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GENERAL DRAFTING

DEPARTMENTS OF THE ARMY AND THE AIR FORCE

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AND THE AIR FORCE

WASHINGTON 25, D.C., *29 October 1962*

GENERAL DRAFTING

CHAPTER 1

BASIC DRAFTING EQUIPMENT

1. Purpose

This manual provides information for the instruction of military personnel in general drafting procedures, and for the guidance of military personnel responsible for the supervision of military drafting operations.

2. Scope

a. This manual covers care and use of instruments; line weights and conventions; freehand lettering; geometrical constructions and orthographic projection; third angle projection; selection of views; charts and graphs; working drawings; notes and dimensions. It also covers auxiliary views; isometrics; fasteners—screws, rivets, and welding; detail and assembly drawing; developments and intersections; elements of construction and cartographic drawing; and reproductions.

b. The material contained herein is applicable without modification to both nuclear and nonnuclear warfare.

3. Recommended Changes

Users of this manual are encouraged to submit recommended changes or comments to improve the manual. Comments should be keyed to the specific page, paragraph, and line of the text in which change is recommended. Reasons should be provided for each comment to insure understanding and complete evaluation. Comments should be forwarded direct to Commandant, U. S. Army Engineer School, Fort Belvoir, Va.

4. Language and Tools

Engineering drawing, known also as technical drawing or drafting, has been called the graphic language of the engineer. It has definite rules of usage to insure that it has the same meaning wherever it is used. Anyone who learns the rules can read engineering drawings. Engineering drawing must present information concerning size and shape in a clear and precise manner, so that craftsmen can use building materials to create the finished product specified by the designer. Special tools, or drawing instruments, are used to record this language with the necessary accuracy, and simple techniques have been worked out for their successful use.

5. Basic Equipment

Figure 1 shows the basic drafting equipment which is discussed in the following paragraphs. An experienced draftsman would have use for all of the items shown and for many others not shown.

6. Drawing Board

A drawing board (A, fig. 1) is made with strips of soft wood, usually white pine, glued together edge-to-edge to prevent warping. End cleats are attached to the board with tongue-and-groove joints to prevent further warping and to allow for expansion. For a right-handed draftsman, the outside edge of the left cleat is the working edge of the drawing board. The working edge must be tested periodically for straightness so that work will be accurate.

7. Set of Drawing Instruments

The set of drawing instruments illustrated in M, figure 1, is standard issue and the tools are common to all sets of drawing instruments.

a. Large Dividers. Dividers are used to transfer measurements and to divide straight or curved lines.

b. Large Compass. The large compass is made to draw circles up to 10 inches in diameter. The needle in the pivot leg is reversible, and separate pen and pencil attachments may be inserted in the drawing leg. A lengthening bar is provided for insertion in the drawing leg to permit circles larger than 10 inches to be drawn.

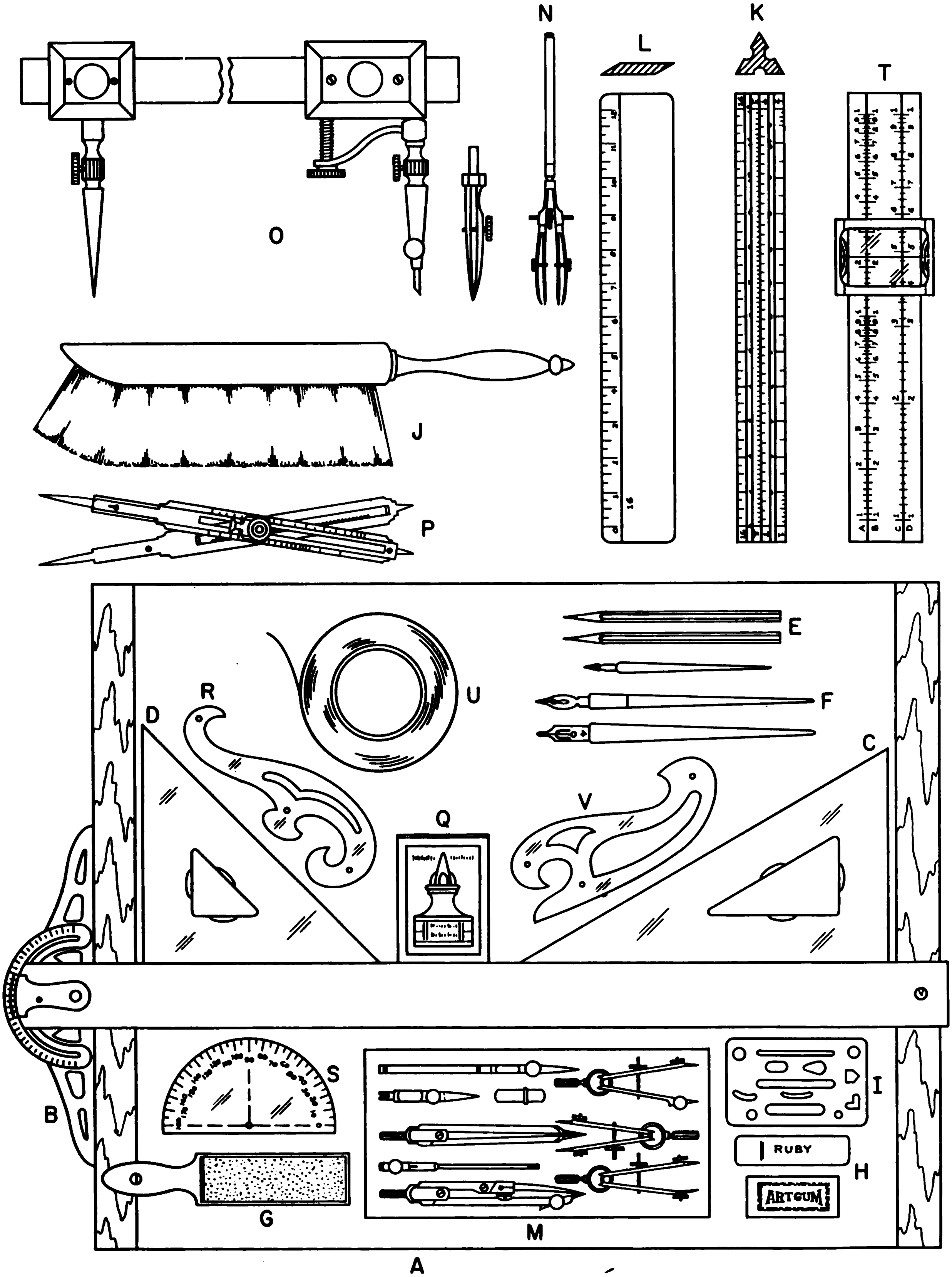


Figure 1. Basic drafting equipment.

c. Bow Instruments. The bow dividers and compasses used as above are capable of more precise adjustments than the larger instruments because of the side adjustment screw arrangement.

d. Ruling Pens. Ruling pens are designed for drawing straight lines and for linking straight lines and noncircular curves. An ink reservoir is formed by the space between the two blades. An adjusting screw controls the thickness of the line by regulating the clearance between the pen nibs. A ruling pen with a larger-than-average ink capacity is called a detail pen. It is used when very long or very heavy ink lines are required.

8. Road Pen

The road pen is a swivel instrument similar to the contour pen, but it has two sets of nibs instead of one (N, fig. 1). Each nib is adjustable for line weight and the two sets can be adjusted with respect to each other. This instrument enables a draftsman to maintain an exact road width by tracing the entire road casing in one motion. This pen is to be used freehand.

9. Railroad Pen

This pen is similar to the road pen (N, fig. 1) except that it has no swivel arrangement. Its purpose is to draw two lines (for example, railroad tracks) in a single motion with the assistance of a straightedge.

10. Beam Compass

A beam compass (O, fig. 1) consists of a long bar with a needlepoint attachment at one end and a pencil or pen attachment at the other. All of the attachments are adjustable, to permit the drawing of large circles easily.

11. T-Square

A T-square consists of a straightedge, called the blade, long enough to span the drawing board and a shorter crosspiece, called the head, attached at one end. The upper edge of the blade and the inner edge of the head are at right angles and are the working edges of the T-square. To prevent warping when not in use, T-squares should be left flat on the drawing board, or should be suspended from the hole in the blade. The working edge of the T-square should never be used as a guide for a knife.

a. T-Square, Protractor Head. The blade is made of stainless steel and is fastened to an adjustable steel head (B, fig. 1). The blade has a vernier corresponding to a protractor fastened to the head so that angles may be set to fractions of a degree.

b. T-Square, Fixed Head. The most common type of T-square has a hardwood blade with transparent celluloid edges attached rigidly to a hardwood head. Care should be taken to avoid marring the celluloid edges.

c. Test for Straightness. A T-square blade can be tested for straightness by drawing a sharp line along the entire length of the working edge, with the T-square in normal position. The square is then turned over so that the underside is exposed and the same line is drawn against the same edge. On a T-square with a plastic edge, the error can often be corrected by first scraping the high spots on the edge with a knife, and then polishing the edge with fine sandpaper. Check the edge regularly by holding it against the surface of a drawing board.

d. Test for Rigidity. Hold the head of the T-square firmly, with the left hand, against the edge of the drawing board in a drawing position. Then test the blade for up-and-down motion or swing. A poor joint can be repaired by regluing the joint and tightening the screws. A protractor-head T-square should be checked for tightness of the adjusting clamp.

12. Triangles

The two triangles are made of transparent plastic and will not discolor, distort, or scratch if handled with reasonable care. One triangle is constructed so as to have angles of 30°, 60°, and 90° (C, fig. 1); the other has two 45° angles and one 90° angle (D, fig. 1). Standard sizes are 10 inches for the longest leg of the 30° x 60° triangle and 8 inches for each leg of the 45° triangle. Triangles should always be kept flat to avoid warping.

a. Testing Triangles. The separate edges may be tested for straightness the same way as the working edge of a T-square blade (par. 11*c*).

The 90° angle can be tested for accuracy by setting the small side of the triangle against the T-square and without moving the T-square, drawing a vertical line along the long edge of the triangle with the hypotenuse of the triangle facing first away from the head and then repeating the process with the hypotenuse facing toward the head of the T-square. When the right angle has been proved correct, accuracy of the 45° angles may be tested. Horizontal and vertical legs of equal length are drawn with the T-square and triangle, after which the hypotenuse is drawn with a straightedge. Using the same T-square, the hypotenuse of the 45° triangle can be checked against the hypotenuse thus constructed. The 60° angle can be checked by drawing a line of specific length with the T-square, and then, with the shorter leg of the 30° by 60° triangle against the T-square, drawing inclined lines from either end of the original line to form a triangle. If the three sides of the triangle thus drawn are not equal, the 60° angle is incorrect.

b. Correcting Triangles. Triangle edges can be corrected by scraping and sanding. Care must be exercised in deciding which portion of a triangle leg to scrape to "true" a faulty angle.

13. Protractor

Protractors are used to measure and set off angles other than those measurable with the draftsmen's triangles. The protractor issued (S, fig. 1) is numbered at 10° intervals. The smallest graduation is one-half of a degree. The scale may be read from either end. In setting off an angle to an existing line, the horizontal line on the protractor is placed against the existing line with the vertical line (called the vertex indicator) at the point from which the angle leg is to be drawn (vertex of the angle). The scale is then used to set off the desired number of degrees.

14. Irregular Curves

Irregular curves (R and V, fig. 1), also known as *French curves*, are used as mechanical guides for drawing curves other than circles or circle arcs. They are made of transparent plastic and their edges represent successive portions of ellipses, parabolas, spirals, and other standard geometric curves.

15. Scales

Because it is not always desirable to show objects to their actual size, dimensions in accurate proportion to the actual dimensions are used. The various scales (figs. 1 and 11) are systematic length ratios that enable draftsmen to lay out proportional dimensions quickly, easily, and accurately. The scale selected may present a final drawing that is smaller or larger than the actual object, depending on the need for clarity.

16. Erasing Equipment

a. Erasers. The oblong, beveled, red rubber eraser (H, fig. 1) should be used for general erasing of both pencil and ink lines. A gum eraser (H, fig. 1) should be used when it is desired to remove smudges from a drawing without affecting existing work. A steel arrowhead or knife eraser should be used only as a last resort for removing small segments of inked lines because it is almost certain to damge the drawing sheet.

b. Erasing Shield. The erasing shield is a small plate of thin spring steel (I, fig. 1) that has slots of various shapes stamped out, allowing unwanted lines to be removed while leaving other work untouched.

c. Dustbrush. A draftsman's dustbrush (J, fig. 1) is a soft-bristled, or "foxtail", brush used for keeping his drawing sheet free of eraser debris. The brush should be kept clean and dry and be used only for its intended purpose.

17. Drawing Pencils

a. Drawing pencils (E, fig. 1) are made of graphite encased in wood, shaped hexagonally, marked according to hardness, and are usually without erasers. Care should be taken not to cut off the hardness mark by sharpening the wrong end. The range is from 6B (very soft and black) through 5B, 4B, 3B, 2B, B, HB and F to H, 2H, 3H, 4H, 5H, 6H, 7H, 8H, and 9H, which is the hardest.

b. A 6H or 5H pencil may be used for a penciled layout on detail paper of good texture and a 4H, 3H, or 2H pencil may be used to blacken these lines in. The 3H to H pencil is used for finished pencil drawings or tracings on vellum.

The F pencil is generally used for technical sketching while the H to HB are used for lettering. In every case the pencil chosen must be hard enough not to blur or smudge, but not so hard as to cut grooves in the paper under reasonable pressure.

18. Pencil Sharpeners

Drawing pencils are sharpened with a pocket knife or with various special mechanical sharpeners. The standard pencil pointer is a flat sandpaper pad with a wooden handle (G, fig. 1). Correct pencil sharpening technique is described in paragraph 28.

19. Freehand Inking Pens

Freehand inking, or lettering, pens (F, fig. 1) are used mainly for lettering and drawing curve segments too small for the convenient use of a compass or irregular curve. Except for the Barch-Payzant, which is a complete unit, pens are used in standard holders. Pens designed for heavy lines have an ink reservoir.

20. Paper Fasteners

The preferred method of fastening a drawing sheet to the drawing board is with drafting tape (U, fig. 1). Thumbtacks or wire staples inserted with a stapling machine may be used when drafting tape is not available, but they shorten the usable life of the drawing board by punching holes in it.

21. Slide Rule

A slide rule (T, fig. 1) is a portable calculating device based on the principle of logarithmic addition and subtraction. Computations are an important part of engineering drawing and a draftsman who is proficient in the use of a slide rule finds it an esesntial aid in rapid calculation.

22. Proportional Dividers

Proportional dividers (P, fig. 1) consist of two legs pivoted in such a way that the distance between the legs at one end is in a specific proportion to the distance between the legs at the other end. To set the legs into the desired relationship, use the adjustable pivot to lock the scale on either leg. Proportional dividers can be used to enlarges or reduce straight lines, including the diameter and radius of a circle, or to divide straight lines and circles into a given number of equal parts. Separate scales give linear and circular settings.

23. Other Items

Certain other items may or may not be available to the draftsman through local purchase or supply, but may be used by the draftsman if available. They include, but are not limited to: isometric-orthographic cross section paper, hatching pens, mapping pens, pantographs, prickers, horn centers (for use with beam compasses), tri-tractor (triangle and protractor combined), templates, mechanical pencils, scale guards (2, fig. 11), map measures, parallel rules, curves of all types, paper cutters, tack lifters, oilstones, drycleaning pads and powder, pencil pointers, electric erasing machines, draftsman's pencil sharpeners, and many more.

24. Materials

a. Drawing Paper. Drawing paper is usually made of rag-content papers which provide good erasing qualities and can stand frequent handling. White drawing papers are generally used for finished drawings, maps, and charts, or drawings for photographic reproduction; while cream colored (buff) paper is more suitable for construction or working drawings because it does not soil too quickly and causes less eyestrain. Preferably, papers should have a medium grain, or tooth, to give a sharp, clean pencil line. Drawing paper comes in sheets or rolls. In general, sheet sizes are proportional to the standard letter sheet sizes established by the American Standards Association (ASA). Standard sheet sizes are discussed in paragraph 39.

b. Tracing Paper. Tracing paper is thin transparent paper which permits tracing of drawings, in either pencil or ink, and from which blueprints or ammonia process prints can be made. It is common practice to prepare original penciled drawings on tracing paper and to make blueprint reproductions directly from these drawings. Tracing papers come in white or tinted colors (mostly blue) and are available in sheets or rolls. Like drawing paper, the surface should be relatively smooth and unglazed, with erasing quality an important factor. It comes in widths from 24 to 57 inches and in lengths of 20 and 50 yards.

c. *Tracing Cloth.* Tracing cloth is woven of thin, transparent cotton or linen and is coated with a special starch or plastic. Drawings are made on the unglazed surface with pencil or ink. Tracing cloth will stand more handling than tracing paper and will not discolor with age; therefore, it should be used when more permanent drawings are desired. It is generally available in rolls only.

d. *Cross Section Paper.* Cross section paper is printed in many different grid sizes; but it is usually printed in green or red squares with 100 squares (10 by 10) or 400 squares (20 by 20) to the square inch and is available in sheets or rolls. Cross section paper is used to plot statistical data, graphs, and road elevations taken transversely to the centerline section of the road.

e. *Profile Paper.* Plan-profile paper is transparent, and the lower half of the paper is printed in orange squares of 4 divisions horizontally by 20 divisions vertically to the square inch. The upper half of the sheet is blank and is used for drawing a plan view, as of a road seen from the air. The portion printed with orange squares is used to plot the elevation of the road along its centerline. Standard sheet sizes are 23 by 36 inches; special sizes and profile paper in rolls are obtainable on special order in quantity.

f. *Drawing Ink.* A standard ink bottle holder provides a stable, weighted base for the bottle plus a lever-operated filling attachment that

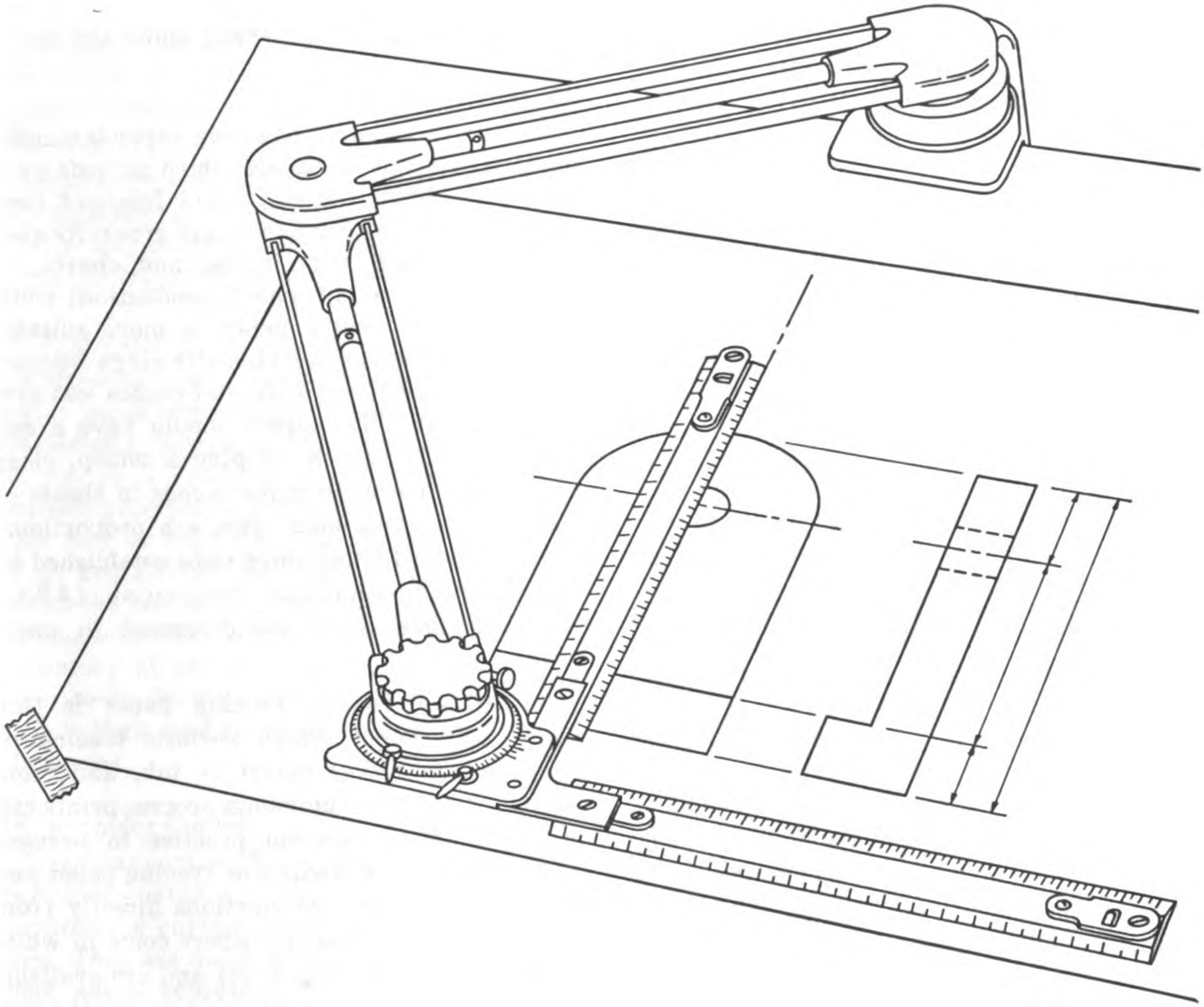


Figure 2. Drafting machine.

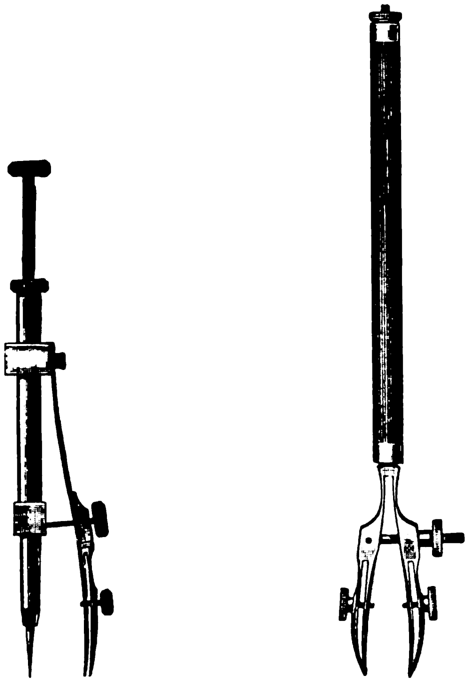


Figure 3. Drop compass and contour pen.

makes pen filling quicker and cleaner. The stopper of a drawing ink bottle (Q, fig. 1) has a quil dropper attachment that is used to fill drawing pens. Ink that has thickened by age or evaporation can be thinned by adding a few drops of a solution of 4 parts aqua ammonia to 1 part distilled water. Colored drawing ink is available for preparing graphs and charts.

25. Drafting Machine

A drafting machine (fig. 2) combines the functions of the T-square and triangles with that of a protractor. Drafting machines are not to be considered basic drafting equipment but are available for issue with or without scales or straightedges and must be requisitioned as required.

26. Drop Compass

The drop compass (fig. 3) is designed for the drawing of small accurate circles. The center rod contains the needlepoint and remains stationary while the tube carrying the pen or pencil revolves around it.

27. Contour Pen

The contour pen (or curve pen) (fig. 3) is an instrument similar to a ruling pen with curved nibs and a swiveling barrel. It is used for drawing irregularly curved lines such as contour lines. The swivel barrel allows the draftsman to change direction of movement with a slight lateral pressure. The contour pen is used freehand and never in conjunction with a straightedge or curve. This pen is held almost perpendicular to the paper, with only a slight inclination in the direction of the stroke.

28. Preparations For Drawing

Drawing equipment should be arranged in an orderly fashion on a flat surface adjacent to the drawing board. Windows should face north or south to avoid the glare of direct sunlight. Drawing tables should be placed so that light comes from the left. The table height should be from 36 to 40 inches above floor level, and the drawing surface should be adjusted at a slope of 1 to 8.

a. Fastening Drawing Sheet. Place left edge of the drawing sheet approximately 1 inch from the left edge of the board. The lower edge of the drawing sheet should be approximately 3 inches from the bottom of the drawing board. Prepare three short lengths of drafting tape and, with the T-square held firmly against the left edge of the drawing board, line up the top edge of the drawing sheet with the working edge of the T-square. Fasten the top of the sheet by placing the drafting tape diagonally—first across the upper left-hand corner, then along the middle upper edge, then across the upper right-hand corner. Using three more strips of drafting tape, fasten the bottom edge of the sheet in the same manner as the top edge.

b. Sharpening Pencil. To sharpen a pencil, cut the wood away from the unlettered end (①, fig. 4) with a draftsman's pencil sharpener or a penknife. The lettered end should be left intact so that the grade of pencil can always be identified. The cut should be started about 1½ inches from the end, leaving a half-inch of lead exposed. To produce a conical or needle point (②, fig. 4), which is best for general use, rotate the pencil between the fingers at the same time as the exposed lead is rubbed back and forth across the full length of the sandpaper pad (③, fig. 4). The resulting needlepoint should be

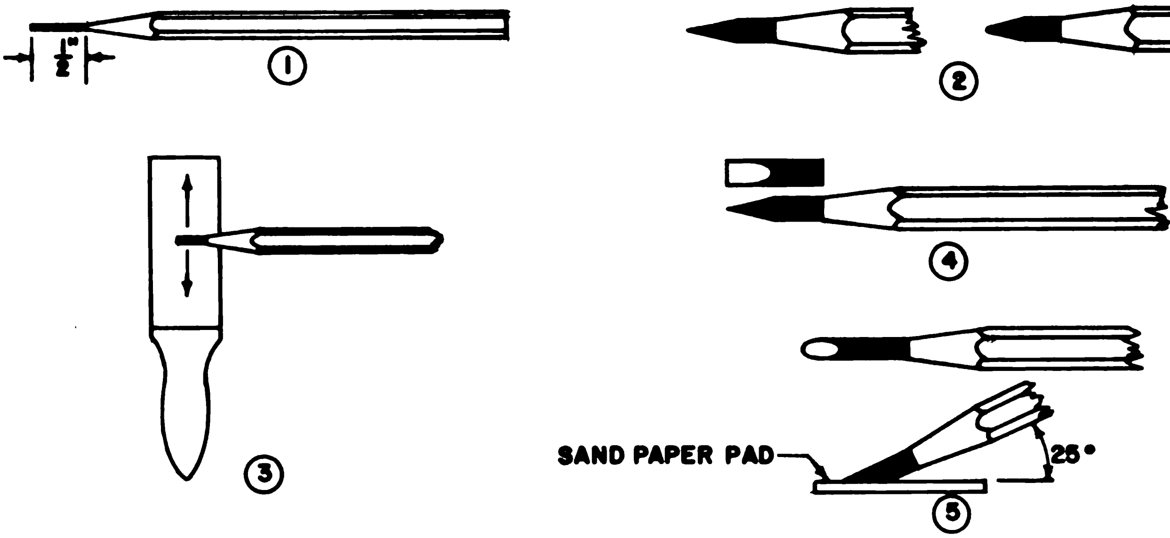


Figure 4. Pencil points.

dulled slightly by rubbing it lightly severa times across a piece of scrap paper. Never sharpen a pencil over the drawing sheet. A wedge point (④, fig. 4) will aid an experienced draftsman in the extensive drawing of straight lines. This point is produced by sharpening a pencil to the conical point just described, then flattening both sides on the sandpaper pad. For an elliptical point, hold the pencil firmly with thumb and fingers and cut lead on sandpaper pad by a "back and forth" motion, keeping the pencil at an angle of about 25° to the pad. Continue until flat ellipse is formed as shown in sketch (⑤, fig. 4). Frequently of sharpening is comparable to the frequency of inking an ordinary writing pen. A good draftsman never uses a dull pencil.

CHAPTER 2

THE MEANING OF LINES

Section I. THE GEOMETRY OF LINES

29. Properties of Lines

Lines in a technical drawing have a dual meaning: they possess both geometric and graphic properties simultaneously, but the two properties are independent of each other.

a. Geometric Properties. Some of the geometric properties of lines are those which define the shape of a line, its location on a drawing sheet, and its relationship to other lines. It is customary to regard the instrumental drawing of geometric lines as line construction. The basic tool for line construction since early Greek times have been the pencil, straightedge, and compass. Constructions performed with these instruments are still used to demonstrate the geometric basis of technical drawing (ch. 5). With the use of the additional instruments described in chapter 1, a modern draftsman can increase his speed and accuracy in line construction.

b. Graphic Properties. Apart from their construction, the lines of a technical drawing may represent a visible edge, hidden edge, centerline, or some other feature of the object being described. The representation of these features depends solely on the width and character of the lines used. Line width and character, or appearance, are graphic properties. To guarantee that a particular feature will be represented by only one particular line width and character combination, standards known as line conventions (pars. 44 and 45) have been established and adopted. The conventions correspond to those used in civilian drafting and cover not only the lines used to represent various features of real objects but auxiliary lines such as leaders and dimension lines (par. 46).

30. Basic Geometrical Definitions

a. A straight line is the shortest distance between two points. When not specified otherwise, the word line means a straight line.

b. A curved line is a line no part of which is straight.

c. A segment is any part of a divided line.

d. A plane is a surface such that a straight line joining any two of its points will lie wholly on that surface. It should be noted that the surface of a flat sheet of drawing paper is a plane.

e. Two lines are perpendicular to each other if they form right angles at their intersection.

f. Vertical is the position described by a string hanging in space with a weight attached to its lower end. Vertical is a direction established by gravity and should not be confused with perpendicular.

g. The perpendicular to a vertical line is a *horizontal* line.

Section II. CONSTRUCTION OF STRAIGHT LINES

31. Horizontal Lines

The draftsman's horizontal line is constructed by drawing from left to right along the working edge of a T-square. This working edge, when true, is perpendicular to the working edge of the drawing board (B, fig. 5). When drawing horiozntal lines, the working edge of the T-square head should be in firm contact with the working edge of the drawing board. The pencil should be inclined to the right at an angle of

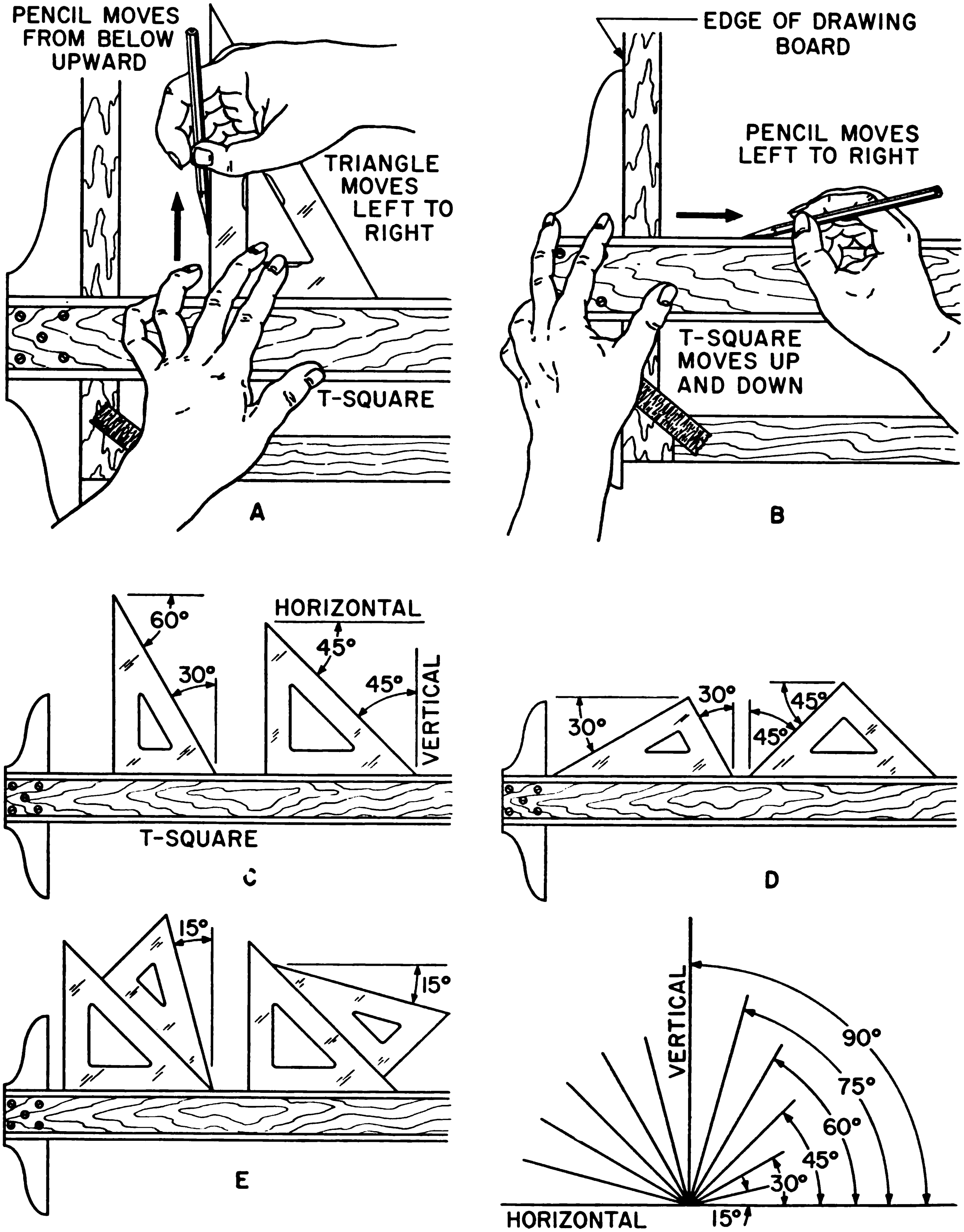


Figure 5. Line formation.

about 60°, with the point close to the junction of the working edge and the paper. The pencil is held lightly and, if sharpened with a conical point, is rotated slowly while the line is being drawn to achieve a uniform line width and preserve the shape of the point. Normally, when a series of horizontal lines is being drawn, the sequence of drawing is from the top down.

32. Vertical Lines

Vertical lines are produced parallel to the working edge of the drawing board by using triangles in combination with a T-square. One leg of a triangle is placed against the working edge of the blade and the other faces the working edge of the board to prevent the draftsman from casting a shadow over his work. Lines are drawn from the bottom up (A fig. 5). The pencil is inclined toward the top of the working sheet at an angle of approximately 60°, with the point as close as possible to the junction of triangle and drawing paper. Sequence in drawing a series of vertical lines is from left to right. At no time should the lower edge of the T-square blade be used as a base for triangles.

33. Inclined Lines

The direction or angle of inclination of an inclined line on a drawing sheet is measured by reference to the baseline from which it is drawn. Inclined lines at standard angles are constructed with the T-square as a base for triangles used either singly or in combination (C and D, fig. 5). Used in combination with the T-square as a base, the triangles serve as guides for producing lines at intervals of 15° (E, fig. 5). Used singly, the 45° triangle will divide a circle into 8 equal parts; the 30° x 60° triangle will divide a circle into 12 equal parts. For drawing lines at angles other than those described above, the protractor is used (par. 13). Either triangle may be used as a straightedge to connect the two points indicating the vertex and angle of inclination.

34. Parallel Lines

To draw a line parallel to a given line, adjust the hypotenuse of a triangle in combination with a straightedge (T-square or triangle) to the given line; then, holding the straightedge firmly in position, slip the triangle to the desired position and draw the parallel line along the hypotenuse.

35. Perpendicular Lines

To construct a line perpendicular to an existing line, use the triangle and straightedge in combination with the hypotenuse of the triangle resting against the upper edge of the straightedge. Adjust one leg of the triangle to a given line. Then the triangle is slid along the supporting straightedge to the desired position. The line is drawn along the leg, perpendicular to the leg that was adjusted to the given line.

Section III. CONSTRUCTION OF CURVED LINES

36. Use of Compass

When drawing circles and arcs in general drafting work, it is important that the lines produced with the compass be of the same weight as those produced with the pencil. For this reason, the lead in the compass should be several grades softer than that of the pencil. The lead is sharpened to a bevel point, as shown in 1, figure 6, and the top is rounded slightly; the heel of the bevel is begun approximately one-fourth inch from the tip of the lead. The needle is inserted with the shoulder point out and permanently adjusted to the pen attachment, as in 2, figure 6. The pencil leg, when used, should be slightly shorter and must be readjusted after each sharpening. To draw circles or arcs, locate the center first by lightly drawing two perpendicular lines intersecting at the desired point, and mark off the radius on the segment extending to the right of the center point. With the needlepoint located accurately, open the compass to the radius mark. The circle is swung in a clockwise direction, beginning and ending at the lowest point with the compass inclined at about 60° in the direction of motion. When drawing concentric circles, draw the smallest circles first. Bow instruments are roughly adjusted by compressing the legs between the thumb and forefinger of the left hand and spinning the nut with the fingers of the right hand; this decreases wear on the threads. Final adjustments are made with the thumb and fore-

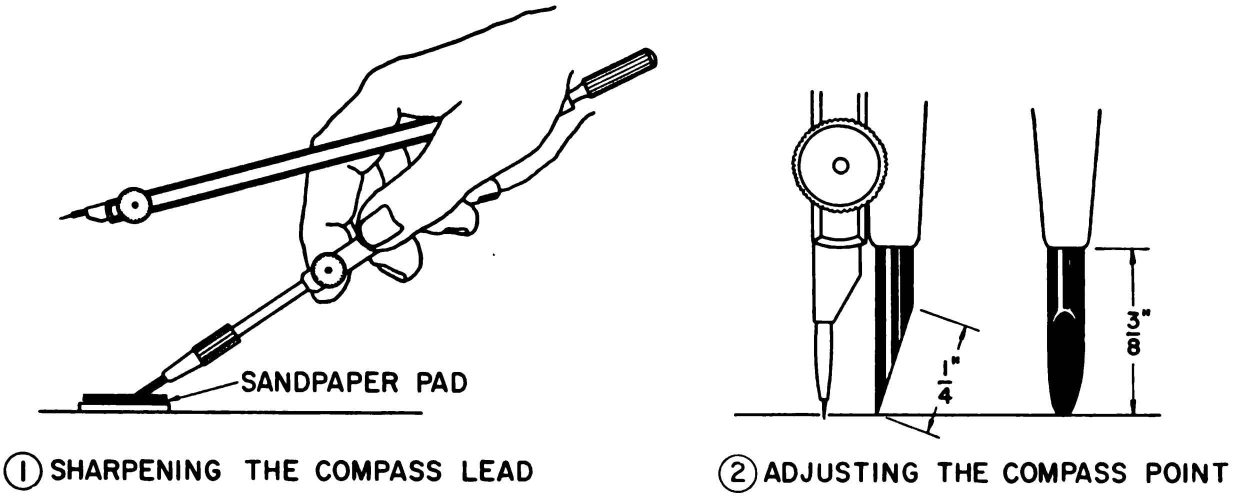


Figure 6. Adjusting a compass.

finger of the right hand when the instrument is in position.

37. Use of Irregular Curves

a. Irregular curves, known as French curves (fig. 7), are used as mechanical guides for drawing curves other than circles or circular arcs. They are made of transparent plastic and their edges represent successive portions of ellipses, parabolas, spirals, and other geometric curves.

b. A uniform and accurate curved line can be produced when two or more points are plotted along each segment of the entire curved line. Figure 7 shows how a smooth line is drawn through a series of plotted points. The *French curve:*

at (a) matches points 1, 2, 3, and 4. Draw line from 1 to 3 only (not to 4).

at (b) matches points 3 to beyond 4. Draw line from 3 to 4 only (not to 5).

at (c) matches points 4, 5, and 6. Draw line from 4 to 6 (just short of 6).

at (d) matches points short of 6 to beyond 7. Draw line from 6 to 7.

at (e) matches points short of 7 to beyond 9. Draw line from 7 to 9.

at (f) matches points short of 9 to beyond 11. Draw line from 9 to 11.

Notice how the French curve is turned over and reversed to find portions which fit the points on the line with increasing or decreasing changes in curvature.

c. Like the triangles, the French curve should always be kept flat to avoid warpage.

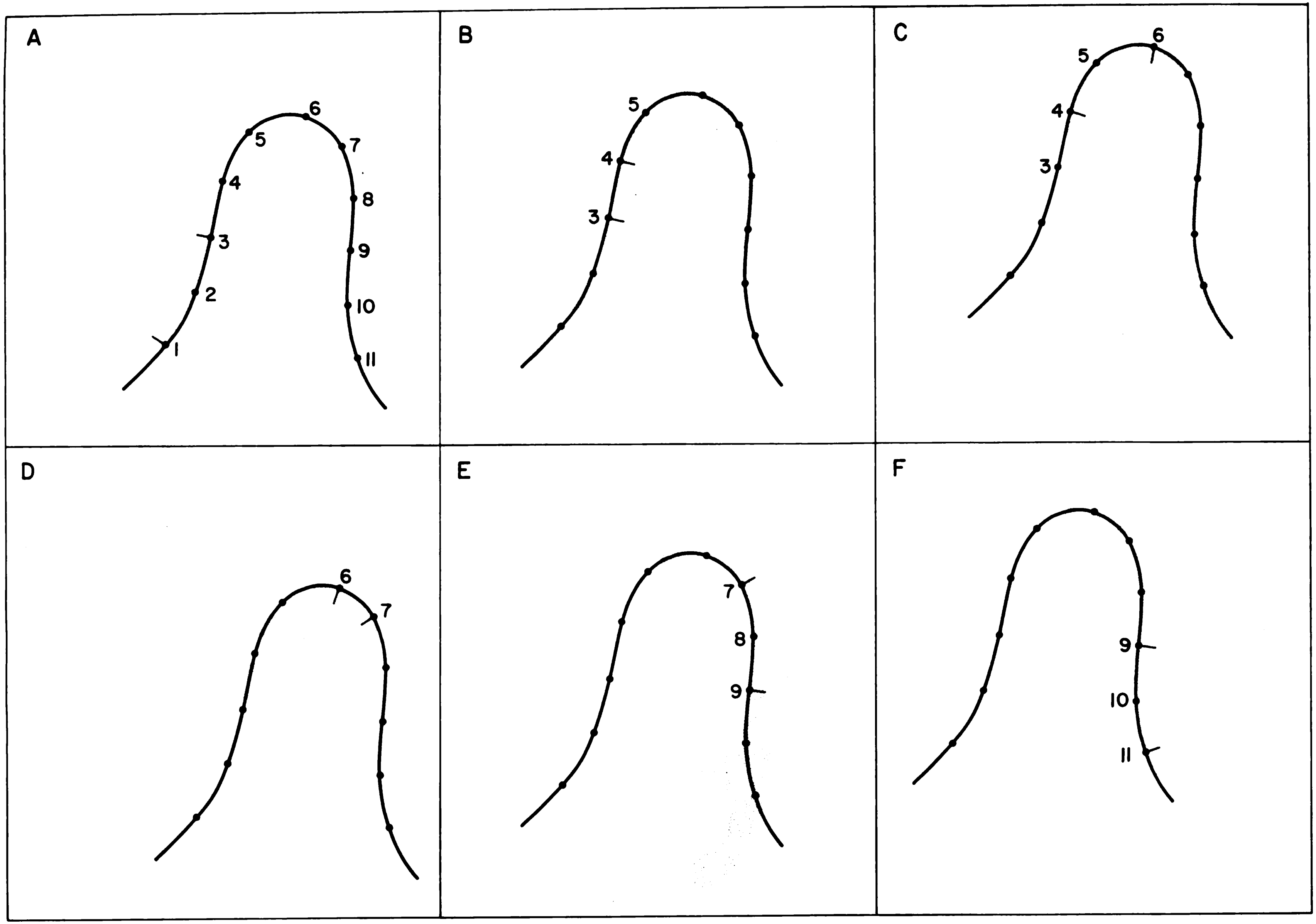


Figure 7. Use of the irregular curve.

38. Drawing Formats

A drawing must not only provide information about the size and shape of the object being represented but must provide information that enables the drawing to be identified, processed, and filed methodically (fig. 8). The systematic arrangement of sheet space to provide a consistent location for this information is known as the format of a drawing. Sizes and formats for military drawings are arranged in accordance with certain standards.

39. Sheet Sizes

Flat size refers to drawings that usually have a printed format and that, because of their relatively small size, can be stored flat. Roll size refers to drawings that, because of their length, are filed in rolls and usually do not have a printed format. To provide protection, a 4-inch margin may be added to the right end of minimum lengths specified for roll sizes. When practicable, the maximum length of roll sizes should not exceed 144 inches. Finished sheet size refers to dimensions between trim lines. Sheet width is measured parallel to the working edge of the drawing board; length is measured perpendicularly to the working edge of the drawing board. Further information on drawing size can be found in table I and MIL–STD–2B.

Table I. Finished Format Sizes (Inches)

Flat sizes				Roll sizes				
Size	X (Width)	Y (Length)	Z (Margin)	Size	X (Width)	Y Min (Length)	Y Max (Length)	Z (Margin)
(A) Horiz	8½	11	¼ and ⅜*	G	11	42	144	⅜
(A) Vert	11	8½	¼ and ⅜*	H	28	48	144	½
B	11	17	⅜	J	34	48	144	½
C	17	22	½	K	40	48	144	½
D	22	34	½					
E	34	44	½					
F	28	40	½					

* Horizontal margin ⅜ inch; vertical margin ¼ inch.

40. Sheet Layout

Sheets of drawing or tracing paper are cut slightly larger than their required finished sizes and are fastened to the drawing board as described in paragraph 28*a*. Using a hard (6H) pencil and a T-square, draw a horizontal trim line near the lower edge of the paper, then draw a vertical trim line near the left edge of the paper with a T-square, pencil, and triangle as described in paragraph 32. Dimensions establishing the finished length of the sheet (distance between vertical trim lines) and the location of the vertical borderlines are marked off on the horizontal trim line. The full-size scale is used when laying off a series of measurements along a line. Dimensions establishing the finished width of the sheet (distance between horizontal trim lines) and the location of the horizontal borderlines, are marked off on the vertical trim line. Dimensions may be scaled along the borderlines. Borderlines are given the required weight (fig. 8) when the drawing has been completed. After the completed drawing has been removed from the board, it is cut to its finished size along the trim lines.

41. Basic Formats

Military drawings are classified as construction or production drawings, depending on the method of manufacture of the object or assembly represented on the drawing or set of drawings. The format of each type is arranged differently, although sheet and margin sizes are common to both.

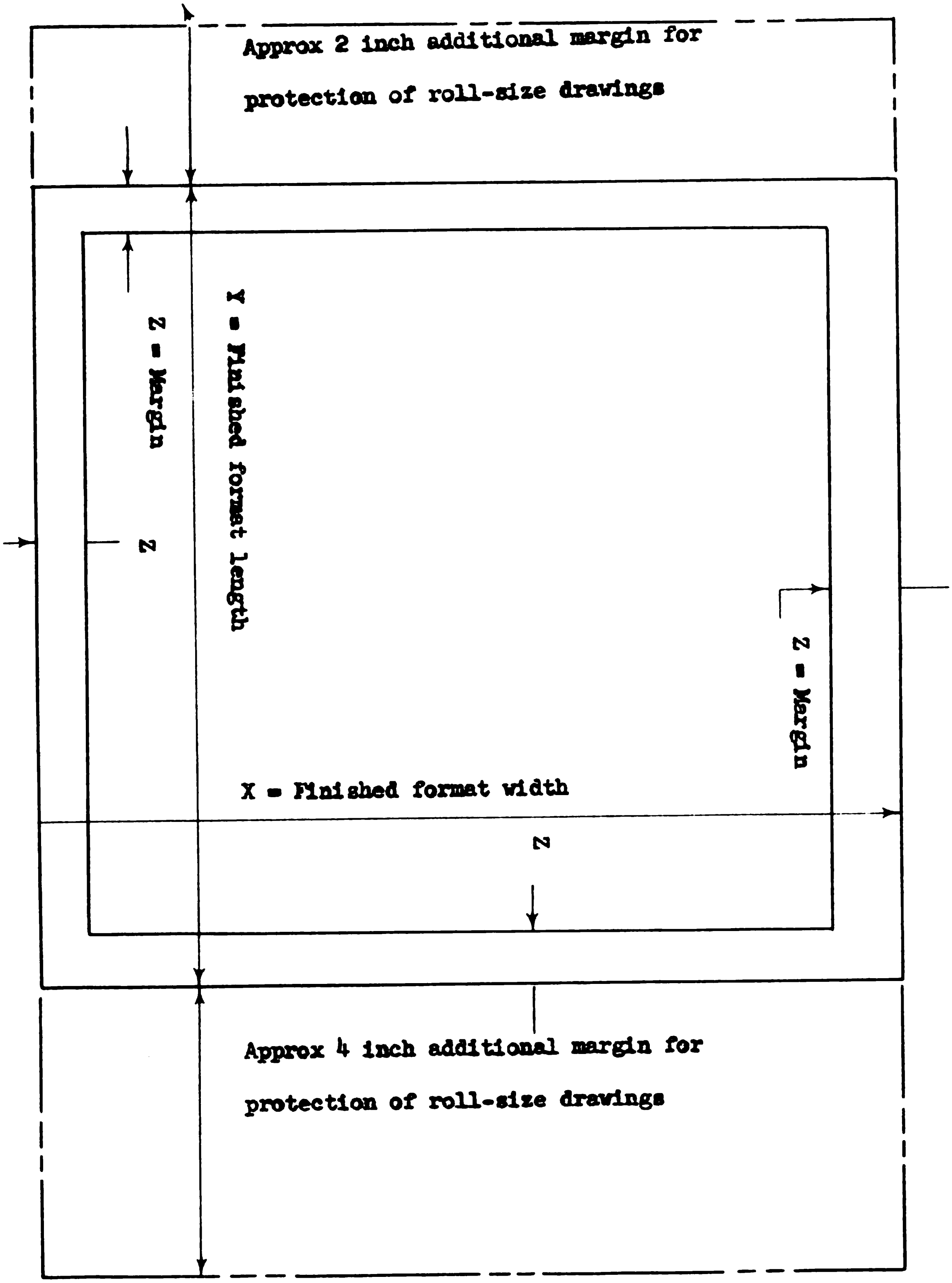
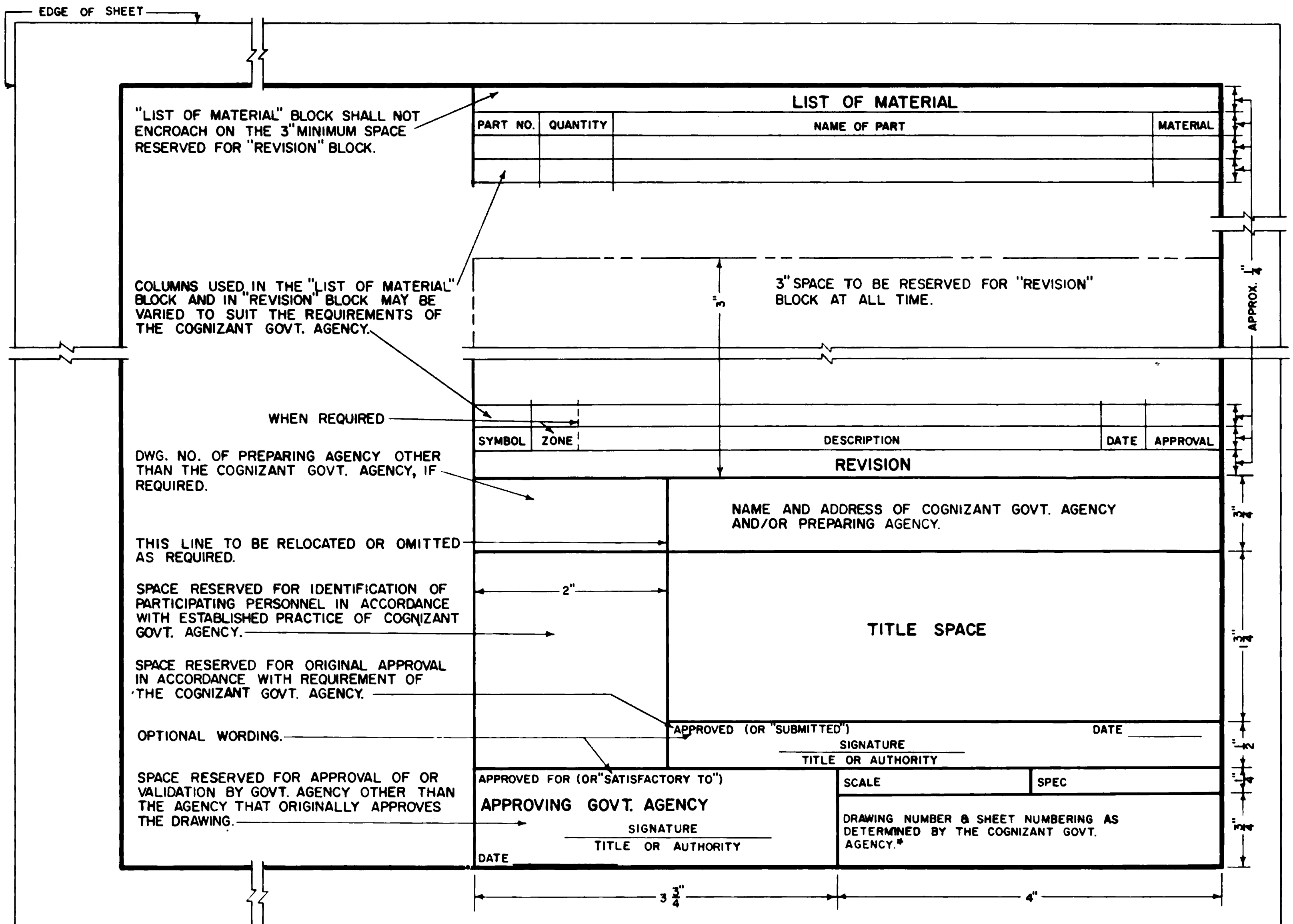


Table I. Finished Format Sizes (Inches)—Continued



* COGNIZANT GOVENMENT AGENCY IS THE AGENCY HAVING COGNIZANT OVER THE PREPARATION OF THE DRAWING, WHETHER PREPARED BY IT OR BY ANOTHER PREPARING AGENCY UNDER ITS DIRECTION.

Figure 8. Format for drawings.

42. Construction Drawings

Construction drawings are drawings developed or used in conjunction with, to illustrate the design of structures or other constructions and the services, utilities, approaches, or any other features involved. Maps (except those with construction drawings), reports, sketches, presentation drawings, or renderings are not considered to be construction drawings within the meaning of this standard. The basic construction drawing format consists of the margin, the title block with its various subdivisions, the revision block, and the block containing the list of material. Figure 8 shows the layout and dimensions of the typical construction drawing format. Table I gives margin requirements between trim and border lines. The following modifications should be applied to the data presented in figure 8:

a. Drawing Number. The drawing number is assigned by the cognizant Government agency.

b. Approval by Government Agency. The use of "Approved For" or "Satisfactory To" is optional in the block requiring the signature of a Government agency. Space should be reserved in this block, to the left of the signature line, for approval or validation by Government activities other than the agency that originally approves the plan.

c. Approval by Individual Authority. The use of "Approved" or "Submitted" is optional.

d. Revision Block. When there is no list of material, the revision block may be placed in the upper right-hand corner and extended downward; headings and column widths can be changed to suit requirements.

e. List of Material. Headings and column widths in the list of material may be changed to suit the requirements of the agency preparing the drawing. Additional columns may be listed as required.

f. Patent Notice, Security Classification. If patent has been requested, a patent notice block should be included. If the drawing is classified, a security classification block must be included. (See MIL–STD–2B).

43. Production Drawings

Production drawings represent those types of equipment or articles that are produced in quantity, or that are of such design as to permit such production. The basic format consists of the margin (table I), title block, and revision block.

a. Title Block. The title block is located in the lower right-hand corner of the drawing. It contains the number that identifies the drawing; the drawing number, located in a block in the lower right-hand corner of the title block; and certain information common to all drawings, including the name and address of the Government agency preparing the drawing, the title of the drawing scale, drafting record, authentication, and date.

b. Line Weights and Lettering. All lettering and numbering that ordinarily would be printed on drawing forms to indicate items such as zoning, column headings, and space identification, may be of any appropriate size. Line weights and all other lettering are the same as specified for construction drawing formats.

c. Additional Specifications. Further specifications concerning size, location, and use of the blocks described above, as well as data on supplementary blocks, security classification, and patent notices, can be obtained from MIL–STD–2B, Engineering Drawing Sizes and Formats.

44. Line Conventions

Line conventions are symbols that furnish a means of representing or describing some basic aspect of a real object. The meaning of the symbols is determined by definition and is expressed by a combination of line weight and characteristic appearance, as presented in MIL–STD–1A, General Drawing Practice.

45. Types of Lines

a. Ink Lines. Ink lines shall be opaque and of uniform width for each type of line. Three widths of lines will be used—thin, medium, and thick, as shown in figure 9, with their widths in proportions of 1:2:4. The actual width of each type of line will be governed by the size and style of the drawing; relative widths of the lines will approximate those shown in figure 9.

b. Pencil Lines. Pencil lines will be opaque and of uniform width throughout their length. The line widths specified above do not apply to pencil lines; however, the thick lines used for

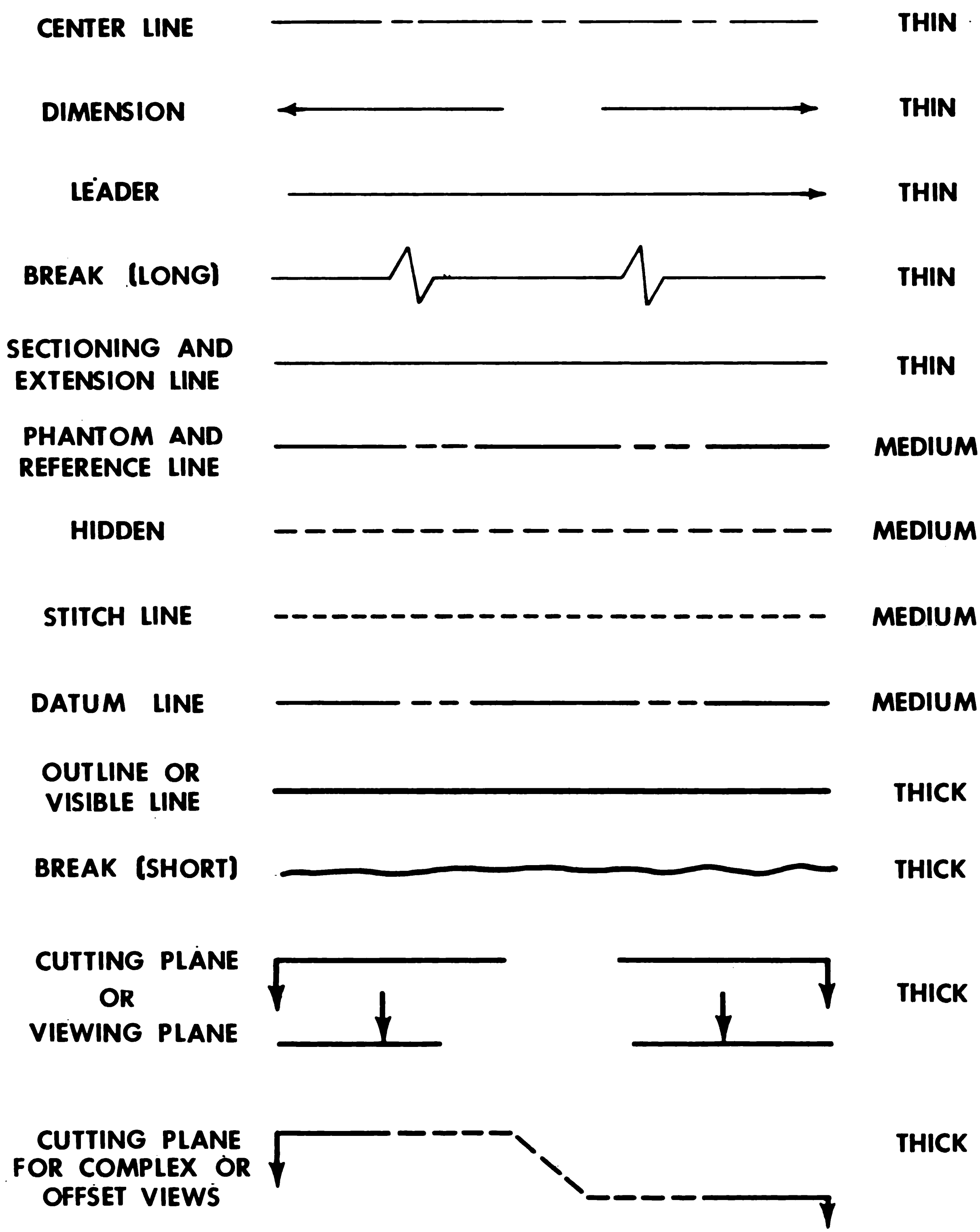


Figure 9. Line characteristics and conventions.

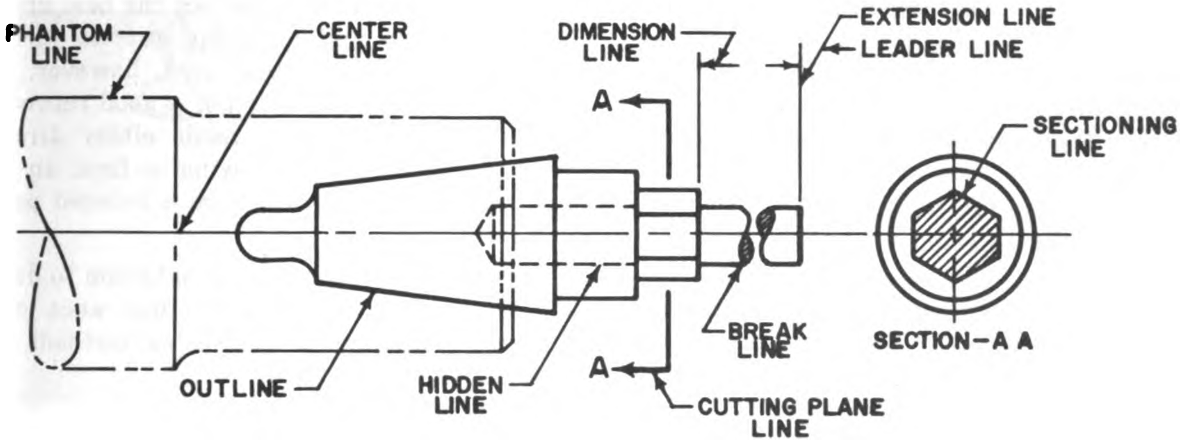


Figure 10. Line conventions.

outlines and other visible lines will be sufficiently prominent to differentiate them immediately from lines used for other purposes. Hidden, sectioning, center, phantom, extension, dimension, and leader lines will be thinner than outlines. In selecting the widths of pencil lines, consideration will be given to the medium of reproduction involved to insure proper reproduction and reduction of the thinner lines.

46. Line Characteristics

The line characteristics described in *a* through *l* below will be used for all drawings other than diagrams, such as schematic. Figures 9 and 10 illustrate the proper presentation and use of line conventions.

a. Centerlines. Centerlines are composed of long and short dashes, alternately and evenly spaced with a long dash at each end, and at intersections the short dashes intersect. Very short centerlines (fig. 10) may be broken if there is no confusion with other lines. Centerlines also are used to indicate the travel of a center.

b. Dimension Lines. Dimension lines will terminate in arrowheads at each end. They will be unbroken on construction drawings and will be broken on production drawings only where space is required for the dimension. The proper method of showing dimensions and tolerance will be presented in chapter 7.

c. Leader Lines. Leader lines are used to indicate a part or portion to which a number, note, or other reference applies and will terminate in an arrowhead or a dot. Arrowheads should always terminate at a line; dots should be within the outline of an object. Leaders should terminate at any suitable portion of the note, reference, or dimension. Penetration of leaders is permissible when necessary for clarity.

d. Break Lines. Short breaks will be indicated by solid, freehand lines. For long breaks (fig. 9), full, ruled lines with freehand zigzags will be used. Shafts, rods, and tubes that have a portion of their lengths broken out will have the ends of the break drawn as indicated (fig. 10).

e. Phantom Lines. Phantom lines will be used to indicate the alternate position of delineated parts of the item, repeated detail, or the relative position of an absent part. They will be composed of alternating one long and two short dashes evenly spaced with a long dash at each end.

f. Sectioning Lines. Sectioning lines will be used to indicate the exposed surfaces of an object in a sectional view. They are generally full thin lines but may vary with the kind of material shown.

g. Extension Lines. Extension lines will be used to indicate the extent of a dimension and will not touch the outline.

h. Hidden Lines. Hidden lines will consist of short dashes evenly spaced and will be used to show the hidden features of a part. They will always begin with a dash in contact with the line from which they start, except when such a dash would form the continuation of a full line. Dashes will touch at corners and arcs will start with dashes at the tangent points.

i. Stitch Lines. Stitch lines (fig. 9) will be used to indicate the stitching or sewing lines on an article. They will consist of a series of very short dashes, approximately half the length of the dash of hidden lines, evenly spaced. Long lines of stitching may be indicated by a series of stitch lines connected by phantom lines.

j. Outlines or Visible Lines. The outline, or visible line, will be used for all lines in the drawing representing visible lines on the object.

k. Datum Lines. Datum lines (fig. 9) will be used to indicate the position of a datum plane and will consist of one long dash and two short dashes evenly spaced. Application of datum planes is covered in chapter 7.

l. Cutting-plane and Viewing-plane Lines. Cutting-plane lines will be used to indicate a plane in which a section is taken. Viewing-plane lines (fig. 10) will be used to indicate the plane from which a surface is viewed.

47. Reading Line Conventions

a. Uniformity. A draftsman must always be aware that he is drawing line conventions for others to read. Their understanding of the meaning of line symbols is based on the definitions in paragraph 46 and illustrations (figs. 9 and 10). Line conventions will conform to th specifications so that only one interpretation is possible. Specific notes must identify and st uctural or mechanical symbolism which requires heavier than standard line weights, for example, steel beam centerlines.

b. Reproduction. Copies of original drawings prepared by draftsmen are produced for distribution to the various mechanics and supervisors responsible for the manufacture of the part or assembly represented. Various reproduction processes are used, but the best known are blueprints and ammonia process prints. Regardless of the process used, however, fine pencil drawing is the basis of a good reproduction. Reproductions are made either directly from a finished pencil drawing or from an inking or ink tracing made from a finished pencil drawing.

c. General Appearance. In addition to drawing technique, the general appearance of a drawing is influenced by erasing methods and cleanliness.

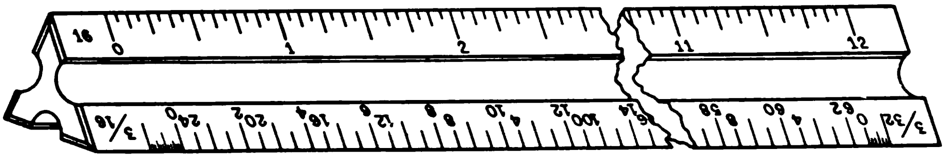
(1) *Erasing.* The red rubber eraser should be used in combination with an erasing shield to avoid wrinkling the drawing sheet. A hard surface beneath the area being erased also is an aid; a triangle may be slipped beneath the drawing sheet for this. Grooves remaining in the drawing sheet after pencil lines have been erased can be reduced by smoothing the area with the thumbnail. Light pencil lines can be removed from tracing cloth by rubbing them gently with a cloth dipped in benzine or gasoline.

(2) *Cleanliness.* Graphite from pencils, pencil lines, or the flint-paper pointer are the principal causes of smudged drawings. In addition to following the pencil sharpening procedure presented in paragraph 28*b*, a draftsman should clean the working edges of his triangles and T-square frequently with a gum eraser or soap and water. All instruments, particularly pens, must be put away clean. Hands must be kept clean and dry. When performing freehand work, a clean sheet of paper should be used to prevent contact between hands and pencil lines. Sliding the T-square and triangles across already penciled lines should be kept to a minimum.

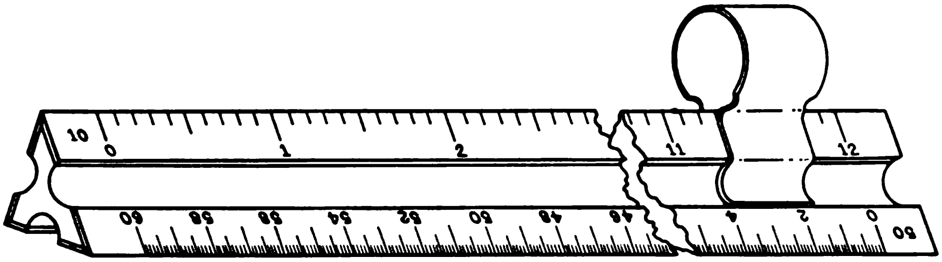
Section V. USE OF SCALES

48. Scale Drawings

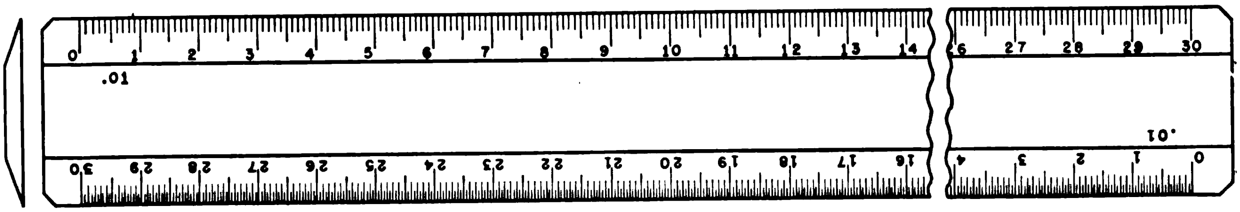
When referring to a drawing made to scale, the scale is used to indicate the ratio of the size of the view as drawn to the true dimensions of the object. When full-size drawings are not practicable, drawings will be made either to reduced or enlarged scales. Enlarged scales may be used when the actual size of the object is so



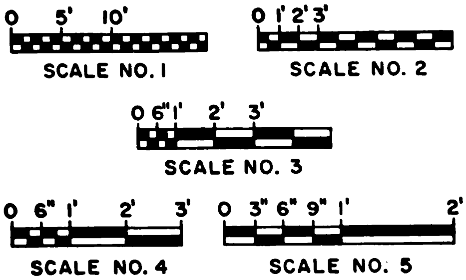
① ARCHITECTS' SCALE



② ENGINEERS' SCALE



③ METRIC SCALE



④ GRAPHIC SCALES

Figure 11. Types of scales.

small that full-size representation would not clearly represent the features of the object. The three types of scales in common use are classified as *architect's*, *engineer's* and *metric* (fig. 11).

a. Architect's Scale. An architect's scale is used for almost all drawings except civil engineering operations such as plotting, map drawing, and the graphic solution of problems. The triangular scale shown in K, figure 1 and figure 11, is standard and contains 11 scales. Six scales read from the left end, five scales read from the right end. The various scales are arranged so that inches and fractions of inches represent 1 foot. Thus, drawings can be made to proportion, such as ¼ size (3 inches equals 1 foot) and $\frac{1}{48}$ size ¼ inch equals 1 foot). On all scales except the full scale, the end unit is divided to represent inches and fractions of an inch. Scales arranged in this way are called *open divided.*

b. Engineer's Scale. An engineer's scale is divided decimally into division of 10, 20, 30, 40, 50, and 60 parts to an inch. The scale is divided uniformly throughout its length and is classified as *full divided.* Because the scales are divided decimally, the 60 scale, for example, can be used so that 1 inch equals 6, 60, or 600 feet. The engineer's scale (fig. 11) is used primarily for civil engineering drawings. A clip-like metal indicator may be placed on either an engineer's or architect's scale to help locate the proper scale quickly after laying the scale down (2, fig. 11).

c. Metric Scales. Metric scales are flat in cross section with a different proportional scale on either edge of the working face. The values assigned are expressed as 1 to 25,000 (1 cm equals 250 m), 1 to 50,000 (1 cm equals 500 m), and so forth. Metric scales (3, fig. 11) may be used in place of architect's and engineer's scales in drawings using the metric system. The conversion factor is 2.54 cm equals 1 inch.

49. Reading an Architect's Scale

A draftsman should form the habit of reading scale dimensions as real dimensions. Once a scale is selected, the full-divided units represent inches or fractions of an inch, depending on the number of divisions in the end unit. In the scale 3″ = 1′-0″, the end unit is divided into 96 parts so that the interval between divisions represents ⅛″; in the scale $\frac{3}{32}$″ = 1′-0″, the end unit is divided into 6 parts so that the interval between divisions represents 2″. The full scale, 12″ = 1′-0″ is full-divided and measures inches and fractions of an inch; the distance between divisions measures $\frac{1}{16}$″. The smallest units can be subdivided by eye on all scales, so that the smallest measurement possible on the full scale is $\frac{1}{32}$″ and the smallest readable distance on the $\frac{3}{32}$ scale is 1″. When reading open-divided scales, feet are read from the zero toward the inside of the scale; inches are read from the zero toward the outside of the scale. This permits direct reading of the scale. The following are the most common scales and the ratios they represent:

48″	=	1′-0″ (quadruple size)
24″	=	1′-0″ (double size)
12″	=	1′-0″ (full size)
6″	=	1′-0″ (½ size)
3″	=	1′-0″ (¼ size)
1½″	=	1′-0″ (⅛ size)
1″	=	1′-0″ ($\frac{1}{12}$ size)
¾″	=	1′-0″ ($\frac{1}{16}$ size)
½″	=	1′-0″ ($\frac{1}{24}$ size)
⅜″	=	1′-0″ ($\frac{1}{32}$ size)
¼″	=	1′-0″ ($\frac{1}{48}$ size)
⅛″	=	1′-0″ ($\frac{1}{64}$ size)
$\frac{3}{16}$″	=	1′-0″ ($\frac{1}{96}$ size)
$\frac{3}{32}$″	=	1′-0″ ($\frac{1}{128}$ size)

50. Use of Architect's Scale

When laying off a measurement to the right of a given point, the required number of inches, reading left from the zero, are placed on the given point. The desired distance in feet is located with a pencil mark opposite the proper open division with a sharp hard lead pencil. The locating mark is a short dash perpendicular to the scale. When laying off a measurement to the left of a given point, place the proper foot graduation on the given point and the locating pencil mark opposite the graduation representing the required number of inches. Inches are therefore read from zero to the left, feet from zero to the right. Accuracy in measuring requires sighting the scale perpendicularly, by placing the eye directly over the graduation being marked, and holding the pencil perpendicularly to the paper directly in front of the graduation. Cumulative errors can be avoided in measuring by keeping the scale in the same setting when laying off a series of measurements from a given point. By keeping the scale in one setting when possible, the sum of the individual measurements can be checked against the graduation in front of which the final measurement is made.

51. Scale Indication

The scale or scales to which drawings are made will be indicated thereon by the following two methods, as required: equation method (architectural) or graphic method.

a. Equation Method. The equation method expresses, in the form of an equation, the relationship of the size of the object as drawn to its true size. This method generally is used for drawings in which the dimensions are expressed in feet and inches. The correct presentation of equation method is demonstrated in the listing in paragraph 49 giving the most commonly used architect's scales. The scale to which the majority of views and sections are drawn will be entered as an equation, such as ¼″ = 1′-0″, ¾″ = 1′-0″, after SCALE in the space provided in the drawing. The scale of each view or section drawn to other than the predominating scale will be entered directly below the title of the view or section as SCALE ⅛″ = 1′-0″.

b. Graphic Method. In the graphic method of representing scale, an actual measuring scale is shown in the drawing (4, fig. 11). This scale provides a means of determining the approximate dimensions of an object on an enlarged or reduced reproduction. Graphic scales may be used for drawings in which complete dimensions of the object or arrangement are not required, such as assembly, installations, subassembly, and welded assemblies, and which are intended for reproduction at other than actual drawing size. Graphic scales will never be used as indications of accurate dimensions. When graphic scales are used to indicate the equation method, a single horizontal bar is divided into appropriate vertical graduations. When graphic scales are used in a drawing, the reference, GRAPHIC, will be entered after SCALE in the space provided on the drawing. When all views and sections are drawn to the same scale, the scale representation and the corresponding fraction followed by SCALE are to be entered near the title block. When more than one scale is used, the graphic scales will be grouped near the title block, and the equation scales will be placed directly below the views to which they pertain.

c. Dimensions Not to Scale. In drawings drawn to scale, but in which certain dimensions are not to scale, the abbreviation NTS (Not To Scale) is placed directly above or below the dimensions affected, or the dimensions are underlined.

52. Use of Dividers

Dividers are used to transfer measurements or divide straight or curved lines into any number of equal parts. They are manipulated with one hand. In setting dividers (1, fig. 12), one leg is held between the thumb and third finger and the other is held between the first and second fingers; the second and third fingers are placed on the inside of the legs and the dividers are opened by spreading these fingers apart. Dividers are closed by squeezing the thumb and first finger together while gradually slipping out the other two fingers. In dividing either a straight (2, fig. 12) or curved line (3, fig. 12) into a given number of equal parts by trial, say four, open the dividers to a rough approximation of the first division (in this case, one quarter of the line length) and step off the distance lightly, holding the dividers by the handle and pivoting the instrument on alternate sides of the line at each step. If the dividers fall short of the end of the line after the fourth step hold the back leg in place and advance the forward leg, by guests, one quarter of the remaining distance. The procedure is repeated until the last step falls at the end of the line. Be careful during this process not to punch holes in the paper, but just barely mark the surface for future reference.

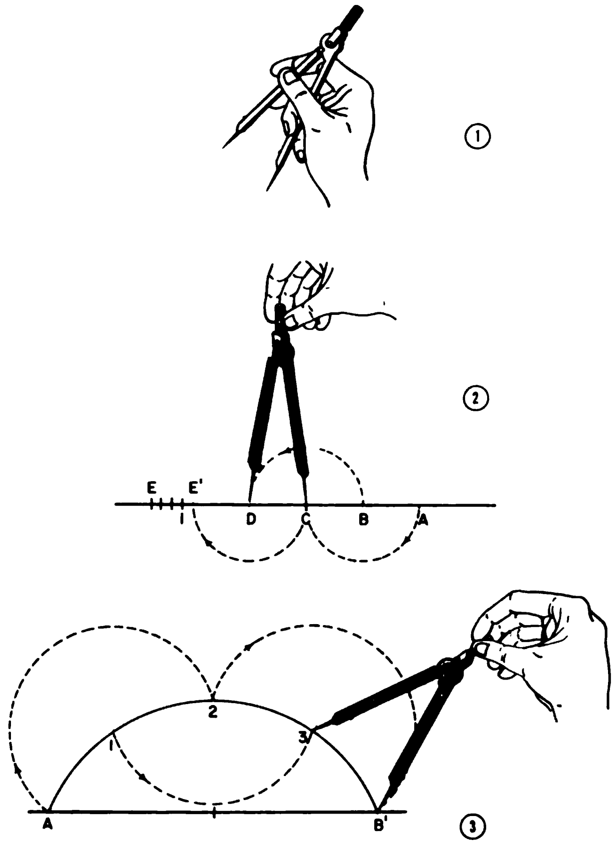


Figure 12. Using dividers.

