first. If all of the preliminary work is done correctly, the assembly and erection of the entire building is accomplished easily and quickly.

All material, except the sheeting, should be uncrated and laid out in an orderly manner so the parts can be located easily. Do not uncrate the sheeting until you are ready to install it. When opening the crates, use care not to cause any damage to the lumber.

This is important since the lumber can be used for sawhorses and various other items around the jobsite.

In most situations, after the building foundation has been prepared, building materials should be placed around the building site near the location where they will be used (*Figure 17-2*). This action provides the greatest accessibility during assembly.

Figure 17-2 — Material layout.

Girts, purlins, eave struts, and brace rods should be equally divided along both sides of the foundation. Panels and miscellaneous parts which will not be used immediately should be placed on each side of the foundation on pallets or skids and covered with tarps or a similar type of covering until needed. Parts making up the rigid-frame assemblies are laid out ready for assembly and in position for raising.

Always use care in unloading materials. Remember that damaged parts will cause delays in getting the job done. To avoid damage, lower the materials to the ground slowly and do not drop them.

Figure 17-3 will help you identify the structural members of the building and their location. Each part has a specific purpose and must be installed in its designated location to ensure a sound structure.

CAUTION

Never omit any part called for on the detailed erection drawings.

Each of the members, parts, and accessories of the building is labeled by stencil so it is not necessary to guess which one goes where. Refer to the erection plans to find the particular members you need as you work.

Figure 17-3 — Location and identity of structural members.

1.2.0 Erection Procedures

When all the pre-erection work is completed, inspected, and passed by Quality Control, and your inventory is completed, you are ready to start erecting the PEB. To give you a general guide to follow, this phase of the discussion will introduce you to the basic PEB erection procedures. However, keep in mind that the drawings provided by the manufacturer must be followed in all cases, even where they might differ from information in this training manual. The manufacturer's standard practice is to pack an erection manual and a set of drawings in the small parts box (Box 1) shipped with each building.

1.2.1 olting Rigid Frames

Before bolting up the rigid-frame assembly, clean all the dirt and debris from the top of the foundation, and then lay out and bolt the base shoes firmly to the concrete. Use appropriate washers between the shoes and nuts. Lay out an assembled column and roof beam at each pair of base shoes, using one bolt on each side of each base shoe to act as pivots in raising the frame (*Figure 17-4*). Use drift pins if needed to line up the holes.

1.2.2 Frame Erection

You can use a gin pole to raise the end frame of the building. To prevent distortion of the frame when it is being raised, attach a bridle securely to each side of the frame below the splice connection and also to the ridge on the roof beam. Drop a drift pin in the frame to prevent the bridle from slipping up. Set up the gin pole with a block at the top. If a gin pole is not available, nail together three 2 x 6’s, 20 feet long, from the longest shipping crate.

Figure 17-4 — Frame assembly.

Attach a tag line to the frame (*Figure 17-5*). Now, pull the end frame into the vertical position, using a crew of four or five people on the erection line. A tag person should have something to take a couple of turns around, such as a pole anchored to the ground. Then if the frame should go beyond the vertical, the tag person would be able to keep it from falling.

To get the frame started from the ground, it should be lifted by several people and propped up as high as practical. Bolt an eave strut to each column (*Figure 17-5*). The eave struts allow the frame to be propped at every stage of the lifting. After the frame is in a vertical position, install guy lines and props to it so it cannot move.

Figure 17-5 — Frame erection.

Now raise the second frame in the same way, and hold it vertically in place by installing purlins, girts, and brace rods.

You can use a crane or other suitable type of power equipment to hoist the frames into place where such equipment is available. When power equipment is used, use the following suggested procedure:

1. Raise the columns, bolt them to the base shoes, and brace them in place.
2. Install all sidewall girts to keep the columns as rigid as possible.
3. Bolt the roof beams together, and install the gable posts and end-wall header.
4. Secure the guy lines and tag lines to the roof beams (*Figure 17-6*). Attach a wire rope sling at approximately the center of each roof beam.
5. Hoist the roof beams into position on top of the columns and bolt them in place.
6. When the second rigid-frame section is secured in position, install all the roof purlins, gable angles, and louver angles. Note: attach the gable clips to the purlins before raising the section into position.
7. Install the brace rods and align the first bay.

Figure 17-6 — Using power equipment.

CAUTION

The first bay must be aligned before erecting additional bays.

1.2.3 Brace Rods

Brace rods must be installed in the first bay erected (*Figure 17-7*). These rods are of paramount importance since they hold the frames in an upright position.

CAUTION

Never omit the brace rods, either sidewall or roof.

The diagonal brace rods are attached to the frames in the roof and sidewall through the slotted holes provided. Use a half-round brace rod washer and a flat steel washer under the nuts at each end of the rods. With the rods installed, plumb each frame column with the carpenter’s spirit level.

Check the distance diagonally from the upper corner of one frame to the lower corner of the adjacent frame. When this distance is the same for each rod, the columns will be plumb. After the sidewall rods are installed, install the roof rods. The length of the roof rods can be adjusted by tightening or loosening the turnbuckle. When the two diagonal measurements are the same, the end bay will be square.

Figure 17-7 — Frame erection.

After the two frames have been plumbed and braced square with the diagonal rods, and the purlins, girts, and eave struts have been installed, the guy lines or props can be removed and the remaining frames of the building can be erected. Note the following precautions:

- Do not omit the diagonal brace rods that are required in the last bay of the building.
- Be sure to bolt the girts, purlins, and eave struts to the inside holes of the end frames.
- Install the eave struts, girts, and purlins in each bay as soon as a frame is erected.
- Exercise care to see that the diagonal brace rods are taut and do not project beyond the flanges of the end frame to interfere with end-wall sheeting.
- To raise the next frame, attach blocks to the last frame raised and proceed to the next bay frame.

1.2.4 Sag Rods

Sag rods are used to hold the purlins and the girts in a straight line. First install the sag rods that connect the two purlins at the ridge of the building. Each rod must be attached from the top hole of one purlin through the bottom hole of the adjacent purlin. Use two nuts at each end of the sag rods, one on each side of each purlin. Adjust the nuts on these rods, so the purlins are held straight and rigid.

Next, install the sag rods between the purlins below the ridge with the rod attached from the top hole of the upper purlin through the bottom hole of the lower purlin. Use two nuts on each end, one on each side of each purlin. Follow the same procedure with the sidewall sag rods.

Remember, the roof purlins should show a straight line from end to end of the building. Do NOT tighten the sag rods so much that the purlins are twisted out of shape.

1.2.5 Brace Angles and Base Angles

After two or more bays have been erected, part of the erection crew can be assigned to install the diagonal brace angles. To install the brace angles, lay the notched portion against the frame flange and bend it into position (*Figure 17-8*). Diagonal brace angles are needed to support the inner flange of the frame. Be sure to install them so that they are taut.

Figure 17-8 — Diagonal brace angles.

CAUTION

Never omit diagonal brace angles. They are needed to support the inner flange of the frame. Install them so they are taut.

While some members of the crew are installing brace angles, other members can be installing base angles. When assigned this duty, first sweep off the top of the concrete foundation so the base angles will set down evenly. Bolt the base angles in place with a flat steel washer under the nut. Leave the nuts loose to permit later adjustments after the wall sheeting has been applied.

1.2.6 End-Wall Framing/Doors/Windows

Refer to the manufacturers' specifications for proper assembly and installation procedures for end-wall framing, doors (both sliding and roll-up), and windows, as these procedures will vary with available building options.

1.2.7 Sheeting

Always start the sheeting, both sidewall and roof, at the end of the building toward which the prevailing winds blow. For example, if the winds are predominately easterlies (from the east), start your sheeting on the west end of the building to ensure that the exterior joint in the side laps is away from the blowing of the prevailing winds. When installing roof sheeting, always use a generous amount of mastic on the upper side of all roof sheets just before moving them to the roof. Turn the sheet over and put a bead of mastic on the lip of one side of the corrugation and along one end--near the end but never more than one 1 inch from the end. Be sure to apply a horizontal bead of mastic between all sheets in the end laps *below the lap holes*. The roof sheets must be dry when mastic is applied. Mastic is extremely important, and you must exercise care whenever applying it to ensure a watertight seal. Apply generous beads, especially at the comers of the sheets. Finally, install the ridge cap, ensuring proper watershed. As previously stated, the information in this manual is general information common to pre-engineered buildings.

1.2.8 Building Insulation

You can insulate a pre-engineered building by any of several methods. You can install a blanket type of insulation in 2-foot wide strips to match the width of the roof and wall sheets between the sheets and structural panels at the same time the sheeting is installed. Alternatively, you can apply a hardboard insulation directly to the inside surface of the structural panels, attaching it by helix nails or by sheet metal screws in holes prepared by drilling the structural panels. A third option is a wood framing attached to the structural panels, and hardboard insulation nailed to the wood.

1.2.9 Multiple buildings Set Side by Side

Pre-engineered buildings can easily be set up side by side to increase the working area under one roof. When this is done, the adjacent rigid frames should be bolted back to back with a channel spacer at each girt location (*Figure 17-9*).

The eave struts are moved up the roof beam to the second set of holes to provide a gutter. This arrangement provides a space between eave struts, and you can install a field fabricated gutter.

Flat, unpainted galvanized steel of 24- to 26-gauge material should be used for the gutter, with downspouts located as required. Gutter ends should be lapped and braze-welded for watertightness. Note that wall sheets can be used to form a gutter if the outside corrugations are flattened and all the end laps are braze-welded.

Roof sheets must be cut shorter where they overhang the gutter. The corrugations can be closed with the continuous rubber closure with mastic applied to the top and bottom surfaces of the closure. An alternate method is to flatten the corrugations at the gutter and seal them with a glass fabric stripping set in plastic.

Figure 17-9 — Buildings side by side.

1.3.1 Disassembly Procedures

Disassembling a pre-engineered building is not difficult once you are familiar with the erection procedures. However, when you disassemble a building, be sure to clearly mark or number all of the parts so you will know where the parts go when reassembling the building. The following are the main steps of the disassembly procedures:

- Remove the sheeting.
- Remove the windows, door leaves, and end wall.
- Remove the diagonal brace angles and sag rods.
- Remove the braces, girts, and purlins.
- Let down the frames.

1.3.1 Marking

It is obvious but worth repeating: In disassembling a building, be sure to clearly mark or number all parts. You will then know where the parts go when reassembling the building.

Carefully handling the building components during disassembly is very important. You may have to reuse these same components at another location. As you complete disassembly, protect those components from damage. Any damaged components will have to be replaced, and time might not be on your side.

In planning a disassembly, remember, you probably no longer have the original shipping containers in which to repack. As offered earlier, the shipping material makes good sawhorses, and sometimes runners for stairs, so it is not likely to be around any longer. If the disassembled PEB will have significant rehandling or lengthy storage, consider making secondary shipping crates of available materials for handling ease and parts accountability.

2.0.0 K-SPAN BUILDINGS

The K-span building has been used in the Seabee community for years (*Figure 17-10*). The intended uses of these buildings are as varied as the PEBs. Training key personnel in the operation of the equipment associated with the K-span is essential. Once trained, these same personnel can instruct other members of the crew in the safe erection of a K-span. The following section gives you some, but not all, of the key elements associated with K-span construction. The ABM 120 and 240 and the UBM 120 and 240 are the machines used in K-span construction. The UBM differs from the ABM in

Figure 17-10 — Typical K-span building.

several ways but the two major differences are the computer input system and the seaming system used by the UBM which eliminates the need for bolting the sections together saving workers and time needed for construction. All other aspects are the same when comparing the ABM and the UBM. ABMs will be discussed in detail below. As with other equipment, always refer to the manufacturer's manuals.

2.1.0 ABM 120 System

The K-span building system consists of a self-contained, metal building manufacturing plant, known as the ABM 120 System/Automatic Building Machine 120. This machine is mounted on a trailer, forming a type of “mobile factory” that is easily towed to even the remotest construction sites (*Figure 17-11*). An important aspect of this machine is that it can easily be transported by air anywhere in the world. In fact, the ABM System has been certified for air transport by the U.S. Air Force in C-130, C-141, C-5, and C-17

Figure 17-11 — Automatic Building Machine (ABM) 120.

aircraft. Once the machine is delivered on site, it can be set up in minutes and turn coils of steel into structural strength arched panels. The panels are then machine seamed together to form an economical and watertight steel structure.

The final shape and strength of the fabricated materials eliminate the need for columns, beams, or any other type of interior support. All of the panel-to-panel connections are joined using an electric automatic seaming machine. Because of this, there are no nuts, bolts, or any other type of fastener to slow down construction or create leaks.

Once delivered to the jobsite, the “on-site” manufacturing abilities of the machine give the ABM operator complete control of fabrication as well as the quality of the building.

2.1.1 Operating Instructions

The main component of the K-span system is the trailer-mounted building machine. *Figure 17-12* shows the primary components of the trailer as well as the general operational steps.

Figure 17-12 — Trailer-mounted machinery.

The key position is the operator's station at the rear of the trailer (*Figure 17-13*). The individual selected for this station must thoroughly understand the machine's operations and manuals, because from there, the operator controls all the elements required to form the panels. The operator must remain at the controls at all times; forming panels is a complex operation that becomes easier with a thorough understanding of the manuals.

The operator first runs the coil stock through the machine to form the panel shape and then cuts it off at the correct length. This length is the required length for one arched panel to run continuously from one footer to the other. After cutting the panel to length, the operator runs it back through the machine to give it the correct arch. From the placement of the trailer on site to the completion of the curved panels, attention to detail is paramount.

Figure 17-13 — Rear of K-span trailer.

If you are selected for the operator's position, as you operate the panel, you will be adjusting the various machine operating components. Make adjustments for thickness, radius, and the curving machine according to the manuals. Do not permit short cuts in adjustments. Any deviations in adjustments or disregard for the instructions found in the operating manuals will leave you with a pile of useless material and an inconsistent building.

2.1.2 Machinery Placement

To avoid setup problems, preplanning of the site layout is important. Uneven or sloped ground is not a concern as long as the bed of the trailer aligns with the general lay of the existing surface conditions. Using *Figure 17-14* as a guide, consider the following items when placing the machinery:

- Allow maneuvering room for the towing of the trailer, or leave it attached to the vehicle (A).
- The length of the unit is 27 feet 8 inches long by 7 feet 4 inches wide (B).
- Allow enough room for run-out stands to hold straight panels. Stands have a net length of 9 feet 6 inches each (C).
- Find point X: From the center of the curve, measure the distance equal to the radius in line with the front of the curved frame. From point X, scribe an arc equal to the radius. This arc will define the path of the curved panel. Add 10 feet for run-out stands and legs (D).
- Allocate room for a storage area required to store coil stock and access for equipment to load it onto the machine (E).
- Consider the direction the curved panels must be carried after being formed (F).

- Allocate a level area in which to lay the panels on the ground for seaming. The building will not be consistent if the panels are not straight when seaming is done (G).
- Allocate space required for crane operations (H).

Figure 17-14 — Machinery placement calculations.

2.1.3 Foundations

While the design of the foundation for a K-span building depends on the building's size, existing soil conditions, and wind load, the foundations are simple and easy to construct. With the even distribution of the load in a standard arch building, the size of the continuous strip footing is smaller and more economical than the foundations for conventional buildings.

The provided concrete forms and accessories to form the foundations are sufficient for a building 100 feet long by 50 feet wide, and forms are available upon request from the manufacturer for different configurations.

The actual footing construction is based, as all projects are, on the building plans and specifications. The location of the forms, placement of steel, and the psi (pounds per square inch) of the concrete are critical. Since the building is welded to the angle in the footer prior to the concrete placement, all aspects of the footer construction must be thoroughly checked for alignment and square. Once concrete is placed, there is no way to correct mistakes.

As mentioned above, forms are provided for the foundation. Using *Table 17-1* as a guide, *Figure 17-15* gives you a simple foundation layout by parts designation. As noted in *Figure 17-15*, the cross pipes are not provided in the kit. They are provided by the contractor.

Table 17-1 – Concrete Forms Included in Kit.

Description **(Each set of forms is sufficient to erect a building 100 feet long by 50 feet wide.)**	**Part Number**
Side form panels, 1’ x 10’, 12-gauge steel	F-1
Transition panels, 1’ x 12”, 12-gauge steel	F-2
Transition panels, 1’ x 28”, 12-gauge steel	F-3
End wall caps, 1’ x 15”, 12-gauge steel	F-4
Side wall caps, 1’ x 19”, 12-gauge steel	F-5
Filler form, 1’ x 12’, 12-gauge steel	F-6
Sidewall inside stop, 1’ x 12”, 12-gauge steel	F-7
End wall inside stop, 1’ x 12”, 12-gauge steel	F-8
Stakes, 1/4” diameter, bar steel	F-9 F-
All-thread rod, 1/2-13 x 18”	10
Hex nuts, 1/2-13	F-11
Hex bolts, 1/8-16 x 1-1/2”	F-12
Hex nuts, 3/8- 6	F-13
Flat washers, 1/8” SAE	F-14
Corner angles, 2” x 2” x 12”, steel angle	F-15

Figure 17-15 — Simple form assembly.

2.1.4 Building Erection

With the placement of the machinery and the forming of the building panels in progress, your next considerations are the placement and the weight-lifting capabilities of the crane. Check the crane's weight-lifting chart for its maximum weight capacity. This dictates the number of panels you can safely lift at the operating distance or reach. As with all crane operations, attempting to lift more than the rated capacity, or extending beyond a rated operating distance can cause the crane to turn over.

Attaching the spreader bar to the curved formed panels is a crucial step (*Figure 17-16*). Failure to clamp the panel tightly can cause the panels to slip and fall, with potential harm to personnel and damage to the panel.

Figure 17-16 — Spreader bar attachment.

With guidelines attached as shown in *Figure 17-17* and personnel attending the lines, lift the panels for placement.

When lifting, consider the following points:

- Lift only as high as necessary.
- Position two crew members at each free end to guide each panel in place.
- Remind crew members to keep their feet out from under the ends of the arches.
- Never attempt lifting any sets of panels in high winds.

Figure 17-17 — Guide rope use.

Place the first set of panels on the attaching angle of the foundation and position it so there will be room for the end wall panels. After positioning the first set of panels, clamp them to the angle, plumb them with guidelines, and secure the lines to previously anchored stakes. Seam each set to standing panels before detaching the spreader bar, then detach the spreader bar and continue to place panel sets.

After about 15 panels (3 sets) are in place, measure the building length at both ends just above the forms and at the center of the arch. This measurement will seldom be exactly one foot per panel, it is usually slightly more, but it should be equal for each panel. Adjust the ends to equal the center measure. Panels are flexible enough to adjust slightly. Check these measurements periodically during building construction. Since exact building lengths are difficult to predict, the end-wall attaching angle on the finishing end of the building should not be put in place until all panels are set.

After the arches are in place, set the longest end-wall panel in the form, plumb, and clamp it in place. Work from the longest panel outward and be careful to maintain plumb.

When all of the building panels are welded to the attaching angle at 12 inches on center, you are ready to place the concrete (*Figure 17-18*). When you are placing the concrete, remember that it is extremely important that it be well vibrated, but not over-vibrated to the point of aggregate separation. This action will help eliminate voids underneath the embedded items. As the concrete begins to set, slope the top exterior portion of the concrete cap about 5 inches to allow water to drain away from the building (*Figure 17-19*). The elevation and type of the interior floor are not relevant as long as the finish of the interior floor is not higher than the top of the concrete cap.

Figure 17-18 — Building foundation concept.

Figure 17-19 — Concrete foundation.

The K-span building system is similar to other types of pre-engineered or prefabricated buildings in that windows, doors, and roll-up doors can be installed only when erection is completed. When insulation is required, you can install (using clips, as shown in *Figure 17-20)* insulation boards (usually 4 by 8 feet) of any semi-rigid material that can be bent to match the radius of the building.

Figure 17-20 — Insulation.

When the integrity of the end-wall panels is continuous from ground to roofline, the end walls become self-supporting. The installation of windows (*Figure 17-21*) and aluminum doors (*Figure 17-22*) presents no problem because the integrity of the wall system is not interrupted. The installation of the overhead door (*Figure 17-23*) does present a problem in that it does interrupt the integrity of the wall system. This situation is quickly overcome by the easily installed and adjustable (in height and width) doorframe package that supports both the door and end wall. This doorframe package is offered by the manufacturer.

Figure 17-24 shows the fundamental steps in constructing a K-span from start to finish.

Figure 17-21 — Aluminum window installation.

Figure 17-22 — Aluminum door installation.

Figure 17-23 — Overhead door frame.

 Figure 17-24 — Steps in K-span construction.

2.2.0 ABM 240 System

There is another type of K-span building, actually referred to as a Super Span by the manufacturer, the ABM 240. Even though it can use heavier coil stock and is a larger version, the construction of the ABM 240 is the same as that for the ABM 120 (K- span). *Figure 17-25* shows the differences between the two.

Keep in mind that the information provided in this section on the K- span building is basic. During the actual construction of this building, you must consult the manufacturer's complete set of manuals.

Figure 17-25 — ABM 120 and 240 comparison chart.

3.0.0 STEEL TOWERS

Towers are framework structures designed to provide vertical support. They may be used to support another structure, such as a bridge, or a piece of equipment, such as a communication antenna, or to serve as a lookout post or weapons mount. Since the prime purpose of a tower is to provide vertical support for a load applied at the top, the compression members providing this support are the only ones that require high-structural strength. The rest of the structure is designed to stiffen the vertical members and to prevent bending under load. Primarily, the bracing members are designed to take loads in tension and are based on a series of diagonals.

Airfield observation towers, harbor shipping control towers, and radio towers are all erected by Steelworkers. Like PEBs, these towers are manufactured and packaged according to military specifications, and shipped with all parts, plans, and specifications.

The framework of the tower is made up of fabricated structural shapes that are bolted together. Anchor angles with base plates are furnished for setting in the concrete foundation (*Figure 17-26*). In most cases, the foundation will be built by the Builders. The manufacturer also furnishes square head bolts, lock washers, and nuts. Spud wrenches and drift pins are supplied for each size of bolt. Field bolts and shipping lists are prepared and packaged with each shipment of a tower.

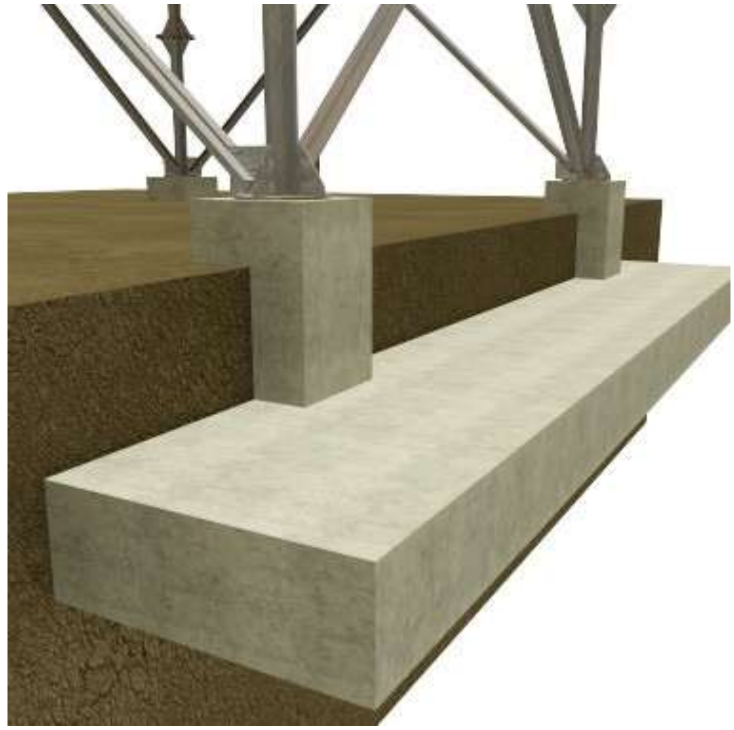


Figure 17-26 — Anchor angles in a concrete foundation.

The tower members are bundled in the most compact manner possible to keep shipping space to a minimum, with erection identification marks and stock list numbers painted on all of the pieces. All the nuts, bolts, and washers are boxed and identified by painted marks.

When you receive a tower shipment, you must inventory all the parts and packages. Check them against the shipping list to be sure that no boxes or bundles have been lost, stolen, misplaced, or damaged in shipment. When all are accounted for, sort the materials. The drawings tell you what is needed for each section. It is smart planning to lay out all of the materials for each section from the foundation to the top before any erection is started; this will save a lot of time later.

3.1.0 Assembly and Erection of Sections

Assemble the first section of the tower on the ground alongside the foundation. Start by assembling the two-column legs on one side of the tower and bolting them loosely, with one bolt each, to two foundation stubs (anchor angle irons); these will act as pivot points. Next, loosely join the angle and the cross braces, and then lift the entire side. You can use a crane or gin pole to rotate it into a vertical position or, if necessary, lift it by hand. Two people can start by lifting the far end and walking it up, while two others, with hand lines, can complete the upward journey.

As the column legs fall into position, use drift pins or spud wrenches to line up the holes with the holes in the embedded anchor angle irons. Then insert the bolts, place lock washers under each nut, and tighten them; use spud wrenches for this job. When one side is standing in the upright position, repeat the process for the opposite legs. Finally, connect the cross braces on the open sides, and add the cross braces on the inside. When the whole first section, or bay, is in place, tighten the bolts. *Figure 17-27* shows the correct connection of diagonal and center horizontal members; notice the alternate connections of the diagonal members at all points.

Figure 17-27 — Connection of diagonal and center horizontal members.

Use a snatch block and line to lift each piece for the next section. Do not tighten the bolts until the entire section is in place. Then start lifting the pieces for the next section, shifting the snatch block as necessary. When the whole section is in place, tighten the bolts. Repeat this process until the whole framework of the tower is erected. Bolts should be hoisted by hand lines in buckets or leather-bottom bolt bags. *Figure 17-28* shows a partially completed tower.

Assemble the ladder for the tower on the ground, raise the sections by hand as the tower is erected, and bolt them in place.

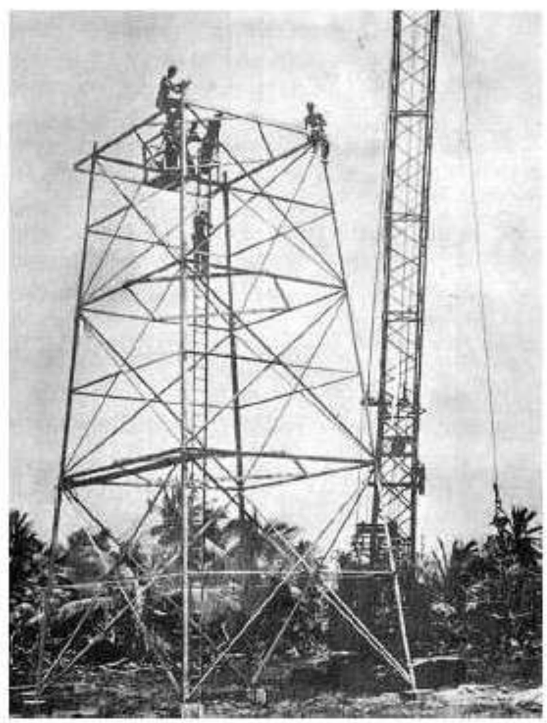


Figure 17-28 — Partially erected tower.

The wooden cabin section shown in *Figure 17-29* was constructed and raised in place by the Builders, but Steelworkers will be called upon to assemble rails and platforms.

After the tower is complete, one or two people must go over all of the nuts to confirm the following:

1. Washers are inserted under each nut.
2. Nuts are tightened to specs.
3. Bolts are center punched to lock them in place.

You can repeat this after a few weeks as a final check. Refer again to *Figure 17-29, which* shows the top of a completed tower with control room and guys in place.

Figure 17-29 — Completed tower.

3.2.0 Dismantling a Tower

Like PEBs, you can take steel towers down when no longer needed and re-erect them at a new location. As the first step, remove the electrical conduit for the aircraft red warning light atop the tower, the cabin, the platform, and any other accessories, then the guy lines.

Next, set up your rigging gear so that one leg of the section (preferably the leg that the ladder is connected to) will serve as the gin pole. Proceed to attach a shackle to the top vacant hole in the gusset plate and have a snatch block in the shackle. Open the snatch block and insert the fiber line to be used as a hoist line. Tie a bowline in the end of the line to keep it from unintentionally slipping through the block. Take the line to be used as the tag line and secure one end to the bowline. Now secure a snatch block to the base of the tower and run the hoist line from the top snatch block through this block to your source of power. Be sure the snatch block at the base of the tower is located in a straight line to a source of power. The source of power can be a dump truck, a weapon carrier, or some other vehicle.

NOTE: When using a vehicle as a source of power, you must keep it back far enough so as it comes forward, it does not arrive at the base of the tower before the load is on the ground.

The tower is dismantled by sections, and the top and second horizontal braces are the first members of the section to be removed. Start by tying the hoist line and tag line to the horizontal braces. Then signal the vehicle operator to back up and take a slight strain on the hoist line. You are now ready to remove the bolts holding the horizontal braces in place. After all the bolts are removed, lower the horizontal braces to the ground by signaling the power source to come forward. Now remove the diagonal braces in the same manner.

The next step is to remove the legs of the tower section, except the leg being used as the gin pole. First, ***shinny*** up the leg to be dismantled, and hang a shackle at the top. Tie the hoist line to the shackle and then come back down the leg. Signal the vehicle operator to take a slight strain on the hoist line, just enough to take up the slack and remove the gusset plate from one side. Remove the remainder of the bolts that hold the leg being removed, leaving the two top bolts in place. Now take the tag line and secure it with a clove hitch and a half hitch to the bottom of the load. Also, take a turn with the tag line around the horizontal bracing in the section that will be removed next. Then remove the two top bolts as you slack off on the tag line and take up on the hoist line until the leg is hanging straight up and down against the gin pole. Release the tag line to the personnel on the ground who will guide the load as it is lowered to the ground.

Repeat this process with all of the remaining legs until only the ladder and the leg used as a gin pole are left. To remove the ladder, secure the hoist line to a rung above the center. Remove the bolts and then lower the ladder to the ground.

When you are ready to start dismantling the leg used as the gin pole, shinny up it and remove the hoist line from the snatch block. Secure the hoist line to the shackle, remove the snatch block and hang it in your safety bit, then come back down the leg to the spliced connection. (Generally, at all spliced connections there will be horizontal brace connections that can serve as working platforms.)

Signal the personnel on the ground to remove the hoist line from the base snatch block; then signal the vehicle operator to take up the slack. Remove the gusset plate from one side of the splice. Remove the remaining bolts in the leg. After all the bolts are removed, ensure that all personnel are clear of where the load will land. Remove the top bolt, and release the nut on the other bolt one-quarter turn. Signal the vehicle operator to back up slowly. As the operator backs up, the leg will pivot downward on the bolt and fall against the leg it has been standing upon, and which will be used as the gin pole in dismantling the next section.

Now insert the shackle in the top hole of the gusset plate and hang the snatch block in it. Put the hoist line back in both snatch blocks. With the hoist line, throw a half-hitch below the center of the leg. Now secure the tag line. Next, signal the vehicle operator to take a slight strain to ease the tension off the bolt. You can then remove the bolt and lower the leg to the ground. This completes the dismantling of an entire section of the tower, so you can proceed to the next section.

Repeat the above procedure with each section until the tower is completely dismantled.

If the tower will be put up again rather than scrapped, assign a crew to wire brush each member of the tower to remove all rust, loose paint, and the like. After the wire brush cleaning, remark each member and store the tower in an orderly manner.

4.0.0 ANTENNA TOWERS

Modern communications in different parts of the world between ships, shore stations, and aircraft, including United States aerospace efforts, require transmitting and receiving facilities be erected all over the globe. Often, Steelworkers from battalion detachments receive the tasking to erect them. This section will describe some of the common communications antenna towers that are erected, and the procedures for erecting them.

4.1.1 Guyed Towers

The most commonly used guyed towers are fabricated from steel in straight sections 10 to 20 feet long. These constant dimensional sections are erected one above the other to form the desired height. Structural stability for this type of tower is provided by attaching guy wires from the tower to ground anchors.

Base supports for guyed towers vary according to the type of tower to be installed. Three commonly used base supports are the following:

1. Tapered tower base — concentrates the load from multiple tower legs to a small area on the foundation.

2. Pivoted tower base — used primarily on lightweight structures for ease of tower erection.

3. Composite base — generally used with heavier towers because it affords much greater supporting strength than the other two types.

All three are shown in *Figure 17-30*.

Sections for lightweight towers are usually assembled before delivery to expedite final tower assembly, whereas heavier weight towers must be assembled completely in the field.

Tower bracing should include diagonal bracing and horizontal struts in the plane of each tower face for the full tower height.

Figure 17-30 — Base support for guyed towers.

4.2.0 Freestanding Towers

Freestanding, or self-supporting, steel antenna towers are characterized by heavier construction than guyed towers, and by a shape that tapers in toward the top from a wide base. Freestanding towers exert much greater weight-bearing pressure on foundations than most guyed towers. Consequently, deeper foundations are required (because of the greater size, weight, and spread of tower legs) to provide sufficient resistance to the load.

Each leg of a freestanding tower must be supported by an individual foundation. *Figure 17-31* shows a typical individual foundation for a freestanding tower, and *Figure 17-32* shows a foundation plan for a triangular steel freestanding tower. Bracing and material specifications for these towers are the same as for guyed towers.

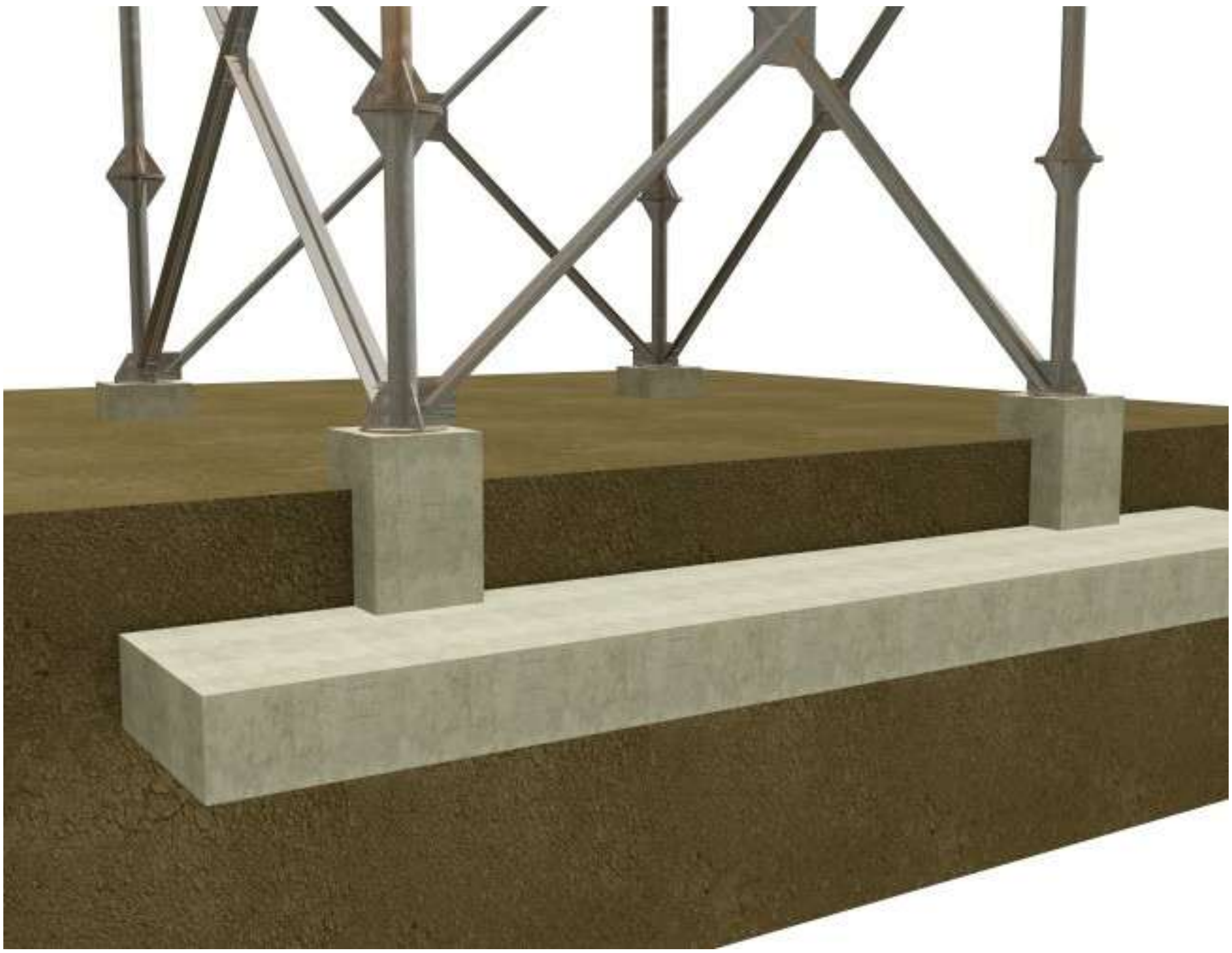


Figure 17-31 — Square self-supporting tower and base.

Figure 17-32 — Base support for guyed towers.

4.3.1 Tower Assembly

For tower assembly and erection, advance planning is absolutely essential to complete the project safely and correctly. Before commencing, study both the installation plan and the manufacturer's instructions to gain a complete understanding of the tower assembly and the phased erection methods to be used. Observe the following general procedures and practices for assembly and erection of towers:

1. Assemble the tower sections on well leveled supports to avoid building in twists or other deviations. Note: Any deviations in one section will be magnified by the number of sections in the complete assembly.

2. Check all of the surface areas for proper preservation. Cover all the holes and dents in galvanized materials with zinc chromate or another acceptable preservative to prevent deterioration.

3. When high-strength bolts are used in a tower assembly, place a hardened steel washer under the nut or bolt head, whichever is to be turned. Exercise care that you do not exceed the maximum torque limit of the bolt. Maximum torque values of several different sizes and types of bolts commonly used in antenna towers are listed in *Table 17-2*.

Table 17-2 — Bolt Torques (foot-pounds).

Size	Mild Steel	High-Strength Steel	Aluminum 24 ST-4	Stainless Steel 18-8
3/8" — 16	17	—	12	30
3/4" — 13	38	105	26	43
5/8" — 11	84	205	60	92
3/4" — 10	105	370	82	128
7/8" — 9	160	530	184	194
1" — 8	236	850	—	—
1 1/8" — 7	340	1100	—	—
1 1/4" — 7	432	1800	—	—

4.4.0 Erection of Guyed Towers

The following paragraphs present methods that have been successfully used to erect guyed towers. The most practical method for any particular tower will be determined by the size, weight, and construction characteristics of the tower, and by the hoisting equipment.

4.4.1 Davit Method

Lightweight guyed towers are frequently erected with a davit hoist anchored to the previously erected section, which then provides a pivoting hoisting arm. The davit arm is swung away from the tower in hoisting the added section and swung centrally over the tower in depositing the section before bolting up the splice plates. *Figure 17-33* shows a ground-assembled unit being hoisted for connection to a previously erected tower section. A snatch block secured to the tower base transmits the hoisting line to a source of power or hand winch. A tag line, secured to the base of section being hoisted, avoids possible contact with the erected portion of the tower.

Figure 17-33 — Typical davit installation.

4.4.2 Gin Pole Method

Light triangular guyed towers furnished with a pivoted base may be completely assembled on the ground and then raised to a vertical position with the aid of a gin pole. *Figure 17-34* shows the lower section of a tower that has an attached pivoted base in a horizontal position preparatory to hoisting. The thrust sling shown counteracts the thrust on the base foundation from hoisting operations. Rigging operations and location of personnel essential to the raising of a pivoted base tower are detailed in *Figures 17-35* and *17-36*.

Figure 17-34 — Pivoted tower-hoisting preparation.

Light towers in lengths of approximately 80 feet may be raised with a single attachment of the winch line. However, longer towers frequently are too flexible for a single attachment, and in the case of *Figure 17-36*, a hoisting sling furnished with a snatch block allows for two points of attachment.

Figure 17-35 — Erection plan for a pivoted tower.

A gin pole with a top sheave to take the winch line is mounted close to the concrete tower base. Permanent guys attached to the tower at three elevations are handled by personnel during hoisting operations (*Figure 17-35*). Temporary rope guys provided with a snatch block anchored to deadmen furnish the necessary lateral stability. As the mast approaches a vertical position, the permanent guys are fastened to the guy anchors, which were installed before erection.

Figure 17-36 — Erection of a pivoted guyed tower.

4.4.3 Hand Assembly

Erection without a davit or gin pole may be accomplished by assembling the individual members piece by piece. As the assembler, you climb inside the tower and work with the lower half of your body inside the previously assembled construction. You then build the web of the tower section around you as you progress upward. As each member is bolted in place, you tighten all of the connections immediately so you are never standing on, or being supported by, any loose member.

4.5.0 Guying

Temporary guying of steel towers is always necessary where more than one tower section is erected. Under no circumstances should the tower be advanced more than two sections without guying, and always install permanent guys before removing temporary guys.

4.5.1 Temporary Guying

Several materials, including stranded wire, wire rope, and fiber line, are acceptable for temporary guying, but new manila line is the most suitable because of its strength and ease of handling. The size of the guyed material you need will be determined by the height and weight of the structure to be guyed, and by weather conditions at the installation site.

Secure the temporary guys to the permanent guy anchors, to temporary type anchors, or to any nearby structure that provides the required supporting strength. Again, leave the temporary guys in place until the structure is permanently guyed and plumbed.

4.5.2 Permanent Guying

Antenna structures are permanently guyed to pre-positioned anchors according to the installation plan with steel cables or fiberglass sections.

Figure 17-37 shows two methods of guying triangular steel towers. Guys A, B, and C are secured to a single anchor, while guys D, E, and F are secured to individual anchors. Both arrangements are satisfactory; however, the anchor that terminates guys A, B, and C must be capable of withstanding much greater stresses than the individual guy anchor arrangement.

Triangular tower guys are arranged so that three guys are spaced 120 degrees apart at each level of guying (*Figure 17*-37). Square towers require four guys spaced 90 degrees apart at each guying level. The following general elevation requirements apply to guy attachments for towers:

Figure 17-37 — Tower guying arrangements.

4.5.2.1 Single-Guy Layer

The cable attachments are placed in position at approximately two thirds of the tower height.

4.5.2.2 Two-Guy Layers

For towers with two-guy layers, cable attachments are placed in positions at approximately 30 and 80 percent of the tower height.

4.5.2.3 Three-Guy Layers

For towers with three-guy layers, cable attachments are placed in positions at approximately 25, 55, and 85 percent of the tower height.

4.5.3 Guy Tension

Setting guy tension and plumbing a tower are done at the same time, and only when wind forces are light. Guy tension adjustment and tower plumbing are done as follows.

4.5.3.1 Initial Tension

The tension on all of the guys is adjusted after the tower is in a stable, vertical position. Adjust all of the guys gradually to the approximate tensions specified in the antenna installation details. If tensions are not specified, adjust guy tension to 10 percent of the breaking strength of the strand of the guy.

4.5.3.2 Final Tension

In one procedure used for final tensioning of tower guys, the final tension is measured with a dynamometer (*Figure 17-38*).

NOTE

Carpenter stoppers or cable grips of the proper skin designed for the lay of the wire must be used in the tensioning operation. Do not use any cable grip assembly that grips the wire by biting into the cable with gripping teeth that could penetrate and damage the protective coating of guy cables.

In Step A of *Figure 17-38*, the Coffing hoist is shown in series with a dynamometer to measure the tension. A turnbuckle is shown in position to receive the guy tail.

In Step B, an additional cable grip and hoist or tackle are attached above the cable grip shown in Step A. The lower end of this tackle is provided with a second cable grip attached to the guy tail previously threaded through the turnbuckle. The second Coffing hoist is operated until sufficient tension is applied to cause the reading on the series dynamometer to fall off.

Step C shows the guy in final position secured in place with clamps. With the tower properly plumbed to a vertical position, only one guy at a given level need be tested with the dynamometer.

On some installations, other procedures for tensioning guys may be necessary because of the type of guys and hardware supplied with the antenna. For example, preformed wire helical guy grips are sometimes used for attaching guy wires to the adjusting turnbuckles. In such cases, the techniques used for the guy assembly, the connection of the guy wire to the anchor, and the tension adjustments must be determined from the detailed installation plan or the appropriate antenna technical manual.

Figure 17-38 — Final tensioning of guys.

4.5.4 Guy Anchors

Antenna design and installation plans specify the required anchor type, location, and hole depth. Anchor shafts, or rods, must project above the grade sufficiently to keep all the connecting guy wire attachments free of vegetation and standing water. Shafts and connecting attachments should be thoroughly cleaned and coated with a petroleum preservative to retard the effects of weather.

4.5.4.1 Screw Anchor

The screw anchor shown in *Figure 17-39* may be used to anchor guys for lightweight towers, or for temporary guying. This anchor is installed by screwing it into the ground in line with the direction the guy will take.

Figure 17-39 — Typical screw anchor.

4.5.4.2 Expansion Anchor

The expansion anchor shown in *Figure 17-40* is suitable for practically all guying applications where the soil is firm. This anchor is placed with its expanding plates in the closed position in an auger-drilled inclined hole, not less than 3 feet deep. The plates are expanded into the firm, undisturbed sides of the hole by striking the expanding bar at Point B with a hammer and thereby forcing the sliding collar downward the distance D shown in *Figure 17-40*. The anchor installation is completed by backfilling the hole with thoroughly tamped backfill.

Figure 17-40 — Expansion anchor.

4.5.4.3 Concrete Anchor

Poured-in-place concrete anchors are normally used for high stress applications and where multiple guys are attached to a single anchorage.

Summary

This chapter discussed the assembly and disassembly of pre-engineered and K-span buildings. It also discussed steel towers and antennas, and presented information on how to secure them with different types of guys and anchors.

Falls and falling objects are the leading cause of injuries in the construction industry. Working with PEBs, K-spans, and towers always includes working with elevated heights. Use your situational awareness, remember to follow the prescribed safety precautions, and use your common sense; don’t get under a hoisting load.

Review Questions (Select the Correct Response)

1. For which use is a K-Span building NOT designed?

    A. Office space
    B. Hangar
    C. Supply building
    D. Warehouse

2. What are the two types of K-Span building machines?

    A. ABM 120 and ABM 240
    B. ABM 250 and ABM 260
    C. ABM 360 and ABM 380
    D. ABM 400 and ABM 410

3. What does the ABM 120 panel-forming machine produce for a K-span building?

    A. L spans
    B. Straight panels
    C. Arched panels
    D. Doorframes

4. The design of the foundation for a K-Span building does NOT depend on the ________.

    A. size of the building
    B. existing soil conditions
    C. wind load
    D. local construction rules

5. **(True or False)** Towers are designed to provide horizontal support.

    A. True
    B. False

6. What is the advantage of a pre-engineered building?

    A. Allows floor to ceiling storage of material
    B. Allows wall to wall placement of machinery
    C. Permits unhindered production flow
    D. All of the above

7. **(True or False)** A PEB is shipped with all materials and instructions necessary for erection.

    A. True
    B. False

8. The 40 by 100 foot, rigid frame, straight walled building can easily be disassembled, moved, and erected again without waste or damage because of what feature?

   A. Pre-stressed concrete pads
   B. Large metal C clamps
   C. Bolted connections
   D. Fiberboard panels

9. Which task should you perform before placing concrete for the foundation piers of a rigid frame building?

   A. Bolt the frames together only.
   B. Place templates and anchor bolts only.
   C. Uncrate the paneling only.
   D. All of the above

10. While the foundation is being prepared for a 40 by 100 foot rigid frame building, which work assignment can you perform?

   A. Glaze the windows only.
   B. Bolt the rigid frame assemblies only.
   C. Assemble the door eaves only.
   D. All of the above

11. Until ready for use, which material should remain crated?

   A. Girts
   B. Sheeting
   C. Eave struts
   D. Brace rods

12. What should you do to ensure building materials are accessible during assembly of a PEB?

   A. Keep all building materials in one central location.
   B. Keep the building materials on trucks.
   C. Place the materials around the building site where they will be used.
   D. Maintain at least 50 feet of clearance between the stockpiles of building materials.

13. How is each of the members, parts, and accessories of the building marked so it is not necessary to guess which one goes where?

   A. Painted with a mark across the bottom of the part
   B. Notched at the base of each part
   C. Embossed with a mark on each part
   D. Labeled by stencil on each part

14. **(True or False)** Once all the parts have been laid out and checked, erection of a 40 by 100 foot PEB should begin with the center frame member.

A. True
B. False

15. Where must brace rods be installed to hold the frames in an upright position?

A. In the first bay erected
B. In the second bay erected
C. In the center bay of the building
D. In the last bay erected

16. Where must sheeting installation be started on the sidewall and roof?

A. On the first bay erected
B. On the last bay erected
C. At the end of the building toward which the prevailing winds blow
D. Anywhere

17. **(True or False)** Pre-engineered buildings can be set up side by side to increase the working area under one roof.

A. True
B. False

18. What space requirements do you consider for K-span operations?

A. Maneuvering room for the towing of the trailer
B. Allocation of space required for crane operations
C. Room for run-out stands to hold straight panels
D. All of the above

19. In a K-span building, installation of which components presents a problem because it interrupts the integrity of the wall system?

A. Windows
B. Aluminum doors
C. Wood doors
D. Overhead doors

Trade Terms Introduced in This Chapter

Guy lines	A **guy-wire** or **guy rope** is a tensioned cable designed to add stability to structures (frequently ship masts, radio masts, wind turbines and tents). One end of the cable is attached to the structure, and the other is anchored to the ground at a distance from the structure's base. They are often configured radially (equally spaced about the structure) in trios, quads (pairs of pairs), or other sets. This allows the tension of each guy-wire to offset the others.
Shinny	American colloquialism--to climb a rope, pole, etc., from the use of shins and ankles to do so.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Facilities Planning Guide, NAVFAC P-437, Naval Facilities Engineering, Command, Alexandria, VA, 1990.

Naval Construction Battalion Table of Allowance, TA-01, Department of the Navy, Naval Facilities Engineering Command, Alexandria, VA, 1987.

MIC-120 ABM (K-Span), Training and Operator Manuals, MIC Industries, Reston, VA, 1993.

Rigging Techniques, Procedures, and Applications, FM 5-125, Department of the Army, Washington DC, 2001

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

Chapter 18

Introduction to Structural Steel

Topics

To hear audio, click on the box.

Overview

This chapter will give you a brief overview of structural steel. Structural steel is used as the framework for many steel structures such as industrial and commercial buildings, advanced base structures, and bridges. Many different pieces go into fabricating and erecting the framework for a steel structure, and as a Seabee Steelworker, you must have a thorough knowledge of the various structural members. We will discuss the most common names of the steel members as well as how to fasten and secure the members to each other and to the concrete foundation they are built upon. We will also discuss where and how in the structure the steel members are used.

Before any structural steel is fabricated or erected, a plan of action and sequence of events, or erection, needs to be set up. The plans, sequences, and required materials are predetermined by the engineering section and drawn up as a set of plans.

This chapter describes the basics of structural steel: the terminology, use of the members, methods of connection, and basic sequence of events during erection.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the different types of structural steel members.
2. Describe the purpose and types of anchor bolts.
3. Describe the purpose and types of bearing plates.
4. Describe the purpose and types of columns.
5. Describe the purpose and types of girders.
6. Describe the purpose and types of beams.
7. Describe the purpose and types of bar joists.
8. Describe the purpose and types of trusses.
9. Describe the purpose and types of purlins, girts, and eave struts.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	STEELWORKER BASIC
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet metal and Fiberglass Duct		
Welding Quality Control		
Flux Cored Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 STRUCTURAL STEEL MEMBERS

As a Steelworker, you will use various structural members manufactured in a wide variety of cross section shapes and sizes. *Figure 18-1* shows many of these shapes.

The three most common types of structural members are the W-shape (wide flange), the S-shape (American Standard I-beam), and the C-shape (American Standard channel). These three types are identified by the nominal depth, in inches, along the web and the weight per foot of length, in pounds. As an example, a W 12 x 27 indicates a W-shape (wide flange) with a web 12 inches deep and a weight of 27 pounds per linear foot.

Figure 18-2 shows the cross-sectional views of the W-, S-, and C-shapes. The difference between the W-shape and the S-shape is in the design of the inner surfaces of the flange. The W-shape has parallel inner and outer flange surfaces with a constant thickness, while the S-shape has a slope of approximately 17° on the inner flange surfaces. The C-shape is similar to the S-shape in that its inner flange surface is also sloped approximately 17°.

Figure 18-1 — Structural shapes and designations.

Figure 18-2 — Closer look at the W, S, and C structural members.

1.1.0 Terminology

You need to know the industry standard names for every structural member you will be using to prevent miscommunications between you and the other members on site, so we will discuss the structural members' names and some of their characteristics and uses.

1.1.1 W-Shape

The W shape is a structural member whose cross section forms the letter H and is the most widely used structural member. It is designed so that its flanges provide strength in a horizontal plane, while the web gives strength in a vertical plane. W-shapes are used as beams, columns, and truss members, and in other load-bearing applications.

1.1.2 Bearing Pile

The bearing pile (HP-shape) is almost identical to the W-shape. The only difference is that the flange thickness and web thickness of the bearing pile are equal, whereas the W-shape has different web and flange thicknesses.

1.1.3 S-Shape

The S-shape (American Standard I-beam) is distinguished by its cross section being shaped like the letter I. S-shapes are used less frequently than W-shapes since the S-shapes possess less strength and are less adaptable than W-shapes.

1.1.4 C-Shape

The C-shape (American Standard channel) has a cross section somewhat similar to the letter C. It is especially useful in locations where a single flat face without outstanding flanges on one side is required. The C-shape is not very efficient for a beam or column when used alone. However, efficient built-up members may be constructed of channels assembled together with other structural shapes and connected by rivets or welds.

1.1.5 Angle

An angle is a structural shape whose cross section resembles the letter L. Two types, as illustrated in *Figure 18-3*, are commonly used: an equal-leg angle and an unequal-leg angle. The angle is identified by the dimension and thickness of its legs, for example, angle 6 inches x 4 inches x 1/2 inch. The dimension of the legs should be obtained by measuring along the outside of the backs of the legs. When an angle has unequal legs, the dimension of the wider leg is given first, as in the example just cited. The third dimension applies to the thickness of the legs, which always have equal thickness. Angles may be used in combinations of two or four to form main members. A single angle may also be used to connect main parts together.

Figure 18-3 — Angles.

1.1.6 Plate

Steel plate is a structural shape whose cross section is in the form of a flat rectangle. Generally, a main point to remember about plate is that it has a width of greater than 8 inches and a thickness of 1/4 inch or greater.

Plates are generally used as connections between other structural members or as component parts of built-up structural members. Plates cut to specific sizes may be obtained in widths ranging from 8 inches to 120 inches or more, and in various thicknesses. The edges of these plates may be cut by shears (sheared plates) or be rolled square (universal mill plates).

Frequently, plates are referred to by their thickness and width in inches, as plate 1/2 inch x 24 inches. The length in all cases is given in inches. Note in *Figure 18-4* that 1 cubic foot of steel weighs 490 pounds. This weight divided by 12 gives you 40.8, which is the weight (in pounds) of a steel plate 1 foot square and 1 inch thick. The fractional portion is normally dropped and 1-inch plate is called a 40-pound plate. In practice, you may hear plate referred to by its approximate weight per square foot for a specified thickness. An example is 20-pound plate, which indicates a 1/2-inch plate. (Refer again to *Figure 18-4*).

Figure 18-4 — Weight and thickness of steel plate.

The designations generally used for flat steel have been established by the American Iron and Steel Institute (AISI). Flat steel is designated as bar, strip, sheet, or plate, according to the thickness of the material, the width of the material, and (to some extent) the rolling process to which it was subjected. *Table 18-1* shows the designations usually used for hot-rolled carbon steels. These terms are somewhat flexible and in some cases may overlap

Table 18-1 — Plate, Bar, Strip, and Sheet Designation.