CHAPTER 3

LETTERING

Section I. FREEHAND LETTERING REQUIREMENTS

53. Information

The shape description of an object or assembly that is presented graphically by the various views in a drawing will be supplemented by figured dimensions and notes that furnish size and manufacturing information. Notes and dimensions in drawings will be legible and suitable for easy and rapid execution.

54. Style

Lettering style will be single-stroke uppercase, commercial Gothic, except when typewritten characters are used. Vertical lettering or inclined lettering may be used, but only one type should appear for a single drawing. Lowercase letters may be used on construction drawings, except for titles. Typewritten characters may be uppercase or lowercase. The expression single-stroke means that the width of lines composing the letters is the same as the width of a stroke of the pen or pencil used for lettering; it does not mean that each letter is executed with a single, continuous movement of the pen or pencil. Uppercase refers to capital letters, lowercase to small letters.

55. Proportions

The ratio of letter width to letter height varies with individual letters. This chapter presents standard proportions that take into consideration the characteristics of individual letters. Letters using these proportions are called normal letters. When letter width is decreased in relation to letter height to conserve space, the letters are said to be compressed letters. When letter width is increased in relation to letter height, the letters are known as extended letters.

56. Stability

If the areas of the upper and lower portions of certain letters and numerals are made equal, an optical illusion is created which causes them to seem top-heavy. To correct this and give the impression of stability, the letters B, E, F, H, K, S, X, and Z, and the numbers 2, 3, 5, and 8 must be drawn smaller at the top than at the bottom. The central horizontal srokes of the letters B, E, F, and H, are drawn slightly above the center. The upper portions of the letters K, S, X, and Z and the numerals 2, 3, 5, and 8 are made slightly narrower than the lower portions.

57. Uniformity

Lettering in a drawing will present a uniform appearance. Height, inclination, alinement, line weight, and spacing are the principal considerations. Uniform height, alinement, and inclination are achieved through the use of guidelines; uniformity in line weight depends on skillful use of the pencil or lettering pen. Uniform spacing of letters in words and of words in sentences is performed by eye; good judgment results from practice.

58. Guidelines

Guidelines are horizontal, vertical, and/or inclined. They are always used in executing freehand lettering. Horizontal guidelines determine horizontal alinement, letter height, and the spacing between lines of lettering. Two horizontal guidlines are used for uppercase letters; the upper line is called the cap line, and the lower line is called the baseline. The distance between cap lines and baselines establishes the height of uppercase letters. Guide lines for lowercase letters are constructed in proportion to uppercase sizes. Four horizontal guidelines are used, cap lines and baselines being the same. The two additional lines are called the waistlines and droplines. Vertical and inclined guidelines serve to keep the verticality or inclination of freehand characters uniform. Guidelines are drawn with either standard or lettering triangles and are spaced at random.

a. Size and Spacing. The size of lettering and the line spacing which should be used on a drawing are controlled by the size of the drawing form in relation to the detail incorporated, and by the amount of reduction, if any, which will be used. The modern procedure of reducing drawings to small size or reproducing them on microfilm and then enlarging them, limits the minimum size of characters and the line spacing which may be used. It is recommended that the minimum size of lettering after reduction be not less than $\frac{3}{64}$ inch. In the absence of factors making larger characters desirable, the recommendations for size of characters for drawing sizes A, B, C (see table I) are—

	Size (inches)	*Lettering guide size*
Drawing and part number	$\frac{1}{4}$	.250
Title	$\frac{3}{16}$	.175
Subtitle	$\frac{5}{32}$	.140
Letters and figures for body of drawing.	$\frac{1}{8}$	.125
Fractions and tolerances	$\frac{3}{32}$	.100
Designation of section and detail views:		
"Section" "Detail"	$\frac{5}{32}$	.140
"A–A" "B"	$\frac{1}{4}$	.250

Note. Lettering and numbering used for special notices, such as patent notices, may be of any size satisfactory for the purpose intended.

For D-size drawings or larger (table I) the sizes of characters shall be governed by the considerations set forth above. When commercial lettering guides are used, sizes corresponding to those given above are acceptable.

b. Lettering Triangle.

(1) *Description.* Lettering triangle are made in many sizes and styles. The 45° triangle shown in figure 13 is typical. It has an elongated slot for drawing standard slant guidelines and six columns of countersunk holes numbered 3, 4, 5, 6, 7, and 8 for drawing horizontal guidelines. The triangle is always used with its hypotenuse sliding against the working edge of the T-square (or another straightedge if lettering lines are not horizontal). The round hole cut through the center of the triangle has beveled edges and is intended for inserting the fingernails as an aid in picking up the triangle.

(2) *Horizontal guidelines.* The six columns of numbered countersunk holes are designed for inserting the cone point of the 6H pencil and drawing horizontal guidelines by sliding the triangle with the pencil inserted along the working edge of the T-square. The

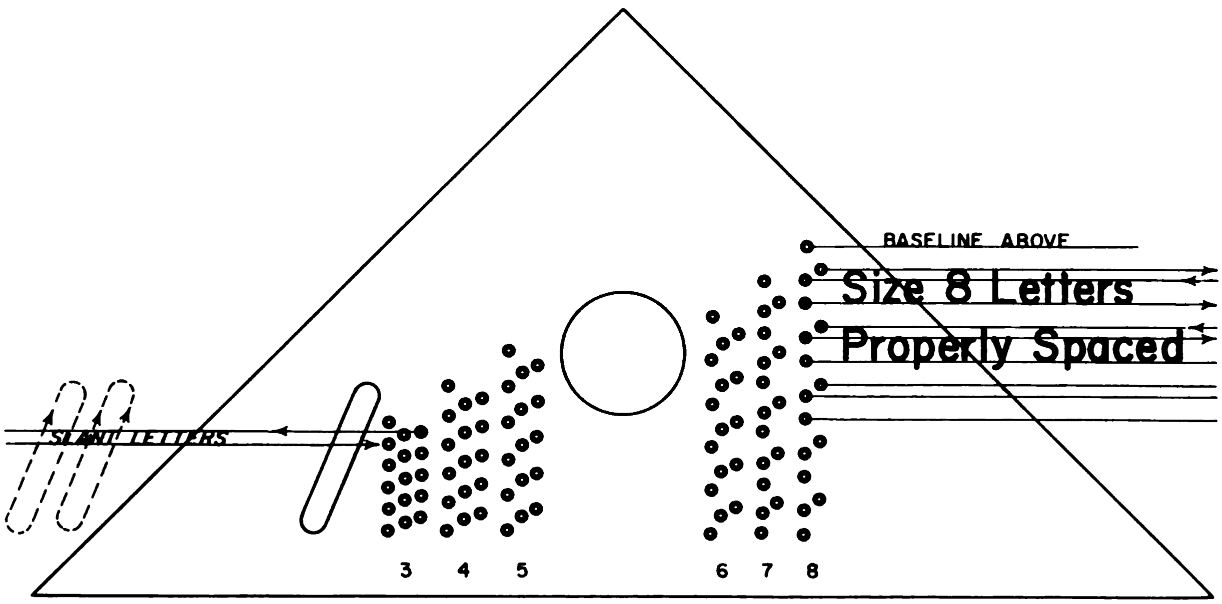


Figure 13. Use of the lettering triangle.

numbers mean 32ds of an inch between cap line and baseline—the size of the capital letters required. —*For example:* (8) = $\frac{8}{32}$ or $\frac{1}{4}''$, (6) = $\frac{6}{32}$ or $\frac{3}{16}''$, (5) = $\frac{5}{32}''$, . . .; also, the numbers correspond to MIL–STD–1A, governing lettering sizes. Note that the holes are grouped in clusters of 3 for drawing a cap line, a waistline and a baseline. No holes are drilled for drawing droplines. The letters requiring a dropline are drawn to size by eye. For normal lettering the standard spacing between lines is two-thirds the height of the capital letters. Line spacing is half capital height for compressed lettering and one and a half capital height for extended lettering. The holes in the lettering triangle are drilled for normal lettering and to give standard spacing between lines, if two or more clusters are used in sequence without relocataing the T-square. Figure 13 illustrates by arrows the manner of drawing guide lines for $\frac{8}{32}$- or $\frac{1}{4}$-inch lettering. In *special cases* where the size of lettering *varies from line to line,* such as in title blocks, the single hole at the top of a column is placed over the baseline of the preceding lettering to determine the spacing between lines.

(3) *Inclined guidelines.* The standard slope for inclined lettering is at an angle of $22\frac{1}{2}°$ to the right of vertical or at an angle of $67\frac{1}{2}°$ with the horizontal. The elongated slot (fig. 13) in the lettering triangle is cut at an angle of $67\frac{1}{2}°$ to the hypotenuse for use as a guide in drawing inclined guidelines for slant lettering. The sides of the slot are parallel so that either side may be used for drawing slant guidelines. The triangle rests with its hypotenuse free to slide along the working edge of the T-square to the desired location for the guidelines. As many inclined guidelines may be drawn as experience dictates—but at least one for each letter for a beginner. There are several other methods of obtaining the correct angle for inclined lettering if no lettering triangle is available. Two simple methods are:

(*a*) Bisect the angle between a vertical line and a 45° line.

(*b*) Construct a small triangle of base equal to 1″ and an altitude of $2\frac{7}{16}''$. The hypotenuse of this triangle will make an angle of 67.7° with the horizontal which is close enough for guidelines. In each case, having established a line at $67\frac{1}{2}°$ it is necessary to draw all slant guidelines parallel to it by using two triangles sliding against each other.

c. Lettering Instrument.

(1) The Ames lettering instrument (fig. 14) works on the same principle as the lettering triangle. The main difference is that it has angles of 68° and 75° for construction of inclined guidelines. The numbers 2 through 10 are numerators of the denominator 32. If the circular disk is turned so that numerator 9 is matched with the line on the frame, the total height of the resultant capital letter would be $\frac{9}{32}$ inch.

(2) If the disk becomes too loose in the frame, remove it and press the edges of the frame about $\frac{1}{4}$ inch together. If the disk is too tight, apply a light powder on the edge of the disk. To clean use soap and water.

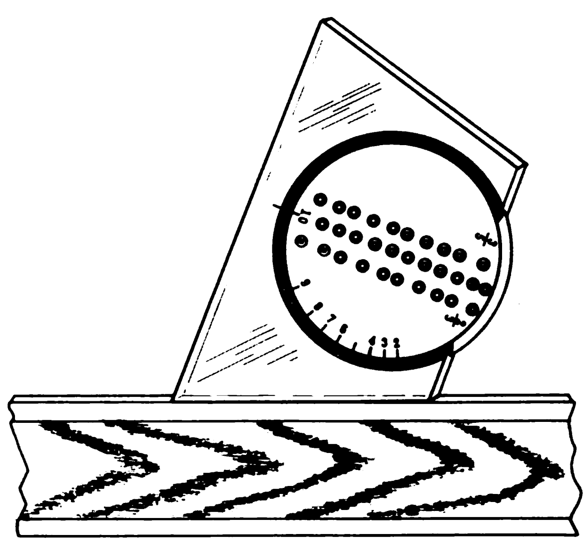


Figure 14. Ames lettering instrument.

59. Pencil Technique

All letters and figures are drawn with the basic strokes illustrated in figure 15. To execute satisfactory letters, a draftman must learn and practice the direction and sequence of strokes used to form each letter.

a. Position. Rest the forearm on the drawing board below the edge of the paper. Hold the pencil between the thumb, forefinger, and second finger so that each rests against a flat side. The third and fourth fingers and the ball of the palm rest on the drawing sheet.

b. Basic Strokes. Vertical strokes are drawn from the top down with an even finger movement. Inclined strokes are drawn in the same way and are slanted in the desired direction. Horiozntal strokes are drawn from left to right with a complete hand movement, pivoting at the wrist. Curved strokes proceed from above downward, moving in the desired direction, and are produced with a combined finger and wrist motion. Lettering strokes are drawn, not sketched; the uniform, single-stroke appearance required of lettering can be achieved only by practicing the fundamental strokes in the manner described.

60. Lettering Pen Technique

The lettering pen is held in the same manner as the pencil, tightly enough for control but allowing a loose, free movement. Strokes are drawn, not sketched, in the same manner as pencil strokes. Avoid pressure on the pen; pressure spreads the nibs and produces an uneven line. Hold the pen in the same manner consistenly because tilting it in different directions causes different stroke weights. Regular practice is the only way to achieve uniform lettering of acceptable quality.

a. Penpoints. Crowquill pens produce the finest line weight. Gillott or equivalent pens produce a heavier line weight and are used for normal lettering. In general, penpoints that are too flexible produce a wavering line and those that are too stiff cause the draftsman to use too much pressure, thus spreading the nibs.

b. Filing and Cleaning. Do not fill pens by dipping them into the bottle. Use the quill in the stopper of the ink bottle and insert ink in the slot on the underside of the pen. Do not ink the pen too heavily or apply ink to the point. If ink flows too freely, blots occur more frequently and the first line strokes made after each filling will be heavier than the rest. While in use, pens

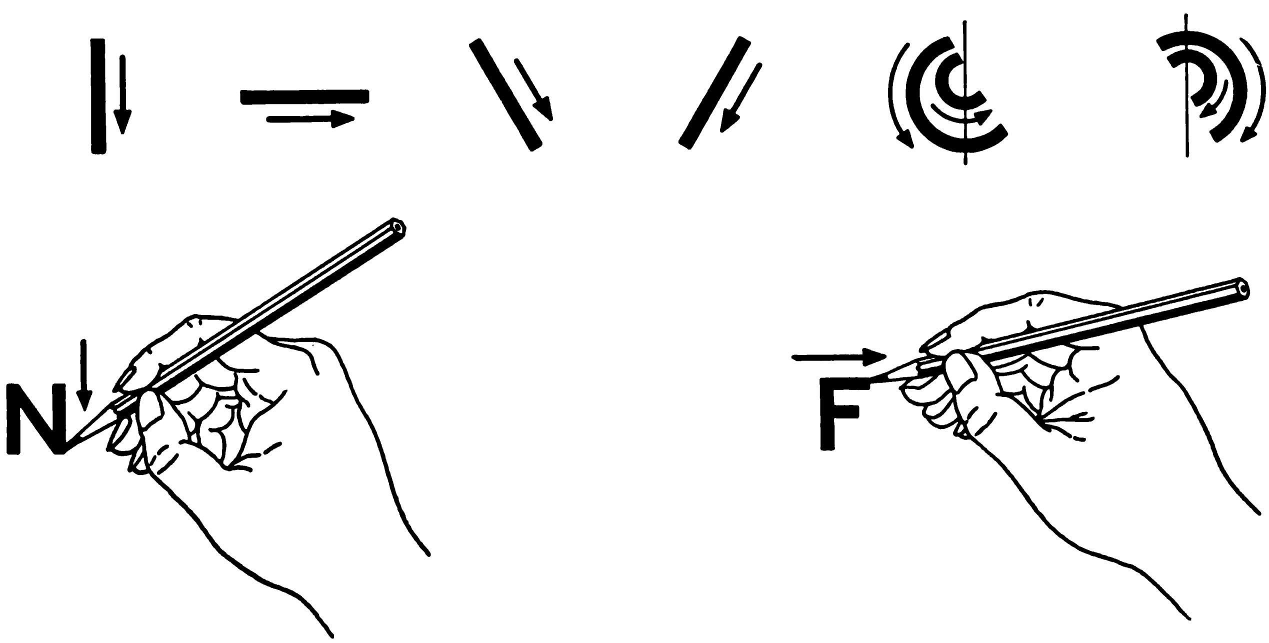


Figure 15. Basic lettering strokes.

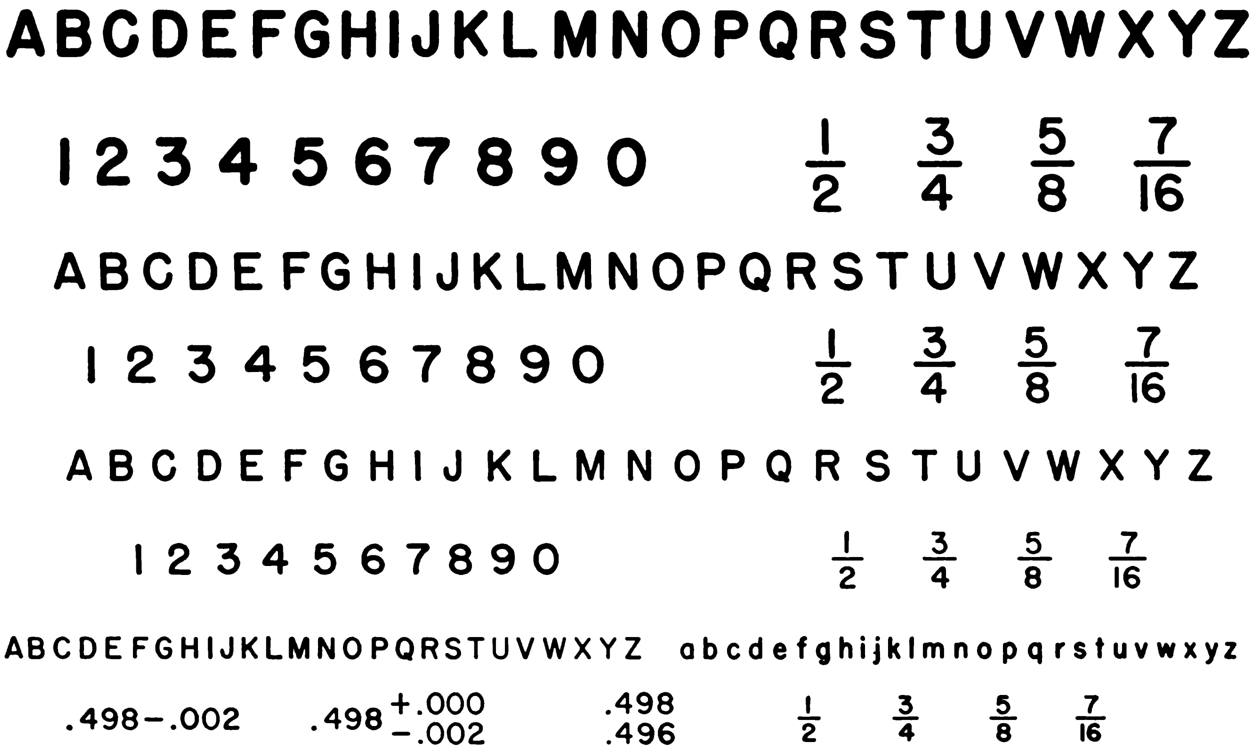


Figure 16. Vertical Gothic lettering.

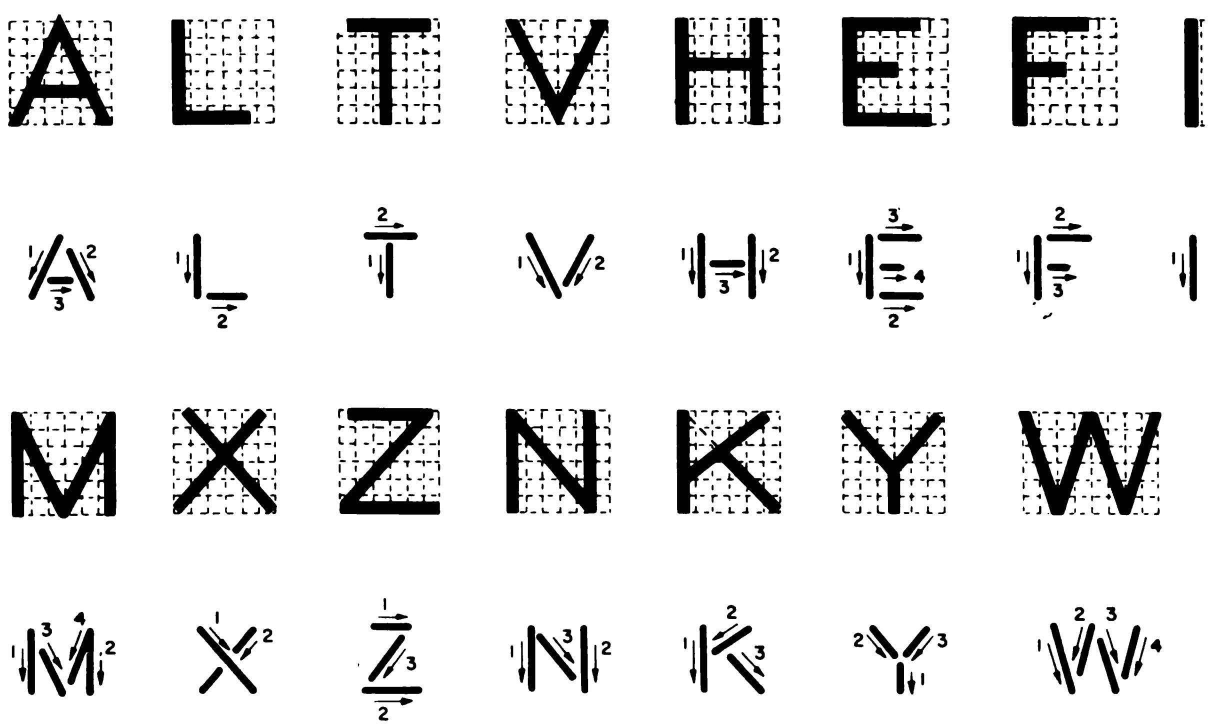


Figure 17. Vertical straight-line capitals.

should be wiped regularly with a soft cloth. They should be thoroughly cleaned before being put away.

61. Vertical Letters

Figure 16 illustrates the required shape of vertical letters and numerals. Figures 17, 18, 19, and 20 illustrate construction of characters against a square background with each side divided into six equal units except the letters I and W. The background serves as a reference framework for comparing the height of the various characters in proportion to their width as well as locating the individual lines that compose these characters. A smaller drawing below each character in figures 17 and 18 shows the direction and sequence of the strokes used in the formation of the character.

a. Straight-Line Capitals (fig. 17).

(1) I, A, L, T. The letter I is the basic vertical stroke. Stroke 3 of the A is located a third of the distance up from the baseline; inclined strokes 1 and 2 intersect just above the cap line. The horizontal stroke of the T is drawn first; the vertical stroke, or stem, is drawn from the center. With both L and T, the horizontal stroke may be lengthened or shortened to balance the letters in a word. If, *for example,* L precedes A, its horizontal stroke is reduced slightly; if T precedes A, its horizontal stroke is extended slightly.

(2) H, F, E. In H, F, and E, the central horizontal bar is placed slightly above the center for stability. In both E and F, the cap line stroke is 4 units long and the central stroke is $\frac{3}{5}$ of this length. The baseline of E is $\frac{1}{2}$ unit longer than its cap line.

(3) V, W, M, N. The 2 inclined strokes of the V intersect just below the baseline. The W is $1\frac{1}{3}$ times the width of a normal letter; note that it is wider than the M. Strokes 1 and 2 and 3 and 4 of the W intersect below the baseline. Strokes 3 and 4 of the M and 2 and 3 of the N intersect on the baseline. Note that the outside strokes of the M and N are drawn first.

(4) Z, X, Y, K. Strokes 2 of the Z is longer than stroke 1. The inclined strokes of the X are closer together at their starting than at their finishing points. The 3 strokes of the Y intersect slightly below the center of the square. Stroke 2 of the K intersects stroke 1 at a point a third of the distance up from the baseline. Stroke 3, if extended, would intersect stroke 1 at the top.

b. Curved and Straight-Line Combination (fig. 18).

(1) O, Q, C, G. The O and Q are complete circles; C and G are not the full width of the square because they are not full circles. The tail of Q, if extended, would intersect the center of the circle. Stroke 4 of G begins at the center of the circle.

(2) U, J, D. Stroke 3 of U is elliptical and connects 2 parallel vertical lines a third of the distance above the baseline. Stroke 2 of J is similar but not so broad. Stroke 4 of D is circular, joining 2 horizontal segments.

(3) P, R, B. The horizontal midstrokes of P and R lie just below the midpoint, and the horizontal midstroke of B lies just above the midpoint. Horizontal stroke 4 in B is slightly longer than strokes 2 and 3, which are the same length.

(4) S and &. The upper and lower portions of S are ellipses, the upper slightly smaller than the lower. The ampersand is basically similar despite a greater difference in the sizes of the ellipses.

c. Lowercase Letters.

(1) *Guidelines.* The waistline is $\frac{2}{3}$ the distance from the baseline to the cap line (fig. 19). The waistline establishes the body height of lowercase letters. Extensions of lowercase letters above the waistline are called ascenders. The dropline is drawn below the baseline (fig. 19) at a distance equal to that between the waistline and cap line. Extensions of lowercase letters below the baselines are called descenders. The dropline is used to establish the length of descenders and can be elimi-

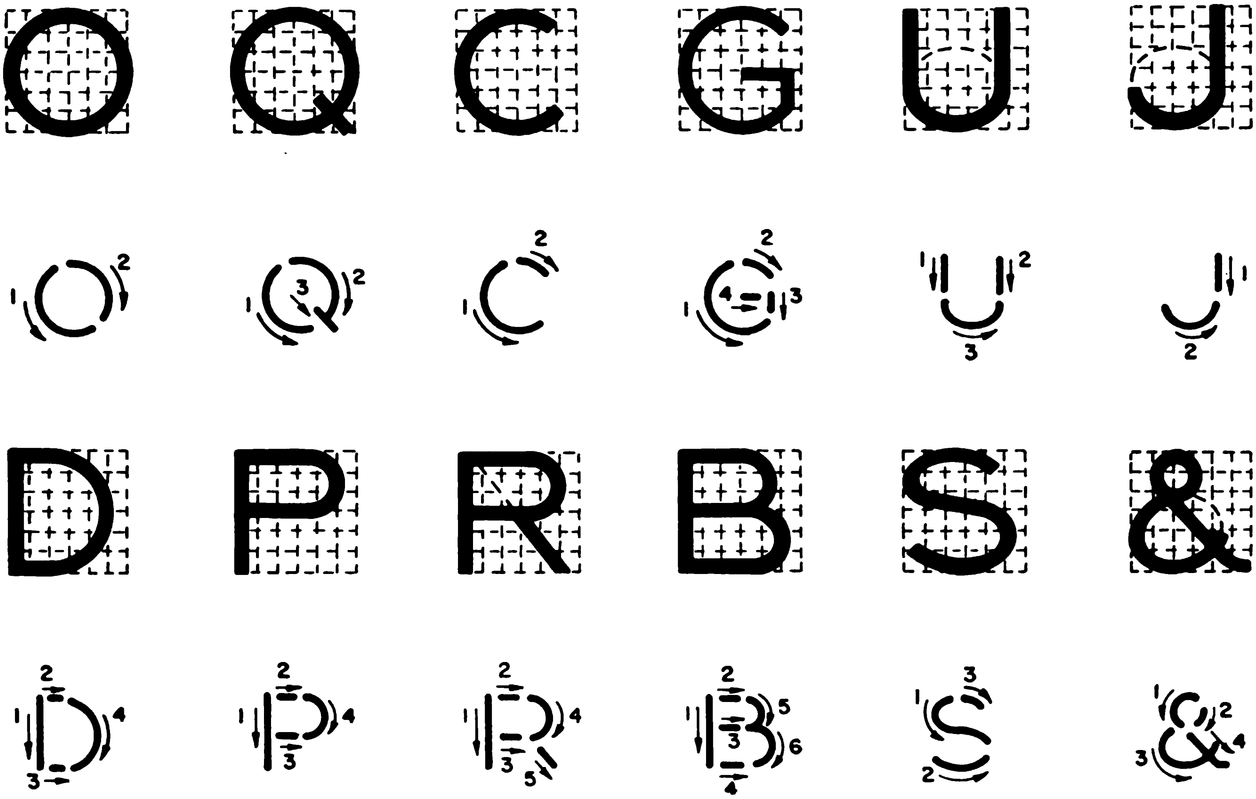


Figure 18. Vertical capitals, curved and straight-line combinations.

nated once a draftsman is able to judge this distance by eye. All ascenders, except that of t, extend to the cap line. All descenders extend to the dropline. As with capital letters, vertical guidelines are drawn at random.

(2) *Characteristics.* The crosses of f and t are on the waistline and extend the same distance on either side of stroke 1. The horiozntal stroke of e is just above midheight. The bodies of a, b, g, p, and q are circular and the vertical strokes of these letters do not increase their width at the points of tangency. The vertical strokes of p and q terminate at the dropline. The vertical strokes of g, j, and y terminate in curves that are tangent to the dropline.

d. Numerals and Fractions. The need for drawing numerals (fig. 20) carefully cannot be overstressed, particularly in the preparation of construction drawings in which a poorly drawn numeral can cause costly errors and delay.

(1) *Guidelines.* Numerals are drawn to the same guidelines as capital letters. Vertical guidelines are spaced at random. Numerals should not be made so small or be crowded so closely as to impair their legibility.

(2) *Characteristics.* The vertical stroke of 4 is placed 2 units from the right side. The horizontal bar is one-quarter the height of the number above the baseline. Note that the closed curves of 0, 6, and 9 are elliptical, not circular. The 6 is an inverted 9. The 8 is composed of 2 ellipses tangent slightly above the center point. The top ellipse also is narrower. The 3 is the same as the 8 with the left portions of the loops cut off. The curved lines of 2 follow the elliptical contours of 8. The top portion of the 5 is slightly narrower than the bottom. The bottom ellipse is two-thirds the height of the figure from the baseline.

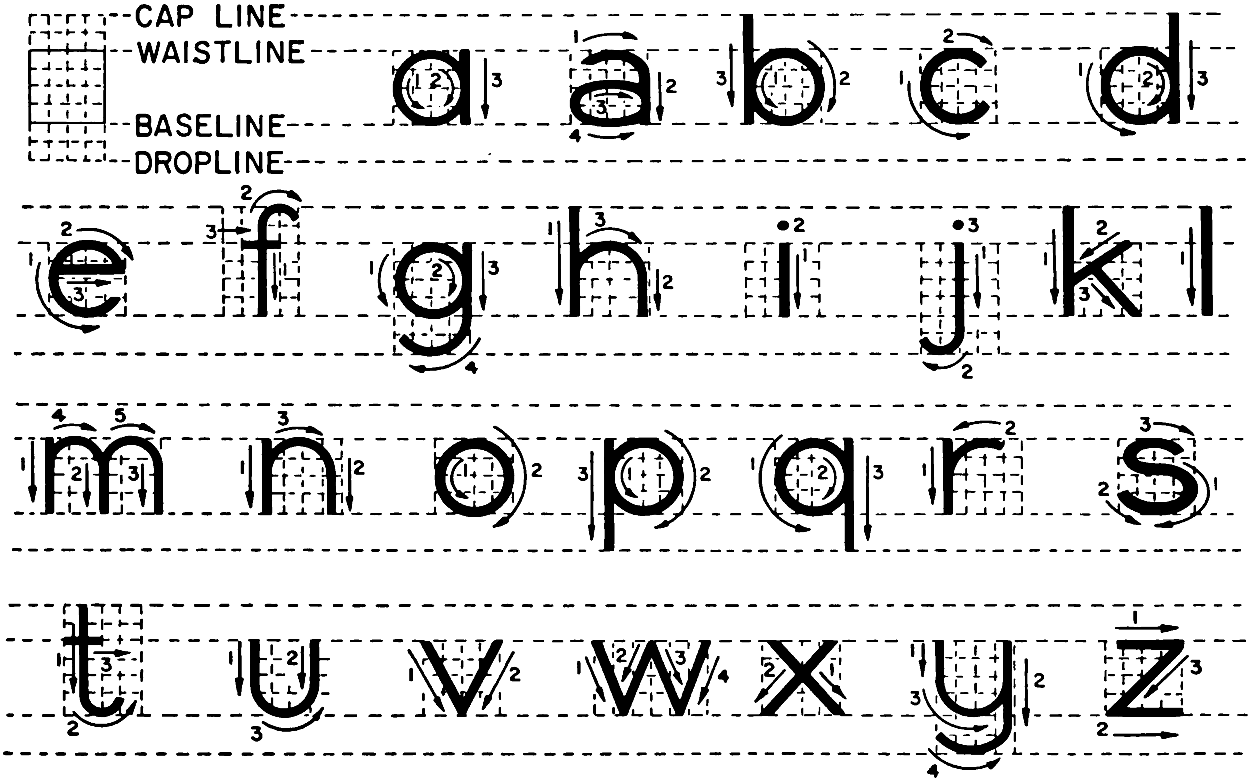


Figure 19. Vertical lowercase letters.

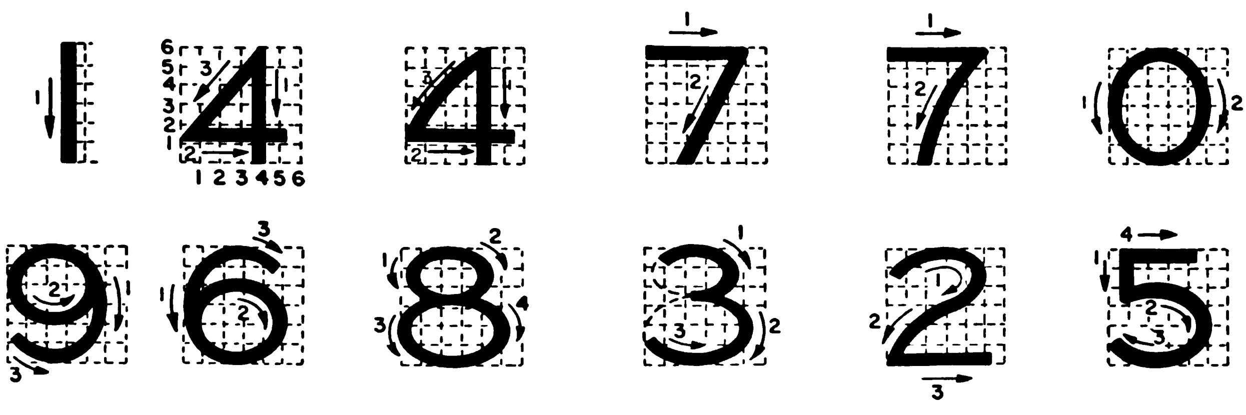


Figure 20. Vertical numerals.

(3) *Fractions.* The division sign of a common fraction (figs. 16 and 21) will be parallel to the direction in which the dimension reads. The complete height of a fraction is twice that of a whole number. The division bar is centered midway between the baseline and cap line. The top guideline of the numerator and the bottom guideline of the denominator are spaced a full number height from the division bar. The numbers composing a fraction are three-quarters the height of a full number. The clear space on either side of the division bar is one-quarter of a full number. Numbers in a fraction are centered about a vertical guideline that cuts the fraction bar in half.

62. Inclined Letters

Figures 21 and 22 illustrates the required formation of inclined letters. The angle of inclination is 67½° with the horizontal. Inclined guidelines may be drawn with the lettering triangle as described, or a line at the proper angle may be laid off with the protractor and parallel lines constructed from it. Horizontal guidelines and sequence of strokes are the same as for vertical letters. Rules of stability, proportion, and balance are similar. The circles and circle arcs

Figure 21. Inclined Gothic lettering.

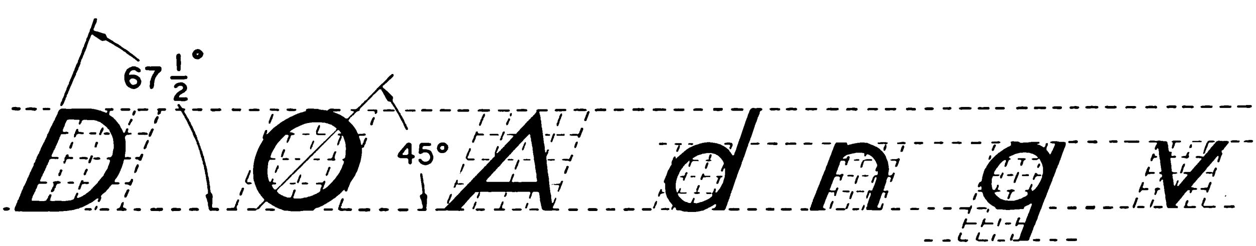


Figure 22. Inclined letter formation.

used in vertical letters become elliptic in inclined letters, their major axes making angles of 45° with the horizontal. Letters such as A, M, and Y should be made symmetrically about a guideline. Inclined lowercase letters follow the same principles as inclined capitals.

63. Words

a. Uppercase Letters. Proper spacing of uppercase letters in words requires that the areas occupied by the letters appear equal rather than that the actual clearance between the letters be equal. In the word MELT, for example, the actual spacing between the L and T can be so close that a vertical dropped from the left end of the horizontal stroke of the T will touch the right end of the horizontal stroke of the L. The areas inclosed in the letters by their vertical strokes give the appearance of adequate clearance. The actual clearance between M and E must be such that the areas inclosed by their adjacent vertical strokes are roughly equivalent to those between the vertical strokes of the L and the imaginary vertical connecting the horizontal strokes of L and T. Actual clearance between E and L can be slightly less than that between M and E. The spacing between words should be equivalent to the basic width of the letters M and O.

b. Uppercase and Lowercase Combinations. Spacing between letters in words using either lowercase or uppercase and lowercase combinations follows the same general rules of word composition as set forth above. Spacing between lines of lettering on a drawing requires that the clear space between the dropline and the cap line below it be equal to one-third the distance between the baseline and cap line (or $\frac{1}{3}$ the height of capital letters) as established for that drawing. If droplines are not used, the distance between one baseline and the cap line below it is equal to $\frac{2}{3}$ the height of capital letters as established for that drawing.

c. Spacing Between Words. Spacing between words should be uniform for the entire drawing and is estimated by the space necessary to insert a capital letter I between words. Thus by erasing the I in WATERIGAP the two words WATER and GAP are properly spaced.

d. Spacing Between Sentences. Spacing between sentences should be uniform for the entire drawing and is a matter of personal choice. For uniformity the space necessary to insert a capital M between the period at the end of a sentence and the first letter of the next sentence is satisfactory.

e. Spacing Between Lines. Spacing between lines is described in paragraph 58*b*(2).

64. Title Blocks

The location and size of letters for title blocks have already been given (pars. 43*a*, *b*, and 58*a*). The remaining problem is one of composition, Using the space allotted, lines of lettering must be arranged symmetrically about a vertical centerline. First, a satisfactory trial title is worked out on a separate sheet of paper, using guidelines marked to equal the space in the title block. When a satisfactory line of lettering has been achieved, count the number of letters (each space between words also counts as a letter) and mark the midpoint of the line. Draw horizontal and vertical guidelines in the title block of the drawing sheet and establish a vertical centerline. If transparent tracing paper or tracing cloth is used, the trial title may be slipped underneath, guidelines and midpoint aligned, and the title traced. If the drawing sheet is not transparent, the trial lettering may be placed directly above the drawing sheet guidelines and centered. The space arrangement worked out on the trial sheet is used as a guide in lettering the drawing sheet title.

Section III. MECHANICAL LETTERING

65. Use

Mechanical lettering is executed with a special pen held in a scriber and guided by a template. The standard lettering set is used for mechanical lettering in military drawings. Because guidelines are not required, uniform, legible characters can be produced more rapidly than by freehand methods. Mechanical lettering is used principally for title blocks and marginal data for special maps, charts, graphs, and

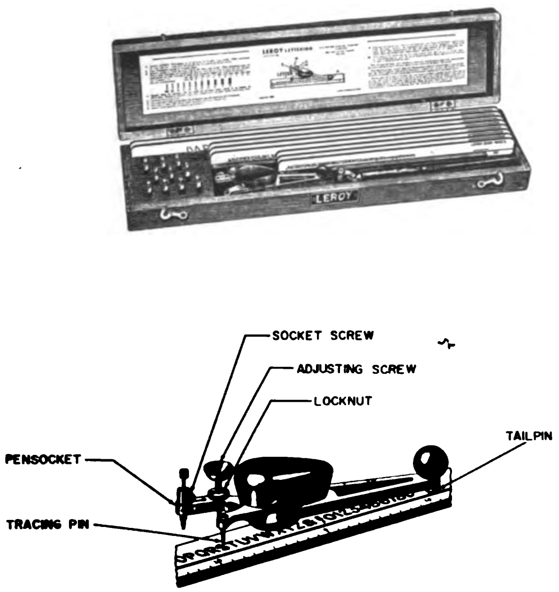


Figure 23. Standard lettering set.

photographs for reproduction. It should be noted that freehand lettering is the required lettering in drafting; mechanical lettering is confined to the special uses just described. The availability of mechanical lettering devices should not deter draftsmen from the daily practice required to execute freehand lettering.

66. Standard Lettering Set

The standard lettering set consists of a set of templates, a scriber, and a set of pens (fig. 23).

a. Templates. Templates (fig. 23) are made of laminated plastic with characters engraved in the face so that their component lines are guide grooves for the scriber. The height of the characters, in thousandths of an inch, is given by a number on the upper right-hand side of the template. The range of character heights offered by a standard set of templates is from 80 (0.08 inch or $5/64$ inch) to 500 (0.5 inch or ½ inch). The scale at the bottom of each template has the zero in the center and is arranged for proper spacing in relation to character heights. The distance between each scale division represents the area required by a normal letter.

b. Pens. A standard set of pens (fig. 23) for producing various line weights consists of 10 sizes ranging from 00, the finest, to 8N. Each pen is composed of two parts: the ink reservoir and the cleaning pin. The reservoir is a series of connected tubes of decreasing diameters, the lowest establishing line thickness. The cleaning pin acts as a valve, protruding beyond the edge of the bottom tube when the pen is not touching the drawing surface. In this position, no ink flows. When the pen is rested on a drawing surface the cleaning pin is pushed up, allowing a flow of ink. Action of the pin in the tube minimizes ink clogging.

c. Scribers. The scriber (fig. 23) holds the pen in alinement and controls its motion as the tracing pin is guided through the character grooves of the template. Two types of scribers are available, adjustable and fixed. An adjustable scriber produces vertical and inclined letters from a single template; a fixed scriber produces only vertical letters. Except for the locknut, which permits the setting of an adjustable scriber to be changed, both scribers consists of a tracing pen, pen socket, socket screw, adjusting screw, locknut, and a tailpin.

67. Lettering Set Operation

a. Line Weight. Recommended combinations of template and pen for best proportion between line thickness and letter size are presented below. If a heavier line weight is required, do not use a pen more than two grades above the recommended size.

Template No.	*Pen No.*
060	000
080	000 or 00
100	00
120	0
140	1
175	2
200	3
240	3
290	4
350	4
425	5
500	6

b. Letter Size and Spacing. The rules for freehand letter sizing and spacing also apply to mechanical lettering. For blocks having more than one line of lettering, horizontal baselines may be drawn at intervals for the proper spacing between each line for the size of letters used. Lines of lettering are arranged symmetrically about a vertical centerline. In centering a line of lettering, count the number of letters in the line, add one-half for spaces between words, and subtract one-half for each letter I. Select the template bearing letters of the desired size and place the zero of its scale on the vertical centerline. Mark the number of divisions equal to half the number of words in the line first to the left and then to the right of the zero. This indicates the starting and finishing points.

c. *Procedure.* Loosen the socket screw (fig. 23). Choose the pen recommended for the template selected. Insert the pen in the pen socket, so that the shoulder seats against the scriber arm, and tighten the socket screw. Loosen the adjusting screw locknut, and fill the pen reservoir with drawing ink. With the template edge against a T-square, set the scriber tailpin, in the straight groove of the template and the scriber tracing pin, in the groove of a character. Using a piece of scrap paper for trial lines, regulate the adjusting screw, so that the cleaning pin is pushed far enough back to allow the ink to flow freely. If the pin is pushed back level with the end of the tube (that is, if no clearance is provided and the tube is allowed to rest against the drawing surface), ink will not flow smoothly. The amount of clearance varies with the consistency of the ink and the nature of the drawing surface. When satisfactory trial lines are produced, tighten the adjusting screw locknut. Proceed with the lettering by moving the tracing pin in the character groove, at the same time keeping the tailpin in the straight groove. Spacing between letters is by eye and involves the same considerations of equal letter areas as in freehand lettering.

d. *Technique.* Hold a T-square in position with the ball of the left hand against the blade. The fingers of the left hand hold the template against the working edge and change the position of the template when necessary. The scriber is held between the thumb and first three fingers of the right hand. The little finger of the right hand presses the right side of the template against the T-square edge, preventing slipping from the motion of the tracing pin in the character grooves.

(1) *Ink flow.* The reservoir should be kept from $\frac{1}{4}$ to $\frac{3}{4}$ full; too low an ink level results in irregular lines. When the pen is filled and not in use, it should be placed so that the tip is not in contact with any surface. Before reusing, the cleaning pin should be twirled in the tube to loosen any clotted ink. Never use pressure on a scriber if the ink does not flow. Check the adjusting screw setting and the reservoir level.

(2) *Fractions.* The numbers in a fraction are made by using a template one size smaller than that used for whole numbers.

e. *Maintenance.* Pens should be cleaned with running water after use and stored in the containers provided for them. If water does not clean a pen satisfactorily, a diluted solution of ammonia may be used. Cleaning pens should be handled with care because they are fragile and easily bent.

CHAPTER 4

ENGINEERING CHARTS AND GRAPHS

Section I. GRAPHIC PRESENTATION OF ENGINEERING DATA

68. Definition

Graphic presentation of engineering data means using charts and graphs, rather than numerical tables or word descriptions, to present statistical engineering information. Properly selected and constructed, each form of charts and graphs offers a sharp, clear, visual statement about a particular aspect of series of related facts. The visual statement either emphasizes the numerical value of the facts or shows the way in which they are related. A chart or graph that emphasizes numerical value is called quantitative; one that emphasizes relationships is called qualitative. The trend of an activity over a period of time, such as the number of tanks produced over a 10-year period, is more easily remembered from the shape of a curve describing the trend than from numerical statistics. Successful graphic presentation of engineering data requires as much drafting ability as the graphic representation of engineering objects. Lines must be sharp, opaque, well contrasted, and of uniform weight. Letters and figures are normally executed with the standard lettering set in accordance with the standards presented in chapter 3.

69. Classification

Graphs and charts are classified as technical and display charts, according to the use for which they are intended.

a. Technical Charts. Technical engineering charts usually are based on a series of measurements of laboratory experiments or work activities. Such measurements examine the quantitative relationship between a set of two factors, or variables. Of the two variables, one has either a controlled or regular variation and is called the independent variable. The other is called the dependent variable, because its values are related to those of the independent variable. The line connecting plotted points is called a curve, although it may be broken, straight, or curved. The curve demonstrates the relationship between the variables and permits reading approximate values between plotted points.

b. Display Charts. Display charts are organized primarily to convey statistical data to nontechnical audiences. The message presents a general picture of a situation, usually comparative. There are many varieties of display charts, includng bar charts, pictorial charts, pie charts, and training aids. These are considered more fully in paragraphs 82 to 93.

70. Graphic Aids in Construction Work

Any construction job involves quantities of men, materials, and equipment. Efficient operation and completion of the job results from planning, organization, and supervision. Graphic presentation of data is important. Statistics of results on past jobs with smilar working conditions provide a basis for predicting the amount of time that a proposed job will take. These statistics offer the best possibilities for study when presented graphically, usually in the form of a curve. The prediction of expected achievement usually is presented as a bar chart and is called a time-and-work schedule. Safety posters are another example of graphic aids in construction supervision.

71. Frame of Reference

When the statement is made that an automobile has moved a mile, it usually is meant that the vehicle has moved a mile relative to the earth's surface. If the position of the automobile is measured relative to the sun, the vehicle may be thousands of miles from where it started. Relative to its passengers, the automobile has not moved at all. The position of a point, like the motion of a body, cannot be expressed except in relation to a known point or framework of lines that must be considered fixed. The way in whch the position of a point is described depends on the choice of a frame of reference.

72. Rectangular Grid Systems

A fixed framework of straight lines intersecting at right angles to each other, made for locating points, is called a rectangular grid system. The system is based on two primary reference lines that intersect and are perpendicular to each other. When a grid system is staked out on the ground these main reference lines are called *zero lines.* The main reference lines of a grid system on paper are called coordinate axes. The auxiliary reference lines or coordinates that complete the framework run parallel to the zero lines and have a numerical value proportional to their perpendicular distance from the zero lines. Once a set of zero lines has been established, the position of any point on the grid can be defined by constructing its coordinates, that is, by measuring the perpendicular distances from the point to the two zero lines.

a. City Grids. Many cities are laid out on a grid system, with the avenues running north and south and the streets running east and west. The directions are not required to be exact, merely approximate enough for identification. The streets and avenues from which the numbering begins become the main reference lines.

b. Local Grids. Rectangular grid systems are used for construction projects and are known as local grids. To prevent confusing the designated direction of the coordinate lines with compass bearings, a north-pointing arrow is shown in the drawing to define the direction of the north-and-south baseline as grid north. Building points, such as corners of foundations, are located in the job area by their coordinates.

73. Coordinate Axes

The principal reference lines in the grid system of a sheet of coordinate paper are called the coordinate axes (fig. 24). Theoretically, coordinate axes extend on either side of the point of intersection, called either the point of origin or 0. The horizontal axis, X X′, is called the abscissa or X-axis. The vertical axis, Y Y′, is called the ordinate or Y-axis. The coordinate axes divide the sheet into four parts, or quadrants, that are numbered counterclockwise. The first quadrant is in the upper right-hand corner. Mathematical graphs (1, fig. 24) use four quadrants; the main axes are considered zero lines and quantities less than zero are plotted below the X-axis and to the left of the Y-axis. Scales for display graphs (2, fig. 24) are, however, arranged so that all values are plotted in the first quadrant, which makes them easier to read. The two coordinate axes form a two-coordinate frame of reference because all points within their boundaries are located by reference to perpendicular distances from the two main axes.

74. Rectangular Coordinates

Coordinate paper provides a readymade framework for locating numerical data. When plotted data falls between coordinate rulings or when coordinate paper is not used, as on display graphs, the same method of perpendicular measurement is used. In a two-coordinate frame of reference, every point has both an X and a Y coordinate. The X coordinate represents the perpendicular distance to the right of the Y-axis, and the Y coordinate represents the perpendicular distance above the X-axis. In figure 24 the coordinates of the points are shown as dotted lines. The main axes are represented with the line symbol for a datum line. A datum line is a reference, or zero, line from which measurements are made.

75. Curves

When only one curve is depicted on a graph, it should be represented by a solid line; when

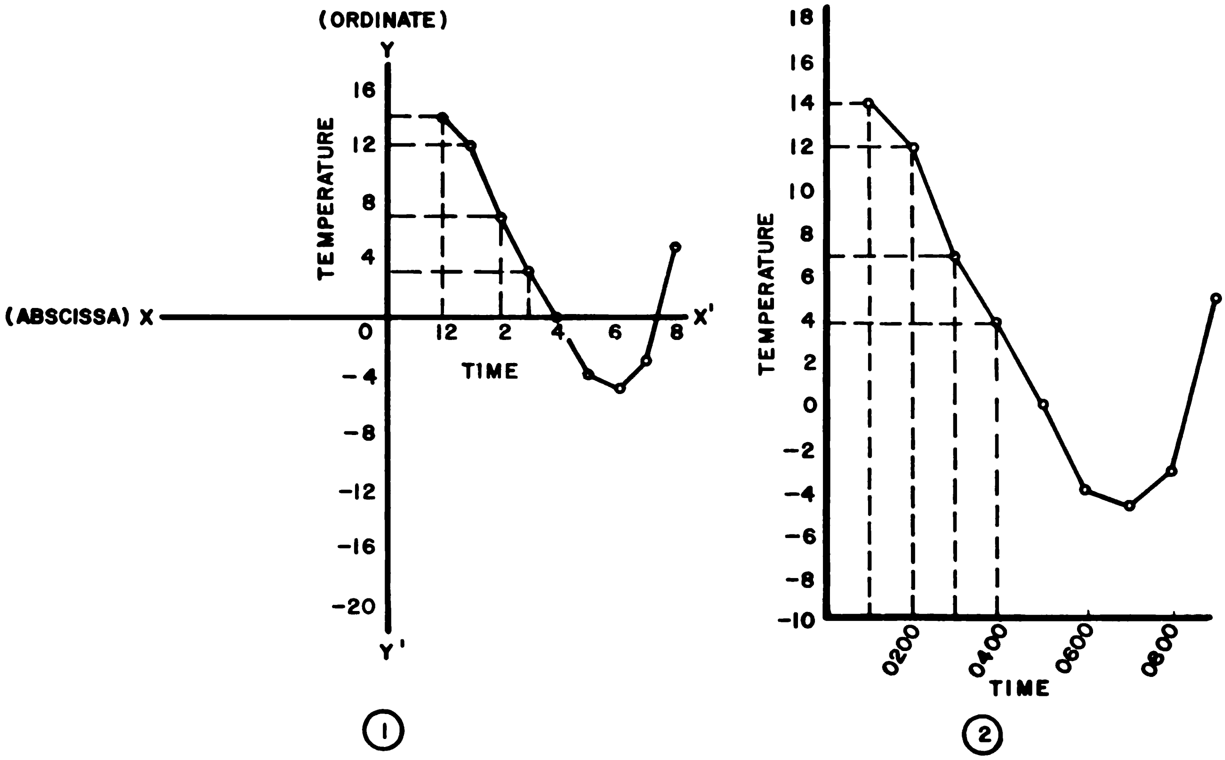


Figure 24. Coordinate axes.

more than one curve is presented on a graph, they should be differentiated by using varied line characteristics. A solid line should be used for the most important curve. When several curves are presented, each should be identified by a brief label placed close to the curve and alined horizontally. These labels should be kept within the vertical and horizontal limits of the curve on the graph. When the label must be connected to a curve to avoid confusion, the connecting arrows should be short, straight, inclined to the coordinate rulings, and parallel to each other.

76. Scale

The choice of scales should be considered carefully because the picture of the relationship between the two variables is affected most sharply by the values assigned to the spaces between coordinate rulings.

a. Range. Separate scales are assigned to the horizontal and vertical axes. In both cases, the range of scales should ensure efficient and effective use of the coordinate area in presenting the message of the chart. The angle of slope (the steepness of the curve) is controlled by expanding or contracting the vertical scale relative to the horizontal scale.

b. Zero Lines. If the chart is quantitative and designed for reading approximate values, the main axes do not have to intersect at the point of origin. Space in the coordinate area may be saved by beginning the marking of a reference line on or just before the first significant measurement.

c. Arithmetic Scales. Values increase arithmetically. Decimal values of 1, 2, and 5 are best for the spaces between coordinate rulings because intermediate values may be interpolated more readily. One square, for example, might equal 0.01, 0.1, 1.0, 10.0, 100.0, and so on. If a value of 0.1 is assigned to a single square, five squares equals 0.5. The independent variable scale values along the abscissa should increase from left to right. The dependent variable scale

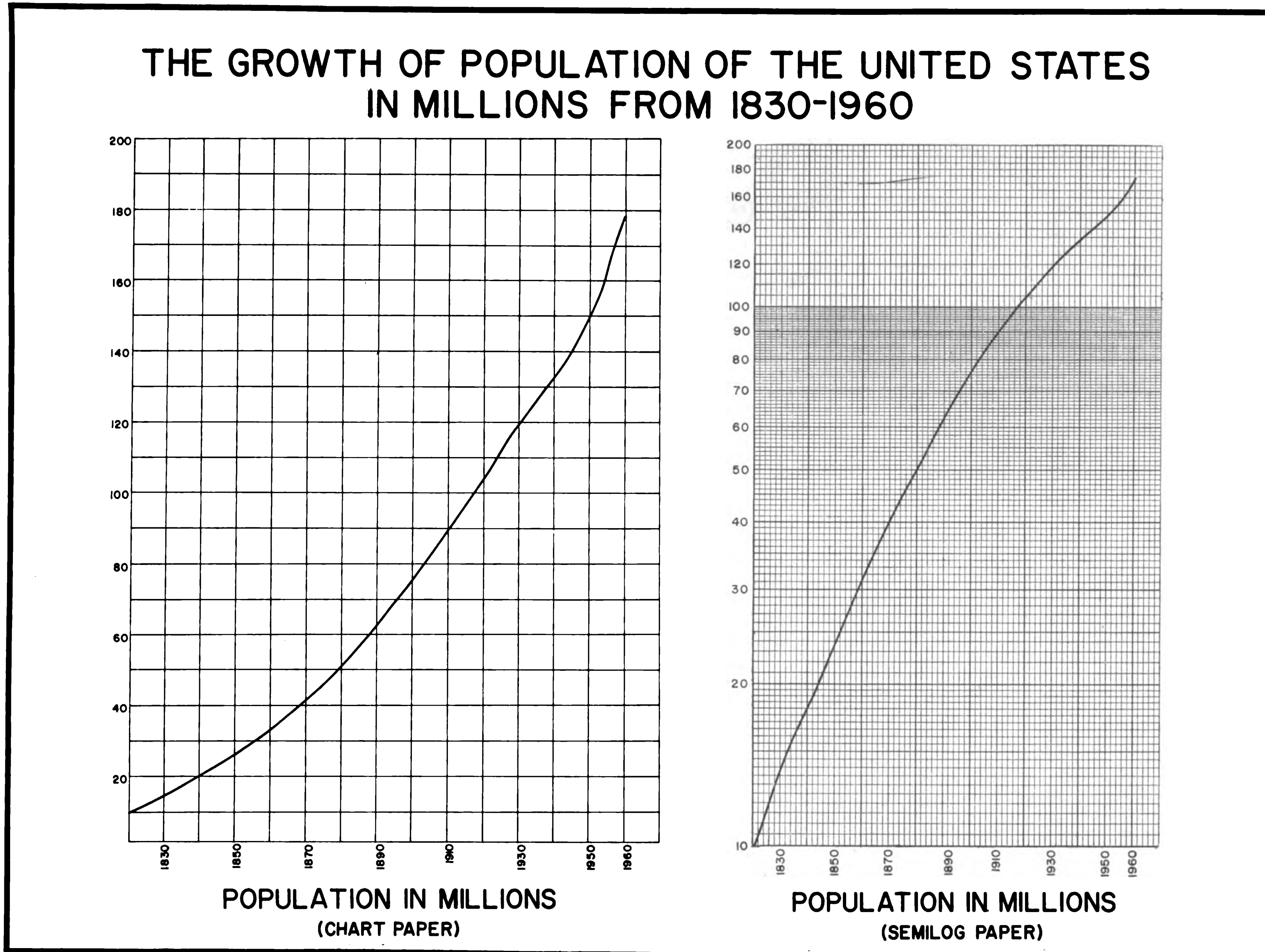


Figure 25. Comparison of amount and rate of change.

values along the ordinate should increase from bottom to top.

d. Scale Indication. Scale values should be placed outside the coordinate axes. They are at the bottom for the horizontal (abscissa) scale and at the left side for the vertical (ordinate) scale. The numerical value of coordinates should be indicated at intervals spaced far enough apart to avoid a crowded apperance while still permitting quick identification. On $\frac{1}{10}$-inch coordinate paper, every fifth ruling provides a suitable interval.

e. Scale Captions. Each scale caption should describe the variable represented and the unit of measurement. In the case of the independent variable in figure 25, the dates of the years are self-explanatory. The dependent variable requires that "Population" be further defined so that the caption reads "Population in Millions." If the symbol P had been used in the text to describe population, the caption should read "Population, P, in Millions." Captions should be readable from the bottom and right side of the graph.

77. Rectilinear Charts

Rectilinear charts are constructed with a two-coordinate frame of reference. Points are located with rectangular coordinates and connected by a curve. Scales are arithmetic, that is, equal spaces on the axes represent equal numerical distances. Rectilinear charts are used to demonstrate the amount of change during a period. They are also used for interpolating values, demonstrating trends, emphasizing movement rather than actual amounts, and for picturing a series in which there are many successive values to be plotted. Several curves can be shown on the same chart. Rectilinear charts are undesirable when the series depicted has relatively few plotted values, when the movement of the data is extremely irregular and does not indicate a trend, when the emphasis should be on change in amounts rather than a trend, or when the presentation is intended for popular appeal.

78. Types of Rectilinear Charts

a. Time Series. A time series chart is the most common form of rectilinear chart. Time in units such as hours, days, months, or years is scaled along the horizontal axis. Amounts, in appropriate units, such as degrees of temperature, thousands of dollars, or millions of population, are scaled along the vertical axis.

b. Profile Graph. A profile graph is made by blackening or crosshatching the area inclosed between the curve and horizontal axis. In such a case, the curve must begin at the vertical axis and end at the right side of the grid area. Profile graphs are used to emphasize the quantities involved in a trend, rather than the amount of variation.

c. Multiple-Curve Graphs. Comparisons between trends of factors representing aspects of a particular problem can be made by plotting several curves within the same frame of reference. If the amounts involved in the comparison are so different that two different vertical scales are required, the second scale is placed either along the right-hand edge of the grid or to the left of the first amount scale. Each scale must have a clear caption and each curve must be labeled in this situation.

79. Coordinate Rulings of Rectilinear Charts

The proper construction of a grid involves more than simply converting a convenient space with cross rulings. As in the matter of general layout, the nature of the data and purpose of presentation must be considered.

a. Vertical Rulings. There should be sufficient number of vertical rulings to aid in reading values on the horizontal scale and to indicate the frequency of plotting. They should be of sufficient weight to guide the eye readily to the horizontal scale. Line weights should be heavier at selected regular intervals to indicate major divisions along the horizontal scale.

b. Horizontal Rulings. Horizontal rulings should be drawn so as to meet the requirements of their two-fold purpose, which is to assist the reading of values on the vertical scale and to provide a series of horizontal bases of comparison. Horizontal rulings should be light enough to contrast sharply with the curves and sufficiently heavy to guide the eye to the vertical scale without conscious effort.

c. Principal Reference Lines. Principal reference lines are wider than other coordinate rulings but narrower than curves. Coordinate rulings are half the weight of reference lines; curves are twice the weight of reference lines.

80. Titles and Notes on Rectilinear Charts

The title of a graph must state its message in a clear, concise manner. Given sufficient thought beforehand, most titles can present adequate information in a single line. If supplementary information is necessary, a subtitle may be used. Further explanatory information is added as a note.

a. Location. The title is located outside the grid area at the top of the graph and should be arranged symmetrically around the approximate centerline of the grid area. Subtitles are placed beneath titles and spaced according to the rules for lettering title blocks. Notes are lettered just above the topmost horizontal grid ruling beginning from the left-hand corner with the word NOTE.

b. Lettering. Lettering for charts and graphs is executed with the standard lettering set. Choice of template and pen number depends on the size of the chart or graph. The title lettering should be the most prominent.

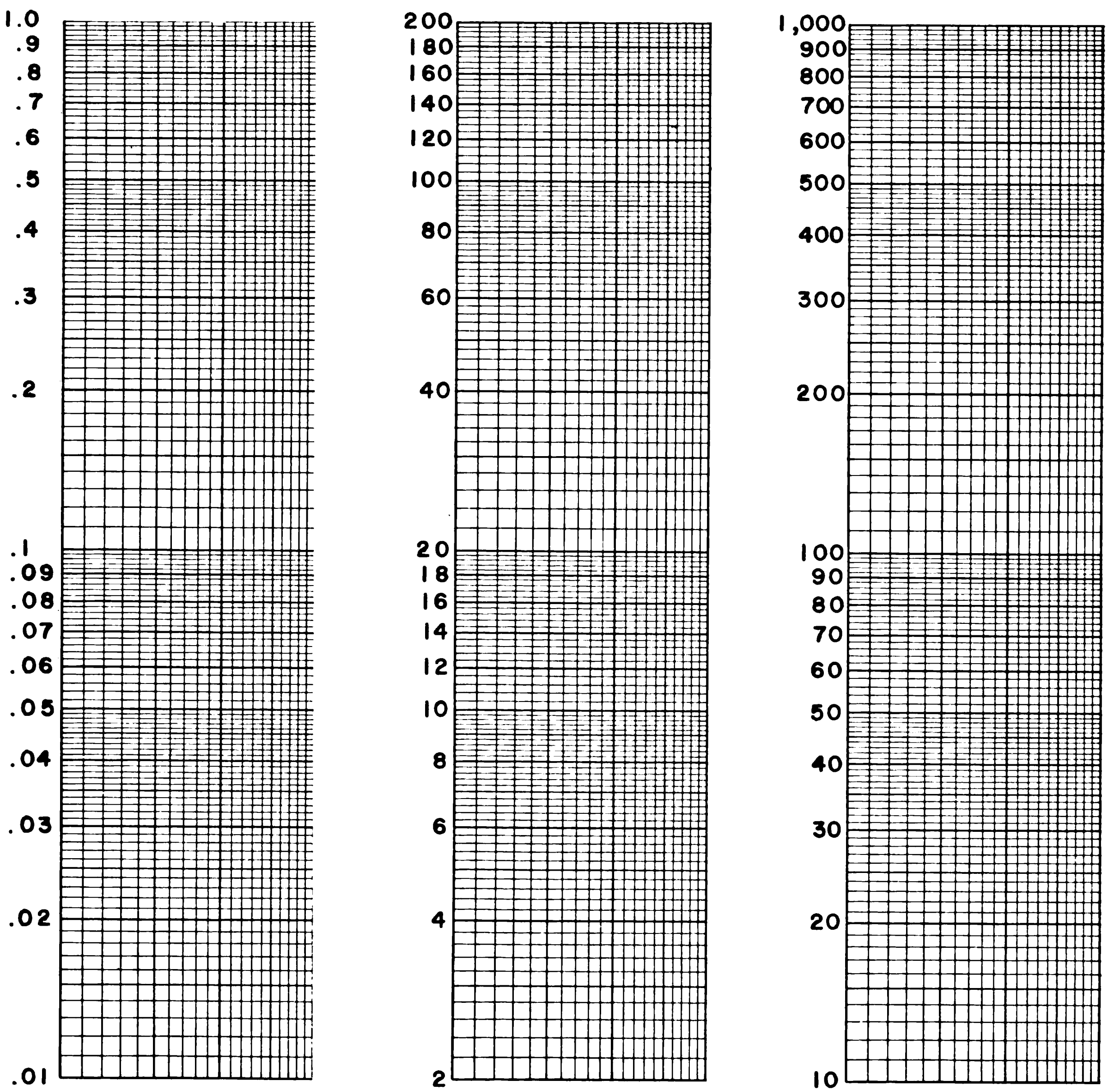


Figure 26. Logarithmic scales.

81. Logarithmic Charts

a. Semilogarithmic Charts. Semilogarithmic grids are constructed by dividing the horizontal scale with equally spaced vertical rulings and dividing the vertical scale with logarithmically spaced horizontal rulings. In a time series chart, time would be arranged along an arithmetic scale and amounts would be arranged along a logarithmic scale. Because semilogarithmic charts are designed to indicate rate of change rather than amount of change, they are also known as rate-of-change charts and ratio charts. Figure 26 illustrates the construction and labeling of a logarithmic scale. Figure 25 compares the amount of change of population as shown by a curve on coordinate paper with rate of change of population as shown by a curve constructed on semilogarithmic paper.

(1) *Uses.* Semilogarithmic charts should be used to indicate the relative movement of a time series, or to compare the relative movements of several time series, but only when the intended audience is likely to be familiar with this form of chart.

(2) *Reading curves.* If the curve is a straight line inclining upward, it indicates a constant rate of change. A convex curve that flattens out, like that in 2, figure 25, indicates an increase at a decreasing rate, despite the increase of population shown on the amount-of-change chart (2, fig. 25). A concave curve that slopes upward as it approaches the right side of the grid indicates an increase at an increasing rate.

(3) *Precautions.* The plotting in rate-of-change charts requires considerable care because of the peculiar character of the logarithmic spacing. When special grids are prepared without intermediate rulings, it is desirable to use a logarithmic plotting scale, which may be made easily from printed commercial paper. Profile graphs are not constructed on semilogarithmic paper. Points are connected with a solid line when a single curve is drawn.

b. Double Logarithmic Charts. Double logarithmic charts are used more for solving problems than for presenting facts. Both horizontal and vertical scales are spaced logarithmically with the result that all algebraic equations representing multiplication, division, roots, and powers are straight lines.

Section III. DISPLAY CHARTS

82. Hundred-Percent Bar Charts

The purpose of a 100-percent bar chart is to show graphically the component percentages of a whole, the whole represented as a single bar and the component percentages as component proportional areas. The bar may be drawn either horizontally or vertically; a common ratio of length to width is 6 inches long to 2 inches wide. A scale can be constructed on a separate sheet of paper dividing the length into 10 divisions, each of which is further subdivided into 10 units. Each unit equals 1 percent. The scale is used to divide the bar into the desired percentages, which are expressed graphically as areas by drawing perpendiculars across the width of the bar at the appropriate percentage markings.

a. Shading. The component segments of a 100-percent bar chart are differentiated from each other by solid or line shading. Solid (black) shading is used only in a series of segmented 100-percent bar charts. Line shading parallel to the length of the bar is easy to construct; horizontal lines are used for horizontal bars, vertical lines for vertical bars. Line shading perpendicular to the length of the bar is not recommended for segmented bars because it confuses the location of the segment limits. Diagonal line shading or crosshatching is used only in small segments because it causes optical illusions of blending if used over a long segment. Crosshatch shading may be used in place of black for wide columns. Dotted shading (pebbled or stippled) is effective for columns of medium width, particularly where a small segment requires a third or fourth distinguishing shading. Lines are spaced uniformly and not too close together. Intersecting diagonal lines also are used for shading.

b. Labels. In addition to shading, each segment is identified by a percentage figure and a word label. The identifying label is placed outside the bar adjacent to the appropriate section and arranged to read horizontally from left to right whether the bar is drawn horizontally or vertically. Numerical percentage figures are placed inside the bar and arranged about the centerline, running parallel to the length. All lettering should be completed before the areas are crosshatched or shaded. When, for reasons of clarity, it is necessary to give the numerical quantities in addition to percentages, the numbers are presented on the side opposite the identifying segment labels; numerical values are then read from left to right and are alined horizontally.

c. Comparisons Between 100-Percent Bar Charts. The 100-percent bar chart presents the component parts of a whole, usually for a specific period or for a particular geographical location. If a chart showing comparisons of component items over a period of years or several geographical locations is desired, a series of 100-percent bars is used. Each bar is the same height and width and contains the same component items. Each item is identified by a different kind of shading; the meaning of the shading is explained through a key placed where it will not interfere with the chart. Darkest shadings are placed nearest the baseline. Such charts require a two-coordinate frame of reference. If the bars extend vertically, percentages are scaled along the vertical axis. Time, location, or other limiting conditions are scaled along the horizontal axis, which also serves as the datum line for the bars.

83. Multiple-Bar Charts

A use of the bar form other than as a 100-percent bar chart is to have the length of each bar proportional to the magnitude of the quantity represented (fig. 27). Bars may be alined vertically or horizontally; when alined vertically, the chart is called a column chart. Rules are given for vertical alinement. The same principles apply for constructing a horizontal chart.

a. Use. The column is effective when used to emphasize comparisons of amount in a single time series, to picture period data as against point data, and to present facts for popular understanding. It should not be used for comparing several time series or for time series over an extended period with many plottings.

b. Layout. A chart consisting of a few columns should be higher than wide; for more than a few columns a wider-than-high chart is preferable.

c. Grids. A completely ruled coordinate surface is not required. The columns themselves make vertical rulings unnecessary. Because multiple-bar charts generally are used for popular presentation and present approximate comparisons, horizontal rulings should be drawn only frequently enough to guide a reader's eye to the vertical scale at major intervals. Horizontal rulings will not extend through bars and need cover only that portion of the field occupied by the columns.

d. Scale Selection. In column charts, the interest generally is in comparisons of amounts for different dates. The amounts are proportionate to the height of the columns; hence the zero line, when it is the principal line of reference, should always be included. When time intervals between values are not equal, columns should be spaced accordingly.

e. Scale Designation. Vertical scale values are placed on the left side, where horizontal rulings are complete. If the tallest columns are at the right, another vertical scale may be placed at the right. Horizontal scale values are centered beneath the columns. Values should not be placed at the top of the individual columns to indicate magnitudes because of the apparent increase they give to the height of the columns.

f. Column Spacing. To space columns equally along the horizontal scale, divide the available horizontal space into twice as many spaces as there are to be columns and center the columns on every other division mark beginning with the first from either end. When there are only a few columns in a chart they should be narrower than the white space between; when there are many columns the reverse should be true.

84. Time-and-Work Schedules and Progress Charts

Figure 27 shows the application of the principle of the 100-percent bar chart for presenting graphically the time estimated for completing various phases of a road construction

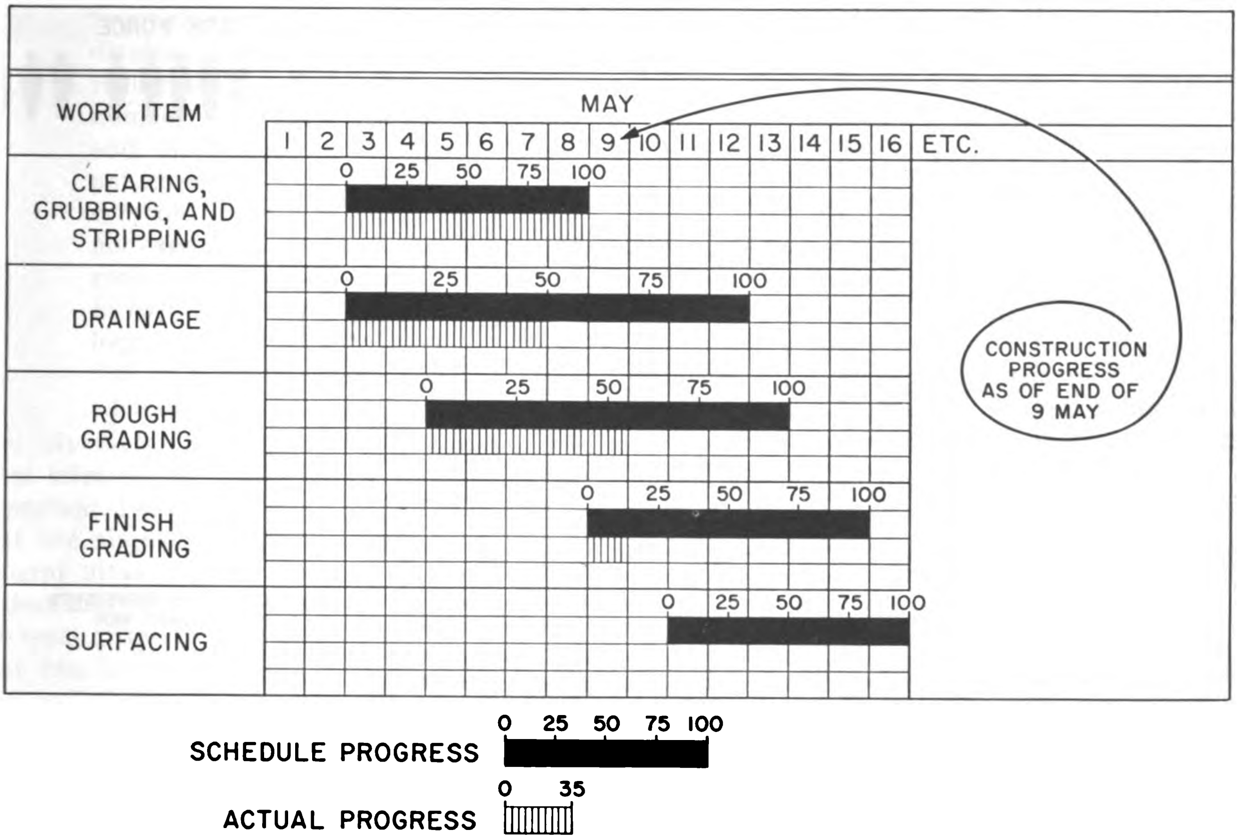


Figure 27. Progress chart.

project. The figure also affords a comparison of a graphic presentation of estimated time, known as a time-and-work schedule and a graphic presentation of the actual time taken, known as a progress report. The end points of each black bar are determined by the estimated starting and finishing dates of each construction phase. The length of each black shaded bar equals 100 percent of estimated time. Subdividing the bar into quarters makes comparison of estimated and actual progress easier. Actual progress is represented by transverse crosshatching. Although not recommended for bar charts having several component items, transverse crosshatching is acceptable in this case because time is the only item depicted, and because daily limits are demonstrated more easily with transverse shading than with diagonal or stripped shading.

85. Hundred-Percent Circles

The circular form (fig. 28) can be used in the same manner as the bar form to show the percentage-wise distribution of the component parts of a whole. Charts using the circular form to show distribution are called sector, or pie, charts.

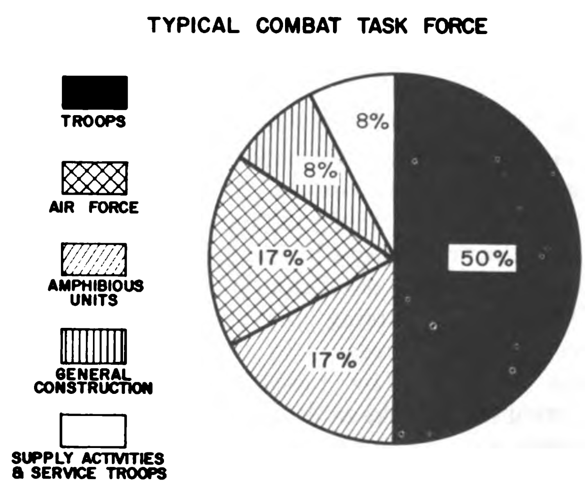


Figure 28. Pie chart.

a. Layout. When several component parts are to be shown, as in figure 28, the circle is regarded as a clock with the 12 o'clock position as the starting point. When only two component parts are to be shown, or when one component occupies most of the circle, a more pleasing appearance is achieved by dividing the smaller segment or segments symmetrically about the 12 o'clock or 6 o'clock marks.

b. Shading. Segments are distinguished from each other with the same shading techniques used in component bar charts. Solid shading is recommended for the largest segment. Color may be used to increase the dramatic effect.

c. Labels. Lettering and numbering should be alined horizontally inside the circle so that the chart can be read without turning. When it is impossible to place the lettering inside a segment being identified, the label is placed in a horizontal plane adjacent to the segment and connected to it by a short, straight arrow. When several circles are used to compare the distribution of the same items in different periods, it is easier to identify the component items with consistent shading patterns than with labels. In such a case, the shading symbols must be explained through a legend or key.