Thickness (inches)	Width (inches)					
	To 3 1/2 Inclusive	Over 3 1/2 To 6	Over 6 To 8	Over 8 To 12	Over 12 To 48	Over 48
0.2300 and Thicker	**Bar**				**Plate**	
0.2299 and 0.2031						
0.2030 and 0.1800						
0.1799 and 0.0449	**Strip**					
0.0448 and 0.0344						
0.0343 and 0.0255				**Sheet**		
0.0254 and Thinner						

Color Key
Blue …..Bar
Green crisscross…..Plate
Orange…..Strip
Horizontal lines…..Sheet

1.1.7 Bar

The structural shape referred to as bar has a width of 8 inches or less and a thickness greater than 3/16 of an inch. The edges of bars usually are rolled square, like universal mill plates. The dimensions are expressed in a similar manner as that for plates, for instance, bar 6 inches x 1/2 inch. Bars are available in a variety of cross-sectional shapes—round, hexagonal, octagonal, square, and flat. Four different shapes are illustrated in *Figure 18-5*. Both squares and rounds are commonly used as bracing members of light structures. Their dimensions, in inches, apply to the side of the square or the diameter of the round.

Figure 18-5 — Bars.

You have now been introduced to the various structural members' characteristics and uses in steel construction. Next, follow along with the development of a theoretical building frame from where you, the Steelworker, would begin the structural phase after the following phases:

1. EOs have completed the earthwork.
2. UTs and CEs have completed the underground rough-in utilities.
3. You (Steelworkers) have placed the rebar for the footings and/or slab foundation, and set the anchor bolts.
4. BUs have poured and finished the concrete, and have stripped the forms.

Remember, this sequence is theoretical and may vary somewhat, depending on the type of structure being erected.

2.0.0 ANCHOR BOLTS

Anchor bolts are the first element of the structural building to be set in place (*Figure 18-6*). They are set in position by either the Steelworkers or the Builders using templates to hold them in place during the concrete pour. They are designed to hold the column-bearing plates, which are the first members of a steel frame placed into position above the concrete. These anchor bolts must be positioned very carefully so that the bearing plates will be lined up accurately.

Figure 18-6 — Anchor bolts.

3.0.0 BEARING PLATES

The column-bearing plates are steel plates of various thicknesses in which holes have been either drilled or cut with an oxygas torch to receive the anchor bolts (*Figure 18-7*). The holes should be slightly larger than the bolts so that some lateral adjustment of the bearing plate is possible. The angle connections, by which the columns are attached to the bearing plates, are bolted or welded in place according to the size of the column (*Figure 18-8*).

In many civilian commercial projects, the bearing plates arrive on the project from the fabrication shop already welded directly to the columns. The fabricator may have used an automatic welder or shop personnel to do the welding, but in either case, it saves additional moves in the field when erectors can set columns and base plates simultaneously.

Figure 18-7 — Column-bearing plate.

Figure 18-8 — Typical column to baseplate connections.

After the bearing plate has been placed into position, shim packs are set under the four comers of each bearing plate as each is installed over the anchor bolts (*Figure 18-9*). The shim packs are 3- to 4-inch metal squares of a thickness ranging from 1 1/6 to 3/4 inch, which are used to bring all the bearing plates to the correct level and to level each bearing plate on its own base.

The bearing plates are first leveled individually by adjusting the thickness of the shim packs. This operation may be accomplished by using a 2-foot level around the top of the bearing plate perimeter and diagonally across the bearing plate.

Upon completion of the leveling operation, all bearing plates must be brought either up to or down to the grade level required by the structure being erected. With the advent of lazar levels, their more common usage, and their subsequent cost reduction, often the tops of the shims are lazar leveled or “shot in” (adjusted for base plate thickness) prior to base plates arriving already welded to the columns.

All bearing plates must be lined up in all directions with each other. One method this may be accomplished by is using a surveying instrument called a builder’s level. String lines may be set up along the edges and tops of the bearing plates by spanning the bearing plates around the perimeter of the structure, making a grid network of string lines connecting all the bearing plates. If you use string lines, especially over extended distances, pay particular attention to eliminate any sag or deflection of the strings that will distort your elevations and grid lines.

After all the bearing plates have been set and aligned, the space between the bearing plate and the top of the concrete footing or slab must be filled with grout, a hard, non-shrinking, compact substance (*Figure 18-9*). When the grout has hardened, the next step is the erection of the columns. Note: If the system used includes the welded base plate/column with the shims “shot in,” the grouting may be done as a collateral event after the columns are plumbed with guy lines.

Figure 18-9 — Leveled bearing plate.

4.0.0 COLUMNS

Typically, wide flange members, as nearly square in cross section as possible, are used for columns, but sometimes large diameter pipe is used, even though pipe columns can present connecting difficulties when you are attaching other members (*Figure 18-10*). Columns may also be fabricated by welding or bolting together a number of other rolled shapes, usually angles and plates (*Figure 18-11*).

Figure 18-10 — Girder span on pipe columns.

Figure 18-11 — Built-up column section.

If the structure is more than one story high, it may be necessary to splice one column member on top of another. If this is required, column lengths should be such that the joints or splices are 1 1/2 to 2 feet above the second and succeeding story levels. This will ensure that the splice connections are situated well above the girder or beam connections so that they do not interfere with other second story work. Notice in *Figure 18-12* how the column splice plates are situated above the horizontal beam splice plates.

Figure 18-12 — Column splice plates.

Column splices are joined together by splice plates which are bolted, riveted, or welded to the column flanges, or in special cases, to the webs as well. If the members are the same size, it is common practice to butt one end directly to the other and fasten the splice plates over the joint (*Figure 18-13*). When the column size is reduced at the joint, a bearing plate is used to cap the lower column, and filler plates are used between the splice plates and the smaller column flanges (*Figure 18-14*).

Figure 18-13 — Spliced column with no size change.

Figure 18-14 — Spliced column with size change.

5.0.0 GIRDERS

Girders are the primary horizontal members of a steel frame structure. They span from column to column and are usually connected on top of the columns with cap plates (bearing connections) (*Figure 18-15*). An alternate method is the seated connection (*Figure 18-16*). The girder is attached to the flange of the column using angles, with one leg extended along the girder flange and the other against the column. The function of the girders is to support the intermediate floor beams.

Figure 18-15 — Girder span on a wide flange column.

Figure 18-16 — Seated connections.

6.0.0 BEAMS

Beams are generally smaller than girders and are usually connected to girders as intermediate members or to columns. Beam connections at a column are similar to the seated girder-to-column connection. Beams are used generally to carry floor loads and transfer those loads to the girders as vertical loads. Since beams are usually not as deep as girders, there are several alternative methods of framing one into the other *(Figure 18-17)*. The simplest method is to frame the beam between the top and bottom flanges on the girder (*Figure 18-18*). If it is required that the top or bottom flanges of the girders and beams be flush, it is necessary to cut away (cope) a portion of the upper or lower beam flange (*Figure 18-19*).

Figure 18-17 — 5 beams and I girder connected to a column.

Figure 18-18 — Beam connections at a girder.

Figure 18-19 — Coped beam ends.

7.0.0 BAR JOISTS

Bar joists form a lightweight, long-span system used as floor supports and built-up roofing supports (*Figure 18-20*). Bar joists generally run in the same direction as a beam and may at times eliminate the need for beams. You will notice in *Figure 18-21* that bar joists must have a bearing surface. The span is from girder to girder (*Figure 18-22*).

Prefabricated bar joists designed to conform to specific load requirements are obtainable from commercial companies.

Figure 18-20 — Clear span bar joists.

Figure 18-21 — Bar joists seat connection.

Figure 18-22 — Installing bar joists girder to girder.

8.0.0 TRUSSES

Steel trusses are similar to bar joists in that they serve the same purpose and look somewhat alike. They are, however, much heavier and are fabricated almost entirely from structural shapes, usually angles and T-shapes (*Figure 18-23*).

Figure 18-23 — Steel truss fabricated from angle-shaped members.

Unlike bar joists, trusses can be fabricated to conform to the shape of almost any roof system and are therefore more versatile than bar joists (*Figure 18-24*).

The bearing surface of a truss is normally the column. The truss may span the entire building from outside column to outside column. After the trusses have been erected, they must be secured between the bays with diagonal braces (normally round rods or light angles) on the top chord plane (*Figure 18-25*) and the bottom chord plane (*Figure 18-26*). After these braces are installed, a sway frame is put into place (*Figure 18-27*).

Figure 18-24 — Styles of trusses.

Figure 18-25 — Diagonal braces; top chord plane.

Figure 18-26 — Diagonal braces; bottom chord plane.

Figure 18-27 — Sway frame.

9.0.0 PURLINS, GIRTS, AND EAVE STRUTS

Purlins are generally lightweight, channel-shaped, z-shaped, or top hat-shaped, and are used to span roof trusses. Purlins are the uppermost element of the erected structural steel, and they support the decking (steel or otherwise) (*Figure 18-28*). If the purlins are channel-shaped, they are installed with the legs of the channel facing outward or down the slope of the roof.

Figure 18-28 — Roof purlin.

Figure 18-29 — Ridge struts.

The purlins installed at the ridge of a gabled roof are referred to as ridge struts. The purlin units are placed back-to-back at the ridge and tied together with steel plates or threaded rods (*Figure 18-29*).

The sides of a structure are often framed with girts. These members are attached to the columns horizontally (*Figure 18-30*). The girts are also channel-shaped, z-shaped, or top hat-shaped, generally the same size and shape as the roof purlins. The siding material is attached directly to the girts.

Figure 18-30 — Wall girt.

Figure 18-31 — Eave strut.

Another longitudinal member similar to purlins and girts is an eave strut. This member is attached to the column at the point where the top chord of a truss and the column meet at the cave of the structure (*Figure 18-31*).

Summary

This chapter briefly introduced you to the basics of structural steel: the terminology, use of the members, methods of connection, and basic sequence of events during erection. They are as valid for use in the civilian construction industry as an Ironworker as they are in the military as a Steelworker.

However, you will come across many more steel working terms as you gain experience. If a term is used that you do not understand, ask someone to explain it or look it up in the manuals and publications available to you.

Always remember to follow the prescribed safety precautions and wear the proper personal protective equipment--times have changed since the Ironworkers had their photo taken in 1932 (*Figure 18-32*).

Figure 18-32 — Old School ironworkers.

Review Questions (Select the Correct Response)

1. A piece of steel plate 3 square feet weighs 180 pounds. What is the classification of this plate?

   A. 20-pound
   B. 40-pound
   C. 60-pound
   D. 80-pound

2. A 10-foot piece of steel that is 3/8 inch thick and 2 inches wide is classified as a _______.

   A. bar
   B. strip
   C. sheet
   D. plate

3. What sequence is the proper order you should follow for the erection of structural members?

   A. Girders, bearing plates, anchor bolts, columns, beams
   B. Anchor bolts, column plates, girders, bearing plates, beams
   C. Anchor bolts, bearing plates, columns, girders, beams
   D. Bearing plates, anchor bolts, columns, girders, beams

4. When cutting the holes in bearing plates to receive anchor bolts, why do you cut the holes larger than the bolts?

   A. To allow for height adjustment
   B. To permit lateral adjustment
   C. To compensate for angle connections
   D. To allow space for welding of columns

5. Bearing plates are brought to their proper levels by _______.

   A. installing shim packs
   B. welding the plates to the bearing plates
   C. forcing the grout under the bearing plates
   D. using locknuts

6. What structural shape is most often used for columns?

   A. Standard beam
   B. Tee shape
   C. Pipe
   D. Wide flange beam

7. What structural steel member is used primarily to span from column to column horizontally?

   A. Beam
   B. Truss
   C. Girder
   D. Column splices

8. Which member forms a lightweight, long-span system used as floor supports and built-up roofing supports?

   A. Bar joist
   B. Truss
   C. Beam
   D. Girder

9. Workers have installed diagonal braces between bays of a truss system. Their next step is to secure the roof system with what structural members?

   A. Angle ties
   B. Sway frames
   C. Diagonal locking bars
   D. Bottom chord extensions

10. When using channel-shaped purlins to span roof trusses, you should ensure the legs face in what direction?

   A. Up toward the center or apex of the roof
   B. Flat with the face of the channel face directly toward the truss
   C. Downward with both legs welded to the truss
   D. Outward or down toward the slope of the truss system

11. What structural members are attached to the outside perimeter columns and used to frame the siding of a building?

   A. Eave struts
   B. Purlins
   C. Girts
   D. Ridge plates

Trade Terms Introduced in this Chapter

None

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Frankland, Thomas, W., *The Pipefitter's and Pipe Welder's Handbook,* Glencoe/McGraw-Hill Publishing Company, Woodland Hills, CA, 1984.

Frankland, Thomas, W., *Pipe Trades Pocket Manual,* Glencoe/McGraw-Hill Publishing Company, Peoria, IL, 1969.

Nelson, Carl, A., *Millwright's and Mechanic's Guide, 2d* ed., Theodore Audel and Company, Indianapolis, IN, 1972.

The *Oxy-Acetylene Handbook,* 2nd ed., Linde Company, New York NY, 1960.

Walker, John, R., *Modern Metalworking,* Goodheart-Wilcox Company Inc., South Holland, IL, 1973.

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

Chapter 19

Introduction to Reinforcing Steel

Topics

To hear audio, click on the box.

Overview

As a Steelworker, you must be able to cut, bend, place, and tie reinforcing steel in its proper sequence and configurations. This chapter describes the purpose of reinforcing steel in concrete construction, identifies the types and shapes of commonly used reinforcing steel, and explains specific properties of rebar (reinforcing steel). This chapter begins with a presentation of fundamental information about concrete to help you understand rebar work fully.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the different materials, purposes, and types of reinforcing steel.

Prerequisites

None

This course map shows all of the chapters in Steelworker Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Introduction to Reinforcing Steel	↑	S T E E L W O R K E R B A S I C
Introduction to Structural Steel		
Pre-Engineered Structures: Buildings, K-Spans, Towers and Antennas		
Rigging		
Wire rope		
Fiber Line		
Layout and Fabrication of Sheet metal and Fiberglass Duct		
Welding Quality Control		
Flux Cored Arc Welding-FCAW		
Gas-Metal Arc Welding-GMAW		
Gas-Tungsten Arc Welding-GTAW		
Shielded Metal Arc Welding-SMAW		
Plasma Arc Cutting Operations		
Soldering, Brazing, Braze Welding, Wearfacing		
Gas Welding		
Gas Cutting		
Introduction to Welding		
Basic Heat Treatment		
Introduction to Types and Identification of Metal		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 REINFORCED CONCRETE

As a Steelworker you will be primarily concerned with reinforcing steel placement, but you should to some extent be concerned with concrete as well. Concrete with reinforcing steel added becomes reinforced concrete. Structures built of reinforced concrete, such as retaining walls, buildings, bridges, highway surfaces, and numerous other structures, are referred to as reinforced concrete structures or reinforced concrete construction. The reinforcement can be as simple as a few continuous bars in a small foundation (*Figure 19-1*) or as complex as a pier/footing combination for a bridge (*Figure 19-2*).

Figure 19-1 — Simple use of reinforcement bars.

Figure 19-2 — Complex use of reinforcement bars.

1.1.0 Concrete Materials

Concrete is a synthetic construction material made by mixing cement, fine aggregate (usually sand), coarse aggregate (usually gravel or crushed stone), and water in proper proportions (*Figure 19-3*). This mixture hardens into a rocklike mass as the result of a chemical reaction between the cement and water called hydration. Concrete will continue to harden and gain strength, in a chemical process known as curing, as long as it is kept moist and warm. Durable, strong concrete is made by correctly proportioning and mixing the various materials and additives, and by properly curing the concrete following placement or "the pour."

The correct proportioning of the concrete ingredients (modern concrete design may include retardants, accelerators, ***plasticizers***, air entraining agents, etc.) is often referred to as "the mix." The quality of the concrete is largely determined by the quality of the cement-water paste that bonds the aggregates together. The strength of concrete will be reduced if this paste has water added to it. The proportion of water to cement is referred as the water-cement ratio. The water-cement ratio is the number of gallons of water per pounds of cement. High quality concrete is produced by using the lowest water-cement mixture possible without sacrificing workability.

Figure 19-3 — Aggregate.

Because concrete is plastic when placed, forms are built to contain and form the concrete until it has hardened. In short, forms and formwork are described as molds that hold freshly placed concrete in the desired shape until it hardens. In some cases, depending on the soil texture and stability, the soil banks of excavated areas act as the formwork for footings and foundations.

All the ingredients of a mix are placed in a concrete mixer, and after a thorough mixing, the concrete is transferred by numerous methods (as determined by the project's conditions), such as bucket, wheelbarrow, chute, transit truck tailgate, pump, and so forth, into the formwork in which the reinforcing steel has already been placed.

Under normal, moderate weather and temperature conditions, concrete reaches its initial set in approximately 1 hour, and hardens to its final set (although not fully cured) in approximately 6 to 12 hours. As the concrete is being placed, and before the initial set, it must be vibrated in the formwork to ensure complete coverage of all reinforcing bars, but not vibrated so much that the aggregate and cement separate to form "rock pockets."

Finish operations, such as smooth troweled finishes, must be performed between initial and final set. After the final set, concrete must be protected from shock, extreme temperature changes, and premature drying until it cures to sufficient hardness. Concrete will be self-supportive in a few days and will attain most of its potential strength in 28 days of moist curing. For further information on concrete, refer to the American Society for Testing and Materials (ASTM) and the American Concrete Institute (ACI)-318*.*

1.2.0 Concrete Strength

As stated previously, the strength of concrete is determined by the water-cement ratio. The strength of ready-mixed concrete ranges from 1,500 to about 5,000 pounds per square inch (psi) and, with further attention paid to proportioning, it can go even higher. Under usual construction processes, lower strength concrete will be used in footers and walls, and higher strength in beams, columns, and floors. The required strength of concrete on a given project can be found in the project plans and specifications for a specific project.

NOTE: Quality control is important to ensure specific design requirements are met. If the design specifications do not meet minimum standards, structural integrity is compromised and the structure is considered unsafe. For this reason, the compressive strength of concrete is checked on all projects.

The strength of the concrete is checked by the use of cylindrical molds that are 6 inches in diameter and 12 inches in height. Concrete samples must be taken on the jobsite from the concrete that is being placed. After being cured for a period that ranges between 7 to 28 days, the cylinders are “broken to failure” by a laboratory crushing machine that measures the force required for the concrete to fail (*Figure 19-4*).

For further information on concrete strength and testing, refer to FM 5-472 Ch. 2 /NAVFAC MO 330/AFJMAN 32-1221(I), ASTM, and ACI 318*.*

Figure 19-4 — Concrete testing machine.

1.3.0 Purposes and Types of Reinforcing Steel

Reinforced concrete was designed on the principle that steel and concrete act together in resisting force.

Concrete is strong in compression but weak in tension (*Figure 19-5*). The tensile strength is generally rated about 10 percent of the compression strength. For this reason, concrete works well for columns and posts that are compression members in a structure. But when it is used for tension members, such as beams, girders, foundation walls, or floors, concrete must be reinforced to attain the necessary tension strength.

Steel is the best material for reinforcing concrete because the properties of expansion for both steel and concrete are considered to be approximately the same, that is, under normal conditions, they will expand and contract at an almost equal rate.

NOTE

At very high temperatures, steel expands more rapidly than concrete and the two materials will separate.

Figure 19-5 — Various concrete stresses.

Another reason steel works well as a reinforcement for concrete is that it bonds well with concrete. This bond strength is proportional to the contact surface of the steel to the concrete. In other words, the greater the surface of steel exposed to the adherence of concrete, the stronger the bond. A deformed reinforcing bar adheres better than a plain, round, or square one because it has a greater bearing surface. In fact, when plain bars of the same diameter are used instead of deformed bars, approximately 40 percent more bars must be used.

The rougher the surface of the steel, the better it adheres to concrete. Thus, steel with a light, firm layer of rust is superior to clean steel; however, steel with loose or scaly rust is inferior. Loose or scaly rust can be removed from the steel by rubbing the steel with burlap or similar material. This action leaves only the firm layer of rust on the steel to adhere to the concrete.

NOTE

Reinforcing steel must be strong in tension and, at the same time, be ductile enough to be shaped or bent cold.

Reinforcing steel can be used in the form of bars or rods that are either plain or deformed or in the form of expanded metal, wire, wire fabric, or sheet metal. Each type is useful for different purposes, and engineers design structures with those purposes in mind.

Plain bars are round in cross section. They are used in concrete for special purposes, such as dowels at expansion joints, where bars must slide in a metal or paper sleeve, for contraction joints in roads and runways, and for column spirals. They are the least used of the rod type of reinforcement because they offer only smooth, even surfaces for bonding with concrete.

Deformed bars are like plain bars except that they have indentations, ridges, or both in a regular pattern. Earlier versions of deformed rebar were available as square or with a spiral twist, and workers may still encounter them during demolition or on remodeling projects of older structures. Current rebar suppliers deform the bars at the mill with patterns and markings unique to their mill and to the tensile strength of the material. *Figure 19-6* shows a few of the types of deformed bars available.

In the United States, deformed bars are used almost exclusively, while in Europe, both deformed and plain bars are used.

There are 11 standard sizes of reinforcing bars (*Figure 19-7*). Bars No. 3 through No. 18, inclusive, are deformed bars. Bar numbers correspond to bar sizes to the nearest 1/8 in. (3. 175 mm) measured at the nominal diameter but not including any deformations. At various sites overseas, rebar could be procured locally and could be metric.

Note: At 13.6 pounds per foot, a #18 bar (#57 metric) of any functional length quickly becomes too heavy for personnel handling and requires mechanical lifting equipment.

Figure 19-6 — Sample mill patterns and tensile strength markings.

Figure 19-7 — Reinforcing steel sizes and their tensile strength markings.

1.3.1 Reinforcing Bars

Reinforcing bars are hot-rolled from a variety of steels in several different strength grades. Generally, reinforcing steel bars are either carbon-steel (conforming to ASTM A615) or low-alloy steel (conforming to ASTM A706). Most reinforcing bars are rolled from new steel billets, but some are rolled from used railroad-car axles or railroad rails that have been cut into rollable shapes. An assortment of strengths is available.

The American Society for Testing Materials (ASTM) has established a standard branding for deformed reinforcing bars. There are a number of important ways to identify reinforcing bar from the production mill to the fabrication shop to the job site. This documentation and marking system helps provide a wealth of useful information about the manufacturing and composition of each bar of reinforcing steel.

Each individual reinforcing bar is manufactured with a series of individual markings. Refer again to *Figure 19-6*:

- The top letter or symbol identifies the producing mill and deformation pattern.
- The next marking is the bar size.
- The third marking symbol designates the manufacturing material — usually either "S" for carbon-steel (ASTM A615) or "W" for low-alloy steel (ASTM A706).
- Finally, there will be a grade marking (4 or 5, for 420 or 520) or the addition of one line (420) or two lines (520) that must be at least five deformations long.

The lower strength reinforcing bars show only three marks: an initial representing the producing mill, bar size, and type of steel.

High strength reinforcing bars use either the continuous line system or the number system to show grade marks. In the line system, one continuous line is rolled into the 60,000 psi bars, and two continuous lines are rolled into the 75,000 psi bars. The lines must run at least five deformation spaces, as shown in *Figure 19-6*.

Reinforcing bars typically come in two primary grades: Grade 60 (minimum yield strength of 60,000 psi) and Grade 75 (minimum yield strength of 75,000 psi). The metric equivalents for these are Grade 420 (equivalent yield strength of 420 MPa (megapascals) and Grade 520 (equivalent yield strength of 520 MPa).

1.3.2 Tension in Steel

Steel bars are strong in tension. Structural grade is capable of safely carrying up to 18,000 psi and intermediate, hard, and rail steel, 20,000 psi. This is the safe or working stress; the breaking stress is about triple this.

When a mild steel bar is pulled in a testing machine, it stretches a very small amount with each increment of load. In the lighter loadings, this stretch is directly proportional to the amount of load (*Figure 19-8, View A*). The amount is too small to be visible and can be measured only with sensitive gauges.

At a point during the pull (known as the Yield Point), such as 33,000 psi for mild steel, the bar begins to neck down (*Figure 19-8, View B*) and continues to stretch perceptibly with no additional load.

Then, when it seems the bar will snap like a rubber band, it recovers strength (due to work hardening). Additional pull is required (*Figure 19-8, View C*) to produce additional stretch and final failure (known as the ultimate strength) at about 55,000 psi for mild steel.

Common specifications are ASTM A 615 for carbon steel rebar, ASTM A 706 for seismic rebar, ASTM A 955 for stainless steel rebar, and ASTM A 996 for rail steel rebar and axle steel rebar. American Association of State Highway and Transportation Officials (AASHTO) Specifications M31M / M 31-02, *Deformed and Plain Billet-Steel Bars for Concrete Reinforcement* contain more information on reinforcing bar tension testing.

Figure 19-8 — Tension in steel bars.

1.4.0 Additional Types of Reinforcing Steel

Not all concrete reinforcing needs heavy reinforcing bars; some projects require only lightweight reinforcing. In these cases, expanded metal or welded wire fabric can be used.

1.4.1 Expanded Metal

Expanded metal is made from sheets of solid metal that are uniformly slit and stretched to create diamond-shaped openings. As expanded metal is made, each row of diamond-shaped openings is offset from the next (*Figure 19-9*). This product is called standard expanded metal. The sheet can be rolled to produce flattened expanded metal.

The lightweight properties and open area percentages of expanded metal allow it to be easily formed for a variety of energy-saving applications, such

Figure 19-9 — Expanded metal.

as light diffusers, screens, grilles, and filters. Expanded metal is also manufactured in heavy gauges for applications such as reinforcing concrete walkways, ramps, and catwalks of all types.

1.4.2 Welded Wire Fabric

Welded wire fabric is fabricated from a series of wires arranged at right angles to each other and electrically welded at all intersections. Welded wire fabric, referred to as WWF within the NCF, has various uses in reinforced concrete construction. In building construction, it is most often used for floor slabs on well compacted ground. Heavier fabric, supplied mainly in flat sheets, is often used in walls and for the primary reinforcement in structural floor slabs. Additional examples of its use include road and runway pavements, box culverts, and small canal linings.

Welded wire fabric (WWF or wire mesh) is available in rolls of lighter gauge wire for light building construction and in sheets of heavier gauge wire for highways and buildings when roll gauge sizes will not give sufficient reinforcement (*Figure 19-10*). WWF is available in square and rectangular patterns in a wide variety of wire gauges welded at each intersection.

Figure 19-10 — Welded wire.

When welded wire fabric in either the old or the new designations is ordered, the wire spacing (in each direction) comes first followed by the wire gauge (in each direction). The old designation used number (in inches) for spacing and number (in wire gauge) for the size of the WWF. The new designation uses number (in inches) for spacing but a letter and a number (in wire cross section) for size.

For example, in the old designation, 6x6 — 4x4 mesh would be 6-in. squares with 4-gauge wire in each direction, whereas 4x4 — 6x6 mesh would be 4-in. squares with 6-gauge wire in each direction. In the new designation, these would be 6x6 — W4xW4, and 4x4 — W2.9xW2.9 respectively. *Table 19-1* provides some typical WWF designations used for structural concrete.

When WWF is used, specifications and designs usually indicate the minimum lap. As a practical matter, although a minimum lap of 2 in. may be sufficient for nonstructural concrete, for placement purposes a 1-square lap, regardless of the mesh spacing, is common to facilitate the installer's ability to tie the laps together at intersections.

The unit weight of WWF is designated in pounds per one hundred square feet of fabric Five feet, six feet, seven feet, and seven feet six inches are the standard widths available for rolls, while the standard panel widths and lengths are seven feet by twenty feet and seven feet six inches by twenty feet.

Table 19-1 – Common Stock Sizes of Welded Wire Fabric.

Style Designation		Weight Approximate Pounds per 100 Square Feet
Current Designation (by W-Number)	**Previous Designation (by Steel Wire Gauge)**	
Panels/Sheets		
6 x 6 – W 1.4 x W 1.4	6 x 6 – 10 x 10	21
6 X 6 –W 2.1 X W 2.1	6 X 6 – 8 X 8	29
6 X 6 – W 2.9 X W 2.9	6 x 6 – 6 x 6	42
6 x 6 – W 4.0 x W 4.0	6 x 6 – 4 x 4	58
4 x 4 – W 1.4 x W 1.4	4 x 4 – 10 x 10	31
4 x 4 – W 2.1 x W 2.1	4 x 4 – 8 x 8	43
4 x 4 – W 2.9 x W 2.9	4 x 4 – 6 x 6	62
4 x 4 – W 4.0 x W 4.0	4 x 4 – 4 x 4	86
Rolls		
6 x 6 – W 1.4 x W 1.4	6 x 6 – 10 x 10	21
6 x 6 – W 2.9 x W 2.9	6 x 6 – 6 x 6	42
6 x 6 – W 4.0 x W 4.0	6 x 6 – 4 x 4	58
6 x 6 – W 5.5 x W 5.5	6 x 6 – 2 x 2	80
4 x 4 – W 4.0 x W 4.0	4 x 4 – 4 x 4	86

1.4.3 Sheet-Metal Reinforcement

Sheet-metal reinforcement is used mainly in floor slabs and in stair and roof construction. It consists of annealed sheet steel bent into grooves or corrugations about one-sixteenth inch (1.59 mm) in depth with holes punched at regular intervals.