86. Pictorial Charts

A pictorial chart (fig. 29) is basically a form of multiple-bar chart with the bars alined horizontally. Magnitudes in the multiple-bar chart are proportional to the lengths of the bars; in a pictorial chart they are proportional to the number of symbols in a line. The subject of a bar chart is presented in its title or the legend that explains the shading symbols; the subject of a pictorial chart is explained through the nature of the pictorial symbols.

a. Scope. Pictorial charts are used to compare approximate quantities. Statistical data are rounded off to fit pictorial units. Symbols should express some basic characteristic of the subject so that a minimum of explanation is required. Increasing quantities are shown by proportional increases in the number of symbols used, not by proportional increases in symbol sizes. Like multiple-bar charts, pictorial charts are used only for comparisons, not for making isolated statements.

b. Layout. Pictorial charts are read from top to bottom and from left to right. The initial problem is to determine the size of the chart. Once this is known, the next step is to divide the space to achieve a balanced effect and clear presentation. A trial chart is blocked out with rectangles of proportions equal to the height and length of the lines of lettering and rows of symbols. Sufficient space must be allowed between rectangles; space between rectangles should not be more than their height or less than half of it. The area occupied by the total of the individual rectangles is represented as a large rectangle and centered in the chart. All rectangles begin from a common, vertical reference line at the left. The reference line is drawn lightly as a guideline and does not appear in the completed chart.

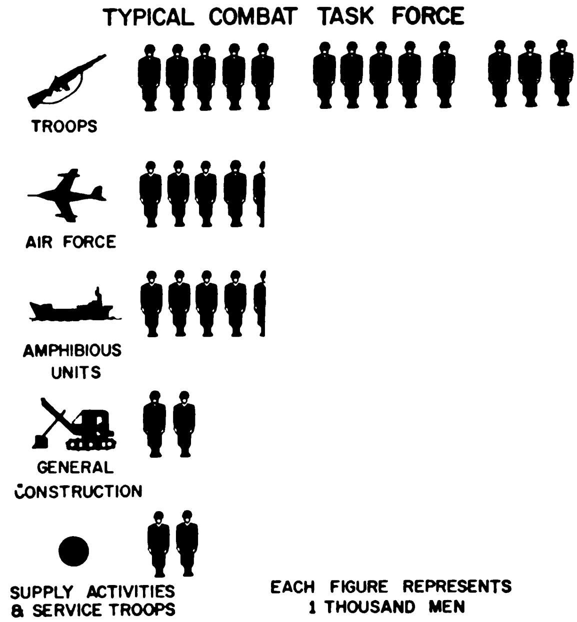


Figure 29. Pictorial chart.

(1) *Rows per chart.* The rule of thumb is to limit the number of rows to between three and six. If the comparison is such that more than six rows are required to present a clear picture of a trend or relationship, the data should be presented as a curve.

(2) *Symbols per row.* Symbols must be large enough to be clear and with enough white space separating each from its neighbor for both to be dis-

tinguishable. Values assigned to the individual symbols influence the number required. For general purposes, the number of wide symbols, buildings, and machinery for example, should not exceed 12. The number of narrow symbols, people for example, should not exceed 25. Symbols should be wide enough for the basic unit to be divided in half vertically. To aid in counting long rows of symbols, make units of five by providing a wider space after each fifth symbol.

c. Symbols. Simplified silhouettes are the most effective for pictorial charts. The most important feature of simplified silhouettes is that the simplest symbols represent the most general situation and are recognized by the widest audience. A general rule for selecting the most characteristic symbol is to use the one that can be drawn from memory. After the size and shape of the basic symbol had been decided, it must be reproduced uniformly in the necessary quantity. A convenient sized rectangle of detail paper is laid out with a horizontal baseline and vertical width lines extending to the edges of the sheet. Figures are drawn between the vertical lines and from the baseline. Guidelines are drawn lightly on the chart surface. If the chart is to be reproduced and tracing paper is used, the figures are placed underneath the tracing sheet and the guidelines alined. If the chart is drawn on an opaque surface, the back of the template may be blackened carefully with a soft pencil to create a carbon paper effect. The figures are traced off from above after guidelines are alined.

d. Titles and Symbols Explanations. Titles are lettered at the top of the chart in uppercase letters, beginning from the common vertical reference line at the left. They should be as concise as clarity allows and should not include facts not shown in the chart. Symbol explanations are located beneath the rows of symbols and are executed in lowercase letters, except for the first letter of the word of the sentence, and begin at the common vertical reference line at the left.

87. Organization and Flow Charts

Although organization and flow charts are used for different purposes, both emphasize the qualitative relationship of the component parts of a whole.

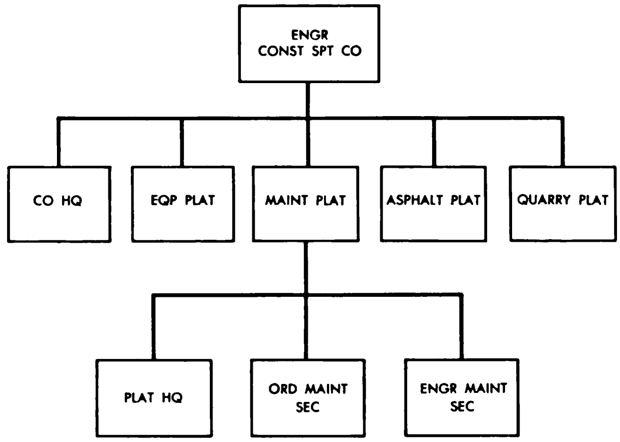


Figure 30. Organization chart.

a. Organization Charts. Figure 30 graphically presents a typical organization chart. The components are identified by activity, rather than strength. The chart reads from top to bottom and the lettering is from left to right. Note that connecting lines are perpendicular to each other, rather than radiating from a focal point. Rectangles offer a convenient form for inclosing the various titles, being easier to letter than circles. Lettering in the rectangles is uniform.

b. Flow Charts. Flow charts are used to show the various steps of a process. Position of the steps on the drawing sheet is according to their position in the process; arrows show the direction of the process. Figure 31 represents the sequence of operations followed in testing soil samples.

c. Layout. The same rules of clarity and balance that have been discussed above apply here. All rectangles in a given row are the same size. Lettering within rectangles is uniform; lines connecting the rectangles may be drawn in a different color from the lines forming the rectangles.

88. Tools and Materials

Working charts not intended for display or reproduction are constructed on coordinate paper with drawing pencils and standard drafting equipment. Charts for display or reproduction are prepared in pencil and traced in

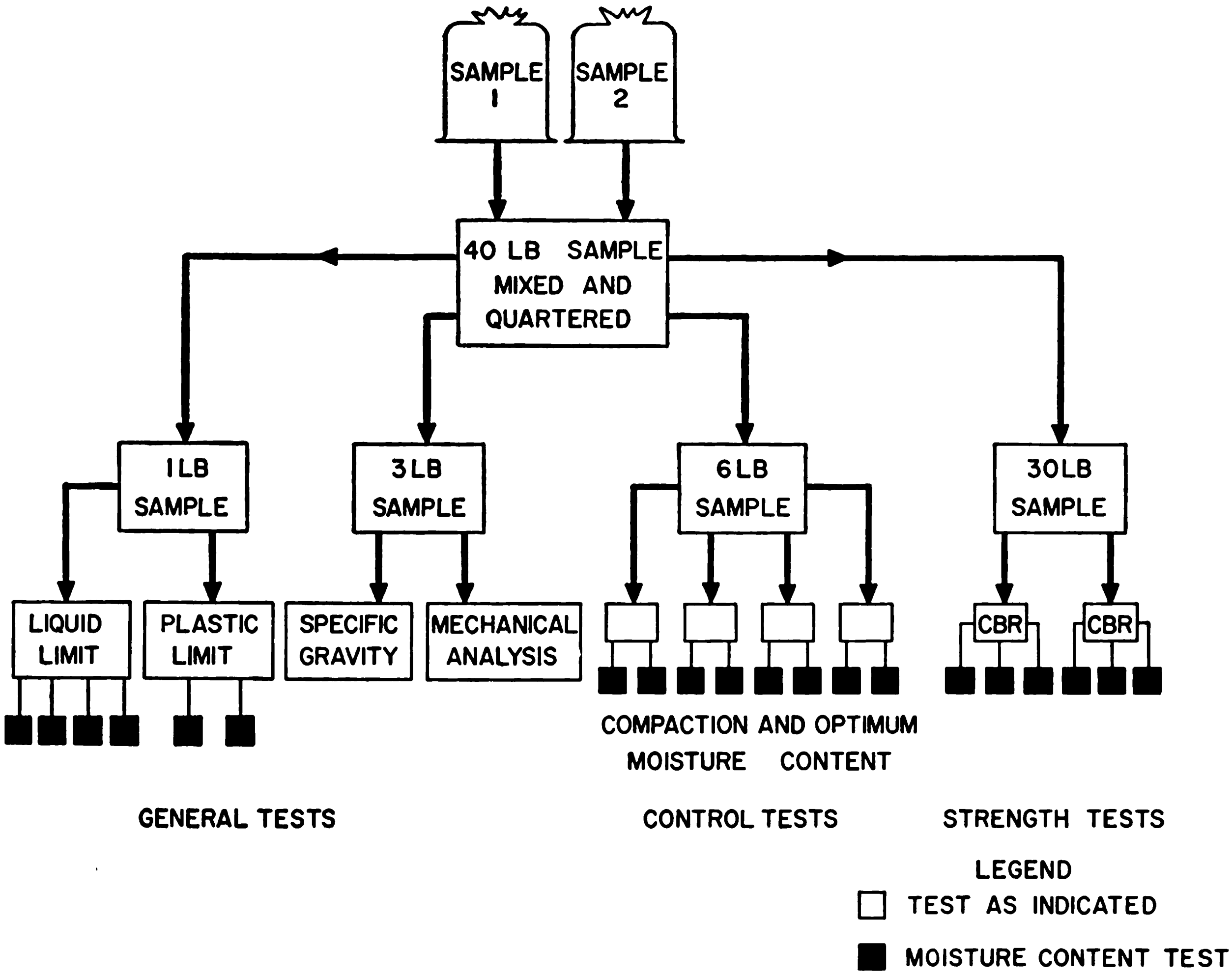


Figure 31. Flow chart.

ink, or inked in. The ruling pen is used for inking lines drawn with a T-square or triangle. Payzant and Speedball pens are used to give the proper weight to curves and other freehand lines.

a. Payzant Pens. Payzant pens have a flat body containing a reservoir and curved nibs resembling a beak. The body of the pen is attached to a round holder. The pens come in 11 sizes ranging from No. 000, the coarsest, to No. 8, No. 000 produces a line approximately 1/4 inch thick, and No. 8 makes a line as fine as an ordinary coarse pen. The pens are filled by placing ink in the reservoir with a quill or dropper. The pen is held in the same manner as a freehand lettering pen and at an angle that permits the nibs to rest flush against the paper. After use, pens are cleaned with running water and by passing a sheet of thin cardboard or a razor blade between the nibs.

b. Speedball Pens. Speedball pens are used with a regular penholder. The pens are made in four styles and resemble ordinary pens with a round, square, oval, or oblong shoe at the end. The pens perform best when only moderately full and should be held at an angle permitting the shoe to rest flat on the paper. Ink flows best when strokes are made downward or from left to right with a full, slow movement.

c. Chart Paper. Smooth, heavy paper provides the best surface for display charts. Bristol board and illustration board normally are available in standard flat sheets 22 by 30 inches and in thicknesses up to 1/8 inch. Both sides of

Bristol board are satisfactory drawing surfaces; illustration board provides only one suitable side. Hot-pressed surfaces are glossy and suitable for pen-and-ink work and water colors. Cold-pressed surfaces are duller and suitable for water colors but are not as good for pen-and-ink work as hot-pressed.

Section IV. TRAINING AIDS

89. Characteristics

A training aid is a simple explicit poster-like representation of an official standard, and is used to direct its audience to a specific decision, selection, or method of behavior. For example, figure 32, provides a quick and ready aid for determining the standard specifications of common nails so that a correct selection can be made. A training aid may consist of a picture plus wording or wording alone. The paragraphs in this section present sufficient information for the draftsman to produce an adequate training aid by using his technical drawing skills.

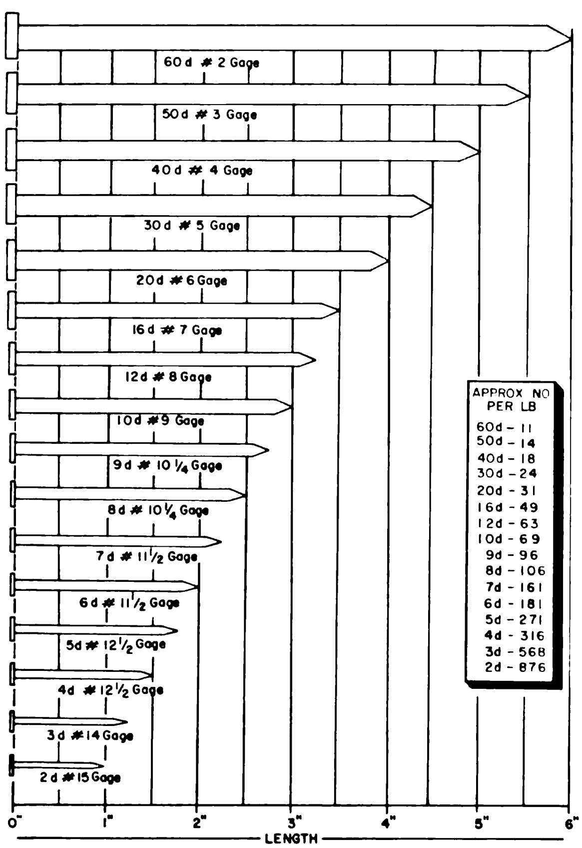


Figure 32. Training aid.

90. Elements of a Training Aid

Wording, or text, and the picture are the principal elements of a training aid. Together they should compose a poster that is simple and bold in design, brief in text, understood at sight, pleasant and strong in color, balanced in composition, and designed to attract attention.

a. Picture. The considerations governing the choice of appropriate pictorial material are similar to those presented for choosing pictorial symbols (par. 86*c*). The picture should convey the same information as the text; it should not be so detailed as to distract attention from its message; and it should be general enough to be recognized by the widest possible audience. Clippings of pictures from newspapers and magazines may be used if drawing talent is not available. If the clipping is cut carefully and given a few touches of color after being mounted, it will give the appearance of having been painted on the card. A file of clippings for tracing or mounting will be helpful to draftsmen engaged in preparing training aids. Whenever a clipping contains a human figure, it should be faced toward the text so that the eye of the observer is led toward the text.

b. Text. Text should be brief; it should make a complete statement; and its meaning should be clear. When a training aid makes a series of statements, the number should not exceed four. Negative statements should be avoided; the poster should tell what to do, rather than what not to do. When not expressed as a directive or command, the text should express a conclusive attitude. Wording is effective by virtue of its message and its mechanical arrangement on the poster.

91. Layout

The layout of a poster is a rough pencil plan that arranges lines, paragraphs, and pictures so that they have a pleasing relation to one another. The important considerations in the layout of a poster are balance, harmony, unity, and simplicity.

a. Balance. The principle of balance is similar to that described in the layout of a pictorial chart. Lines of lettering and pictures are represented as rectangles and arranged symetrically about vertical and horizontal centerlines or along intersecting diagonals drawn between opposite corners of the card. The lines of the rectangles parallel the borderlines of the poster. Balance also is affected by tones. If one line of lettering is quite dark, it must be balanced by an equal area of the same tone or a larger area of a lighter tone.

b. Harmony. Harmony implies a relationship between the various layout rectangles. Size, shape, tone, and color must have qualities in common throughout.

c. Unity. The component parts of a training aid must blend to focus audience attention on the most important units. This can be done by arranging the most important parts of the inscription at the most important points on the poster. Unrelated statements should be avoided.

d. Simplicity. Training aids should not be overornamented. Letter styles, borders, and backgrounds should be simple enough to permit concentration on the central message. Lettering is drawn to the size required by good balance and emphasis.

e. Lettering. Letters are sketched in with a soft pencil, and with guidelines to establish letter height and inclination. If many posters are to be made with the same size and style of lettering, templates can be made by drawing the alphabet and numbers on a sheet of cardboard and cutting the letters out with a sharp knife and steel straightedge. Beginners should construct block letters of the kind shown in figure 16. The outlines are drawn with a ruling pen after the letters have been sketched, and the open areas are filled in with a brush or ruling pen.

92. Use of Color

India inks are available in various colors. Draftsmen should limit themselves at first to two colors in preparing training aids.

a. Color Combinations. Red is the most suitable single color for use in combination with black and white. It provides brightness and effective contrast and its intensity permits the eye to focus readily at normal reading distance. Black lettering against a yellow background provides the best visibility both for those with normal vision and for those who are color blind. For this reason the black-and-yellow combination is used on highway safety signs. Green against red, blue against red, and red against green should be avoided because these combinations seem to make the letters vibrate and difficult to read.

b. Application of Colors. Poster color or ink may be applied with a wide-point pen or a brush. If sufficiently diluted, poster color may be used in place of ink to produce fine lines drawn with a ruling pen. If a stencil is used for uniformity, letters may be cut out of colored paper and pasted on a poster with rubber cement or glue.

93. Materials

Illustration and Bristol board are satisfactory for preparing training aids.

a. Brushes. Brushes are made of sable or camel's hair with the former preferable. They are in two styles, round and flat, and have square ends. The widths of the sizes most generally used range from 1/4 to 1 inch. Brushes are used for lettering with water colors.

(1) *Use.* A brush is held between the thumb and the first two fingers in a nearly vertical position and should not be gripped too tightly. Strokes are made with a full, swinging movement of the arm and with the extreme tip of the brush. The brush should be kept well filled with color and should be lifted abruptly from the paper at the end of the stroke to give the stroke a square tip. Persistent practice is essential for the development of a satisfactory technique.

(2) *Care.* Brushes should always be kept clean and stored either flat or upright on the handle. To clean a brush, use the proper solvent or thinner for the color or colors used to remove as much of the color as possible. Wet the brush in lukewarm water, Apply a mild soap, and work up a lather by rubbing the brush on the palm of the hand, then rinse it throughly. Reshape the brush and put it away.

b. Color. Prepared water colors are available in jars. The beginner needs only white, black, red, yellow, and blue. If additional colors are desired, they can be made by mixing the prepared colors.

c. Zip-a-Tone. Zip-a-tone is a clear cellulose, printed with patterns, letters, or symbols and backed with a special wax adhesive. It provides a quick, easy technique of obtaining mechanical letters and shadings of various styles and tones by direct application to chart, graph, or drawing.

(1) *Application.* It is applied to the desired area and rubbed down lightly. The shaded section or letter is then outlined with a cutting-needle and the surplus material is stripped off, after which the portion remaining on the work is rubbed down firmly.

(2) *Advantages.* Its greatest advantages are ease and speed of application and ease of removal.

CHAPTER 5
GEOMETRICAL CONSTRUCTIONS

94. Introduction

a. The entire field of plane geometry was developed by the use of only a pencil, straightedge, and compass. The principles of geometry are used constantly in engineering drawing, but the construction of geometrical figures differs in many cases from the draftsman's method. The draftsman may make use of the many instruments at his disposal in drawing straight lines, parallel and perpendicular lines, circles, arcs, irregular curves, and tangents; also in drawing plane figures such as triangles, squares, polygons, and so on. However, the term geometrical construction means to construct a figure with the aid of a pencil, straightedge (not a scale), and compass (or divider) only.

b. An understanding of the geometrical constructions as presented in this chapter is essential to the draftsman because of their frequent occurrence in engineering drawing. A great number of geometrical constructions may be necessary from time to time, but only those most frequently used are covered. Each construction problem is described by a sequence of steps.

95. Postulates

All constructions are based on three postulates stated by Euclid:

a. A straight line can be drawn from one point to any other point.

b. A straight line can be extended to any length.

c. A circle can be described with a given point as center and any given line as radius.

96. Basic Problems

Any compass and straightedge construction is composed of a succession of three fundamental problems:

a. To draw a straight line through two points.

b. To find the point at which two lines intersect.

c. To draw a circle of given center and radius.

97. To Bisect a Line

a. With point A as center (1, fig. 33) and radius R_1 of any convenient length which is greater than half the length of AB, draw arcs on both sides of line AB.

b. With point B as a center and radius R_2 equal to R_1, draw arcs on either side of line AB intersecting the previously drawn arcs at points C and D.

c. Draw the line CD which will intersect the line AB at its midpoint E.

98. To Bisect an Arc

a. With point A (1, fig. 33) as a center and radius R_1 of any convenient length, draw arcs on either side of the given arc AB.

b. With point B as a center and radius R_2 equal to R_1, draw arcs on either side of the given arc AB intersecting the previously drawn arcs at points C and D.

c. Connects points C and D, bisecting arc AB at point F. It will be noted that this solution is identical to the preceding solution. It is not necessary to construct line AB.

99. To Bisect an Angle

a. With point V (2, fig. 33), the apex of the given angle AVB, as a center and with radius R_1, of any convenient length, draw an arc intersecting both sides of the angle.

b. With the points of intersection thus formed as centers and with radius R_2 of any convenient length, draw arcs intersecting at point C.

c. Connect points V and C, bisecting the given angle.

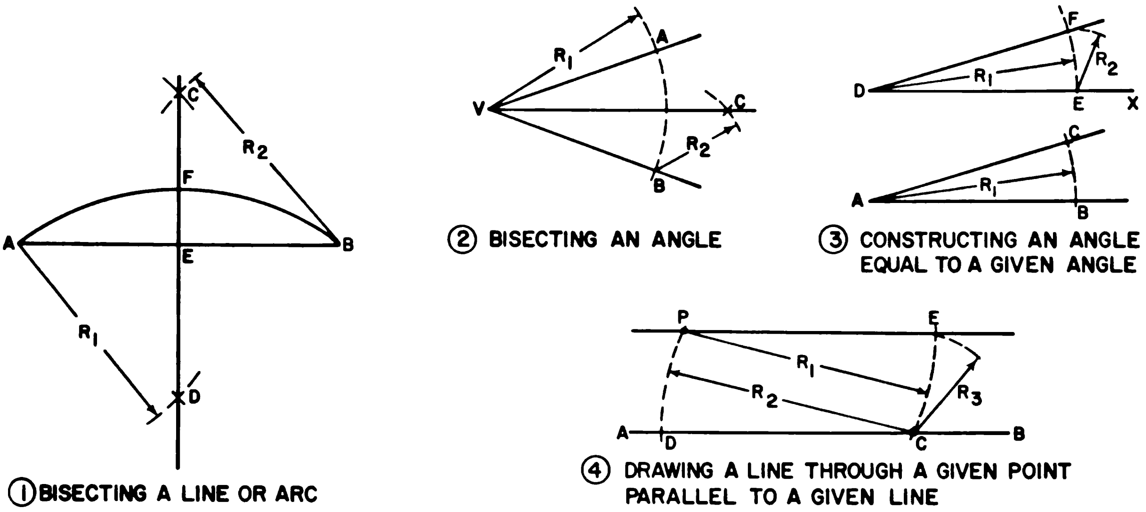


Figure 33. Elementary constructions.

100. To Construct an Angle Equal to a Given Angle

a. Draw line *DX* (3, fig. 33) of convenient length as one side of the angle to be constructed.

b. With point *A* as a center and any convenient radius R_1, strike an arc intersecting both sides of the given angle *A* in points *B* and *C*.

c. With point *D* as center and the same radius R_1, strike an arc of convenient length, intersecting the line *DX* at point *E*.

d. Set compass to the radius R_2 equal to the chord *BC*.

e. With point *E* as a center and a radius R_2 strike an arc which intersects first arc at point *F*.

f. Draw line *DF*, making angle *D* equal to angle *A*.

101. To Draw a Line Through a Given Point Parallel to a Given Line

a. With given point *P* (4, fig. 33) as a center and a radius R_1 of any convenient length, draw an arc intersecting the given line *AB* at point *C*.

b. With point *C* as a center and with radius R_2 equal to R_1 draw an arc intersecting line *AB* at point *D*.

c. With point *C* as a center and radius R_3 equal to *PD*, draw an arc intersecting the arc drawn in *A* at point *E*.

d. Connect given point *P* with point *E*, forming the required parallel to given line *AB*.

102. To Erect a Perpendicular to a Line From a Given Point

a. With given point *P* (1, fig. 34) as a center and radius R_1 of any convenient length, draw arcs intersecting given line *AB*.

b. With these intersections as centers and radius R_2 of any convenient length, draw arcs intersecting at point *Q*.

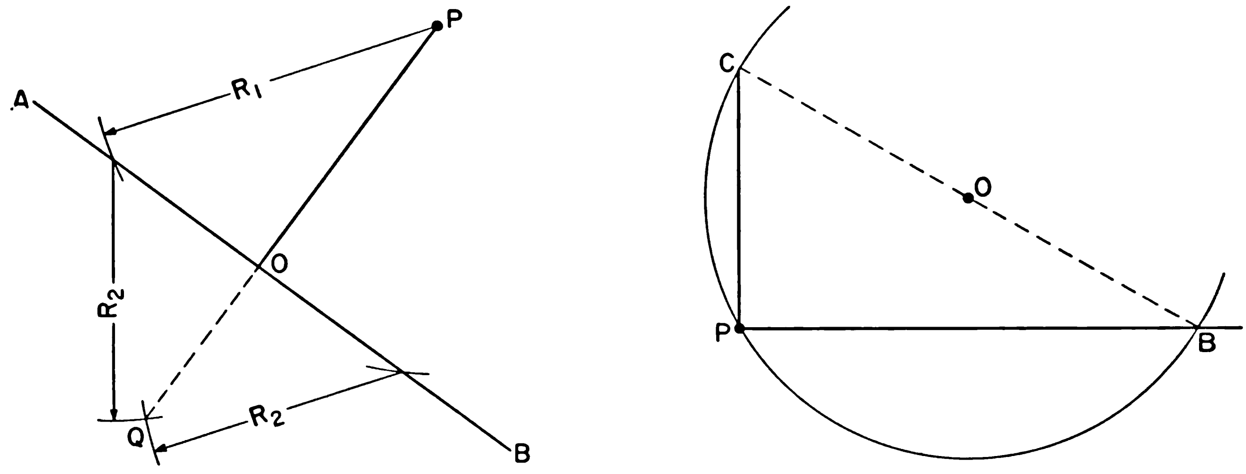
c. Line *PQ* is then the required perpendicular, with point *O* the intersecton of the perpendicular with the given line.

d. Join the points thus formed.

103. To Erect a Perpendicular to a Line at a Given Point

a. To erect a line perpendicular to line *PB* at point *P* (2, fig. 34), select any convenient point *O* as a center and, with radius *OP*, draw an arc slightly greater than a semicircle from line *PB*.

b. Extend a line from the intersection of the arc and line *PB* through point *O*, intersecting the arc at point *C*.



(1) ERECTING A PERPENDICULAR FROM A POINT TO A LINE

(2) ERECTING A PERPENDICULAR AT THE END OF A LINE

Figure 34. Erecting perpendiculars.

c. Connect points *P* and *C*, forming the required perpendicular.

104. To Divide a Line Into a Given Number of Equal Parts by Construction

a. Draw *AC* at any convenient angle to *AB* (fig. 35).

b. With compass or dividers, mark off required number of parts along *AC*.

c. Connect *B* with last point located on *AC* (No. 7 is shown).

d. Using method of paragraph 101 (repeated for each point on the line *AC*), draw lines from points 1 through 6 parallel to 7*B* and intersectng *AB* at *D*, *E*, *F*, *G*, *H*, and *J*.

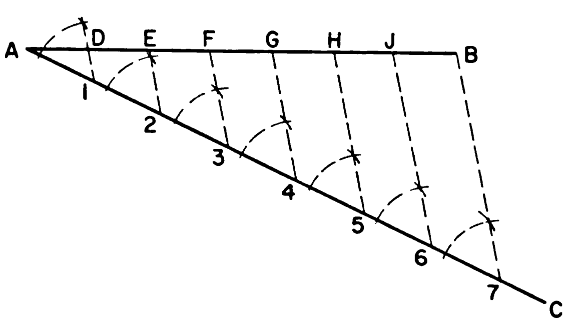


Figure 35. Dividing a line equally.

Note. A draftsman would do this by using two triangles to transfer points. It is not necessary to draw dotted lines to transfer points from *AC* to *AB*.

105. To Construct an Equilateral Triangle Given One Side

a. With side AB as a radius and centers at *A* and *B*, strike arcs intersecting at *C* (1, fig. 36).

b. Draw *AC* and *BC* forming equalateral triangle *ABC*.

106. To Construct an Isosceles Triangle Given Base and One Side

a. With side *DE* as a radius and centers *A* and *B*, strike arcs intersecting at *C* (2, fig. 36).

b. Draw *AC* and *BC* forming isosceles triangle *ABC*.

107. To Construct a Scalene Triangle Given Three Sides

a. With side *DE* as a radius and *A* as a center, strike an arc (3, fig. 36).

b. With side *FG* as a radius and *B* as a center, strike an arc which intersects first arc at *C*.

c. Draw *AC* and *BC* forming scalene triangle *ABC*.

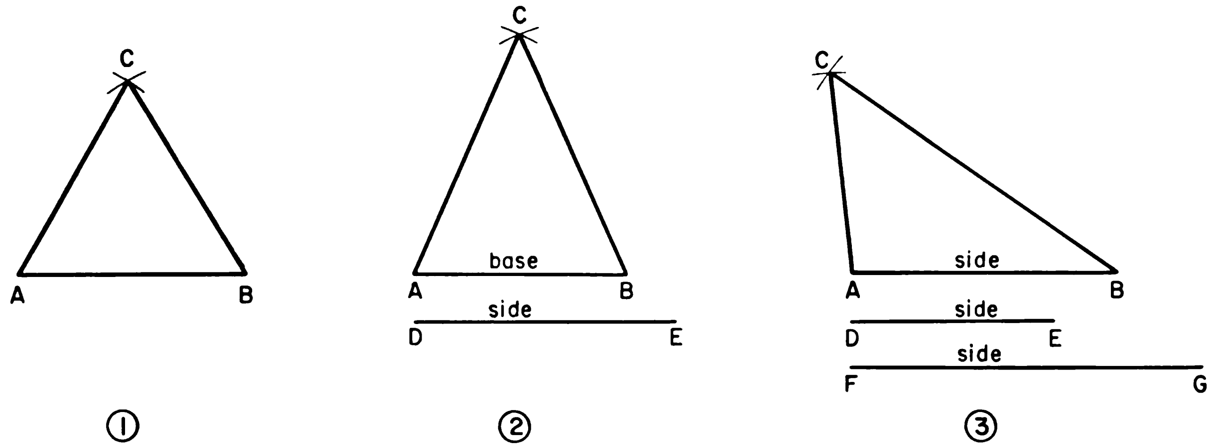


Figure 36. Constructing triangles.

108. To Construct a Square Given One Side

a. Extend side AB to a convenient length AD (1, fig. 37).

b. Erect a perpendicular BOC to line AD at point B (par. 6).

c. With side AB as a radius and B as a center strike and arc intersecting BO extended at point C.

d. With same radius and with centers A and C strike arcs intersecting at point E.

e. Draw AE and EC completing square $ABCE$.

Note. The draftsman could use 90° triangles and a T-square to draw perpendiculars.

109. To Construct a Regular Hexagon, Given the Distance Across Corners

a. Bisect the given line AB at point O (1, fig. 38).

b. With point O as a center and with distance OA as a radius, scribe a circle about line AB.

c. With A and B as centers and with the same radius, draw arcs intersecting the circle at points C and D and at E and F.

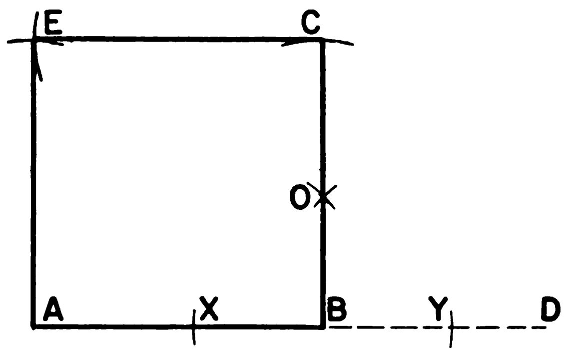


Figure 37. Constructing a square given one side.

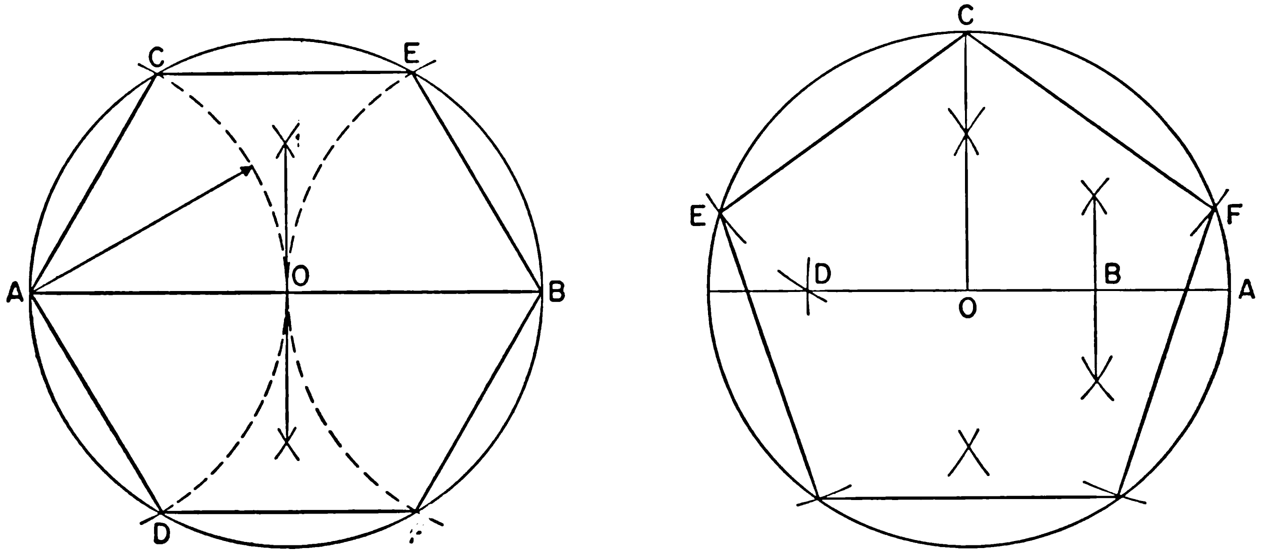
110. To Inscribe a Regular Pentagon Within a Circle

a. Draw a diameter of the given circle (2, fig. 38).

b. Draw radius OC perpendicular to the diameter.

c. Bisect line AO at point B.

d. With point B as a center and using BC as a radius, draw an arc intersecting the diameter at point D.



① CONSTRUCTING A REGULAR HEXAGON, GIVEN THE DISTANCE ACROSS CORNERS

② INSCRIBING A REGULAR PENTAGON IN A CIRCLE

Figure 38. Constructing polygons.

e. With point C as a center and using CD as a radius, draw an arc intersecting the circle at point E.

f. Draw line EC, thus forming one side of the required pentagon.

g. Using the dividers, step off distance EC around the circle. Connect the point thus formed to complete the required pentagon.

111. To Construct a Regular Hexagon Given the Distance Across Flats

a. Find O the midpoint of given distance AB (par. 97).

b. With point O as acenter (1, fig. 39) and radius $R_1 = OB$, strike arc of at least 60° from point B in clockwise direction.

c. With point B as a center and radius R_1, strike arc intersecting first arc in point 1 and extending at least 60° in a counterclockwise direction.

d. With point 1 as a center and radius R_1, strike an arc intersecting second arc in point 2 and extending at least 60° in clockwise direction.

e. With point 2 as a center and radius R_1, strike an arc intersecting third arc in point 3.

f. Draw lines $B3$ and $O2$ intersecting in point 4.

g. With point O as a center, and $O4 = R_2$ as a radius, draw complete circle.

h. Starting at point 4 and radius of R_2, step off points 5, 6, 7, 8, and 9.

i. Connect points 4, 5, 6, 7, 8, and 9 to complete the hexagon.

112. To Construct a Regular Octagon Given the Distance Across Flats

a. Construct a square with one side equal to given distance AB (par. 108).

b. Draw diagonals of the square which intersect in point O (2, fig. 39).

c. With each corner of the square as a center and a radius R equal to half the diagonal AO, strike arcs intersecting the sides of the square in eight points.

d. Connect the eight points to complete the octagon.

113. To Draw a Circle of Given Radius Tangent to a Given Line and Passing Through a Given Point

a. Given the required radius $R_1 = 1\frac{1}{8}''$ (1, fig. 40) draw line CD parallel to given line AB at a distance equal to this radius.

b. Using the given point P as a center and

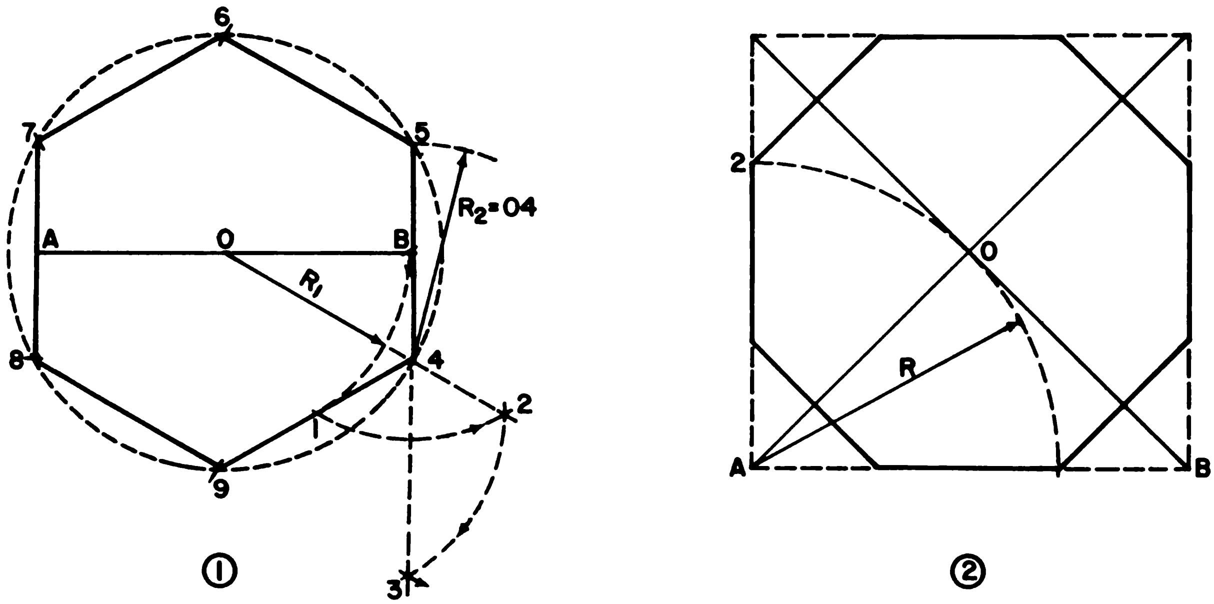
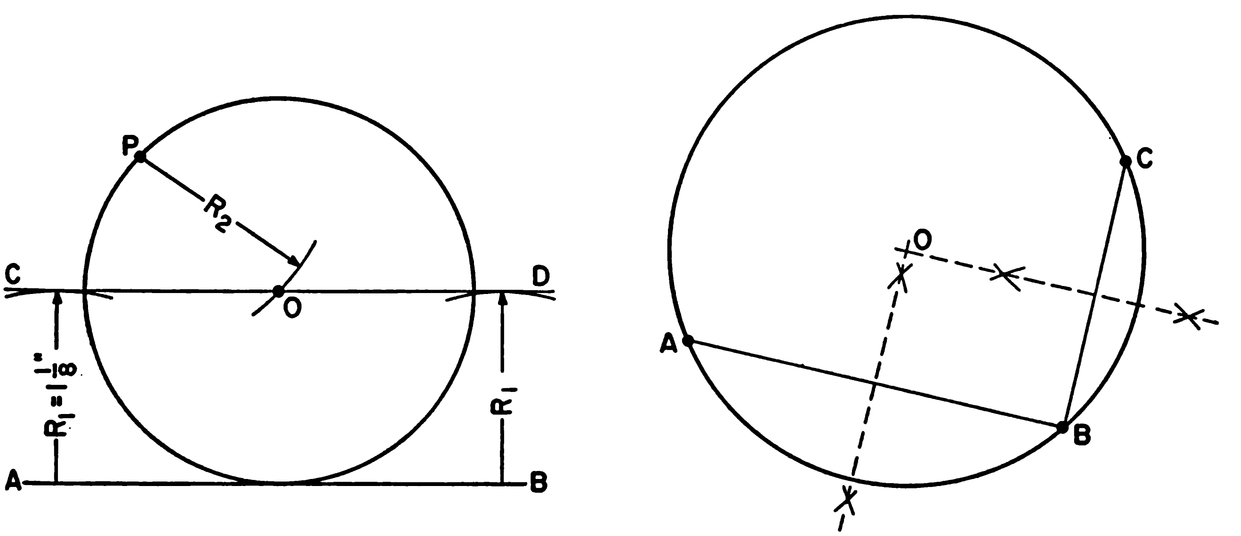


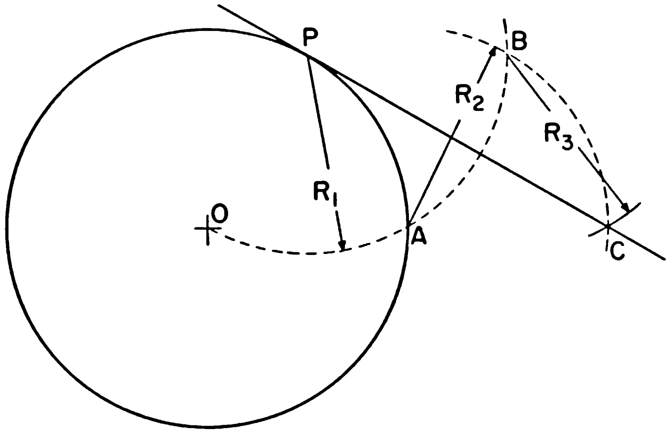
Figure 39. Constructing a hexagon and octagon given distance across flats.

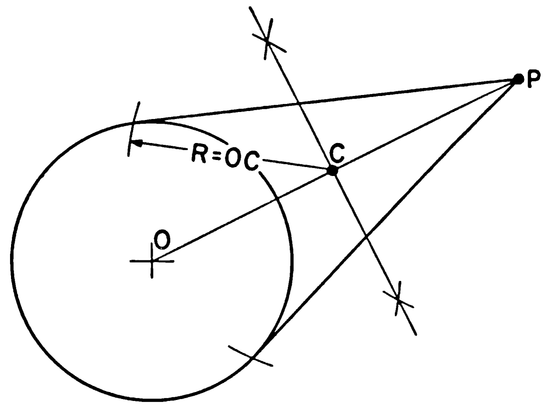


① DRAWING A CIRCLE TANGENT TO A LINE AND PASSING THROUGH A POINT

② DRAWING A CIRCLE THROUGH 3 POINTS

Figure 40. Circles.





① DRAWING A TANGENT TO A CIRCLE AT A GIVEN POINT

② DRAWING 2 TANGENTS TO A CIRCLE FROM A GIVEN POINT

Figure 41. Tangents to circles.

using the same radius, draw an arc intersecting line *CD* at point *O*.

c. Using point *O* as a center and with the same radius, draw circle through point P tangent to line *AB*.

114. To Draw a Circle Through Three Given Points

a. Draw chords *AB* (2, fig. 40) and *BC* connecting the three given points.

b. Draw the perpendicular bisector of chords *AB* and *B* so that they intersect at point *O*.

c. Using point *O* as a center and distance *OA* as a radius, draw the required circle through the three given points.

115. To Draw a Tangent to a Circle at a Given Point on the Circle

a. With given point *P* (1, fig. 41) on the circumference of the given circle as a center and with radius R_1 equal to the radius of the given circle, draw arc *OAB* intersecting the circumference of the circle at point *A*.

b. With point *A* as center and R_2 equal to R_1, strike an arc as indicated in 1, figure 41. Point *B* is the point of intersection.

c. With point *B* as center and R_3 equal to R_2 strike an arc with *C* as the points of intersection.

d. Connect points *P* and *C* forming the required tangent.

116. To Draw Two Tangents to a Circle From a Given Point

a. Draw line *OP* connecting center of circle *O* with the given point *P* (2, fig. 41).

b. Bisect line *OP* at point *C*.

c. With point *C* as a center and OC as a radius, draw arcs intersecting the circle.

d. From the points of intersection thus formed, draw the required tangents to point *P*.

117. To Draw a Crossed Belt Around Two Pulleys

a. Draw a line through centers of circles *O* and *S* (1, figs. 42).

b. Erect perpendiculars *OA* and *SB* at centers of circles.

c. Draw line *AB* intersecting line *OS* at point *P*.

d. Bisect lines *OP* and *PS*, providing points C_1 and C_2.

e. With point C_1 as a center and using OC_1 as a radius, draw arcs intersecting the circumference of the circle at points 1 and 2.

f. With point C_2 as a center and using C_2S as a radius, draw arcs intersecting the circumference of the second circle at points 3 and 4.

g. Connect the intersections formed in *e* and *f* above, forming the required tangents.

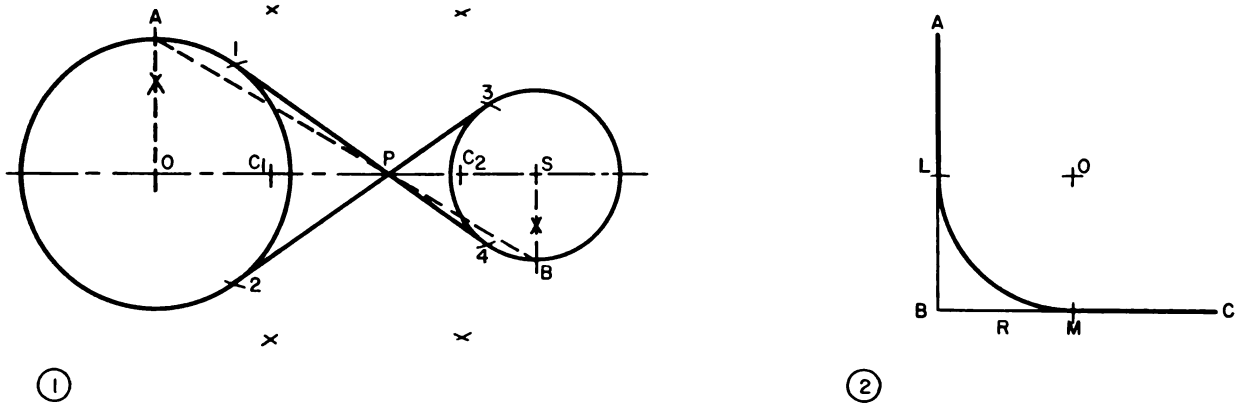


Figure 42. Drawing a crossed belt around two pulleys and rounding off a right angle with an arc of given radius.

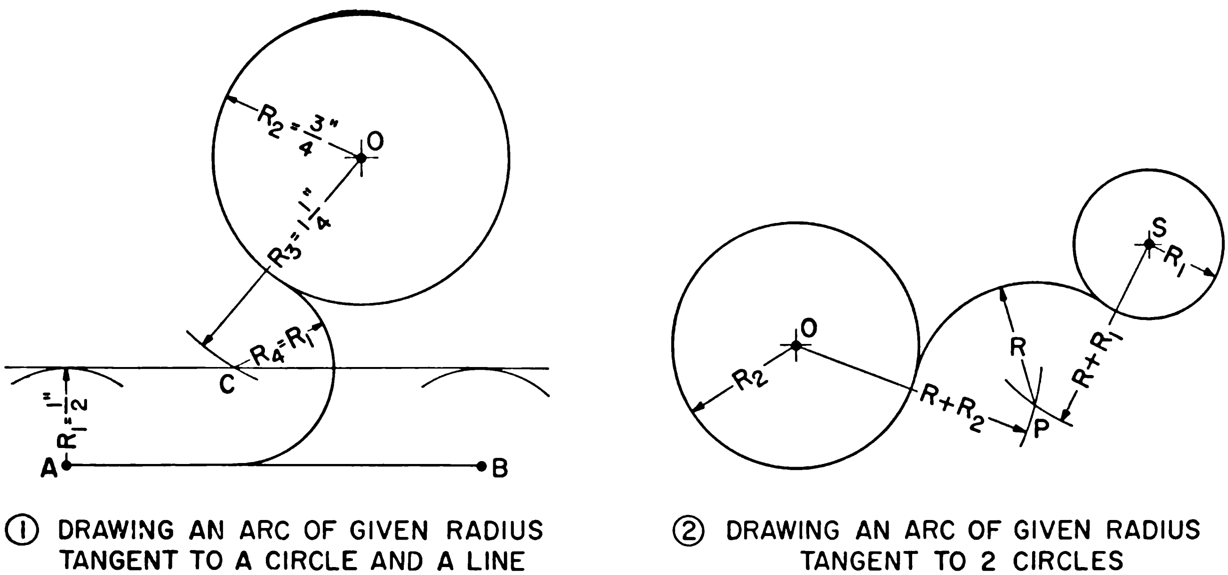


Figure 43. Arcs tangent to circles.

118. To Round Off a Right Angle With an Arc of Given Radius

a. With point *B* (2, fig. 42) as a center and given radius *R*, draw arcs intersecting the sides of the right angle at points *L* and *M*.

b. With points *L* and *M* as centers and with the same radius, draw arcs intersecting at point *O*.

c. With point *O* as a center and with the same radius, draw the required arc *LM*.

119. To Draw an Arc of Given Radius Tangent to a Line and a Circle

a. Let line *AB* (1, fig. 43) be the given line, R_1 the given radius, and R_2 the radius of the given circle. Draw a line parallel to line *AB* at a distance equal to R_1.

b. With point O as a center and radius R_3 equal to R_1 plus R_2, draw an arc intersecting the constructed parallel at point C.

c. With point C as a center and a radius R_4, equal to the given radius R_1, draw the required arc tangent to the given line and circle.

120. To Draw an Arc of Given Radius Tangent to Two Circles

a. Let R (2, fig. 43) be the given radius and R_1 and R_2 the radii of the given circles. With point O as a center and a radius equal to R plus R_2, draw an arc.

b. With point S as a center and a radius equal to R plus R_1, draw an arc intersecting the first arc at point P.

c. With point P as the center and the given radius R, describe the required arc tangent to the given circle.

121. To Draw a Reverse Curve Between Two Lines

a. Let parallel lines AB (fig. 44) and DC represent the given lines. Draw line AC intersecting the given lines at points A and C.

b. Bisect the line AC at point E.

c. Erect perpendiculars from the given lines at points A and C.

d. Bisect line AE, with the bisector intersecting the perpendicular drawn from point A at point F.

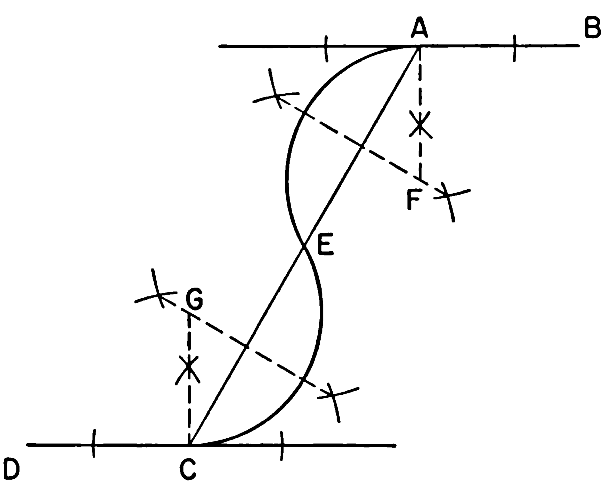


Figure 44. Drawing a reverse curve between two lines.

e. With point F as a center and a radius FA, draw the upper half of the required reverse curve tangent to line AB.

f. Bisect line EC, with the bisector intersecting the perpendicular draw from point C at point G.

g. With point G as a center and a radius GC, draw the lower part of the required reverse curve tangent to line DC. It should be noted that the given lines do not have to be parallel in order to use this construction. Also, point E may be located at any point on line AC. Line AC was bisected in this solution to make the reverse curve symmetrical.

122. To Construct an Ellipse — Four Center Method

The four center method is used for small ellipses. Given major axis AB and minor axis CD, mutually perpendicular at their midpoint O, (1, fig. 45).

a. Draw AD, connecting end points of two axes.

b. With dividers set to DO, measure DO along AO and reset dividers on remaining distance to O. With difference of semiaxes thus set on dividers, mark off DE equal to AO minus DO.

c. Draw perpendicular bisector of AE, and extend it to intersect major axis at K and minor axis extended at H.

d. With dividers mark off OM equal to OK, and OL equal to OH.

e. With H as a center and radius R_1 equal to HD, draw bottom arc.

f. With L as a center and SAME radius R_1, draw top arc.

g. With M as a center and radius R_2 equal to MB draw end arc.

h. With K as a center and SAME radius R_2, draw end arc.

Note. The four circular arcs thus drawn meet, in common points of tangency P, at the ends of their radii in their line of centers.

123. To Construct an Ellipse—Parallelogram Method

The parallelogram method is satisfactory for constructing large ellipses.

a. Given AB as the major axis and CD as the

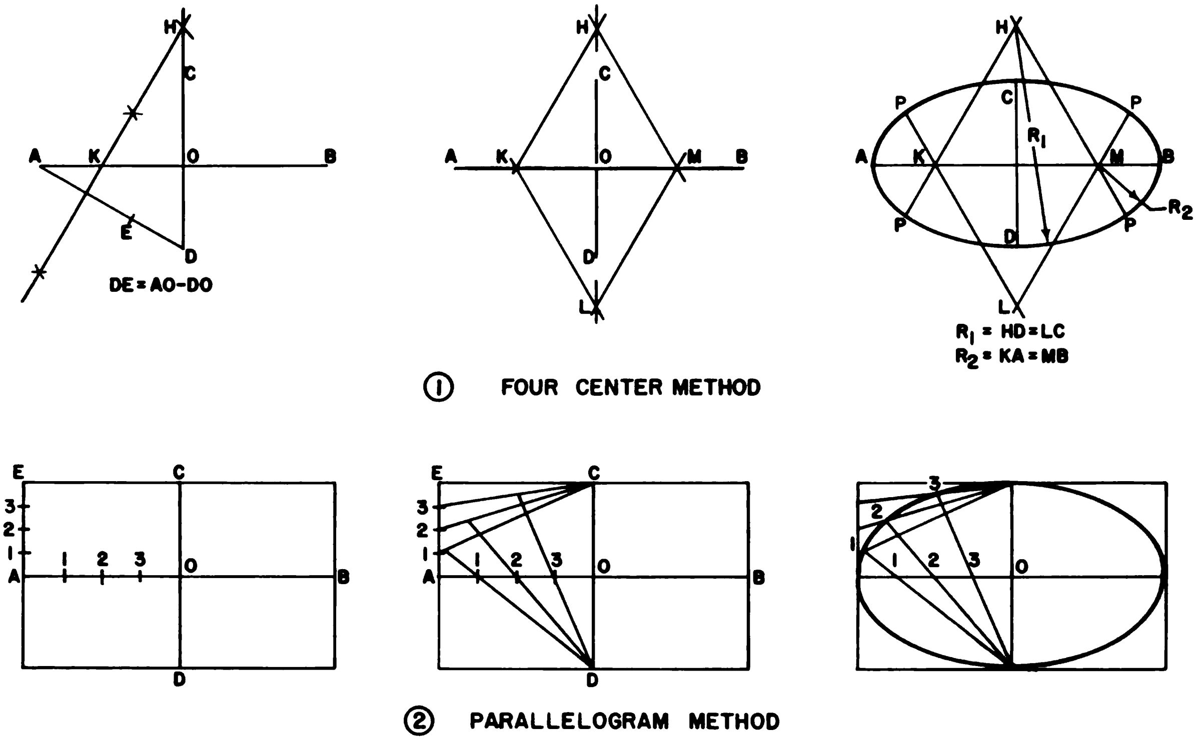


Figure 45. Constructing an ellipse.

minor axis, construct a rectangle with sides equal in length and parallel to the axes (2, fig. 45).

b. Divide *AO* and *AE* into the same number of equal parts.

c. From *C*, draw a line to point 1 on *AE*.

d. Draw a line from *D* through point 1 on *AO*. The intersection of this line with the line just drawn establishes point 1, on the ellipse. The remaining points in the quadrant and points in the other three quadrants are established similarly.

e. Connect the points freehand to complete the ellipse.

Note. It would be preferable to use a French curve to accomplish step *e*.

CHAPTER 6

VIEWS AND PROJECTIONS

Section I. ORTHOGRAPHIC PROJECTION

124. Introduction to Projected Drawing

The method of representing the true shape of a three-dimensional object, by drawing it on a flat sheet of drawing paper having only two dimensions, forms the basic theory or starting point of all engineering drawing. The draftsman must be able to represent the ideas of an inventor, designer, or architect, in an unmistakable manner for transmission to the workman or builder. The workman or builder must know the exact shape and the exact size of an object before he can produce or build it. The standard method used by draftsmen to accomplish these objectives is by the use of orthographic projection.

125. Basic Theory of Projection—By Perspective

An observer standing in one position and looking at an object from a fixed distance generally will get a good impression of the shape and size of an object. Usually, he will see more than one side and will be aided in his evaluation of its size and shape by the way that light and shadow fall on it. Light and shadow effects are rarely used in technical drawing; in general, only the outline of the object is considered. To understand the drawing process, imagine that a transparent plane—a plane of glass, for example—is placed between the observer and the object and that it is observed with one eye, through the plane. Lines of sight extend from the observer's eye to all points on the object, and each point on the object is marked on the plane where its line of sight intersects the plane. If the outline of the object is sketched on the plane by connecting the points, the result is a projection drawing. The sight lines are called projectors, and the eye is called the center of projection. The transparent plane is called a plane of projection. A drawing that represents an object as it actually appears to an observer is called a perspective drawing. The convergence of the sight lines to the center of projection prevents the image on the projection plane from appearing in its true proportions.

126. Description of Orthographic Projection

For an object to be manufactured, all its features must be shown systematically in their true dimensions and in their relationship to other features of the object. To do this, a number of views of the angle of viewing are determined by the rules of orthographic projection. Imagine that a projection plane is placed in front of an object and parallel to one of its faces. If an observer stands at an infinite distance from the object and views it through the plane, his sight lines will be perpendicular to the plane at all points. The sight lines, or projectors, all intersect the projection plane at the same angle (90°) and all the projectors are parallel to each other. Theoretically, a projector occurs whenever two lines intersect or a line changes direction. If every point is marked where the projectors intersect the picture plane, the points on the picture plane will have the same relationship to each other as the points on the parallel face of the object. In orthographic projection, only those lines and surfaces that are parallel to the picture plane project in their true length and shape.

127. Principal Axes

The principal dimensions of a plane or object are measured parallel to their principal axes. It has been demonstrated that the principal axes of a plane are intersecting perpendicular lines commonly known as horizontal and vertical axes. On a drawing sheet, these directions correspond to the direction of the working edges of the drawing board and T-square. The principal axes of three-dimensional objects are three mutually perpendicular lines. These axes usually are related to the earth by making one vertical and the other two horizontal. The purpose of orthographic projection is to give an accurate shape description of the principal dimensions. The true shape of a dimension is projected only onto a plane parallel to the axis of a dimension. To obtain a true shape description of an object, a frame of reference must be constructed with projection planes parallel to the three main axes.

Section II. THIRD ANGLE PROJECTION

128. Quadrants

In chapter 4, a frame of reference was constructed to located points on a plane. The frame consisted of two intersecting perpendicular lines, or axes, that formed a two-coordinate frame of reference and divided the plane into four quadrants. By adding a third axis, mutually perpendicular to the first two, a three-coordinate frame of reference can be created for measuring the principal dimensions of three-dimensional objects. The three-coordinate frame of reference is represented by two intersecting projection planes that divide all the space into four quadrants (fig. 46). The vertical axis therefore becomes a vertical plane, and the horizontal axis becomes a horizontal plane. A third projection plane, mutually perpendicular to the others, is called the profile plane. It provides a limit, or place, or origin for the other two planes, which otherwise extend infinitely. Although in theory an object may be placed in any of the four quadrants and its principal dimensions projected onto the appropriate plane, in practice only the first and third quadrants are used. An object may be drawn by projection in any quadrant but the American practice is to use the third quadrant; and it is called third angle projection (fig. 46).

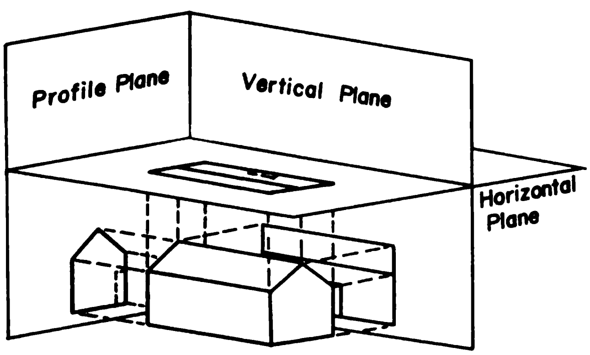


Figure 46. Third angle projection.

129. Planes of Projection

Each projection plane shows two principal dimensions in their true size; with an height appear in their true size on the vertical plane. The projection perpendicular to the vertical plane is the front view. Width and depth appear in their true size on the horizontal plane. This projection is called the top view and represents the object as it would appear to an observer looking down perpendicularly on the horizontal plane. Depth and height appear in their true size on the profile plane. The projection perpendicular to the profile plane is called the profile, or side view, which may be taken from either the left or right side. Bottom and rear views may also be taken, making a total of six principal views.

130. Glass Box

There are six principal plans of projection corresponding to the six principal views. In third-angle projection, the planes of projection are between the observer and the object. Placed in their proper relationship to each other, the planes of projection form a transparent box, and the object being examined appears suspended within. The object should be oriented so that its most characteristic shape is parallel to the frontal plane and will project in the front view. At least one, and usually two, related views are necessary to describe the shape of an object satisfactorily. Related views are perpendicular to each other and share a common dimension. *For example,* front and top views are related; width is the common dimension. Front, top, and right-side views usually are adequate for actual drawing practice. The three other principal views—left-side, rear, and bottom—are used only to meet a particular need.

a. Reference Lines. The intersections of adjacent projection planes are represented by lines known as reference, or folding, lines. The common dimension of two related views can be projected along the surface of the projection planes by extending perpendiculars to the reference lines. *For example,* width is extended between front and top views by constructing perpendiculars to the horizontal reference line. When considering the problem of representing all the projection planes in the plane of the paper, the reference lines should be thought of as hinge connections.

b. Revolving Planes. The vertical plane is considered to be in the plane of the paper. To arrange the other planes on the surface of the drawing sheet they must be revolved around their imaginary hinges, as shown in figure 47, until they are in the same plane as the front view. Figure 48 shows the standard arrangement for views obtained by orthographic projection. Top, bottom, right-side, and left-side views are hinged to the four sides of the front view. The rear view is revolved as if attached to the right-side view.

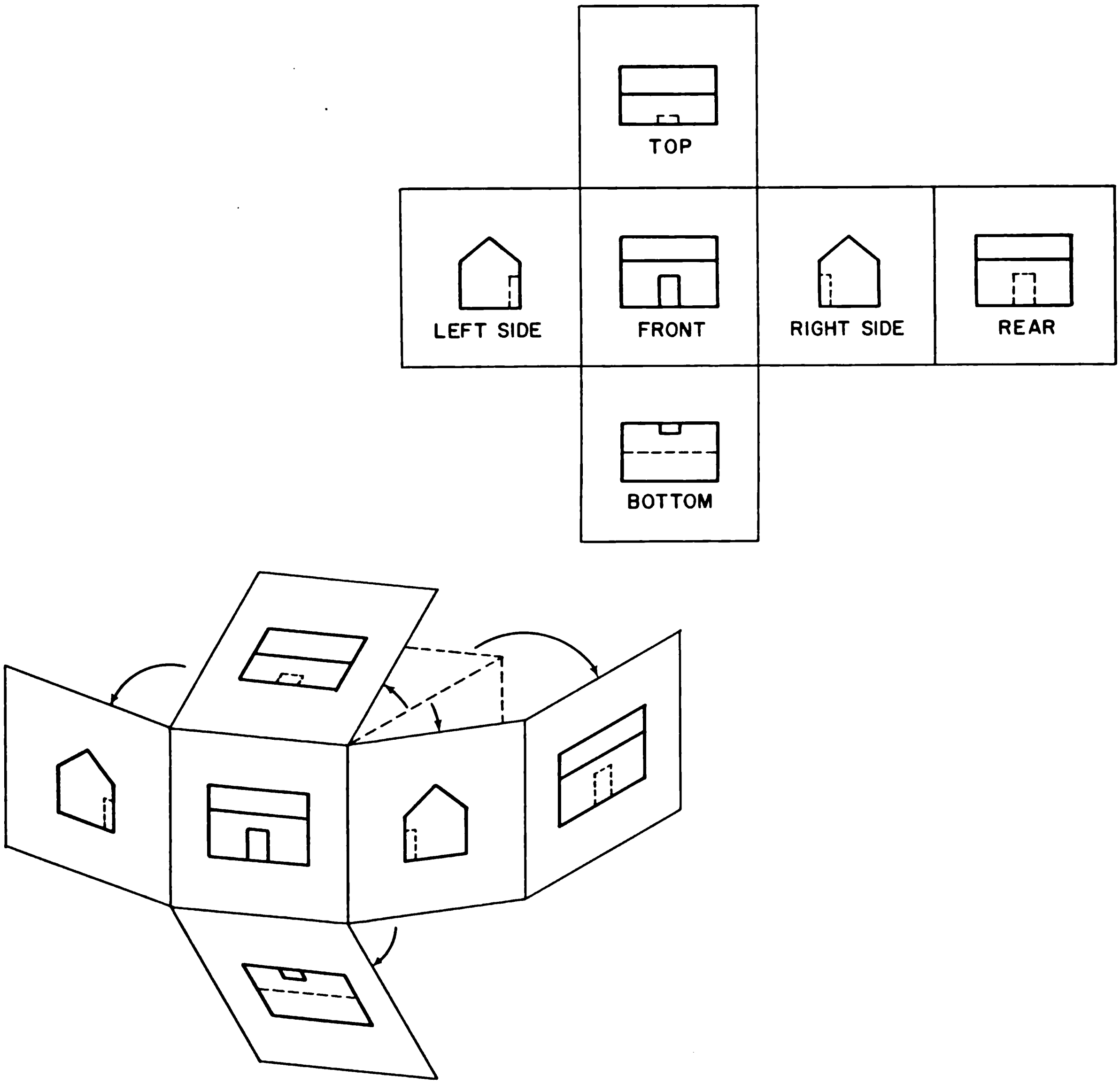


Figure 47. Revolving planes into planes of paper.

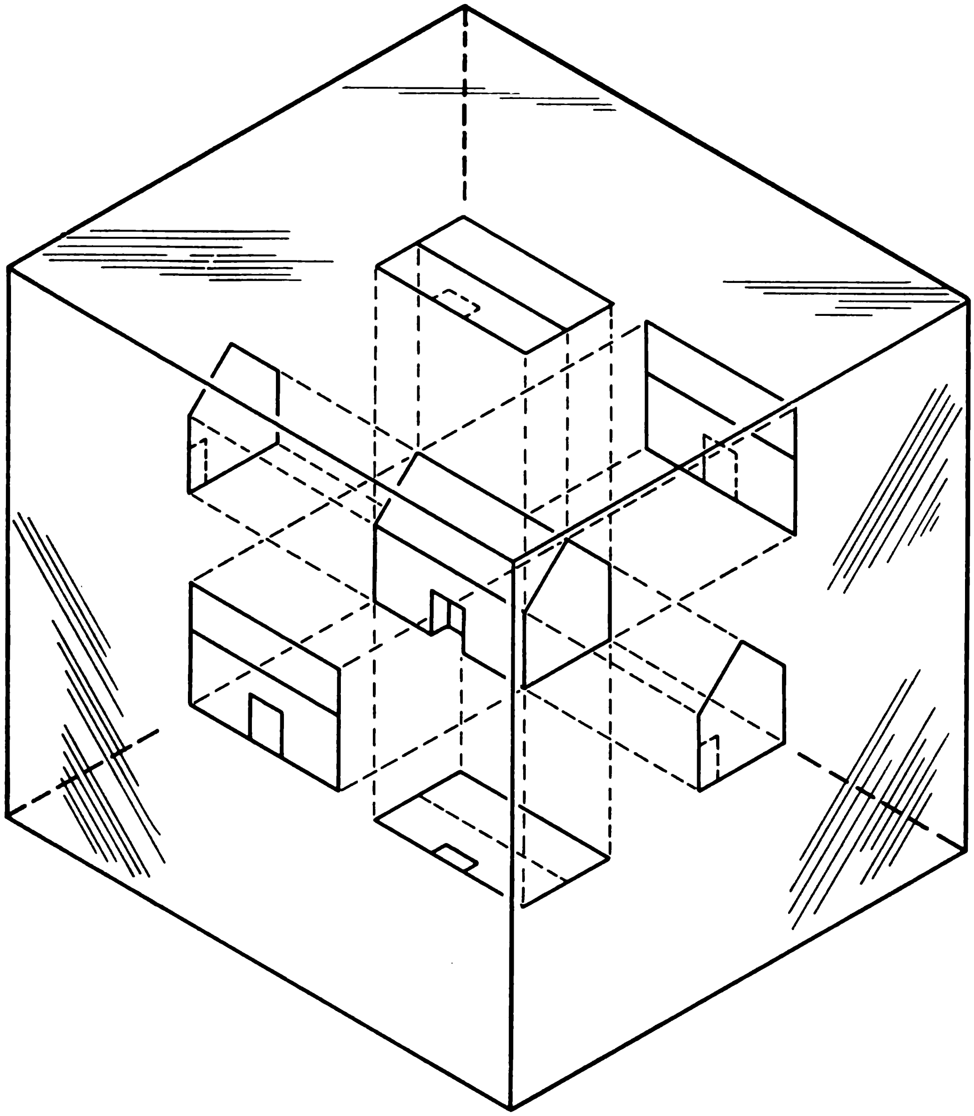


Figure 48. Orthographic projection.

Note. The front, top, and bottom views are alined vertically; the front, right-side, left-side, and rear views are alined horizontally.

c. View Titles. The projection on the vertical plane is called the front view, vertical projection, or front elevation. On the horizontal plane, the projection is called the top view, horizontal projection, or plan. The projection on the profile plane is called the side view, profile projection, side elevation, or end elevation. The last title given in each series is used for describing views of buildings and other structures.

131. Position of Observer

In third-angle projection, the position of the observer for the front view is considered to be an infinite distance to the right of the vertical plane. A further examination of third-angle projection is given in paragraph 130.

132. Hidden Features

When viewing an object one plane at a time, it is customary to represent all edges and intersections whether or not they can be seen from the viewing position. The location of these hidden details is shown by dotted lines called hidden lines (par. 46*h*). When a hidden line coincides with an object line, or outline, the hidden line is not drawn.

133. Measurement

All linear measurements represent a direction and a distance from a known reference point or position. A consideration of how the principal dimensions of objects follow this rule will be helpful in later work. Because the principal dimensions are measured parallel to three mutually intersecting lines, the rules of linear measurement apply. The three intersecting planes are reference positions and the direction of measurement is perpendicular to them.

Note. The *principal dimensions* of an object describe the direction of measurement and should not be confused with *size dimensions*, which are expressed in numbers and units and tell how many units high, wide, or deep an object is. Principal dimensions also are *called space dimensions.*

Section III. VIEWS

134. View Combinations

The three views usually selected to describe an object are the front, top, and right-side views. The left-side view may be substituted for the right-side view if it presents fewer hidden lines. Front, right-side, and bottom are sometimes combined. A four-projection arrangement of front, top, right-side, and rear views is required to present the rear view in standard arrangement. Note that all these combinations include the front view because it is considered to be in the plane of the paper.

a. Alternate Position Views. Two alternatives are possible for the standard arrangement of views. Both are achieved by imagining that the planes are hinged at other than the standard intersections.

(1) *Right-side view.* If it is imagined that the right-side view is hinged to the top view, the right-side view is placed adjacent to the top view. In that position it is at an angle of 90° to its position when adjacent to the front view. A three-view alternate position projection will show the front, top, and right-side views.

(2) *Rear view.* The rear view may be imagined as hinged to the top rather than the right-side view. When rotated into the plane of the paper, the three-view projection will show the front, top, and rear views alined vertically. Drawing the rear view in alternate position eliminates the need for a four-view projection.

b. Object Visualization. A draftsman must think of himself as examining the object itself through a projection plane whenever he reads a drawing. Visualization is the process of mentally adding the missing dimension to each two-dimensional view, which is always obtained from an adjacent view. The draftsman examining a front view mentally calculates the depth of all features. In visualizing an object from a top view, he must add an estimation of height to the object lines and hidden lines shown in that view. Models made from drawings are a valuable aid in visualizing. Soap and softwood, such as balsa, are suitable materials for modeling. By combining views to produce a three-dimensional object, the draftsman learns how views are related.

135. Selection of Views

In orthographic drawing, objects will be represented by the least number of views that will describe their shape accurately and permit complete dimensioning. Proper selection of views is a skill that improves with practice and with ability to visualize. Certain fundamental principles will assist a beginner in selecting views.

a. Front View. The view of an object that shows its most characteristic shape should be selected as the front view. The front view of a house, for example, shows its width, height, and front entrance. It gives more information about the real shape of the house than any of the other views. Whenever possible, mechanical objects are shown in their normal, or functioning, position in the front view. Vertical and horizontal axes are alined with the vertical and horizontal axes of the drawing sheet. The front view of an automobile jack should show the jack standing on its base rather than lying flat.

b. Objects. Objects are composed of geometric shapes, either singly or in combination. Cylinders, spheres, prisms, pyramids, and cones, are examples of geometric shapes. The number of views required to represent an object adequately is determined largely by the kind and number of shapes of which the object is composed.

(1) *One-view drawings.* Simple cylindrical pieces can be shown resting on their sides with the axis as a centerline. If the piece is complicated by several holes or slots that cannot be shown easily in one view, additional views are added. A single view of a cylinder is called a longitudinal, or profile, view. The third dimension is described by a note. Diameters must be identified by a description note or abbreviation, which should follow the numerical dimension and be connected to the proper part with an arrow-tipped leader. The abbreviation for diameter is DIA. A cube may be shown in one view. The abbreviation for square (SQ) follows the dimension to distinguish the cube from a cylinder because both look the same in a profile view. Thin objects of uniform thickness, such as shims, gaskets, and plates, also may be shown by one view with a dimensional note giving the thickness.

(2) *Two-view drawings.* Two-view drawings may be arranged as any two adjacent views in the relation shown when the glass box is revolved into the plane of the paper. When space is limited, it is permissible to represent symmetrical objects by half views extended slightly beyond the centerline of symmetry and terminated with a breakline. If the adjacent view is an exterior view, the near half of the symmetrical view will be drawn. If the adjacent view is a full or half section the far half of the symmetrical view will be drawn.

(3) *Three-view drawings.* The majority of objects represented in orthographic drawings are irregularly shaped and require three views. Complicated objects may require more. If an important face of an object is not parallel to any of the principal planes of projection, either a primary auxiliary or secondary auxiliary view must be used to show its true shape (par. 147).

136. Spacing Views

The glass box, when opened and revolved into the plane of the paper, gives an idea of the proper spacing between views. Because all of the projection planes are considered equal in size, and the object itself is thought of as being suspended in the center of the inclosed space, related views are always spaced an equal distance apart. Distance between views is from 1 to 2 inches. The remaining problem in representing a three-dimensional object is to balance the spacing of the views within the working area of the drawing sheet.

a. Working Area. The working area of a drawing sheet is the horizontal distance between the left- and right-hand borderlines and the vertical distance between the top of the title block and the top borderline. The working area, therefore, is bounded on three sides by the boderlines and on the bottom by an imaginary line extending horizontally from the top of the title block to the left-hand borderline.

b. Working Area Layout. The first step is to determine the horizontal and vertical dimensions of the working area. The next step is to make a rough sketch of the three views and determine their horizontal (side-view depth plus front-view width) and vertical (front-view height plus top-view depth) dimensions. If H and V are taken as the horizontal and vertical dimensions of the working area, respectively, a formula for determining spacing between views and borderlines would read

$$HS = \frac{H - (\mathrm{d} + \mathrm{w} + \mathrm{s})}{2}$$

and

$$VS = \frac{V - (\mathrm{h} + \mathrm{d} + \mathrm{s})}{2}$$

where

h = object height
w = object width
d = object depth
s = spacing between views

HS and VS represent the amount of horizontal and vertical space, respectively, on either end of the working area.

c. Selecting Sheet Sizes. The size required for any drawing can be determined by making

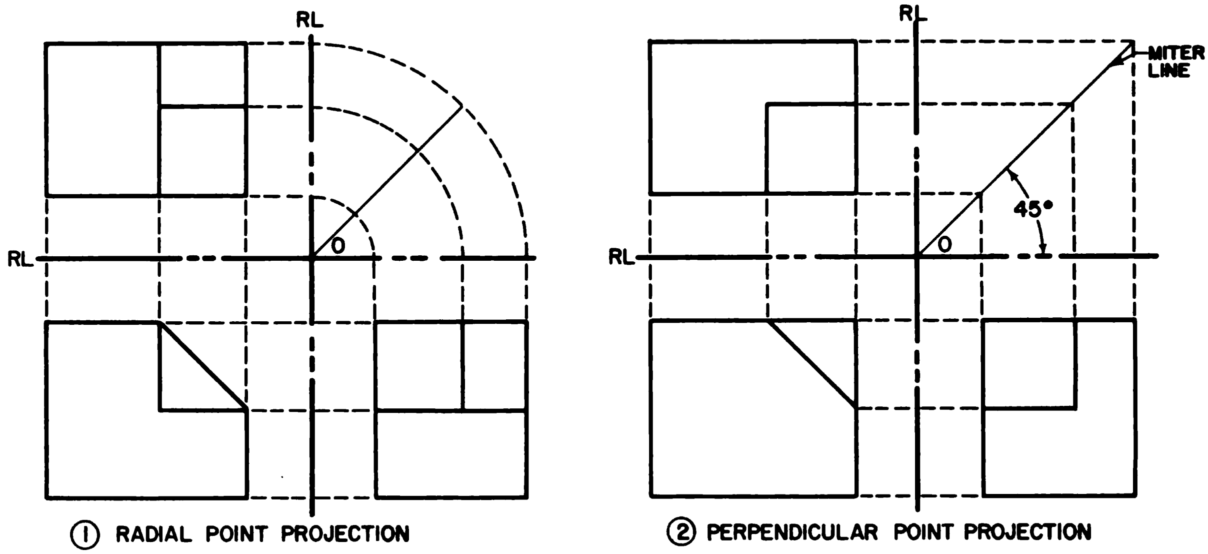


Figure 49. Projecting principal dimensions.

the views to scale in the preliminary sketch. Actual measurement of the scale views, with consideration for spacing, will aid in the selection of an appropriate sheet size.

d. Views in Projection. It is essential to keep the views on the drawing sheet alined in positions corresponding to their positions in the planes of projection. The principal dimensions of the front view are blocked in lightly with the main outlines and centerlines. The location of the front view is determined as explained above. Width and height dimensions are projected to the top and side views, respectively, with the triangles and T-square. To project depth measurements between top and right-side views, a point of intersection must be established between the horizontal projection of the lowest point on the top view and the vertical projection of the point on the side view closest to the front view. Both points are equally distant from the front view and are represented by *s* in the equation in *b* above. A 45° line, called a miter line, is drawn from the point of intersection. Depth measurements are projected to and from this line. Points may be projected by swinging arcs. Figure 49 shows both methods of projecting depth measurements.