Summary

This chapter discussed the fundamental information about reinforced concrete and the reasons why it is necessary to use reinforcement steel with concrete. Also discussed were the different materials, purposes, and types of reinforcing steel. Specifically discussed was the identification system used on the most common reinforcement bar used by the Seabees. The mechanical properties of the steel and ASTM specifications of the steel reinforcement bars were also discussed.

Always remember to follow the prescribed safety precautions and wear the proper personal protective equipment.

Review Questions (Select the Correct Response)

1. What is the primary factor that determines the strength of concrete?

   A. Dryness
   B. Water-to-cement ratio
   C. Age
   D. Type of steel reinforcement

2. **(True or False)** Concrete is strong in tension but weak in compression.

   A. True
   B. False

3. Which factor makes steel the best material for reinforcing concrete?

   A. Steel adds compressive strength.
   B. The expansion properties of both steel and concrete are approximately the same.
   C. Steel is easily bent to fit all shapes of forms.
   D. Steel adheres well to concrete.

4. What type of surface condition on rebar provides the best adherence with concrete?

   A. Clean and smooth
   B. Loose or scaly rust
   C. Painted
   D. Light, firm layer of rust

5. On what part of rebar are diameter measurements taken?

   A. On the round/square where there are no deformations
   B. On the deformations where the diameter is greatest
   C. On the diagonal of its widest section
   D. On the diameter of the deformation plus the height of the deformation

6. What does the first letter or symbol identify on a reinforcement bar brand?

   A. Producing mill
   B. Bar size
   C. Manufacturing material
   D. Grade mark

7. What is the metric equivalent to a grade 60 reinforcement bar?

   A. 220
   B. 320
   C. 420
   D. 520

8. At what pounds per square inch will a steel bar begin to neck down?

A. 22,000
B. 33,000
C. 66,000
D. 77,000

9. When the number designation 8x8x10x10 is used, what do these numbers indicate about a roll of wire mesh?

A. The wire gauge is 8 and the crosswise spacing is 10 inches.
B. The wire gauge is 10 and the crosswise and lengthwise spacing is 8 inches.
C. The wire gauge is 8 and the length spacing is 8 inches.
D. The crosswise spacing is 10 inches and the wire gauge is 10.

10. What is the common spacing, in square laps, on wire mesh fabric that facilitates the installer's ability to tie laps together?

A. 1
B. 2
C. 3
D. 4

Trade Terms Introduced in this Chapter

Plasticizer	An admixture for making mortar or concrete workable with little water.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Consolidated Cross-Reference, TA-13, Department of the Navy, Navy Facilities Engineering Command, Alexandria, VA, 1989.

Concrete and Masonry, FM 5-428, Headquarters Department of the Army, Washington, DC, 1998.

Concrete Construction Engineering, 2nd ed. Nawy, E.G. Boca Raton, FL, 2008

Construction Print Reading in the Field, TM 5-704, Headquarters Department of the Army, Washington, DC, 1969*.*

Placing Reinforcing Bars, 8th ed, Concrete Reinforcing Steel Institute*,* Schaumburg, IL, 2005.

CSFE Nonresident Training Course – User Update

CSFE makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in CSFE manuals, please write or email us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: CSFE N7A
3502 Goodspeed St.
Port Hueneme, CA 93130

FAX: 805/982-5508

E-mail: CSFE_NRTC@navy.mil

Rate_ Course Name_

Revision Date_ Chapter Number_ Page Number(s)_

Description

___

___

___

(Optional) Correction

___

___

___

(Optional) Your Name and Address

___

___

___

APPENDIX I

MATHEMATICS

The purpose of this mathematics appendix is twofold; first, it is a refresher for the Seabees who have encountered a time lapse between his or her schooling in mathematics; second, and more important, this section applies mathematics to the tasks that can not be accomplished without the correct use of mathematical equations.

Linear Measurement

Measurements are most often made in feet (ft) and inches (in). It is necessary that a Seabee know how to make computations involving feet and inches.

Changing Inches to Feet and Inches

To change inches to feet and inches, divide inches by 12. The quotient will be the number of feet, and the remainder will be inches.

Changing Feet and Inches to Inches

To change feet and inches to inches, multiply the number of feet by 12 and add the number of inches. The results will be inches.

Changing Inches to Feet in Decimal Form

To change inches to feet in decimal form, divide the number of inches by 12 and carry the result to the required number of places.

Changing Feet to Inches in Decimal Form

To change feet in decimal form to inches, multiply the number of feet in decimal form by 12.

Addition of Feet and Inches

A Seabee often finds it necessary to combine or subtract certain dimensions which are given in feet and inches.

Arrange in columns of feet and inches and add separately. If the answer in the inches column is more than 12, change to feet and inches and combine feet.

Subtraction of Feet and Inches

Arrange in columns with the number to be subtracted below the other number. If the inches in the lower number are greater, borrow 1 foot (12 Inches) from the feet column in the upper number. Subtract as in any other problem.

Multiplication of Feet and Inches

Arrange in columns. Multiply each column by the required number. If the inches column is greater than 12, change to feet and inches then add to the number of feet.

Division of Feet and Inches

In dividing feet and inches by a given number, the problem should be reduced to inches unless the number of feet will divide by the number evenly.

To divide feet and inches by feet and inches, change to inches or feet (decimals).

Angles

When two lines are drawn in different directions from the same point, an angle is formed.

Angles are of four types:

- Right angle is a 90° angle.
- Acute angles are angles less than 90°.
- Obtuse angles are angles greater than 90°, but less than 180°.
- Reflex angle is an angle greater than 180°.

Measurement of Angles

Observe that two straight lines have been drawn to form four right angles. Refer to *Figure A-1*.

In order to have a way to measure angles, a system of angle-degrees has been established. Assume that each of the four right angles is divided into 90 equal angles. The measure of each is 1 angle degree; therefore, in the four right angles, there are 4 x 90°, or 360 angle degrees. For accurate measurement, degrees have been subdivided into minutes and minutes into seconds.

1 degree= 60 minutes (’).

1 minute= 60 seconds (“).

Figure A-1 — Right angles.

Relationship of Angles

Figure A-2 — Relationship of angles.

1. $\angle$ZOY and $\angle$ZOX are supplementary angles and their total measure in degrees is equal to 180°. When one straight line meets another, two supplementary angles are formed. One is the supplement of the other. Refer to *Figure A-2, View 1*.

2. $\angle$DAC and $\angle$CAB are complementary angles and their total is a right angle or 90°. Refer to *Figure A-2, View 2*.

Two angles whose sum is 90° are said to be complementary, and one is the complement of the other.

3. $\angle$MOP and $\angle$RON are a pair of vertical angles and are equal. Refer to *Figure A-2, View 3*.

When two straight lines cross, two pairs of vertical angles are formed. Pairs of vertical angles are equal.

Bisecting Angles

To bisect an angle merely means to divide the angle into two equal angles. This may be done by use of a compass.

Perpendicular Lines

Lines are said to be perpendicular when they form a right angle (90°).

Parallel Lines

Two lines are said to be parallel if they are equidistant (equally distant) at all points.

Facts about parallel lines:

Two straight lines lying in the same plane either intersect or are parallel.

Through a point there can be only one parallel drawn to a given line.

If two lines are perpendicular to the third, and in the same plane, they are parallel.

Plane Shapes

A plane shape is a portion of a plane bounded by straight or curved lines or a combination of the two.

The number of different types of plane shapes is infinite, but we are concerned with those which are of importance to you as a Seabee. We will cover the circle, triangle, quadrilateral, other polygons, and ellipses.

Circles

Definitions:

A CIRCLE is a closed curved line in which any point on the curved line is equidistant from a point called the center. (Circle O). Refer to *Figure A-3*.

A RADIUS is a line drawn from the center of a circle to a point on a circle. (As OA, OB, OX, and OY). Refer to *Figure A-3.*

A DIAMETER is a line drawn through the center of a circle with its ends lying on the circle. Refer to *Figure A-3*.

A DIAMETER is twice the length of a radius. (AB is a diameter of circle O) Refer to *Figure A-3*.

A CHORD is a line joining any two points lying on a circle. (CD is a chord of circle O.) Refer to *Figure A-3*.

Figure A-3 — Circle.

An ARC is a portion of the closed curved lines which forms the circle. It is designated by CD. An arc is said to be subtended by a chord. Chord CD subtends arc CD. Refer to *Figure A-3*.

A TANGENT is a straight line which touches the circle at one and only one point. (Line MZ is a tangent to circle O.) Refer to *Figure A-3*.

A CENTRAL ANGLE is an angle whose vertex is the center of a circle and whose side are radii of the circle. (As XOY, YOA, and XOB.) Refer to *Figure A-3*.

CONCENTRIC CIRCLES are circles having the same center and having different radii.

The CIRCUMFERENCE of a circle is the distance around the circle. It is the distance on the curve from C to A to X to Y to B to D and back to C. Refer to *Figure A-3*.

Triangles

A triangle is a plane shape having 3 sides. Its name is derived from its three (tri) angles.

1. Equilateral - all sides are equal, all angles are equal, and all angles are 60°. Refer to *Figure A-4*.
2. Isosceles - two sides are equal and two angles are equal. Refer to *Figure A-4.*
3. Scalene - all sides are unequal and all angles are unequal. Refer to *Figure A-4.*
4. Right - one right angle is present. Refer to *Figure A-4*.

Figure A-4 — Types of triangles.

Altitudes and Medians

The altitude and median of a triangle are not the same; the difference is pointed out in the following definitions:

1. The altitude of a triangle is a line drawn from the vertex, perpendicular to the base. Refer to *Figure A-5, View 1*.
2. The median of a triangle is a line drawn from the vertex to the midpoint of the base. Refer to *Figure A-5, View 2*.

Figure A-5 — Altitude and median of a triangle.

Construction of Triangles

There are many ways to construct a triangle, depending upon what measurements are known to you. The following definitions will assist you.

1. A triangle may be constructed if the lengths of three sides are known.
2. A triangle may be constructed if two sides and the included angle (angle between the sides) are known.
3. A triangle may be constructed if two angles and the included side are given.
4. A right triangle may be constructed if the two sides adjacent to the right angle are known.
5. A right triangle may be constructed by making the sides 3, 4, and 5 inches or multiples or fractions thereof.

Quadrilaterals

A quadrilateral is a four-sided plane shape. There are many types, but only the trapezoid, parallelogram, rectangle, and square are described here.

Trapezoid is a quadrilateral having only two sides parallel. If the other two sides are equal, it is an isosceles trapezoid. BF is the altitude of the trapezoid. See *Figure A-6*.

Figure A-6 — Trapezoid.

Parallelogram is a quadrilateral having opposite sides parallel. Refer to *Figure A-7*.

1. AB is parallel to CD.
2. AC is parallel to BD.
3. AD and CB are diagonals.
4. Diagonals bisect each other so CO = OB and AO = OD.
5. Opposite angles are equal. ACD = DBA and CAB = BDC.
6. If two sides of a quadrilateral are equal and parallel, the figure is a parallelogram.
7. A parallelogram may be constructed if two adjoining sides and one angle are known.

Figure A-7 — Parallelogram.

Rectangle is a parallelogram having one right angle. Refer to *Figure A-8*.

1. ABCD is a parallelogram having one right angle. This, of course, makes all angles right angles.
2. AC and BD are diagonals.
3. O is the midpoint of AC and BD and OB = OC = OD = OA.
4. O is equidistant from BC and AD and is also equidistant from AB and CD.
5. A rectangle may be constructed if two adjoining sides are known.

Figure A-8 — Rectangle.

Square is a rectangle having its adjoining sides equal. Refer to *Figure A-9*.

1. ABCD is a square.
2. AC and BD are diagonals.
3. O is the geometric center of the square. AO = OC = OB = OD.
4. O is equidistant from all sides.
5. A square may be constructed if one side is known.

Figure A-9 — Square.

Polygons

A polygon is a many-sided plane shape. It is said to be regular if all sides are equal and irregular when they are not. Only regular polygons are described here.

Triangles and quadrilaterals fit the description of a polygon and have been covered previously. Three other types of regular polygons are shown in *Figure A-10*. Each one is inscribed in a circle. This means that all vertices of the polygon lie on the circumference of the circle.

Note that the sides of each of the inscribed polygons are actually equal chords of the circumscribed circle. Since equal chords subtend equal arcs, by dividing the circumference into an equal number of arcs, a regular polygon may be inscribed in a circle. Also note that the central angles are equal because they intercept equal arcs. This gives a basic rule for the construction of regular polygons inscribed in a circle as follows:

To inscribe a regular polygon in a circle, create equal chords of the circle by dividing the circumference into equal arcs or by dividing the circle into equal central angles.

Dividing a circle into a given number of parts has been discussed, so construction should be no problem. Since there are 360 degrees around the center of the circle, you should have no problem in determining the number of degrees to make each equal central angle.

Figure A-10 — Types of polygons.

Methods for Constructing Polygons

The three methods for constructing polygons described here are the pentagon, hexagon, and octagon.

The Pentagon is a developed by dividing the circumference into 5 equal parts.

The Hexagon is developed by dividing the circumference into 6 equal parts.

The Octagon method has been developed by creating central angles of 90° to divide a circle into 4 parts and bisecting each arc to divide the circumference into 8 equal parts.

Ellipses

An ellipse is a plane shape generated by point P, moving in such a manner that the sum of its distances from two points, F_1 and F_2, is constant. Refer to *Figure A-11.*

$BF_1 + PF_2 = C =$ (a constant)

AE is the major axis.

BD is the minor axis.

Figure A-11 — Ellipses.

Perimeters and Circumferences

Perimeter and circumference have the same meaning; that is, the distance around. Generally, circumference is applied to a circular object and perimeter to an object bounded by straight lines.

Perimeter of a Polygon

The perimeter of a triangle, quadrilateral, or any other polygon is actually the sum of the sides.

Circumference of a Circle

Definition of Pi: Mathematics have established that the relationship of the circumference to the diameter of a circle is a constant called Pi and written as π. The numerical value of this constant is approximately 3.141592653. For our purposes 3.1416 or simply 3.14 will suffice.

The formula for the circumference of a circle is $C = 2\pi D$ where C is the circumference and D is the diameter since D = 2R where R is the radius, the formula may be written as $C = 2\pi R$.

Areas

All areas are measured in squares.

The area of a square is the product of two of its sides and since both sides are equal, it may be said to be square of its side.

NOTE

The area of any plane surface is the measure of the number of squares contained in the object. The unit of measurement is the square of the unit which measures the sides of the square.

Area of Rectangle

A = L x W

Where:

A = area of a rectangle

L = length of a rectangle

W = width of a rectangle

Area of a Cross Section

The cross section of an object is a plane figure established by a plane cutting the object at right angles to its axis. The area of this cross section will be the area of the plane figure produced by this cut.

The area of the cross section is L x W.

The most common units are square inches, square feet, square yards and in roofing, "squares."

1 square foot = 144 square inches

1 square yard = 9 square feet

1 square of roofing = 100 square feet

Common Conversions

1. To convert square inches to square feet, divide square inches by 144.
2. To convert square feet to square inches, multiply by 144.
3. To convert square feet to square yards, divide by 9.
4. To convert square yards to square feet, multiply by 9.
5. To convert square feet to squares, divide by 100.

Conversion of Units of Cubic Measure

It is often necessary to convert from one cubic measure to another. The conversion factors used are as follows:

1. 1 cubic foot = 1,728 cubic inches
2. 1 cubic yard = 27 cubic feet
3. 1 cubic foot = 7.48 US gallons (liquid measure)
4. 1 us gallon (liquid measure) = 231 cubic inches
5. 1 bushel (dry measure) = 2,150.42 cubic inches

Area of a Circle

The formula for the area of a circle is:

$$A = \pi r^2$$

Where:

A = area of circle

r = radius of circle

π = 3.1416

Since r = d/2 where d is the diameter of a circle, the formula for the area of a circle in terms of its diameter is:

$$A = \pi(\frac{d}{2})^2 = \frac{\pi d^2}{4}$$

Geometric Solids

In describing plane shapes, you use only two dimensions: width and length; there is no thickness. By adding the third dimension, you describe a solid object.

Consider the solids described below.

Prism - is a figure whose two bases are polygons, alike in size and shape, lying in parallel planes and whose lateral edges connect corresponding vertices and are parallel and equal in length. A prism is a right prism if the lateral edge is perpendicular the base. The altitude of a prism is the perpendicular distance between the bases.

Cone - is a figure generated by a line moving in such a manner that one end stays fixed at a point called the “vertex.” The line constantly touches a plane curve which is the base of the cone. A cone is a circular cone if its base is a circle. A circular cone is a right circular cone if the line generating it is constant in length. The altitude of a cone is the length of a perpendicular to the plane of the base drawn from the vertex.

Pyramid - is a figure whose base is a plane shape bounded by straight lines and whose sides are triangular plane shapes connecting the vertex and a line of the base. A regular pyramid is one whose base is a regular polygon and whose vertex lays on a perpendicular to the base at its center. The altitude of a pyramid is the length of a perpendicular to the plane of the base drawn from the vertex.

Circular Cylinder - is a figure whose bases are circles lying in parallel planes connected by a curved lateral surface. A right circular cylinder is one whose lateral surface is perpendicular to the base. The altitude of a circular cylinder is the perpendicular distance between the planes of the two bases.

Measurement of Volume

Volume is measured in terms of cubes.

Common Volume Formulas

All factors in the formulas must be in the same linear units. As an example, one term could not be expressed in feet while other terms are in inches.

Volume of a Rectangular Prism

$$V = L \times W \times H$$

Where:

V = Volume in cubic inches

W = Width of the base in linear units

L = Length of base in linear units

H = Altitude of the prism in linear units

Volume of a Cone

$$V = \frac{A x h}{3}$$

Or

$$V = \frac{\pi r^2 h}{3}$$

Or

$$V = \frac{\pi d^2 h}{12}$$

Where:

V= Volume of a cone in cubic units

A = Area of the base in square units

h = Altitude of a cone in linear units

r = Radius of the base

d = Diameter of the base

Volume of a Pyramid

$$V = \frac{Ah}{3}$$

Where:

V = Volume in cubic units

A = Area of base in square units

h = Altitude in linear units

Volume of a Cylinder

V = Ah

Or

$$V = \pi r^2 h$$

Or

$$V = \frac{\pi d^2 h}{4}$$

Where:

V = Volume in cubic units

A = Area of the base in square units

h = Altitude in linear units

r = Radius of the base

d = Diameter of the base

Volume of the Frustum of a Right Circular Cone

The frustum of a cone is formed when a plane is passed parallel to the base of the cone. The frustum is the portion below the plane. The altitude of the frustum is the perpendicular distance between the bases.

$$V = 1/3\,\pi h\left(r^2 + R^2 + Rr\right)$$

Where:

h = Altitude in linear units

r = Radius of the upper base in linear units

R = Radius of the lower base in linear units

Volume of a Frustum of a Regular Pyramid

A frustum of a pyramid is formed when a plane is passed parallel to the base of the pyramid. The frustum is the portion below the plane. The altitude is the perpendicular distance between the bases.

$$V = 1/3h\,(B + b + \sqrt{Bb}\,)$$

Where:

V = Volume of the frustum in cubic units

h = Altitude in linear units

B = Area of the lower base in square units

b = Area of the upper base in square units

Ratio

The ratio of one number to another is the quotient of the first, divided by the second. This is often expressed as a:b, which is read as the ratio of a to b. More commonly, this expressed as the fraction a/b.

Ratio has no meaning unless both terms are expressed in the same unit by measurement.

Percentage

Percentage (%) is a way of expressing the relationship of one number to another. In reality, percentage is a ratio expressed as a fraction in which the denominator is always one hundred.

Proportion

Proportion is a statement of two ratios which are equal.

Example: 1/3 = 5/15 or 1:3 = 5:15

Solving proportions is done by cross multiplying.

Example: $\frac{a}{b} = \frac{c}{d}$ = a x d = b x c

Law of Pythagoras

The Law of Pythagoras is the square of the hypotenuse of a right triangle equals the sum of the two legs. It is expressed by the formula $a^2 + b^2 = c^2$.

Right Triangle: a triangle having one right angle

Hypotenuse: The hypotenuse of a right triangle is the side opposite the right angle

Leg: The leg of a right triangle is a side opposite and acute angle of a right triangle.

METRIC CONVERSION TABLES

Length Conversion

When You Know:	You Can Find:	If You Multiply By:
inches	millimeters	25.4
inches	centimeters	2.54
feet	centimeters	30
feet	meters	0.3
yards	centimeters	90
yards	meters	0.9
miles	kilometers	1.6
miles	meters	1609
millimeters	inches	0.04
centimeters	inches	0.4
centimeters	feet	0.0328
meters	feet	3.3
centimeters	yards	0.0109
meters	yards	1.1
meters	miles	0.000621
kilometers	miles	0.6
meters	nautical miles	0.00054
nautical miles	meters	1852

Weight Conversion

When You Know:	You Can Find:	If You Multiply By:
ounces	grams	28.3
pounds	kilograms	0.45
short tons (2000 lbs)	megagrams (metric tons)	0.9
grams	ounces	0.0353
kilograms	pounds	2.2
megagrams (metric tons)	short tons (2000 lbs)	1.1

Temperature Conversion

When You Know:	You Can Find:	If You Multiply By:
Degrees Fahrenheit	Degree Celsius	Subtract 32 then multiply by 5/9
Degrees Celsius	Degree Fahrenheit	Multiply by 9/5 then add 32
Degrees Celsius	Kelvins	Add 273.15°

Volume Conversion

When You Know:	You Can Find:	If You Multiply By:
teaspoons	milliters	5
tablespoons	milliters	1 5
fluid ounces	milliters	3 0
cups	liters	0.24
pints	liters	0.47
quarts	liters	0.95
gallons	liters	3.8
milliters	teaspoons	0.2
milliters	tablespoons	0.067
milliters	fluid ounces	0.034
liters	cups	4.2
liters	pints	2.1
liters	quarts	1.06
liters	gallons	0.26
cubic feet	cubic meters	0.028
cubic yards	cubic meters	0.765
cubic meters	cubic feet	35.3
cubic meters	cubic yards	1.31

Area Conversions

When You Know:	You Can Find:	If You Multiply By:
Square inches	Square centimeters	6.45
Square inches	Square meters	0.000 6
Square feet	Square centimeters	929
Square feet	Square meters	0.0929
Square yards	Square centimeters	8.360
Square yards	Square meters	0.836
Square miles	Square kilometers	2.6
Square centimeters	Square inches	0.155
Square meters	Square inches	1550
Square centimeters	Square feet	0.001
Square meters	Square feet	10.8
Square centimeters	Square yards	0.00012
Square meters	Square yards	1.2
Square kilometers	Square miles	0.4

Table A-1 — Decimal Equivalents.

Fraction	16th	32nd	64th	Decimal	Fraction	16th	32nd	64th	Decimal
			1	.015625				33	.515625
		1	2	.03125			17	34	.53125
			3	.046875				35	.54875
	1	2	4	.0625		9	18	36	.5625
			5	.078125				37	.578125
		3	6	.09375			19	38	.59375
			7	.109375				39	.609375
1/8	2	4	8	.125	5/8	10	20	40	.625
			9	.140625				41	.640625
		5	10	.15625			21	42	.65625
			11	.171875				43	.671875
	3	6	12	.1875		11	22	44	.6875
			13	.203125				45	.703125
		7	14	.21875			23	46	.71875
			15	.234375				47	.734375
1/4	4	8	16	.25	3/4	12	24	48	.75
			17	.265625				49	.765625
		9	18	.28125			25	50	.78125
			19	.296875				51	.796875
	5	10	20	.3125		13	26	52	.8125
			21	.328125				53	.818225
		11	22	.34375			27	54	.84375
			23	.359375				55	.859375
3/8	6	12	24	.375	7/8	14	28	56	.875
			25	.390623				57	.890625
		13	26	.40625			29	58	.90625
			27	.421875				59	.921875
	7	14	28	.4375		15	30	60	.9375
			29	.453125				61	.953125
		15	30	.46875			31	62	.96875
			31	.484375				63	.984375
1/2	8	16	32	.5	1	16	32	64	1.0

Table A-2 — Metric measures of length.

10 millimeters	=	1 centimeter (cm)
10 centimeters	=	1 decimeter (dm)
10 decimeters	=	1 meter (m)
10 meters	=	1 decameter (dkm)
10 decameters	=	1 hectometer (hm)
10 hectometers	=	1 kilometer (km)

Table A-3 — Conversion of inches to millimeters.

Inches	Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters
1	25.4	26	660.4	51	1295.4	76	1930.4
2	50.8	27	685.8	52	1320.8	77	1955.8
3	76.2	28	711.2	53	1346.2	78	1981.2
4	101.6	29	736.6	54	1371.6	79	2006.6
5	127	30	762	55	1397	80	2032
6	152.4	31	787.4	56	1422.4	81	2057.4
7	177.8	32	812.8	57	1447.8	82	2082.8
8	203.2	33	838.2	58	1473.2	83	2108.2
9	228.6	34	863.6	59	1498.6	84	2133.6
10	254	35	889	60	1524	85	2159
11	279.4	36	914.4	61	1549.4	86	2184.4
12	304.8	37	939.8	62	1574.8	87	2209.8
13	330.2	38	965.2	63	1600.2	88	2235.2
14	355.6	39	990.6	64	1625.6	89	2260.6
15	381	40	1016	65	1651	90	2286
16	406.4	41	1041.4	66	1676.4	91	2311.4
17	431.8	42	1066.8	67	1701.8	92	2336.8
18	457.2	43	1092.2	68	1727.2	93	2362.2
19	482.6	44	1117.6	69	1752.6	94	2387.6
20	508	45	1143	70	1778	95	2413
21	533.4	46	1168.4	71	1803.4	96	2438.4
22	558.8	47	1193.8	72	1828.8	97	2463.8
23	584.2	48	1219.2	73	1854.2	98	2489.2
24	609.6	49	1244.6	74	1879.6	99	2514.6
25	635	50	1270	75	1905	100	2540

Table A-4 — Conversions of fractions and decimals to millimeters.

Fraction of inch (64ths)	Decimal of Inch	Millimeters	Fraction of inch (64ths)	Decimal of Inch	Millimeters
1	.015625	.3968	33	.515625	13.0966
2	.03125	.7937	34	.53125	13.4934
3	.046875	1.1906	35	.546875	13.8903
4 (1/16”)	.0625	1.5875	36	.5625	14.2872
5	.078125	1.9843	37	.578125	14.6841
6	.09375	2.3812	38	.59375	15.0809
7	.109375	2.7780	39	.609375	15.4778
8 (1/8”)	.125	3.1749	40 (5/8”)	.625	15.8747
9	.140625	3.5817	41	.640625	16.2715
10	.15625	3.9686	42	.65625	16.6684
11	.171875	4.3655	43	.671875	17.0653
12	.1875	4.7624	44	.6875	17.4621
13	.203125	5.1592	45	.703125	17.8590
14	.21875	5.5561	46	.71875	18.2559
15	.234375	5.9530	47	.734375	18.6527
16 (1/4”)	.25	6.3498	48 (3/4”)	.75	19.0496
17	.265625	6.7467	49	.765625	19.4465
18	.28125	7.1436	50	.78125	19.8433
19	.296875	7.5404	51	.796875	20.2402
20	.3125	7.9373	52	.8125	20.6371
21	.328125	8.3342	53	.818225	21.0339
22	.34375	8.7310	54	.84375	21.4308
23	.359375	9.1279	55	.859375	21.8277
24 (3/8”)	.375	9.5248	56 (7/8”)	.875	22.2245
25	.390623	9.9216	57	.890625	22.6214
26	.40625	10.3185	58	.90625	23.0183
27	.421875	10.7154	59	.921875	23.4151
28	.4375	11.1122	60	.9375	23.8120
29	.453125	11.5091	61	.953125	24.2089
30	.46875	11.9060	62	.96875	24.6057
31	.484375	12.3029	63	.984375	25.0026
32 (1/2”)	.5	12.6997	64 (1”)	1.0	25.3995

Table A-5 Conversions of measurements.

Conversion Chart for Measurement								
inches								centimeters
Cm							inches	
Feet						meters		
Meters					feet			
Yards				meters				
Meters			yards					
Miles		kilometers						
km	miles							
1	0.62	1.61	1.09	0.91	3.28	0.30	0.39	2.54
2	1.21	3.22	2.19	1.83	6.56	0.61	0.79	5.08
3	1.86	4.83	3.28	2.74	9.81	0.91	1.18	7.62
4	2.49	6.44	4.37	3.66	13.12	1.22	1.57	10.16
5	3.11	8.05	5.47	4.57	16.40	1.52	1.97	12.70
6	3.73	9.66	6.56	5.49	19.68	1.83	2.36	15.24
7	4.35	11.27	7.66	6.4	22.97	2.13	2.76	17.78
8	4.97	12.87	8.75	7.32	26.25	2.44	3.15	20.32
9	5.59	14.48	9.84	8.23	29.53	2.74	3.54	22.86
10	6.21	16.09	10.94	9.14	32.81	3.05	3.93	25.40
12	7.46	19.31	13.12	10.97	39.37	3.66	4.72	30.48
20	12.43	32.19	21.87	18.29	65.62	6.10	7.87	50.80
24	14.91	38.62	26.25	21.95	78.74	7.32	9.45	60.96
30	18.64	48.28	32.81	27.43	98.42	9.14	11.81	76.20
36	22.37	57.94	39.37	32.92	118.11	10.97	14.17	91.44
40	24.37	64.37	43.74	36.58	131.23	12.19	15.75	101.60
48	29.83	77.25	52.49	43.89	157.48	14.63	18.90	121.92
50	31.07	80.47	54.68	45.72	164.04	15.24	19.68	127.00
60	37.28	96.56	65.62	54.86	196.85	18.29	23.62	152.40
70	43.50	112.65	76.55	64	229.66	21.34	27.56	177.80
72	44.74	115.87	78.74	65.84	236.22	21.95	28.35	182.88

Table A-6 — Cubic conversion chart.

Cubic Conversion Chart					
Cubic Meters				Cubic Feet	Cubic Yard
Cubic Yard			Cubic Meters		
Cubic Feet		Cubic Meters			
Cubic Inches	Cubic Centimeters				
1	16.39	0.028	0.76	35.3	1.31
2	32.77	0.057	1.53	70.6	2.62
3	49.16	0.085	2.29	105.9	3.92
4	65.55	0.113	3.06	141.3	5.23
5	81.94	0.142	3.82	176.6	6.54
6	98.32	0.170	4.59	211.9	7.85
7	114.71	0.198	5.35	247.2	9.16
8	131.10	0.227	6.12	282.5	10.46
9	147.48	0.255	6.88	317.8	11.77
10	163.87	0.283	7.65	353.1	13.07
20	327.74	0.566	15.29	706.3	26.16
30	491.61	0.850	29.94	1059.4	39.24
40	655.48	1.133	30.58	1412.6	52.32
50	819.35	1.416	38.23	1765.7	65.40
60	983.22	1.700	45.87	2118.9	78.48
70	1174.09	1.982	53.52	2472.0	91.56
80	1310.96	2.265	61.16	2825.2	104.63
90	1474.84	2.548	68.81	3178.3	117.71
100	1638.71	2.832	76.46	3531.4	130.79
Example: 3 cu. Yd = 2.29 cu. M Volume: The cubic meter is the only common dimension used for measuring the volume of solids in the metric system.					

Table A-7 — Gallon and liter conversion chart.

Gallon	Liter	Gallon	Liter	Gallon	Liter
.1	.38	1	3.79	10	37.85
.2	.76	2	7.57	20	57.71
.3	1.14	3	11.36	30	113.56
.4	1.51	4	15.14	40	151.42
.5	1.89	5	18.93	50	189.27
.6	2.27	6	22.71	60	227.12
.7	2.65	7	26.50	70	264.98
.8	3.03	8	30.28	80	302.83
.9	3.41	9	34.07	90	340.69
NOTE: 1 us Gallon = 3.785412 Liters 100 us Gallons = 378.5412 Liters					

Table A-8 — Weight conversion chart.

Weight Conversion Chart						
Ounces						Grams
Grams					Ounces	
Pounds				Kilograms		
Kilograms			Pounds			
Short Ton		Metric Ton				
Metric Ton	Short Ton					
1	1.10	0.91	2.20	0.45	0.04	28.1
2	2.20	1.81	4.41	0.91	0.07	56.7
3	3.31	2.72	6.61	1.36	0.11	85.0
4	4.41	3.63	8.82	1.81	0.14	113.4
5	5.51	4.54	11.02	2.67	0.18	141.8
6	6.61	5.44	13.23	2.72	0.21	170.1
7	7.72	6.35	15.43	3.18	0.25	198.4
8	8.82	7.26	17.64	3.63	0.28	226.8
9	9.92	8.16	19.81	4.08	0.32	255.2
10	11.02	9.07	22.05	4.54	0.35	283.5
16	17.63	14.51	35.27	7.25	0.56	453.6
20	22.05	18.14	44.09	9.07	0.71	567.0
30	33.07	27.22	66.14	13.61	1.06	850.5
40	44.09	36.29	88.14	18.14	1.41	1134.0
50	55.12	45.36	110.23	22.68	1.76	1417.5
60	66.14	54.43	132.28	27.22	2.12	1701.0
70	77.16	63.50	154.32	31.75	2.17	1981.5
80	88.18	72.57	176.37	36.29	2.82	2268.0
90	99.21	81.65	198.42	40.82	3.17	2551.5
100	110.20	90.72	220.46	45.36	3.53	2835.0
NOTE: 1 pound = 0.4535925 KG; 1 US Short Ton = 2,000 pounds; and 1 Metric Ton = 1,000 KG						

FORMULAS

Conversion Factors and Constants

$\pi = 3.14$	$2\pi = 6.28$
$\pi^2 = 9.87$	$(2\pi)^2 = 39.5$
$\varepsilon = 2.718$	$\sqrt{2} = 1.414$
$\sqrt{3} = 1.732$	LOG = 0.497

Sinusoidal Voltages and Currents

Effective Value	=	0.707 x Peak Value
Average Value	=	0.637 x Peak Value
Peak Value	=	1.414 x Effective Value
Effective Value	=	1.11 x Average Value
Peak Value	=	1.57 x Average Value
Average Value	=	0.9 x Effective Value

Temperature

(F to C) C = 5/9 (F – 32)

(C to F) F = 9/5 C = 32

(C to K) K = C + 73

Power

1 kilowatt = 1.341 horsepower

1 horsepower = 746 watts

Trigonometric Formulas

$$\sin A = \frac{a}{c} = \frac{\text{Opposite Side}}{\text{Hypotenuse}}$$

$$\cos A = \frac{b}{c} = \frac{\text{Adjacent Side}}{\text{Hypotenuse}}$$

$$\tan A = \frac{a}{b} = \frac{\text{Opposite Side}}{\text{Adjacent Side}}$$

$$\cot A = \frac{b}{a} = \frac{\text{Adjacent Side}}{\text{Opposite Side}}$$

Figure A-12 — Trapezoid.

Ohm's Law- Direct Current

Ohm's Law- Alternating Current

Figure A-13 — Direct Current.

Figure A-14 — Alternating Current.

Speed vs. Poles Formulas

$F = \frac{NP}{120}$ $N = \frac{F\ 120}{P}$ $P = \frac{F\ 120}{N}$

F = frequency

N= speed of rotation

P = number of poles

120 = time constant

Power Factor

$PF = \frac{\text{actual power}}{\text{apparent power}} = \frac{\text{watts}}{\text{volts x amperes}} = \frac{kW}{kVA} = \frac{R}{Z}$

Single-Phase Circuits

$kVA = \frac{EI}{1,000} = \frac{kW}{PF}$ $kW = kVA \times PF$

$I = \frac{P}{E \times PF}$ $E = \frac{P}{I \times PF}$ $PF = \frac{P}{E \times I}$

P = E x I x PF

Two-Phase Circuits

$I = \frac{P}{2 \times E \times PF}$ $E = \frac{P}{2 \times I \times PF}$ $PF = \frac{P}{E \times I}$

$kVA = \frac{2 \times E \times I}{1,000}$ $\frac{kW}{PF}$ $kW = kVA \times PF$

P = 2 x E x I x PF

Three-Phase Circuits, Balanced Wye

I phase = I line

$E_L = \sqrt{3}\, E_P = 1.73\, E_P$

$E_P = \frac{E_L}{\sqrt{3}} = 0.577\, E_L$

Three-Phase Circuits, Balanced Wye

E phase = E line

$I_L = \sqrt{3}\, I_P = 1.73\, I_P$

$I_P = \frac{I_L}{\sqrt{3}} = 0.577\, I_L$

Power: Three-Phase Balanced Wye or Delta Circuits

P = 1.732 x E x I x PF VA = 1.732 x E x I

$E = \frac{P}{PF \times 1.73 \times I} = \frac{0.577 \times P}{PF \times I}$

$I = \frac{P}{PF \times 1.73 \times E} = \frac{0.577 \times P}{PF \times E}$

$PF = \frac{P}{PF \times 1.73 \times E} = \frac{0.577 \times P}{I \times E}$

VA = apparent power (volt-amperes)

P = actual power (watts)

E = line voltage (volts)

I = line current (amperes)

WEIGHTS AND MEASURES

Dry Measure

2 cups = 1 quart (pt)

2 pints = 1 quart (pt)

4 quarts = 1 gallon (gal)

8 quarts = 1 peck (pk)

4 pecks = 1 bushel (bu)

Liquid Measure

3 teaspoons (tsp) = 1 tablespoon (tbsp)

16 tablespoons = 1 cup

2 cups = 1 pint

16 fluid ounces (oz) = 1 pint

2 pints = 1 quart

4 quarts = 1 gallon

31.5 gallons = 1 barrel (bbl)

231 cubic inches = 1 gallon

7.48 gallons = 1 cubic foot (cu ft)

Weight

16 ounces = 1 pound (lb)

2,000 pounds = 1 short ton

2,240 pounds = 1 long ton

Distance

12 inches = 1 foot (ft)

3 feet = 1 yard (yd)

5-1/2 yards = 1 rod (rd)

16-1/2 feet = 1 rod

1,760 yards = 1 statute mile (mi)

5,280 feet = 1 statute mile

Area

144 square inches = 1 square foot (sq ft)

9 square feet = 1 square yd (sq yd)

30- ¼ square yards = 1 square rod

160 square rods = 1 acre (A)

640 acres = 1 square mile (sq mi)

Volume

1,728 cubic inches = 1 cubic foot

27 cubic feet = 1 cubic yard (CU yd)

Counting Units

12 units = 1 dozen (doz)

12 dozen = 1 gross

144 units = 1 gross

24 sheets = 1 quire

480 sheets = 1 ream

Equivalents

1 cubic foot of water weighs 62.5 pounds (approx) = 1,000 ounces

1 gallon of water weighs 8-1/3 pounds (approx)

1 cubic foot = 7.48 gallons

1 inch = 2.54 centimeters

1 foot = 30.4801 centimeters

1 meter = 39.37 inches

1 liter = 1.05668 quarts (liquid) = 0.90808 quart (dry)

1 nautical mile = 6,080 feet (approx)

1 fathom = 6 feet

1 shot of chain = 15 fathoms

Feet	x.00019	= miles
Feet	x 1.5	= links
Yards	x .9144	= meters
Yards	x .0006	= miles
Links	x .22	= yards
Links	x .66	= feet
Rods	x 25	= links
Rods	x 16.5	= feet
Square inches	x .007	= square feet
Square inches	x 6.451	= square centimeters
Square centimeters	x 0.1550	= square inches
Square feet	x .111	= square yards
Square feet	x .0929	= centares (square meters)
Square feet	x 929	= square centimeters
Square feet	x 144	= square inches
Square yards	x .0002067	= acres
Acres	x 4840.0	= square yards
Square yards	x 1,296	= square inches
Square yards	x 9	= square feet
Square yards	x 0.8362	= centares
Square miles, statute	x 640	= acres
Square miles, statute	x 25,900	=ares
Square miles, statute	x 259	= hectares
Square miles, statute	x 2,590	= square kilometers
Cubic inches	x .00058	= cubic feet
Cubic feet	x .03704	= cubic yards
Tons (metric)	x 2,204.6	= pounds (avoirdupois)
Tons (metric)	x 1,000	= kilograms
Tons (short)	x 2,000	= pounds (avoirdupois)

Tons (short)	x 0.9072	= metric tons
Tons (long)	x 2,240	= pounds (avoirdupois)
Tons (long)	x 1.016	= metric tons
π	= 3.14592654	
1 radian	= 180°/ π = 57.2957790°	= approx. 57° 17' 44.8"
1 radian	= 1018.6 miles	
1 degree	= 0.0174533 radian	
1 minute	= 0.0002909 radian	
1 mil	= 0.0009817	
π radians	= 180°	
π /2 radians	= 90°	
Radius	= arc of 57.2957790°	
Arc of 1° (radius $= 1$)	= .017453292	
Arc of $1'$(radius $= 1$)	= .000290888	
Arc of $1'$ (radius $= 1$)	= .000004848	
Area of sector of circle	= ½ Lr	(L= length of arc; r = radius)
Area of segment of parabola	= 2/3 cm	(c = chord; m = mid. ord.)
Area of segment of circle	= approx 2/3	
Arc – chord length	= 0.02 foot per 11 ½ miles	
Curvature of earth's surface	= approx. 0.667 foot per mile	

APPENDIX II

Hand Signals

Emergency Stop
Stop all motion as quickly as possible.

Stop

Kill Engine
Secure engine as prescribed

Manuever Forward Slowly
When manuevering in close quarters or to move a foot or two at a time.

Slow Down

Guide On Me
Hand open and palm facing inward.

Increase Speed

Raise Hoist Slowly
Hurry up and move out, double time, etc.

Lower Hoist Slowly

Raise Load

Lower Load

Raise Boom

Lower Boom

Raise Boom and Hold Load

Lower Boom and Hold Load

Lower Boom Slowly

Raise Boom Slowly

Lower Boom and Raise Load

Raise Boom and Lower Load

Swing In Direction Finger Points

Close Bucket

Open Bucket

Use Whip Line For Preceding Signals
(Auxilliary Hoist)
Tap elbow then use regular signals

Make Left Turn

Make Right Turn

Travel Both Tracks

Cut, Fill, or Drag Road
Point to road to be dragged or bladed, then rub palms together.
Applies to scrapers, motor graders, and bulldozers.

Raise a Little

Lower a Little

Dump Load Now
Start dumping and spreading load to proper depth if given.

Rehaul or Retract

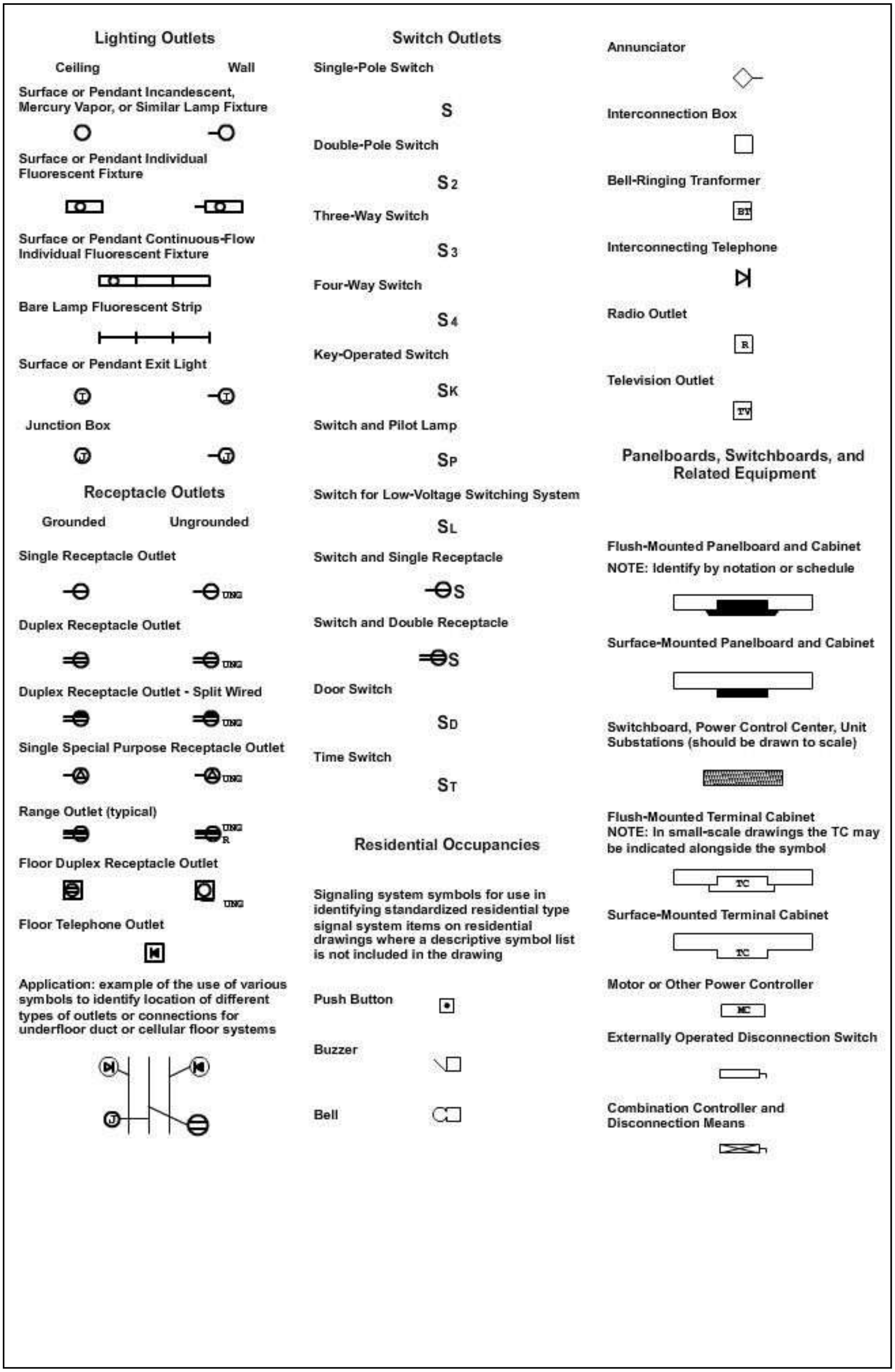
Crowd or Extend

Turn Right (Operator's Right)

Turn Left (Operator's Left)

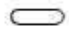
APPENDIX III

COMMON CONSTRUCTION SYMBOLOGY

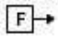


Remote Control Stations for Motors or Other Equipment

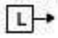
Push-button Stations in General



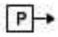
Float Switch - Mechanical



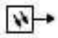
Limit Switch - Mechanical



Pneumatic Switch - Mechanical



Electric Eye - Beam Source



Electric Eye - Relay

Thermostat

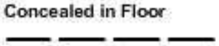
Circuiting

Wiring method identification by notation on drawing or in specifications.

Wiring Concealed in Ceiling or Wall

Note: Use heavy weight line to identify service and feed runs

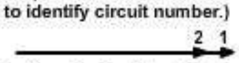
Wiring Concealed in Floor



Wiring Exposed

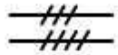
Branch Circuit Home Run to Panelboard

Number of arrows indicates number of circuits. (A numeral at each arrow may be used to identify circuit number.)



NOTE: Any circuit without further identification indicates a 2-wire circuit. For a greater number of wires, indicate with cross lines.

Application:



Unless indicated otherwise, the wire size of the circuit is the minimum size required by the specification.

Indicate size in inches and identify different functions of wiring system, such as signaling, by notation or other means.

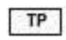
Wiring Turned Up

Wiring Turned Down

Manhole

Handhole

Transformer Pad

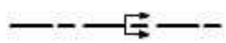


Underground Direct Burial Cable

Indicate type, size, and number of conductors by notation or schedule.

Underground Duct Line

Indicate type, size, and number of ducts by cross section identification of each run by notation or schedule. Indicate type, size, and number of conductors by notation or schedule.

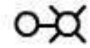


Streetlight Standard Fed from Underground Circuit

Electrical Distribution or Lighting Systems, Aerial

Pole

Pole, with Streetlight



Pole, with Down Guy and Anchor

Transformer

Transformer, Constant-Current

Switch, Manual

Circuit Recloser, Automatic

Circuit, Primary

Circuit, Secondary

Circuit, Series Street Lighting

Down Guy

Head Guy

Sidewalk Guy

Service Weather Head

Qualifying Symbols

Connection Symbol

For use adjacent to other symbols

3-phase, 3-wire, delta

3-phase, 3-wire, delta, grounded

3-phase, 4-wire, delta, grounded

3-phase, open delta

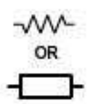
3-phase, wye or star, ungrounded

3-phase, wye, grounded neutral

Graphic Symbols for Fundamental Items

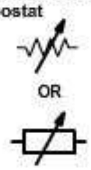
Resistor

General



See Note

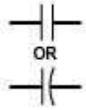
Application: adjustable or continuously adjustable (variable) resistor rheostat



See Note

NOTE: Always add identification within , or adjacent to, the rectangle.

Capacitor



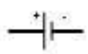
Antenna

General

Types or functions may be indicated by words or abbreviations adjacent to the symbol.

Battery

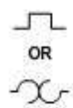
The long line is always positive, but polarity may be indicated in addition. Example:



Multicell

Thermal Element

Actuating device, self-heating or with external heater. (Not operated primarily by ambient temperature.)



Graphic Symbols for Transmission Path

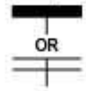
Transmission Path
Conductor
Cable
Wiring

Guided path, general

A single line represents the entire group of conditions or the transmission path needed to guide the power or signal.

When required, details of structure, type, impedance, ratings, etc., may be added adjacent to or within any symbol or in a note.

Busbar (with connections shown)
Use only if essential to distinguish bus from other circuit paths.

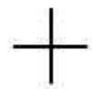


Conductive path or conductor; wire

Two conductors or conductive paths

Crossing of paths or conductors not connected

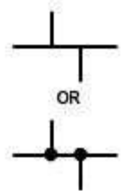
The crossing is not necessarily at a 90° angle.



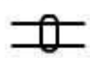
Junction of paths or conductors
Junction (if desired)

Junction of paths, conductors, or cable. If desired, indicate path type, or size.

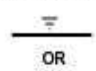
Junction of paths, conductors, or wires



2-conductor cable

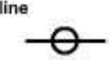


Cable underground; underground line



These are long dashes

Overhead line



Circuit Return

Ground general symbol

NOTE: Supplementary information may be added to define the status or purpose of the earth if this is not readily apparent.

(1) A direct conducting connection to the earth or body of water that is a part therof.

(2) A conducting connect to a structure that serves a function similar to that of an earth ground (that is, a structure such as a frame of an air, space, or land vehicle that is not conductively connected to earth).

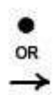
Chassis or frame connection, equivalent chassis connection (of printed-wiring boards)

A conducting connection to a chassis of frame (or equivalent chassis connection of a printed-wiring board) may be at substantial potential with respect to the earth or structure in which this chassis or frame (or printed-wiring board) is mounted.

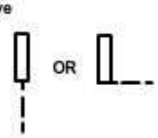
Graphic Symbols for Contacts, Switches, Contacts, and Relays

Electrical Contact

Fixed contact for jack, key, relay, switch, etc.



‡ Sleeve

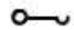


‡ The broken line --- indicates where line connection to a symbol is made and is not part of the symbol.

Moving Contact

Adjustable or sliding contact for resistor, inductor, etc.

Locking

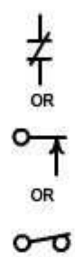


Nonlocking

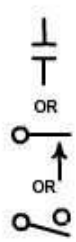
Basic Contact Assemblies

The standard method of showing a contact is by a symbol indicating the circuit condition it produces when the actuating device is in the de-energized or nonoperated position. The actuating device may be of a mechanical, electrical, or other nature, and a clarifying note may be necessary with the symbol to explain the proper point at which the contact functions; for example, the point where a contact closes or opens as a function of changing pressure, level, flow, voltage, current, etc. In cases where it is desirable to show contacts in the energized or operated condition and where confusion may result, a clarifying note shall be added to the drawing.

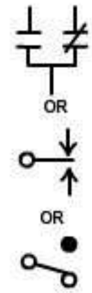
Closed contact (break)



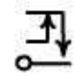
Open contact (make)



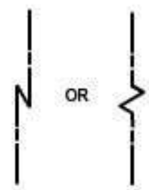
Transfer



Make-before-break

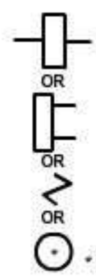


Magnetic Blowout Coil



Operating Coil

Relay Coil

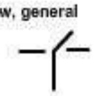


Switch

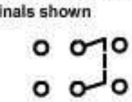
Fundamental symbols for contacts, mechanical connections, etc, may be used for switch symbols.

Single-throw, general

Double-throw, general



2-pole double-throw switch with terminals shown

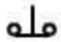


NOTE: The asterisk is not part of the symbol. Always replace the asterisk by a device designation.

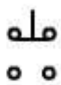
Push button, Momentary or Spring-Return

Circuit closing (make)

Circuit opening (break)



Two-circuit

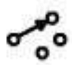


Selector or Multiposition Switch

The position in which the switch is shown may be indicated by a note or designation of switch position.

General (for power and control diagrams)

Any number of transmission paths may be shown.

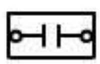


OR

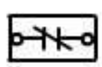
Limit Switch
Sensitive Switch

NOTE: Identity by LS or other suitable note.

Track-type, circuit-closing contact



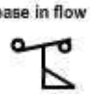
Track-type, circuit-opening contact



Flow-Actuated Switch

Closes on increase in flow

Opens on increase in flow



Liquid-Level-Actuated Switch

Closes on rising level

Opens on rising level

Pressure-or Vacuum-Actuated Switch

Closes on rising pressure

Opens on rising pressure

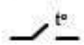
Temperature-Actuated Switch

Closes on rising temperature

Opens on rising temperature

Thermostat

Closes on rising temperature



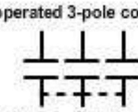
* See Note

Contactor

See also CIRCUIT BREAKER

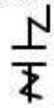
Fundamental symbols for contacts, coils, mechanical connections, etc, are the basis of contactor symbols and should be used to represent contactors on complete diagrams. Complete diagrams of contactors consist of combinations of fundamental symbols for control coils, mechanical connections, etc, in such configurations as to represent the actual device. Mechanical interlocking should be indicated by notes.

Manually operated 3-pole contactor

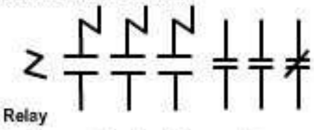


NOTE: The t° symbol shall be shown or be replaced by data giving the nominal or specific operating temperature of the device.

Electrically operated 1-pole contactor with series blowout coil



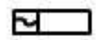
Electrically operated 3-pole contactor with series blowout coils; 2 open and 1 closed auxiliary contacts (shown smaller than the main contacts)



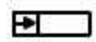
Relay

Fundamental symbols for contacts, mechanical connections, coils, etc, are the basis of relays on complete diagrams.

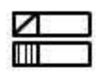
The following letter combinations or symbol elements may be used with relay symbols. The requisite number of these letters or symbol elements may be used to show what special features a relay possesses.



AC Alternating-current or ringing relay
D Differential
DB Double-biased (biased in both directions)
DP Dashpot
EP Electrically polarized
FO Fast-operate
FR Fast-release
L Latching
MG Marginal
ML Magnetic-latching (re-manent)
NB No bias
NR Nonreactive



P Magnetically polarized using biasing spring, or having magnet bias
SA Slow-operate and slow-release

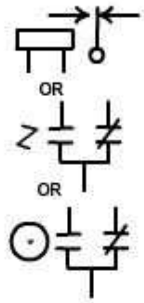


SO Slow-operate
SR Slow-release
SW Sandwich-wound to improve balance to longitudinal currents

The proper poling for a polarized relay shall be shown by the use of + and - designations applied to the winding leads. The interpretation of this shall be that a voltage applied with the polarity as indicated shall cause the armature to move toward the contact shown nearer the coil on the diagram. If the relay is equipped with numbered terminals, the proper terminal numbers shall alson be shown.