137. Detailed Views

A detail view shows a part of the drawing in the same plane and in the same arrangement but in greater detail and larger scale than is shown in the principal view. That part of the drawing to be detailed will be encircled with an extra thick dash line accompanied by a leader line to the notation: SEE DETAIL A. The enlarged detail will be designated DETAIL A.

Section IV. LINES IN ORTHOGRAPHIC PROJECTION

138. Introduction

Paragraph 46 identified the various line characteristics and conventions used in orthographic projection and presented rules for drawing them, which might be reviewed at this time. However, further explanation of lines will help visualize the shape of an object from its principal views.

139. Line Representation

Apart from their characteristics, the lines of an orthographic projection may represent three different kinds of change of direction in the contours of an object. The first is an *edge view* of a receding surface, which is a surface perpendicular to the plane of projection. A plane appearing in its true shape in a front view will appear as a line in the top or side view, these being edge views in which the plane appears to recede directly away from the observer. The second is an *intersection* in which a line is formed by the meeting of two surfaces. The third is a *surface limit*, such as is shown in the profile view of a cylinder.

140. True Length of Lines

Lines are further classified by their position with regard to the planes of projection.

a. Horizontal Line. A horizontal line appears in its true length in the top view.

b. Frontal Line. A frontal line is parallel to the vertical plane and appears in its true length in the front view.

c. Profile Line. A profile line is parallel to either one of the side planes and appears in its true length in either side view.

d. Oblique Lines. A line that is inclined to two principal planes of projection and parallel to a third will project in its true length on the parallel plane. Its projection on the planes to which is not parallel will be *foreshortened*, or less than its true length. A line that is oblique to all the principal planes of projection, not parallel to any, will project as a foreshortened line in all the principal views.

e. Point Projection. A line that appears as a point in one plane of projection will appear in its true length in an adjacent plane, and vice versa.

141. Curved Lines

The edge view of a curved surface is projected from one view to another by establishing a series of numbered points along the curve. The points are projected to the other views, located with corresponding numbers, and connected by a smooth curve.

142. Precedence of Drawing

In any projection plan there is always a possibility of coinciding lines. Hidden edges and visible outlines often project identically. Centerlines may fall in the same place as hidden or visible lines. The precedence with which lines are drawn in determined by clarity of presentation. Visible outlines take precedence over hidden lines because the boundary lines of an object are more important. Both full and dotted lines take precedence over the centerline, although the centerline may be extended beyond the boundaries of the object. When a cutting-plane line coincides with a centerline, the line more important to understanding is shown. Dimensions and extension lines are placed so that they do not coincide with other lines.

Section V. CIRCLES, ELLIPSES, AND SURFACES

143. Circles

A circle that lies on the normal plane, namely, parallel to one principal projection plane and perpendicular to the other two, will project in its true size and shape on the parallel plane and as a straight line on the adjacent planes. If a circle lies on a plane perpendicular to a principal projection plane and inclined to the other two, it will project as a straight line on the plane to which it is perpendicular and as ellipses on the adjacent projection planes. If a circle lies on a plane that is oblique to the principal projection planes, it will appear as ellipses in the principal views.

144. Ellipses

An ellipse that lies on a normal plane, one parallel to one principal projection plane and perpendicular to the other two, will project in its true size and shape on the parallel plane and as a straight line on the adjacent planes. If an elipse lies on a plane perpendicular to a principal projection plane and inclined to the other two, it will project as a straight line on the plane to which it is perpendicular and as another ellipse on the adjacent projection planes. If an ellipse lies on a plane that is oblique to the principal projection planes, it will appear as another ellipse in the principal views.

145. True Shape of Planes

Surfaces are classified by their position with reference to the planes of projection. Horizontal, frontal, and profile planes are parallel to the planes of the same name. A plane is shown in its true shape only when parallel to a plane of projection. A plane inclined to two of the three principal planes of projection is an auxiliary plane and shows its true shape in a primary auxiliary view. A plane inclined to all three principal planes is an oblique plane and appear in its true shape only in a secondary auxiliary view.

Section VI. AUXILIARY VIEWS

146. Introduction

For an object to be manufactured, all of its features must be shown in their true dimensions and in their true relationship to other features of the object. The true length of a line and the true shape of a plane are shown only when parallel to a plane of projection. When an object has a surface that is not parallel to any of the three principal planes of projection, the surface (inclined or oblique) does not project in its true shape in any of the principal views. It projects as a foreshortened view, which is not easily understood, and is difficult to draw. Furthermore, a foreshortened view is not dimensioned because surfaces are dimensioned only in those views that show their true shape. When this occurs, the true shape and size of the inclined plane can only be projected on an *auxiliary plane* placed parallel to it. If the inclined plane is *perpendicular* to one of the principal planes of projection, the auxiliary plane is visualized as "hinged" and therefore "related" to that principal plane. The inclined surface shows as an edge or a single straight line on the plane to which it is perpendicular. The hinged intersection of the auxiliary plane with the principal plane to which it is related is called a *reference line.* Reference lines are drawn as light construction lines, and the auxiliary plane is *revolved* into the plane of the drawing paper about the hinged reference line. The view on the auxiliary plane is called a *single auxiliary view* (par. 148).

147. Auxiliary Planes

The glass box helps in visualizing the problems of auxiliary projection. The auxiliary plane is thought of as hinged to the place to which it is perpendicular. The hinged intersection is represented as a *reference line.* As with the principal views, an auxiliary view is revolved into the plane of the paper along its reference line. Auxiliary views are classified according to which projection plane the auxiliary plane is related.

a. Partial Views. A view that does not show a complete projection is called a partial view. When an object is projected on an auxiliary plane, the inclined surface appears in its true shape but the other faces are foreshortened. Foreshortened details are not included in an auxiliary view because they appear in their true shape in the principal views.

b. Measurement. The principal dimensions of an object are measured perpendicularly to the projection planes (par. 129). A single auxiliary plane is perpendicular to a principal plane. One of its two dimensions will be the same as the principal dimension, which is measured perpendicular to the same principal plane.

148. Single Auxiliary Views

There are three kinds of single auxiliary views: auxiliary elevations perpendicular to the top view or horizontal plane; right and left auxiliaries perpendicular to the front view or frontal plane; and front and rear auxiliaries perpendicular to the side views or profile planes.

a. Elevation Auxiliary. The true shape of a plane surface perpendicular to the top view and inclined to the front and side views can be shown in an auxiliary elevation. The front view is the third view required in drawing an auxiliary elevation. The top view must be included because it is the only principal view to which an auxiliary elevation is related. Both the front view and the auxiliary elevation are perpendicular to the top view. Both reference lines lie in the horizontal plane. The perpendicular distance from any point on the auxiliary elevation to its reference line will be exactly equal to the perpendicular distance from the same point on the front view to its reference line. Height measurements made from their respective reference lines are common to both the auxiliary elevation and the front view. Height is the common principal dimension. Whenever three planes are related, the plane son either side of the middle plane are perpendicular to it and share the principal dimension measured perpendicularly to that plane. Height is the space dimension measured relative to the horizontal plane.

b. Right and Left Auxiliary Views. If a plane surface is perpendicular to the front view and is inclined to the top and side views, its true shape will be shown on an auxiliary plane placed parallel to the inclined surface and perpendicular to the frontal plane. Right and left represent the direction of viewing perpendicular to the auxiliary plane. The three necessary views are the top, front, and auxiliary side views. The side view may be substituted for the top view. Both the side and the auxiliary side views are perpendicular to the front view in figure 50. Depth is the principal dimension common to both side and auxiliary side views. Any depth measurement made on the side view from the reference line to a specific point can be transferred to the auxiliary side view by measuring the same distance from the reference line to locate the same point.

c. Front and Rear Auxiliary Views. If a plane is perpendicular to the side view and inclined to the top and front views, its true shape will be shown on an auxiliary plane parallel to the inclined surface and perpendicular to the profile plane. The three necessary views are either a front or rear auxiliary and a front view and side view. The auxiliary views and the front view are perpendicular to the side view. Width is the principal dimension measured perpendicularly to the profile plane and is therefore common to both front and auxiliary views. All features that appear on front and auxiliary views will be the same distance from their respective reference lines.

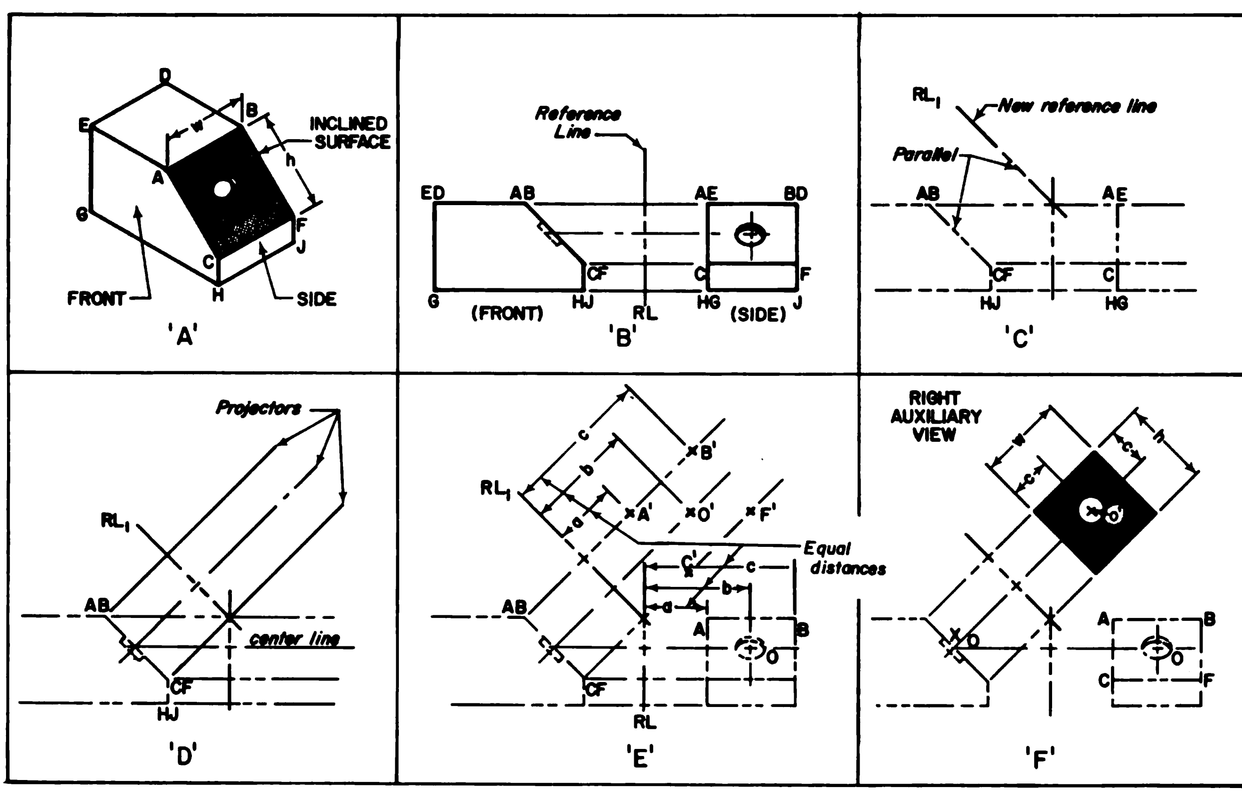


Figure 50. Single auxiliary views.

149. Projection to Single Auxiliary Views

Figure 50 illustrates the procedure for drawing a right auxiliary view. The procedure, typical of the procedure for drawing all single auxiliary views, is as follows:

a. Principal View. Select two related principal views, one of which will show the inclined surface as an edge. In figure 50, the inclined surface appears on edge in the front view and the front and side views are the related views selected. Draw the two related orthographic views (separated by the reference line *RL* as in block B, fig. 50) located so as to allow space on the drawing for the auxiliary view.

b. Reference Lines (par. 130a). Draw a reference line RL_1 (block C, fig. 50) which is parallel to the edge of the inclined surface and at a convenient distance from the principal view. This new reference line (RL_1) forms the base from which the inclined plane is projected into the auxiliary. Just as the reference line *RL* separates the front and side views, reference line RL_1 will separate the front and right auxiliary views. Both reference lines represent the intersection of two perpendicular projection planes, and are visualized as hinged connections.

c. Point Projection. Draw projectors *perpendicular to* RL_1 from the end points *AB* and *CF* of the edge of the inclined surface in the principal (front) view, and extend these lines a reasonabl distance (block D, fig. 50). Also draw projector of centerline perpendicular to RL_1 at point of intersection on edge of inclined surface.

d. Transferring Measurements. With the dividers, transfer points *A′*, *B′*, *C′*, *F′*, and *O′* (measurements a, b, and c) from the side view to the right auxiliary view as illustrated in block E, figure 50. Note that the depth of an object is measured perpendicular to the frontal plane, and that the side and auxiliary planes are both perpendicular to the frontal plane. Thus the perpendicular distance from any point in the side view to RL is exactly equal to the distance of the same point in the auxiliary view measured from RL_1 along a projector drawn perpendicular to RL_1.

Note. The transfer of measurements by this method, between the two principal views, actually develops the true shape and size of the inclined surface. It is NOT necessary to visualize the shape and size beforehand; the projections develop true shape and size. A scale may also be used to transfer measurements (architect's 16 scale being preferable).

From the above, it is seen that the method of projecting the true image of the inclined surface to an auxiliary plane is the same as projecting an image of an object to one of the principal planes.

e. Completing View. After all the principal points of the inclined surface have been located in the auxiliary view, connect the points with visible edge lines (block F, fig. 50), thus showing the true size and shape of the inclined surface. To complete the auxiliary view, set bow compass to the measurement *OX* on the edge of the inclined surface (front view), and using center *O′* draw circle on the auxiliary view.

Note. In blocks B, E, and F, the inclined surface *ABFC* appears as distorted or foreshortened in the side view, as an edge in the front view and in its true size and shape in the right auxiliary view. *The auxiliary view shows the inclined surface only.* All other features of the object are omitted.

150. Projection to Double Auxiliary Views

An oblique surface is a surface which does not project as an edge on any principal view. Two operations are required to find its true shape and size. First, it is necessary to present the oblique surface as an edge on a preliminary (single) auxiliary view, and second, to project the final (double) auxiliary view from this new view. A single auxiliary is always projected from a principal view; a double auxiliary is always projected from a single auxiliary. Figure 51 illustrates the procedure for drawing a double auxiliary view.

a. Related Views. Select two related principal views one of which will show a line on the oblique plane in its true length. Draw the two related orthographic views separated by a reference line *RL*, similar to the procedure for projection of single auxiliary views given in paragraph 148*a*. In figure 51, the front and side views are the related views selected. Note that the line *AC* (top view) lies on the oblique plane and is parallel to *RL*. *AC* therefore projects in its true length in the front view (block B, fig. 51).

b. Preliminary Auxiliary View. After the front view has been drawn, showing *AC* in its true length, draw the reference line RL_1 perpendicular to *AC* (block C, fig. 51). Project

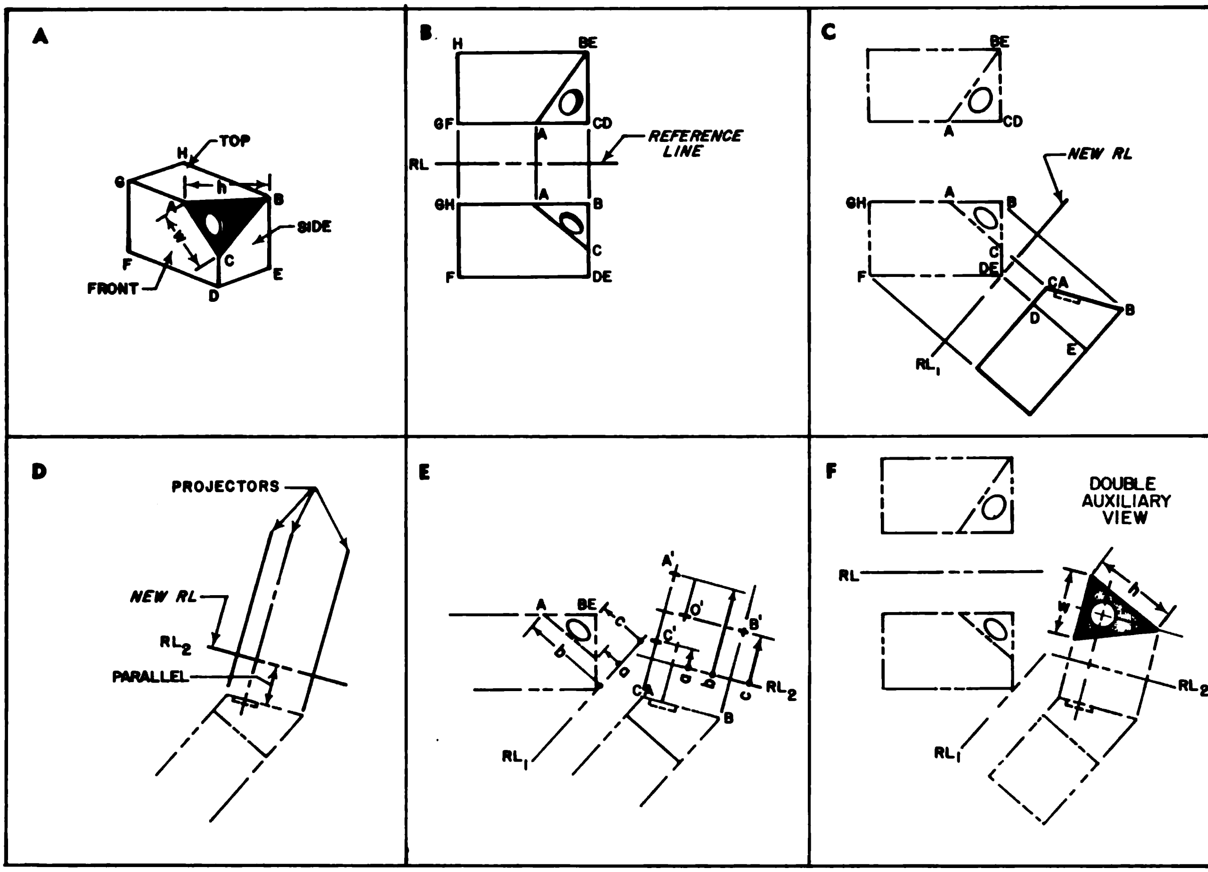


Figure 51. Procedure for drawing double auxiliary or oblique views.

points A, B, C, D, and E into the preliminary auxiliary, locating their positions on their projectors, using the dividers (or scale), by taking the corresponding depths in the top view and transferring these to the auxiliary. Complete the preliminary auxiliary view as in block C, figure 51. Note that the line $CA–B$ now projects the oblique plane as an edge on the preliminary auxiliary view.

c. Reference Line for Double Auxiliary. Draw a reference line RL_2 parallel to the edge of the oblique surface. Extend projectors perpendicular to RL_2 from the points CA and B, a reasonable distance as in block D, figure 51. Also draw projector of centerline perpendicular to RL_2 at point of intersection on edge of oblique surface.

d. Transferring Measurements. Project points A', B', C', *and* O' into the final double auxiliary view, locating their positions on their projectors, by taking the corresponding measurements in the preliminary auxiliary and transferring these to the double auxiliary (block E, fig. 51).

e. Completing View. The procedure for completing the double auxiliary, showing the true shape and size of an oblique surface, is the same as that for a single auxiliary. After all the points have been located, connect the points with visible edge lines and complete the circle for the hole as in block F, figure 51.

151. Partial Auxiliary Views

A view that does not show a complete projection is called a *partial* view. When the inclined

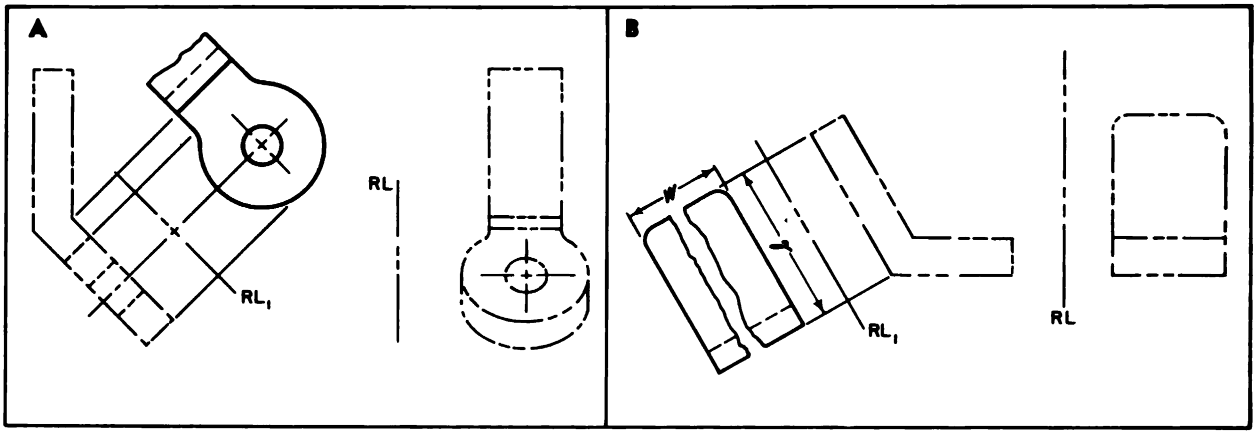


Figure 52. Partial auxiliary views.

surface of an object is projected on an auxiliary plane, the inclined surface appears in its true shape and size but the other surfaces are foreshortened. Foreshortened details are omitted from auxiliary views because they are shown in their true shape and size in the principal views. Partial auxiliary views (fig. 52) may be used to represent shape and details of an inclined surface only. A partial auxiliary view decreases drawing time and clarifies the true shape description of an inclined surface by eliminating unnecessary lines and details. *For example,* notice that the partial auxiliary in block A, figure 52, gives all the essential information concerning the inclined surface, and yet is much clearer and takes less time to draw than to project a complete auxiliary view. Block B, figure 52, shows how a section of an auxiliary might be broken out to save space on a drawing, or when the size of the sheet limits the space available.

152. Dimensions

All dimensions should be shown on a view where their true length appears. The basic reason for using auxiliary views is "to present the true size and shape of inclined or oblique surfaces so that they can be dimensioned." Thus the dimensions of such surfaces should be shown only on an auxiliary view, and are drawn in accordance with the general rules for dimensions. On figures 50 and 51 the inclined and oblique surfaces are dimensioned in the auxiliary views as shown in block F of each figure. Notice that the dimensioning of the auxiliary view in block B, figure 53, includes the broken out section.

153. Curved and Circular Forms

Given a symmetrical, curved surface inclined to two principal planes of projection and perpendicular to the front plane (front view), select two principal adjacent views. One must be the front view because it shows the curved surface as an edge view; the adjacent principal view will be a side view.

a. Reference Lines. The reference line for the principal views is passed through the center of the side view and is drawn over the centerline of the symmetrical curve. The curve is therefore symmetrical about its reference line. The reference line for the auxiliary view is drawn parallel to the edge view of the inclined surface. The true shape projection of the curve in the auxiliary view will be symmetrical about its reference line. Depth dimensions, taken on either side of the reference line in the side view, are transferred to the auxiliary view.

b. Projecting Points to the Edge View. Establish any convenient number of points along the edge of the curve in the side view. For symmetrical curves, points are marked on only one side of the reference line. Project the points perpendicularly from the reference line to the curve on the other side of the reference line and to the edge view. Number the points on the curve lightly.

c. Projecting Points to the Auxiliary View. Points on the edge view represent the intersection of the numbered projectors with the edge view. Project these points perpendicularly to the auxiliary reference line; projectors pass beyond the reference line.

d. Transferring Measurements. Use dividers to take depth measurements in the side view; measurements are made along the projector lines. Each line is numbered to correspond to the point it projects. The measurements are then transferred to the projectors passing through the auxiliary reference line. After all points have been plotted, draw the curve in its true shape projection.

154. Rules for Secondary Auxiliary Views

The following rules of orthographic projection apply to double auxiliary views.

a. Reference-Line Symbol. As used in this chapter, the reference-line symbol represents the edge formed by the intersection of two projection planes perpendicular to each other. It may also be thought of as the edge view of a projection plane. Two planes with a common reference line are related (perpendicularly).

b. Projection. Points are projected perpendicularly to reference lines on a plane surface. A line perpendicular to a reference line will project as a point in a related view; a line parallel to a reference line will project in its true length in the related view. A plane surface projects as a line in the related view; the edge view of a plane surface projects in its true shape in the related view.

c. Oblique Planes. If a line on an oblique plane appears in its true length in a principal view, a projection plane passed perpendicularly to the line also will be perpendicular to the oblique plane. In such a case, the line will project as a point and the oblique plane as an edge view on the perpendicular plane. A projection plane that shows an oblique plane as an edge view is a single auxiliary plane.

Section VII. SECTION VIEWS

155. Introduction

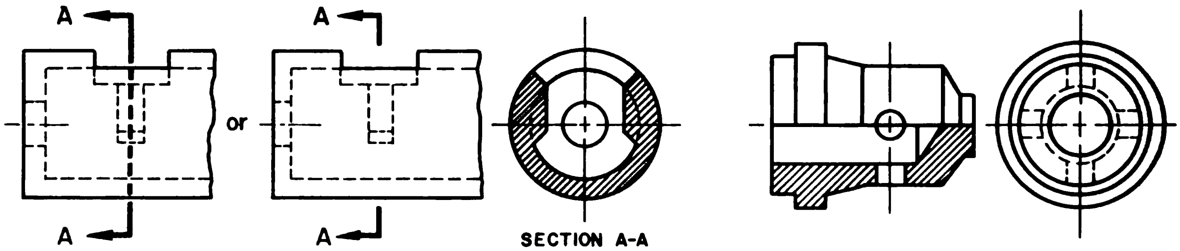
Although simple objects are adequately described with the system of views described in paragraphs 132 through 137 many cases arise where the interior features are either complex or detailed. An attempt to show these features as hidden parts represented by dotted lines results in a drawing in which the dotted lines not only fail to show the hidden features clearly but confuse the recognition of visible outlines. In such a case, the interior features can be represented clearly by making a view in section. A *sectional view*, or *cross section*, exposes the interior features as if the portion of the object between the observer and the previously hidden features had been cut away and discarded. The cutting is done by passing an imaginary cutting plane through the object in a selected position. The symbolic cutting-plane line (fig. 10) represents an edge view of the cutting plane and appears in the principal view to which the section view is adjacent. A *sectional view* of an object is one taken lengthwise; a *cross section* is taken crosswise. Except for the addition of the cutting-plane line in one view, the principal views are drawn in the usual fashion. Sectional views are made through outside views, not through another sectional view unless the detail can be shown in no other way. Hidden lines and details beyond the cutting plane will be omitted unless required to portray the subject adequately.

156. Cutting-Plane Indications

The cutting-plane lines, together with the arrows and letters, make up the cutting-plane indication. The arrows at the end of the cutting-plane lines are used to indicate the direction in which the sections are viewed. Figure 53 shows the cutting-plane indication for a simple view; figure 54 shows the indication for a complex view.

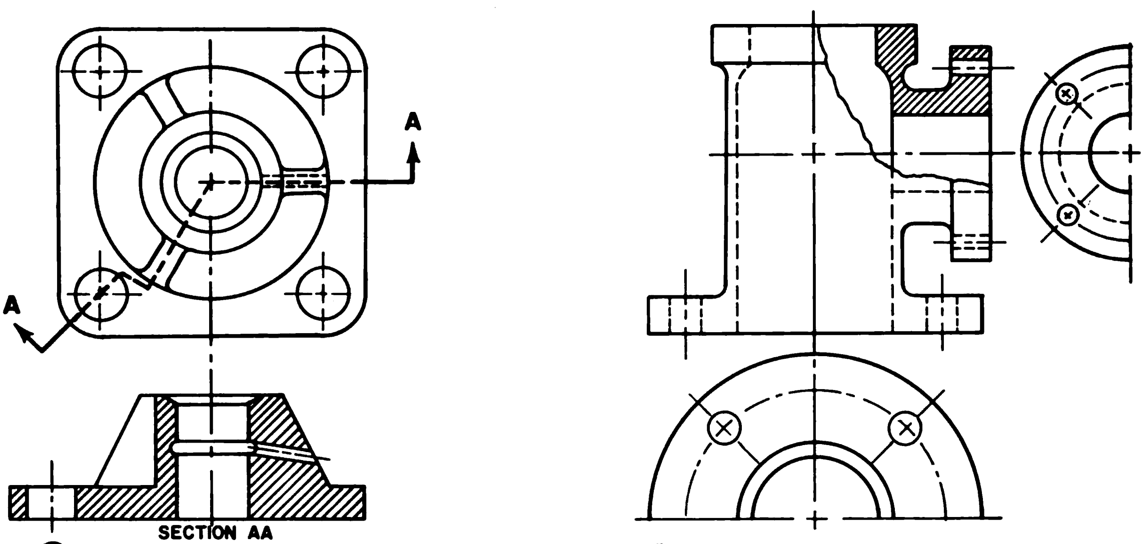
a. Position. The cutting plane may be a single continuous plane or may be bent or offset if the detail can be shown to better advantage (1, fig. 53). When an offset section is drawn, no lines are shown to indicate the points where the cutting plane changes direction. The position of the cutting plane is obtained from the cutting-plane indication in the principal view.

b. Identification. All cutting-plane indications will be identified by the use of reference letters placed at the point of the arrowheads. However, if a change in direction of the cutting



① FULL-SECTIONAL VIEW ② HALF-SECTIONAL VIEW

Figure 53. Full- and half-section views.



① OFFSET SECTION ② BROKEN-OUT SECTION

Figure 54. Sectioning conventions.

plane is not clear, reference letters may also be placed at each change of direction. When more than one sectional view appears in a drawing, the cutting-plane indications will be lettered alphabetically.

c. Section Titles. The reference letters that are part of the cutting-plane indication will always appear as part of the title, which will be placed directly under the sectional view, for example, SECTION A–A, SECTION B–B. If the single alphabet is exhausted, multiples of the letters may be used, for example, SECTION AA–AA, SECTION BB—BB. The word "section" may be abbreviated to SEC."

157. Section Placement

Whenever practicable, sectional views are arranged as though the cutting plane were revolved into the plane of the paper by considering it hinged to the plane to which it is perpendicular. Sectional views will always be shown in this position, whether they are adjacent or removed and shown at a distance from the cutting planes to which they apply. When it is necessary to draw sectional views on a separate sheet from the one on which the exterior views appear, they will be arranged from left to right in alphabetical order. This arrangement will apply to all rows in which two or more are used.

When a sectional view appears in a drawing other than the one containing the cutting-plane indication, the number of the drawing, including sheet number if any, in which such cutting-plane indication appears will be entered directly below the section title, thus:

SECTION B–B
ON (DWG NO.)

The drawing in which the cutting planes appear will reference the drawing in which the sectional views are shown.

158. Types of Sectional Views

a. Full-Sectional View. When the cutting plane is a single continuous plane passing entirely through the object, the resulting view is called a *full-sectional view.* The most usual position of the cuting plane is through the longest dimension, or main longitudinal axis and parallel to the front view. The cutting plane may be drawn parallel to any plane of projection if it shows the required internal features of the object .1, fig. 53, is a two-view drawing with the cutting plane parallel to the plane of projection of the right side view.) All rules of projection apply but hidden lines beyond the cutting plane are omitted except when essential to a complete understanding of the view.

b. Half-Sectional View. When an object is symmetrical about its main longitudinal axis, all the required internal features of the object can be shown by half of a full-sectional view or *half-sectional view.* In effect the object is cut by two perpendicular planes and only *half* of a full section is cut away or removed. Thus only one quarter of the object is removed (2, fig. 53). In this case the cutting plane line and section titles are omitted, and invisible edge lines are not shown in the portion of the view which is not cut away.

c. Offset-Sectional View. In some cases it is necessary to draw a series of two or more cutting planes in different directions which pass through the object. When the cutting plane is not a single continuous plane but two or more intersecting planes through different portions of the object, the resulting view is called an *offset section* (1, fig. 54). Reference letters may be used at the points where the cutting planes change direction—but they are omitted if no loss in clarity results, and the lines of intersection where the cutting planes intersect or change direction are not shown. The direction or position of each cutting plane is shown by the cutting plane line in the principal view.

d. Broken-out Sectional View. In cases where the sectional view of only a small part of the object is required, a broken-out sectional view is used. The partial section is combined with the principal view, by assuming that an irregular piece of the object is broken away as shown by an irregular wavy line across the principal view. No reference letters or titles are necessary (2, fig. 54), and no cutting plane is shown in the related view. Drilled holes are shown at their true distance from the center of their flange and not by true projection.

e. Alined Section. In some cases it may be necessary to violate the strict rules of projection to obtain added clarity. In those cases the true projection may be misleading, and parts such as ribs, spokes, drilled holes, or similar elements are drawn as though they were rotated into or out of the cutting plane. The resulting section is called an *alined section.* It is not a true projection but it is easier to read and gives a true description of the object. (1, fig. 55, shows an alined full section). Alined sections may be used in conjunction with the other types of sectional views.

f. Revolved Section. A revolved section is made directly on one of the principal exterior outline views, and provides a convenient and useful method of showing the shape of the cross section of a part such as a rib or the arm of a wheel. The cutting plane is passed perpendicular to the center line or axis of the part to be sectioned, and the resulting section is revolved 90° into the plane of the paper. The visible background beyond the sectional view is omitted as shown in 2, figure 54. No cutting plane line or section title is used. A revolved section cannot be enlarged with respect to the rest of the object. Revolved sections are used primarily for shape description, and dimensions are sometimes required, although limited space makes dimensioning difficult.

g. Removed Section. Removed sections serve the same purpose as revolved sections, but instead of being drawn directly on the view, they are placed on some adjacent part of the paper. A centerline extends through the object and the removed section (3, fig. 55). No cutting-plane indication, other than the centerline, or section

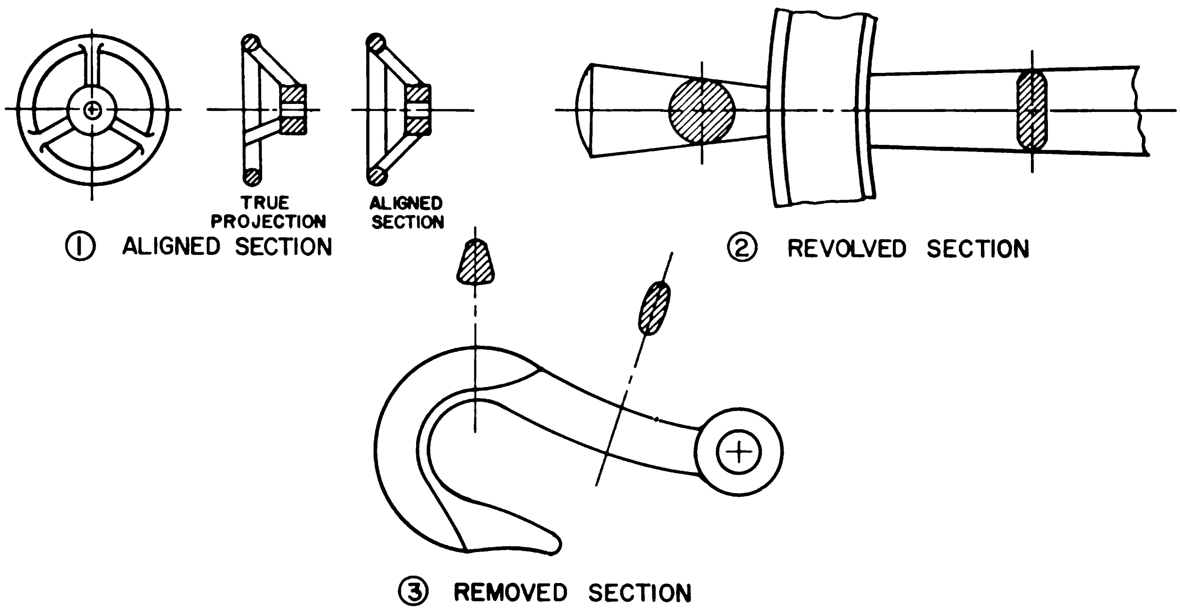


Figure 55. Sections through ribs and webs.

title is shown. The removal of the section from the object and the possibility of enlargement provide for easier and clearer dimensioning if size description of the cross section is necessary.

h. Unlined Sections. Shafts, bolts, nuts, rods, rivets, keys, pins, and similar parts with axes lying in the cutting plane generally will not be section lined; when the cutting plane passes at right angles to the axis of such parts (cross section), they will be section lined.

i. Auxiliary Sections. A sectional view related to an auxiliary plane of projection is called an auxiliary section. Auxiliary sections conform to the rules of auxiliary projection as presented in paragraphs 146 through 154. Full sections, half sections, and broken-out sections may be used in auxiliary views.

j. Fillets and Rounds. The intersections of inside and outside edges on a cast object are rounded. Rounded inside intersections are called fillets; rounded outside intersections are called rounds. Small fillets and rounds may be drawn freehand in both pencil and ink. In construction drawings, fillets and rounds are shown in detail drawings of structural steel shapes.

k. Thin Sections. Sections such as structural shapes, sheet metal, or packing gaskets which are too thin for section lining may be shown solid with a very narrow space left between them.

159. Sectioning Conventions

In addition to showing shape and construction, sectional views also are used to distinguish the individual components of an assembly or subassembly. This is done by drawing sectioning conventions on the exposed surfaces of the sectional view; however, they do not cross dimensions or obscure other conventions in drawings. In large areas, sectioning conventions may be shown along the boundary lines only, not across the entire area. In sectional views, the metal symbol may be used as far as practicable to indicate other materials. Section lining for the metal symbol is composed of uniformly spaced lines at an angle of 45° to the baseline of the section. On adjacent parts, the 45° lines will be drawn in opposite directions. On a third part, adjacent to the other two parts, the section lining will be drawn at an angle of 30° or 60°. In a drawing of a part made of only one material the metal symbol may be used, regardless of the material. Where the 45° section lining is parallel, or nearly parallel, with the outline of the object, another angle shall be chosen.

a. Pitch. The distance between section-lining lines is called pitch and is established by eye and is proportional to the surface area. For ordinary work the pitch is 1/16 inch; however, it should be no more than 1/8 inch for large areas and no less than 1/16 inch for small areas. Lines will be sharp, thin, and well-contrasted with the lines of the object. Equal spacing is attained only with care. If the first few lines are properly drawn, they will serve as a guide for the rest.

b. Angle. Although 45° is suitable angle for section lining, the draftsman should take care that section lines do not parallel object contour lines. When contour lines parallel standard section-lining angles, triangles are used in combination to produce nonparallel section lining.

160. Scale

It is preferable to draw sectional views to the same scale as the outside views from which they are taken. However, when it is desirable to use a different scale, it will be specified directly below the section title on the drawing, as follows:

SECTION C–C

SCALE $\frac{2}{1}$

or

SECTION C–C

SCALE 3″ = 1′–0″

161. Section-Lining Symbols

Appendix III presents the different symbols used to identify various materials such as iron, brass, masonry, and glass when these are shown in section views. These symbols, also known as symbolic conventions, are not meant to give exact descriptions of materials but to serve as an aid in reading a drawing. Exact material descriptions are given in notes, specifications, and bills of materials.

Section VIII. ISOMETRIC DRAWING

162. Pictorial Drawing

It is easier for nontechnical persons to visualize an object if its features can be shown in a single view. To represent a three dimensional object approximately as it appears to the eye, the draftsman frequently uses a single plane projection which shows the external features only. Such a representation is called a pictorial drawing. Perspective drawing, which shows an object as it actually appears to the eye, is largely used in architechtural drawing but has the disadvantage that measurements to scale cannot be taken from the drawing. To obtain a pictorial effect and to obtain the advantage of being able to measure dimensions to scale, the isometric drawing is most adaptable. It can be drawn quickly, either freehand or with instruments, and it can be dimensioned directly by use of architects' or engineers' scales.

163. One-Plane Projection

Rather than viewing an object through the several planes of the glass box, a draftsman should imagine himself standing in one position with a single projection plane between himself and the object.

a. Axonometric Projection. In axonometric projection, projectors are parallel to each other and perpendicular to the plane of projection. The object is placed so that its principal axes are inclined to the projector plane, thus showing three or more surfaces in a single view. Axonometric projection is classified as isometric, dimetric, and trimetric depending on how the principal axes are inclined relative to the projection plane.

b. Oblique Projection. In oblique projection, projectors are parallel to each other but are not perpendicular to the plane of projection.

The principal surfaces project on a single plane, and the object is placed so that one surface is parallel to the projection plane and appears in its true size and shape.

c. Perspective. Perspective, or central projection, is discussed in paragraph 125. Unlike the principal lines in isometric and oblique drawings, the lines of a perspective drawing cannot be measured directly.

164. Isometric Projection

Before the draftsman can develop isometric drawings, it is first necessary to understand isometric projection. This type of projection is made as though viewing the object through a single projection plane, the projection lines being parallel to each other and perpendicular to the projection plane. The object is oriented so that each one of its three principal dimensions are inclined at the same angle to the projection plane, thus exposing three sides in a single view. This is called *isometric projection.* An excellent example is the isometric projection of a cube. The cube in position 1, figure 56 is first turned 45° about its vertical axis as in position 2. Notice that the front and side orthographic views (position 1) are each turned 45° in the horizontal plane, thus showing three vertical faces of the cube in position 2. The cube (right elevation) is then tipped toward the plane of projection as in 3 until all three of its principal dimensions (edges 4–8, 4–3, and 4–1) are equally foreshortened, thus exposing three faces as in position 4. The front view in this position is now an isometric projection of the cube. Notice that the cube is tipped forward until the body diagonal through 4 (3, fig. 56) is perpendicular to the front plane. This makes the top face slope approximately 35.3°.

a. Isometric Axes. The point where the three principal dimensions of an object, height, width, and depth (such as 4–8, 4–3, and 4–1, view 4 in figure 56) converge is called their point of origin, "0." These are called the isometric axes. The angle between each pair of axes is always 120° as in figure 57.

b. Alternate Positions of Isometric Axes (fig. 58). Isometric axes may be arranged in various positions on the drawing sheet according to the requirements of the problem. Angles between

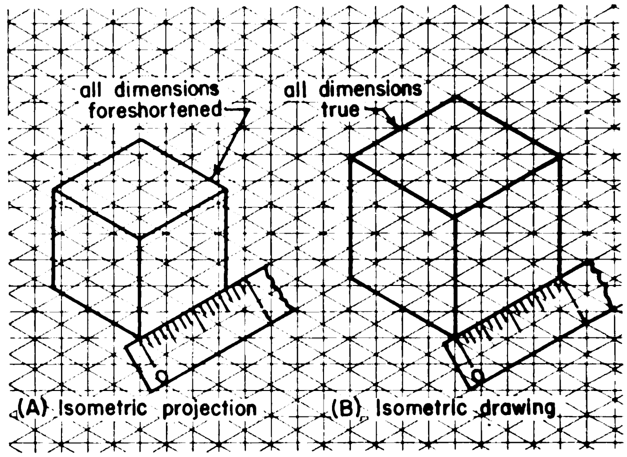


Figure 56. Isometric projection of a cube.

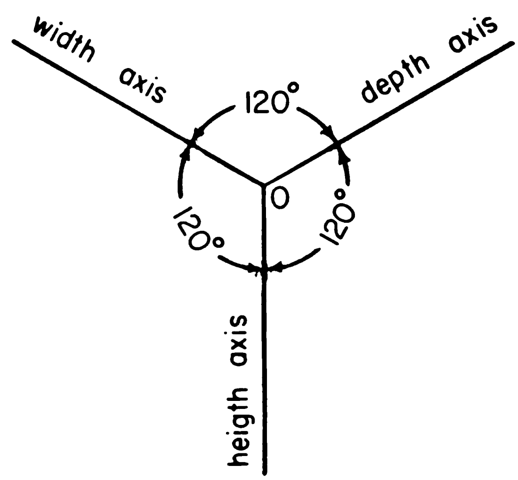


Figure 57. Isometric axes.

axes remain the same. The vertical axis may be drawn in alternate horizontal position.

(1) *Receding axes with vertical axis.* Zero may be placed at either end of the vertical axis. The receding axes may extend from zero toward the edges or center of the drawing sheet. They must be 120° apart and each must take an angle of 30° with an imagniary line drawn perpendicular to the vertical axis at zero.

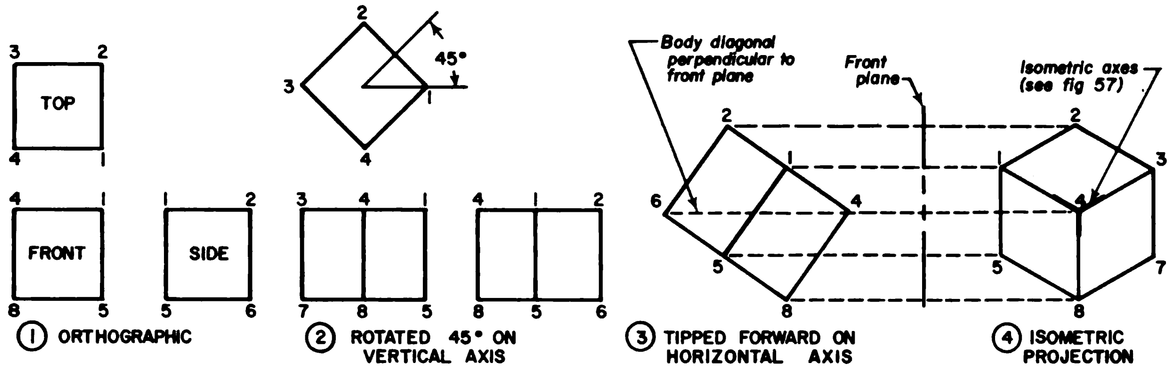


Figure 58. Alternate isometric axes.

(2) *Receding axes with horioznatal axis.* Zero may be placed at either end of the horizontal axis. The receding axes may extend from zero toward the center or edges of the drawing sheet. They must be 120° apart and each must make an angle of 30° with an imaginary line drawn perpendicular to the horizontal axis at zero.

c. Isometric and Nonisometric Lines. All lines parallel to the isometric axes in an isometric drawing are called isometric lines. Nonisometric lines are not parallel to any of the isometric axes. Measurements can be made only on isometric lines and axes. Measurements cannot be made along nonisometric lines.

d. Isometric Drawing. An *isometric drawing* resembles an isometric projection in all respects except that the foreshortening of lines is disregarded, and all measurements are drawn true to scale along the isometric axes. Figure 59 shows an isometric drawing in comparison with an isometric projection. Notice the full size measurement of one inch as compared with the foreshortened ($^{13}/_{16}$ inch or approximately 81% of true length) dimension.

165. Transferring Measurements With Coordinates

Nonisometric lines, angles, and irregular curves are transferred from orthographic to isometric drawings by employing a two-coordinate frame of reference (par. 73).

a. Scales. Orthographic and isometric views are drawn to the same scale. Two coordinate

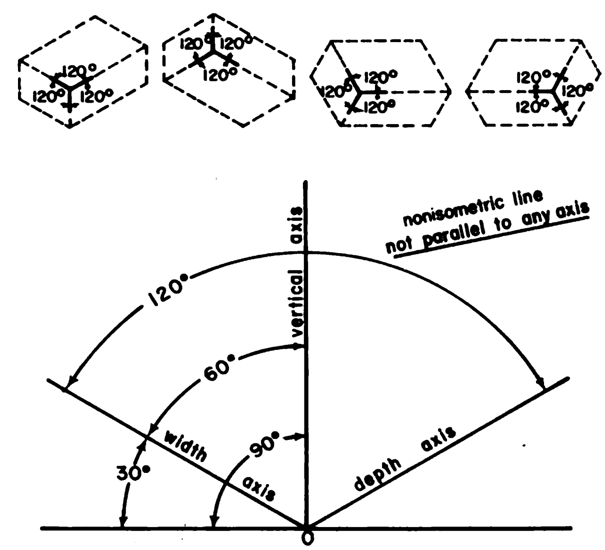


Figure 59. Comparison of isometric methods.

axes are constructed in each orthorgraphic view by drawing intersecting horizontal and vertical tangents to the points nearest the reference line in each view. The coordinate axes in the orthographic views are divided into equal units. Principal axes on the isometric rectangle are divided into the same units.

b. Coordinates. Any point in an orthographic view can be located by its rectangular coordinates (par. 77). Coordinates to locate the same point in the corresponding isometric view are extended parallel to the isometric axes. Straight nonisometric lines can be located with two points (two coordinates for each point). Irregular curves are located by plotting enough points to produce a satisfactory curve. Angles are located by transferring the true lengths of their sides to isometric lines.

166. Drawing Rectangular Solids

A rectangular solid is the basic shape in isometric drawing and serves as a framework for locating the important features of an object.

a. Procedure. The required tools are pencil, T-square, 30°–60° triangle, and scale. Establish zero in the desired location on the drawing sheet. Draw the vertical axis from zero with the triangle perpendicular to the T-square. With the triangle making angles of 30° with the T-square, draw the two receding axes toward the left and right from zero. Establish the correct measurements along the principal axes, using the scale; all measurements are made from zero. Height is measured along the vertical axis, width toward the left of the vertical axis, and depth toward the right. With the terminal points established on the axes, use the triangle and T-square to draw six isometric lines parallel to the three axes to inclose the three isometric planes of a simple rectangular solid. Two 30° lines are drawn parallel to the receding axes from the height measurement on the vertical axis, and two lines are drawn parallel to the vertical axis from the width and depth measurements on the receding axes. The intersections of these lines establish the points from which the two remaining isometric lines are drawn, at 30°, that converge toward each other and intersect to bound the top or bottom plane.

b. Hidden Lines and Centerlines. Hidden lines are omitted in isometric drawing unless their use is essential to the clarity and understanding of a drawing. Centerlines are not included unless they are required for dimensioning purposes.

c. Basic Framework. Make an orthographic drawing of the object first, and construct an isometric rectangle with light pencil lines. Draw the isometric axes the same length as the principal scale dimensions in the orthographic drawing. Only features parallel to the principal axes in orthographic drawing can be measured directly along the isometric axes; nonisometric (nonparallel) features are located with coordinates. After all points have been located on the isometric rectangle, draw the outlines of the object. Unwanted framework lines may then be erased.

167. Circles in Isometric Drawing

An ellipse is the isometric drawing of a circle. An exact ellipse can be produced by using the coordinate method described in paragraph 165. The time spent in plotting points and transferring measurements makes this method impractical for working drawings. A satisfactory method of approximating an ellipse is the center method presented in figure 60. The first step is to construct an isometric square with sides equal in length to the diameter of the circle. Next locate the midpoint M of each side. Next, use the 60° triangle to construct perpenciulars to each midpoint. The resulting lines, if properly constructed, intersect the opposite corners of the square. The two corners where the perpendiculars intersect are center points for large arcs. The other two intersections of the perpendiculars are center points for the smaller arcs.

a. Concentric Circles. Concentric circles appear as a series of ellipses on an isometric plane. A set of four centers must be constructed for each ellipse.

b. Rounded Corners. To round off an isometric corner (fig. 61) with an arc of known radius, mark off the radius length on the two sides that form the center beginning from their point of intersection and, from the two points so marked, erect perpendiculars to the sides. The intersection of the perpendiculars is the center for the arc that rounds off the corner and is tangent to the two sides. If the rounded corner is on a receding edge, a second arc is required. Draw a line from the first center point parallel to the receding edge. Mark off the width of the recedent edge to establish the second center point. Swing the visible part of the second arc from the second center point and connect the two arcs with an isometric line tangent to both.

c. Rounded Edges. If an entire edge is to be rounded off, arcs must be swung for the two corners of the edge; a small and a large arc are required tangent to the edge at the same point. Each center point is found by measuring from the corner along the component sides and marking off the radius distance. Perpendiculars are

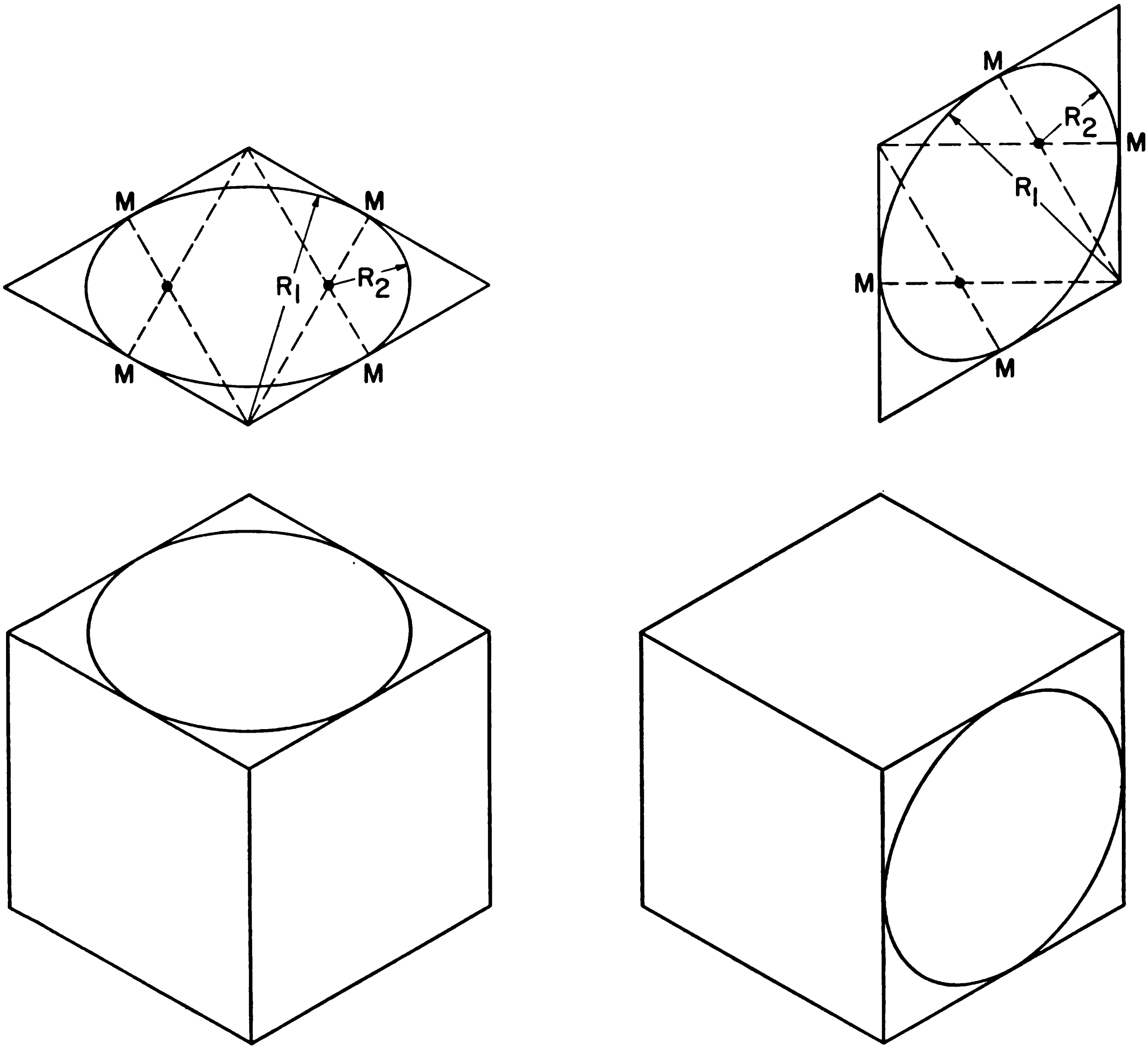


Figure 60. Drawing an isometric circle.

erected from the marks; their intersections form the center points from which the arcs are swung. If the edge shows as a plane, each center point is moved isometrically the width of the plane to locate the center points for drawing the farthermost arcs.

168. Spheres in Isometric Drawing

A circle is the isometric drawing of a sphere. The diameter of the sphere is drawn as a vertical line located in the center of an isometric square. The sides of the square are the same length as the diameter of the sphere. The four-center method is used to draw an ellipse in the square; the long diameter of the ellipse is the diameter of the circle, which is the isometric representation of a sphere.

169. Isometric Sections and Dimensioning

a. Sections. Although isometric drawings are intended to show exterior details, isometric section views may be used to show unusual details of interior construction. The cutting plane is passed through the object parallel to one of the receding axes. The cut face is drawn according to the principles of isometric drawing. Section

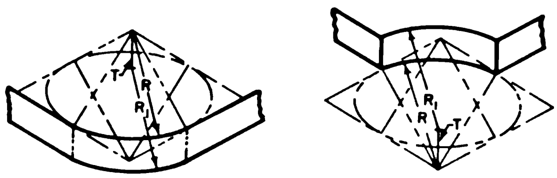


Figure 61. Isometric rounding of corners.

lining is drawn at any standard angle that does not parallel the angles of the principal object lines. Sixty degrees is generally a satisfactory slope for isometric section lining. The imaginary cutting planes for an isometric half section are passed parallel to the receding axes and intersect so as to cut out the front quarter of the object.

b. Dimensions. The same general rules are used for dimensioning isometric drawings as for dimensioning orthographic drawings (ch. 7). Dimension lines, extension lines, and dimension figures are all drawn parallel to the isometric axes. Notes are alined horizontally and lettered to read from left to right.

CHAPTER 7
DIMENSIONS AND NOTES

Section I. DIMENSIONS

170. Defintion

The discussion of technical drawing so far has covered only shape description. To manufacture an object in accordance with a designer's specifications, a mechanic or craftsman needs more informtaion than that furnished by the scale drawings of its shape. The systematic description of shape must be accompanied by a systematic description of size. Height, width, and length of the object, size and location of its features, plus other important numerical details must be stated clearly. The system of lines, symbols, numerals, and dimensional notes furnishing this information is called dimensioning. Dimensions are numerical values, expressed in appropriate units of a measure, that define the geometrical characteristics of an object and establish its location.

171. Requirements

The purpose of dimensioning is to give workmen on the job sufficient size data to proceed as effeciently and conveniently as possible. They should not have to seek additional information by scaling the drawing or performing calculations. All dimensioning practice follows certain basic procedures presented in this chapter. Applications of the basic procedures differ in various phases of manufacture and construction, however, because of different methods of assembly and construction; they are discussed in the appropriate chapters. In all situations in which a draftsman is required to make a choice of the dimensions to include in a drawing, his decision will be influenced by the basic principles of dimensioning and his knowledge of the particular construction practices involved. The following apply to all dimensioning:

a. Interpretation of Dimensions. In applying the rules presented in this chapter, it is important that the statement of a dimension should be clear and permit only one intepretation. It is permissible to deviate from the ordinary rules of dimensioning in unusual circumstances only if clarity can be improved.

b. Adequacy of Dimensions. All dimensions will be complete without repetition.

c. Extent of Dimensioning. Each surface, line, or point will be located by one, and only one, set of dimensions that will not be duplicated in other views.

172. General Rules

The following general rules should be considered by the draftsman in order to decide how to dimension a completed drawing:

a. Place dimensions applying to related views between them whenever possible.

b. Avoid placing dimensions directly on the object.

c. Place dimensions applying to more than one view on the view which most clearly shows the feature being dimensioned.

d. Do not place dimensions to hidden edges.

e. Avoid unnecessary duplication of dimensions.

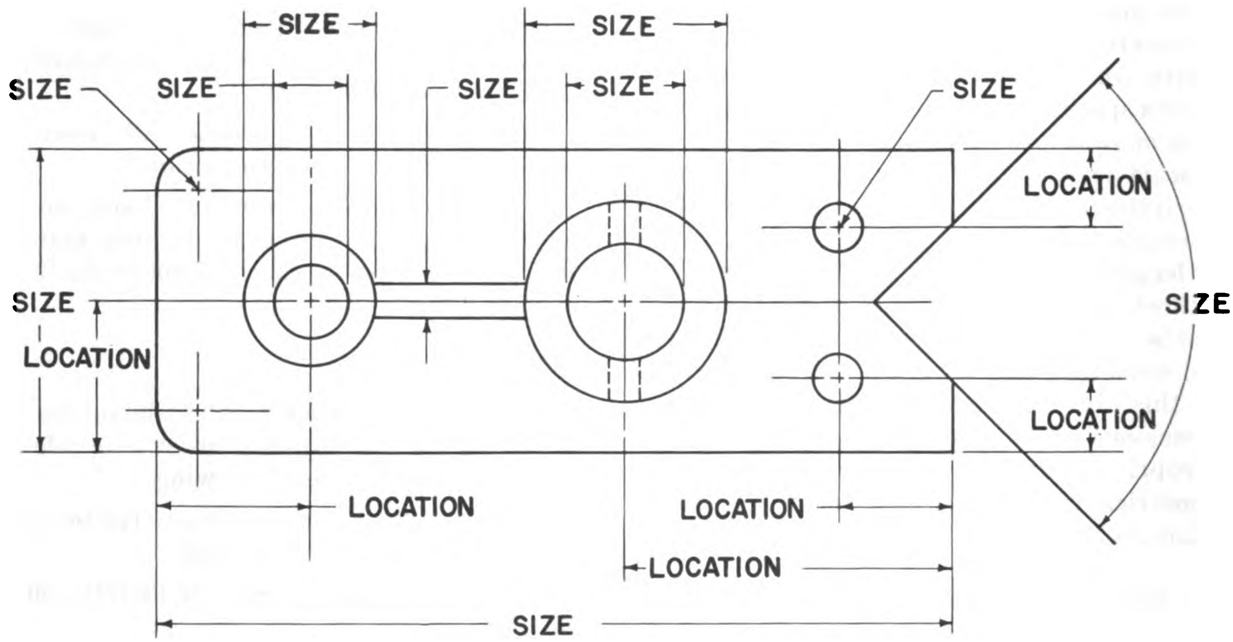
f. Locate dimensions for entire drawing so that they all read from the bottom or right side of the sheet.

g. Place small dimensions near the object and increasingly larger dimensions farther away from the object.

***Caution:* GENERAL PRUDENTIAL RULE. In observing and applying the above rules, careful consideration should be given to any speical circumstances involved, which may make a departure from these rules necessary in order to preserve clarity and understanding.**

173. Theory of Dimensioning

Any part can be dimensioned easily and systematically by breaking it down into a group of assembled, simple geometric shapes. Prisms, cylinders, cones, and pyramids are examples of basic geometric forms. The dimensioning of each follows familiar geometric practice. An object is dimensioned by giving the individual sizes of the component geometric forms and establishing their location relative to each other (fig. 62). Two types of dimensions are required to describe an object: size dimensions, and location dimensions.



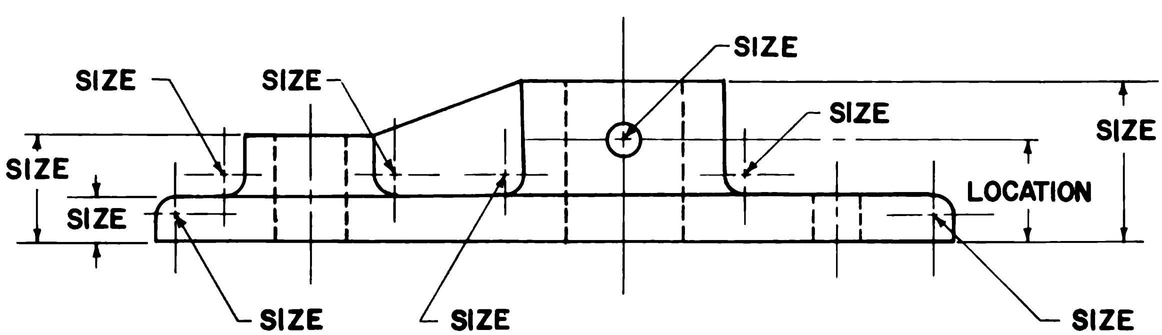


Figure 62. Size and location dimensions.

a. Size Dimensions. A size dimension is a specified value of a diameter, width, length, or other geometrical characteristic directly related to the size of an object.

(1) *Prism.* A prism is dimensioned by giving its height, width, and depth. In a drawing, two dimensions are given in the principal view and the third in a related view.

(2) *Cylinder.* The size of a cylinder is shown by two dimensions when it appears in a profile view. One dimension gives its length, the other, accompanied by the note DIA, gives its diameter.

(3) *Cone.* A cone is dimensioned by giving its altitude and the diameter of its base. Both appear in the same view.

(4) *Pyramid.* A pyramid is dimensioned by three dimensions. Width and depth are given in the view showing the base; height is given in a related view.

b. Location Dimensions. A location dimension is one that specifies the position or distance relationship of one feature of an object with respect to another. Location dimensions give distances between centers (center to center), between a surface and a center, or between two surfaces.

(1) *Datum elements.* Datum surfaces, datum planes, and so on, are features of a part and are assumed to be exact for purposes of computation or reference, although another feature or other features of the part may vary with respect to the datum. The zero lines of a local grid (par. 72*b*) are datum lines because significant construction points, such as foundation walls, are located with respect to the zero lines. The finished floor or building is a datum plane. Door and window heights are established with location dimensions relative to the finished floorline.

(2) *Reference dimensions.* A reference dimension is a dimension used for informational purposes only and does not govern shop operations in any way. Reference dimensions will be indicated on the drawing by writing the abbreviation REF directly following or under the dimension.

174. Dimensioning Elements

The elements described here are used as the basic means of indicating linear dimensions. Line weights and characteristics are described in paragraph 45 and 46 and illustrated in figure 9. Approved use of dimension, extension, center, and other lines is illustrated in figure 10.

a. Dimension Lines. Dimension lines will be used to show the extent of lengths, breadths, and thicknesses to which dimensions apply. The spacing suitable for most drawings is about 3/8 inch between parallel dimension lines, or between the dimension line and the outline of the object.

b. Extension Lines. Extension lines will be used to denote locations, such as points or surfaces between which the dimension applies. They will be drawn perpendicularly to the dimension lines but when required, they may be drawn at an angle if their starting point is not questionable. They generally start about 1/16 inch from the outline of the part and extend about 1/8 inch beyond the outermost dimension line.

c. Numerals and Letters. All numerals used for dimensioning and all lettering used for dimensional notes will conform to the requirements of MIL–STD–1A as presented in chapter 3.

(1) *Spacing.* It is important to provide ample spacing between letters or numerals to prevent them from becoming blurred when reproduced in a reduced scale.

(2) *Reading position.* All horizontal dimensions and all dimensional notes will be placed to read from the bottom of a drawing. Vertical dimensions read from the right of the drawing. All other dimensions may be placed to read either from the bottom or in the direction in which the dimension applies.

d. Centerlines. Centerlines will be used to indicate points and axes of symmetry. Centerlines may be extended to show relationships between symmetrical features and to serve as extension lines for dimensional purposes. Two centerlines will be drawn at right angles to each other in views showing the circular contour of a cylinder to indicate the center of a circle. The centerline will have an actual intersection at the center of the circle, with the short dashes forming the intersection.

e. Leaders. Leaders composed of straight, ruled lines will be used to indicate exactly where dimensions and dimensional or explanatory notes are to be applied. The note end of the leader will always run either to the beginning or end of the note dimension, never to the middle.

(1) *Application.* In general, the leader will be applied in the view showing the profile of the surface to which the requirement applies.

(2) *Appearance.* Drawings present a better appearance if all adjacent leaders are parallel; however, leaders will not be parallel to adjacent dimensions or extension lines.

(3) *Symmetrical features.* Leaders drawn to symmetrical features will be in line with the center of the feature, and the arrowhead of the leader will terminate exactly on the line representing the profile of the feature.

f. Arrowheads. Each arrowhead on a drawing should be of uniform size and shape. They are made with two concave strokes terminating at the end point of the line. The width should be approximately one-third the length. The head may be filled in solid on large arrowheads.

g. Units of Measurement. The unit of measurement in drawings will be only the inch unless other units are specifically indicated. When the dimension is in units of inches only, inch marks will be omitted.

(1) *Combination of units.* When there is a combination of units of measurement, unit symbols will be used. Dimensions will be hyphened thus, 3′-7″; 5′-0¼″; 5′-0″.

(2) *Unit marks.* The symbol (″) may be used to indicate inches and common decimal fractions of an inch. The symbol (′) may be used to indicate feet.

(3) *Fractional divisions.* Dimensions in all construction drawings will be expressed in units and common fractions. In machine drawing, dimensions of parts that can be produced with sufficient accuracy when measured with an ordinary scale should be dimensioned in the same manner. The smallest fractional divisions used in dimensions will be 1/64.

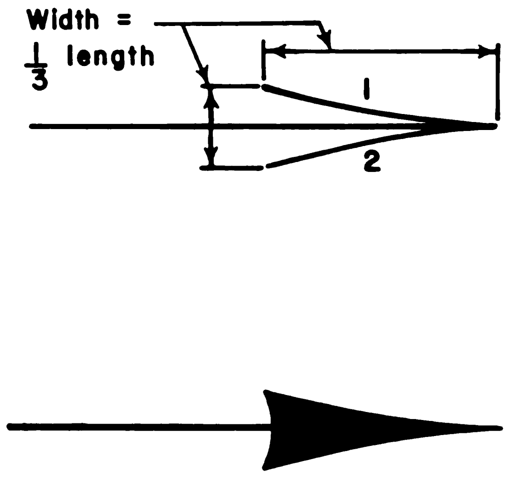


Figure 63. Typical arrowheads.

h. Angular Units. Angles will be expressed in units of degrees with divisions of minutes or seconds or may be expressed as degrees, minutes, and decimals thereof. The symbol (°) is used for degree, (′) is used for minutes, and (″) is used for seconds; 10°45′30″ means 10 degrees, 45 minutes, and 30 seconds.

175. Dimensional Systems

Size, form, and location may be specified with two fundamental dimensional systems—rectangular dimensioning (1, fig. 64) and angular dimensioning (2, fig. 64). Both systems may be used on the same drawing; however, any given surface or any given point must be located only by the rectangular system or only by the angular system.

a. Rectangular Dimensioning. The rectangular dimensioning system is a method of indicating distances, locations, and sizes with linear dimensions measured parallel to reference lines or planes that are perpendicular to each other.

b. Angular Dimensioning. The angular dimensioning system is a method of indicating the

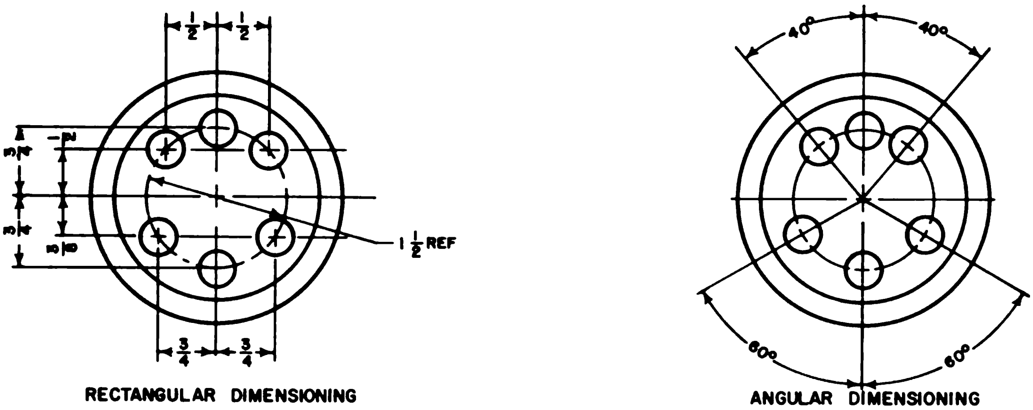


Figure 64. Rectangular and angular dimensions.

position of a point, line, or surface with linear dimensions and angles other than the 90° angle formed by the horizontal and vertical centerlines.

c. Preferred Method of Dimensioning. The rectangular method is preferable to the angular. The angular method is most useful for circular dimensioning, which includes specifying the location of several nonprecision holes on a common arc or dimensioning graduation on a circular scale.

176. Rules for Applying Dimensions

a. Choice of Views. A line is dimensioned only in a view showing its true length. Indicate as many dimensions as practicable, without crowding, in the front view. The front view is always selected to show the most characteristic shape of an object. In general, all dimensions for surfaces that show as edge views (receding surfaces) should be given in this view. Dimensions will usually be given in auxiliary views only for those lines and surfaces not shown in their true length or shape in a principal view.

b. Crossing Lines. When practicable, lines used in dimensioning a drawing should not be crossed.

(1) *Dimension lines.* To avoid crossing, the dimension line for the shortest length will be placed nearest the outline of the object, and adjacent parallel dimension lines will be added in the order of their size. The longest dimension line is placed outermost. Rules of spacing presented in paragraph 173 will be observed. When crossing dimension lines with leader or extension lines is unavoidable, a break will be made in the extension or leader line at the point of crossing.

(2) *Extension lines.* When it is necessary to cross an extension line, it is permissible to break the extension line to improve clarity.

(3) *Leader lines.* Care will be taken to avoid crossing leaders but when the crossing is absolutely necessary, a break should be made in one of the leaders at the point of crossing. Leader lines will not be drawn parallel to adjacent dimension or extension lines.

c. Grouping Dimensions. Clarity is improved by placing dimension lines and numerals where space permits when grouping dimensions (1, fig. 65).

d. Staggering Dimensions. Dimension figures should be located at the center of the dimension line except when another line interferes. When space is restricted or a number of parallel dimension lines occur together, it is desirable to stagger columns or dimensions in two or more rows (2, fig. 65).

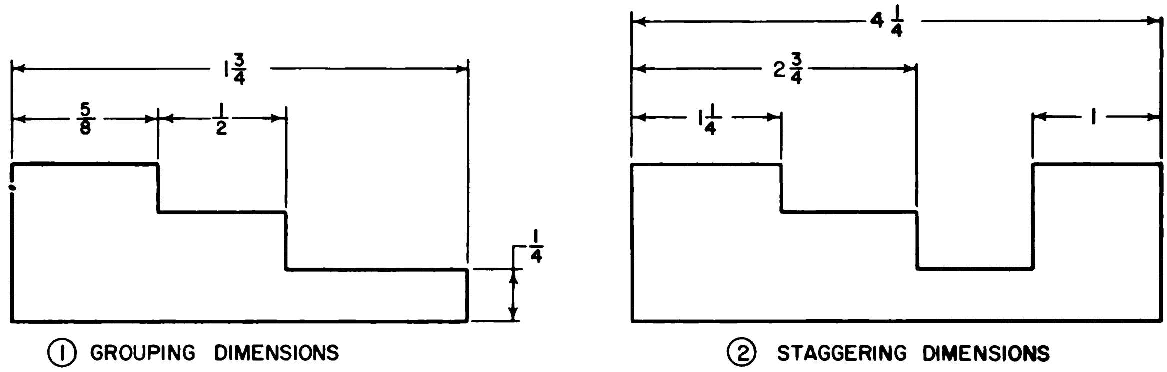


Figure 65. Grouping and staggering dimensions.

e. Placement of Dimensions. Dimensions should be placed outside the view being dimensioned. It is preferable to place overall dimensions above and to the right of the principal view. Overall dimensions of surfaces that show in profile in two views are preferably placed between these views. When dimensions are placed between views, however, they should apply to one view only. Overall dimensions are those showing the extent of the principal dimensions of an object, namely, length, height, and width. Avoid placing dimensions directly on the object.

177. Contour Dimensioning

The size and location of holes and curved surfaces should be shown in the views in which their contours appear namely, when they appear as circles and curves. An exception to this rule is when a sectional or profile view is taken along the axis of two or more concentric cylindrical surfaces. In this case, it is usually clearer and more convenient to show the magnitude of the diameters in the profile view.

a. Use of DIA to Eliminate and End View. The end view of a cylindrical object need not be drawn if the note DIA is placed after the diametrical dimension appearing in the profile view. The end view must be drawn, however, if the cylindrical surface includes special features such as keyways and flats.

b. Holes. Size dimensions and notes pertaining to holes will be given with a leader drawn in the view where the hole appears as a circle.

(1) *Diameter.* When the size of a circle permits (above 3/8 inch in diameter), use a graphic diameter indication. It consists of a line drawn at approximately 45° to the horizontal passing through the center point of the circle and terminating on either side at the circumference. Arrowheads are drawn at the terminal points pointing outward. The leader is drawn at the same angle as the diameter indication and represnts a continuation of the line; also, it requires no arrowhead and is accompanied only by a numerical dimension. On circles too small to permit use of the graphic diameter indication, the leader terminates in an arrowhead touching the circumference. The size dimension is accompanied by the note DIA. No diameter line is used inside a circle; centerlines are drawn in both cases.

(2) *Depth.* When a hole passes completely through a piece, depth is not given if the information appears in a related view. The word THRU may be used for through holes if a related view does not show this feature.

c. Location of Holes. Holes will be located by dimensions to extensions of centerlines (fig. 64). Nonprecisions holes may be located by the angular dimensioning system if their centers lie on a common circle, such as a circular flange. Generally, precision holes should be located by rectangular coordinates. Holes will never be located by drawing extension lines to their circumferences.

d. Radii. Curved surfaces shown on arcs of circles will be dimensioned by drawing a radial dimension line through the origin of the radius to the surface in question. On small radii, the radial dimension line passes through the origin of the radius to the surface in question. On small radii, the radial dimension line may be drawn on the side opposite the center, rather than through it. The letter R will always follow the dimension of the radius.

e. Fillets and Rounds. In instances where there are a large number of fillets or rounded edges of the same size, it is acceptable to specify them in the form of a note, rather than specifying each radius on the drawing of each part. Such notes may read—

All edges____R unless otherwise specified.
All fillets____R unless otherwise specified.

f. Chamfers. Chamfers are dimensioned in the profile view that shows their angle of inclination (fig. 66). A 45° chamfer is dimensioned by giving the horizontal or vertical span, rather than the length of the inclined edge; 1/16 x 45° indicates a 45° slope across a strip 1/16 inch wide. Other chamfers are dimensioned by giving the angular dimension as an arc and the width as a horizontal or vertical distance. It is unnecessary to use the word chamfer in the drawing.