Basic

Relay with transfer contacts



Graphic Symbols for Terminals and Connectors

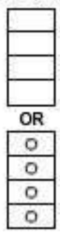
Terminals

Circuit terminal

Terminal board or terminal strip, with 4 terminals shown; group of 4 terminals

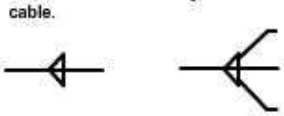
Number and arrangement as convenient.

NOTE: Internal lines and terminals may be omitted if terminal identifications are shown within the symbol.



Cable Termination

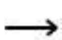
Line shown on left of symbol indicates cable.



Connector
Disconnecting Device
Jack
Plug

The contact symbol is not an arrowhead. It is larger and the lines are drawn at a 90-degree angle.

Female contact 

Male contact 

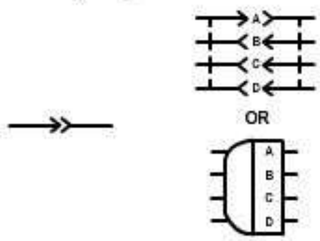
Receptacle or jack (usually stationary)

NOTE: The asterick is not part of the symbol. If desired, indicate the type of contacts: male (⟶) or female (—<).

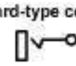
Plug (usually movable) OR

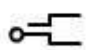
Separable connectors (engaged)

Engaged 4-conductor connectors; the plug has 1 male and 3 female contacts with individual contact designations shown in the complete-symbol column



Communication switchboard-type connector

2-conductor (jack) 

2-conductor (plug) 

Graphic Symbols for Transformers, Inductors, and Windings

Core

General or air core

If it is necessary to identify an air core, a note should appear adjacent to the symbol of the inductor or transformer

NO SYMBOL

Magnetic core of inductor or transformer

Not to be used unless it is necessary to identify a magnetic core.

Inductor
Winding (machine or transformer)
Reactor
Radio-Frequency Coil
Telephone Retardation Coil

See also OPERATING COIL

General

Magnetic-core inductor
Telephone loading coil

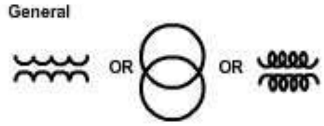
If necessary to show a magnetic core.

Tapped

Adjustable inductor

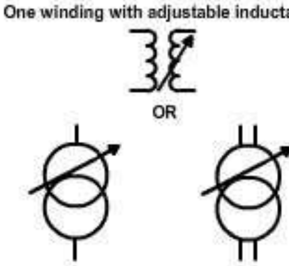
Transformer

General

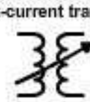


Shielded transformer with magnetic core shown

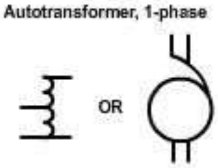
One winding with adjustable inductance



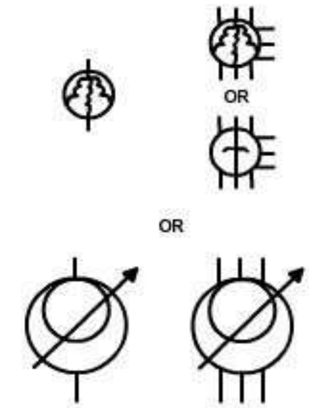
Adjustable mutual inductor; constant-current transformer



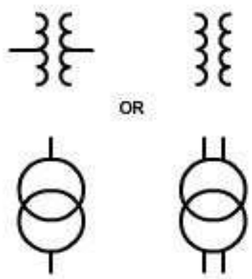
Autotransformer, 1-phase



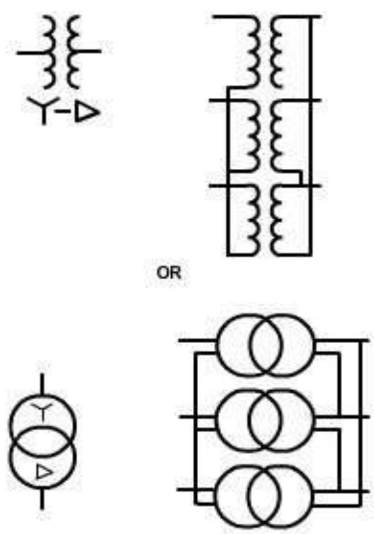
3-phase induction voltage regulator



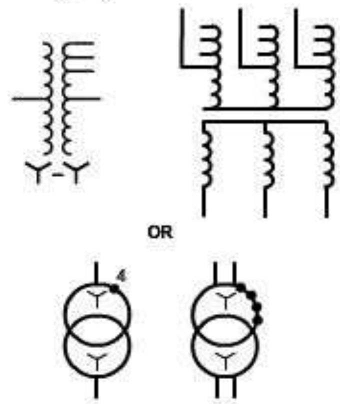
1-phase, 2-winding transformer



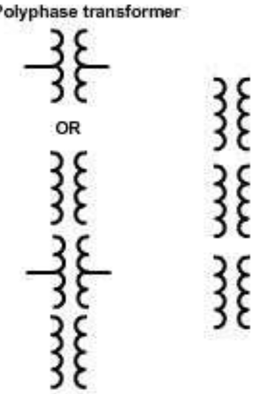
3-phase bank of 1-phase, 2-winding transformers with wye-delta connections



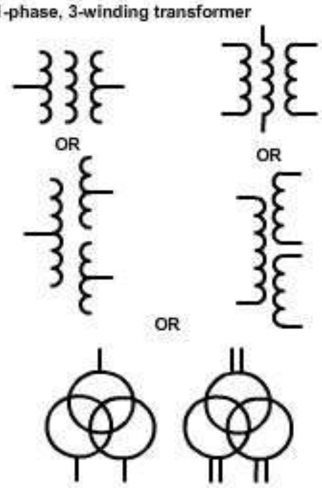
These phases transformer with 4 taps with wye-wye connections



Polyphase transformer

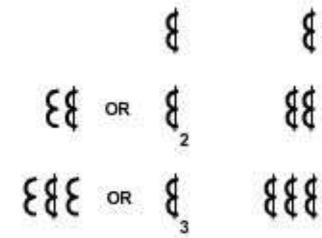


1-phase, 3-winding transformer

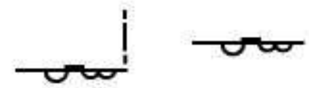


Current transformer(s)

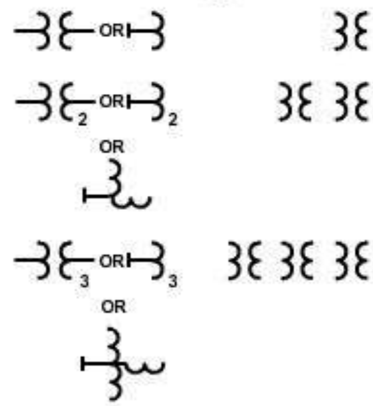
Avoid conflict with symbol for loaded line if used on the same diagram.



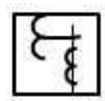
Bushing-type current transformer



Potential transformer(s)



Outdoor metering device



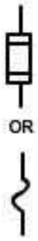
SHOW ACTUAL CONNECTION INSIDE BORDER

Graphic Symbols for Circuit Protectors

Fuse (one-time thermal current-over-load device)

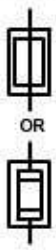
General

OR



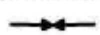
Isolating fuse-switch: high-voltage primary fuse cutout, dry

High-voltage primary fuse cutout, oil



Current Limiter (for power cable)

The arrowheads in this case are filled.



Lightning Arrester
Arrester (electric surge, etc)
Gap

General

Carbon block; telephone protector block

Horn gap

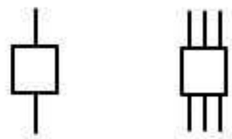
Circuit Breaker

Air circuit breaker, if distinction is needed; for alternating-current circuit breakers rated at 1,500 bolts or less and for all direct-current circuit breakers

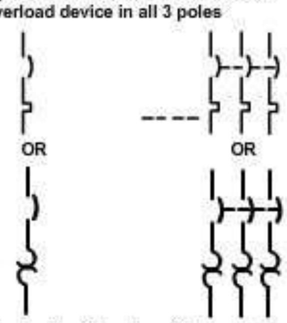
Network protector

Circuit breaker, other than covered by the above symbol

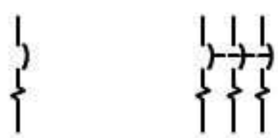
The symbol in the right column is for a 3-pole breaker.



3-pole circuit breaker with thermal-overload device in all 3 poles



3-pole circuit breaker with magnetic-overload device in all 3 poles



3-pole circuit breaker, drawout type

Protective Relay

Fundamental symbols for contacts, coils, mechanical connections, etc, are the basis or relay symbols and should be used to represent relays on complete diagrams.

See RELAY COIL; OPERATING COIL and RELAY

Graphic Symbols for Acoustic Devices

Audible-Signaling Device

Bell, electrical; telephone ringer

NOTE: If specific identification is required, the abbreviation AC or DC may be added within or adjacent to the symbol.

Single-stroke

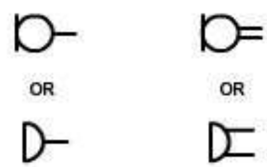
Buzzer

Loudspeaker
Horn, Electrical
Sirem

General

Microphone
Telephone Transmitter

General



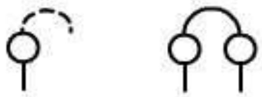
Handset
Operator's Set

General

Telephone Receiver
Earphone

General

Headset, double

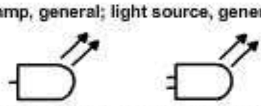


Headset, single

Graphic Symbols for Lamps and Visual-Signaling Devices

Lamp

Lamp, general; light source, general



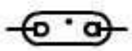
NOTE: This symbol may be used to represent one or more lamps with or without operating auxiliaries.

NOTE: If it is essential to indicate the following characteristics, the specified letter or letters may be inserted within or placed adjacent to the symbol.

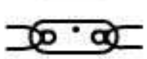
A	Amber
B	Blue
C	Clear
G	Green
O	Orange
OP	Opelescent
P	Purple
R	Red
W	White
Y	Yellow
ARC	Arc
EL	Electroluminescent
FL	Fluorescent
HG	Mercury vapor
IN	Incandescent
IR	Infrared
NA	Sodium vapor
NE	Neon
UV	Ultraviolet
XE	Xenon
LED	Light-emitting diode

Fluorescent lamp

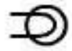
2-terminal



4-terminal

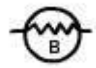


Incandescent lamp (incandescent-filament illuminating lamp



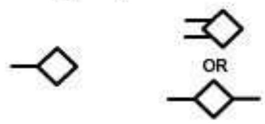
Ballest lamp; ballast tube

The primary characteristic of the element within the circle is designed to vary non-linearity with the temperature of the element.



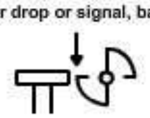
Visual-Signaling Device

Annunciator (general)

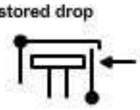


Annunciator drop or signal, shutter or grid type

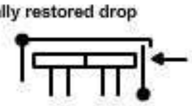
Annunciator drop or signal, ball type



Manually restored drop



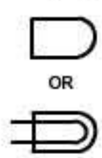
Electrically restored drop



Communication switchgoard-type lamp; indicating lamp

Indicating, pilot, signaling, or switch-board light; indicator light signal light

If confusion with other circular symbols may occur, the D-shape symbol should be used.



OR

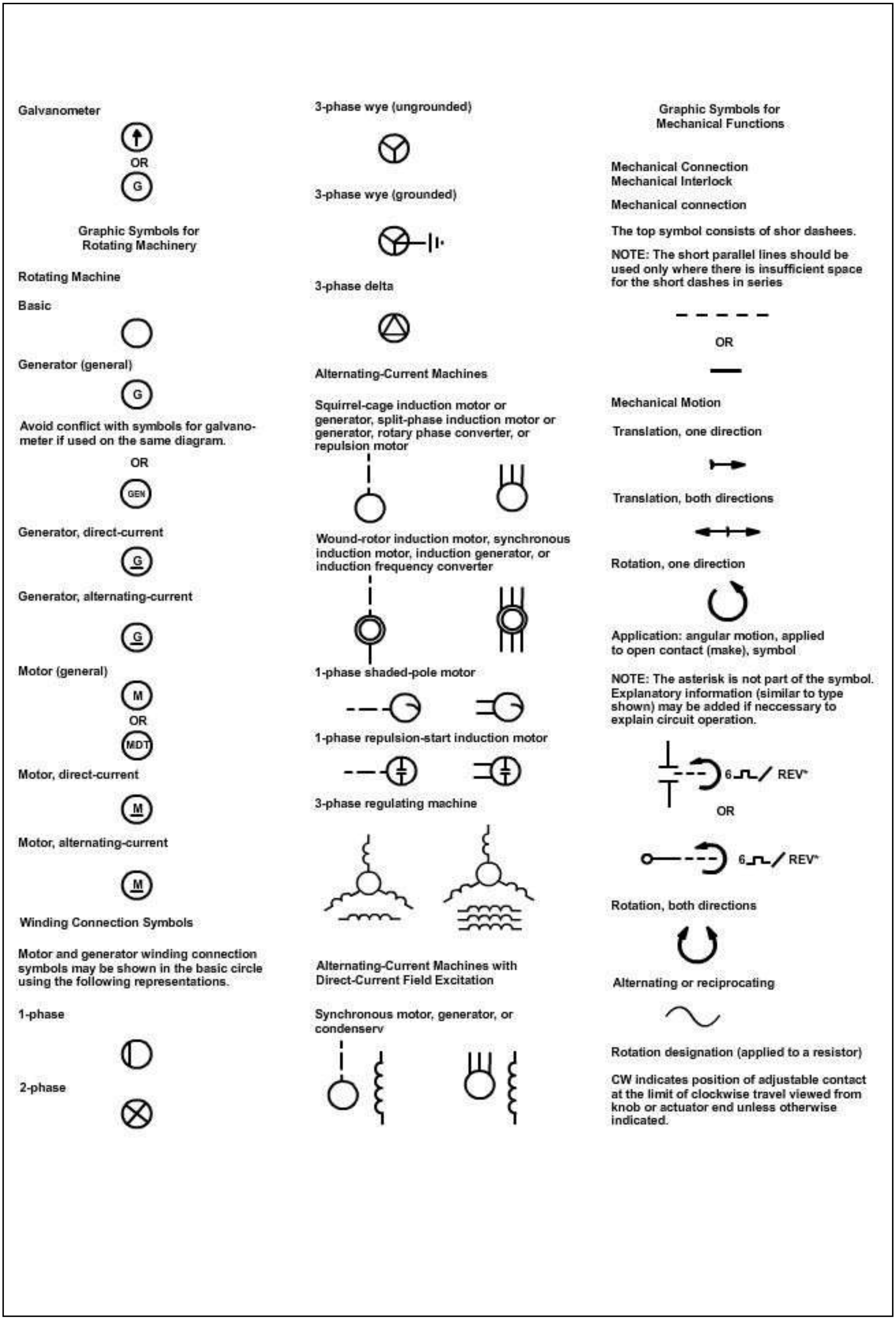
Jeweled signal light

Graphic Symbols for Readout Devices

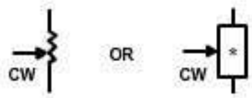
Meter Instrument

NOTE: The asterisk is not part of the symbol. Always replace the asterisk by one of the following letter combinations, depending on the function of the meter or instrument, unless some other identification is provided in the circle and explained on the diagram.

A	Ammeter
AH	Ampere-hour meter
C	Coulombmeter
CMA	Contact-making (or breaking) ammeter
CMC	Contact-making (orbreaking) clock
CMV	Contact-making (or breaking) voltmeter
CRO	Oscilloscope Cathode-ray oscillograph
DB	DB (decibel) meter Audio level/meter
DBM	DBM (decibels referred to 1 milliwatt) meter
DM	Demand meter
DTR	Demand-totalizing relay
F	Frequency meter
GD	Ground detector
I	Indicating meter
µ A or UA	Microammeter
MA	Milliammeter
NM	Noise Meter
OHM	Ohmmeter
OP	Oil pressure meter
OSCG	Oscillograph
PF	Power factor meter
PH	Phasemeter
PI	Position indicator
RD	Recording demand meter
REC	Recording meter
RF	Reactive factor meter
SY	Synchroscope
t°	Temperature meter
THC	Thermal converter
TLM	Telemeter
TT	Total time meter Elapsed time meter
V	Voltmeter
VA	Volt-ammeter
VAR	Varmeter
VARH	Varhour meter
VI	Volume indicator Audio-level meter
VU	Standard volume indicator Audio-level meter
W	Wattmeter
WH	Watthour meterv


Galvanometer
OR
G
Graphic Symbols for Rotating Machinery
Rotating Machine
Basic
Generator (general)
G
Avoid conflict with symbols for galvano-meter if used on the same diagram.
OR
GEN
Generator, direct-current
G
Generator, alternating-current
G
Motor (general)
M
OR
MDT
Motor, direct-current
M
Motor, alternating-current
M
Winding Connection Symbols
Motor and generator winding connection symbols may be shown in the basic circle using the following representations.
1-phase
2-phase
3-phase wye (ungrounded)
3-phase wye (grounded)
3-phase delta
Alternating-Current Machines
Squirrel-cage induction motor or generator, split-phase induction motor or generator, rotary phase converter, or repulsion motor
Wound-rotor induction motor, synchronous induction motor, induction generator, or induction frequency converter
1-phase shaded-pole motor
1-phase repulsion-start induction motor
3-phase regulating machine
Alternating-Current Machines with Direct-Current Field Excitation
Synchronous motor, generator, or condenserv
Graphic Symbols for Mechanical Functions
Mechanical Connection
Mechanical Interlock
Mechanical connection
The top symbol consists of shor dashees.
NOTE: The short parallel lines should be used only where there is insufficient space for the short dashes in series
OR
Mechanical Motion
Translation, one direction
Translation, both directions
Rotation, one direction
Application: angular motion, applied to open contact (make), symbol
NOTE: The asterisk is not part of the symbol. Explanatory information (similar to type shown) may be added if neccessary to explain circuit operation.
6 REV*
OR
6 REV*
Rotation, both directions
Alternating or reciprocating
Rotation designation (applied to a resistor)
CW indicates position of adjustable contact at the limit of clockwise travel viewed from knob or actuator end unless otherwise indicated.

NOTE: The asterisk is not part of the symbol. Always add identification within or adjacent to the rectangle.



Manual Control

General

Operated by pushing

Operated by pushing and pulling (pudh-pull)

Graphic Symbols for Composite Assemblies

Circuit Assembly
Circuit Subassembly
Circuit Element

NOTE: The asterisk is not part of the symbol. Always indicate the type of apparatus by appropriate words or letters.

NOTE: The use of a general circuit-element symbol is restricted to the following:

a. Diagrams drawn in block form.
b. A substitute for complex circuit elements when the internal operation of the circuit element is not important of the purpose of the diagram.

General

Accepted abbreviations from ANSI Z32.13-1950 may be used in the rectangle.

The following letter combinations may be used in the rectangle:

CLK	Clock
EQ	Equalizer
FAX	Facsimile set
FL	Filter
IND	Indicator
PS	Power supply
RG	Recording unit
RU	Reproducing unit
DIAL	Telephone dial
TEL	Telephone station
TPR	Teleprinter
TTY	Teletypewriter

Amplifier

General

The triangle is pointed in the direction of transmission.

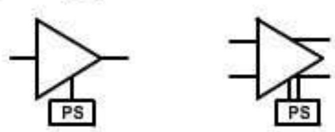
The symbol represents any method of amplification (electron tube, solid-state device, magnetic device, etc).

NOTE: If identification, electrical values, location data, and similar information must be noted within symbol, the size or aspect ratio of the original symbol may be altered providing its distinctive shape is retained.

Amplifier use may be indicated in the triangle by words, standard abbreviations, or a letter combination from the following list:

BOG	Bridging
BST	Booster
CMP	Compression
EXP	Direct-current
LIM	Limiting
MON	Monitoring
PGM	Program
PRE	Preliminary
PWR	Power
TRQ	Torque

Application: amplifier with associated power supply

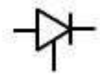


General

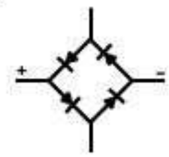
NOTE: Triangle points in direction of forward (easy) current as indicated by a direct-current ammeter, unless otherwise noted adjacent to the symbol. Electron flow is in the opposite direction.

NOTE: This symbol represents any method of rectification (electron tube, solid-state device, electrochemical device, etc).

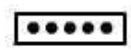
Controlled



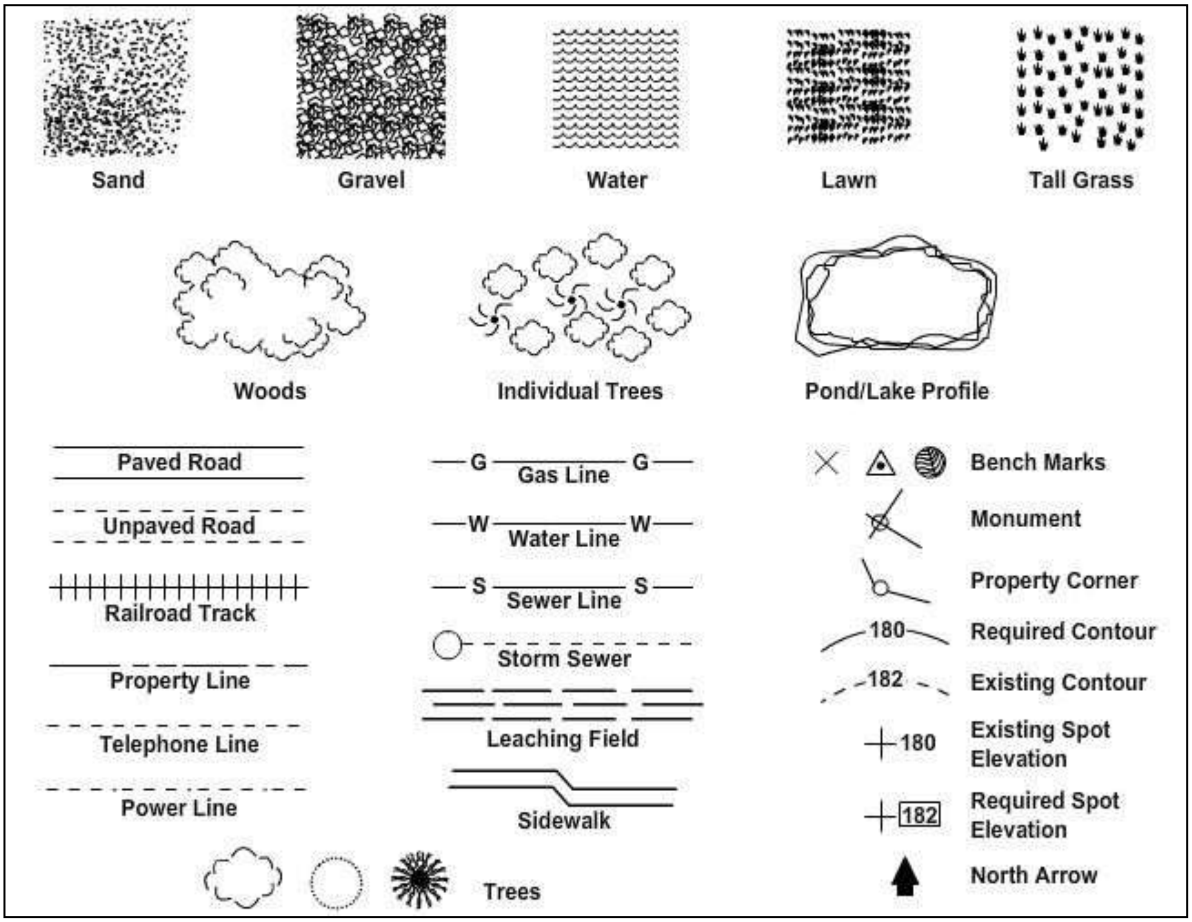
Bridge-type rectifier



On connection or wiring diagrams, rectifier may be shown with terminals and plarity marking. Heavy line may be used to indicate nameplate or positive-polarity end.