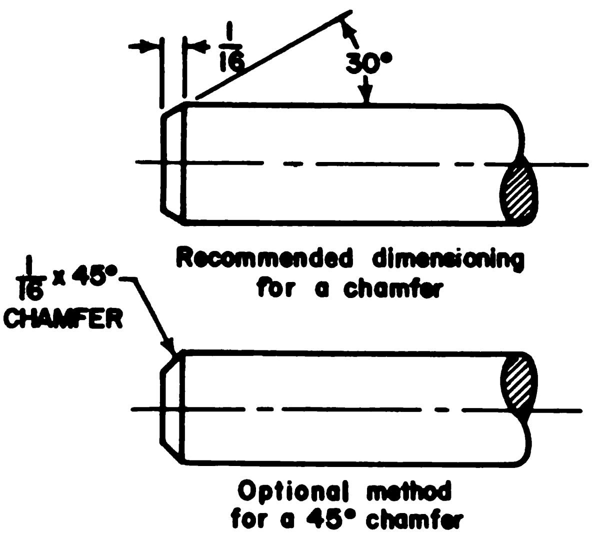


Figure 66. Dimensioning chamfers.

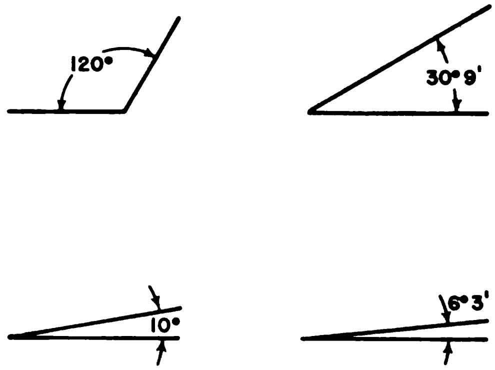


Figure 67. Angle dimensions.

g. Angles. Dimension lines of angles will be arcs drawn with the apex of the angle at the center whenever practicable. The position of the dimension inside or outside the extension lines describing the angle varies according to the size of the angle in degrees, minutes, and seconds. Some acceptable variations are shown in figure 67.

h. Slots With Rounded Ends. These will be dimensioned by giving the overall length of the slot with the width and the radius of the end curve.

i. External Surfaces With Rounded Ends. These are dimensioned by specifying the overall length and width of the piece and the radius of the ends. If the arcs at the opposite ends of the piece are the same, centerlines for both circles can be drawn but only one arc need be dimensioned. When the radii of the arcs are less than 1/2 inch, the size dimension of the piece is given from end to end; the dimension is given between the centerlines of the arcs when the radii are 1/2 inch or larger.

178. Checking Dimensions

A summary of the most important dimensioning rules will aid a draftsman in checking his work.

a. Completeness. Check to see that all parts are dimensioned without duplication so that workmen will not have to scale the drawing or calculate any dimensions.

b. Overall Dimensions. Check to see that overall dimensions have been applied and that the figures used are those necessary for the manufacture of the object and not those used to make the drawing. Check the size and location dimension totals against overall dimensions.

c. View Selection. Check to see that dimensions are placed between the views, and that extension lines are drawn to one view only; this view should be the one showing the distance in its true length.

d. Spacing. Spacing between parallel dimension lines and between object outlines and dimension lines should be $\frac{3}{8}$ inch. Check to see that no object outline or centerline has been used as a dimension line.

e. Alinement. Check to see that all horizontal dimensions can be read from the bottom of the drawing, and that all vertical dimensions can be read from the right of the drawing.

f. MIL–STD–8B. Reference should be made to MIL–STD–8B for further information about approved dimensioning and tolerancing practice for military drawings. Information contained in this standard covers specific machine drawing practices such as decimal dimensioning, tolerancing, fits, and limits.

179. Specification Lists

Nonstandard construction methods or materials are stated or specified in a separate list of instructions in a structural drawing. The list is called a specifications list, or specifications for a set of construction drawings. Working information contained in the specifications, such as door and window sizes, materials used for flooring and interior walls, and so on, is included in the general notes and presented under the appropriate schedule heading.

Section II. NOTES

180. Notes Defined

Instructions relating to the materials and manufacturing operations of an object not appearing in the title block are placed in a drawing and are called notes. In combination with the shape descriptions of orthographic projection and the numerical size descriptions furnished by dimensioning, these instructions provide the total information necessary for the manufacture of an object or assembly. Notes are classified as specific and general (fig. 68) and lettering will conform to the standards presented in chapter 3. Notes will always read horizontally.

181. Specific Notes

Specific notes are placed adjacent to the features to which they apply and are connected to them by leaders.

a. Machine Drawings. Specific notes for machine drawings also are known as dimensional notes because they may be used to eliminate extra numerical dimensions; "$\frac{3}{4}$ Drill, 4 Holes" is an example. "Drill and Ream" and "Carburize, Harden, and Grid" are examples of notes describing a specific operation.

b. Construction Drawings. Specific construction notes give information about the different kinds of material, the sizes and names

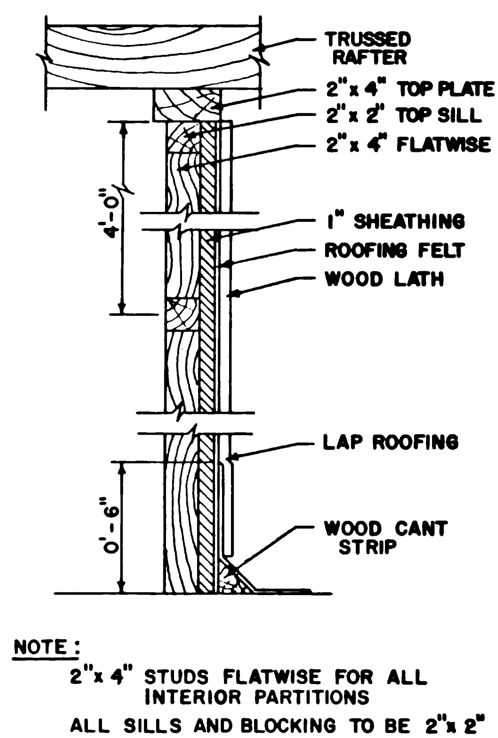


Figure 68. Specific and general notes.

of structural members, the number, size, and kind of connectors, and so on. Unlike specific notes for machine drawings, which usually are accompanied by numerical dimensions, specific notes for construction drawings often are placed without numerical dimensions. In such cases, they serve to identify features of building materials.

182. General Notes

General notes usually are grouped in the lower right-hand corner of the drawing sheet, either to the left or above the title block, but may be center below the view to which they pertain. They do not require a leader.

a. Machine Drawings. General notes for machine drawing indicate sizes and operations pertaining to the entire drawing. "Finish All Over" and "Fillets and Rounds $\frac{1}{8}$, unless otherwise specified" are examples of general notes used for machine drawings.

b. Construction Drawings. The general notes shown in figure 68 are centered beneath the detail drawing. The general notes of a plan or section view are grouped in a tabular arrangement called a schedule. Notes are grouped under different schedules and all are arranged in vertical files that can be read from the bottom of the drawing sheet.

CHAPTER 8
TECHNICAL SKETCHES AND WORKING DRAWINGS

Section I. TECHNICAL SKETCHING

183. Freehand Technical Drawing

a. Applications. There are many occasions when graphic size-shape data can be presented more conveniently in a freehand sketch than in a drawing prepared with instruments. A freehand technical drawing is the most suitable way for a designer to show a draftman what is wanted in a finished drawing. The man who is sent out to record information about a bridge that needs repair will find it easier to move around with a sketch pad and pencil than with a drawing board and a complete set of instruments. In both cases, the primary need is to furnish essential information quickly and efficiently. A technical sketch is a freehand orthographic drawing. A pictorial sketch is a freehand isometric drawing. The principles of orthographic projection and isometric drawing are the same whether a drawing is executed freehand or with instruments. Although it is expected that an experienced draftsman will develop an individual style, the fundamentals presented in this chapter will provide the beginner with a satisfactory technique for preparing accurate, legible freehand sketches.

b. Classification. Sketches may be classified in relation to the building of an object, or structure. There are two general categories: those that precede the building of the object, and those that follow it. In the first category are principally design sketches representing the designer's instructions to the draftsman and working sketches that may be used as a substitute for working drawings. Sketches made after a structure has been completed generally are for the purpose of repair or reconnaissance and fall in the second category. A sketch showing a part requiring repair may be as complete as a working drawing. A reconnaissance sketch is required to establish relative locations rather than to furnish accurate size and shape descriptions.

c. Materials. Paper, pencils, sharpening equipment, an eraser, and a measuring instrument are the only materials required for freehand sketching.

(1) *Pencil.* A soft pencil, H or HB, is best for freehand lines. Sharpen the pencil to a long conical point. A pocket knife and a sandpaper pad or small file should be carried to maintain a sharp point. As in an instrument drawing, the sharpest lines are the most legible and are produced with a sharp pencil point.

(2) *Paper.* A pad $8\frac{1}{2}$-x 11-inch cross section paper is recommended. For sketching, the most satisfactory grids are composed of $\frac{1}{4}$-inch squares or 16 squares to the inch. Cross section paper is an aid in drawing straight lines and in maintaining a reasonably accurate scale.

(3) *Eraser.* Carry a rubber or gum eraser to remove unwanted lines and to keep the drawing clean.

(4) *Measuring equipment.* The choice of measuring equipment is determined by the size of the object to be sketched. For small machine objects, a machinist's steel scale and calipers are adequate. A 6-foot folding rule is satisfactory for most routine construction measurements. Measurements over 40 feet in length can be made more easily with a 100-foot surveyor's tape. The size of the object will also decide the value to be assigned each grid square, that is, the scale to which the object is drawn.

184. Technique

As in instrument drawing, the purpose of developing a satisfactory technique is to produce lines of direction, weight, and characteristic construction to provide the reader with a single, clear understanding of their meaning. The pencil should rest on the second finger and be gripped lightly by the thumb and index finger about 1½ inches from the tip. It is held in a vertical plane and inclined at about 30° in the direction of the line being drawn. A draftsman should be able to observe the point of the pencil during the execution of each stroke. The layout is made first in light construction lines. The lines are darkened in after the layout has been checked for accuracy. The same procedure is used for both light and heavy lines.

185. Straight Lines

a. Procedure. Straight lines are usually drawn from left to right and from the top down with wrist and finger movements. The paper may be turned and the pencil held in any convenient manner—as the only purpose is to make the lines "freehand" and "straight." Figure 69 shows how the paper may be turned to make lines 1–2, 2–3, 3–4, and 4–1 all horizontal and thus capable of being drawn as most natural with a left-to-right wrist movement. It is good practice to mark the extremities of a line with dots, or long lines with several dots, before drawing. Two or more line segments should meet end to end without overlap. A practice motion without making a mark is sometimes advisable to be sure the hand can complete the desired stroke without error.

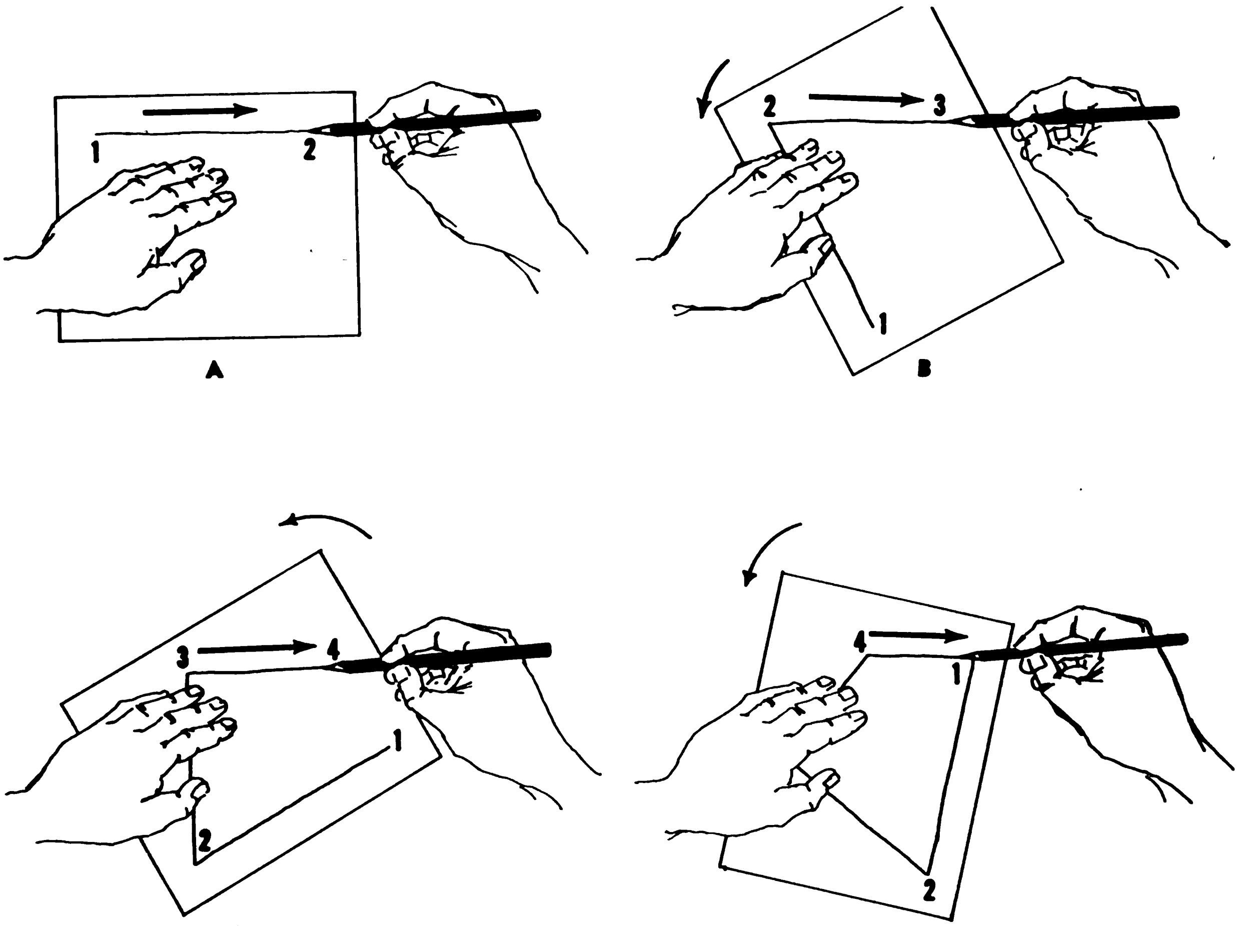


Figure 69. Sketching straight lines.

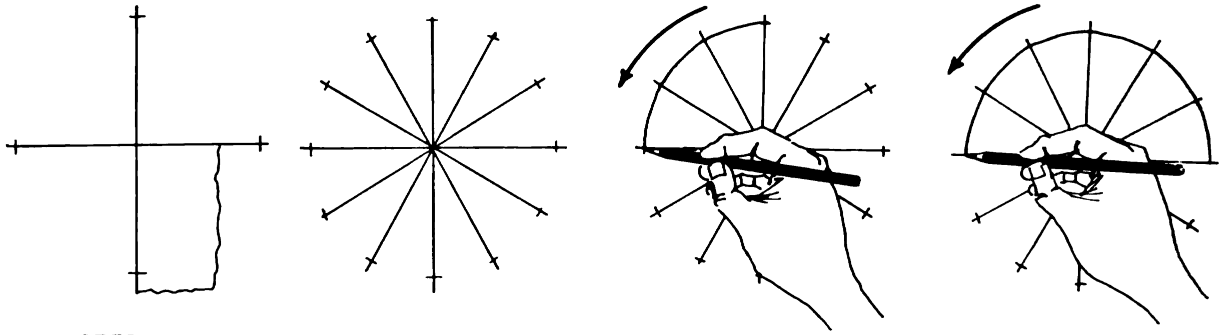


Figure 70. Radial method of sketching circles.

b. Alternate Methods. An experienced draftsman may find it quicker to draw vertical lines from the top down, using a finger motion rather than turning the sketch pad to draw horizontal lines. Inclined lines slanting from upper left to lower right may be drawn in horizontal position by turning the sheet slightly, and inclined lines slanting from upper right to lower left may be drawn in vertical position by turning the sheet slightly. Inclined lines slanting from right to lower left may be drawn in vertical position by turning the paper the required amount in the opposite direction.

c. Line Weights and Conventions. The same line conventions used in instrument drawing are used in sketching to denote the function of a line or its position with respect to the viewer. Whereas three line weights are prescribed for ink drawings (par. 45), only two are required for technical sketching: medium for outline, hidden, cutting-plane, and alternate-position lines; and thin for section, center, extension, and dimension lines. The width and intensity of freehand lines are determined by the size of the pencil point and the amount of pressure applied to it. Circles and arcs require particular attention in sketching because it is more difficult to produce a curved line of uniform weight than a straight line.

186. Circles and Circular Arcs

The same procedure is used for sketching circles and circular arcs (figs. 70 through 73). Four methods are acceptable.

a. Radial Method. Sketch the horizontal and vertical axes to intersect at the center point. Mark off the radius of the circle, on a scrap of paper, with two points and transfer the measurement to the main axes (step 1, fig. 70). Sketch diagonal lines at approximately 30° intervals and use the piece of paper to transfer the measurements to the radial lines (step 2, fig. 70). After all points have been marked with light, distinct dots, sketch the circle one quadrant at a time (steps 3 and 4, fig. 70). By rotating the sketch pad, the stroke can be swung in the same direction each time.

b. Outline Method. Sketch the main axes (step 1, fig. 71) and mark off the radius (step 2,

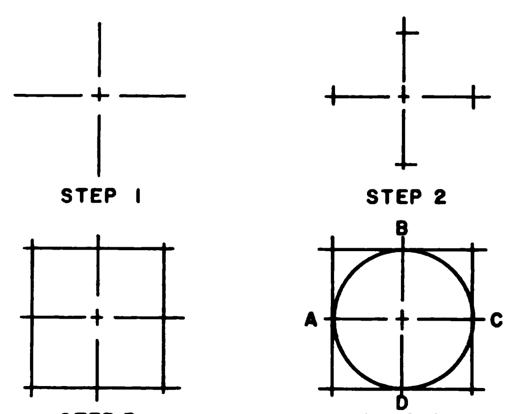


Figure 71. Outline method of sketching circles.

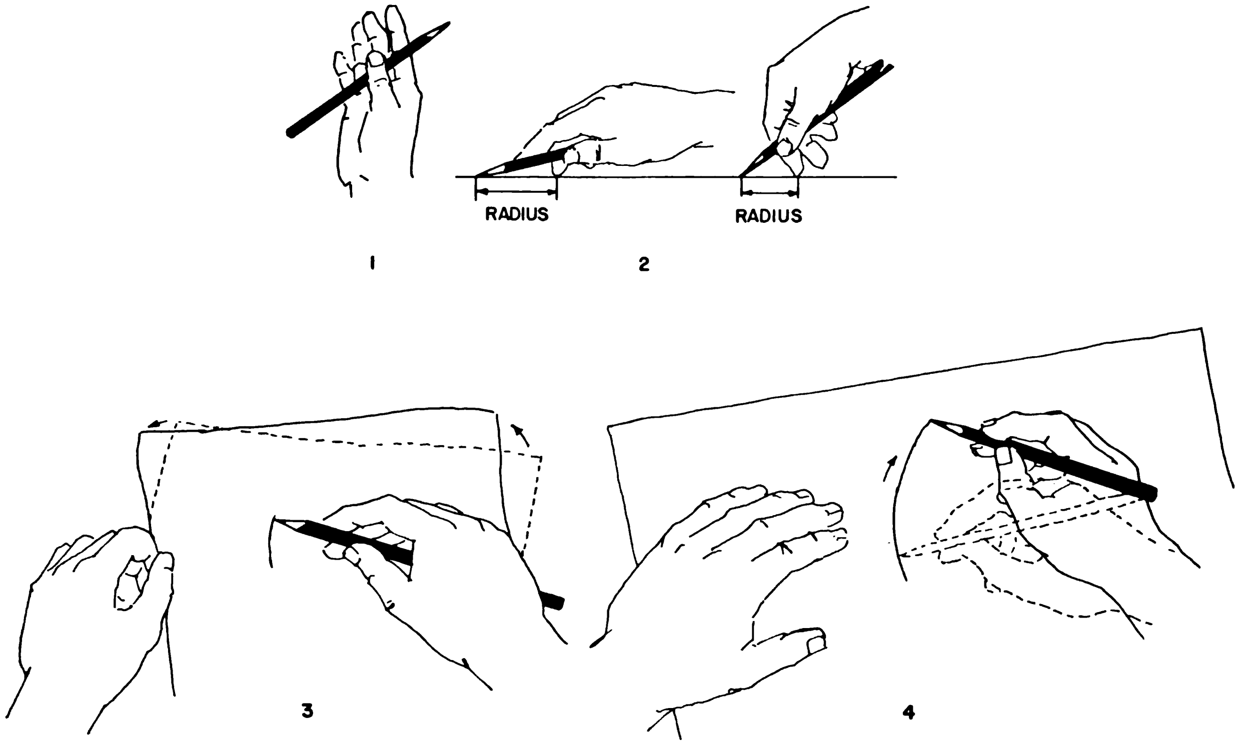


Figure 72. Hand compass method of sketching circles.

fig. 71) for small circles. Construct a square (step 3, fig. 71) by drawing lines parallel to the main axes at the radius points. Draw the circle (step 4, fig. 71) within the square and tangent to it at the midpoint of the sides. For larger circles, add two intersecting lines drawn at 45° to the horizontal. Mark off the radius on the lines and sketch an octagon. Draw the circle within the octagon and tangent to it at the midpoint of each side.

c. Hand Compass Method. Grasp the pencil as shown in 1 and 2, figure 72, so that it is the radius distance from the fingernail that is to be used as the pivot finger. (It may be preferable for some people to use the little finger instead of the forefinger as shown.) Then place the fingernail of the pivot finger on the point that is to be the center of the circle and turn the paper

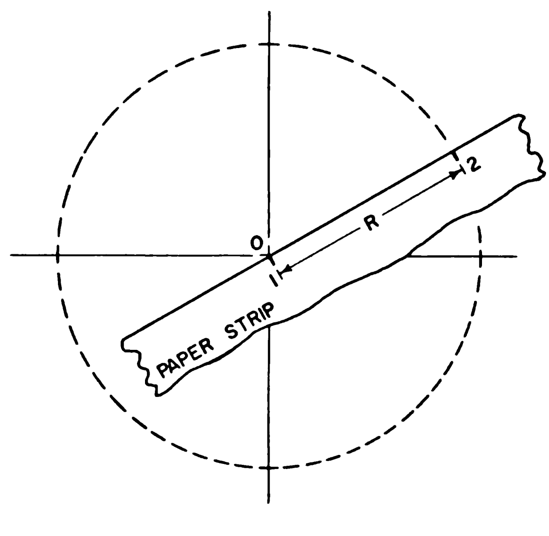


Figure 73. Paper strip method of sketching circles.

(3 and 4, fig. 72) using the hand as a compass to draw the circle.

d. Paper Strip Method. First locate the center point *O*, by drawing the vertical and horizontal centerlines (fig. 73). Then mark off the radius (line 1–2) of the circle on the strip of paper. With point 1 always on *O*, rotate the strip and mark off points where 2 falls. Then sketch in the circle through all points located.

187. Ellipse

Figure 74 illustrates a paper strip method of sketching an ellipse if the center and both axes are known. First draw the major and minor axes *AB* and *CD* intersecting at center *O*. Mark off one-half of major axis (*O′A*) and one-half of minor axis (*O′C*) on a strip of paper. Move the paper so that point *A* is always on the minor axis and point *C* is always on the major axis. For each change in position of *A* and *C*, as the paper strip is rotated, mark off point *O′* on the sketch sheet. Connect all points located by movement of point *O′*.

188. Irregular Curves

An irregular curve can be drawn by locating a series of individual points (by dots) along its path at ½-inch intervals. Sketch a smooth curve through all points located, without overlapping strokes.

189. Technical Working Sketches

A systematic procedure should be followed in preparing a technical working sketch. Draftsmen will find that this not only aids in laying out the views on the sheet but also provides a checklist for including the necessary details methodically.

a. Preliminary Work. Examine the object carefully, and select for a front view the surface that offers the most characteristic shape or requires the least number of hidden lines. Determine the number of views necessary to describe the object adequately. Form a mental picture of the arrangement of the views on the sketch sheet and the spacing required between them.

b. Sketching Sequence. Locate the main centerlines of the views, remembering to leave enough space between views for notes and dimensions (①, fig. 75). Remember also that all preliminary lines are sketched lightly. Block in the views with the principal dimensions of each rectangle proportional to the principal dimensions of each rectangle proportional to the principal overall dimensions of each view (②, fig. 75). Keep all views in projection. Next locate all radius points and sketch in circles, arcs, curves, and rounded edges (③, fig. 75). As a final step in drawing construction lines, put in the hidden lines (④, fig. 75). After checking the drawing to see that all views are complete, darken the outlines to provide the proper line weight and intensity.

c. Dimensioning. Objects are sketched in proportion, not drawn to scale as in instrument drawings. The rules for dimensioning are the same in all drawing. Sketch extension and dimension lines first to indicate where dimensions are required. Next measure the object and record the necessary dimensions. As a final step, add notes and a title block. Sketches should always be dated.

190. Pictorial Sketching

Sketches made in isometric projection (fig. 76) are satisfactory for purposes of pictorial representation. Isometric sketches conform to the principles of isometric drawing presented in chapter 6. The freehand technique is the same as for technical sketching. A draftsman should understand that the angle of the receding isometric axes, when drawn freehand, will only approximate 30° with the horizontal.

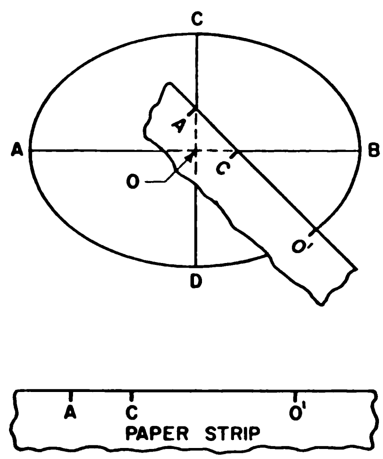


Figure 74. Ellipse—paper strip method.

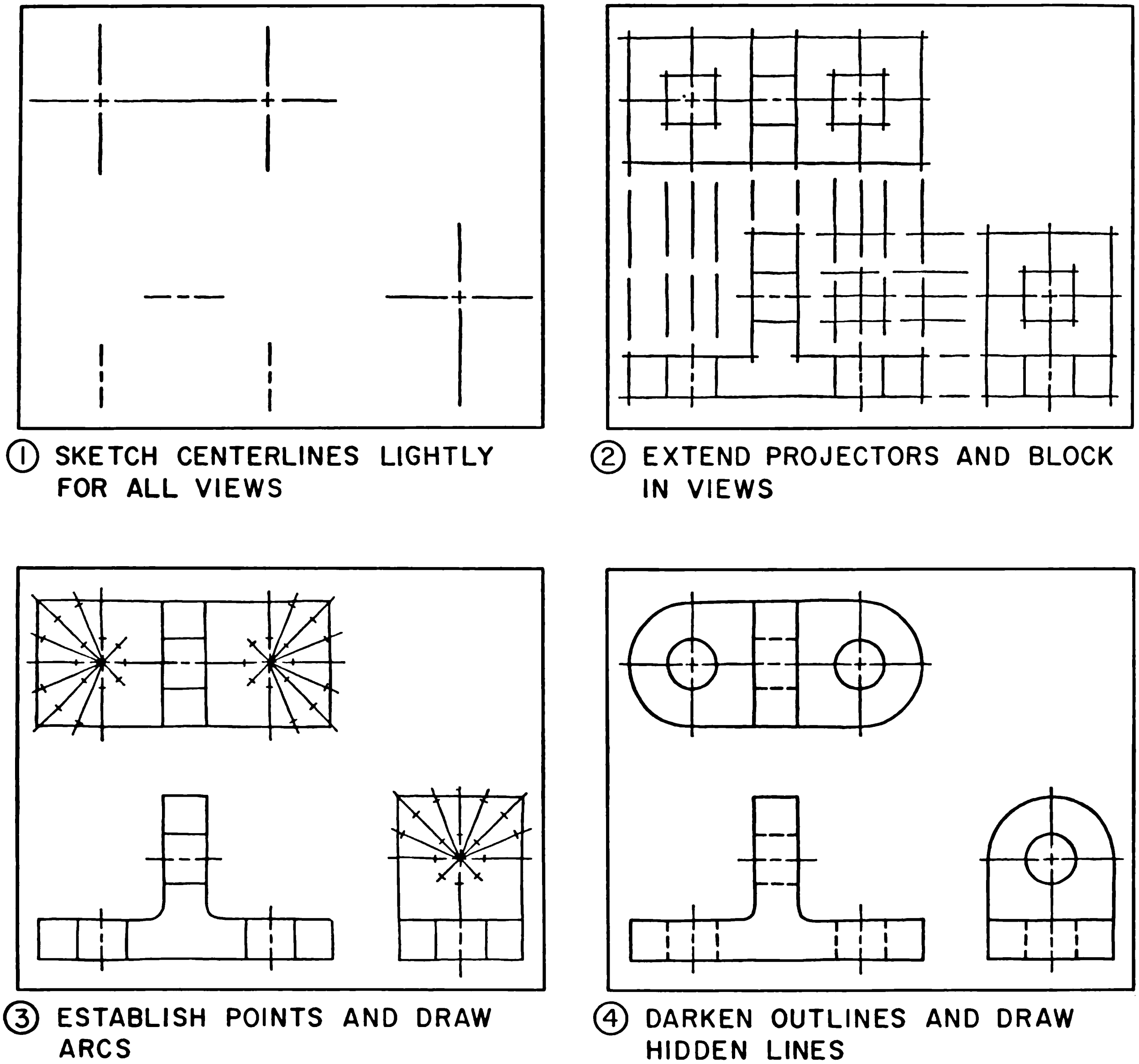


Figure 75. Sketching a simple object.

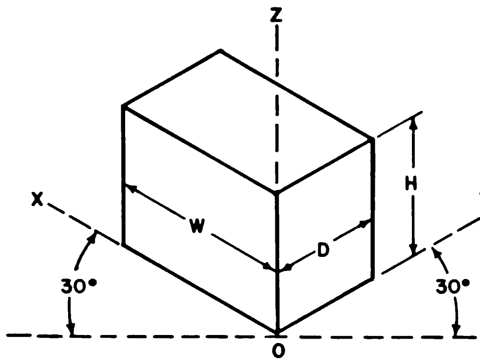


Figure 76. Application of isometric sketching.

a. Advantages. The advantages of a freehand pictorial sketch lie principally in the visualizing of a new object when it shows three dimensions in the same view. Draftsmen will find isometric sketching an assistance in reading an orthographic drawing. At other times, a technical sketch will often be clarified if accompanied by an isometric sketch.

b. Object Orientation. As in technical sketching, a primary requirement in pictorial sketching is good proportion. Objects should be viewed so that the most complex faces are represented on a receding plane.

Section II. WORKING DRAWINGS

191. Definition

A working drawing is any drawing that furnishes the information required by the craftsmen who manufacture a machine part or erect a structure; it is prepared from a freehand sketch or a design drawing. Complete information is presented in a set of working drawings, complete enough so that the workmen who use them will require no further information. A complete set of drawings consists of detail drawings, assembly drawings, and a bill of materials. It also may include drawings showing a foundation plan, piping diagram, wiring diagram, and so on. Each drawing sheet must be identified by a title block. Both detail and assembly drawings must be properly dimensioned and accompanied by general and specific notes wherever necessary. A list of specifications covering materials and methods of workmanship is prepared along with a set of working drawings, and those specifications of importance to the workmen are incorporated in the general notes. The list of specifications itself is not included in the set of working drawings used on the job.

192. Design Drawings

The freehand sketches of the original ideas of the designer along with necessary calculations determine whether the design is feasible. From these sketches and calculations, the design draftsman prepares preliminary instrument drawings working out further details, such as essential dimensions and locations of centers, to perfect the design. These drawings accompanied by the designer's notes and specifications are called design drawings. From these drawings, the draftsman proceeds to make the detail and assembly drawings to complete a set of working drawings.

193. Detail Drawings

A detail drawing gives complete information for the manufacture of a single item and provides an exact description of its shape, dimensions, and construction. In addition, it tells the workman what shop operations are necessary, the number of parts required, and so on. In machine drawing, the detail drawings of each piece are placed on separate sheets that may be used to present several views of the same piece. In construction drawing, details of different drawings are grouped together on the same sheet. When space allows, some details are placed on the same sheet showing a plan view or elevation. Regardless of the kind of drawing, a detail must be complete enough to enable a workman to build a part exactly as it has been designed. In making a detail drawing, a draftsman should select views in accordance with the principles outlined in chapter 6. The most characteristic surface of the object is shown in the front view, and the number of views required is determined by clarity.

194. Assembly Drawings

An assembly drawing is either an exterior or sectional view of an object showing the details in the proper relationship to one another. They can be traced from the design assembly drawing. More often they are drawn to a smaller scale from the dimensions of the detail drawings, which provides a check on the accuracy of the design and detail drawings and often discloses errors.

a. Drawing Practice. Certain general drawing practices are common to both machine and construction drawings.

(1) *Principal view.* The principal view in an assembly drawing should include as many of the individual details as possible; usually, it is drawn in full section. Additional views are shown only when they present information essential to understanding the drawing.

(2) *Hidden lines.* Assembly drawings are usually prepared to small scale, such as $\frac{1}{4}'' = 1'\text{-}0''$. As a result, hidden lines tend to overcrowd the drawing and create confusion, and so should be omitted. It is not necessary to attempt a complete shape description in an assembly drawing because the various parts are either standard or described completely in a detail drawing.

(3) *Dimensions.* An assembly drawing may give the overall dimensions and distances between centers showing the relationship between the various parts. Except for the overall dimensions, it gives location dimensions primarily; size dimensions are presented more suitably in a detail drawing.

b. Types of Assembly Drawings.

(1) *Outline assembly drawings.* An outline assembly drawing (fig. 77) gives a general description of the exterior of a machine or structure but contains only the principal dimensions. When this type of drawing is used to show where equipment is to be located or installed, it is known as an installation drawing.

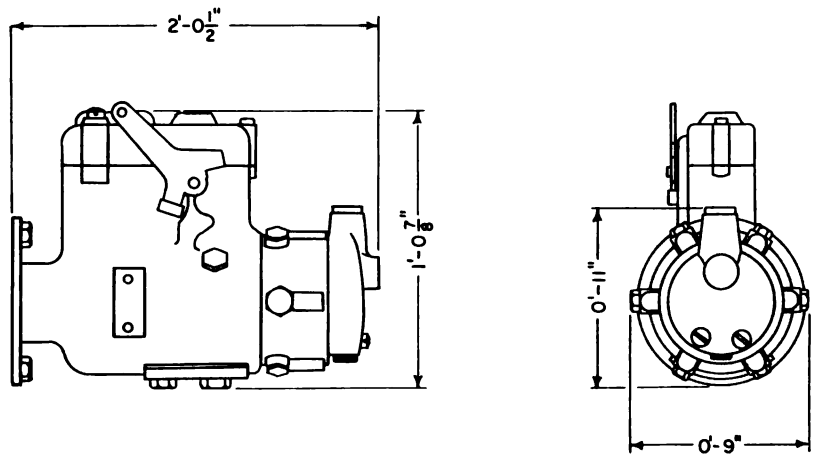


Figure 77. Outline assembly drawing.

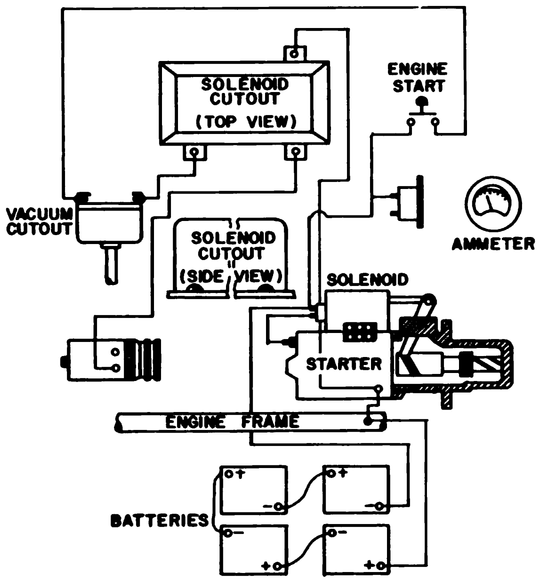


Figure 78. Daigram drawing of a cranking circuit.

(2) *Diagram drawings.* These drawings are used to show the installation of piping and wiring (fig. 78). They are also used in structural drawings to identify and locate the various members of a truss or other structure. Diagram drawings are often presented as isometric.

(3) *Unit assembly drawings.* When a drawing is made of a complex piece of machinery, it is sometimes necessary to show separate assembly drawings of the various units to include all the important details (fig. 79).

(4) *Assembly working drawings.* Simple objects can be described adequately enough in a single drawing to provide the necessary manufacturing information (fig. 80). In such an instance, the drawing presents several orthographic views of the object in addition to the necessary notes, dimensions, titles, and list of materials.

(5) *General drawings.* The assembly drawings used in construction drawings are called general drawings and show the relationship of doors, windows, and strutcural members to each other. General drawings consist of plan elevations, and framing plans.

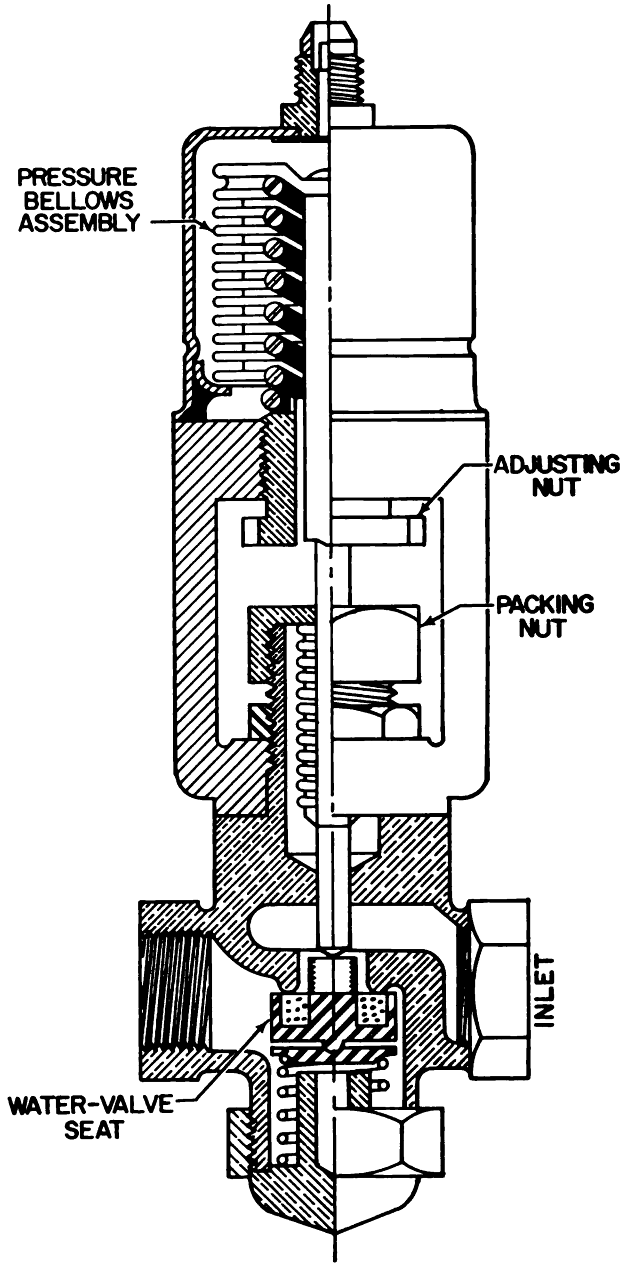


Figure 79. Unit assembly drawing.

195. Bill of Material

It is the practice in construction drawing to list the quantity, kind, size, and units of the materials required to construct the object represented in the drawing. It is imperative that

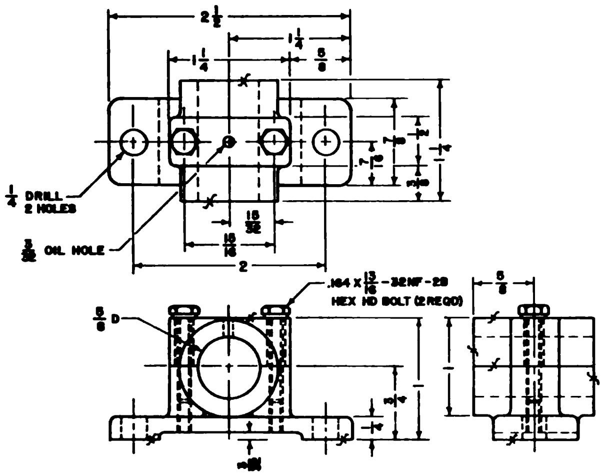


Figure 80. Working drawing assembly (bearing journal)

there be no omissions. There should be some order of listing, by chronology or by size, to insure completeness. In the case of a simple object that can be represented in an assembly working drawing, the list of material column provides enough space to list the various materials. More complex objects are constructed from so many kinds and sizes of material that they must be listed in a separate drawing prepared in tabular form and called a bill of material. The bill of material is the last drawing to be made in a set of working drawings. The draftsman who prepares the working drawings tallies the various materials as he draws the line and object symbols that represent them.

196. Title Block and Revision Strip

The purpose of the title block and revision strip is to present, in an organized manner, essential information not provided by the drawing, notes, or dimensions.

197. Zoning

Both vertical and horizontal zoning may be used on large or complex drawings. Zoning is done by dividing the horizontal and vertical dimensions of the drawing into equal subdivisions, or zones. Division marks are perpendicular to the borderline between the border and trim lines. Horizontal zones are indicated numerically and are numbered from right to left. Vertical zones are indicated alphabetically beginning with *A* at the bottom. Letters and numbers are centered in their respective zones outside the borderline of the drawing.

198. Security Classification

The security classification and notation will be shown in the top left-hand side of the drawing, on all drawings requiring a security classification. The security stamp on each sheet will be that of the highest classification for any item shown on that individual sheet, and not the general overall classification of the entire set of drawings or the end item. All lettering for the security classification shall be at least 1/4 inch high.

199. Procedure for Making a Working Drawing

A draftsman will find that by following an orderly procedure, rather than working unsystematically, he can produce accurate working drawings with increasing ease and speed. Accuracy and speed are the primary requirements of a draftsman, and both are increased by an organized approach.

a. Sheet Layout. The first step is to lay off the sheet to a standard finished size by drawing trim lines and borderlines. Finished size refers to dimensions between trim lines. Standard finished sheet sizes and formats for production drawings are described in paragraphs 38 through 42.

b. Views. Orthographic projection is the basis of all working drawings; pictorial drawing is used only in special cases. A draftsman must always be aware of his primary responsibility to present information to readers of the drawing in the clearest way. Whenever a section view, auxiliary view, or additional orthographic view is necessary to describe an object more clearly, it should be included. The surface that shows the most characteristic shape of the object or the fewest hidden lines will always be chosen as the front view.

c. Scale. Make a preliminary freehand sketch of the object to aid in deciding on a suitable scale, planning the arrangement of the sheet, and spacing the views. Choose a scale large enough to allow, without crowding, a balanced arrangement of all views and the inclusion of all notes and dimensions. When detail and section views are shown in an assembly drawing, they may be drawn to a larger scale. When this is done, the scale to which these views are drawn must be noted directly beneath the view title. A note is added to the notation in the title block giving the scale of the main view; *for example*, "Scale 1/4" = 1' 0" and as noted" is an acceptable form.

d. Centerlines. Draw the centerlines for each view with a 6H pencil to produce light, sharp pencil lines, and block in the general outline of each view by laying off the principal dimensions. Draw all lines as construction lines, and make sure to keep all views in projection.

e. Completing Views. Draw all circles and arcs in finished weight, and finish the projections by working back and forth between views. Project the features from the front view to the related views and vice versa. The views should be completed jointly. Put fillets and rounds in last and complete the views by darkening the object lines.

f. Dimensioning. Draw dimension lines, extension lines, and leaders; add arrowheads and dimensions; draw guidelines and letter notes.

g. Title. Draw guidelines and letter the title.

h. Checking. Check the drawing as described below.

200. Checking Working Drawing

A working drawing must be checked for errors and omissions before being reproduced and distributed to the men who will work from it. Checking is done best by someone other than the draftsman who executed the drawing; a draftsman who checks his own drawing is liable to overlook his omissions. The checker may be another draftsman or may be in charge of the drafting room. In either case, he must be familiar with the shop practices or construction methods used to make the object or assembly represented in the drawing. All notes, computations, and sketches will be saved for the checker who will use them to discover the source of errors. It is necessary for the checker to proceed systematically in reviewing a drawing as it is for the draftsman to work systematically in producing it. Corrections are made with either a soft or colored pencil. To prevent repeating work, place a light checkmark after each item that has been reviewed.

a. Readability. The most important question that a working drawing must answer is: "Can a mechanic work from this?" A checker must put himself in the position of the craftsmen who are to use the drawing. Before becoming accustomed to its contents, he must find out if the drawing presents its information simply and directly.

b. Design. Consider the materials to be used; they must be the proper type, strength, and size. Check for clearance between moving parts. See that conventional practices, such as the spacing between joists, have been adhered to that stock sizes have been used for standard parts.

c. Views. Check the number of views to see that the object has been described completely without unnecessary duplication. See that all views are in projection and conform to the rules of orthographic projection. Check the correctness of section symbols. Check to see that views are drawn to the scale specified either in the title block or the view title.

d. Dimensions. Check dimensions by calculations if necessary. A quick check can be made by scaling. Make sure that overall dimensions are furnished in all assembly drawings. See that those who will use the drawings do not have to make any further calculations to obtain needed working dimensions.

e. Notes. Check notes for location and correctness; add explanatory notes wherever required to improve the clarity of the drawing.

f. Title Block. Check all the items in the title block and the bill of material; see that all parts are specified completely.

g. Final Review. Examine the drawing carefully to see that checkmarks have been placed opposite all the items requiring review.

201. Reproduction of Working Drawings

The working drawings used on a job are almost always reproductions of original drawings prepared in the drafting room. Prints provide a rapid and economical means of furnishing as many sets of drawings as are needed, particularly on construction projects for which several sets of working drawings are required. Draftsmen should know that although the clarity of a print is influenced by printing factors, such as intensity of transmitted light, time of exposure, and the quality of the paper or cloth on which the original drawing has been prepared, the acceptability of the print depends most on the quality of the original drawing.

202. Pencil Drawings

Most prints are made from pencil drawings prepared directly on tracing paper. Ink tracings are prepared on tracing cloth and are traced from pencil drawings on detail paper. Good pencil drawings are the basis of good drafting.

a. Paper. Lines are drawn on the dull side of the tracing paper, which has a rougher texture, or tooth, without which it is impossible to produce the sharp, dark pencil line necessary for good reproduction.

b. Pencil Lines. Pencils used for working on tracing paper range from HB to 2H. Harder pencils, 3H and up, do not produce heavy enough lines and tend to dig into the surface of the paper. Pencil lines drawn on tracing paper should be darker and wider than those drawn on detail paper. The more opaque a line, namely, the better its light-stopping qualities, the better it will reproduce. Draftsmen must be careful to avoid smudging when working with the softer pencils required for tracing paper.

203. Ink Drawings

Ink tracings are usually made if a permanent record of the original drawing is to be kept. As stated previously, display charts and graphs are frequently prepared with drawing ink. In addition, reproductions made from ink tracings present sharper and clearer lines than those made from pencil drawings. Finally, it is possible to produce a wider range of line widths and, consequently, to obtain better line contrast with a ruling pen.

204. Use of Ruling Pen

A ruling pen is never used freehand; it is always used against a guiding edge such as the working edge of a T-square, triangle, or irregular curve. The pen is held in a vertical plane, that is, perpendicular to the plane of the paper, and inclined 30° in the direction of movement. It is held between the thumb and forefinger with the adjusting screw pointing outward and the blade resting against the second finger. The

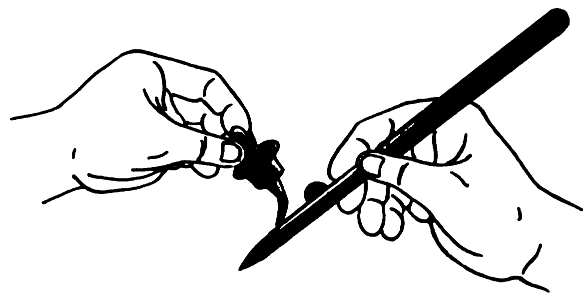


Figure 81. Filling the inking pen.

third and fourth fingers slide along the blade of the guiding edge and aid in steadying the pen. Lines are drawn with a steady, regular arm motion. Short lines are drawn with a motion of the fingers holding the pen; the fingers resting on the straightedge remain stationary. Long lines are finished with this finger motion. Do not allow the pen to rest at the end of a completed line; pick it up smartly and move the straightedge from the line.

a. Filling Pen. A pen is alaways filled with the quill (fig. 81) which is attached either to an inkstand filler or to the stopper of the ink bottle. Remove the stopper of the ink bottle with a twisting motion to avoid snapping off the head. Take the pen to the bottle and pass the quill filler between the blades, near the point. Do not fill the pen more than ¼ inch from the point; too much ink cause blotting. Take care that no ink gets on the outside surface of the blades; if it does, wipe the pen clean and refill it.

b. Regulating Line Width. Line width is determined by the distance between the pen blades at their points; the greater the separation, the wider the line. Spacing between the blades is regulated by the adjusting screw. The width of a new setting should always be tested by drawing trial lines on a piece of scrap tracing paper or in the margin outside the trim lines of the sheet of tracing cloth.

205. Inking Practice

Many of the routine mishaps (fig. 82) encountered by a new draftsman when preparing an ink drawing or tracing can be avoided by paying attention to a few basic principles of

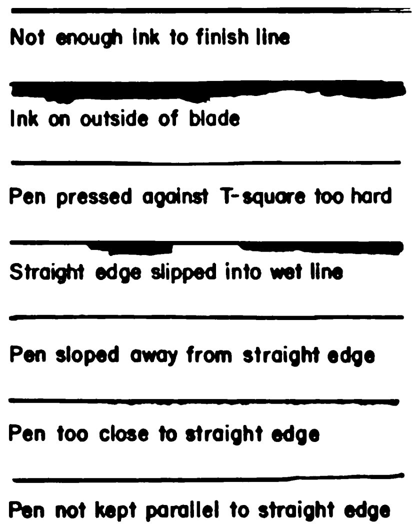


Figure 82. Routine mishaps in inking.

inking technique. Remember that it takes time for ink to dry; and be careful when moving the guiding edge. It is generally a good practice for the beginning draftsman to attach pennies or other suitable devices to the bottom of the straightedge (triangle) when inking to lessen the chances of ink running under the straightedge.

a. Inclining Pen. If a pen is held so that its top leans outward, the point leans against the guiding edge and causes ink to run under the edge and blot (fig. 82). If the top of the pen leans too far inward, the outer nib does not touch the paper and causes an irregular line.

b. Pressure. The amount of pressure necessary varies with the quality of the paper and sharpness of the pen. Pressure should be just strong enough to produce a clean, even line. Excessive pressures compresses the blades and either narrows the width of the line along its length or causes a line of varying width. The pressure against the guiding edge need be only enough to control the direction.

c. Intersections and Tangents. Ink must be allowed to dry before intersecting lines are joined or the ink will form a puddle and blot. Ink lines must be centered over pencil lines to produce smooth tangent points.

d. Curved Lines. When inking circles and circle arcs, the compasses are inclined slightly in the direction in which the line is drawn. Both pen nibs must be kept on the paper. To do this when drawing circles over 9 inches in diameter, use the lengthening bar in conjunction with the large compass and pen attachment. The ink bow compass is used for circles up to 2 inches in diameter, and the drop compass with a pen attachment is used for inking small circles accurately. Always ink in centerlines before using compasses to prevent ink from blotting in the hole formed by the needlepoint. French curves are used as guides when inking irregular curves. A small piece of cardboard, or a triangle placed beneath the curve, will raise it off the drawing sheet and decrease the possibility of ink running underneath the working edge. Lean the pen only slightly in the direction of movement to prevent wandering away from the penciled curve. Overlapping curve segments can be avoided by drawing segments short of the end points of the section to which the french curve has been fitted. The separate segments can be joined after they have been dried by fitting the curve to form a continuous line.

e. Ink refuses to Flow. If ink refuses to flow, it may be started by pinching the blades slightly or drawing the pen across the thumbnail. Dried ink or particles from the wiping cloth clog the pen an cause an uneven line if allowed to accumulate.

f. Cleaning Pen. For the best results, a pen must be wiped before each filling and before placing it aside. It is not necessary to change the adjusting screw when wiping the pen; merely fold the wiping cloth, pass it between the blades, and pull it gently through the ends. Dried ink can be removed by washing the pen in a weak solution of ammonia. *Always* put inking instruments away clean.

206. Sharpening Pens

Fine lines and lines of even width can be produced only by a ruling pen with sharp, properly shaped nibs. A draftsman who has trouble producing fine lines, or lines of even width, may find that his ruling pen needs

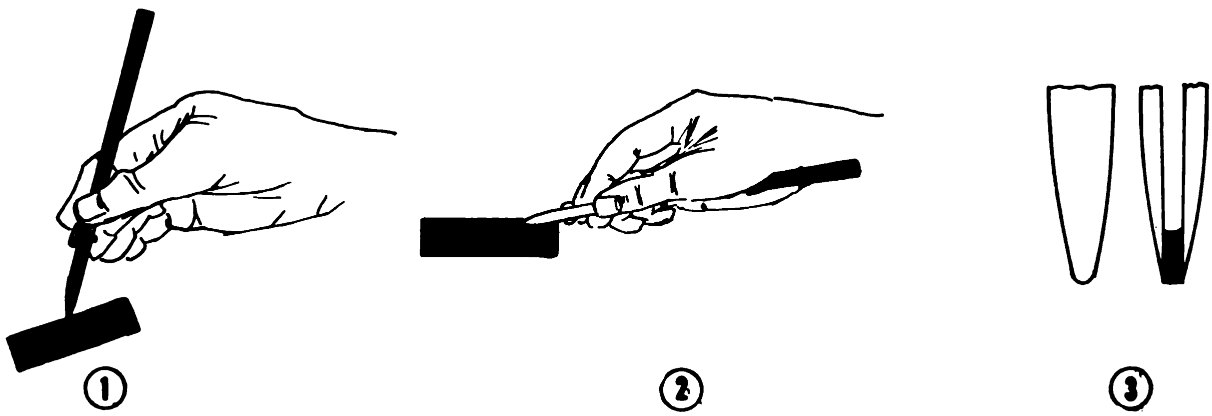


Figure 83. Sharpening the inking pen.

sharpening or reshaping either because it is a poorly shaped new pen or because it is worn from constant use. He should know how to detect and remedy these conditions.

a. Examining Pen. The nibs of a correctly shaped pen are elliptical in form and are rounded equally. When filled and viewed from the side, the ink arches inward slightly at the point. If the nibs are pointed too sharply, the ink forms a concave arch between the blades and is difficult to start. If the nibs are blunt and rounded, the ink forms a convex arch that extends beyond the tips and causes blots and thickened lines at the ends. A dull pen shows a spot of reflected light that passes from the side of the blade over the end of the point as the pen is turned in the hand.

b. Sharpening Pen. Clean the blades thoroughly first in a weak ammonia solution, dry, and screw the nibs together until they just touch. Use a fine-grained Arkansas oilstone and hold the pen against it in line-drawing position (1, fig. 83). Draw the pen along the stone, as if drawing a line, moving the handle in a pendulm motion from an angle 30° through perpendicular position to an angle of 30° opposite to the direction of movement. Repeat the motion until the nibs are equally rounded in the proper elliptical shape (3, fig. 83). Next open the nibs slightly and sharpen each blade on the outside, holding the pen almost horizontal to the stone (2, fig. 83); use a slight rocking motion, following the contour of the blade. Test the pen at intervals to see that the ink flows easily without blotting and that the blades do not cut the tracing paper. Burs or wire edges formed on the inside of the blade can be removed by drawing a strip of leather or detail paper through the closed nibs.

207. Use of Freehand Pen

Lettering for notes, dimensions, and title blocks in ink tracing is executed with a freehand pen. Draw horizontal and inclined or vertical guidelines in pencil on the tracing cloth. Do not attempt to trace the letters on the pencil drawing; use them as a guide for spacing the lettering on the ink drawing. Freehand pen technique is prescribed in paragraph 60.

208. Tracing Cloth

a. Preparation. Tracing cloth should be cut several inches larger than the required finish size. For large drawings, allow the tracing cloth to lie flat for a short time before tacking it down. Occasional traces of oil that appear on tracing cloth prevent a smooth flow of ink; dusting the sheet with pounce or powered chalk after it has been tacked down and wiping it with clean, dry cloth will remove any traces of oil.

b. Erasing. Erasing inked lines must be done with care if re-inking is contemplated; a pencil eraser can be used in conjunction with an erasing shield to avoid wrinkling the paper. A triangle slipped underneath the tracing cloth at the point of erasure also minimizes wrinkling. The erased spot should be furnished with a thumbnail or triangle edge after erasing. A cloth dipped in carbon tetrachloride or benzine can be used to remove graphite smudges and pencil lines from tracing cloth. Never use a knife eraser on a line that must be re-inked because it will invariably damage the surface enough to permit ink to seep through. Use a draftsman's dustbrush to remove eraser debris.

c. Moisture. Certain types of tracing cloth are sensitive to moisture and atmospheric changes. Do not allow moist hands and arms to come in contact with tracing cloth. For large tracings, it is advisable to cut a shield from detail paper to protect finished work. When necessary to leave a tracing unfinished overnight, complete all views that have been started to prevent atmospheric expansion or contraction from affecting the finished drawing.

209. Order of Inking

Lines are inked in a definite order to save time that would otherwise be wasted in waiting for inked lines to dry, and to produce lines of the same width from the same adjusting screw setting. The natural progression for the right-handed person for drawing horizontal lines is from top to bottom; vertical lines normally are drawn in sequence from the left- to the right-hand side of the sheet.

a. Centerlines. Ink all centerlines first; begin with centerlines for full circles.

b. Thick Lines. Ink all cutting- and viewing-plane lines, outlines, visible lines, and datum lines. Ink small circles then large circles, small arcs, large arcs, irregular curves, horizontal lines from the top down, vertical lines beginning at the left, and inclined lines.

c. Medium Lines. Ink all hidden and stitch lines in the order described above.

d. Thin Lines. Ink all dimensions, extension, leader, phantom, and sectioning lines. Ink vertical lines first, horizontal lines next, and inclined lines last. When drawing sectioning lines, do not attempt to trace them; place a blank sheet of paper between the pencil drawing and the tracing cloth and draw sectioning lines by eye.

e. Freehand Lettering. Ink all arrowheads, dimension figures, specific notes, and general notes including the list of matrials.

f. Border. Ink borderlines, and letter the title block.

Section III. DRAWING REPRODUCTION

210. Requirement for Reproduction

a. A drawing when completed represents too much time and effort to be treated casually. It is a valuable record, and must be preserved with care. If an original drawing were to be used on the pob and passed from man to man, it would soon become worn and too dirty to read. For this reason, working drawings used on the job are almost always reproductions of original drawings prepared in the drafting room. The original may be either a pencil or an ink drawing made on translucent tracing paper or tracing cloth. Pencil or ink lineweights should be *sharp, opaque,* and *uniform* to produce a clear, sharp reproduction of the original drawing.

b. There are a number of different processes for reproducing drawings, all of which give best results from inked tracings. However, pencil drawings on tracing paper give satisfactory results when the penciling is done skillfully. In fact, very few drawings are inked; only those of a permanent nature such as those required for map reproduction, charts, and so on, are inked . The various methods of duplication may be divided into three categories: contact, photo, and copy. The method to be used depends on a number of factors. One factor, of course, is the type of duplicating equipment available; another is the relative cost of the various processes; and a third is the use to which the duplicate will be put. The most widely used reproduction processes are described briefly.

211. Contact Prints

All contact printing processes involve photochemical processes of one type or another. The paper upon which the drawing is to be printed is coated or sensitized with a chemical preparation affected by the action of light. When such paper is exposed to light in a printing frame or machine, with the tracing so positioned (used as a negative) that the light must pass through the tracing to reach the sensitized paper a chemical reaction is produced in all parts of the print except those which are protected by the opaque (pencil or ink) lines of the drawing. After the paper has been exposed a sufficient length of time, it is removed from the printing frame or machine and subjected to a developing bath and fixing bath, or to a fixing bath only, according to the method employed. The important item in making such prints is to be sure that the sensitized paper adheres so closely to the back of the tracing that no light can leak between it and the drawing lines. When space is left between the drawing and the sensitized paper, the lines on the reproduction will be fuzzy.

212. Blueprints

Blueprinting is the oldest and most generally used of the modern processes for reproducing drawings in quantity. They appear to be white line drawings on a blue background. The prints are made by exposing a piece of sensitized paper and a tracing in close contact with each other to sunlight or electric light in a printing frame or machine made for that purpose. Blueprints can be made from a typewritten sheet if carbon backed so as to produce black imprints on both sides of the sheet. Changes may be made on blueprints by using an alkaline solution in a writing or drawing pen.

a. Blueprint papers. Blueprint papers are available in various speeds and in rolls of various widths, or may be obtained in sheets of specified size. The coated side of fresh paper is a light yellowish-green color. It will gradually turn to a grey-bluish color if not kept carefully away from light, and may eventually be rendered useless. For this reason, it must be kept wrapped or be stored in light-tight containers. The length of exposure depends NOT only upon the kind of paper used and the intensity of the light, but also upon the age of the paper. The older the paper the quicker it prints and the longer to wash; the fresher the paper the slower it prints and the quicker to wash.

b. Sun Frame. The simplest equipment for making blueprints is a sun frame. It has a glass front and removable back, somewhat like a picture frame. In loading—the back is removed and the drawing is inserted with the inked side against the glass; the blueprint paper is placed with its sensitive side against the drawing; and the back of the frame is closed (anchored) so that it exerts enough pressure to insure a perfect adherence of the tracing and the paper. When the glass front of the frame is exposed to bright sunlight, the sensitized paper will print in from 20 seconds to 4 minutes. The fact that prints can only be made when the sun is shining is an inherent disadvantage of the sun frame. Also, large drawings cannot be printed because frames to accommodate them would be too cumbersome to handle.

c. Development. After exposure, the blueprint paper is washed in clear water and the parts that were exposed to light turn dark blue; the parts that were protected from the light by the lines on the drawing wash clean of the chemical coating, leaving the original white paper. Dipping the blueprint in a solution of potassium dechromate *fixes* it. Fixing makes it more permanent. Then it is washed in clear water a second time.

d. Blueprint Machines. Modern blueprint machines are available in noncontinuous types in which cut sheets are fed through the blueprint machine for exposed only and then washed in a separate washer. The continuous blueprint machine combines exposure, washing, and drying in one continuous operation. Both types of machines use carbon arcs as the light source.

213. Vandyke Prints and Blueline Prints

A vandyke print is composed of white lines on a dark brown background made by printing, in the same manner as for blueprinting, upon a special thin paper from an original pencil or ink tracing. Vandykes can be used as negatives from which to print other duplicates, whereas this is not true of blueprints; then this negative can be printed on blueprint paper, giving a positive print with blue lines on white. The reversed blueprint or "blueline blueprint" is often preferred because it can be easily marked on with an ordinary pencil or pen. Blueline prints have the disadvantage of soiling easily with handling in the shop.

a. Vandyke Paper. Vandyke paper is a thin, sensitive paper which turns brown when it is exposed to light. Since vandyke paper is transparent, the lines on a vandyke (brownprint) are transparent. Therefore it is used as a negative from which to make other prints.

b. Printing and Developing As has already been indicated, vandykes may be made on regular blueprint machines. However, different chemicals are used in coating the paper and fixing it after it has been printed. The developing solution, commonly called *hypo*, is made of four ounces of fixing salts to a gallon of water. Vandykes must be dried like blueprints after they are developed. A set of two liquids is available for making changes on vandykes.

214. Ozalid Prints

Ozalid prints are used extensively when positive prints are desired. They may have black, blue, or red lines on white backgrounds, according to the type of paper used. All have the advantage of being easily marked upon with pencil, pen, or crayon.

a. Ozalid Paper. Ozalid paper is coated with certain dyestuff intermediates which have the characteristic of decomposing into colorless substances when exposed to actinic (ultraviolet) light. On the other hand, they react with coupling components to form diazo dyestuff (the printed lines) upon exposure to ammonia vapors. Unlike blueprint paper, ozalid materials can be handled under normal indoor illumination.

b. Printing and Developing. The ozalid method of reproduction is based upon the transmission of light through the original for the reproduction of positive prints. There is no negative step involved; positive prints are made directly from the drawing tracings. The subject matter may be pen or pencil lines, typewritten or printed matter, or any opaque subject. It involves two simple steps—exposure and dry development. Exposure is made in a printer equipped with a source of ultraviolet light, *for example,* a mercury vapor lamp, carbon arc, or even by sunlight. A regular blueprint machine may be used. The exposed print is dry developed in a few seconds in an ozalid developer which releases ammonia vapors. A special ozalid machine combines exposure and development in one continuous operation.

215. Black and White (BW) Prints

BW prints have black lines on a white background and like ozalid prints may be made from ordinary pencil or inked tracings by exposure in the same manner as for blueprints, directly upon special blackprint paper. Exposure may be made in a blueprint machine or any machine using light in a similar way. However, the prints are not washed, as in blueprintings, but must be fed through a special developer which dampens the coated side of the paper to bring out the black lines of the print. A popular machine exposes and develops BW paper in two separate operations: the tracing and BW paper are fed into the printer slot, and when they emerge, the BW paper is then fed through the developer slot. Within a minute or two after developing, the prints are practically dry and are ready for use. BW prints, together with ozalid prints, are coming into greater use and eventually may largely replace the more cumbersome blueprint process.

216. Photostats

The photostat machine is essentially a specialized camera. Photostats are printed by focusing the image through a lens, and in the making of a photograph. Unlike a photograph, the photostat negative as well as the positive is made directly on sensitized paper rather than on film. Also, photostat negatives are not reversed images as are photographic negatives. A photostat print may be the same size, larger, or smaller than the original; large drawings can even be reduced to letter size for use in engineering reports.

a. Procedure. The original may be transparent or opaque. It is simply fastened in place and the camera is adjusted to obtain the desired print size. The print is made, developed, and dried in the machine with no darkroom required. The result is a negative print with white lines on a near-black background. A positive print having near-black lines on a white background is made by photostating the negative print.

b. Disadvantages. Photostats have certain inherent disadvantages as compared with contact prints. Even the best photostats are not as clear as good contact prints and there is a certain amount of distortion when they are enlarged or reduced. If just the negative is reduced or enlarged, the distortion is almost imperceptible. If the positive printed from this negative is further reduced or enlarged, the distortion is greater. Another disadvantage of photostats is their size limitation. The maximum size is 24 x 36 inches. If a larger size is required for some types of work, the print must be made in two or more overlapping pieces.

217. Copying Methods

Small drawings are often duplicated by such methods as the mimeograph and other forms such as the hectograph or gelatin pad.

a. Mimeographing. While mimeographing is especially used for reproducing typed materials, it can also be very satisfactory in reproducing small and fairly simple drawings. The excellence of the reproduction of such drawings will depend upon the skill of the draftsman in drawing upon the stencil. However, mimeograph manufacturers have not developed a photochemical process by means of which a complicated drawing may be reduced and incorporated into the stencil, which is then used to produce very satisfactory prints.

b. Hectographing. In the hectographig process an original is produced by typing on plain paper through a special carbon paper or drawing with a special pencil or ink. This original is then placed on a gelatin pad which absorbs the coloring from the lines made on the paper. The original is then removed and prints are made by bringing sheets of blank paper in contact with the gelatin. A number of different machines using this basic principle are available.

c. Gelatin Duplicator. The gelatin duplicator is used largely in map reproduction to print small quantities of line sketches and to overprint on existing maps. Various colored dyes (inks) are applied to the gelatin surface to form the printing image. This image is printed by placing paper in contact with the gelatin so some of the dye is transferred to the paper. Since the original inked image can only make a limited number of copies (25 to 100) and the ink cannot be replenished, the color intensity diminishes with each impression until the dye is exhausted and prints are illegible.

CHAPTER 9

INTERSECTIONS AND DEVELOPMENTS

218. Introduction

The subject matter of this chapter is important in various occupations, principally sheet mental work and pattern making. A mechanic who makes a box out of sheet metal has a far easier task if he cuts out a single piece of metal, in a design that allows him to bend it into the desired shape, than if he cuts out a series of flat pieces and builds his box by soldering or riveting them together. Anyone who has used scissors, paste, and heavy paper to build a three-dimensional shape is familiar with this problem. The single, flat piece of metal or paper, before it is bent or folded into the box shape, is known as the developed shape. Rather than confuse a beginning draftsman with practical sheet metal problems such as the allowances of extra metal for seams and bends, the developments in this chapter deal only with basic principles.

a. Intersections. The intersections considered so far have been primarily between two plane surfaces and easily represented by establishing two or three points and drawing in the line showing the intersection. Other kinds of intersections must be established more carefully. In air-conditioning and warm air heating, for example, intersection often occur between more complicated geometric shapes. In laying out a developed shape, a sheet metal mechanic working on a plane surface must take into account the shape of the perimeter of the opening that is to reecive (intersect with) a section of duct work. The complete line of intersection between two geometric shapes is determined by establishing a series of points formed by the intersection of lines lying on one surface with lines lying on the other surface. Such lines are known as elements; an element is defined as any single position of a line that generates a surface.

b. Development. Most objects can be classified as geometric shapes and the shapes can be defined as surfaces of one kind or another. The development of a surface is that surface laid out in a single plane. The glass box used to demonstrate orthographic projection is, when laid out flat, namely, lying in a single plane, an example of the development of a cube. The standard method of representing a developed surface is to draw it with the inside surface up. This is how the object would appear if it were unrolled or unfolded.

c. Developable Surfaces. Only objects with complete surfaces made up of planes and single-curved surfaces can be developed. The practical way of determining a developable surface is to see whether a single sheet of paper can be wrapped around it; if it can, the surface is developable.

d. Surfaces. A surface is the boundary of a solid. A geometric surface is generated by the motion of a geometric line, either straight or curved, called the generatrix. Any position of the generatrix is called an element of the surface.

(1) A *plane* is a flat surface in which any two points could be joined by a straight line which lies entirely on the surface.

(2) A *curved* surface is a surface no part of which is a plane surface.

(3) A *solid* object is a portion of space which is completely inclosed by plane or curved surfaces, or a combination of planes and curved surfaces.

(4) A *ruled* surface is a surface which can be ruled or generated by a straight line moving in a prescribed manner.

(5) A straight line which moves along a plane curve while remaining parallel to a fixed line generates a *cylindrical* surface.

The moving line is called a *generatrix,* the curve is called a *directrix*, and any one position of the generatrix is called an *element.*

(6) A straight line which moves so that it always intersects a closed plane curve while passing through a fixed point not in the plane of the curve, generates a *conical* surface.

If the closed curve is a polygon, the surface generated is a *pyramidial* surface. The fixed point is called a *vertex.* Two conical or pyramidal surfaces are generated, one on each side of the vertex, called *nappes.*

(7) If two surfaces intersect, the line joining all points common to both surfaces is called the *line of intersection.*

219. To Develop a Truncated Pentagonal Prism

When a solid has all of its surface areas made up of plane figures , the development is made by constructing the surface areas in the same sequence in which they must be when the development is unfolded. It is necessary to select which edges will be cut for opening, and which edges will be fold or bend lines when the development is unfolded. Usually the cut lines are taken as the shortest lines in order to save time and material in making seams. Figure 84 shows the development of a regular pentagonal prism, cut by a plane *ABCDE* not parallel to the base making it a truncated prism. The procedures are:—

a. Draw a stretchout line or baseline and measure off five equal spaces; equal to the edges of the base pentagon.

b. Draw vertical construction lines at each point (1, 2, 3, 4, 5, and 1) measured off in step 1 along the stretchout line.

c. Locate points lettered *A, B, C, D, E,* and *A* by projection from the front view to the vertical construction lines drawn in step 2, and join these points using a straightedge.

d. Draw auxiliary view, to find true size and shape of the upper base (top), and draw bottom view (lower base) of the prism.

e. Draw upper and lower bases by construction in their proper position on the development. The pictorial view is shown in figure 84 as an aid in visualization of the object.

220. To Develop a Right Cylinder

Cylinders and cones may be developed in their rolled-out-flat shape by constructing the position of the generatrix at regular intervals and connecting the end points with a staright-edge or French curve depending upon the object being developed. Figure 85 shows the steps in drawing the development of a right circular cylinder as follows:

a. Draw the stetchout line for a distance estimated to be slightly longer than the perimeter of the base.

b. The top view, showing the base of the cylinder, is subdivided into a number of equal parts. The number of subdivisions must be great enough (say 12, or 30° segments) that the length of the chord measured by the dividers is nearly equal to the length of the arc subtended by the chord.

c. With the dividers set to the length of one subdivision of the base (*B*), step off the same number of spaces in the stretchout line as stepped off on the perimeter of the base.

d. Erect perpendiculars at the end points (1 and 1), and mark height *A* on the development by projection from the front view.

221. To Develop a Right Pyramid

a. Right Pyramids. A right pyramid (fig. 86) is a solid bounded by plane surfaces. The sides are triangular and meet at a point called the apex. The base adjoining is a polygon. The axis is a straight line adjoining the apex with the midpoint of the base. The altitude is a perpendicular from the apex to the base. The altitude and axis coincide.

b. Views. Draw the front and top views. To develop a pyramid, it is necessary to draw the true shape of each side because all edges of a pyramid are equal in length; the true length of one edge and one side of the base will permit drawing the developed view. As stated previously, any line parallel to a reference line will project in its true length in the related view. The method of obtaining a true length of line by revolution is described in paragraph 149. If line *A*1 is revolved, pivoting at *A*, so

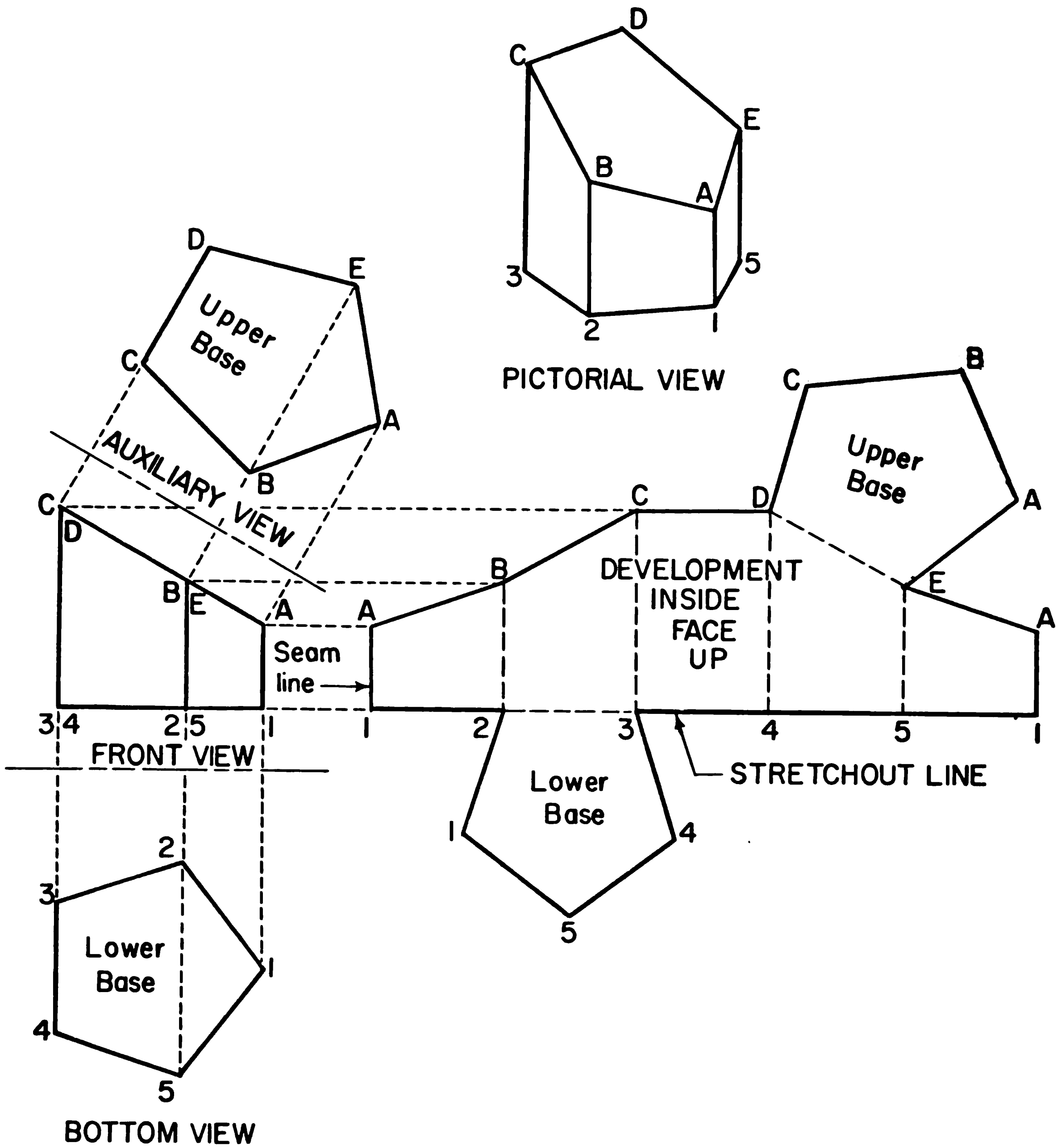


Figure 84. Developing a pentagonal prism.