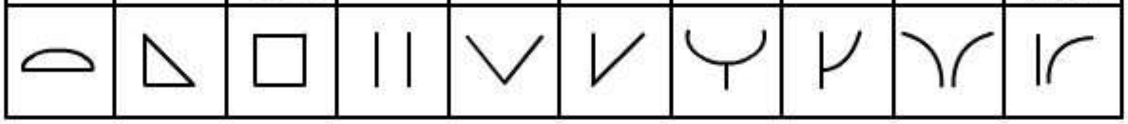


For connection or wiring diagram

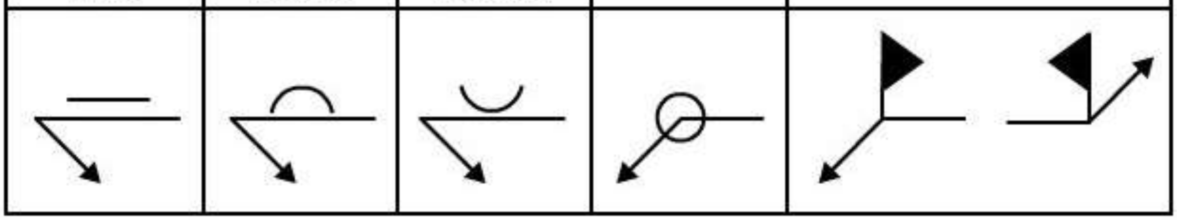


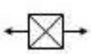
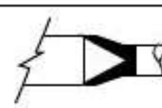
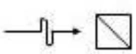
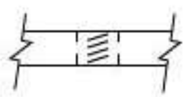
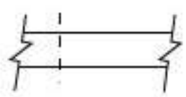
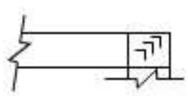
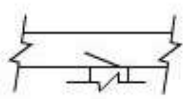
Description	Example	Symbol	Illustrated Use
W- Shape (Wide Flange)		W	W24 x 78
Bearing Pile		BP	BP14 x 73
S-Shape (American STD I-Beam)		S	S15 x 42.9
C-Shape (American STD Channel)		C	C9 x 13.4
M-Shape (Misc Shapes Other Than W, BP, S, & C)		M	M5 x 34.3 M5 x 17 M7 x 5.5
MC-Shape (Channels Other Than American STD)		MC	MC12 x 45 MC 12 x 12.8
Angles:			3x 3x
Equal Leg		L	L 3x 3x 1/4
Un-equal Leg		L	L 7x 4x 1/2
Tees, Structural:			
Cut From W-Shape		WT	WT 12x38
Cut From S-Shape		ST	ST 12x38
Cut From M-Shape		MT	MT 12x38
Plate		PL	PL 1/2x18"x30"
Flat Bar		BAR	BAR 2 1/2 x 1/4
Pipe, Structural			Pipe 4 STD Pipe 4x-STRG Pipe XX-STRG

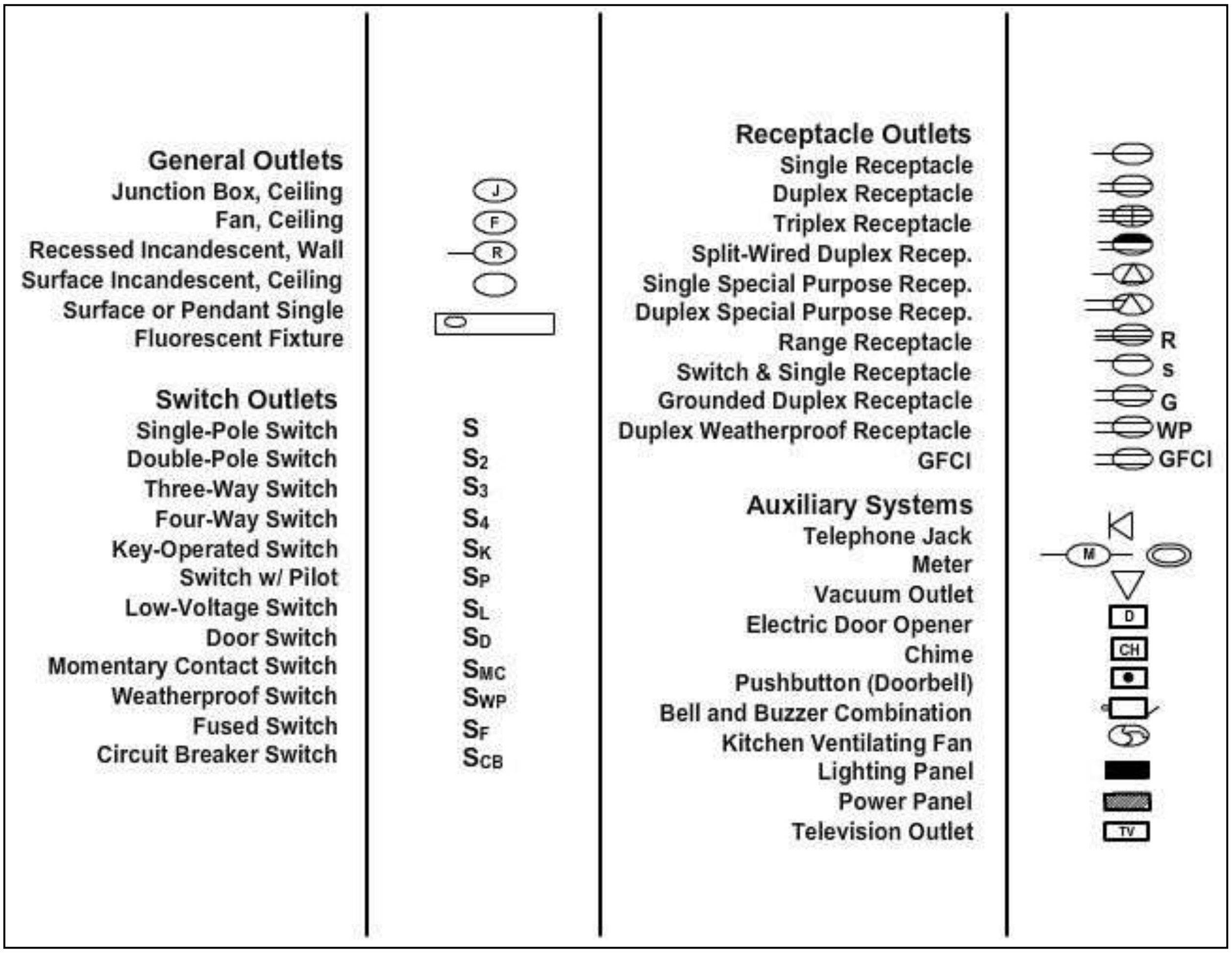
BASIC WELD SYMBOLS										
BEAD	FILLET	PLUG OR SLOT	GROOVE OR BUTT							
			SQUARE	V	BEVEL	U	J	FLARE V	FLARE BEVEL



CONTOUR			WELD-ALL-AROUND	FIELD WELD
FLUSH	CONVEX	CONCAVE		

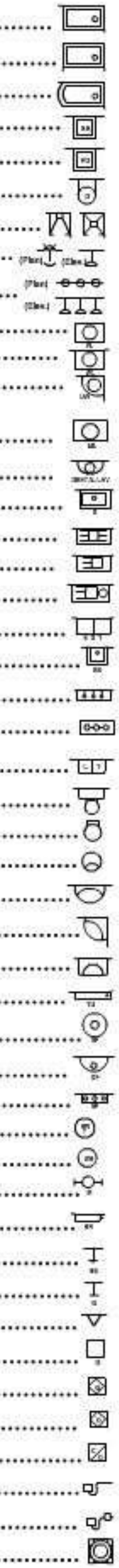


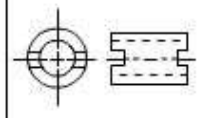
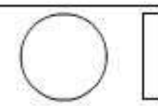
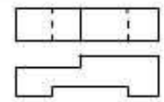
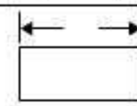
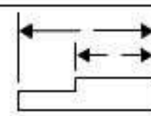
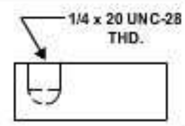
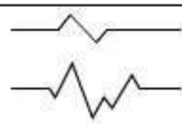
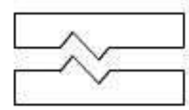
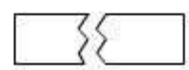
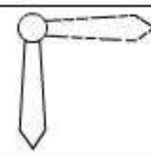
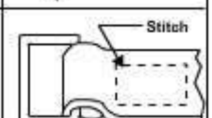
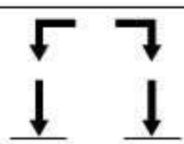
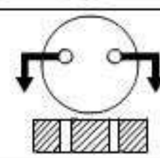
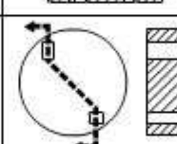
Symbol	Description	Symbol	Description
	Ceiling Diffuser (Arrows Indicate Direction of Air Flow)		Square to Round Transition
	Return Air Grille		Parallel Blade Damper
	Supply Duct Up		Fire Damper (Wall) (Floor)
	Supply Duct Down		Airfoil Blade Turning Vanes
	Return Duct Up		Air Extractor
	Return Duct Down	Ø	Diameter
		¢	CFM (Cubic Feet Per Minute)
6"ϕ CD / 200 ¢	Neck Size/ Air Device CFM	RA	Return Air
		OSA	Outside Air
(T)	Thermostat	CD	Condensate Drain


General Outlets
Junction Box, Ceiling
Fan, Ceiling
Recessed Incandescent, Wall
Surface Incandescent, Ceiling
Surface or Pendant Single Fluorescent Fixture
J
F
R
Switch Outlets
Single-Pole Switch
Double-Pole Switch
Three-Way Switch
Four-Way Switch
Key-Operated Switch
Switch w/ Pilot
Low-Voltage Switch
Door Switch
Momentary Contact Switch
Weatherproof Switch
Fused Switch
Circuit Breaker Switch
S
S2
S3
S4
SK
SP
SL
SD
SMC
SWP
SF
SCB
Receptacle Outlets
Single Receptacle
Duplex Receptacle
Triplex Receptacle
Split-Wired Duplex Recep.
Single Special Purpose Recep.
Duplex Special Purpose Recep.
Range Receptacle
Switch & Single Receptacle
Grounded Duplex Receptacle
Duplex Weatherproof Receptacle
GFCI
R
s
G
WP
GFCI
Auxiliary Systems
Telephone Jack
Meter
Vacuum Outlet
Electric Door Opener
Chime
Pushbutton (Doorbell)
Bell and Buzzer Combination
Kitchen Ventilating Fan
Lighting Panel
Power Panel
Television Outlet
M
D
CH
TV

Plumbing

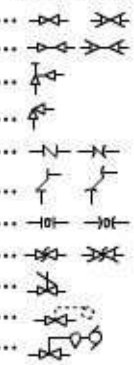
Corner Bath
Recessed Bath
Roll Rim Bath
Sitz Bath
Floor Bath
Bidet
Shower Stall
Shower Head
Overhead Gang Shower
Pedestal Lavatory
Wall Lavatory
Corner Lavatory
Manicure Lavatory
Medical Lavatory
Dental Lavatory
Plain Kitchen Sink
Kitchen Sink, R & L Drain Board
Kitchen Sink, L H Drain Board
Combination Sink and Dishwasher
Combination Sink & Laundry Tray
Service Sink
Wash Sink (Wall Type)
Wash Sink
Laundry Tray
Water Closet (Low Tank)
Water Closet (No Tank)
Urinal (Pedestal Type)
Urinal (Wall Type)
Urinal (Corner Type)
Urinal (Stall Type)
Urinal (Trough Type)
Drinking Fountain (Pedestal Type)
Drinking Fountain (Wall Type)
Drinking Fountain (Trough Type)
Hot Water Tank
Water Heater
Meter
Hose Rack
Hose Bibb
Gas Outlet
Vacuum Outlet
Drain
Grease Separator
Oil Separator
Cleanout
Garage Drain
Floor Drain With Backwater Valve
Roof Sump



LINE STANDARDS			
Name	**Convention**	**Description and Application**	**Example**
Center Lines		Thin lines made up of long and short dashes alternately spaced and consistent in length. Used to indicate symmetry about an axis and location of centers.	
Visible Lines		Heavy unbroken lines Used to indicate visible edges of an object	
Hidden Lines		Medium lines with short evenly spaced dashes Used to indicate concealed edges	
Extension Lines		Thin unbroken lines Used to indicate extent of dimensions	
Dimension Lines		Thin lines terminated with arrow heads at each end Used to indicate distance measured	
Leader		Thin line terminated with arrowhead or dot at one end Used to indicate a part, dimension or other reference	
Break (Long)		Thin, solid ruled lines with freehand zigzags Used to reduce size of drawing required to delineate object and reduce detail	
Break (Short)		Thick, solid free hand lines Used to indicate a short break	
Phantom or Datum Line		Medium series of one long dash and two short dases evenly spaced ending with long dash Used to indicate alternate position of parts, repeated detail or to indicate a datum plane	
Stitch Line		Medium line of short dases evenly spaced and labeled Used to indicate stitching or sewing	
Cutting or Viewing Plane Viewing Plane Optional		Thick solid lines with arrowhead to indicate direction in which section or plane is viewed or taken	
Cutting Plane for Complex or Offset Views		Thick short dashes Used to show offset with arrowheads to show direction viewed	

Valves

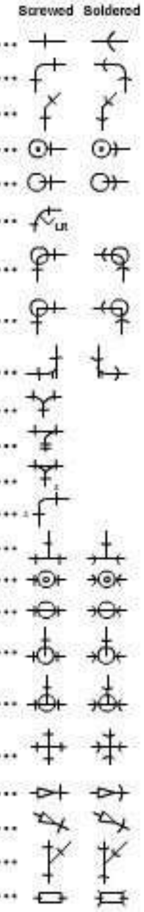
Screwed Soldered



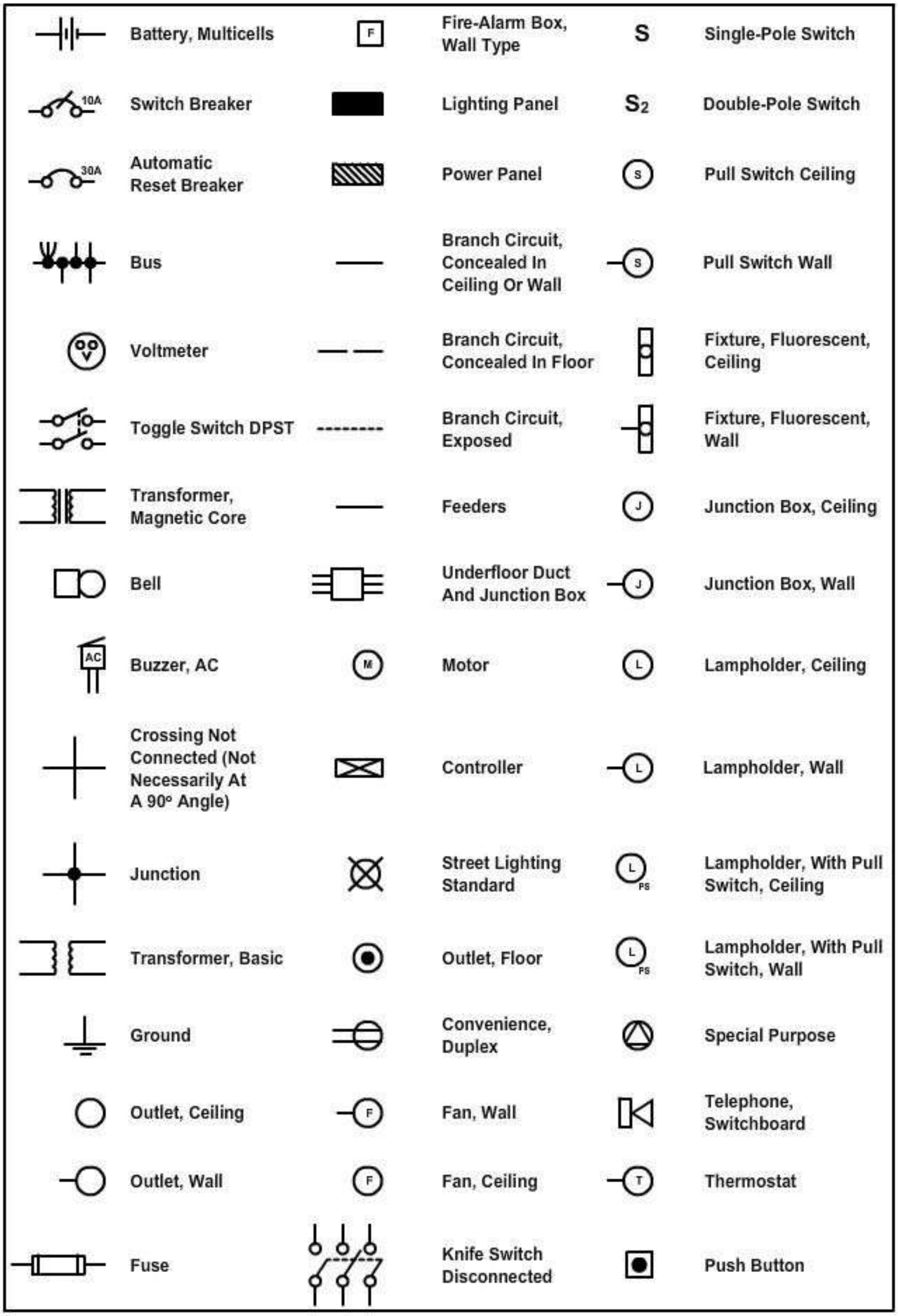
- Gate Valve
- Globe Valve
- Angle Glove Valve
- Angle Gate Valve
- Check Valve
- Angle Check Valve
- Stop Cock
- Safety Valve
- Quick Opening Valve
- Float Opening Valve
- Motor Operated Gate Valve

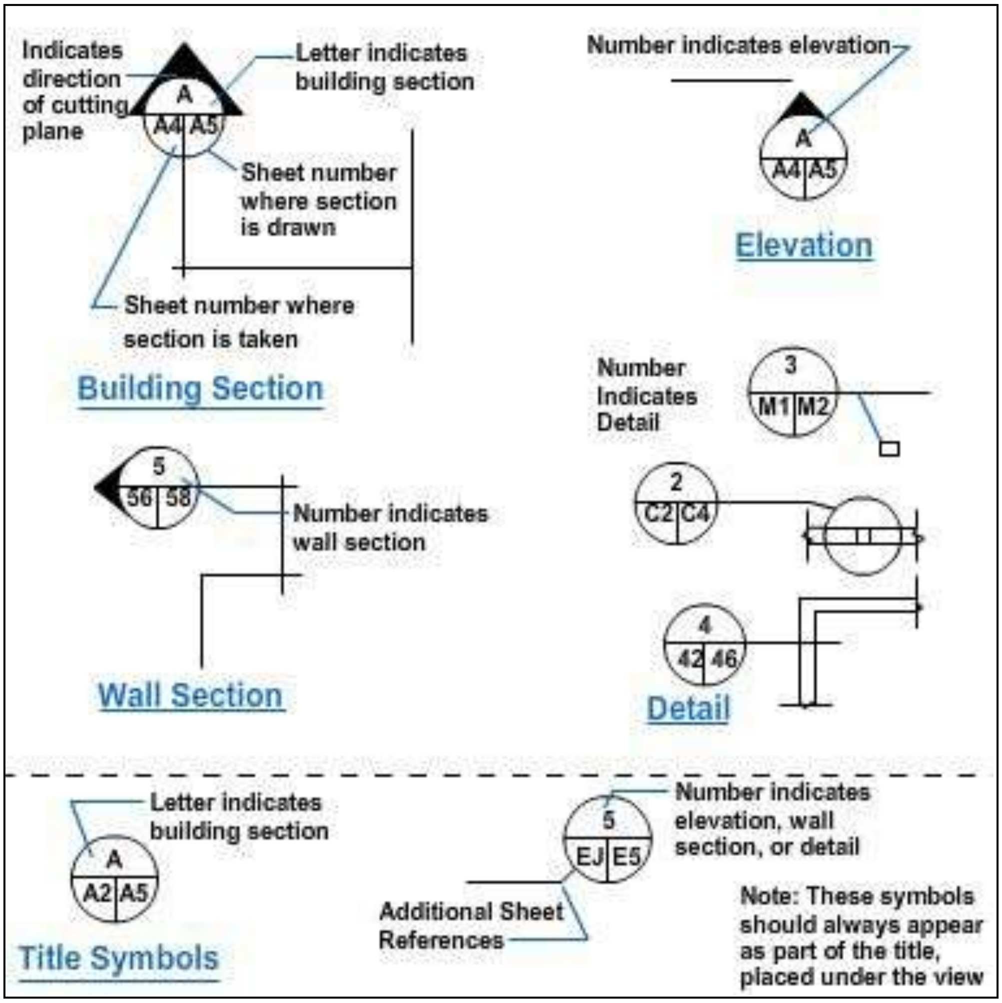
Pipe Fittings

Screwed Soldered

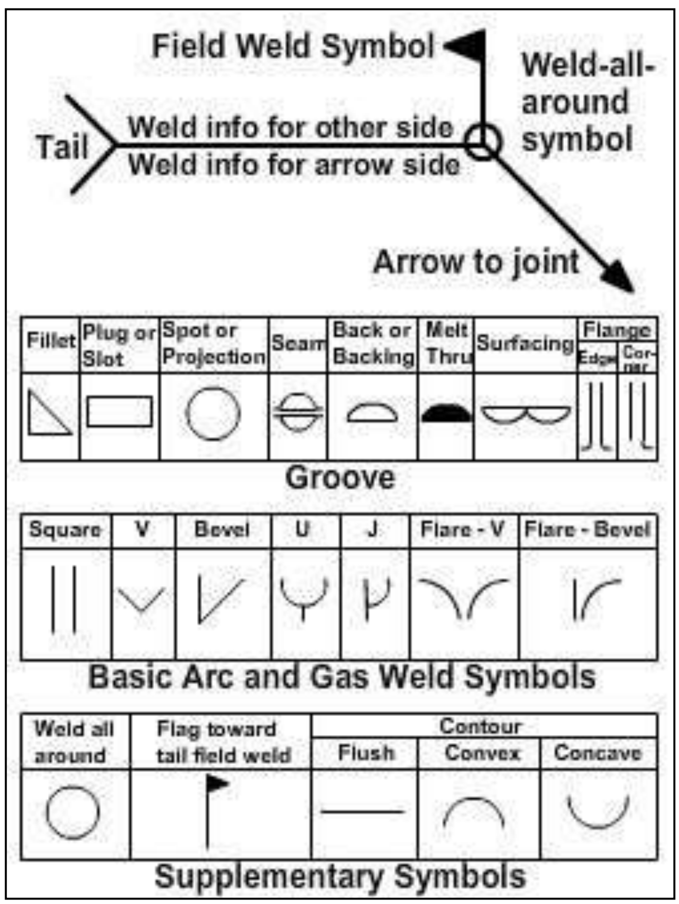


- Joint
- Elbow - 90
- Elbow - 45
- Elbow - Turned Up
- Elbow - Turned Down
- Elbow Long Radius
- Side Outlet Elbow- Outlet Down
- Side outlet Elbow - Outlet Up
- Base Elbow
- Double Branch Elbow
- Single Sweep Tee
- Double Sweep Tee
- Reducing Elbow
- Tee
- Tee - Outlet UP
- Tee - Outlet Down
- Side Outlet Tee - Outlet Up
- Side Outlet Tee - Outlet Down
- Cross
- Reducer
- Eccentric Reducer
- Lateral
- Expansion Joint Flanged

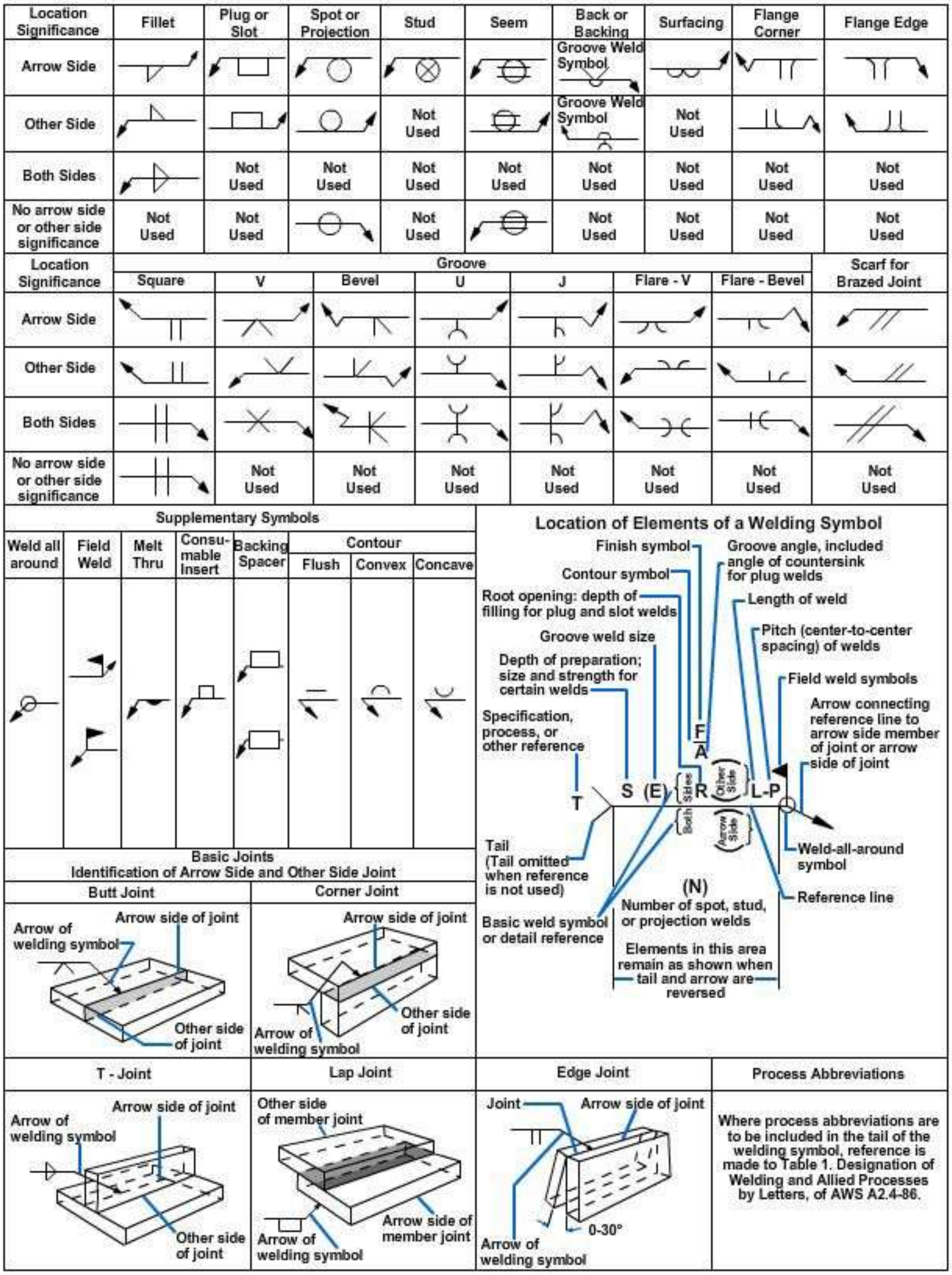

Battery, Multicells
10A
Switch Breaker
30A
Automatic Reset Breaker
Bus
Voltmeter
Toggle Switch DPST
Transformer, Magnetic Core
Bell
AC
Buzzer, AC
Crossing Not Connected (Not Necessarily At A 90° Angle)
Junction
Transformer, Basic
Ground
Outlet, Ceiling
Outlet, Wall
Fuse
F
Fire-Alarm Box, Wall Type
Lighting Panel
Power Panel
Branch Circuit, Concealed In Ceiling Or Wall
Branch Circuit, Concealed In Floor
Branch Circuit, Exposed
Feeders
Underfloor Duct And Junction Box
M
Motor
Controller
Street Lighting Standard
Outlet, Floor
Convenience, Duplex
F
Fan, Wall
F
Fan, Ceiling
Knife Switch Disconnected
S
Single-Pole Switch
S2
Double-Pole Switch
S
Pull Switch Ceiling
S
Pull Switch Wall
Fixture, Fluorescent, Ceiling
Fixture, Fluorescent, Wall
J
Junction Box, Ceiling
J
Junction Box, Wall
L
Lampholder, Ceiling
L
Lampholder, Wall
L PS
Lampholder, With Pull Switch, Ceiling
L PS
Lampholder, With Pull Switch, Wall
Special Purpose
Telephone, Switchboard
T
Thermostat
Push Button

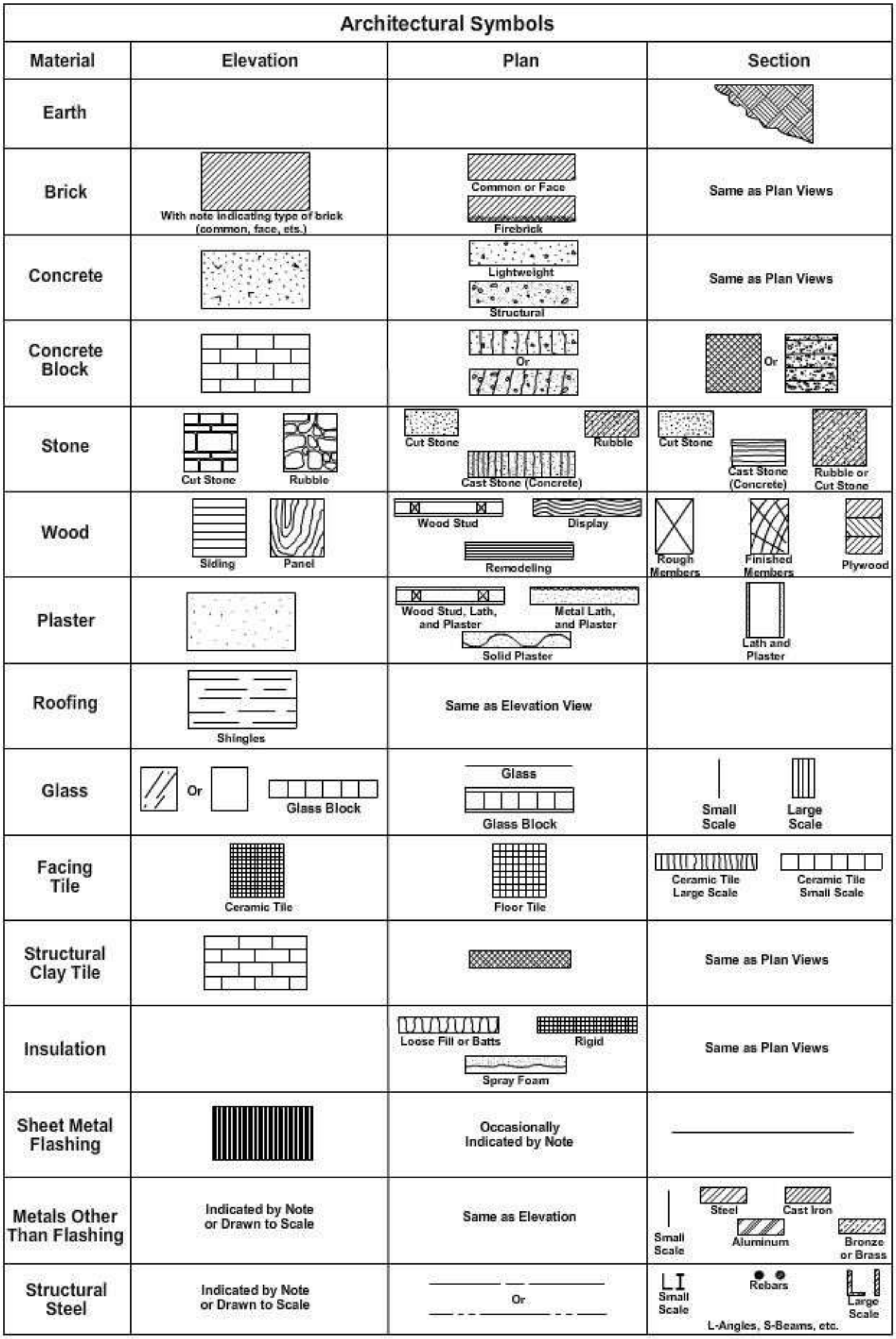


Indicates direction of cutting plane
Letter indicates building section
A
A4 A5
Sheet number where section is drawn
Sheet number where section is taken
Building Section
Number indicates elevation
A
A4 A5
Elevation
Number Indicates Detail
3
M1 M2
2
C2 C4
4
42 46
Detail
5
56 58
Number indicates wall section
Wall Section
Letter indicates building section
A
A2 A5
Title Symbols
Number indicates elevation, wall section, or detail
5
EJ E5
Additional Sheet References
Note: These symbols should always appear as part of the title, placed under the view

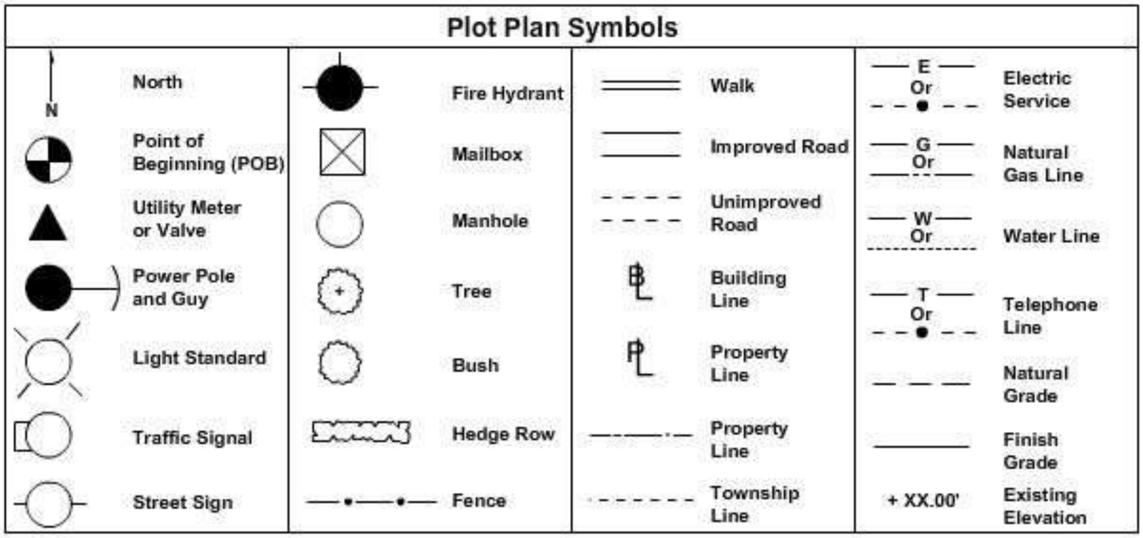


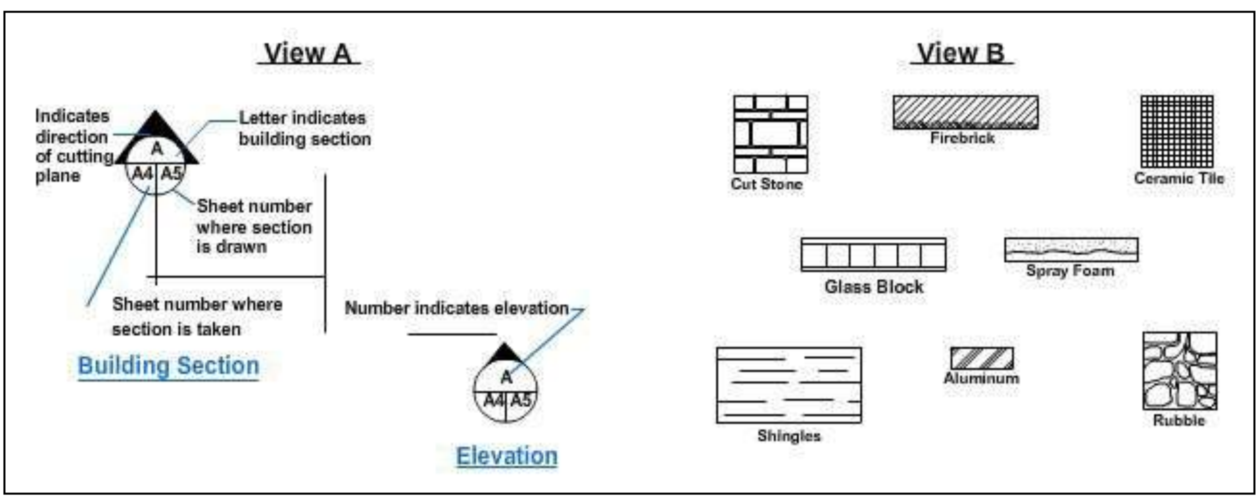
Field Weld Symbol
Weld-all-around symbol
Tail
Weld info for other side
Weld info for arrow side
Arrow to joint
Fillet
Plug or Slot
Spot or Projection
Seam
Back or Backing
Melt Thru
Surfacing
Flange
Edge
Corner
Groove
Square
V
Bevel
U
J
Flare - V
Flare - Bevel
Basic Arc and Gas Weld Symbols
Weld all around
Flag toward tail field weld
Contour
Flush
Convex
Concave
Supplementary Symbols

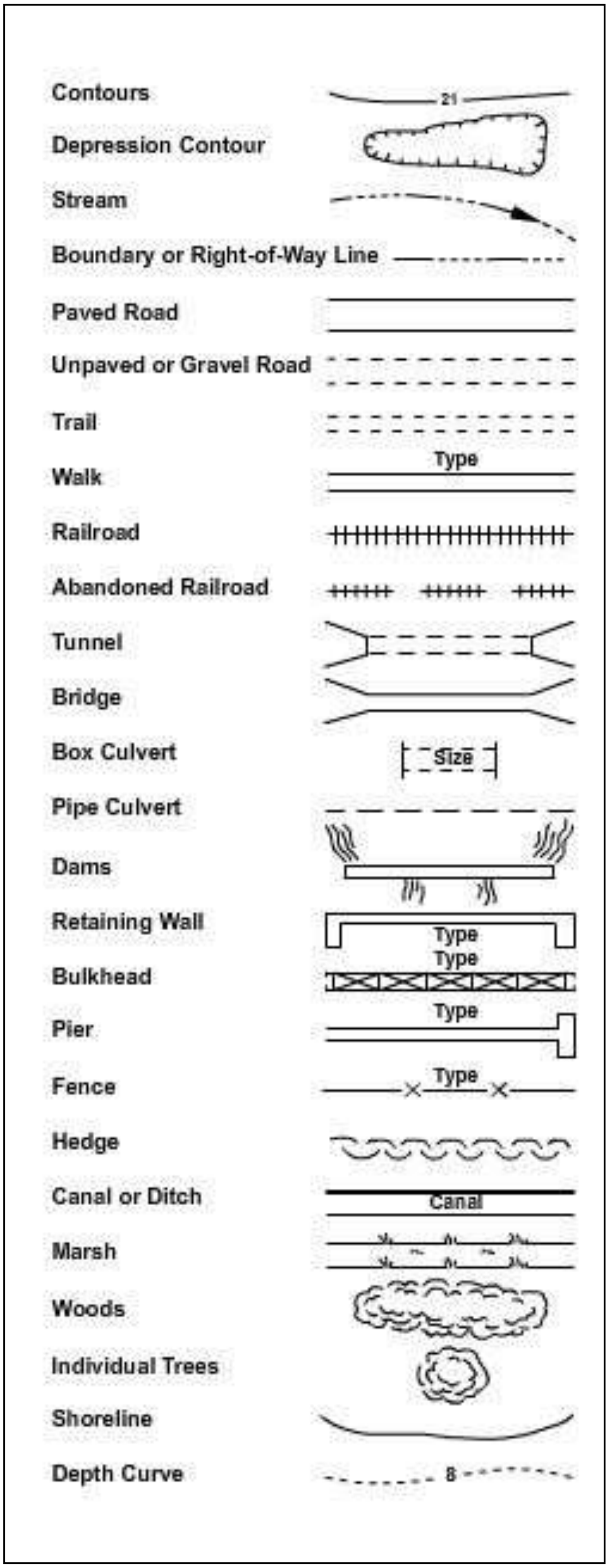

Location Significance
Fillet
Plug or Slot
Spot or Projection
Stud
Seem
Back or Backing
Surfacing
Flange Corner
Flange Edge
Arrow Side
Other Side
Both Sides
No arrow side or other side significance
Groove Weld Symbol
Not Used
Groove
Square
V
Bevel
U
J
Flare - V
Flare - Bevel
Scarf for Brazed Joint
Supplementary Symbols
Weld all around
Field Weld
Melt Thru
Consu-mable Insert
Backing Spacer
Contour
Flush
Convex
Concave
Location of Elements of a Welding Symbol
Finish symbol
Groove angle, included angle of countersink for plug welds
Contour symbol
Root opening: depth of filling for plug and slot welds
Length of weld
Groove weld size
Pitch (center-to-center spacing) of welds
Depth of preparation; size and strength for certain welds
Field weld symbols
Arrow connecting reference line to arrow side member of joint or arrow side of joint
Specification, process, or other reference
F
A
T
S (E)
R
L-P
Both Sides
Other Side
Arrow Side
Tail (Tail omitted when reference is not used)
Weld-all-around symbol
(N)
Number of spot, stud, or projection welds
Reference line
Basic weld symbol or detail reference
Elements in this area remain as shown when tail and arrow are reversed
Basic Joints
Identification of Arrow Side and Other Side Joint
Butt Joint
Arrow of welding symbol
Arrow side of joint
Other side of joint
Corner Joint
T - Joint
Lap Joint
Other side of member joint
Arrow side of member joint
Edge Joint
Joint
0-30°
Process Abbreviations
Where process abbreviations are to be included in the tail of the welding symbol, reference is made to Table 1. Designation of Welding and Allied Processes by Letters, of AWS A2.4-86.

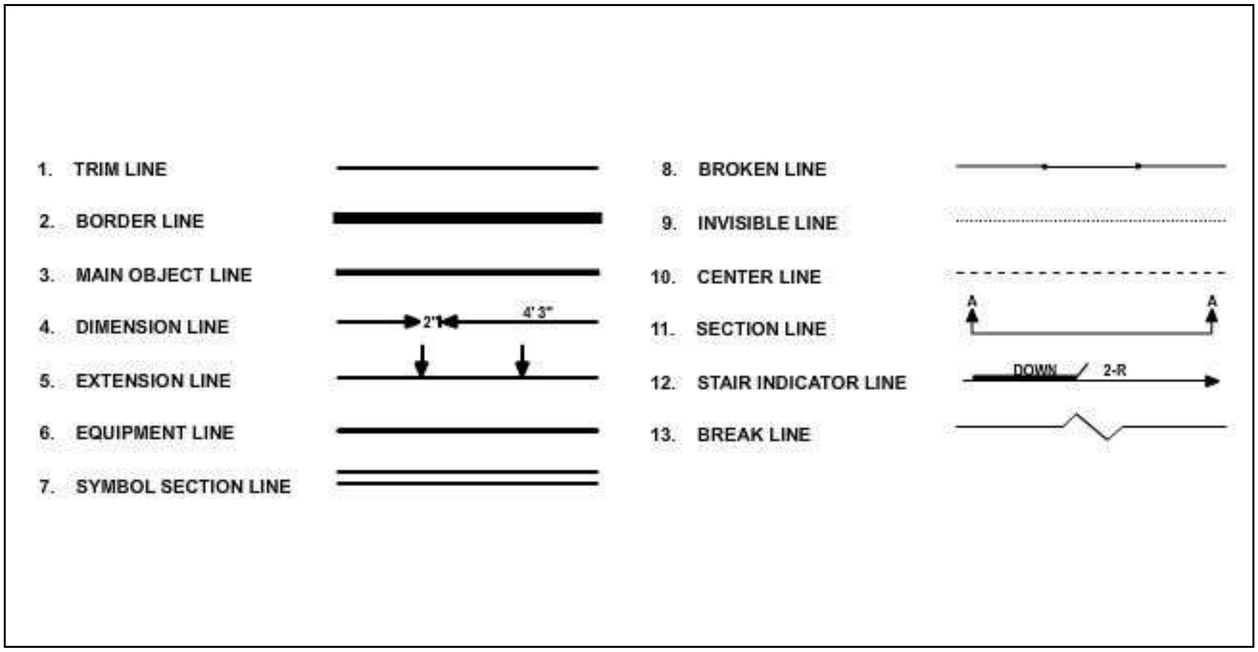


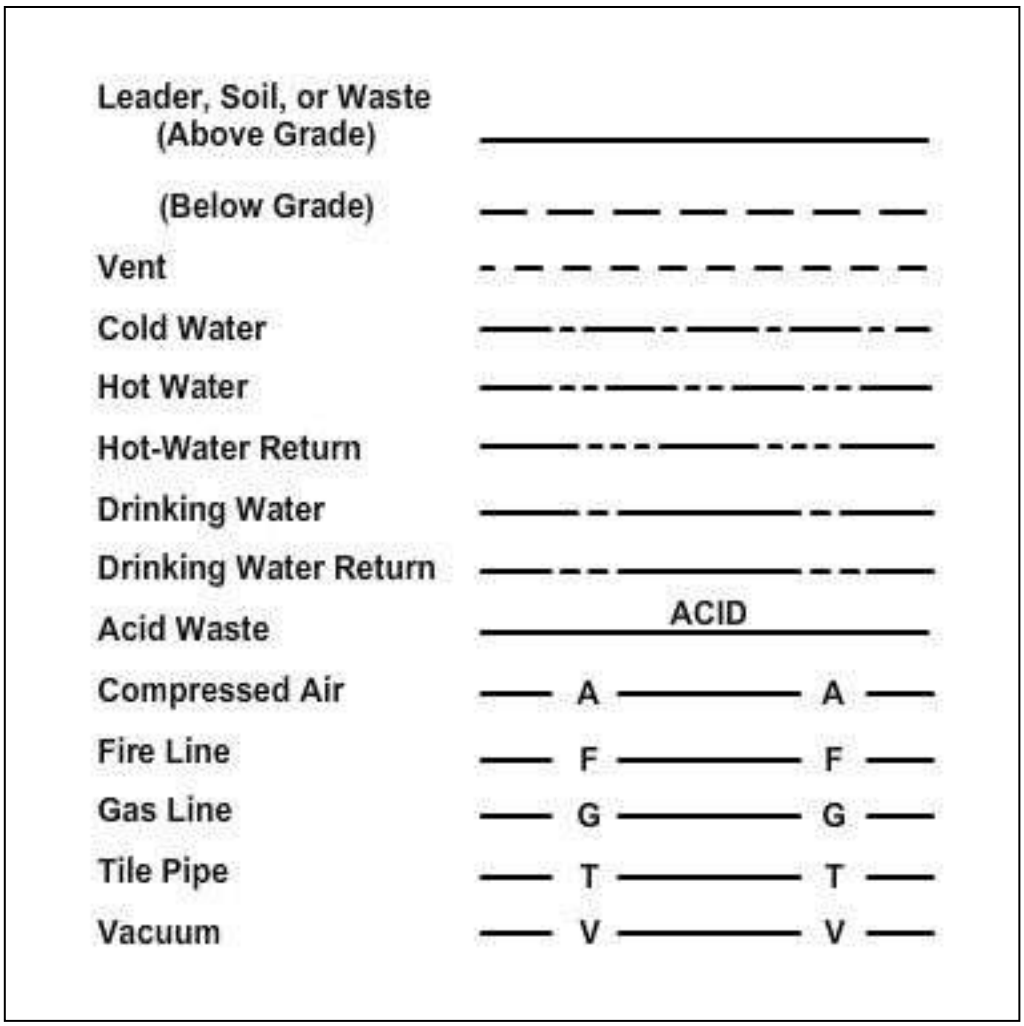
Architectural Symbols			
Material	**Elevation**	**Plan**	**Section**
Earth			
Brick	With note indicating type of brick (common, face, ets.)	Common or Face Firebrick	Same as Plan Views
Concrete		Lightweight Structural	Same as Plan Views
Concrete Block		Or	Or
Stone	Cut Stone Rubble	Cut Stone Rubble Cast Stone (Concrete)	Cut Stone Cast Stone (Concrete) Rubble or Cut Stone
Wood	Siding Panel	Wood Stud Display Remodeling	Rough Members Finished Members Plywood
Plaster		Wood Stud, Lath, and Plaster Metal Lath, and Plaster Solid Plaster	Lath and Plaster
Roofing	Shingles	Same as Elevation View	
Glass	Or Glass Block	Glass Glass Block	Small Scale Large Scale
Facing Tile	Ceramic Tile	Floor Tile	Ceramic Tile Large Scale Ceramic Tile Small Scale
Structural Clay Tile			Same as Plan Views
Insulation		Loose Fill or Batts Rigid Spray Foam	Same as Plan Views
Sheet Metal Flashing		Occasionally Indicated by Note	
Metals Other Than Flashing	Indicated by Note or Drawn to Scale	Same as Elevation	Small Scale Steel Cast Iron Aluminum Bronze or Brass
Structural Steel	Indicated by Note or Drawn to Scale	Or	Small Scale Rebars Large Scale L-Angles, S-Beams, etc.

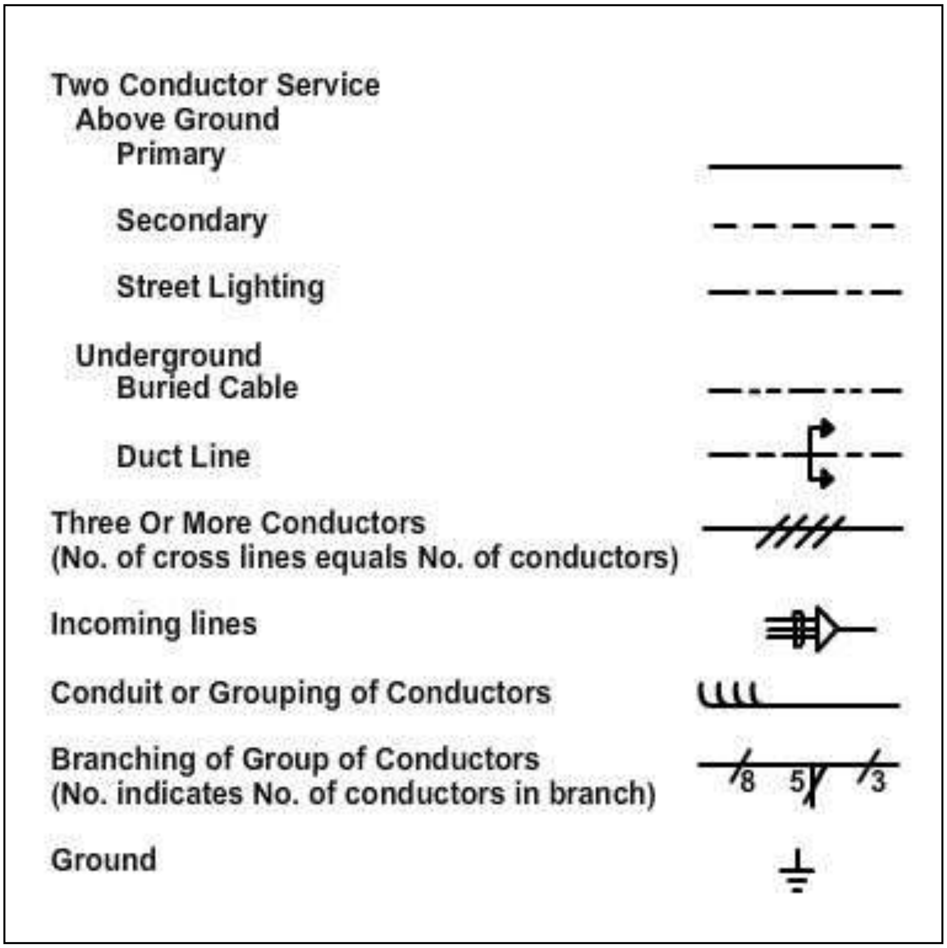

Plot Plan Symbols
North
N
Point of Beginning (POB)
Utility Meter or Valve
Power Pole and Guy
Light Standard
Traffic Signal
Street Sign
Fire Hydrant
Mailbox
Manhole
Tree
Bush
Hedge Row
Fence
Walk
Improved Road
Unimproved Road
Building Line
Property Line
Property Line
Township Line
E Or
Electric Service
G Or
Natural Gas Line
W Or
Water Line
T Or
Telephone Line
Natural Grade
Finish Grade
+ XX.00'
Existing Elevation

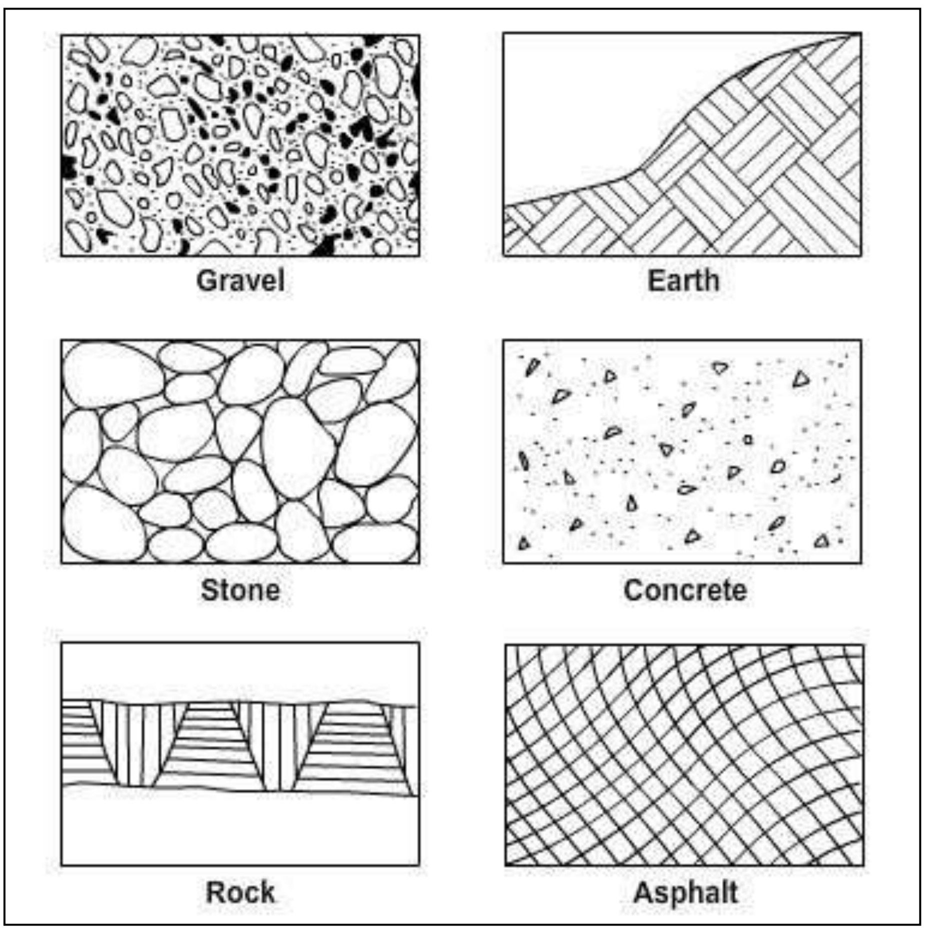

View A
Indicates direction of cutting plane
Letter indicates building section
A
A4 A5
Sheet number where section is drawn
Sheet number where section is taken
Building Section
Number indicates elevation
A
A4 A5
Elevation
View B
Cut Stone
Firebrick
Ceramic Tile
Glass Block
Spray Foam
Shingles
Aluminum
Rubble

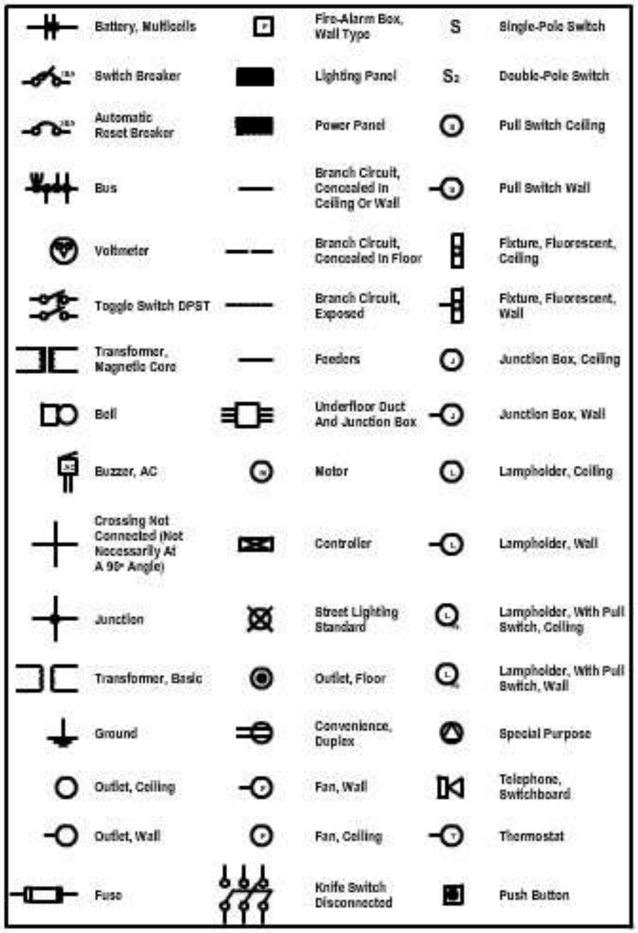

Contours
21
Depression Contour
Stream
Boundary or Right-of-Way Line
Paved Road
Unpaved or Gravel Road
Trail
Walk
Type
Railroad
Abandoned Railroad
Tunnel
Bridge
Box Culvert
Size
Pipe Culvert
Dams
Retaining Wall
Type
Bulkhead
Type
Pier
Type
Fence
Type
Hedge
Canal or Ditch
Canal
Marsh
Woods
Individual Trees
Shoreline
Depth Curve
8


1. TRIM LINE
2. BORDER LINE
3. MAIN OBJECT LINE
4. DIMENSION LINE
2'1
4' 3"
5. EXTENSION LINE
6. EQUIPMENT LINE
7. SYMBOL SECTION LINE
8. BROKEN LINE
9. INVISIBLE LINE
10. CENTER LINE
11. SECTION LINE
A
A
12. STAIR INDICATOR LINE
DOWN
2-R
13. BREAK LINE


Leader, Soil, or Waste (Above Grade)
(Below Grade)
Vent
Cold Water
Hot Water
Hot-Water Return
Drinking Water
Drinking Water Return
Acid Waste
ACID
Compressed Air
A
A
Fire Line
F
F
Gas Line
G
G
Tile Pipe
T
T
Vacuum
V
V


Two Conductor Service
Above Ground
Primary
Secondary
Street Lighting
Underground
Buried Cable
Duct Line
Three Or More Conductors
(No. of cross lines equals No. of conductors)
Incoming lines
Conduit or Grouping of Conductors
Branching of Group of Conductors
(No. indicates No. of conductors in branch)
8
5
3
Ground


Gravel
Earth
Stone
Concrete
Rock
Asphalt


Battery, Multicells
Fire-Alarm Box, Wall Type
Single-Pole Switch
Switch Breaker
Lighting Panel
S2
Double-Pole Switch
Automatic Reset Breaker
Power Panel
Pull Switch Ceiling
Bus
Branch Circuit, Concealed In Ceiling Or Wall
Pull Switch Wall
Voltmeter
Branch Circuit, Concealed In Floor
Fixture, Fluorescent, Ceiling
Toggle Switch DPST
Branch Circuit, Exposed
Fixture, Fluorescent, Wall
Transformer, Magnetic Core
Feeders
Junction Box, Ceiling
Bell
Underfloor Duct And Junction Box
Junction Box, Wall
Buzzer, AC
Motor
Lampholder, Ceiling
Crossing Not Connected (Not Necessarily At A 90° Angle)
Controller
Lampholder, Wall
Junction
Street Lighting Standard
Lampholder, With Pull Switch, Ceiling
Transformer, Basic
Outlet, Floor
Lampholder, With Pull Switch, Wall
Ground
Convenience, Duplex
Special Purpose
Outlet, Ceiling
Fan, Wall
Telephone, Switchboard
Outlet, Wall
Fan, Ceiling
Thermostat
Fuse
Knife Switch Disconnected
Push Button