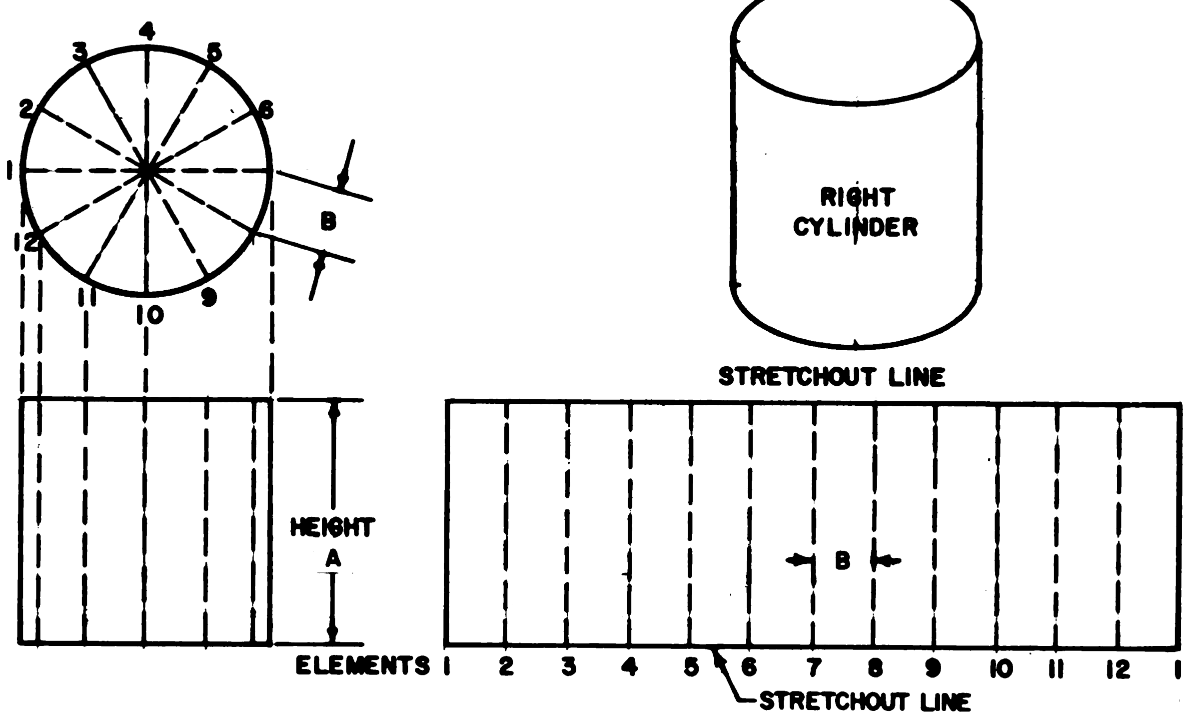


Figure 85. Developing a right cylinder.

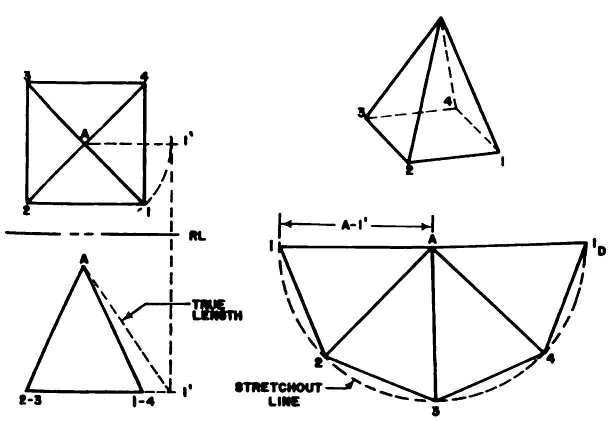


Figure 86. Developing a right pyramid.

that it is parallel to the reference line between the top and front views, it will project in its true length in the front view. The edge of the base, 1–2, is parallel to the reference line and projects in its true length in the front view.

C. Development. Establish any point *A* and swing an arc with a radius equal to the true length of a side as shown in the front view (A–1, fig. 86). From any starting point on the arc, step off four distances on the arc equal to the edge of the base, 1–2, and to each other. Connect the points so established to each other with successive straight lines to establish the bend lines along which the developed shape is folded to form the lateral surface of the pyramid.

222. True-Length Diagrams

When developing a surface having many oblique lines, it is often more convenient to construct a true-length diagram than to draw double auxiliary views. The true length of many lines may then be measured and transferred to the development with dividers. Figure 87 illustrates the construction of a true length diagram for the development of an oblique cone. Given the top and front views in

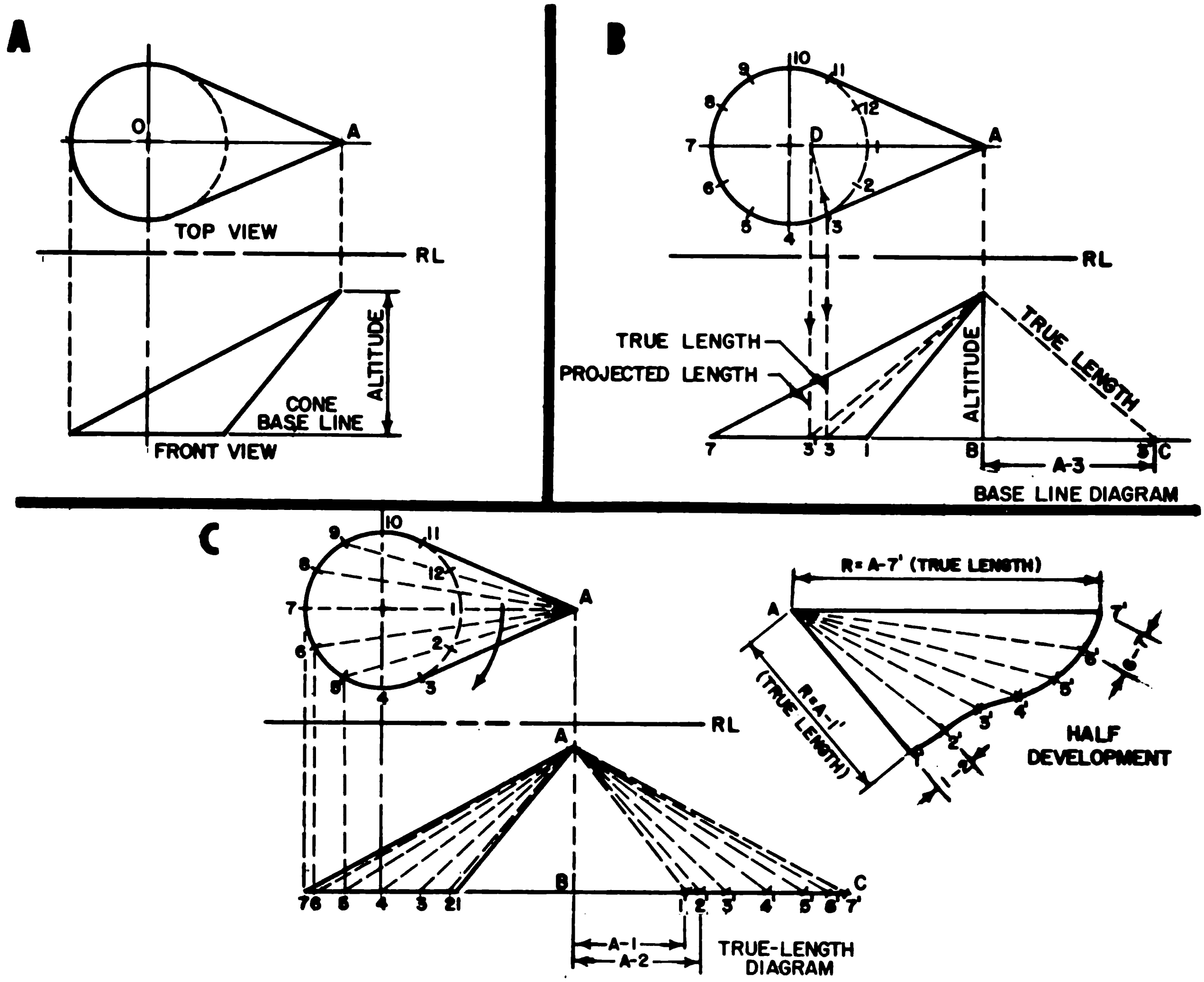


Figure 87. True-length diagram.

block A, to draw the true length diagram and the development, proceed as follows:

a. Divide the base circle in the top view into a number of equal parts (12 parts are used in block B, figure 85). The point numbered 3 will be used to illustrate how to find the true length of an element such as the oblique line *A*–3.

b. Set dividers on the end points of the oblique line, *A* and 3, in the top view of block B and then with *A* as a center, swing or rotate the line *A*3 until it is parallel to the reference line *RL* in position *AD*. The line *AD* will project to the front view in its true length *A*3′.

c. The same result is obtained in the diagram to the right of the front view as follows. Extend the baseline of the front view a convenient length to *C*, and drop a perpendicular from vertex *A* to the baseline at *B*. With dividers transfer the distance *A*3 from the top view to the baseline of the diagram, measuring from *B* to locate the point 3′. Then the distance *A*3′ in the diagram is the true length of the element *A*3.

d. Block C (fig. 87) shows how this diagram is used to find the true lengths of the oblique elements of the cone as numbered in the top view. The development consists of constructing a series of adjacent triangles with the true lengths of the elements being taken from the true length diagram, and distances between points 1–2, 2–3, 3–4, and so on, being taken from the base circle in the top view The points 1′, 2′, 3′, and so on, are joined by using a French curve. Only half of the development is shown in block C, figure 87. Carefully observe that the true length of a line can be found by rotating it into a position parallel to a projection plane, and then projecting its true length on that plane.

223. To Develop a Truncated Cone

a. Cones. A cone is a solid bounded by a single-curved surface. The surface is generated by a straight line, one point of which is fixed, moving along the path fixed by the curved base. Each position of the generating line is an element of the surface. The axis of a cone is a straight line connecting the apex with the center point of the base. The altitude is a perpendicular from the apex to the base. When the altitude and axis coincide, a right cone results; when they do not coincide, the cone is oblique.

b. Views. Draw the top and front views as shown in figure 88. Divide the top view into any convenient number of equal segments. Note that the front view shows the cut surface, or frustum, of the cone as an edge view. The elements of the frustum are revolved to line

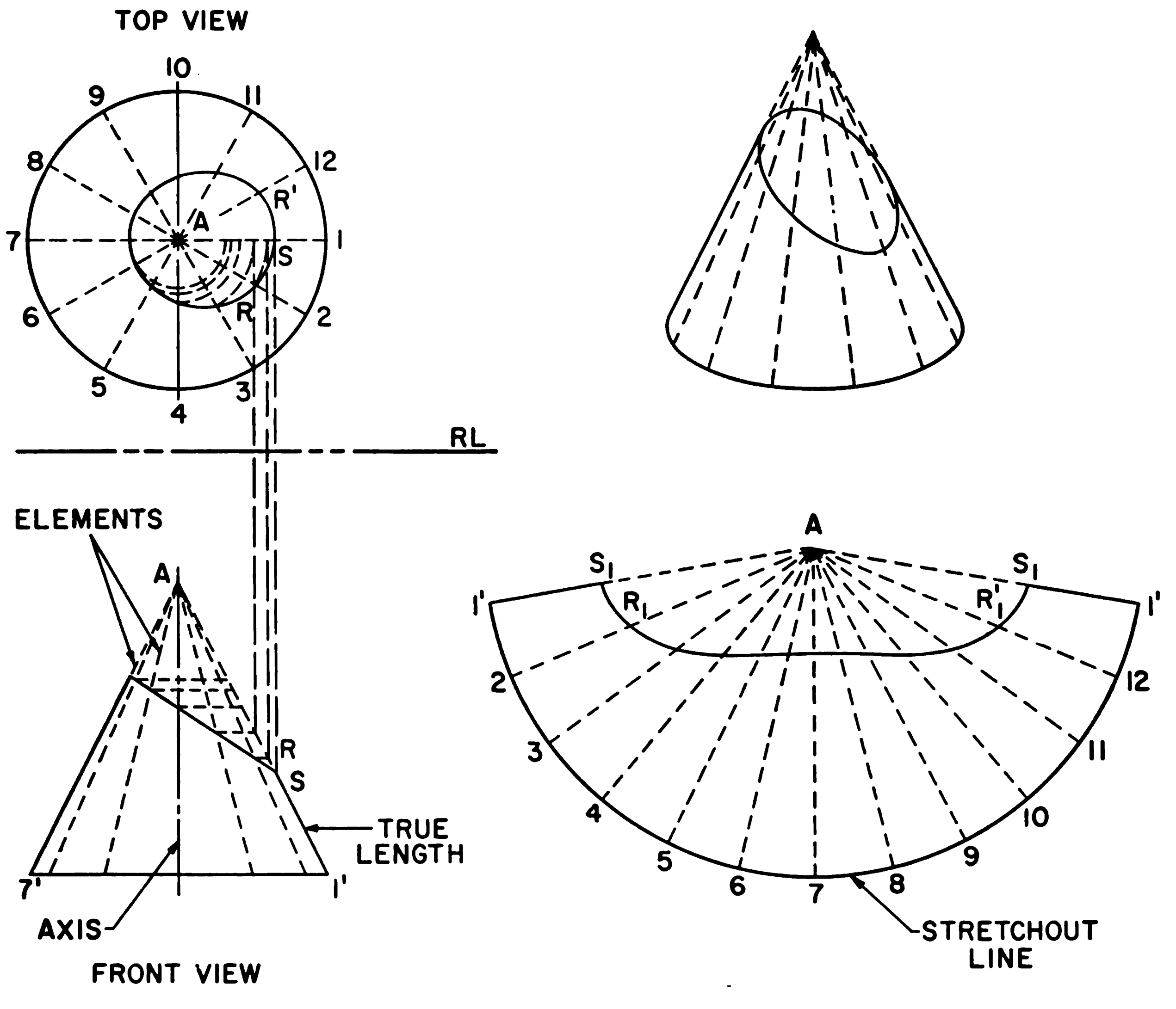


Figure 88. Developing a truncated cone.

A–1, which projects in its true length in the front view. The true-length projection established the slant height of the cone. The points of the frustum are projected to line A–1 in the front view.

c. Development. Use line$A$–1′ in the front view as a radius and swing an arc from any point A^1. The extent of the stretchout line may be computed from the formula

$$\frac{r}{s} \times 360°$$

where

r = radius of the base
s = the slant height of the cone

or it may be established by transferring measurements from the perimeter of the top view to the stretchout line. Number all the points and draw element lines to them from A^1. Establish the perimeter of the top face by measuring along line A–1′ in the front view from A to the points projected from the top view. Transfer these measurements to the appropriate element in the development and connect the points with an irregular curve.

224. To Develop an Oblique Cone

a. Views. Draw the top and front views as shown in figure 89. Extend the base line drawn in the front view and establish an altitude A-I perpendicular to it. The vertical height of the altitude is projected from the front view. Construct the true-length diagram by the right-triangle method as described previously.

b. Development by Triangulation. Nondevelopable surfaces can be developed by approximate methods. The most common method is to divide the surface into small developable surfaces, in this case, triangles. The triangles constructed in the true-length diagram of figure 89 are laid out consecutively in their true shapes. Establish A at any convenient point and draw a line from A equal in length to A–7′ in the true-length diagram. To establish the point 6 in the development swing an

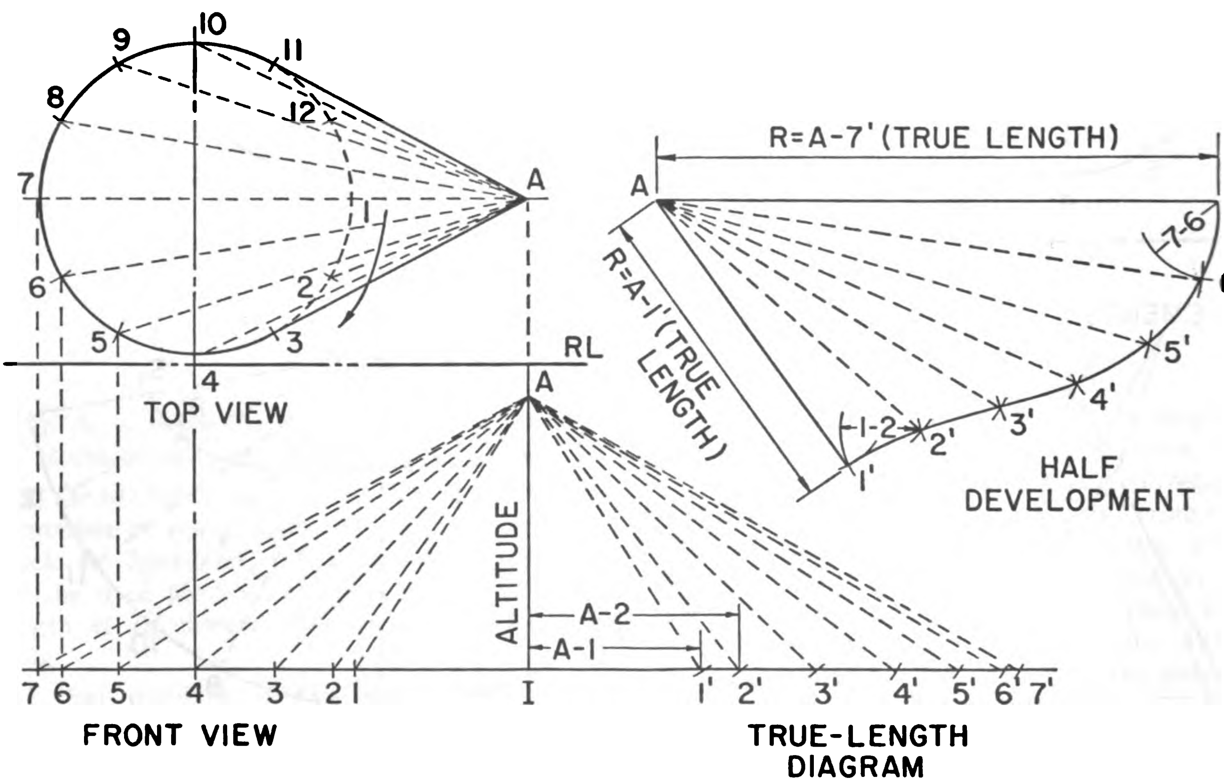


Figure 89. Developing an oblique cone.

arc, with A as center, with a radius equal to line A–$6'$ in the true-length diagram; intersect the arc with a second swung with point 7 as center and equal in length to the true distance 7–6 taken from the top view. Establish the necessary points of the half development with intersecting arcs swing from point A and successive points along the perimeter of the base. Distances of the long arcs are obtained from the true-length diagrams, and the distances of the short arcs are obtained from the top view. When all points in the half development have been established, draw the element (or bend) lines and connect the points with the aid of an irregular curve. The development, although only approximate, is accurate enough for most practical purposes.

225. To Develop a Transition Piece

a. Transition Pieces. Transition pieces are used frequently when fabricating ducts or other sheet metal constructions to connect openings of different shapes or sizes. The transition piece shown in figure 90 connects a rectangular duct with a circular pipe. An analysis of the pictorial view reveals that the surface may be broken down into four isosceles triangles the bases of which form the square base connecting the piece to the duct, and four conical surfaces the upper edges of which form the circular opening connecting the piece to the round pipe. The development is achieved by taking the component surfaces separately and developing each in succession, proceeding around the entire piece until the complete surface has been developed.

b. Views. Draw the front and top views as shown. The conic surfaces are triangulated and the true lengths of their elements are obtained by constructing a true-length diagram adjacent to the front view. The true lengths of the

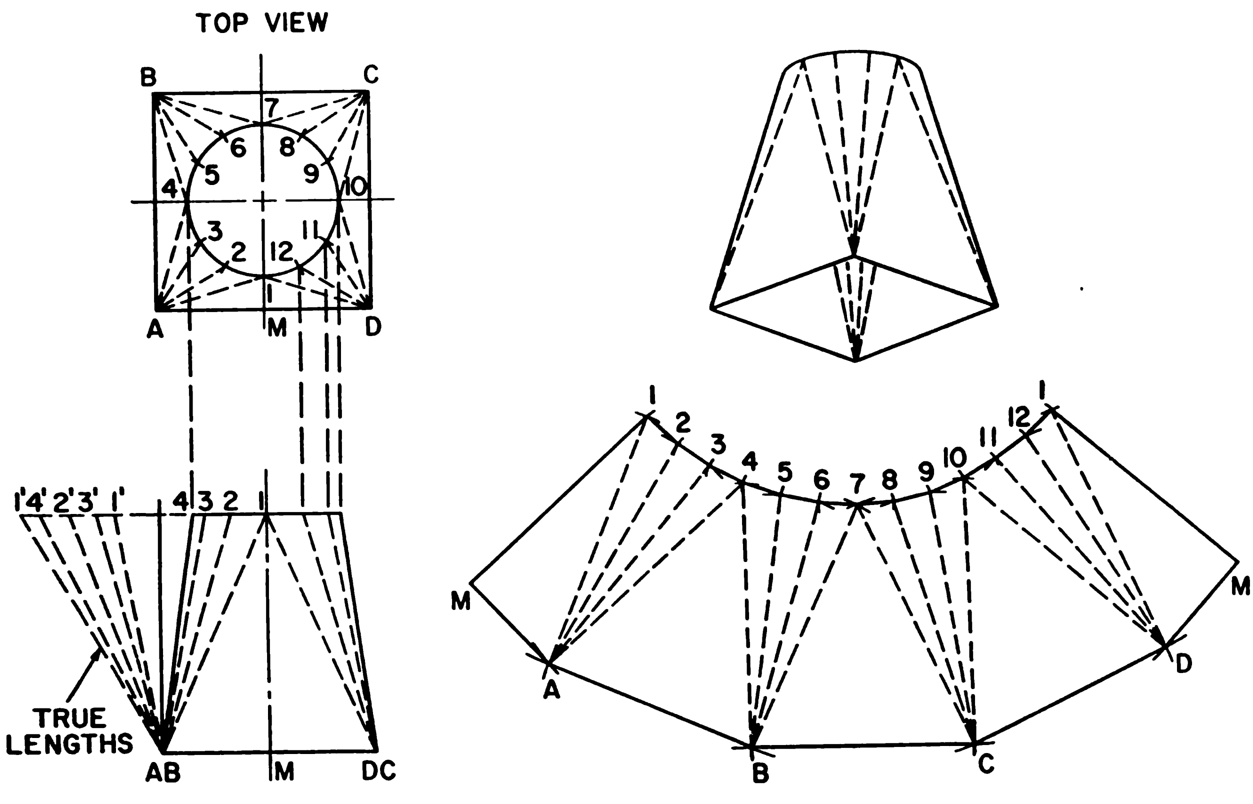


Figure 90. Developing a transition piece.

edges of the rectangular base and the segments of the circular opening are shown in the top view.

c. Development. Establish point M at any convenient location and draw line M–1 as it appears in its true length in the front view. Next establish point A by swinging a short arc from point M equal in radius to the distance M–A in the top or front view and intersecting this with a long arc swung from point 1 and equal in radius to line A–1′ in the true-length diagram (fig. 90). Draw lines M–A and M–1 in the development. Establish successive points by triangulation, using the true lengths of the lines or segments as the radii of the arcs. When all the points along the perimeter of the circular opening have been established, they may be connected with an irregular curve. The remaining points are connected with a straightedge.

226. To Develop the Surface of a Sphere

a. Spheres. The surface of a sphere is a double curved surface generated by a curved line and containing no straight-line elements. Double-curved surfaces can be developed only by approximate methods. As stated previously, development by approximate methods requires dividing the complete surface into smaller segments that are developable.

b. Views. Draw the top and front views as shown in figure 91. The sphere is considered cut by a series of planes passed perpendicularly to the axis in the front view. Their projection in the top views shown them as circles. A quarter section of the sphere is cut by vertical planes. Their projection in the top view represents them as edges. Although the development of only one quarter is described here, the remaining quarters are developed in the same way.

c. Development. The development of one longitudinal section provides the pattern for the remaining sections. Line D is the stretchout line. The height of each section, PP, and the vertical spacing between the horizontal cutting planes are taken from the front view. The widths of successive segments are taken from the top view. Each section is symmetrical about PP and the stretchout line. A full development requires 16 sections.

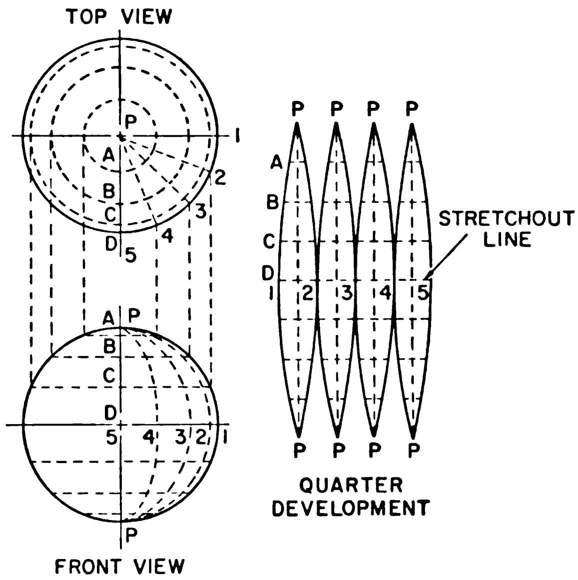


Figure 91. Developing the surface of a sphere, gore method

227. Intersections

In sheetmetal work, whenever two pieces intersect, the intersections must be found before the piece can be developed. In addition, a draftsman must be able to determine the line of intersection to represent objects accurately. Almost all problems can be solved by resolving the objects into a combination of geometric shapes. The simplest problems are those involving two objects, both of which are bounded by plane surfaces. In such cases, the view in which an intersecting surface appears as a line allows an observer to determine by inspection the points through which a given line is penetrated by the lines of the other surfaces. Problems involving intersections between two single-curve or double-curved surfaces can be solved by drawing element lines on one lateral surface near the line of intersection. Points are established wherever the element lines intersect the other surface, which determine the line of intersection because they are common to both surfaces. The usual method of determining the line of intersection of any two surfaces is to pass a series of imaginary cutting

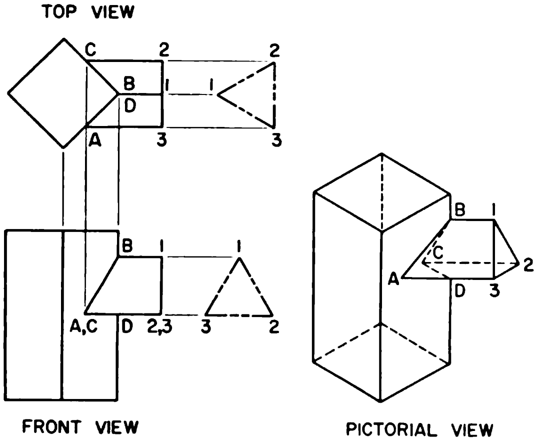


Figure 92. Intersection of two prisms.

planes through the objects in a direction perpendicular to the principal plane of projection. Each plane is passed to cut the simplest lines from each surface. One or more points on the line of intersection will be established by the intersection of lines cut from each surface by a plane.

228. Intersection of Two Prisms

The pictorial view in figure 92 shows the edges of the triangular prism piercing the faces of the rectangular prism at points *A*, *B*, and *C*. These points are called the critical points, or vertices, of the intersection. Draw two related orthographic views. The top and front views were selected in figure 92. The side view could be used instead of either top or front views, but a third orthographic view is not necessary. It may be helpful to sketch an end view of the triangular prism as shown by △ 1, 2, 3 in figure 92. The edges of the triangular prism in the top view intersect the faces of the rectangular prism in points *A*, *B*, *C*, and *D*. Project points *A*, *B*, *C*, *D* to front view and extend the edges of the triangular prism in the front view, this locating the points *A*, *B*, *C*, and *D*.

229. Intersection of Two Cylinders

When two objects having curved surfaces intersect, their line of intersection is an irregular curve, which must be plotted by passing a series of construction planes cutting each object. Two orthographic views are selected, and points of the intersection are determined by projection between the two views. Figure 93 illustrates the steps in plotting the intersection of two cylinders, as follows:

a. A series of construction planes are passed through both cylinders parallel to their centerlines.

b. The first plane through the centerlines of both cylinders cuts the small cylinder in elements numbered 1 and 7, and the large cylinder in element numbered 8.

c. When these elements are projected to the front view they intersect in points lettered *A* and *G*.

d. The second plane parallel to the first, cuts the small cylinder in elements numbered 2 and 6, and the large cylinder in element numbered 9

e. When these elements are projected to the front view they intersect in points *B* and *F*.

f. Likewise the plane through elements 3 and 5 on the small cylinder and element numbered 10 on the large cylinder, intersect in the front view in points *C* and *E*.

g. The plane tangent to the small cylinder in element numbered 4 cuts the large cylinder in element numbered 11, and these elements intersect in point *D*. A French curve is used to draw the line of intersection through points *A*, *B*, *C*, *D*, *E*, *F*, and *G*.

230. Intersection of a Plane and a Right Cone

When one object having plane surfaces intersects an object with curved surfaces, the line of intersection is a curved line. Figure 94 illustrates some of the various intersection which may result from the intersection of a plane and a right circular cone. If the plane is parallel to the base and cuts all elements of the cone, the intersection is a circle (A, fig. 94). If the plane is not parallel to the base and cuts all elements, the intersection is an ellipse (B, fig. 94). If the plane is parallel to an element of the cone, the intersection is a parabola (C, fig. 94). If the plane is parallel to the axis of the cone, it cuts both nappes, and the intersection is a hyperbola (D, fig. 94). Some special cases not shown are a point, a single straight line, and two intersecting straight lines.

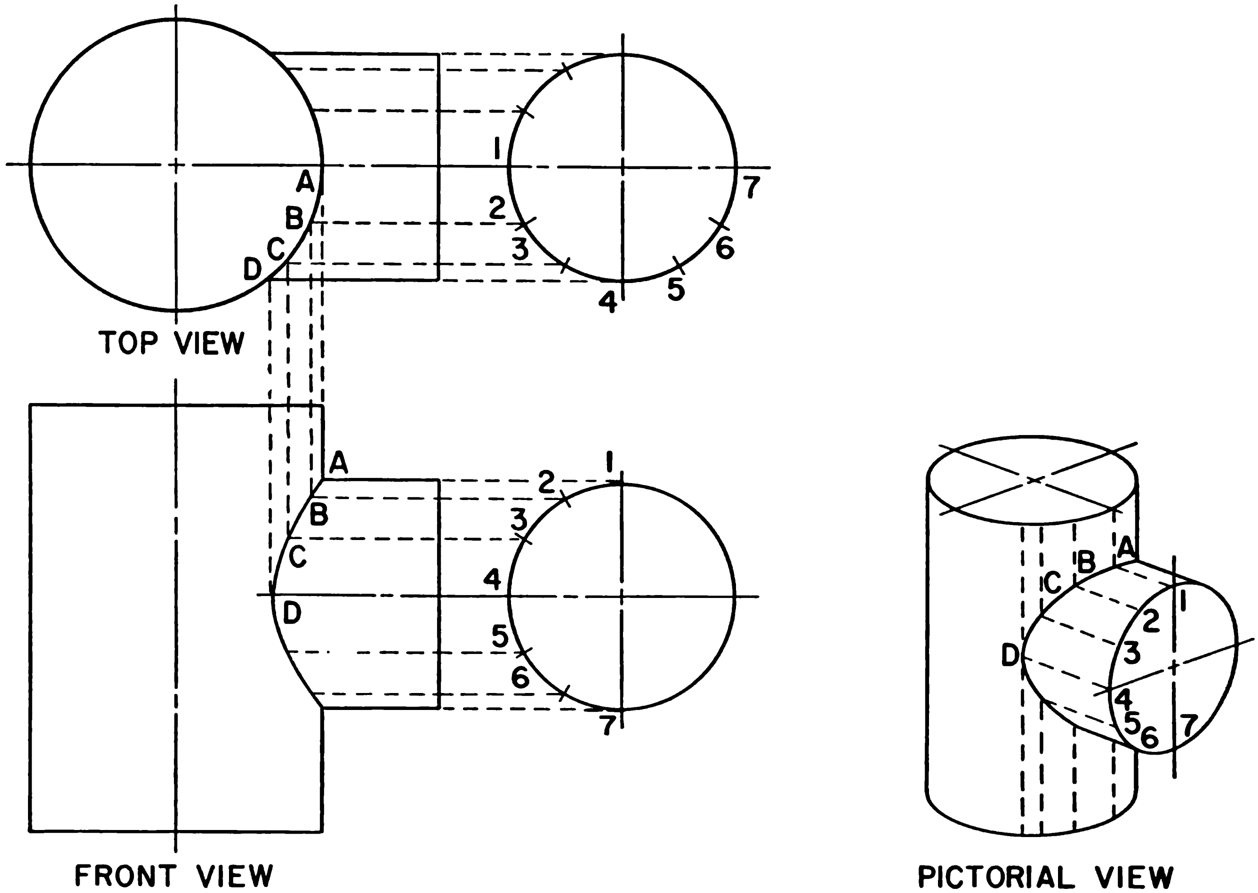


Figure 93. Intersection of two cylinders.

231. Intersection of a Prism and a Cone

The practical method of determining the intersection between a prism and a cone by passing a series of cutting planes is shown in figure 95. Each face of the prism will cut the cone in a hyperbola (D, fig. 95) and the intersection will be a series of six hyperbolic curves joined end to end. Two related orthographic views are necessary in order to plot points on the intersection. In figure 95 the top and front views are used. The top view shows the regular hexagonal prism *A, B, C, D, E, F* centered at *O*, the vertex of the cone. The procedure for plotting points on the intersection is as follows:

a. In the top view draw a circle circumscribing the hexagon. Project the points *A* and *D*, the ends of the diameter, to the front view where the projection lines meet the side elements of the cone at *A′* and *D′*. Draw cutting plane I–I, which is the circle on edge, through *A′* and *D′*. Also project points *B* and *C* to the points *B′* and *C′* on the plane I–I. The intersection of a plane parallel to the base of a cone is a circle as shown at A in figure 95.

b. In the top view inscribe a circle within the hexagon. Project this circle to the front view by projecting the end points of its diameter to the side elements of the cone, where it appears on edge as the cutting plane II–II. Also mark the points *G, H,* and *J*, the points where the inscribed circle is tangent to the faces of the prism, in the top view, and project points *G, H,* and *J* to the points *G′, H′* and *J′* on the plane II–II, thus locating the high points of each hyperbolic curve.

c. In the top view draw a circle approximately halfway between the inscribed and cir-

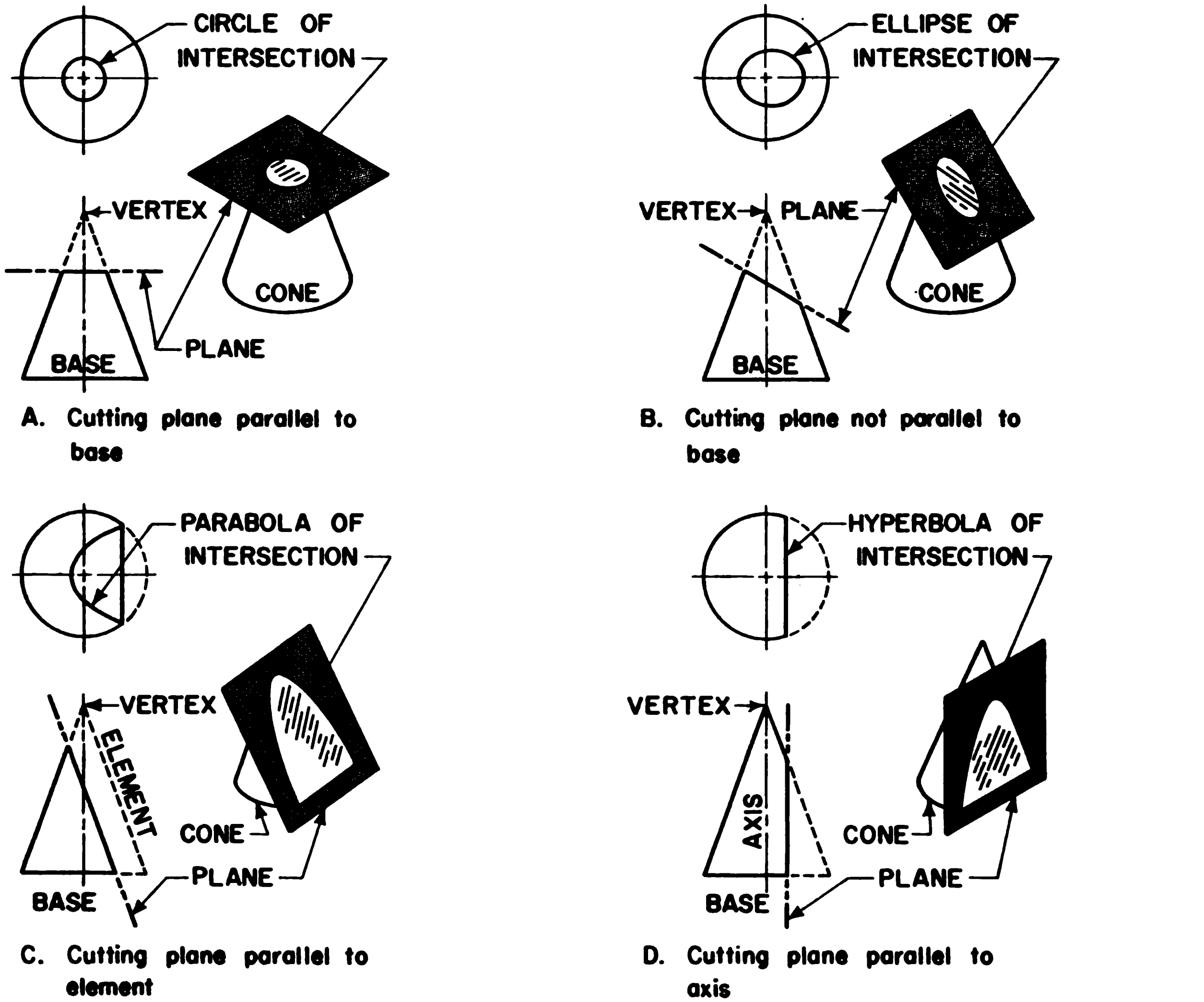


Figure 94. Intersection of a plane and a right cone (conic sections).

cumscribed circles. Project this circle to the front view where it appears on edge as the cutting plane III–III. In top view find points where the last circle drawn intersects the sides of the prism and project these points to the plane III–III thus locating two more points on each curve.

d. Using a French curve, draw the hyperbolic curves through the points located in *a*, *b*, and *c* above. These curves are visible outlines, and take precedence over the identical curves formed by the other three sides *DE*, *EF*, and *FA* of the prism.

232. Intersection of a Cylinder and a Cone

To find the line of intersection of a cone and a cylinder, the cutting planes are passed perpendicularly to the axis of the right cone to cut circles from the cone (fig. 96). To obtain an accurate curve, be careful in selecting the number and location of cutting planes. Planes are passed through critical points and in areas where the line of intersection changes sharply in curvature. More points need to be found at these areas than elsewhere.

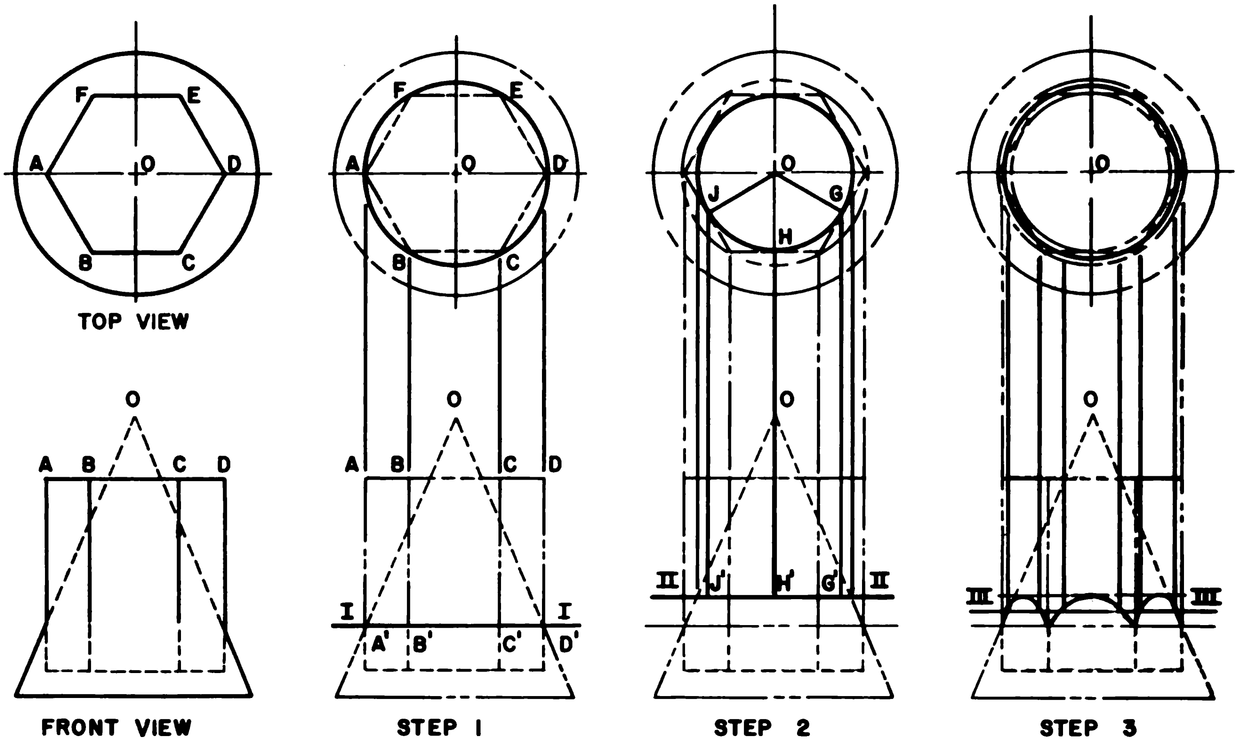


Figure 95. Intersection of a prism and a cone.

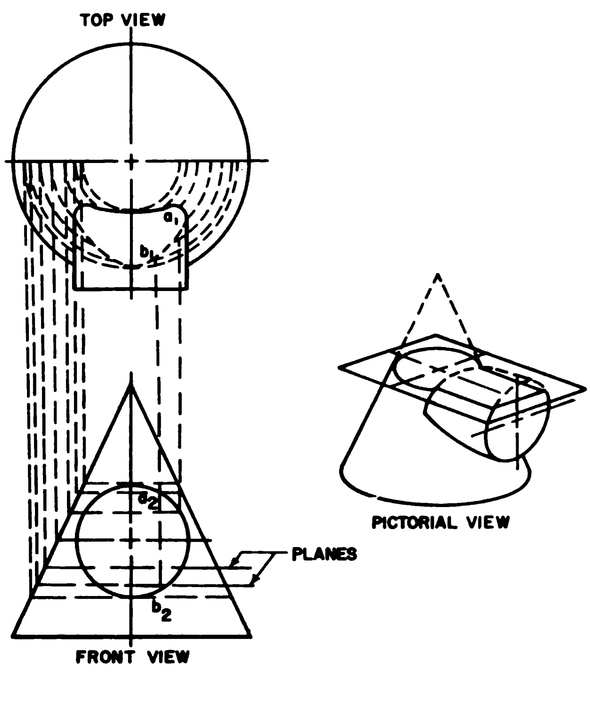


Figure 96. Intersection of a cone and a cylinder.

CHAPTER 10

ELEMENTS OF CONSTRUCTION DRAWING

233. Introduction

The term construction drawing has but one meaning; a drawing from which construction can be performed. The building of any structure is described by a set of related drawings and specifications that give the workmen a complete, graphic description of each phase of the total operation. In most cases, a set of drawings begins by showing the boundaries, contours, and outstanding physical characteristics of the construction site and its adjoining areas. Succeeding drawings give instructions for the excavation and disposition of existing ground; erection of the foundations and superstructure; installation of heating, lighting, and plumbing facilities; and whatever else is required to complete the structure. Construction drawings are prepared from sketches and instructions forwarded to draftsmen by the designers.

a. Architecture Versus Engineering. The design of any structure represents close cooperation between architects and engineers. One of the principal factors influencing the design of a structure is its function, that is, the use for which it is intended.

(1) In the case of a building, factors such as overall size, external appearance, arrangement of internal space, and number, size, and kind of doors, windows, and fittings are the responsibility of the architect.

(2) The engineer prepares design sketches of the structure based upon calculations concerned with the strength of the supporting members. In addition, the mechanical systems of a building, such as plumbing, lighting, heating, ventilating, and air-conditioning, are designed by engineers rather than architects.

(3) The architect and engineer together determine the construction materials to be used and methods of work.

b. Architectural Working Drawings. Architectural drawings are prepared as presentation drawings or as working drawings. The former category needs techniques of pictorial drawing such as perspective and shading. A construction draftsman is not concerned with presentation drawings. He prepares architectural working drawings consisting of plans, elevations, sections, and details, and isometric views.

c. Engineering Drawings. Engineering drawings include structural plans, grading plans, electrical plans, plumbing plans, heating and ventilating plans, and site plans.

234. Theory of Structure

A structure is built of parts, called members, intended to support and transmit loads while remaining in equilibrium relative to each other. The points at which members are connected are called joints, and the methods of connection are determined principally by the kinds of material being connected. All structures, whether bridges, towers, or buildings, have certain factors in common. A construction draftsman whose task is to produce drawings concerning structures will be aided by some understanding of these basic factors.

a. Loads. The principal loads present in every structure are classified as dead load and live load.

(1) *Dead load.* Dead load means the weight of the structure itself, which increases gradually as the structure is being built and remains constant once it has been completed. The weight of all structural members plus floors, walls, heating equipment, and all other nonmovable items in a building also are considered dead load.

(2) *Live load.* Live load means the weight of movable objects on the floor of a building or deck of a bridge. This would mean people and furniture in a building and the traffic across a bridge.

(3) *Load distribution.* All structures are designed with the same basic theory of load distribution, which states that all live loads are supported by horizontal structure members that, in turn, are supported by vertical structural members. The loads are transmitted from the horizontal members to the supporting vertical members. Vertical members are supported by footings or foundation walls that rest on the ground. All structural loads are therefore dispersed into the ground supporting the structure. The ability of the ground to support loads is called soil bearing capacity.

(*a*) *Soil bearing capacity.* The bearing capacity of ground is measured in pounds per square foot and is determined by test; it varies for different soils. The area over which a footing extends is a factor in distributing the load received from a column in accordance with the bearing capacity of the soil. The size of a footing, therefore, is determined by the bearing capacity of the soil on which a structure is built.

(*b*) *Uniformly distributed and concentrated loads.* The load on a structural member is classified as uniformly distributed or concentrated. A concentrated load is exerted at a particular point on a member as, for example, the load of a beam on a girder. A uniformly distributed load is one which is spread throuhout a member, such as a slab on a beam.

(*c*) *Eccentric loading.* Eccentric loading occurs when force on a member such as a column is not applied at the center of the column, but rather "off center."

b. Stresses. The loading of structural members has a tendency to deform them. The ability of a member to withstand certain kinds of deformation is called stress.

(1) *Tension.* Tension is the stress that resists the tendency of forces acting in opposite directions to pull a body apart.

(2) *Compression.* Compression is the stress that resists the tendency of forces acting toward each other to push a member together.

(3) *Shear.* Shear is the stress that resists the tendency of parallel forces acting in opposite directions to cause adjoining planes of a body to slide onto each other.

(4) *Torsion.* Torsion is the stress that resists the tendency of a body to twist.

(5) *Stiffness.* The stiffness of a member is its ability to resist bending.

(6) *Strength.* The strength of a member is its ability to resist breaking.

235. Structural Members

The following are the most frequently encountered structural members, classified according to use:

a. Footings. Footings rest on soil material and transmit their received load thereto. The natural material on which a footing rests is called the foundation bed. Footings support columns, piers, pilasters, walls, and similar loads. In the case of masonry walls, however, spread footings are used, so called because a spread footing extends the length of the structure. Usually, footings are made of concrete (fig. 103), although wood, or timber, may be used.

b. Vertical Members. Vertical members are in compression, that is, they support loads acting downward at the top. Columns, posts, studs, and piers are the most frequently encountered vertical members.

(1) *Columns.* Columns may be of steel, timber, or concrete construction. They rest on footings and are the principal load-carrying vertical members.

(2) *Piers.* Piers are of concrete, timber, or masonry construction. They rest on footings and support horizontal or vertical members. In bridge construction, the term signifies an intermedi-

ate support for the adjacent ends of two bridge spans.

(3) *Studs and posts.* Studs are vertical members used in wood-frame construction and are spaced closely together in walls. Posts are heavier vertical members used in wood-frame construction, usually at the corners.

c. Horizontal Members. The following are the most frequently encountered horizontal structural members.

(1) *Joists.* Joists are light beams spaced up to 4 feet center-to-center. They take the load directly from the floor.

(2) *Beams.* Beams, like joists, take the load of the floor directly, but they are spaced more than 4 feet on center.

(3) *Girders.* Girders take the load of either joists or beams and are generally the heaviest horizontal members in a structure.

(4) *Lintels.* Lintels are beams which span door or window openings and carry the structure above those openings.

d. Roof Members.

(1) *Rafters, common.* Those which run square with the plate and extend to the ridge.

(2) *Rafters, cripple.* Those which cut between valley and hip rafters.

(3) *Rafters, hip.* Those extending from the outside angle of the plates toward the apex of the roof.

(4) *Rafters, jacks.* Those square with the plate and intersecting the hip rafter.

(5) *Rafter, valley.* Those extending from an inside angle of the plates toward the ridge or center line of the house.

(6) *Purlin.* A timber supporting several rafters at one or more points, or the roof sheeting directly.

(7) *Trusses.* Trusses are wood or steel structural members connected together to span the space between the walls of a building and support the roof load.

e. Flooring. Subflooring is laid atop joists; building paper is placed between subflooring and finished flooring wherever required.

f. Framing. Paragraph 292 and figure 126 show the framing of a theater of operations building and identify all the framing members.

g. Sheathing, Siding, and Roofing. Structural members are covered with suitable materials to form the outside walls and the roof; insulation is placed between sheathing and finish materials.

h. Utilities. Heating, wiring, and plumbing are the utilities or mechanical systems of a building and are represented by diagrammatic and orthographic drawings.

i. Finishing and Painting. Glazing, plastering, finish trim, and painting complete the building.

236. Materials of Building Structures

The major differences in construction drawings, notes, and dimensions are caused by the different methods of manufacturing the construction materials as well as the different construction practices used in assembling or installing these materials. To successfully prepare a drawing showing how material is assembled, the materials must be known. They are identified below and discussed in detail later.

a. Wood. Wood is one of the most commonly used materials of construction. In Army building, wood is used in every type of construction from tent frames to large buildings and bridges. Because of the wide usage of wood, particularly in temporary Army structures, a draftsman must know the terminology of wood, the nomenclature of structural members, the function and location of the various members. In addition, he must know the size standards for wood to execute detail drawings.

b. Concrete. Concrete is the material used most frequently for footings and foundations. It may be strengthened by the addition of steel bars, in which case it is known as reinforced concrete, and may be used to support heavy structural loads. Draftsmen also must know the materials used to make concrete as well as the methods of building concrete structures and representing reinforcing steel

c. Masonry. Masonry materials can be classified roughly as those bonded together with mortar. This includes clay bricks, stone, concrete blocks, and the various tile products. Each has specific uses and properties, such as standard unit sizes, that draftsmen must know to prepare accurate drawings of masonry construction.

d. Steel. Steel construction usually consists of assembling structural steel members that have been fabricated at the mill for the particular structure being erected. Draftsmen must know the shapes and sizes of standard members, the methods of connecting them, and the drawing practices peculiar to steel construction.

237. Principles of Construction Drawing

Construction drawings are based on the same general principles as are all other technical drawings. The shape of a structure is described in orthographic views drawn to scale. Its size is described by figured dimensions, whose extent is indicated by dimension lines, arrowheads, and extension lines. Overall relationships are shown in general drawings similar to assembly drawings. Important specific features are shown in detail drawings usually drawn to a larger scale than the general drawings. Additional information about size and material is furnished in the specific and general notes. All these principles, however have certain applications and terminology, peculiar to construction drawing, that are determined by the materials and methods of construction and the conventional practices of construction drawing.

238. Views in Construction Drawings

The views of a structure are presented in general and detail drawings. General drawings consist of plans and elevations; detail drawings are made up of sectional and detail views.

239. Plans

A plans corresponds to a top view, namely, a projection on a horizontal plane. There are several types of plan views which are used for specific purposes, such as site plans, foundation plans, and floor plans.

a. Site Plan. A site plan shows the building site with boundaries, contours, existing roads, utilities, and other physical details such as trees and buildings. Figure 97 is atypical site plan. Site plans are drawn from notes and sketches based upon a survey. The layout of the structure is superimposed on the contour drawings, and corners of the structure are located by reference to established natural objects or other buildings.

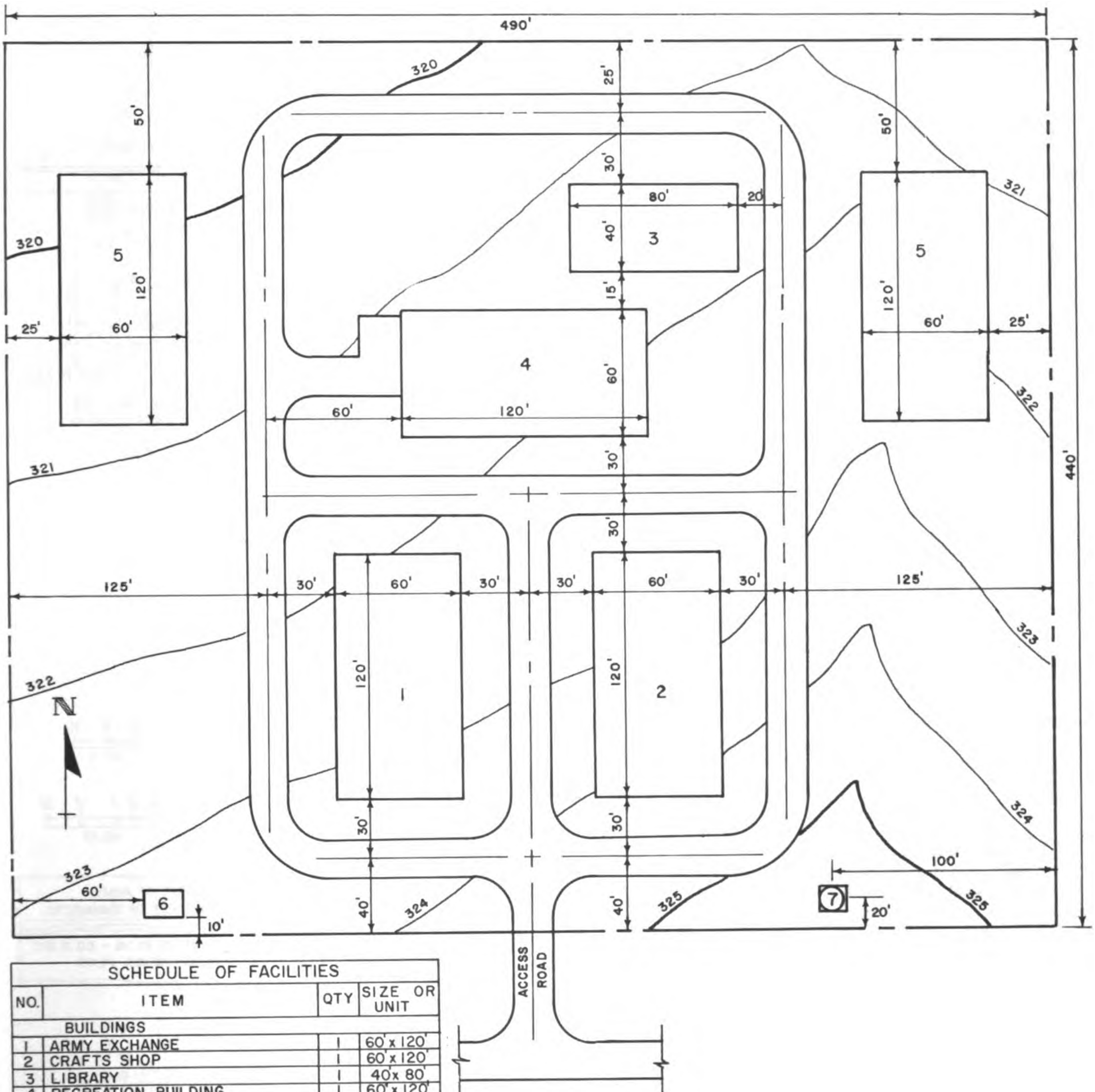
b. Foundation Plan. A foundation plan is a top view of the footings or foundation walls, showing their area, and location by distances between centerlines and distances from reference lines or boundary lines. Foundation walls are located by dimensions to their corners, and all openings in foundation walls are shown. Figure 98 shows the typical foundation plans for alternate conditions.

c. Floor Plan. Floor plans, commonly referred to as plan views, are cross section views of a building. The horizontal cutting plane is passed so that it includes all doors and window openings. A floor plan (fig. 99) shows the outside shape of the building; the arrangement, size and shape of rooms; the type of materials; the thickness of walls and partitions; and the type, size, and location of doors and windows for each story. A plan also may include details of framework and structure, although these features are usually shown on separate drawings called framing plans.

d. Procedure for Drawing Plans. Plan views are drawn first because other views depend upon the plan views for details and dimensions. In preparing plan views, a draftsman's job is simplified by following a systematic procedure.

(1) *Orientation.* Plan views may be drawn so that the front of the building is at the bottom or right of the sheet. However, when this is not practical, they may be drawn in any arrangement which space permits. Select a suitable scale and lay out the line representing the exterior face of the front wall. Draw the line lightly and allow enough space for notes and dimensions at the bottom or right of the working area. Then, for a symmetrical plans such as figure 99, draw the main axis. The main axis corresponds to the centerline of a view and is helpful in centering a plan view.

(2) *Walls and openings.* Proceed from the line representing the exterior face of the front wall. Draw all walls and



SCHEDULE OF FACILITIES			
NO.	ITEM	QTY	SIZE OR UNIT
	BUILDINGS		
1	ARMY EXCHANGE	1	60' x 120'
2	CRAFTS SHOP	1	60' x 120'
3	LIBRARY	1	40' x 80'
4	RECREATION BUILDING	1	60' x 120'
	OTHER CONSTRUCTION		
5	ATHLETIC COURTS	2	60' x 120'
6	SUMP FIRE PROTECTION	1	10,000 Gal.
7	WATER TANK	1	10,500 Gal.
	ROAD- 22' WIDE-(2 lane) 6" MACADAM	0.5	MILE
	SITE AREA	11.2	ACRES

DEPARTMENT OF ARMY
OFFICE OF THE CHIEF OF ENGINEERS

RECREATION BUILDING—60' x 120'
SITE PLAN

Figure 97. Typical site plan.

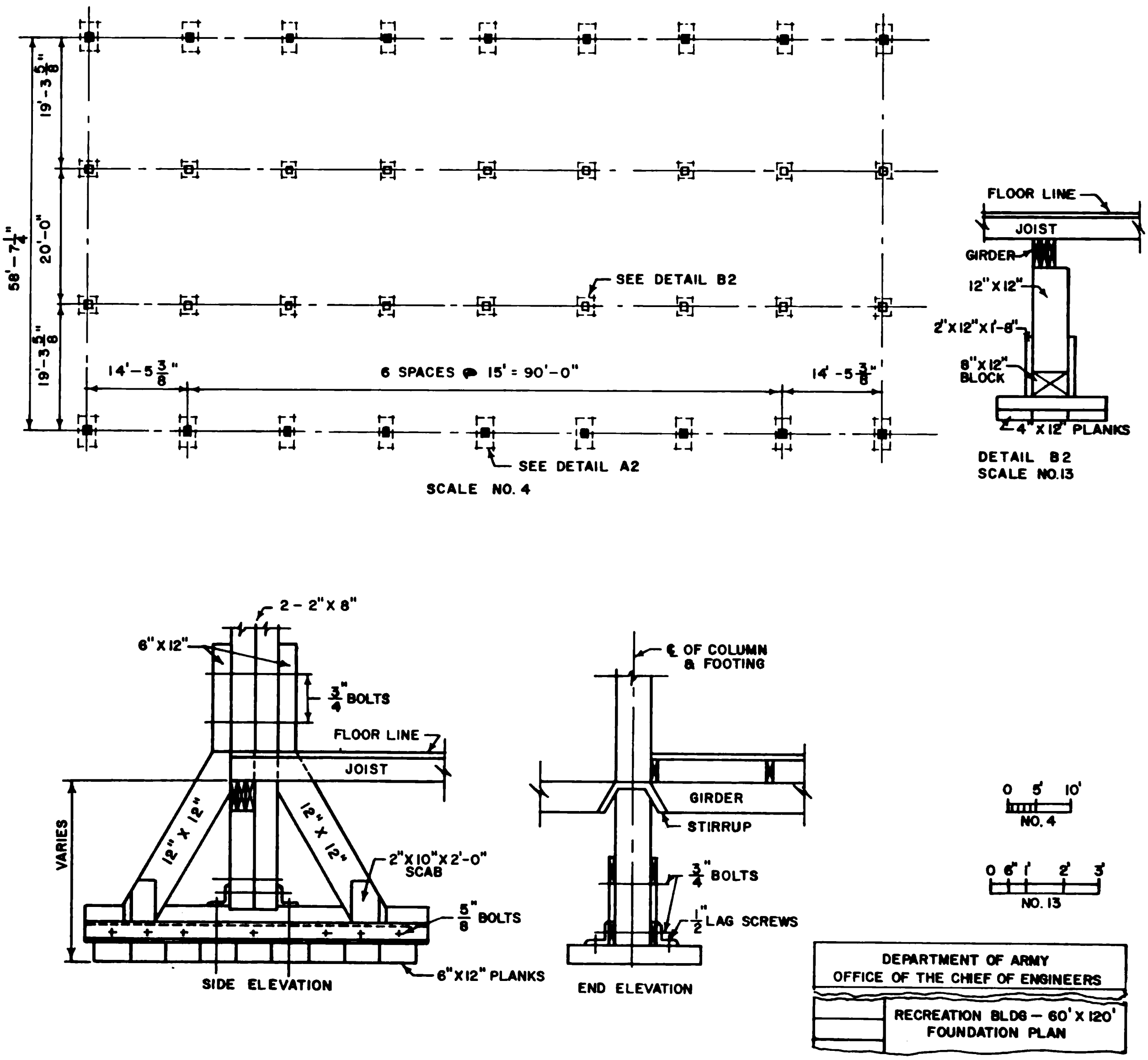


Figure 98. Foundation plan.

partitions to scale with light pencil lines. Block out all door and window openings. After all walls, partitions, and openings have been located, darken wall and partition lines to a medium line weight.

(3) *Symbols.* After completing wall and partition lines, draw symbols for doors, windows, fixtures, and other details shown in the plan view. Door and window openings are laid out accurately to scale. Door and casement window swings are also drawn to scale; the remaining lines in door and window symbols are spaced by eye.

(4) *Number of views.* In most cases, separate drawings are made for each plan view and they will be the only views on the drawing sheet, but, on occasion, they may be accompanied by detail or section views. The number of views to be included on a single drawing

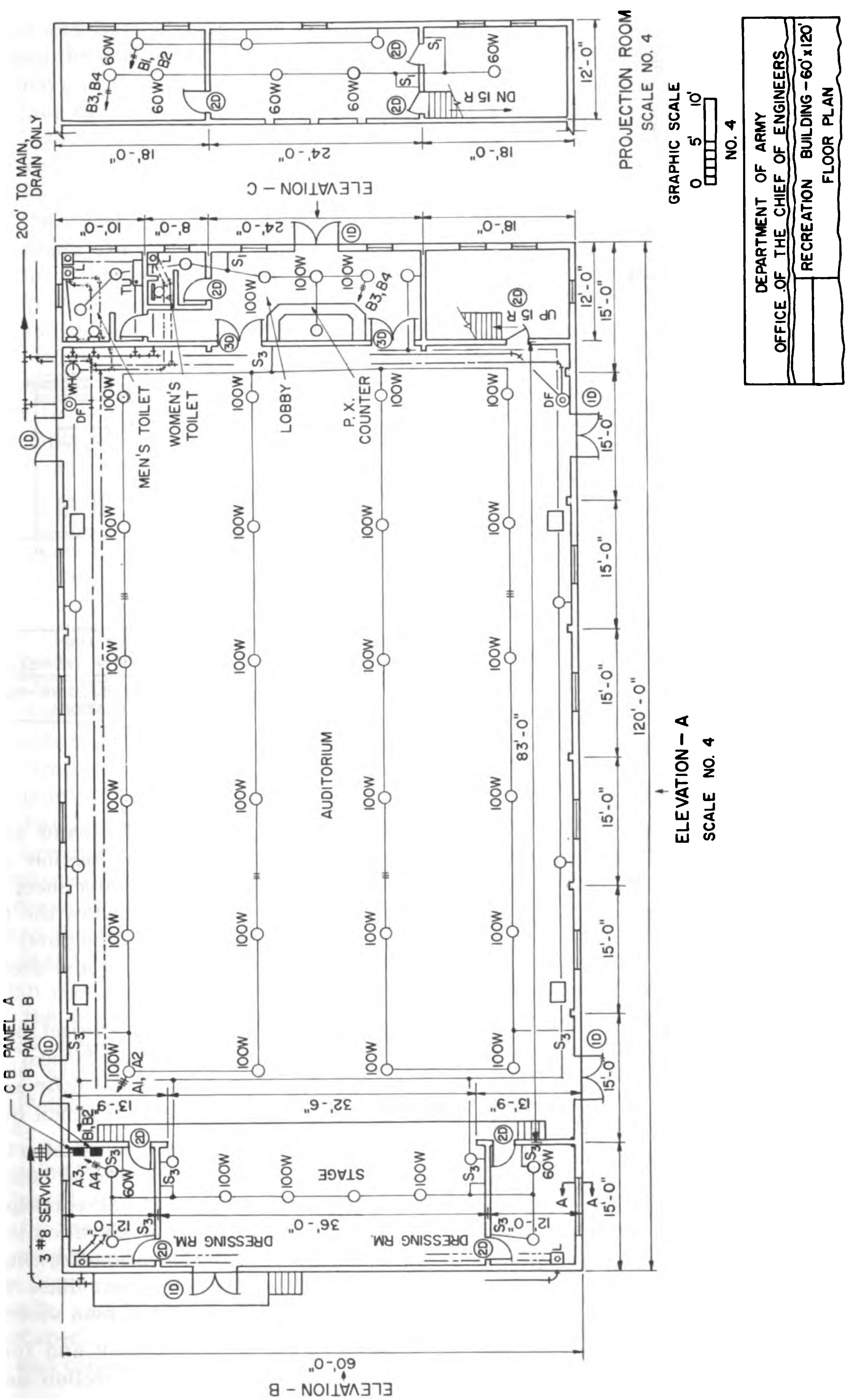


Figure 99. Typical floor plan.

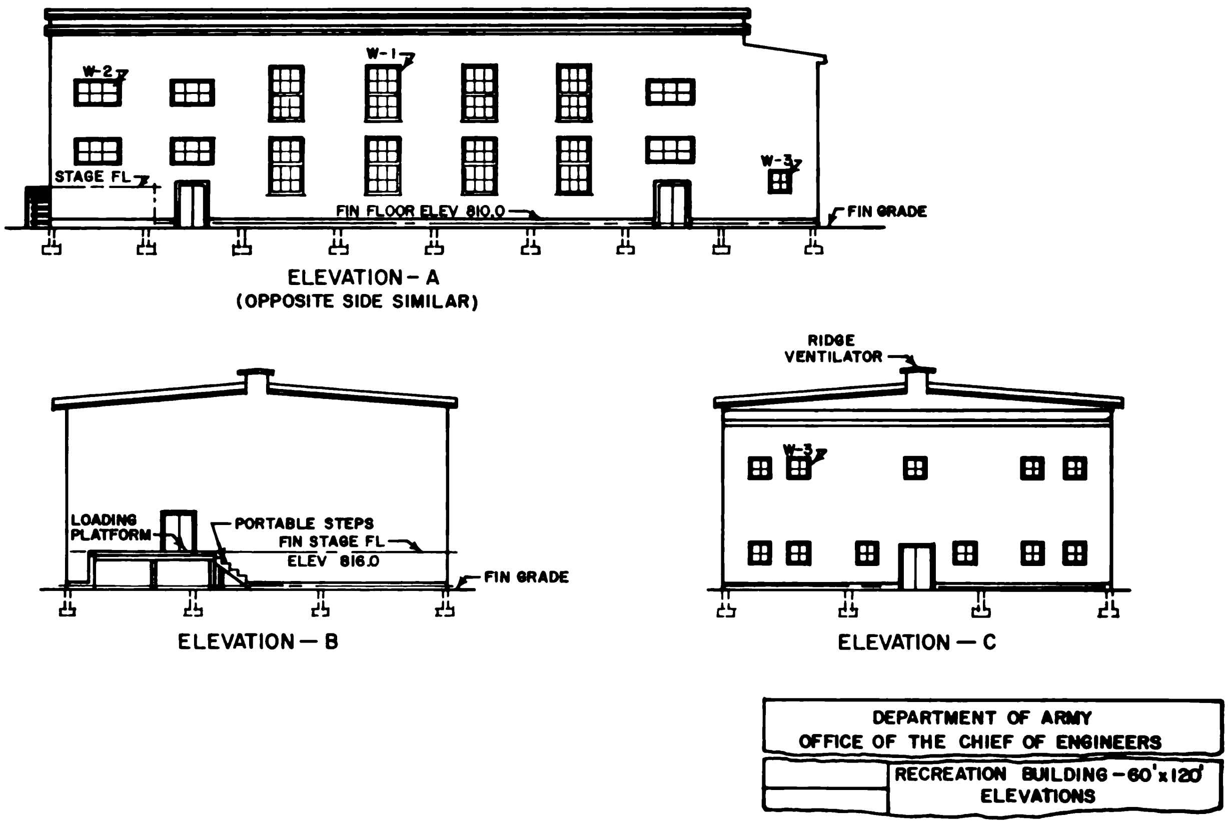


Figure 100. Elevation views.

sheet should be determined by discussion with the man in charge while the drawing is still in the preliminary stage.

240. Elevations

Elevations are external views of a structure and may be drawn to show the front, rear, right or left side views. They correspond to the front, rear, or side views in orthographic projection because they are projections on vertical planes. An elevation is a picture-like view of a building that shows exterior materials and the height of windows, doors, and rooms as in figure 100. It may also show the ground level surrounding the structure, called the grade. The following procedure is used for developing an elevation:

a. Projection. Complete a related plan view and a typical section before beginning to draw an elevation. These are equivalent to top and side views in machine drawing. The plan and section should be drawn to the same scale decided for the elevation. The section may be placed to one side on the drawing sheet for the elevation. The section should show the foundation, gradeline, finished floor heights, heights of sills and heads for windows and doors, and the pitch of the roof.

(1) *Vertical dimensions.* Project the gradeline across from the typical section first. Next project the floor and ceiling heights. Use light pencil lines.

(2) *Horizontal dimensions.* Fasten the plan view above the drawing sheet, arranged so that the wall corresponding to the one drawn in elevation is placed nearest to the elevation drawing sheet and parallel to the floor lines. Project lines down from the plan view.

(3) *Procedure.* Work back and forth between the plan and section until ex-

terior details for the elevation in question have been located.

b. Lines and Symbols. Darken the building outlines and the outlines of doors and windows, and add line and material symbols.

(1) *Line symbols.* Finished floor lines are indicated in an elevation by alternate long and short dashes (same as center line symbol, (see fig. 100)) drawn over the other lines. Foundations below grade are shown by the line symbol for hidden details.

(2) *Roof drains.* When used, rain gutters and downspouts are shown in an elevation view.

c. Notes and Dimensions. Draw guidelines and letter the specific notes identifying building materials. If more than one view is shown on a drawing sheet, identify each view by title. If any view is drawn to a scale different from that shown in the title block, note the scale beneath the view title. No horizontal dimensions are given in an elevation.

(1) *Elevations.* Finished floor and grade elevations are written as a note, accompanied by a dimension, written on the line symbol denoting the finished floor; the line symbol is extended outside the building area for this purpose. Grade elevations may be given at two points for a sloping gradeline.

(2) *Pane dimensions.* Pane dimensions are given in the window schedule.

d. Number of Elevations. The number of elevations drawn for any building is principally determined by the complexity of its shape. A building that is symmetrical about a centerline in the plan view may show adjacent half elevations of the front and rear. Roof, floor, and foundation lines are continuous; a vertical centerline symbol separates the two halves, which are identified by titles centered under each one.

241. Framing Plans

Framing plans show the size, number, and location of the structural members (steel or wood) constituting the building framework. Separate framing plans may be drawn for the floors, walls, and the roof. The floor framing plan must specify the sizes and spacing of joists, girders, and columns used to support the floor. Detail drawings must be added, if necessary, to show the methods of anchoring joists and girders to the columns and foundation walls or footings. Wall framing plans show the location and method of framing openings and ceiling heights so that studs and posts can be cut. Roof framing plans show the construction of the rafters used to span the building and support the roof. Size, spacing, roof slope, and all details are shown.

a. Floor Framing. Framing plans for floors are basically plan views of the girders and joists. The unbroken double-line symbol is used to indicate joists, which are drawn in the positions they will occupy in the completed building. Double framing around openings and beneath bathroom fixtures is shown where used. Figure 101 shows the manner of presenting floor framing plans.

(1) *Bridging* is shown by a double-line symbol with a broken line in the center drawn parallel to the outside lines.

(2) *Notes* identify floor openings, bridging, and girts or plates. Use nominal sizes in specifying lumber.

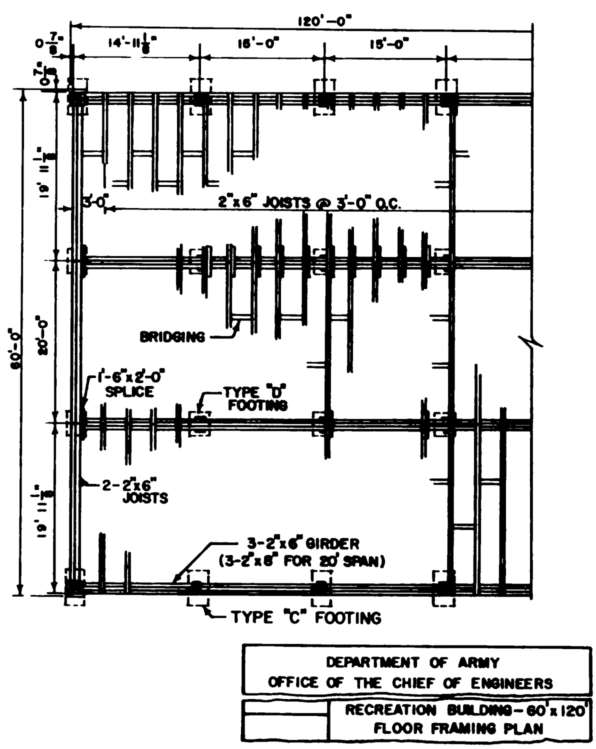


Figure 101. Floor framing.

(3) *Dimensions* need not be given between joists. Such information is given along with notes. *For example,* 1″ x 6″ joists @ 2′-0″ o.c., indicates that the joists are to be spaced at intervals of 2′-0″ from center to center of joists. Lengths are not required in framing plans; the overall building dimensions and the dimensions for each bay or distances between columns or posts provide such data.

b. Wall Framing. Wall framing plans are *detail* drawings showing the location of studs, plates, sills, girts, and bracing. They show one wall at a time and usually are shown as elevation views.

(1) *Door* and *window* framing is shown in wall framing details; openings are indicated by intersecting, single-line diagonals and are identified by the abbreviations D and W.

(2) *Bracing* is indicated by a dashed, double-line symbol and is drawn to scale in its correct location.

(3) *Dimensions.* Vertical dimensions give overall height from the bottom of the sill (for first floor) to the top of the plate or girt. Horizontal dimensions give the spacing of studs on centers.

(4) *Notes.* Specific notes identify types of doors and windows or make reference to general notes. General notes give instructions about such factors as variations in door and window framing, and the installation of bracing.

c. Roof Framing. Framing plans for roofs are draw in the same manner as floor framing plans. A draftsman should visualize himself as looking down on the roof before any of the roofing material (sheathing) has been added. Rafters are shown in the same manner as joists.

242. Sectional Views

Sectional views, or sections, provide important information as to height, materials, fastening and support systems, and concealed features. They show how a structure looks when cut vertically by a cutting plane. The cutting plane is not necessarily continuous but, as with the horizontal cutting plane in building plans, may be staggered to include as much construction information as possible. Like elevations, sectional views are vertical projections. Being detail drawings, they are drawn to large scale. This facilitates reading and provides information that cannot be given on elevation or plan views. Sections may be classified as typical and specific.

a. Typical Sections. Typical sections represent the average condition throughout a structure and are used when construction features are repeated many times. The wall section de-

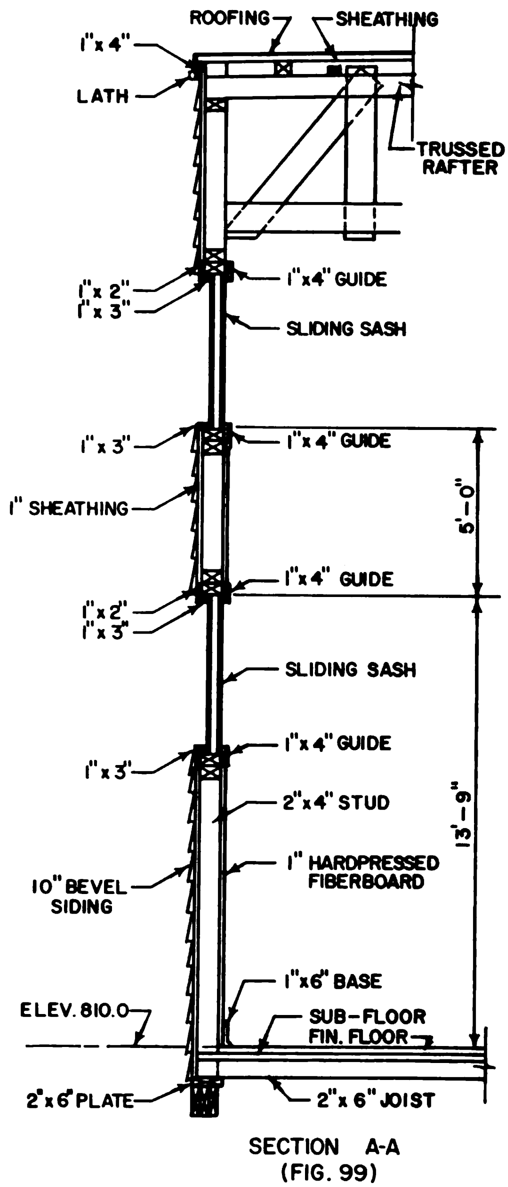


Figure 102. Typical wall section detail.

tail of the theater of operations recreation building shown in figure 102 is a typical section. It shows the construction details which are repeated at regular intervals throughout the building.

b. Specific Sections. When a particular construction feature occurs only once and is not shown clearly in the general drawing, a cutting-plane is passed through that portion (fig. 111); the cutting-plane indication is used and identified with the same letter at either arrowhead. These letters then become part of the title, for example, Section A–A. The cutting-plane line indicates the extent of the portion through which the section is taken. The arrows indicate the direction of viewing.

243. Details

Details are large-scale drawings showing the builders of a structure how its various parts are to be connected and placed. Details do not use a cutting-plane indication, but they are closely related to sections, in that sections are often used as parts of detail drawings. The construction at doors, windows, and eaves in customarily shown in detail drawings of buildings. Detail drawings are used whenever the information provided in elevations, plans, and sections is not clear enough for the mechanics on the job. They are usually grouped so that references may be made more easily from general drawings.

244. Drawing a Section

Drawing a section parallels the steps taken in constructing a building. Begin with the elevations of the foundation bed or gradeline and draw the structural members in sequence. Show the methods used in connecting members and make sure that all parts fit. The number of sections drawn influences the number of details needed for a set of drawings. In general, sectional views are preferable to details because they show various features in relation to the rest of the building.

a. Wall Sections. Wall sections (fig. 102) also are known as part sections because they are taken through a supporting wall only rather than through the entire building. Wall sections extent vertically from the foundation bed to the roof and are drawn to large scale ($\frac{3}{4}'' = 1'\text{-}0''$ is customary). They show the construction of the wall as well as the way in which structural members and other features are joined to it. Typical wall sections generally are drawn with the exterior face of the wall at the draftsman's left. Because of the large scale, wall sections employ breaklines frequently; the eliminated portions of wall contain no important connections of doors, windows, or structural members. A wall section can be thought of as a collection of details arranged in their proper relationship and separated by breaklines. Distances between finished floor lines are shown by dimensions. The cutting-plane indication may be staggered to include door and window openings in a single wall section, or several sections may be drawn.

b. Still Details. The soleplate, or sill, is the horizontal member on which the studs (vertical members) rest. The manner in which it is supported depends on the types of footings or foundations used in the construction of the building. Typical variations of sill details are illustrated in figure 103. They must not be confused with the sills shown in door and window details.

c. Girder and Joist Connections. Joists are connected to sills and girders by several methods. In modern construction, the method that requires the least time and labor and yet gives the maximum efficiency is used. The same rule is followed in the theater of operations. Figure 104 shows three constructions for girders and methods of supporting the inside ends of floor joists; outside ends of floor joists are supported as shown in figure 103.

d. Windows. Such a wide variety of windows are in use that it is not practical to attempt to show them here. A few contemporary types are: (1) casement, hinged at the sides to swing open, (2) slider, move sideways, and (3) double hung windows, which move up and down usually balanced with cast iron weights. A drawing of a wood sash with nomenclature of parts is illustrated in figure 105. Figure 106 shows the detail of a typical window for a TO building (fig. 99).

e. Doors. The heights of doors may vary by 2-inch increments from 6′-6″ to 8′-0″, but the usual height is 6′-8″; width may vary from 2′-0″ to 3′-0″, but the standard is 2′-8″. Sizes

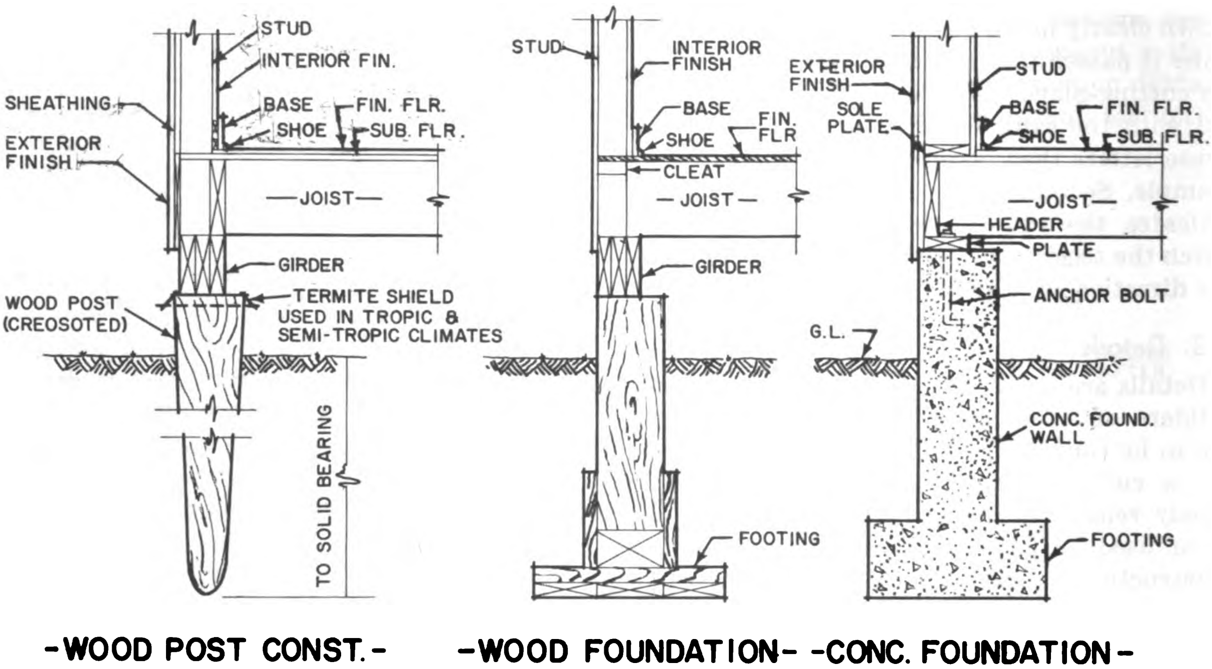


Figure 103. Typical sill details.

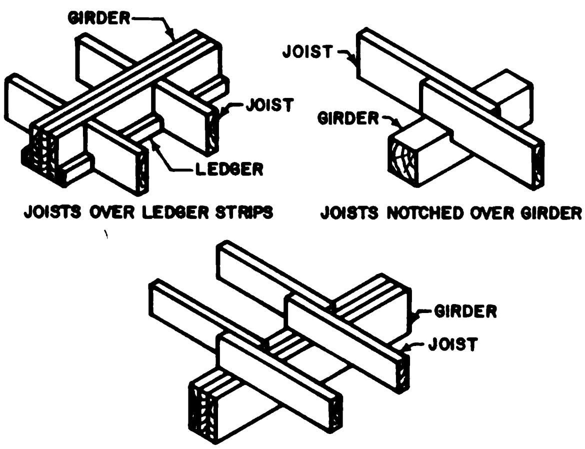


Figure 104. Girder and joist connections.

are indicated as width x height x thickness. An interior door with nomenclature of parts is shown in figure 107, and an exterior door is shown next to it. Figure 108 shows the detail of a typical door for a TO building (door 2D, fig. 99). Notice how figures 106 and 108 are titled and given a code (capital letter and number) in order that each detail can be identified on plan and elevation drawings (figs. 99 and 100). Also note that the scale of each detail is indicated with the detail subtitles.

f. Cornice Details. The usual roof-framing members are shown and named in figures 126 and 127. Rafter ends are inclosed with fascia boards or wooden cornices. Various methods of cornice construction are illustrated in figure 109.

g. Floor Detail. Floor detail shows short sections of wall above and below the floor and a small section of the floor to indicate the method

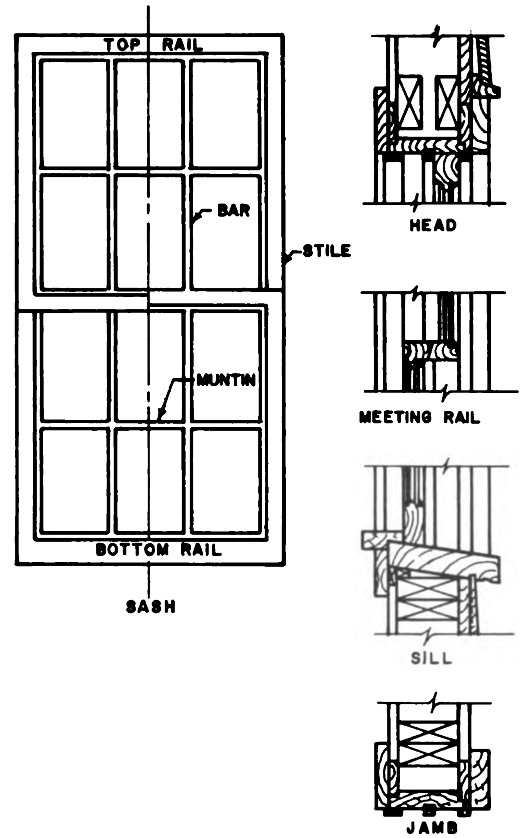


Figure 105. Typical wood sash detail.

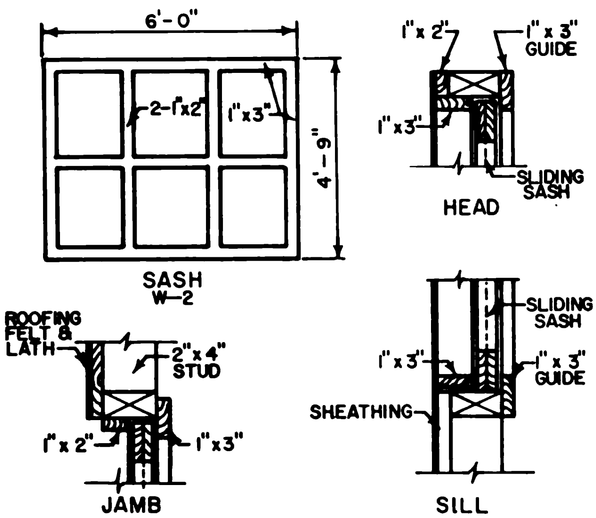


Figure 106. Detail of window W2 (see fig. 100).

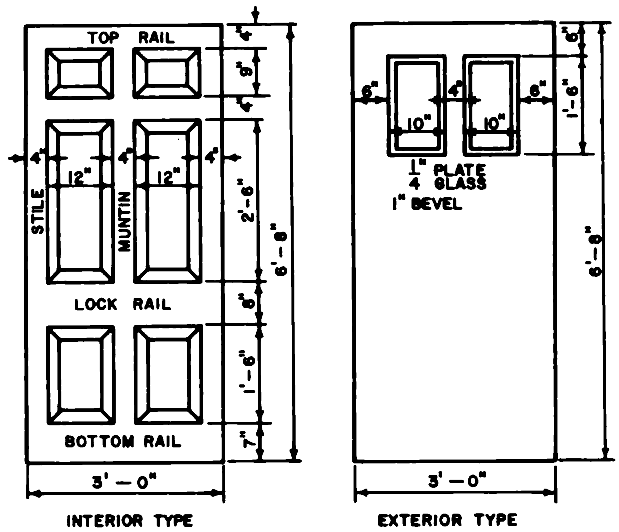


Figure 107. Doors.

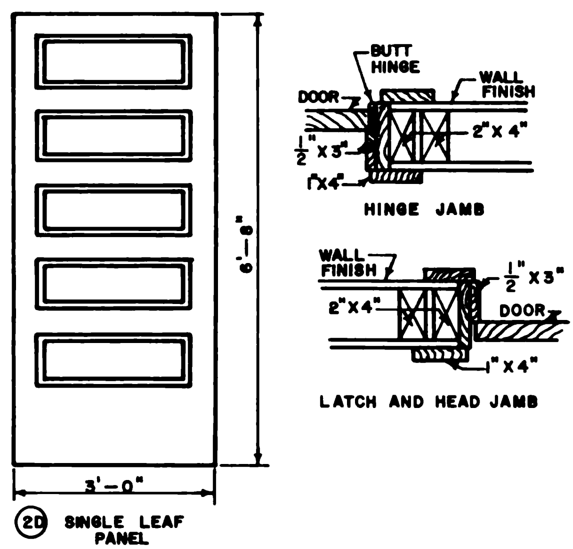


Figure 108. Detail of door 2D (see fig. 99).

of framing joists into the wall at that point. In addition, it shows the materials used for the ceiling below and the floor and walls above.

h. Thruogh (Cross) Sections. A through section shows the interior construction of a building. It is generally taken completely through the building, but, in the case of a symmetrical building, may be taken to the centerline. A through section can be prepared to the same scale as plan and elevation because its purpose is to show the relation of the interior members rather than to furnish detailed construction

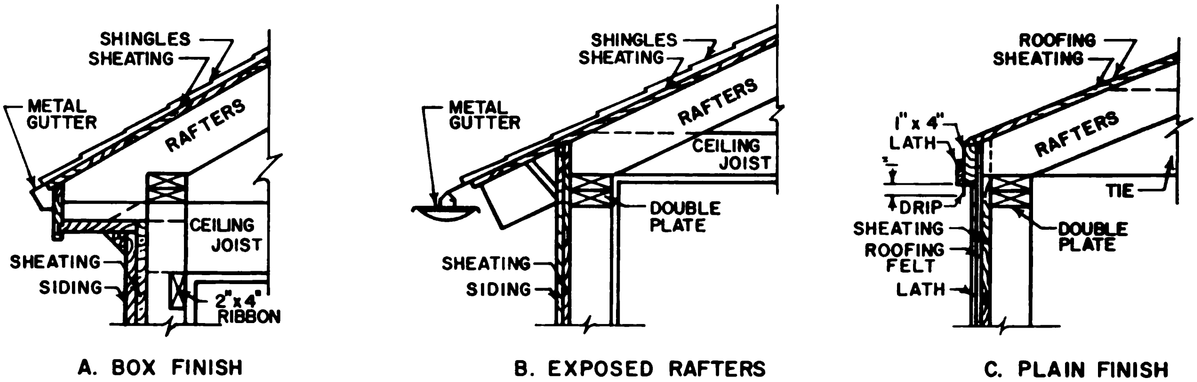


Figure 109. Cornice details.

information. A through section is laid out in the same way as an elevation. Section symbols for materials must be used.

i. Slope Diagram. The slope of the roof is shown by a triangular diagram that shows the ratio of vertical rise in inches per horizontal foot in inches (fig. 170). The hypotenuse of the triangle represents the slope of the roof. The slope diagram when used is always placed just above the roof.

245. Scale

Objects are drawn to scale to show proportions. Distances are never scaled from drawings. All size information must be shown by figured dimensions. Selection of scale is determined by the size of the structure as related to the size of the drawing sheet.

a. General Drawings. The scale most commonly used for general drawings is $\frac{1}{4}'' = 1'\text{-}0''$. Other scales frequently used are $1\frac{1}{16}'' = 1'\text{-}0''$ and $\frac{1}{8} = 1'\text{-}0''$.

b. Detail Drawings. Detail drawings of large features requiring routine construction are commonly prepared at scales of $\frac{1}{2}'' = 1'\text{-}0''$, $\frac{3}{4}'' = 1'\text{-}0''$, and $1\frac{1}{2}'' = 1'0''$. Detail drawings of small features requiring special construction may be drawn at quarter ($3'' = 1'\text{-}0''$) or half ($6'' = 1'\text{-}0''$) size.

c. Choice. Scales other than those listed above may be used by the draftsman if the clarity of a drawing is improved. In most cases, the above scales will be found satisfactory.

246. Symbols in Construction Drawings

Because of the small scale used in general drawings, draftsmen are forced to use the graphic shorthand of symbols to include all the factors needed to present complete information concerning construction items and materials. Occasionally, as with piping and heating drawings, a key or legend is provided to interpret certain line symbols. In most cases, however, no key is necessary. Typical symbols are used so frequently in construction drawing that their meaning must be familiar to those who prepare and read the drawings. Each symbol used for military construction drawing has its specific characteristic appearance and meaning. Appendix III shows the symbols used to indicate materials in section and exterior view, compiled from MIL–STD–1A. Appendix IV shows door and window symbols used to plan views, compiled from MIL–STD–14A.

a. Exterior Symbols. Exterior symbols are used in preparing elevations and are more pictorial than those used in plan views.

(1) *Walls.* The wood symbol is used only with exterior views of small objects drawn to large scale; the wood siding of a frame building is indicated by equally spaced, light horizontal lines. Brick and cinder blocks are drawn with horizontal and vertical lines spaced to approximate their size and appearance.

(2) *Doors and windows.* Doors and windows in elevation views are drawn accurately to scale.

b. Section Material Symbols. The material symbols for plans and sectional views are the same, the former being a horizontal and the latter a vertical section. Those symbols derive their characteristic appearance from the direction and spacing of lines, and are drawn with a T-square and triangle. The symbols for concrete, gravel, sand, and other materials composed of aggregate particles are drawn freehand, as is the symbol for wood in cross sections.

c. Plan Symbols. Plans are made up laregly of symbols which simply and compactly identify and locate the various parts of a building.

(1) *Walls.* Exterior walls and interior partitions are constructed from many different kinds of materials assembled in various ways. The basic wall symbol consists of two parallel lines. The distance between the lines is laid out to scale and represents the thickness of the wall or partition. The approximate material symbol is drawn in the space between the parallel lines.

(2) *Doors and windows.* Appendix IV gives plan symbols for several types of doors and windows set in walls constructed of different materials. A study of the door and window details in figures 106 and 108 discloses that these symbols are derived from the detail drawing of door and window construction. Door symbols show width of the opening, extent and direction of swing, and the type of door. Window symbols show the kind of window and its width.

(3) *Stairs.* Stair symbols (fig. 110) are drawn as if looking down vertically on a flight of stairs. The stringers are represented by two parallel lines spaced proportionally to the stairway width. The treads are formed by parallel lines drawn at right angles to the stringer lines, the number of spaces representing the number of treads. An arrow is drawn across the tread lines half the length of the run, or stair span. It is located midway between the stringer lines and labelled UP or DN to show the direction of the stairs from the floor depicted in the plan. UP and DN are preceded by a number giving the amount of risers in the run. For example, 17 DN followed by an arrow means that there are 17 risers in the run of stairs proceeding from the floor shown on the plan to the floor below in the direction indicated by the arrow. In drawing an inside stairway, a diagram (fig. 110) is made to determine the number of steps and space requirements. The standard for the riser, or height from step to step, is from 6½ to 7½ inches. The tread width is usually such that the sum of riser and tread approximate 17½ inches (A 7″ riser and 11″ tread is an accepted standard.) On the plan, the lines represent the edges of the risers and are drawn as far apart as the width of the tread. The handrail is represented by a line drawn parallel to the stringer indication. Notice how the scale may be used to divide the height (floor to floor) into the number of steps. For outside stairs or steps, as for a porch or platform, the risers and treads may vary from the above standard. The type of step most common in field construction is illustrated in figure 111.

(4) *Miscellaneous.* Specialized symbols are used to show circuits and equipment for plumbing (app. V), heating (app. VI), and electricity (app. VII).

247. Dimensioning Construction Drawings

a. Dimensioning. Plan views are dimensioned both outside and inside the building lines. Outside dimensions describe changes and openings in the exterior wall in addition to overall dimensions. Inside measurements locate partitions relative to each other and exterior walls. All horizontal dimensions are shown in a plan view. Dimensioning construction drawings differs in some applications from dimensioning general technical drawings, primarily because of the material sand methods of construction.

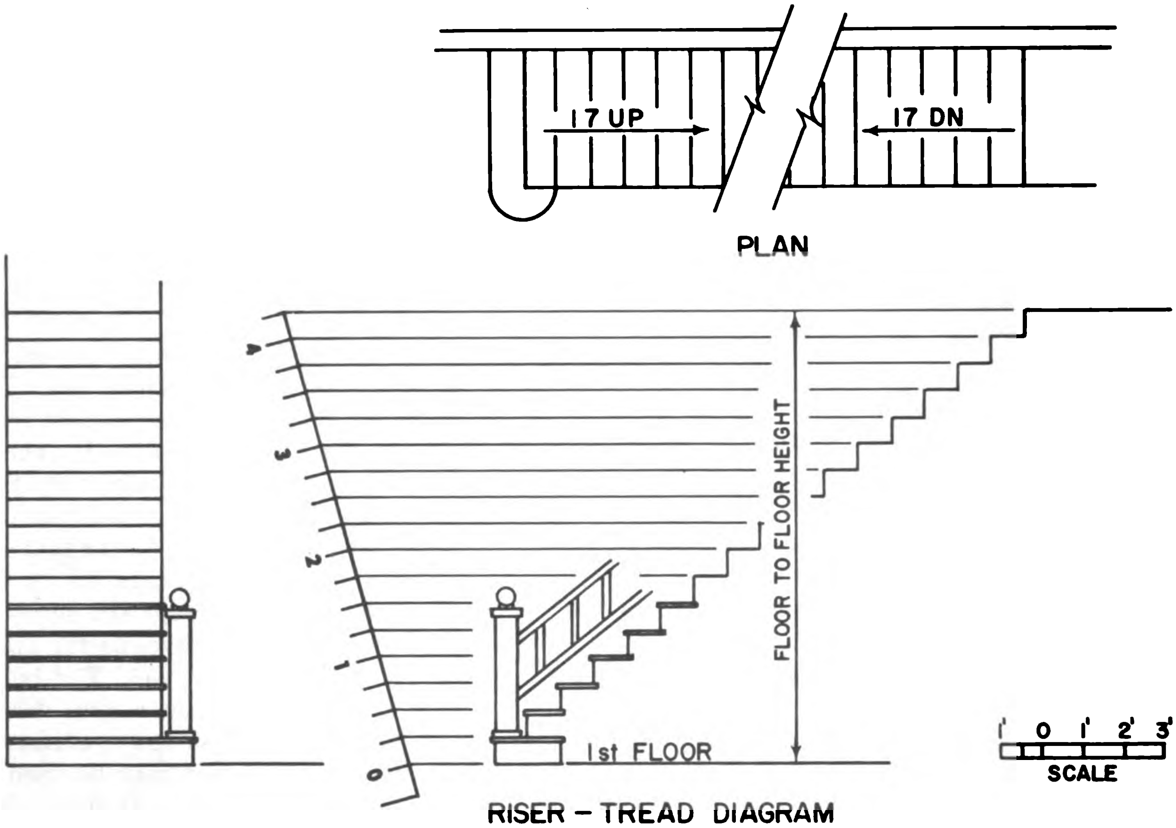


Figure 110. Stairways and steps.

(1) *Outside dimensions.* For wood frame construction, draw two continuous dimension lines on each side. Space the first line approximately 2 feet to scale from each exterior wall face or its farthest projection. Use the same scale as for the plan. Space the second dimension line 1 foot to scale from the first. Draw extension lines to the near dimension line from door and window centerlines, any exterior features that require dimensions, and the stud lines at each corner (fig. 112). Draw arrowheads where the extension lines intersect the near dimension lines and write the dimensions. The far dimension line gives overall dimensions of each side and represents the total of the string of dimensions on the near line. Extension lines are drawn to the outside line only from the building corners. Three dimension lines are required for exterior masonry walls. The near dimension line gives distances to wall openings for doors and windows, the middle line gives distances between door and window centerlines, and the dimension line farthest from the building gives overall dimensions.

(2) *Inside dimensions.* Inside dimension lines are drawn unbroken between the inside faces of building walls. One string of dimensions spans the inside width of the building, and a second spans its length. As shown in figures 99 and 112, dimensions are given to the centerline of wood frame partitions.

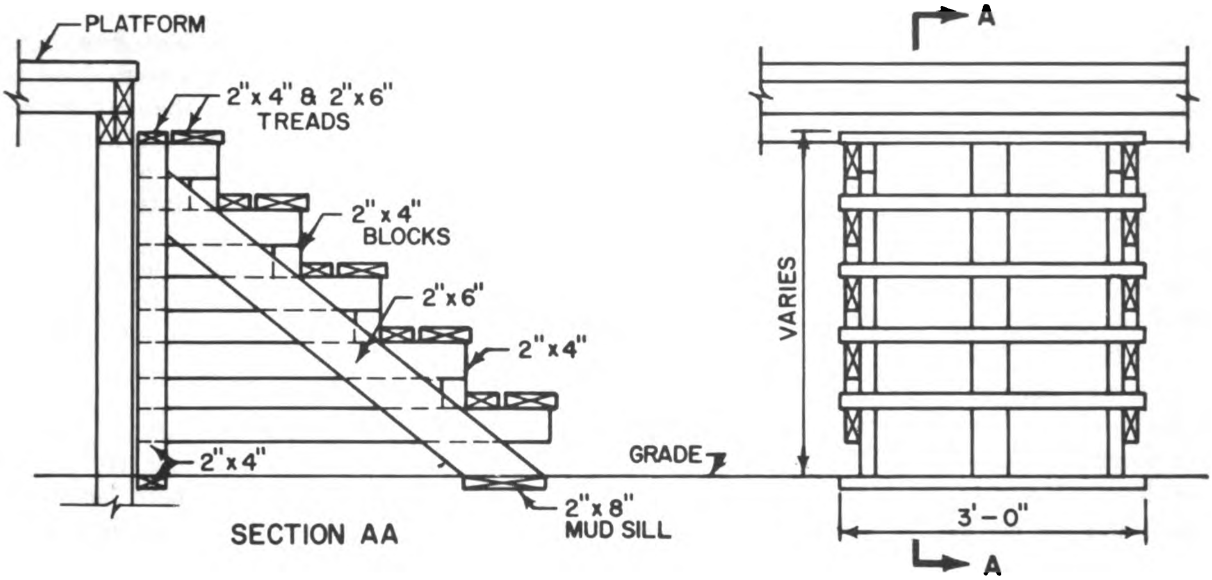


Figure 111. Outside steps.

b. Dimension Line. Dimension lines in construction drawings are unbroken from one extension line to another. This type of line is much easier and faster to make. An ordinary construction drawing contains numerous dimensions all in line and continuous, which saves considerable time.

c. Dimension Accuracy. Construction procedure does not involve fine measurements, and tolerancing is not a consideration. Often, as with lumber, the materials used in constructing are not accurate enough to obtain satisfactory placement by giving dimensions to the edge of the structural member. This difficulty is overcome by giving center-to-center dimensions. Thus, even if the dimensions of certain kinds of lumber vary considerably, their placement is constant. Dimensions are given to the centerlines of door and window openings, frame partitions, beams, and columns.

d. Writing Dimensions. Dimensions are given in feet and inches, with the exception noted below. Unit marks are used and the feet and inch numerals are separated by a hyphen. A typical construction drawing dimension is written 2′-7″. The following specific rules apply to placing dimensions for construction drawings other than steel drawings.

(1) *Fractions.* For indicating fractions of an inch alone, no zero is used, thus: ¼″.

(2) *Inches alone.* For indicating inches alone, no zero is used, thus: 5″.

(3) *Combinations.* For indicating inches in combination with fractions no zero is used, thus: 3⅛″.

(4) *Feet and inches.* For indicating feet and inches no zero is used, thus: 5′-9″.

(5) *Feet without inches.* For indicating feet without inches, a zero is used, thus: 6′-0″.

(6) *Feet and fractions.* For indcating feet and no inches with fractions of an inch a zero is used, thus: 4′-0⅜″.

(7) *Foot symbol.* For indicating 1 foot use 1′-0″, never 12″.

e. Placing Dimensions. Dimensions are placed slightly above the dimension line. The exact distance varies depending on the scale, size of lettering, and available space. For most conditions, one-fourth to one-half the lettering size is used. The figure should never be closer to another dimension line than to the line it represents. Lettering size is normally 1/8 inch. Guidelines should be used for drawing all figures.

f. Decimal Dimensions. Elevations are always given in decimals in construction drawings. These are vertical reference heights and are not to be confused with elevation views. They should be preceded by the abbreviation EL, thus: EL 810.0 (fig. 100). Decimals may also be written as 810<u>00</u>. The latter form is used when the loss of a decimal point might occur because of dirt or poor reproduction, as in field work. Elevations freqently noted are ground level, footing elevation, anchor bolt elevation, and the elevations of drainage lines.

g. Variations Cause by Materials. Figure 112 gives a few examples of variations in dimensioning practice caused by differences in materials and methods of construction. In addition, it presents dimensioning conventions for doors, windows, and walls. Note that concrete and solid brick walls are dimensioned to the outside corner because the structural material and the siding material are homogenous. In brick veneer and frame construction, structural materials are not integral with siding materials. Wall dimensions in a plan view are therefore given to the wood frame in brick veneer construction and to the studs in frame construction. All dimensioning in figure 112 is applicable to plan views only.

248. Notes in Construction Drawings

Notes in a construction drawing are classified as specific and general. Their lettering, size, location, and general preparation have

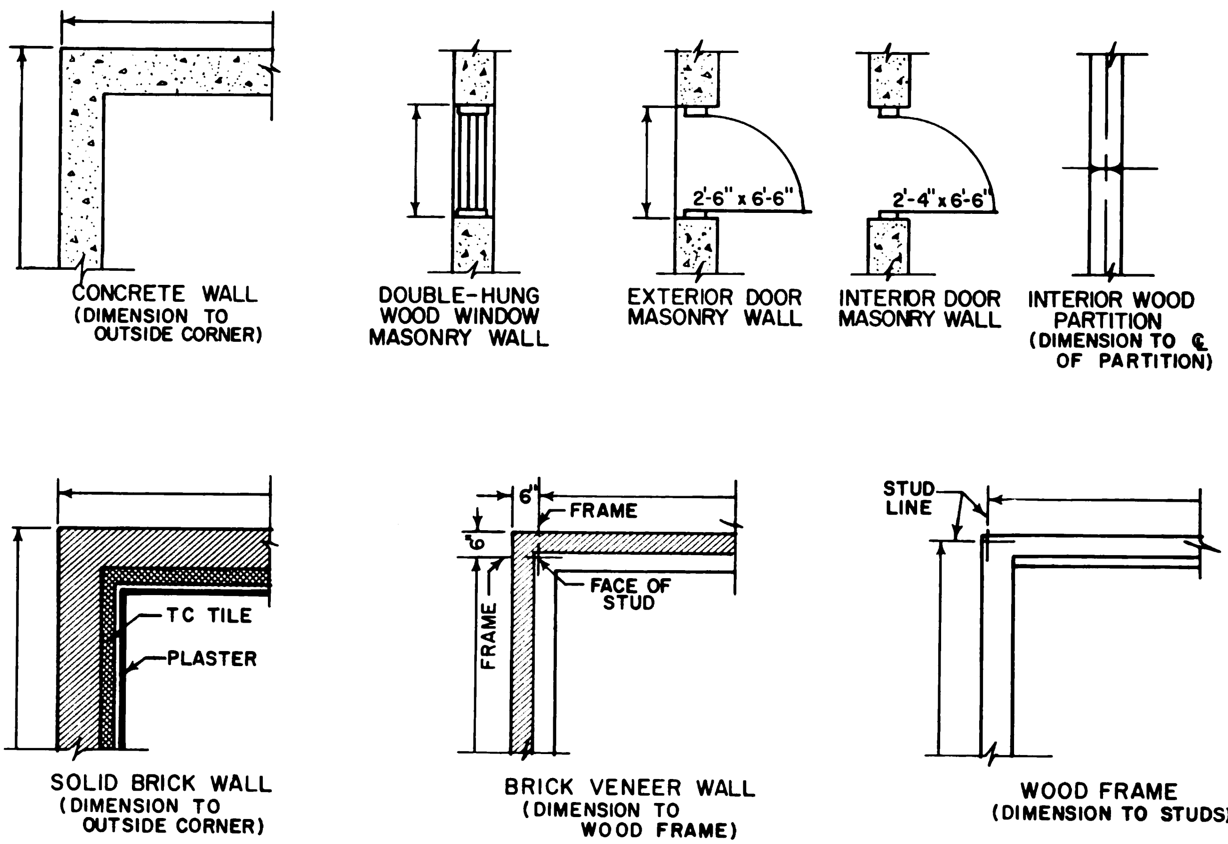


Figure 112. Masonry and frame conventions.

been described in Chapter 7. Briefly, notes are clear, explicit statements regarding material, construction, and finish. They are used so extensively that a separate compilation is made and referred to as specifications. These are written instructions, organized into a document, stating the manner in which work will be performed, designating what materials and finishes are to be used, and establishing the responsibility of the unit performing the work.

a. Specific Notes. Specific notes may be used either to augment dimensioning information or to be explanatory. When more than one line of explanatory notes is placed in a drawing, lowercase lettering is used. Titles and subtitles are always prepared in uppercase letters. Many of the terms frequently used for construction drawings are expressed as abbreviations, to save space.

b. General Notes. General notes usually are grouped according to materials of construction in a tabular form called a schedule. As used in this manual, the category, General Notes, refers to all notes on the drawing not accompanied by a leader and arrowhead. Item schedules for doors, rooms, footings, and so on, are more detailed. Typical door and window schedule formats are presented below.

(1) *Door schedule.* The doors shown by symbol in a plan view may be identified as to size, type, and style with code numbers placed next to each symbol (figs. 99 and 100). This code number, or mark, is then entered on a line in a door schedule and the principal characteristics of the door are entered in successive columns along the line. The No. column allows a quantity check on doors of the same design as well as the total number of doors required. By using a number with a letter, the mark can serve a double purpose: the number identifies the floor on which the door is located, and the letter identifies the door designwise. Mark 1–D would mean door style D on the first floor. The sequence of writing door sizes is width x height x thickness. The description column allows identification by type (panel, flush), style, and material. The remarks column allows reference to the appropriate detail drawing. The schedule is a convenient way of presenting pertinent data without making mechanics and builders refer to the specifications.

Door schedule

No.	Mark	Size	Description	Remarks
6	1–D	5 x 7	Flush	Double door hinged
9	2–D	2½ x 7	Panel	Single door hinged

(2) *Window schedule.* A window schedule is similar to a door schedule for providing an organized presentation of the significant window characteristics. The code mark (fig. 100) used in the schedule is placed next to the window symbol that applies on the plan view.

Window schedule

No.	Mark	Size	Description	Remarks
16	W–1	5 x 9	Double Hung	Slide from bottom to top and top to bottom.
12	W–2	4 x 7	Casement	Hinged at top.

249. Specifications in Construction Drawings

Although it is not a draftsmen's responsibility to prepare specifications, for two outstanding reasons he should be familiar with them: specifications give detailed instructions regarding materials and methods of work and constitute and important source of pertinent information for the set of drawings; and a draftsman experienced in preparing construction drawings can be of assistance to the specifications writer. Specifications should be written with clear, concise statements. The use of vague statements, such as " . . . the material specified or its equivalent . . . ", should be avoided by stating first and second choices for substitute materials.

a. General Conditions. Every list of specifications begins with a statement of general conditions, which are routine declarations of responsibility and conditions to be adhered to on the job. These often are prepared in printed form and used for all construction work falling within a general category.

b. Specific Conditions. A construction job is classified by phases, each phase related to a particular material or operation. A separate specification is written for each phase of a particular job, and these are compiled to parallel the job sequence of the phases. A phase specification establishes the following in the order stated: general conditions, scope of work, quality and inspection of materials, conditions of workmanship, kinds of equipment, delivery and storage of materials, and protection of finished work.

250. Bill of Material in Construction Drawings

A bill of material is a tabulated statement of requirements for a given project that shows the item number, name, description, quantity, material, stock size, number, and, sometimes, the weight of each piece.

a. Materials Takeoff. Bills of material are sometimes called materials estimate sheets or materials takeoff sheets. Actually, a bill of material is a grouped compilation based on takeoffs and estimates of all material needed to complete a structure. The takeoff usually is an actual tally and checkoff of the items shown, noted, or specified on the construction drawings and specifications. The estimated quantities are those known to be necessary but which may not have been placed on the drawings, such as nails, cement, concrete-form lumber and tie wire, temporary bracing or scaffold lumber, and so on. These are calculated from a knowledge of construction methods that will be used for field erection.

b. Tally Sheets. Draftsmen use tally sheets to list the material and record the quantities as each item is drawn. A series of tally sheets is required for each material, depending on the complexity of the classification. When a series of tally sheets is prepared for an electrical takeoff, *for example,* one sheet lists the kinds and sizes of conduit, another the kinds and sizes of wire, a third the outlets and fittings. The quantities of each are tallied next to the appropriate classification as they are drawn and noted.

c. Quantities. Bulk quantities classified by cubic measurement, such as concrete and earth, may be calculated after the drawing has been completed. Draftsmen will find that facility with a slide rule is an aid in performing rapid calculations of this kind. When a set of drawings has been completed, quantities are totaled and the various types are regrouped by sizes beginning with the smallest and progressing to the largest.

d. Tabulation. The tabulation should include headings for each item, including: (a) item number; (b) item description; (c) unit of measure; and (d) quantity.

e. Final Tabulation. The final tabulation of material is by type under appropriate subheadings: frame, roof, cladding, miscellaneous, and hardware.

f. Wastage Estimates. Wastage estimates also are made to allow for field breakage, waste, transit damage, and construction losses. Breakage allowances usually are taken as a percentage of the final grouped item summaries and are shown in the material type quantity columns before the grand totals. Wastage percentages vary with the classification of material under consideration and generally are based on past experience, anticipated field conditions, and calculated shipment risks.

g. Sample Bill of Material. A partial bill of material for a single structure is given in figure 113 in which items needed for the construction of a standard frame building are tabulated for the preparation of the necessary requisitions.

251. Nominal and Actual Sizes

The sizes given in specific notes for structural members shown in figure 127 are called nominal sizes. The actual size of a joist 2 inches thick by 6 inches wide is 1⅝ x 5⅝ inches. The difference in dimensions is caused by material lost in finishing or surfacing the piece of lumber. Nominal sizes are always used to identify a piece in notes, specifications, and bills of material. In preparing any drawing at a scale of ½″ = 1′-0″ or larger, the actual sizes are drawn to scale. For drawings prepared at a smaller scale, nominal sizes are used. The actual sizes of wood (ch. 12), steel shapes (ch. 14), and masonry units (ch. 11) such as brick and cinder block differ from their nominal sizes.

Figure 113. Bill of materials.
(Located in back of manual)

252. TM 5–302

By this time, student draftsmen should have some appreciation of the variety of materials and methods used in construction, and should realize that the complete information required for a set of drawings needs extensive reference material. Particularly in the preparation of detail drawings, graphic reference data, rather than written information, is necessary. To a large extent, TM 5–302, *Construction In The Theater of Operations*, fills a military draftsmans need for such graphic reference material.

a. Scope. Besides graphic examples of construction requirements, TM 5–302 provides guidance for design, layout, and construction of installations (a balanced grouping of facilities designed to be located in the same vicinity), facilities (a grouping of items and/or set in the necessary quantities required to provide a specific service), and individual buildings.

b. Use of TM 5–302. Many theater of operations buildings have the same details of construction, which can be divided into standard details, special details, and standard wood frame building details. The relation of the details to the use of the manual is discussed below.

c. Standard Details. Standard details are those which are common to two or more facilities. They are identified by a code consisting of a number followed by single or double capital letters and are shown in separate drawings from the facilities to which they pertain. This makes it unnecessary to show a particular detail on every facility drawing to which it pertains. All standard details pertaining to a particular facility group are shown on one series of drawings. These drawings are identified by the two-digit number "98" which appears as the last two digits of the four-digit drawing number. *For example:* Drawing No. 59–98 (22 sheets) shows all standard details pertaining to hospital and medical facilities, and Drawing No. 13–98 (4 sheets) shows all standard details pertaining to communication facilities. A drawing of a standard detail may appear a number of times in TM 5–302, dependent upon its usage with different facilities groups. An index of all standard details is provided.

d. Special Details. Special details are those which pertain to a single facility or to a group of similar facilities. They are identified by a code consisting of a letter followed by a number or by the words "Detail No. ________" and are shown on the same drawing with the facility, or on separate drawings immediately following the group of facilities to which they pertain. Drawings showing the special details pertaining to a particular group of facilities are numbered in sequence with the drawings of the facilities. *For example:* Drawing No. 13–22 (2 sheets) shows all special details pertaining to Radio Receiver and Transmitter Building Facilities, and Drawing No. 13–41 (2 sheets) shows all special details pertaining to Standard Wood Frame Airfield Control Tower Facilities. A drawing of a special detail appears only once in TM 5–302. Such drawings may be located by referring to the facility index; referring to the table on the drawing titled "Schedule of Drawings," which is shown next to the title block of the respective drawing sheet; title of the sheet in question under "Special Details."

253. Site Selection

Before making the final selection of a site for housing or storage of supply, it is necessary to consider probable future needs, terrain, transportation facilities, provision for utilities, and proximity to other military installations.

a. Preliminary Planning. It is frequently possible to base preliminary drawings on information from maps, photographs, aerial reconnaissance, and personal familiarity with the area. Ground reconnaissance, however, should be made whenever practicable because it is the most reliable method of determining the suitability of a site. The basic features of a site are classified either as "required" or "desirable," depending on the type of project and size of the installation. Because a site cannot be used if it does not have "required" features, they must be given first consideration.

b. Major Considerations. The following factors influence the selection of a site and should be included in the ground reconnaissance reports and sketches presented to the draftsman.

(1) *Transportation facilities.* If a project requires access to transportation facilities, selection of a site adjacent or close to such facilities results in a saving of labor, material, and time.

(2) *Terrain.* Selection of a site with terrain requiring a minimum of grading becomes more important as the size of the area to be covered by the project increases. Relatively flat, well-drained terrain requires only a small expenditure in labor, material, and time for grading.

(3) *Soil.* For major depots and large troop housing projects, stable, easily drained soil is particularly desirable. If soil conditions are unfavorable, some type of surfacing is necessary for the storage of equipment or the continual use of areas by troops.

(4) *Protective concealment.* It takes much more time to camouflage a nondispersed area than to develop a site where dispersion of supplies and structures is relatively easy. The following items are some of the things to remember when selecting a site.

(*a*) *Landmarks.* Sites should be avoided near landmarks such as; bends of rivers, points of land, and road and railroad intersections.

(*b*) *Boundary lines.* A site should have irregular boundary lines formed by natural features such as roads, streams, and hedgerows.

(*c*) *Concealment.* Barren sites are poor from the standpoint of camouflage. A wooded site should be selected for concealment of buildings.

(*d*) *Hills or mountains.* The approach of hostile planes can be limited when a site is surrounded by, or adjacent to, sharply rising hills or mountains.

(5) *Water.* A water supply that is either initially potable or can be made so by ordinary chlorination and filtration is a prerequisite for large group housing and hospital projects.

(6) *Sewage disposal.* If the site requires waterborne sewage, a suitable outlet for the sewers must be considered. If the project utilizes pit latrines, it is necessary to have open soil draining away from any source of existing or proposed water supply.

(7) *Electric power.* Sites for projects requiring electric power should be located near commercial electric power lines from which 50- or 60-cycle alternating current is available. This usually is obtainable only in rear areas. Facilities requiring power in forward areas usually must depend on portable generator sets.

(8) *Proximity to other military installations.* Dispersion of sites must not be carried so far as to interfere with the efficient operation of a project. A general depot, for example, may have to be set up at the point on a main line where turnouts to dispersed areas are installed. Ammunition and fuel storage sites should be located far enough from the depot so that if they are bombed other services will not be interrupted.

(9) *Expansion.* A reasonable degree of expansion should be allowed for in projects, and the areas chosen should be large enough to make this possible.

(10) *Available existing facilities.* Choosing a site where essential requirements exist results in a saving of material, transportation, labor, and time.

254. Locating Boundary Lines

The perimeter of any site is formed by a series of connected imaginary lines, each line extending a definite distance is a specific direction. Measurement of these distances and directions in the field is called running a traverse. Traverses usually are run by a survey party using a transit to determine direction and a 100-foot tape to determine distance. (Rough traverses can be run by substituting a compass for a transit. When the survey returns to its original starting point after following the boundary lines in sequence, thus forming a closed figure, it is called a closed traverse.)

a. Running a Traverse. In running a traverse, the transit is set up over a corner, sighted along a known traverse line and an angle turned with the transit to establish or measure the direction of the connecting traverse line. The terminal points of traverse lines are called corners. A corner may be indicated in the field by a stake, pipe, or spike driven into the ground, a tack in a tree stump, a chisel mark on an embedded rock, or some other appropriate method. Such a mark is required whenever a traverse line changes direction. Two corners establish the length and direction of a traverse line.

b. Measuring Traverse Angles. Traverse angles are commonly indicated in field notes as interior or deflection angles and/or bearings.

(1) *Interior angles.* An interior angle is swung through the inside of the closed figure formed by the traverse lines. It may be greater than 180°, depending on the directions of the connecting lines.

(2) *Deflection angle.* A deflection angle is the angular distance between a line representing a continuation of a traverse line and the connecting traverse line. In other words, a deflection angle is the difference between the interior angle and 180°. Deflection angles are turned either to the right or left and are marked in the field notes as so many degrees R or L.

(3) *Bearings.* Interior and deflection angles express the direction of a traverse line relative to its connecting line. A bearing gives the direction of a line relative to a meridian. For example, a bearing is written N 76 E. If the northpointing arrow in the drawing points toward the top of the drawing sheet, this bearing means that the traverse line is drawn from its starting point (corner) toward the right (east) and makes an angle of 76° with any line parallel to the northpointing arrow.

c. Measuring Distances. Distance measurements do not take into consideration the irregularities of terrain. The tape is always held horizontally and all distances written in a plan view express a horizontal measurement between two points. The distance between the top and bottom of a slope that appears in field notes represents the sum of a series of horizontal measurements. The slant height of the slope is calculated as the hypotenuse of a triangle from a knowledge of the elevations at top and bottom (vertical distance) and the horizontal distance between these points. The use of horizontal distances only in a plan view is consistent with the principles of orthographic projection. Distances are written decimally in field notes because the 100-foot tape is divided into feet and decimal subdivisions thereof.

255. Measuring Elevations

In ground reconnaissance, elevations usually are measured with the aid of a surveying instrument called a level, which is used to establish ground heights relative to a reference elevation called a bench mark.

a. Bench Mark. A bench mark is given either an arbitrary elevation or an elevation in relation to some common datum. Elevations, bench marks, and contours shown on standard maps refer to mean sea level, which is considered zero. When indicated in a drawing, a bench mark is indicated by a symbol, a written elevation, and the abbreviation B.M. A note may be used to identify the symbol as a stake, geodetic monument, or other marker.

b. Contour Lines. Contour lines can be pictured best by imagining a cone-shaped hill with the sides fluted or otherwise irregular. If a horizontal cutting plane is passed through the hill, the outline of the section thus exposed forms a closed figure with an irregularly shaped perimeter. Because the cutting plane is horizontal, all points on the perimeter are at the same elevation. Outlines of horizontal sections taken at different elevations will show figures of different size and shape. In all cases the height taken at any point on the perimeter of the figure is equal to the height taken at any other point on the perimeter of the same figure. A contour forms a closed figure either within or beyond the limits of the drawing sheet. Any point on a contour has the same elevation as any other point.

c. Laying Out a Grid to Measure Contours. The usual method of establishing contours is to run a series of parallel transit lines spaced at equal intervals. Nails or other markers are used to establish the terminal points of each line. Markers are also placed at equal intervals along the lines between the terminal points. The effect is to create a grid or rectangular coordinate framework. Each point may be given a unique designation by numbering the lines progressing in one direction and lettering the lines progressing in the other. Ground elevation is taken at each point and recorded in the field notes.

256. Locating Physical Details

a. Grid. Existing physical details lying within the boundaries of a construction site may be located easily by using the grid that was laid out to establish contours. As in the construction of a graph, points on a grid are located by their rectangular coordinates. This involves only a distance measured perpendicularly to a reference line and establishes the two coordinates of the point. When laid out, a grid provides convenient reference lines for measuring horizontal linear distances both before and during construction. As described in paragraph 72*b*, a grid system laid out for locating construction points is called a local grid.

b. Traverse Lines. The location of the physical details relative to traverse lines may be indicated in field notes by one of the following methods.

(1) *Perpendicular offsets.* This method is useful in locating roads, streams, or utilities lines running adjacent to a traverse line. At measured intervals along the traverse line and the perpendicular distance between the traverse line and adjacent detail, the measured intervals are related to convenient reference points, such as corners, called stations. The measurements to the detail from successive stations are called perpendicular offsets.

(2) *Ties.* A horizontal linear measurement from a known point to a point whose location is unknown is called a tie. A point may be located by ties from two known points.

(3) *Polar coordinates.* A point located by an angle and a distance from a known point.

257. Plotting Site Plan Data

A site plan is drawn by plotting the survey data contained in field notes and sketches.

a. Boundary Lines.

(1) *Tools.* A protractor and engineer's scale are the only measuring tools needed for plotting angles and distances. A pencil, triangle, and straightedge are the necessary basic drawing tools.

(2) *Drawing boundary lines.* First draw a rough sketch of the traverse to scale, which will give an idea of the relative lengths of the traverse lines. Select a scale suitable to the size of the area being represented and the amount of detail shown. Using the sketch as a guide, draw the first line of the traverse so that the other traverse lines will lie on the drawing sheet. Use the scale to mark the two extremities at the first line and allow the line to extend beyond the angle points just marked. Place the vertex mark of the protractor on the angle point with the 0° and 180° marks on the line just drawn. Lay off the angle corresponding to the traverse angle at this point, and line up the straightedge along the corner point and the point just marked. Draw the connecting traverse line, scale the length of the second line, and repeat the process just described until all traverse lines have been drawn. If a traverse is a closed traverse, the boundary lines of the site plan should close on paper. If the plot does not close, check the scale and protractor measurements against the distances and angles given in the field notes. Make sure that angles are drawn in a direction corresponding to the direction that they were turned in the field. Cumulative angular errors can be avoided by plotting half of the traverse from one end of the starting line and the other half from the other end.

b. Contour Lines. Drawing contour lines in a plan view permits the three principal dimensions, height, width, and depth, to be shown in a single view.

(1) *Plotting contour points.* On the drawing sheet, construct to scale the grid used in the field notes, using a pencil (4H) and drawing the lines lightly. Mark the elevations at the intersec-

tions of the grid lines and interpolate, by eye, and mark points where the elevations approximate a multiple of 10. *For example*, if the elevation at an intersection is 105 and at intersection vertically above it is 115, mark a point midway between on the vertical gridline connecting the two intersections. This point represents an elevation of 110. Locate all elevations representing a multiple of 10 in the same manner; if there is little variatoin in elevation, a smaller interval than 10 may be used. In a plan drawn to small scale, representing a large area with steep contours, an interval larger than 10 may be used to avoid crowding the drawing with contour lines.

(2) *Drawing contour lines.* All points on a contour have the same elevation and should form a closed figure if they lie on the drawing sheet. Connect all points of the same elevation freehand so they form a closed figure or extend to the site boundary lines. Contour lines should be unbroken except at one point to allow the elevation to be written. Every fifth contour line should be heavier.

(*a*) *Elevations.* Elevations are written as simple figures without any unit indications. When possible, they should be alined so that the elevations of the contours may be read at a glance.

(*b*) *Inking.* When inking contours on tracing paper or cloth, use a fine freehand pen, such as Gillott's 170 or Esterbrook's 356.

c. Plotting Details. Details are located in the site plane by methods of measurement corresponding to those used in the field.

(1) *Locating details from traverse lines.* When points have been located in the field by ties (par. 256 *b*(1)), a large compass may be used to swing arcs from the points on the drawing sheet to represent those used in the field. The radius of each arc corresponds to a tie distance. Perpendicular offset and polar coordinate methods are repeated, with distances measured to scale and angles measured with a protractor.

(2) *Grid.* Gridlines and measurements are reproduced to scale on the drawing sheet.

(3) *Symbols.* Topographic details are represented by symbols showing physical features such as water surfaces, soil composition, limits of cultivation, roads, fences, and buildings in their proper relative locations. Figure 114 presents soil symbols used to indicate soil composition in a site plan. Buildings are represented by a single-line plan view showing the shape of their exterior walls. Other topographic symbols can be found in FM 21–31. Topographic drafting is covered in detail in TM 5–240.

d. Notes and Dimensions. Each boundary line is identified by a distance and bearing written parallel to the line. A northpointing arrow is placed on the drawing. Utility lines, buildings, roads, and streams are identified by name in specific notes. The scale is written in the title box. Distances are given between principal details and reference lines.

e. Area Layout. Figure 97 shows a typical layout. Note the rectangular arrangement constituting a grid. The coordinate reference lines in this case are the centerlines of the roads surrounding the area.

f. Drawing Area Layout. Road centerlines are drawn first. Note that all dimensions are location dimensions and related to the main reference lines. Buildings are diagrammatic; no architectural symbols are used. Size dimensions and building types are given in the schedule at the foot of the drawing. Buildings are located first, then drawn to scale.

(1) *Roads.* Road centerlines are not indicated in the finished drawing. Roads are indicated by parallel lines; the distance between them includes the distance between them includes ditches, shoulders, and travelways. With given radii, curves at perpendicular intersections can be drawn as demonstrated in 2, figure 42.

MAJOR DIVISIONS 1	2	LETTER 3	SYMBOL HATCHING 4	SYMBOL COLOR 5	NAME 6
COURSE GRAINED SOILS	GRAVELS AND GRAVELLY SOILS	GW		RED	GRAVEL OR SANDY GRAVEL WELL GRADED
		GP			GRAVEL OR SANDY GRAVEL POORLY GRADED
		GM		YELLOW	SILTY GRAVEL OR SILTY SANDY GRAVEL
		GC			CLAYEY GRAVEL OR CLAYEY SANDY GRAVEL
	SANDS AND SANDY SOILS	SW		RED	SAND OR GRAVELLY SAND WELL GRADED
		SP			SAND OR GRAVELLY SAND POORLY GRADED
		SM		YELLOW	SILTY SAND OR SILTY GRAVELLY SAND
		SC			CLAYEY SAND OR CLAYEY GRAVELLY SAND
FINE GRAINED SOILS	SILT AND CLAY SOILS (LOW LIQUID LIMIT)	ML		GREEN	SILTS, SANDY SILTS, GRAVELLY SILTS, OR DIATOMACEOUS SOILS
		CL			LEAN CLAYS, SANDY CLAYS, OR GRAVELLY CLAYS
		OL			ORGANIC SILTS OR LEAN ORGANIC CLAYS
	SILT AND CLAY SOILS (HIGH LIQUID LIMIT)	MH		BLUE	MICACEOUS SILTS, DIATOMACEOUS SOILS, OR ELASTIC SILTS
		CH			FAT CLAYS
		OH			FAT ORGANIC CLAYS
FIBROUS ORGANIC SOILS		Pt		ORANGE	PEAT, HUMUS, AND OTHER ORGANIC SWAMP SOILS

Figure 114. Soil symbols.

(2) *Buildings.* Each building is given a code letter (fig. 97) by which it can be identified in the schedule. This prevents cluttering the drawing area with dimension lines and figures in a drawing made to small scale and involving many buildings of standard construction.

g. Area Layout and Site Plan. When locating an area layout in a site plan, the area layout must be oriented with northpointing arrows to distinguish site north from magnetic north; figure 97 gives an example. Physical details such as contours, streams, and railroads are included in the drawing.

258. Grading

Grading is the process of removing or lessening the irregularities of ground by cutting off high spots and filling in low places. At theater of operations construction sites, extensive grading is avoided because it destroys natural camouflage and is time consuming. The roads that service a construction site, however, must be built within definite limits of grade and alinement. Whether for roads or construction areas, the principles of grading are the same; a quantity of earth must be moved by machinery in an organized manner to achieve a required elevation, shape, and smoothness. How large a quantity of earth, its distribution, the elevation of the finished grade, and other related decisions are reached after a study of elevation views of the site under construction. These views are called profiles and cross sections; they show horizontal and vertical dimensions and are plotted from field data compiled by survey groups. Horizontal dimensions are obtained from transit and tape measurements and are plotted in a plan view as described for traverse lines. The information in this paragraph pertains to roads, but, with slight modifications, can be applied to any grading or earthmoving operation.

259. Grading Definitions

The following definitions will familiarize draftsmen with grading terms and operations.

a. Horizontal. The precise location and direction given to the horizontal centerline of a road; it is determined by the act or process of setting in line (alining) two or more points or elements.

b. Backfill. Material used in filling around and over culverts and similar structures.

c. Base Course. The course or combined courses of specially selected soils, treated soils, or aggregates placed and compacted on the subgrade to increase the wheel-load capacity.

d. Borrow. The material obtained from an area lying outside the construction area to complete a section of fill or embankment.

e. Cut. A cut may be defined as: (a) the difference in elevation between a point on the original ground, or on a stake, and a designated point of lower elevation on the final grade; (b) an excavation through which a road passes below the original ground level; and (c) the material removed in excavating (also called excavation).

f. Fill. Fill may be defined as: (a) the difference in elevation between a point on the original ground, or on a stake, and a designated point of higher elevation on the final grade; (b) the bank of earth, rock, or other material placed above the natural surface of the ground, or on top of the stripped surface, to support a road or similar structure (also called an embankment); (c) the space occupied by the bank defined in (b) above; and (d) the material used to form the bank defined in (b) above.

g. Grade. The rate of ascent or descent of a road. The amount usually is designated in percentage. A 10 percent grade is one that goes up or down 10 feet vertically for every 100 feet horizontally.

h. Station. When a line is measured continuously from one end to the other, as the centerline of a road, the starting point is considered station 0 + 00. Succeeding 100-foot intervals are called full stations and are written as 1 + 00, 2 + 00, and so on. An interval falling between 2 full stations, such as 176.2, is written 1 + 76.2. Any station expresses a continuous horizontal to that point from the starting point measured along the centerline.

i. Slopes and Slope Ratio.

(1) *Fore slope.* The incline extending downward from the center edge of the shoulder to the ditch line (also known as the fill slope).

(2) *Back slope.* The incline extending up-

ward from the ditch to the natural ground surface (also known as the cut slope).

(3) *Side slope.* Inclination or slope of the sides of cuts and fills.

(4) *Slope ratio.* A term expressed in ratio of horizontal distance to vertical rise. Thus, a slope of 3:1 is one in which the side diverges from the horizontal at a rate of 1 foot measured vertically for every 3 feet measured horizontally.

j. Subgrade. Subgrade applies either to the natural soil in place or to fill material on which a base or pavement is to be constructed.

k. Waste. Unsuitable material that must be removed to obtain a satisfactory job.

260. Profile

After the survey with tape and transit to establish the horizontal alinement of the road centerline, an elevation survey is run over the proposed road centerline to establish points of known ground elevation and location. The notes from this survey are used to plot a profile for the proposed road.

a. Definition. A profile is the line formed by the intersection of a longitudinal vetrical section with the original ground surface or finished subgrade. A profile usually is the centerline of the original ground surface or finished subgrade, but it can be any other line that may be desired, such as a shoulder line. Unless otherwise specified, the term profile implies centerline profile of the original ground.

b. Leveling.

(1) *Equipment.* The field procedure of running a line of levels involves use of an engineering level and a level rod. The engineering level is a telescope, mounted on a tripod, that serves the dual purpose of fixing the line of sight and magnifying the apparent size of objects in the field of view. The telescope can be adjusted with a ball-and-socket joint and adjusting screws so that the optical axis lies in a horizontal plane. The rod is nothing more than a wooden rod scaled to hundredths of a foot.

(2) *Procedure.* To obtain the elevation of a point, the level is set up in a location where readings can be taken on both the unknown point and a point of known elevation. Suppose the point of known elevation is a bench mark (BM) with an elevation of 130.4. The rodman sets the rod atop the BM and holds it vertically. The man at the level takes a backsight (BS), reading the mark on the rod where the horizontal crosshair intersects the rod. This establishes the elevation of the horizontal crosshair and is known as the height of the instrument (*HI*). If the rod reading is 4.2, the *HI* is 134.6. The *HI* remains the same so long as the level remains in the same place and the telescope remains in an undisturbed horizontal plane. The elevation of the unknown point is obtained by reading the rod held vertically atop the unknown point. The rod reading indicates the vertical distance of the unknown point below the horizontal crosshair. If the crosshair intersects the rod at 3.1, the elevation of the unknown point is 131.5. The unknown point now becomes a point of known elevation and may be used to carry the line of levels further along the centerline. When the terrain is too rough or the sights become too long, intermediate points called turning points (*TP*) must be established. These points serve the purpose of establishing a point of known elevation until the instrument can be moved forward and a new *HI* established. As soon as the *HI* is determined the *TP*'s are abandoned and forgotten.

(3) *Notes.* Field notes are arranged in columns titled Station, BS, HI, FS, Elev., and Remarks, in that order. A draftsman is concerned with only three of these, the first, fifth, and sixth reading from left to right.

c. Plotting. Points are plotted on coordinate paper in the same manner as that described for rectilinear charts (ch. 4). The horizontal coordinate of any point is its station, the vertical coordinate is its elevation. Figure 115 shows a profile with a finished gradeline superimposed.

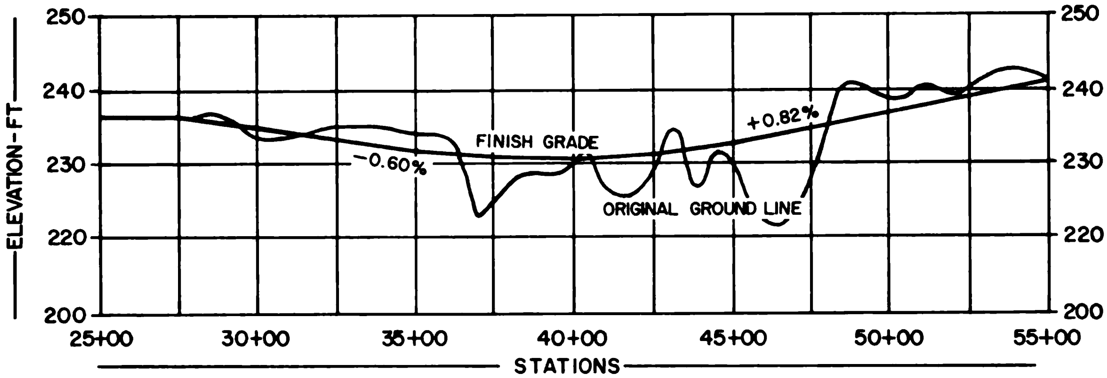


Figure 115. Ground profile with gradeline.

(1) *Scales.* The vertical scale usually is 10 or more times larger than the horizontal scale. By exaggerating everything in the vertical direction, computation and visualization are made easier. A draftsman chooses the scales to be used, selecting scales that allow the profile to fit and make plotting easy. Common horizontal scales are 1″ = 40′, 1″ = 30′, and 1″ = 100′, Vertical scales are in the ratio described above.

(2) *Paper.* Special profile paper is used to plot profiles. Ruled horizontally and vertically, the paper is divided finer along the vertical scale. Horizontal scales should be laid out so that full stations fall on the heavy vertical rulings. Vertical scales should be arranged so that even 5- or 10-foot elevations fall on a heavy horizontal ruling.

(3) *Curve.* After all points have been located by their coordinates and plotted, they are connected with straight dashed lines.

(4) *Labeling.* The figures covering the range of profile elevations are labeled on each heavy horizontal line at the left and right sides of the sheet. A 2½-inch strip should be left across the bottom of the sheet for dimensioning purposes. Stations usually are labeled at the bottom of each heavy vertical line, the vertical line of the + sign falling on the vertical line. Station labeling is shown in figure 115.

(5) *Gradeline.* After the profile of the original ground line has been plotted, the gradeline is drawn on the profile. The gradeline is determined from a study of profile and cross section views and represents the final profile of the subgrade or the finished surface of the road along centerline. Gradeline design attempts to balance cut and fill sections while keeping the road within definite grade limits.

261. Cross Sections

Cross sections are elevations of the original ground lying on either side of the centerline and are taken along a line running perpendicularly to the centerline. The transverse lines usually are established at 50-foot intervals along the centerline, although intervals are closer together when there are abrupt changes in terrain.

a. Field Procedure. Cross sectioning combines horizontal and vertical measurements. The horizontal measurements include the stations along the centerline and the perpendicular distances to the right and left of each, where the rod is held. Right and left distances are random and are measured to points, within the road width, where the ground changes slope most abruptly. Vertical measurements are the elevations taken at the centerline stations and the measured points on either side.

b. Field Notes. Field notes for cross sections occupy two adjacent pages of the notebook used for recording survey party data. The left-hand page corresponds to the leveling notes kept for profiles. The right-hand page gives elevations and distances out for each station recorded on the left.

(1) *Sequence of notes.* Level notes for cross sections usually are recorded up the page, with the lowest station at the bottom.

(2) *Typical notes.* Field notes may record the actual ground elevation rather than leaving these calculations to be made in the office. Using this method, the right-hand page of field notes for figure 116 would appear as follows.

Left		Centerline			Right
$\frac{34}{65.2}$	$\frac{20}{63.3}$	$\frac{5}{64.4}$	$\frac{0}{64.3}$	$\frac{15}{63.5}$	$\frac{37}{64.4}$

Note that the distance out from the centerline appears as the numerator in the field notes. The centerline elevation needs no numerator. Left and right on the page correspond to these directions in the field when standing at station 1 + 00 and facing station 2 + 00. The station number 1 + 00 would appear on the left-hand page, adjacent to the cross section data, with other leveling information.

c. Plotting Cross Sections. Cross sections are plotted on cross section paper (fig. 116). The subgrade elevation of the finished section at each station is read from the profile. Cross section levels are taken with an instrument in the field or, if time does not permit, ground elevations may be read from a contour map. Cross sections are usually plotted to the same vertical and horizontal scale, but if the vertical cut or fill is small in comparison with the width, an exaggerated vertical scale may be used without reducing accuracy. If an exaggerated scale is used, it should be used throughout to avoid errors and the proper factor must be applied to instrument reading when the planimeter is used to determine cross section areas. The use of a template of the finished section, constructed to the proper scale, will facilitate the plotting of cross sections. Cross sections are also plotted at any intermediate place where there is a distinct change in slope along the centerline, where the

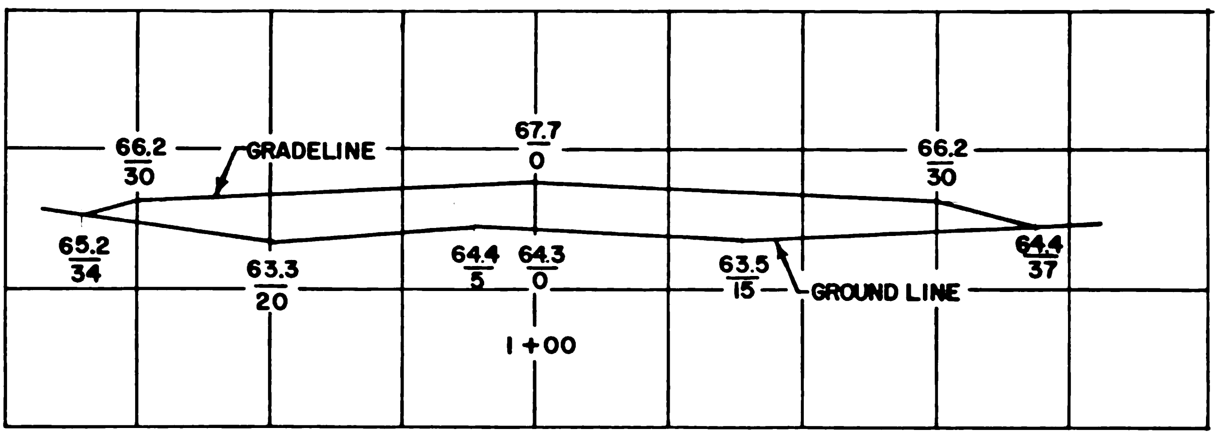


Figure 116. Cross section of a road.

natural ground profile and the grade line correspond, i.e., the earthwork changes from cut to fill, and where the surface on either side of the centerline is uneven enough to require plotting a section in order to represent properly the volumes indicated between the cross sections.

262. Estimate of Earthwork

Planning earthmoving operations is an important as planning any other phase of construction work. Detailed progress schedules are set up so that maximum efficiency can be attained. As in other construction operations, schedules are based on the estimate of the quantities involved. It is necessary to know where the cut and fill sections are located, the quantity to be removed in cut, and the quantity to be added in fill. Earthwork quantities are measured by volume with the cubic yard as the unit of measurement. Volumes are estimated by computing the area of cut or fill in each cross section, averaging it with the area of cut or fill in the next cross section and multiplying the average area by the distance between the two cross sections. This tells how much earth must be added in fill or taken away in cut between the two points at which çross sections where taken. The procedure is repeated for the entire length of the road.

263. Determination of End Areas

The area to be calculated is inclosed between the ground line and the gradeline. The figure formed in this fashion is called an end area; it rarely, if ever, assumes a simple geometric shape. End areas, therefore, cannot be determined by a simple geometric formula. Several methods are used, depending on the degree of accuracy desired.

*a. **Planimeter.*** The simplest method utilizes an instrument called a planimeter. It has two arms, one of which has a pin in the end and the other a calibrated wheel. The arm with the pin is pressed into the board, off to the side of the drawing, and held stationary; the other arm, with the calibrated wheel, is traced over the perimeter of the cross section. The area is then read directly from the instrument.

b. Counting Squares. This method consists of counting the inclosed squares formed by the cross section paper rulings; the total of the inclosed squares is multiplies by the area in square feet of one square to give the area of the section in square feet. The area in square feet of one square is determined by the horizontal and vertical scales used in plotting the cross section.

c. Double-Meridian Distance Method. To determine areas of cross sections, the Army uses the modified double-meridian distance method. This method involves more computations than other methods of determining cross sectional area, but it is adaptable to a cross section of any shape. In studying the double-meridian distance method (DMD) it is important to remember that distances are added and elevations are subtracted.

d. Trapezoidal Method. The area in the trapezoidal method is obtained by breaking the cross section into a series of trapezoids and triangles. Areas of component parts are calculated and added together. When the procedure uses the sum of the bases of the trapezoids and the entire base length of the triangles, the area obtained will be double the true area until the division by two is made in the final step of the operation. Bases of the trapezoids are taken as vertical lines drawn through break points on either the grade or ground line. Length of bases is equal to difference in elevation in feet between ground line and gradeline. (All areas of individual trapezoids are triangles and are added to and then divided by two to obtain the area of the cross section points.)

e. TM 5–233. Complete details on the calculation of end areas are contained in TM 5–233.

264. Graphic Organization of Earthwork

A mass diagram is the best means of making a study of excavation, embankment, and haul requirements to determine the quickest way to complete an earthmoving job. It also serves as a guide in determining what equipment to assign to specific portions of the haul. The diagram is a graph in which the algebraic sum of the embankment and excavation is plotted as the ordinate and the linear distance as the abscissa. Algebraic sums are obtained by using excavation quantities as positive and embankment quantities as negative.

a. Use of Mass Diagram. The mass diagram is used also to determine the most economical distribution of materials. Because the amount of excess material between any two points can be determined, a careful study of the diagram will show where it will be expedient to waste material and to borrow closer to the area to be filled. In making a decision to borrow, the work involved in opening and closing a borrow pit and in wasting excess material must be balanced against the decreased yardage output of the same equipment determined. When there are both cut and fill volumns between stations, the diagram shows only the volume of earth necessary to complete the balance; therefore, when cut and fill volumes balance between two stations the diagram may show no earth haul necessary. Earthwork sheets should be used with the diagram in determining equipment requirements.

b. TM 5–330. Further details of the mass diagram method are contained in TM 5–330. (To be published.)

CHAPTER 11
CONCRETE AND MASONRY DRAWING

Section I. CONCRETE

265. Description

Concrete is a mixture of cement, water, and aggregate. Aggregate is classified as fine and coarse; fine aggregate refers to sand, coarse aggregate either to crushed stone or gravel. Mixed together in specified proportions, fine aggregate fills the voids in coarse aggregate, and cement and water form a paste that hardens to bend the aggregate together in a unified mass. Concrete is poured into forms while it is still plastic. Once hard, concrete retains the shape imparted to it by the form. When steel reinforcing rods are embedded in concrete, it is known as reinforced concrete. In general, bar reinforcing steel embedded in the concrete is assumed to provide for all tension and shear stresses, and the concrete resists compressive stress.

266. Mix

The compressive strength and consistency of concrete are determined by the proportions in which cement, water, and aggregate are combined. The particular combination required for any structural member is called the mix, which is always stated either in the specifications or general notes in the set of drawings. It may be written out, or expressed as a ratio. In the later case, the sequence is always sacks of cement, parts of sand, parts of coarse aggregate. The quantity of water per sack of cement is stated separately. The Army uses volume measurement in concrete mixes. The units of measurement are sacks of cement (1 sack weighs 94 pounds, its volume is 1 cu ft), cubic yards of aggregate, and gallons of water (7.5 U. S. gallons of water equal 1 cubic foot).

a. Compressive Strength. Concrete strength usually is expressed in pounds per square inch in compression 28 days after it is placed in the form. Within routine mix limits, the water-cement ratio is the key consideration in calculating concrete strength.

b. Consistency. Within the limits of a given water-cement ratio, a mixture can be classified as stiff, medium, or wet depending on the ratio between coarse and fine aggregate. Increasing the ratio of sand to coarse aggregate makes a stiffer mixture. Notes and specifications state that aggregate is to be measured dry because sand swells, or bulks, when partially wet, and its ratio of weight to volume decreases unless it is completely wet (inumdated) or dry.

267. Forms

Form dimensions are not shown in drawings but are easily obtainable from the views of concrete structures presented in general sectional, and detail drawings. Although only the most complex forms are shown in construction drawings, form lumber should be accounted for on takeoff sheets or bills of material.

a. Earth Forms. When soil, such as clay, is sufficiently rigid it may be used as forms for footings; holes excavated to the proper dimensions serve as forms without further preparation.

b. Wood Forms. Many types of wood forms are used for concrete work. Design varies according to the structure and the pressures of pouring. A typical form (fig. 117) for a wall consists of 1- x 6-inch tongue and groove sheathing fastened to 2- x 4-inch studs. The sheathing is the inside face of the form; the distance between faces is equal to the thickness of the wall. Studs are braced by 2- x 4-inch wales, which are horizontal strips placed on edge in pairs behind the sheathing to stiffen the form. The wales are held in position by form ties, which are metal strips or threaded rods fastened with clamps or bolts at either end. They help keep the form apart before concrete is placed and help resist bursting pressures after it is poured. Most ties are designed to be broken off in the concrete after it hardens. Forms are further strengthened with diagonal 2- x 4-inch bracing extending between studs, and stakes driven into the ground and spiked to these supports at either end.

c. Stripping Forms. To prevent concrete from adhering to it, form lumber is coated with oil before being used. After the concrete has hardened sufficiently, forms are removed, or stripped. If properly cared for, the form lumber can be used several times.

268. Footing, Foundations, and Floors

a. Footings. Footings may be constructed of plain or reinforced concrete. Plain concrete footings have limited use, being restricted to low, wall-bearing structures and columns resting on solid rock. Of the several types of reinforced concrete footings, wall footings and independent column footings are the most fre-

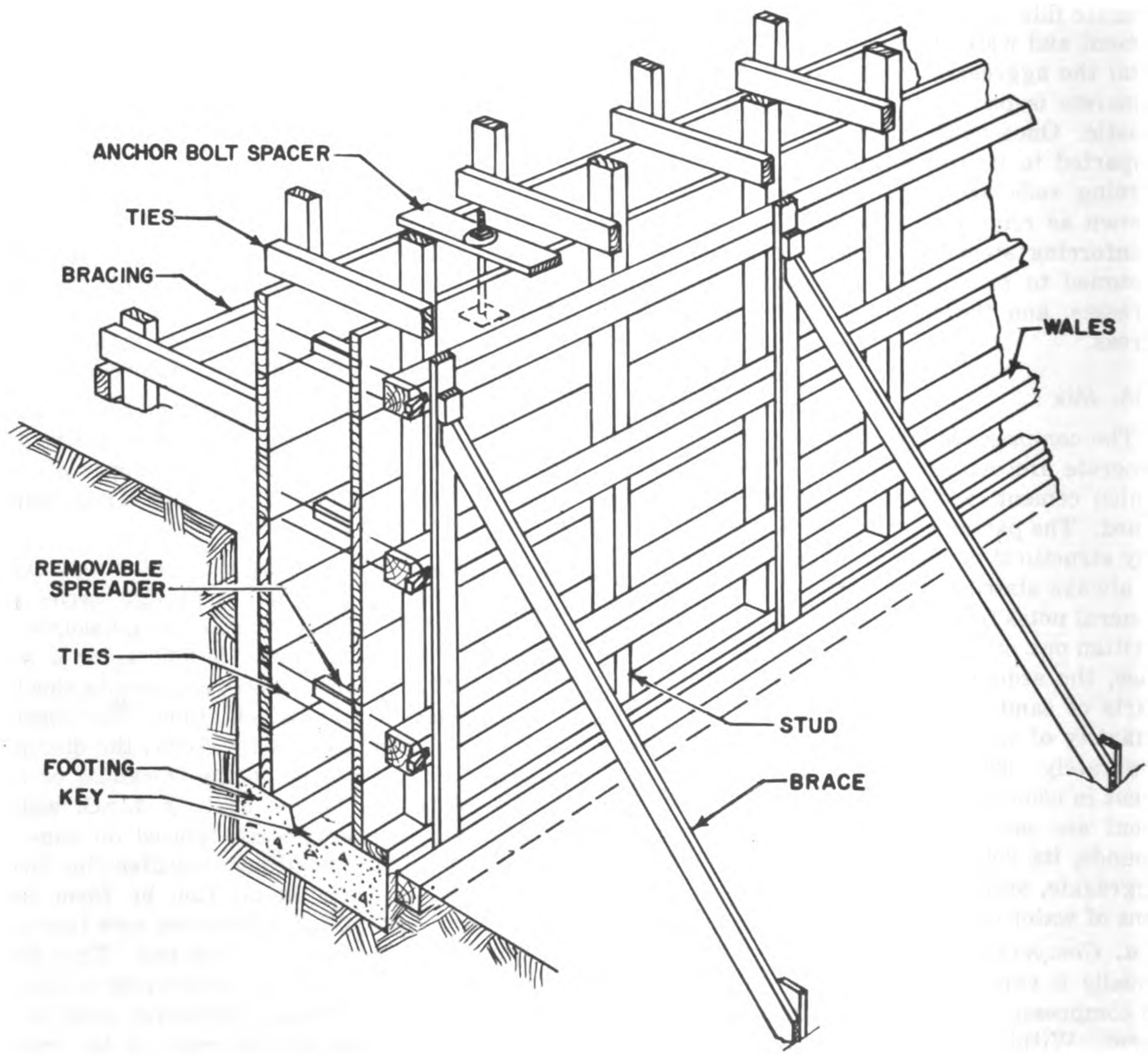


Figure 117. Typical wood form.

quently used. If the ground does not offer suitable support for footings at a reasonable depth, it is necessary to use piles. (Piles may be wood, concrete, or steel.) They are usually driven vertically into the ground. Piles derive their bearing strength from two conditions. They may be driven to rock or hardpan, in which case the load is transmitted through the pile point to the bearing surface supporting it. Those not reaching hardpan derive their bearing strength from the frictional resistance between the piles and the soil into which they are driven.

b. Foundations. The extent and wall thickness of a foundation wall is shown in foundation plans; its elevation is shown in an elevation view. Reinforcing details are given in a section view (par. 271) of a foundation wall.

c. Floors. Reinforced concrete floor systems are composed of beams, slabs, and girders made of reinforced concrete. The overall relationship of beams, slabs, and girders is shown in a through section. Plans show the location of contraction and expansion joints, which usually are located around the perimeter of all slabs on ground and elsewhere as indicated by design sketches. Plans should locate all points at which pipes pass through the floor so that sleeves can be inserted before slabs are poured. Plans also identify beams, slabs, and columns by number or mark.

269. Reinforcing Steel for Concrete Structures

Reinforcing for concrete structures is usually made up of steel bars and welded-wire mesh (fig. 118). The bars may be round or square in cross section, have plain or deformed surfaces, and be made of mild billet steel or hard rail steel. Welded reinforcing mesh normally is used to prevent cracks and checks in slab or wall concrete.

a. Sizes. Table II gives sizes, areas, and weights of plain and deformed reinforcing bars in common use.

b. Plain and Deformed Bars (fig. 118). Plain bars have smooth surfaces. Deformed bars have lugs, ribs, and projections of various kinds on their surfaces that do not change the cross sectional dimensions but do afford a better mechanical bond between the bars and concrete.

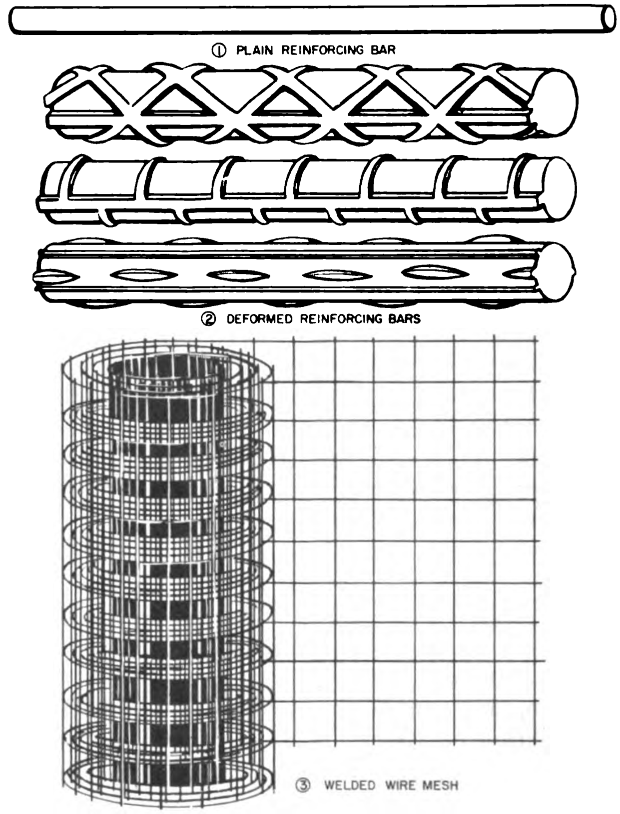


Figure 118. Types of reinforcing bars.

Table II. Sizes, Areas, and Weights of Reinforcing Bars

(in.)	Size[a] (numbers)	Weight (lb per ft)	Nominal diameter (in.)	Dimensions-round cross sectional area (sq in.)	Section perimeter (in.)
¼	2[b]	0.167	0.250	0.05	0.786
⅜	3	0.376	0.375	0.11	1.178
½	4	0.688	0.500	0.20	1.571
⅝	5	1.043	0.625	0.31	1.963
¾	6	1.502	0.750	0.44	2.356
⅞	7	2.044	0.875	0.60	2.749
1	8	2.670	1.000	0.79	3.142
1	9	3.400	1.128	1.00	3.544
1⅛	10	4.303	1.270	1.27	3.990
1¼	11	5.313	1.410	1.56	4.430

[a] The bar numbers are based on the number of ⅛ inches included in the nominal diameter of the bar.
[b] Bar number 2 in plain rounds only. Bars numbered 9, 10, and 11 are rounded bars and equivalent in weight and nominal cross sectional area to the old type 1", 1⅛", and 1¼" square bars.

c. Bending and Placing Bars. Bars are manufactured in straight lengths and are cut and bent. Bars are bent by the steel fabricator in the shop and sent to the job ready to place without further cutting or bending. They are placed and wired in position before concrete is poured.

270. Joints and Connections

One of the principal responsibilities of a construction draftsman is to show, in detail drawings, the manner in which structural members and construction materials are connected to each other.

a. Foundation Walls. Foundation walls are bonded to footings with vertical reinforcing bars called dowels which are placed in footings and extend 3 to 4 feet up into the wall. A wedge-shaped through, (fig. 117) called a key, is built into spread footings to strengthen the bond between footings and walls that are poured later.

b. Construction Joints. Construction joints are divisions between concrete work done at periods far enough apart to allow partial hardening. For horizontal work, such as floor slabs, construction joints should be in a vertical plane. For vertical work, such as columns, the joints should lie in a horizontal plane. Although construction joints have no permanent function but to represent a convenient stopping place, they affect the strength of the structure. Their location is indicated in a drawing with a heavy, unbroken line and the note "permissable construction joint," or "construction joint."

c. Contraction and Expansion Joints. Concrete usually contracts while hardening and expands after it has hardened because of changes in atmospheric temperature. To provide for the changes in volume that occur at these times, it is necessary to provide joints at frequent intervals.

(1) *Contraction joints.* Various designs of contraction joints are used. In all cases, however, they represent a clean break between the two sections; no reinforcing extends across the break, which should be filled with an elastic joint filler or protected in some other way. Joint details can be shown in a detail drawing.

(2) *Expansion joints.* Expansion joints are required wherever expansion might cause a concrete slab to buckle. Mastic joints are commonly used to separate sections from each other, thus allowing room for expansion.

d. Masonry Units. Masonry units such as brick, structural tile, and cinder block are bonded to foundation walls with mortar. Metal ties may be added to increase the strength of the bond.

e. Grout. Grout is a mixture of cement, sand, and water. Grouting is the process of adding a layer of concrete to concrete that has been poured previously. It is frequently used to bring bearing surfaces, such as column footings and foundation walls, to the exact grade desired. It is not indicated symbolically on drawings but thickness of the grout is stated in the notes.

f. Bearing Plates. When heavily loaded beams or columns bear on masonry or concrete supporting members, metal plates are used to distribute the load and prevent crushing the surface of the supporting member. The plates are made of steel or cast iron and may be held in place by grout, dowels, anchor bolts, or the weight of the supported member.

(1) *Beam supports.* Bearing plates are used to distribute the loads of horizontal members bearing on masonry walls. Usually they are of a simple rectangular shape.

(2) *Column supports.* Base plates are used to distribute the loads of columns bearing on concrete or masonry piers and footings and may be plain or ribbed. Base plates for pipe columns may have a vertical projection or dowel to fit inside the column to hold the column in place.

(3) *Anchor bolts.* Anchor bolts are the most frequently used means of connecting wood and steel to concrete. The end embedded in the concrete is hooked to provide a stronger bond. Anchor bolt dimensions are given in specific notes and state diameter and length. For example, the note "½″ x 1′-2″ anchor bolts @ 4′-8″ OC" means that the bolts are ½″ in diameter, 1′-2″ long and are spaced at intervals of 4′-8″ measured on centers around the perimeter of the foundation wall.

271. Reinforced Concrete Details

The drawing of concrete structures requires careful attention in representation and specification. Location of the reinforcing steel is shown in detail drawings of the various structural members. However, it is not possible to show the shapes and sizes of the reinforcing bars by the usual orthographic views, and a systematic method of marking is used in which bars are identified by symbols and reference numbers. Once assigned, the same reference number is used to identify the bar in any view in which it appears. Reinforcement size-and-shape details are provided in a separate reinforcement detail drawing which consists of a reinforcement schedule and diagrammatic bar-bending details.

a. Symbols. The symbols used in preparing drawings of reinforced concrete structures include the material symbol for concrete in section and the symbols for reinforcing steel.

(1) *Concrete.* The symbol for concrete in appendix I indicates coarse and fine aggregate and is drawn freehand. Fine aggregate is represented by fine dots and coarse aggregate by irregularly drawn triangles. Draw the large aggregate symbol first in random pattern and fill in sparsely with dots.

(2) *Reinforcement.* Figure 119 presents the symbols for typical shapes of reinforcing steel. Figures 120, 121, and 122 demonstrate some applications of these symbols. Notice that in addition to their symbolic representation, reinforcing bars parallel to the section are represented by heavy dashed lines; those perpendicular to the section are represented by heavy round or square dots, depending on the cross sectional shape of the bars.

b. Reinforcing Schedules. Figure 120 shows a portion of a main floor plan and example of reinforcing schedules for slabs, bar bends, and beams as located on the plan. The No. column lists the quantity requirement; size refers to the bar diameter; length to the stretchout length; type to the shape of bar; and bending details to the outside lengths of the straight and curved segments. The shipping mark gives dimensions in code, the first number given bar diameter in multiples of ⅛ inch and the other 3 or 4 numbers giving overall bar length in feet and inches. Mark 4073 means ½″ dia @ 7′-3″ long; mark 31810 means ⅜″ dia @ 18′-10″ long.

c. Bar-Bending Details. Bar-bending details resemble the diagram-matic shapes shown in figure 119. Note the manner in which bar-bending details are indicated in reinforcing schedules (fig. 120).

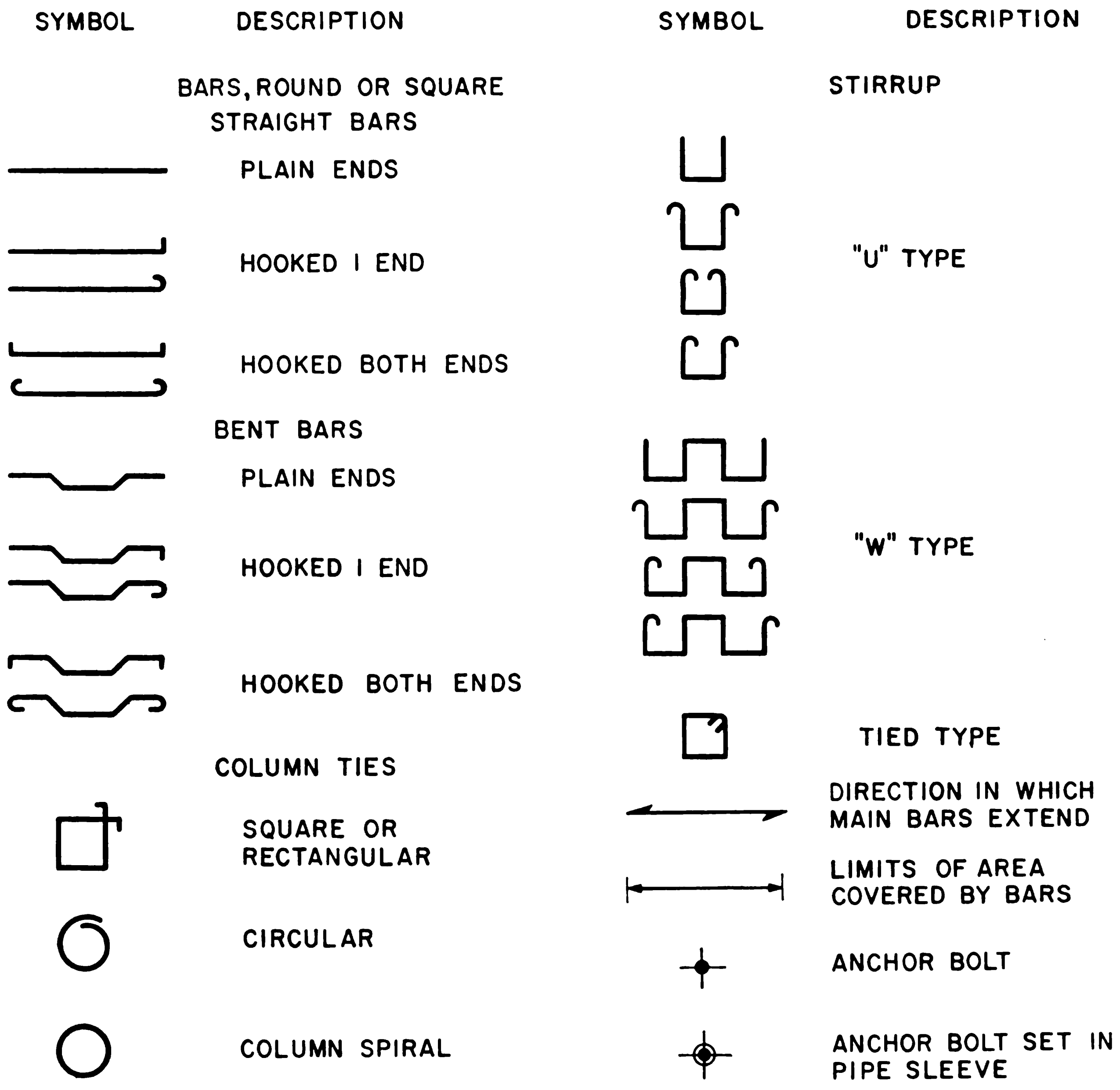
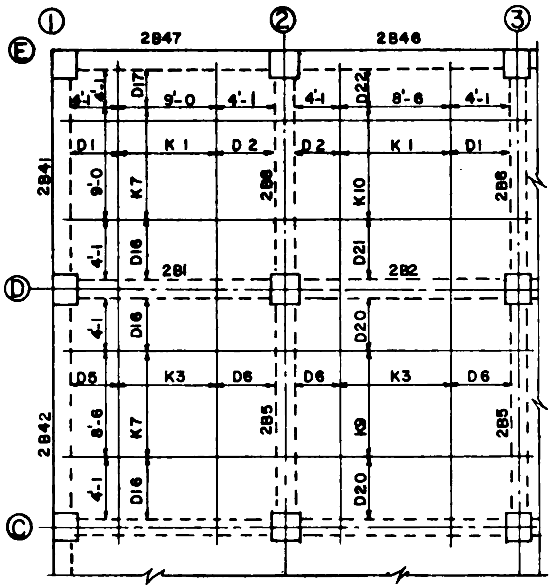


Figure 119. Reinforcement symbols.

d. Section Details. Figures 121 and 122 illustrate the manner in which basic information is given in typical reinforcement section details.

272. Concrete Takeoff

Calculation of the total quantity of concrete required for a job involves listing all the concrete structures and tallying the sum of their individual volumes. In calculating the quantity of concrete in a structure, no allowance is made for space occupied by reinforcing steel. Steel quantities can be calculated from reinforcement schedules. The table of reinforcing bar weights can be used to arrive at a total weight for reinforcing steel because steel is listed by pounds or tons in a bill of material.



SECOND FLOOR FRAMING PLAN
ALL SLABS 5" THICK

SLAB SCHEDULE

	No. of Bands	Band Mark	Bar Spacing	Bottom Bars No.	Bottom Bars Length	Bottom Bars Type	Bottom Bars Sketch	Bottom Bars Shipping Mark	Truss Bars No.	Truss Bars Length	Truss Bars Type	Truss Bars Sketch	Truss Bars Shipping Mark	$\frac{7}{8}$ Slab Bolsters No.	$\frac{7}{8}$ Slab Bolsters Length	Continuous High Chairs No.	Continuous High Chairs Length	Continuous High Chairs Height
Lower Layer	2	D1	$8\frac{3}{4}$	2	19'-8	R500		5196	3	24'-6	R501		5246					
	2	D2	11	2	19'-6	R500		5196	2	24'-6	R501		5246					
	2	K1	$8\frac{3}{4}$	5	18'-6	R503		5186	8	29'-11	R502		52911	4	16'-0	4	18'-3	$4\frac{1}{4}$
Upper Layer	3	D16	11	2	17'-3	R506		5173	2	24'-6	R511		5246					
	1	D17	$8\frac{3}{4}$	2	17'-9	R507		5179	3	24'-6	R511		5246					
	2	K7	$8\frac{3}{4}$	5	19'-6	R500		5196	8	24'-6	R511		5246			2	12'-0	$4\frac{3}{4}$

BENDING SCHEDULE

Type	Hk		Length	Type	Hk		S1		S2		H	J	Length
R500	6	19'-0	19'-6	R501	6	2'-9	$6\frac{1}{2}$	11'-6	$6\frac{1}{2}$	6'-8	$4\frac{1}{2}$		24'-6
R504	6	20'-3	20'-9	R502		8'-2	$6\frac{1}{2}$	9'-10	$6\frac{1}{2}$	8'-2	$4\frac{1}{2}$		23'-3

Note: All slab bars are $\frac{5}{8}\phi$
All bending detail detail dimensions are out to out

BEAM SCHEDULE

No. of Beams	Beam Mark	Size Width	Size Depth	Straight Bars No.	Straight Bars Size	Straight Bars Length	Straight Bars Remarks	Straight Bars Shipping Mark	Hook Bars No.	Hook Bars Size	Hook Bars Length	Hook Bars Hook	Hook Bars	Hook Bars Hook	Hook Bars Shipping Mark	Truss Bars No.	Truss Bars Size	Truss Bars Length	Truss Bars Hook	Truss Bars	Truss Bars S1	Truss Bars	Truss Bars S2	Truss Bars	Truss Bars Hook	Truss Bars H	Location ℄ of support	Location Remarks	Truss Bars Shipping Mark	Stirrups No.	Stirrups Size	Stirrups Length	Stirrups BxC	Stirrups Type	Stirrups Spacing each end	2" Beam Bolsters
2	2B6	14	20	1	$\frac{7}{8}$	20'-6		7206	2	$\frac{7}{8}$	17'-10	9	18'-6		71710	2		26'-7	1'-1	2'-4	1'-11	11'-0	1'-10	7'-7		1'-4			8267	14	$\frac{1}{2}$	5'-6	11x17	S1	2-3,3-6, 5-9	4 at 1'-1
2	2B7	14	20	2	$\frac{7}{8}$	18'-6		7166								2		28'-1												14	$\frac{1}{2}$	5'-6	11x17	S1	do	4 at 1'-1

Figure 120. Typical reinforcing plan.

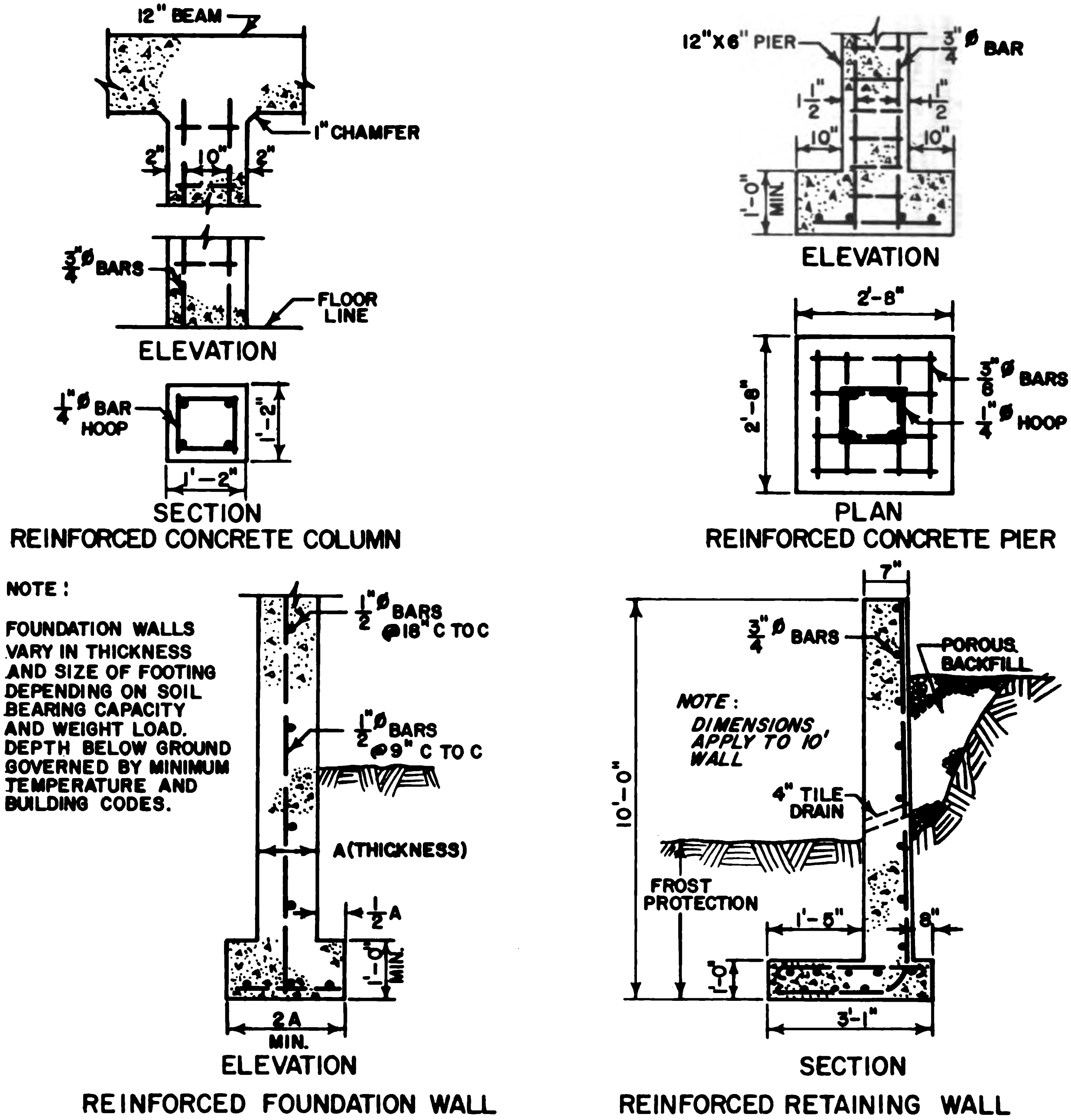


Figure 121. Common reinforced concrete details.

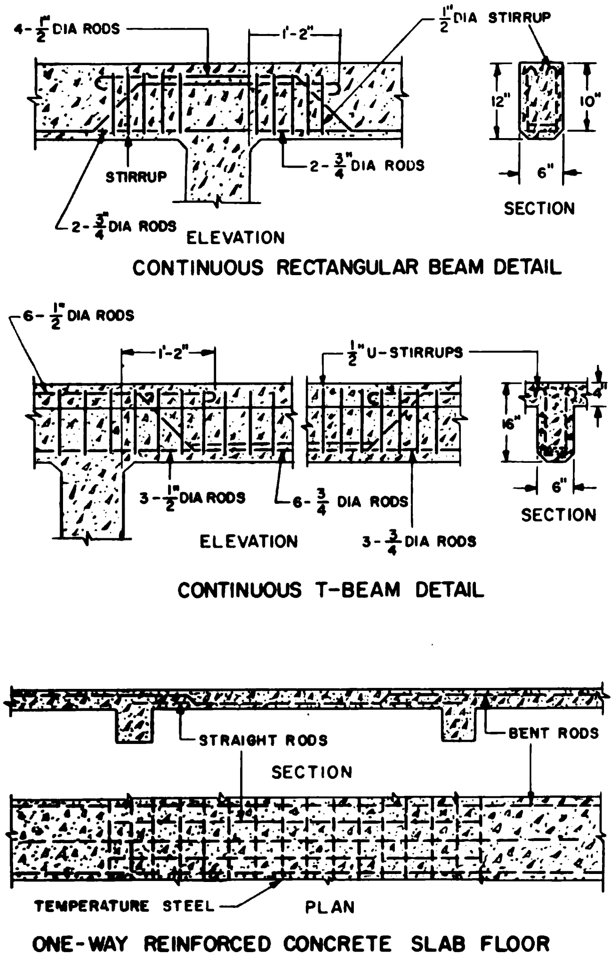


Figure 122. Reinforced details for beam and slab floor.

a. Takeoff Organization. A concrete takeoff (table III) also is known as a quantity survey. In making the quantity survey, it is important for a draftsman to use a logical, clear form for his work. In this way, a check on the takeoff can be made more easily in the event of error. A quantity surveyor may be forced to adopt a takeoff form suited to the peculiarities of the structure. Following a standard form such as the one above, however, gives the best results. Note that the location is clearly marked; the dimensions are given in decimals, rather than inches, to facilitate extension; and that no separate listing of dimensions for forms is necessary. Cubic feet of concrete and square feet of forms are totaled by classification, namely, footings, walls, structural slabs, and so on, because specifications for each classification may be different and the pricing and scheduling factors vary for each type of concrete pour and classification. The cubic-feet totals for each classification are converted into cubic yards by dividing by 27.

b. Calculation of Compounds From Takeoff. Mix ratios and water-cement ratios are stated in the specifications. With this information and the results of the concrete takeoff expressed in cubic yards, a draftsman can use tables IV and V to calculate the sacks of cement needed for a job or structure. If aggregate is obtained locally, only the cement and reinforcing quantities need be listed in the bill of materials.

Table III. Concrete Takeoff

CONCRETE								
Item	Location	No.	L	W	H	Extension	Cu ft	Form lumber (sq ft)
Footings	1A, 1C (list all footings)	2	4.0	4.0	1.33	2(4x4x1.33)	43	42.7
Piers	1A, IC (list all piers)	2	2.0	2.0	4.0	2(2x2x4)	32	48.0
Walls	N. Elev. Cols. 1–6	1	75.0	1.0	6.0		450	900
Structural slabs	S–1 (etc.)	1	12.0	8.0	0.33		32	96

Table IV. Concrete Mixes

Mix by dry-rodded volume	Quantities per cu yd [1]			Approx total water [2] (gal per bag)	Concrete per 1-bag cement (cu ft)
	Cement bags	Sand (cu yd)	Gravel or stone (cu yd)		
1–3½–6	3.6	0.56	0.84	10.0	7.5
1–3–6	3.7	0.51	0.88	9.6	7.3
1–3–5	4.2	0.56	0.82	9.1	6.4
1–3–4	4.7	0.64	0.74	8.4	5.7
1–2½–5	4.4	0.50	0.87	8.5	6.1
1–2½–4½	4.7	0.54	0.83	8.2	5.7
1–2½–4	5.0	0.56	0.79	7.6	5.4
1–2–4	5.4	0.49	0.85	7.0	5.0
1–2–3½	5.8	0.52	0.79	6.9	4.7
1–2–3	6.3	0.56	0.74	6.4	4.3
1–1¾–3	6.5	0.51	0.77	6.2	4.1
1–1½–3	6.8	0.46	0.81	5.8	4.0
1–1½–2½	7.5	0.50	0.74	5.5	3.6
1–1½–2	8.3	0.51	0.66	5.0	3.3
1–1–2½	8.4	0.38	0.82	4.9	3.2
1–1–2	9.4	0.42	0.74	4.6	2.9
1–1–1½	10.7	0.48	0.63	4.2	2.5
1–1–1	12.5	0.56	0.49	3.7	2.2

[1] Quantities are based on materials measured damp and loose; sand 5% moisture, 85 lb. per cu ft; gravel 1% moisture, 95 lb per cu ft; specific gravity, 2.65.

[2] Includes water in aggregate. Quantities are net; no allowance for waste. 1 sack cement = 1 cu ft = 94 lb; 4 sacks cement = 1 bbl. = 376 lb; 1 cu yd sand = 2600–2900 lb; 1 cu yd gravel = 2500–2900 lb; 1 cu yd broken stone = 2,400–2,700 lb.

Table V. Slabs, Sidewalks, Walls (materials per 100 sq ft)

Thickness (in.)	Concrete (cu yd)	1:2½:5			1:2:4			1:1½:3		
		Cement bags	Sand (cu yd)	Gravel or stone (cu yd)	Cement bags	Sand (cu yd)	Gravel or stone (cu yd)	Cement bags	Sand (cu yd)	Gravel or stone (cu yd)
1	0.31	1.4	0.15	0.27	1.7	0.15	0.26	2.1	0.14	0.25
2	0.62	2.7	0.31	0.54	3.4	0.30	0.52	4.2	0.28	0.50
3	0.93	4.1	0.46	0.81	5.0	0.45	0.79	6.9	0.43	0.75
4	1.23	5.5	0.62	1.07	6.7	0.61	1.05	8.4	0.57	1.00
5	1.54	6.8	0.77	1.34	8.4	0.76	1.31	10.5	0.71	1.25
6	1.85	8.2	0.93	1.61	10.0	0.91	1.57	12.7	0.85	1.50
7	2.16	9.6	1.08	1.88	11.7	1.06	1.84	14.7	1.00	1.75
8	2.47	10.9	1.23	2.15	13.3	1.21	2.10	16.8	1.09	2.00
9	2.77	12.3	1.39	2.41	15.0	1.36	2.36	18.9	1.28	2.25
10	3.09	13.6	1.54	2.68	16.7	1.51	2.62	21.0	1.42	2.50
11	3.39	15.0	1.70	2.95	18.3	1.66	2.88	23.1	1.56	2.75
12	3.70	16.4	1.85	3.22	20.0	1.81	3.15	25.2	1.70	3.00

Section II. MASONRY

273. Masonry Construction

Bricks, stone and tile, concrete or cinder blocks, are used in various combinations in masonry construction. The sizes, shapes, and characteristics of masonry units determine their applicability and use in construction. The specified type and placement of masonry units are shown in plans of masonry structures.

a. Brick Types. Brick types (1, fig. 123) are determined by sizes, shape and usage. A whole brick is a standard 2¼ x 3¾ x 8-inch brick; a split brick, or soap, is a flat half-brick, having been split lengthwise. A quarter, or closer, is a quarter segment of brick broken across the narrow section at quarter length. A three-quarter brick is the remainder of a brick with the quarter removed. A soldier is a whole brick laid vertically with the narrow face showing in the wall; a stretcher is a whole brick laid flat longitudinally with the wall. A king closer is a whole brick with a corner clipped off. A half, or bat, is half a brick; a header is a whole brick laid flat across the wall, with one end showing in the wall face. A rowlock is a brick laid on its edge across two rows of flat brick with one end showing in the wall. A queen closer is a brick split lengthwise through its short axis.

b. Brick Joints. Joints in brick masonry (2, fig. 123) are formed by the mortar that bends the masonry together. To finish the joints and make a waterproof bond between brick and mortar in the exterior faces of brickwork, the joints are struck, or ironed, with various shapes of jointers or a pointing trowel. Some typical joints are the flush or plain joint, in which the mortar joint is struck flush with the exterior of the masonry wall and the raked joint, in which some of the mortar is removed with the point of the trowel to make the brickwork stand out. Other joints are the V, concave, struck, or weathered joints, all of which are made with the proper use of the trowel. The type of joint to be used is included in the notes of the plan or is included in the brickwork specifications.

c. Brick Bond. Bond is an arrangement of built-up bricks or other units laid so that their overlapping thoroughly ties the units together (fig. 124). This is not to be confused with the term *bond* as applied to a bonding material such as mortar. The specifications or notes in the plans will specify the type of bond required. There are many types of brick bonds. The type bond generally used in military construction is the commond bond (1 fig. 124). A few typical bonds are described below.

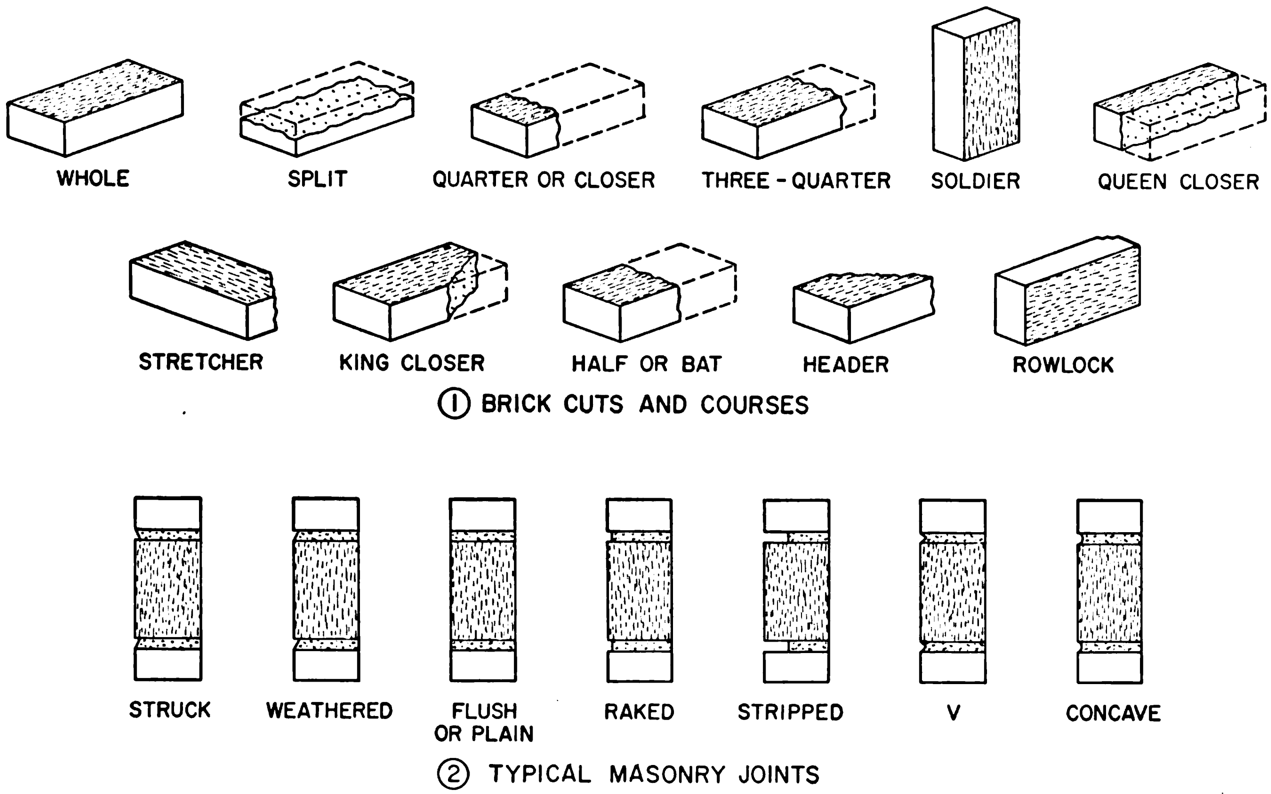


Figure 123. Types of bricks.

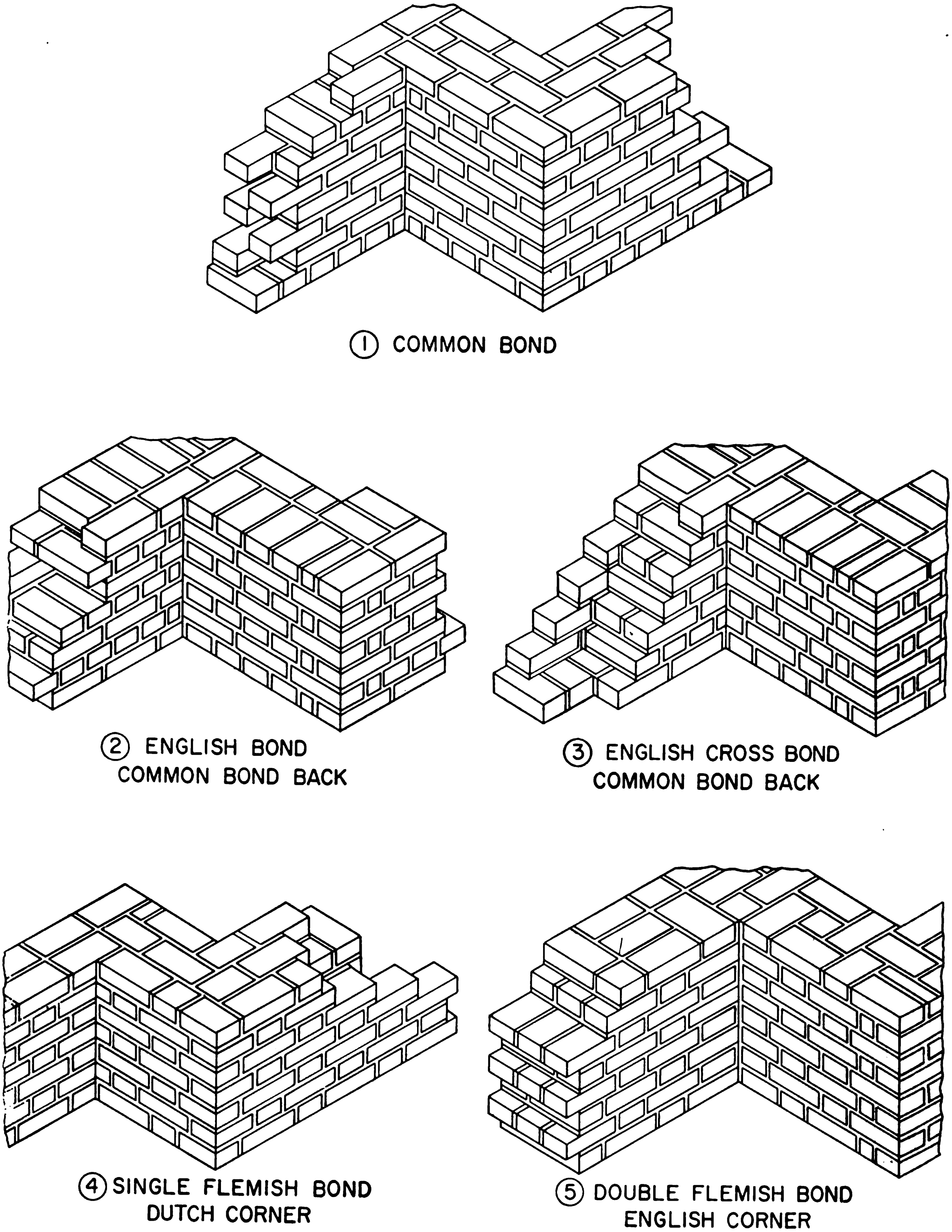


Figure 124. Brick bonds.

(1) *Common bond.* Common bond (1, fig. 124) describes a coursing in which every sixth course is composed of heads with five courses of stretchers between. A three-quarter brick at each corner starts each sixth, or header, course.

(2) *English bond.* English bond (common bond back), shown in 2, figure 124, has alternating header and stretcher courses with closers on the header courses.

(3) *English cross bond.* English cross bond (common bond back), shown in 3, figure 124, has alternating courses in a sequence of header with closers, combined header and stretcher laid alternately in the course, header course and stretcher course.

(4) *Single Flemish bond.* Single Flemish bond (Dutch corner), shown in 4, figure 124, is the third of the three fundamental bonds and consists of alternate headers and stretchers in every course, each header centering on the stretchers in the courses above and below. Closers or three-quarter brick are necessary at the corners. In this instance the Flemish bond is only on the outside of the wall, the backing being common bond and the majority of the exposed headers being bats. This is the most usual type of Flemish bond wall.

(5) *Double Flemish bond.* Double Flemish bond (English corner), shown in 5, figure 124, has both the inner and outer surfaces of the wall laid in Flemish bond with all true headers and no bats.

274. Hollow Clay Tiles

Hollow clay tiles are units of burned clay constructed with hollow cores and laid in cement mortar. Their use may be indicated in the plans or the specifications for the construction of partitions, furring, and outside walls faced either with stucco or brick tied to the tile by headers or metal ties. Plans of small military buildings of hollow clay will normally show the exterior walls to be tile without brick facing.

275. Concrete and Cinder Blocks and Tiling

Concrete blocks and tiling are molded units, either solid or hollow, of portland cement and fine- aggregates and are laid in cement mortar. Lightweight units of cinders with portland cement and sand, called cinder blocks, also are manufactured; they are formed and dimensioned to the same sizes and shapes as concrete blocks. Concrete, tile, or cinder blocks are used for walls, partitions, and foundations and can be used for low retaining walls. As in the case of other types of building units, the units themselves will not be shown in the plans but will be specified in notes or specifications as to required block types and designated uses in the construction. Concrete blocks usually are made in standard sizes of various thicknesses, the most common size being 8 x 16 inch nominal size. The nominal size allows for the mortar joint.

276. Stone

When used as found in the field or quarry, stone is called rubble. When cut and shaped into fairly regular forms, it is called squared stone, or ashlar. When cut into rectangular blocks, it is known as cut stone. Stone masonry is composed of either solid stone or stone backed with other types of masonry and is laid in mortar to a specified type of pattern consistent with the type of stone available in military construction. In theater of operations construction, stone masonry is normally used only in foundation walls, retaining walls, piers, and drainage structures. In the building of military structures, stone as a building unit is seldom used unless other materials are difficult to obtain.

277. Construction Methods

Walls normally are at least 8 inches thick. A flat stone or concrete footing course may be used. Masonry units may be laid in common bond with half-inch, or thicker, joints. In constructing walls, door frames are set first and masonry is built up against the frames to window sill height. Window frames are then set and masonry is continued to the top of frames. If lintels are necessary, they may be masonry, steel, stone-beam, timber-beam, reinforced concrete, or hollow-tile units. If possible, masonry should be omitted above door and window frames. A few 20*d* nails driven into jambs of frames provide anchorage to the masonry. Masonry joints should be well filled with mortar and pointed with a metal rod or trowel. Joints around frames should be tight because no trim is used. Roof rafters may bear on a wood plate bolted to the top of the masonry wall or may be built into the masonry. As a rule, the roof should be overhanging to shed water clear of the wall. If wooden floor joists are used, they may be built into the masonry. Joists should bear 4 inches on the wall. Brick walls 8 inches or more thick should be bonded with headers every sixth course.

278. Masonry Drawings

Masonry drawings furnish a description of masonry units and show materials and exact dimensioning for construction purposes.

a. Masonry Symbols. Appendix III illustrates the symbols used in military drawing to represent masonry units in section and exterior views. Figure 125 (views 1 and 2) shows the correct use of the brick symbol in section. In drawing exterior views for working drawings, it is too time-consuming to detail masonry units, as in elevations of 1 and 2, figure 125. Horizontal lines are spaced to scale and drawn a few courses high in the left-hand corner of the wall as in 3, figure 125. A few vertical lines are spaced and drawn to scale for a short distance, allowing the horizontal lines to trail off. The material is then identified by note.

b. Lintel Symbols. As shown in 3 and 4, figure 125, the heavy, dashed-line symbol for lintels is drawn in plan views. The line symbol is drawn to scale, indicating lintel length and showing the extent of its bearing on masonry walls. Lintel shapes and construction are shown in section views, *for example*, three 3½″ x 3½″ x ¼″ steel angles or an 8″ x 8″ reinforced concrete lintel. Figure 168, shows forms of structural-steel shapes. The lintel symbol is used if lintels are not an integral part of the framing, or loose. If a lintel is part of a steel frame, no detailed information or symbol is used because steel framing plans indicate all members.

279. Masonry Walls

The most common use of masonry is in wall construction.

a. Types. The principal types of masonry walls are bearing, curtain, and veneer walls.

(1) *Bearing walls.* A bearing wall is one that supports a vertical load other than its own weight; its thickness is regulated by its height. The minimum thickness of a brick bearing wall for a dwelling is 8 inches; for buildings such as warehouses, which carry heavy loads, minimum thickness is 12 inches.

(2) *Curtain walls.* A curtain wall is a masonry wall inclosing a framework of steel or reinforced concrete; it is not a bearing wall. It may support its own weight or may be supported at intervals on the frame of a building. The minimum thickness of a brick curtain wall is 8 inches.

(3) *Veneer.* Veneer implies a masonry facing over an exterior bearing wall. The veneer is not self-supporting and is fastened to the frame of the building with metal clips spaced at specified intervals. Some examples of masonry veneer are stone on a wood frame, brick on a wood frame, or cement tile.

(4) *Hollow walls.* Buildings with masonry walls are occasionally constructed with parallel walls separated by an airspace. Hollow-wall or cavity construction permits plaster to be placed directly on the interior wall without first building a backing out from the wall.

b. Plans. Symbols, dimensions, and notes are used in a plan view to show location, thickness, and types of masonry walls. Dimensions give overall length and width and location and width of all doors and window openings. The double-line wall symbol is drawn to scale, and the appropriate section symbol is used to indicate the masonry material graphically. Brick walls are dimensioned to the outside corner in plan views.

c. Elevation. Door and window openings are drawn to scale. Wall material is indicated by drawing a few courses of brick, block, stone,

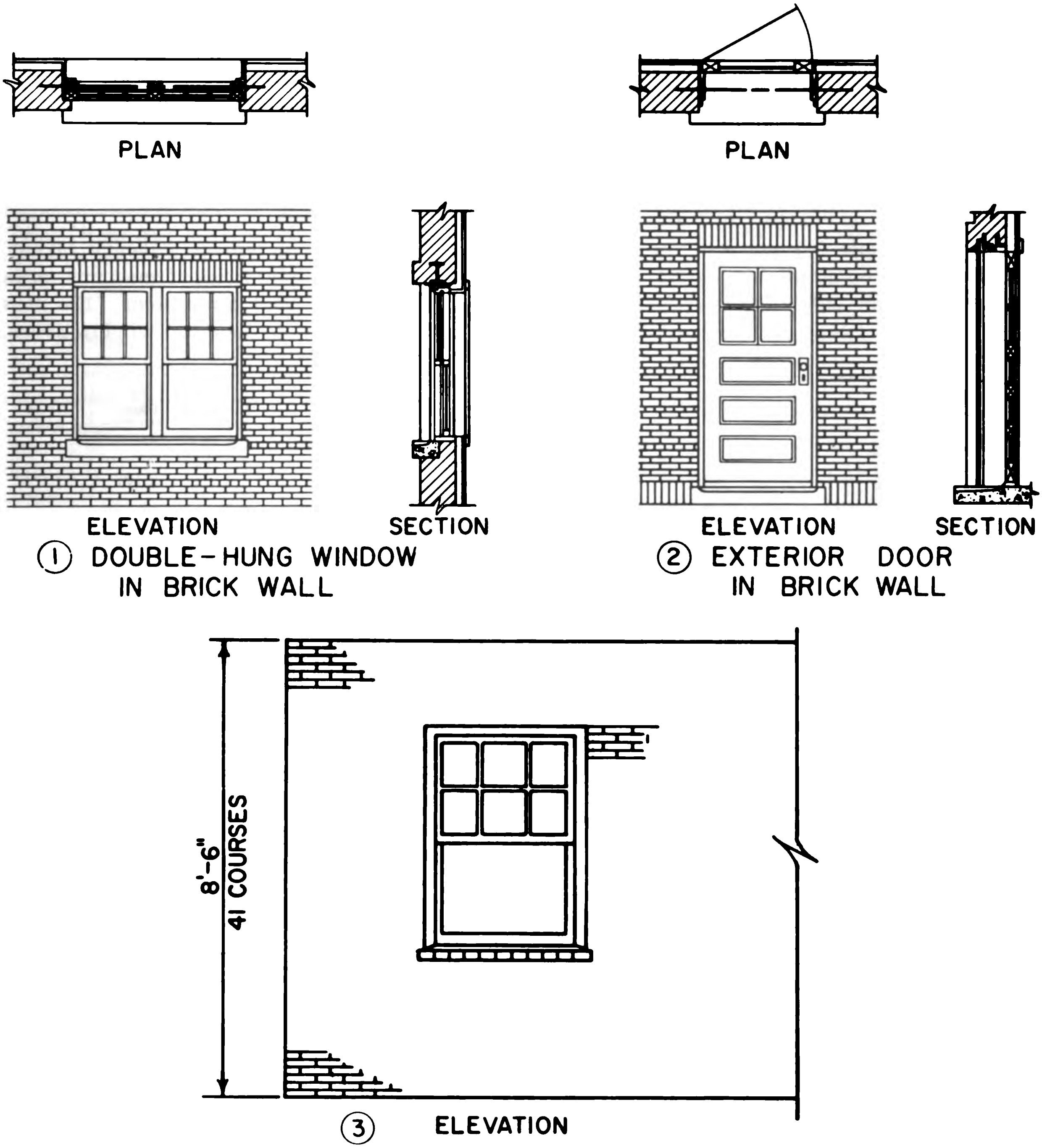


Figure 125. Lintel conventions.

or tile as required. The number and dimensions of courses are shown in elevations between finished floor lines, from finished floor line to the bottom of a window opening, and to the other vertical construction points from datum lines as required (4, fig. 125 shows the method of indicating number and dimensions of courses) (3 and 4, fig. 125 show the surface appearance of brick in common bond). Bricks above doors and windows are in row-lock bond.

d. Wall Sections. The details of masonry construction are indicated in wall sections drawn to large scale (¾″ = 1′-0″ or 1½″ = 1′-0″). Construction details are shown at building sill, head, jamb, sills of door and windows, and at the eaves. Additional sections should be drawn if there are departure from the typical, such as variations of roof and floor framing into th masonry wall. In large-scale wall sections, it is necessary to show the actual sizes of masonry units to represent joints by a space to scale between unit outlines, and to show all other items exactly to scale in order that mechanics will have a clear picture. Joint dimensions, masonry material, and any details of construction requiring explanation should be explained by specific notes or dimensions.

280. Masonry Takeoff

The following is a typical masonry takeoff sheet showing how quantities of masonry units are obtained from wall dimensions (12- inch wall). "Outs" refers to door and window areas.

Location	No.	L	H	Face brick (sq ft)	Outs (sq ft)	Common brick (sq ft)	Outs (sq ft)	8″ Block (sq ft)	Outs (sq ft)
North elev. Cols. 1–5		80.0	30.0	2,400				2,400	
	5	6.0	6.0		180				180
	1	3.0	7.0		21				21
(at spandrel)		80.0	2.0			160			160
Cols. 5–8		60.0	20.0	1,200				1,200	
	3	6.0	6.0		108				108
(at spandrel)		60.0	2.0			120			120

When totals have been completed, the actual number of face and common bricks can be computed in accordance with the type of bond. *For example,* in a 12-inch brick wall of common running bond with a header course every sixth course, there would be about 7⅔ face brick and 12⅓ common brick per square foot. The number of cinder or concrete blocks in a wall can be computed from the area and size of the blocks. Quantities of mortar can be calculated from table VI, once the quantities of brick or block have been totaled.

281. TM 5–742

For more detailed information on concrete and masonry construction methods, see TM 5–742, Concrete and Masonry.

Table VI. Masonry Materials (per 100 sq ft)

Materials	Concrete blocks			Brick	Clay tile
	8″ x 16″	8″ x 18″	5″ x 12″	2¼″ x 3¾″ x 8″	12″ x 12″
4-Inch walls					
Units—No.	112	100	220	617	93
Mortar—cu ft	3.25	3.1	5	8	2.5

6-Inch walls					
Units—No.	112	100	220	----	93
Mortar—cu ft	3.25	3.1	4	----	3.6
8-Inch walls					
Units—No.	112	100	220	1233	93
Mortar—cu ft	3.25	3.1	5	20.5	4.9
12-Inch walls					
Units—No.	112	100	---	1849	93
Mortar—cu ft	3.25	3.1	---	32.9	7.3

Mortar for concrete block, ⅜-in. joints on ends and bed planes of face shells. ½-in. for brick and tile. Waste 25% for hollow blocks; 10% for brick.

Materials	Mortar—mat'l per cu ft			Mortar: cu ft per 1,000 brick			
	Mix by vol			Wall thickness			
	1–3	1–0.15–3	1–1–6	Joint	4"	8"	12"
Cement bags	0.30	0.28	0.15	⅜"	9.0	11.8	13.0
Lime, cu ft	---	0.08	0.15	½"	11.7	15.1	16.3
Sand, cu ft	0.97	0.93	0.99	⅝"	14.8	18.3	19.6

CHAPTER 12
WOOD CONSTRUCTION

282. Wood Classification

Wood is a basic, almost universal, construction material and is used widely by the Army, particularly in theater of operations (TO) building. To prepare detail drawings, notes, schedules, and bills of material for wooden structures, a construction draftsman should be familiar with the classification of wood.

283. Species

Native species of trees are divided into two classes: hardwoods, which have broad leaves; and softwoods, which have leaves like needles or scales. No definite degree of hardness divides them. In fact, many hardwoods actually are softer than an average softwood.

a. Hardwoods. Some familiar native species of the hardwood, or deciduous, class are ash, birch, hickory, oak, beech, and maple. All are board leaved. Lumber cut from hardwoods is not generally used for the construction of structural framing, but is used principally for flooring, special interior paneling, trim, and doors.

b. Softwoods. Most native species of softwood bear cones and are called coniferous woods. Some familiar softwoods are pine, spruce, fir, cedar, and redwood. These woods are worked easily and make suitable material for structural framing. Of the various softwoods, southern yellow pine and Douglas fir are the varieties used most frequently for construction.

(1) *Southern yellow pine.* All southern yellow pine used for structural purposes is classified as longleaf or shortleaf. The wood is dense, moderately hard, and strong. When described in a bill of material or specifications, longleaf yellow pine is abbreviated as LLYP, and shortleaf yellow pine is abbreviated as SLYP.

(2) *Douglas fir.* Douglas fir in the form of lumber and timber is one of the most desirable woods for structural purposes. It also has extensive use as poles, piling, and ties, and large quantities are cut into veneer for plywood and other purposes. It is strong, moderately hard, and heavy. In general, it has a tendency to check and split and does not hold paint well.

284. Grading

Softwoods and hardwoods are graded by different standards. Only softwood grading is considered here because as explained previously, hardwoods are rarely used for structural purposes and the construction draftsman is seldom required to described hardwoods in the notes or bill of material.

a. Grading Criteria. In most cases, the grade of lumber is based on the number, character, and location of features such as knots, pitch pockets, and so on, which are commonly called defects and defined as any irregularity occurring in or on wood that may lower its strength, durability, or utility values. The best grades are practically free of these features; others, comprising the greater bulk of lumber, contain fairly numerous knots and other natural growth characteristics.

b. Select Lumber. Select lumber is the general classification for lumber of good appearance and finishing qualities. Grades A and B are suitable for natural finishes; grades C and D are suitable for paint finishes.

• *c. Common Lumber.* Common lumber is the general classification for lumber containing the defects and blemishes described above. The grades are numbers 1 through 5. Nos. 1 and 2 are for use without waste in framing and sheathing; No. 3 can be used for temporary construction. Nos. 4 and 5 are NOT generally used in construction because they are of poor quality and are subject to much waste.

285. Surfacing and Worked Lumber

Lumber is further classified according to the manner in which it is milled.

a. Surfacing. Lumber is classified as rough or dressed, according to the amount of planing done in the mill.

(1) *Rough.* Rough lumber is as it emerges from the saw, or unplaned; when indicating rough lumber, the abbreviation is RGH.

(2) *Dressed.* Dressed, or surfaced, lumber is the rough lumber after it has been run through a planer. It may have any combination of edges and sides dressed, such as S1S, surfaced on one side; S2S, surfaced on two sides; S1S1E, surfaced on one side and one edge; and S4S, surfaced on four sides.

b. Worked Lumber. Worked lumber has been run through a machine such as a matcher, shaper, or moulder; it can be matched, shiplapped, or patterned.

(1) *Matched lumber.* Matched lumber is cut so that it interlocks. A common type is tongue and groove (T & G), in which a groove is cut in one edge and a mating bead, or projection, is cut on the other edge. Boards are frequently dressed and matched (D & M), with the tongue and groove in the center, making the pieces center matched.

(2) *Shiplapped lumber.* Shiplapped pieces are cut with a square step on either edge, the projection on one edge at the bottom and at the top of the piece on the other edge; in this way, adjacent boards overlap each other to form a joint.

(3) *Patterned lumber.* Patterned lumber is cut in many designs and is used for trim.

286. Actual and Nominal Sizes of Lumber

Sizes of lumber are specified by nominal dimensions which differ from the actual dimensions of the milled pieces. When lumber is run through a saw and planer its nominal size remains the same but its actual size is reduced by the amount of surfacing it undergoes. Approximately 1/4 inch is planed off each side in surfacing. Lumber is also divided into groups according to size, namely: strips—pieces less than 2 inches thick and under 8 inches wide; boards—less than 2 inches thick and more than 8 inches wide; dimensioned lumber—2 to 6 inches thick and of any width; and timber—6 or more inches in the least dimension. Dimensions of some common sizes are given in table VII.

Table VII. Standard Sizes of Lumber (inches)

STRIPS

Nominal size	1 x 2	1 x 3	1 x 4	1 x 6
Dressed size	25/32 x 1 5/8	25/32 x 2 5/8	25/32 x 3 5/8	25/32 x 5 5/8

BOARDS

Nominal size	1 x 4	1 x 6	1 x 8	1 x 10	1 x 12
Actual size, common			25/32 x 7 1/2	25/32 x 9 1/2	25/32 x 11 1/2
Actual size, shiplap *	25/32 x 3 1/8	25/32 x 5 1/8	25/32 x 7 1/8	25/32 x 9 1/8	25/32 x 11 1/8
Actual size, T & G *	25/32 x 3 1/4	25/32 x 5 1/4	25/32 x 7 1/4	25/32 x 9 1/4	25/32 x 11 1/4

* Width of face.

DIMENSIONED LUMBER

Nominal size	2 x 4	2 x 6	2 x 8	2 x 10
Actual size	1 5/8 x 3 5/8	1 5/8 x 5 1/2	1 5/8 x 7 1/2	1 5/8 x 9 1/2
Nominal size	4 x 4	4 x 6	4 x 8	4 x 10
Actual size	3 5/8 x 3 5/8	3 5/8 x 5 1/2	3 5/8 x 7 1/2	3 5/8 x 9 1/2
Nominal size	6 x 6	6 x 8	8 x 8	8 x 10
Actual size	5 1/2 x 5 1/2	5 1/2 x 7 1/2	7 1/2 x 7 1/2	7 1/2 x 9 1/2

287. Board Feet

Lumber quantities are measured by feet, board measure, or board feet, abbreviated as FBM or BF in the bill of material. One board foot is equivalent to a piece of wood 1 foot square and 1 inch thick, or 144 cubic inches. To calculate FBM multiply the thickness in inches by the width in feet and the length in feet and divide by 12. *For example,* the number of board feet in a 2 x 10-inch piece, 12 feet long can be calculated as—

$$2 \times \frac{10}{12} \times 12 = 20 \text{ board feet or } 20 \text{ FBM}$$

Table VIII gives the number of feet, board measure, for the more common sizes of lumber.

Table VIII. Wood Construction

Size of lumber (in.)	Length in feet							
	8	10	12	14	16	18	20	22
	Feet, board measure							
1 by 4	2⅔	3⅓	4	4⅔	5⅓	6	6⅔	7⅓
1 by 6	4	5	6	7	8	9	10	11
1 by 8	5⅓	6⅔	8	9⅓	10⅔	12	13⅓	14⅔
1 by 10	6⅔	8⅓	10	11⅔	13⅓	15	16⅔	18⅓
1 by 12	8	10	12	14	16	18	20	22
1 by 14		11⅔	14	16⅓	18⅔	21	23⅓	25⅔
2 by 4	5⅓	6⅔	8	9⅓	10⅔	12	13⅓	14⅔
2 by 6	8	10	12	14	16	18	20	22
2 by 8	10⅔	13⅓	16	18⅔	21⅓	24	26⅔	29⅓
2 by 10	13⅓	16⅔	20	23⅓	28⅔	30	33⅓	36⅔
2 by 12	16	20	24	28	32	36	40	44
2 by 14	18⅔	23⅓	28	32⅔	37⅓	42	46⅔	51⅓
2 by 16	21⅓	26⅔	32	37⅓	42⅔	48	53⅓	58⅔
3 by 6	12	15	18	21	24	27	30	33
3 by 8	16	20	24	28	32	36	40	44
3 by 10	20	25	30	35	40	45	50	55
3 by 12	24	30	36	42	48	54	60	66
3 by 14	28	35	42	49	56	63	70	77
3 by 16	32	40	48	56	64	72	80	88
4 by 4	10⅔	13⅓	16	18⅔	21⅓	24	26⅔	29⅓
4 by 6	16	20	24	28	32	36	40	44
4 by 8	21⅓	26⅔	32	37⅓	42⅔	48	53⅓	58⅔
4 by 10	26⅔	33⅓	40	46⅔	53⅓	60	66⅔	73⅓
4 by 12	32	40	48	56	64	72	80	88
4 by 14	37⅓	46⅔	56	65⅓	74⅔	84	93⅓	102⅔
4 by 16	42⅔	53⅓	64	74⅔	85⅓	96	106⅔	117⅓
6 by 6	24	30	36	42	48	54	60	66
6 by 8	32	40	48	56	64	72	80	88
6 by 10	40	50	60	70	80	90	100	110
6 by 12	48	60	72	84	96	108	120	132
6 by 14	56	70	84	98	112	126	140	154
6 by 16	64	80	96	112	128	144	160	176
8 by 8	42⅔	53⅓	64	74⅔	85⅓	96	106⅔	117⅓
8 by 10	53⅓	66⅔	80	93⅓	106⅔	120	133⅓	146⅔
8 by 12	64	80	96	112	128	144	160	176
8 by 14	74⅔	93⅓	112	130⅔	149⅓	168	186⅔	205⅓
8 by 16	85⅓	106⅔	128	149⅓	170⅔	192	213⅓	234⅔
10 by 10	66⅔	83⅓	100	116⅔	133⅓	150	166⅔	183⅓
10 by 12	80	100	120	140	160	180	200	220
10 by 14	93⅓	116⅔	140	163⅓	186⅔	210	233⅓	256⅔
10 by 16	106⅔	133⅓	160	186⅔	213⅓	240	266⅔	293⅓
12 by 12	96	120	144	168	192	216	240	264
12 by 14	112	140	168	196	224	252	280	308

Size of lumber (in.)	Length in feet							
	8	10	12	14	16	18	20	22
	Feet, board measure							
12 by 16	128	160	192	224	256	288	320	352
14 by 14	130⅔	163⅓	196	228⅔	261½	294	326⅔	359⅓
14 by 16	149⅓	186⅔	224	261⅓	298⅔	336	373⅓	410⅔
16 by 16	170⅔	213⅓	256	298⅔	341⅓	384	426⅔	469⅓

288. Light Framing

The wood framing for a structure is a skeleton of light structural members. Wood-framed building may be from one to three stories in height. Figure 126 is an isometric view of a theater of operations building, giving the nomenclature of the varous framing members.

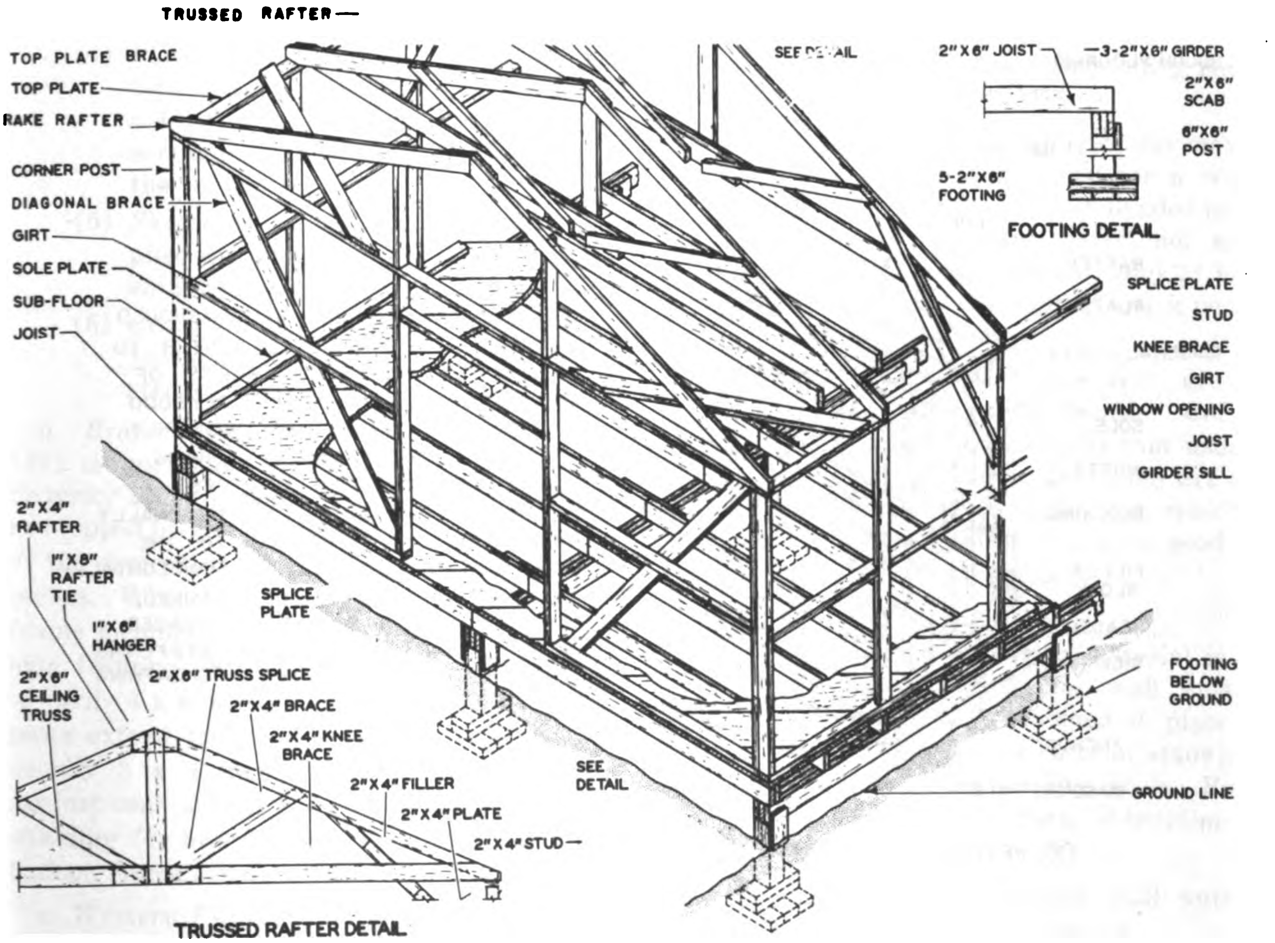


Figure 126. Light framing details.

289. Types of Light Framing

There are three principal types of framing for light structures: balloon, braced, and western (fig. 127).

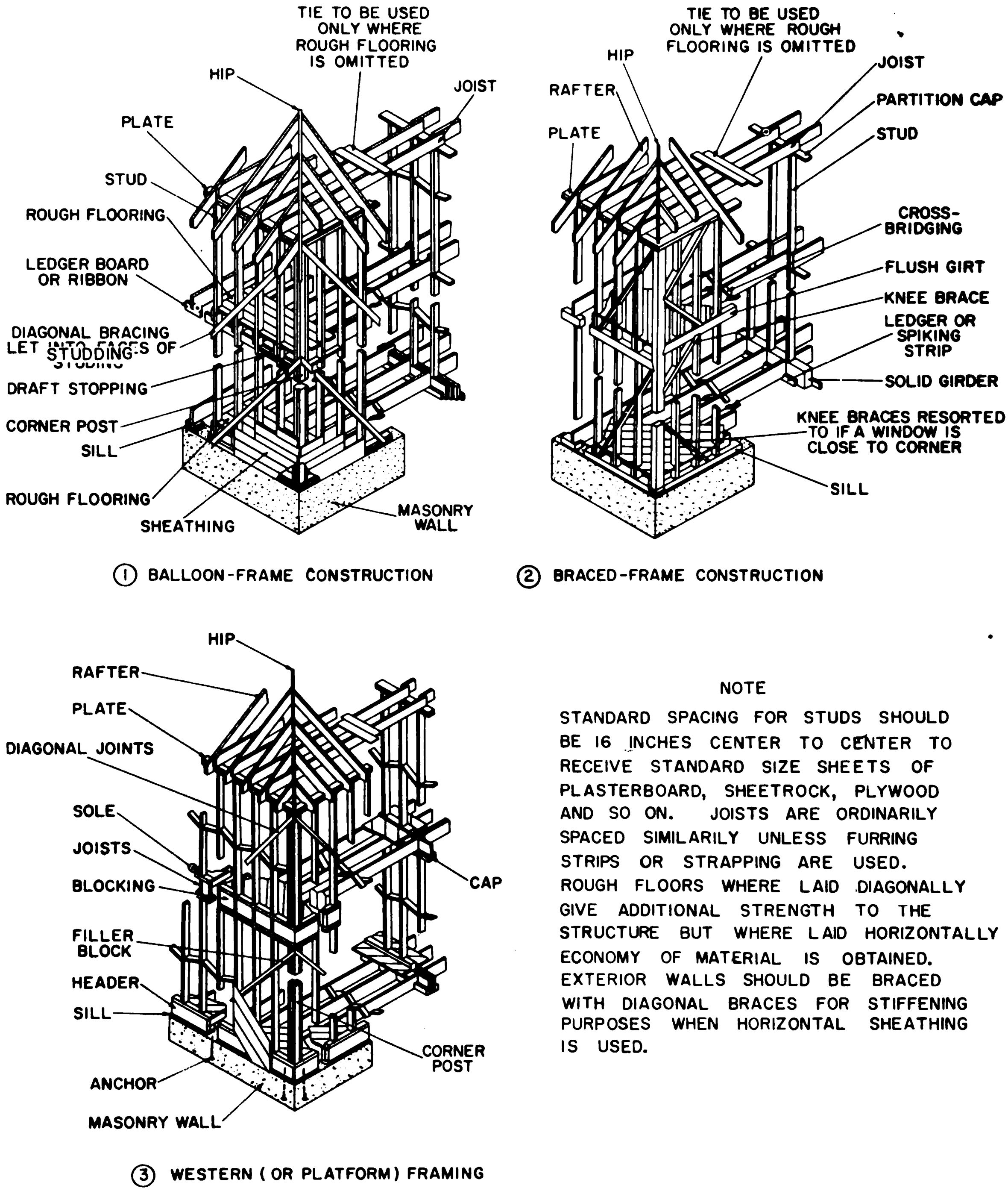


Figure 127. Framing for light structures.

a. Balloon Frame. The balloon frame (1, fig. 127) is the most widely used type of light framing, chiefly because it is economical. The major difference between balloon and braced framing in a multistory building is that in balloon framing the studs run the full length, from sill to rafters. It is customary for second-floor joists to rest on a 1 x 4-inch ribbon that has been set into the studs. Although a balloon frame is less rigid than a braced frame, it represents a saving in labor and material and is quite suitable for two-story structures. Typical components for a balloon frame are—

(1) *Sill.* The sill may be a 4 x 4 or two 2 x 4 pieces spiked together.

(2) *Posts.* Corner posts are 4 x 4 inches.

(3) *Studs.* Studs are 2 x 4's set 16 inches on centers; the 16 inch centering is a satisfactory standard because of the spacing requirements for interior lath and exterior sheathing; it also enables floor joists to be nailed to the studs.

(4) *Plates.* The plate is placed across the tops of the studs. The plate, which is a 4 x 4 or two 2 x 4's spiked together, serves as a lower base for the ends of the roof rafters.

(5) *Sheathing.* Sheathing is generally applied diagonally to assist in strengthening the structure.

(6) *Cross bracing.* Cross bracing between joists is required for balloon-framed structures to increase their rigidity.

b. Braced Frame. A braced frame (2, fig. 127) is much more rigid than a balloon frame. Exterior studs extend only between floors and are topped by girts that form a sill for the joists of the succeeding floor. Girts usually are 4 x 6 inches. With the exception of studs, braced-frame members are heavier than those in balloon framing. Sills and corner posts are customarily 4 x 6 inches. Unlike the studs, corner posts extend from sill to plate. Knee braces, usually 3 x 4 inches, are placed diagonally against each side of the corner posts. Interior studding for braced frames is the same as for balloon frame construction.

c. Western Frame. The western or platform frame (3, fig. 127) is used extensively in military construction. It is similar to the braced frame, but has boxed-sill construction at each floor line. For one-story structures, the western frame is preferred since it permits both the bearing walls and the nonbearing walls, which are supported by the joist, to settle uniformly.

290. Covering Frame

a. Rough Sheathing. Joists are covered with subflooring usually made of tongue-and-groove (T & G) boards. Studs are covered on the outside with sheathing that may be placed hozizontally or diagonally. Rough roofing is placed across the rafters. Fabricated fiber boards or a sheathing grade of plywood can be used for rough flooring and sheathing in place of T & G boards.

b. Exterior Finished Siding. Rough-finished sheathing is covered with building paper first, then the selected siding material is fastened in place. Siding may be boards worked into specific shapes, for example bevel siding, drop siding, and shiplap siding. Theater of operations buildings may be constructed with no siding covering the roofing paper.

(1) *Venner.* Brick or stone veneer may be used as exterior siding for a wood-frame building. Brick is bonded to the sheathing at intervals of not more than 16 inches vertically and 24 hozizontally. Lintels support brick veneer over all openings.

(2) *Fascia boards.* Rafter ends are inclosed with fascia boards, wooden cornices, or verge boards that usually are cut to a specific size. They are frequently made of white pine, which is easily worked and presents a good appearance when painted.

c. Interior Finishes.

(1) *Insulation.* Insulation material is installed before interior wall finishes and is normally fastened in place by nailing between the exterior studs and, if required, the ceiling joists. Rockwool is a common form of building insulation.

(2) *Wall finishes.* Interior wall finishes may be one of the following:

(*a*) *Plaster on metal lath.* Metal lath is an expanded ribbed metal that is nailed to the studding where it serves as a base for plaster. Before plaster is applied, grounds, usually 1- x 2-inch strips, are placed around the base and top of the studs and around all openings. These serve as a stop for the plaster, which is usually applied in three coats.

(*b*) *Plaster and composition board.* The base for the plaster in this instance is a composition board usually perforated to provide a key for the plaster.

(*c*) *Plasterboard.* Plasterboard is a composition board forming a finished surface after painting. It is nailed directly to the studs.

(*d*) *Miscellaneous.* Plywood and various kinds of wood paneling may be used to cover studding in the building interior.

(3) *Ceilings.* Ceilings can be finished in the same manner as sidewalls. Acoustic tiles often are used when sound deadening is desired.

(4) *Flooring.* Floor finishes are placed over the subflooring. A deadening felt may be placed between it and the finished floor. Hardwoods such as maple, birch, oak, and beech are commonly used in permanent construction. Wood-block strips joined together at the factory to make 9 x 9-inch blocks are used sometimes and are fastened to the subfloor with a mastic adhesive. Other floor coverings include plywood, asphalt tile, and linoleum.

d. Finish Schedule. A type of schedule used for buildings with a number of different rooms is the finish schedule. This schedule lists the individual spaces either by room or space number and lists the finish requirements of walls, floors, ceilings, and other portions for each room. An abbreviated typical finish schedule (first floor) is presented below.

Room no.	Room name	Floor	Base	Walls	Ceilings	Wainscot	Remarks
101	Hall	Asphalt tile	Rubber	Plaster	Plaster		
102	Office	Asphalt tile	Rubber	Plaster	Plaster		
103	Lavatory	Terrazzo	Terrazzo	Plaster	Plaster	Ceramic tile	Wainscot 6'-0" except shower room full height
104	Conference room	Oak strip	Wood	Plaster	Acoustic tile	Pine panels	Wainscot 6'-0"

291. General Drawing Practices With Wood Structures

The basic procedures in preparing drawings for a frame structure have been described in chapter 10. A construction draftsman, however, should remain aware that he is translating a designer's construction into a conventional, graphic language and that when transmitted to mechanics in the field the set of working drawings should contain all the information needed for the erection and completion of a structure.

292. Roof Trusses

Roof trusses are designed to span clear areas up to 200 feet. Many different types of trusses, among them the bowstring, crescent, Belgian, and Fink, have been designed to account for various practical requirements. Timber connections on a wood truss are made with the use of some of the connectors shown in figure 129. Truss details are shown in TM 5–302.

293. Roofing

Although the term roofing usually is interpreted to mean the material covering the rough sheathing of a roof, it also may be considered to include roof framing members such as rafters and purlins as well as flashing and trim.

a. Framing Members. In most instances of light framing, roof sheathing can be applied directly over the rafters. If wider spans are encountered, purlins are used over roof trusses to stiffen roof structure, in which case the trusses correspond to girders and the purlins to joists. Where purlins are used, sheathing is applied over them.

b. Roofing Materials. Roofing areas and materials are measured by the square, which is equivalent to 100 square feet. Shingles are the exception to this, being measured by the bundle of 1,000. Some of the more frequently encountered roofing materials are described below.

(1) *Roofing paper and felt.* Roofing paper and felt can be used under roofing materials such as asphalt shingles (paper) and asbestos or slate shingles (felt); the felt is impregnated with tar or asphalt. Both are applied to the sheathing with large-headed nails.

(2) *Asphalt-roll roofing.* Asphalt-roll roofing can be used as an outside roofing material for temporary buildings and can be applied directly over sheathing without roofing paper underneath. It is classified by weight, for example, 45-pound and 65-pound roofing. Prepared 45-pound roofing should be lapped 4 inches horizontally and 8 inches vertically; edges should be cemented with roofing cement and nailed with roofing nails 3 inches on centers.

(3) *Wood shingles.* Wood shingles are nailed to 1- x 4-inch shingle strips on 6-inch centers that are nailed to the sheathing. Shingles come in random widths and usually are from 16 to 18 inches long. They overlap to form a roof covering three layers thick.

(4) *Built-up roofing.* Built-up or composition roofing is used for comparatively flat roofs. It is applied in layers or plies, a ply consisting of a layer of roofing felt over a layer of tar or asphalt. The tar or asphalt is applied hot, creating a bond for the felt. Two- to five-ply composition roofs are customary.

(5) *Other materials.* Shingles are available in asphalt, asbestos, slate, and metal as well as wood. Metal roofing comes in flat, crimped, or corrugated sheets. Two- or three-ply canvas bonded to the sheathing with paint and fastened with galvanized steel tacks also is used as a roofing material; it is waterproofed by applying additional coats of paint.

294. Water Control on Roofs

a. Flashing. Flashing signifies both the material used and the process of making watertight the roof intersections and other exposed places such as those caused by the penetration of a chimney or smokejack (fig. 128) through the roof.

(1) *Roof intersections.* The most frequently encountered roof intersections are classified as ridges, hips, and valleys. The angle at which a roof slopes is called the pitch.

(2) *Flashing materials.* Normally sheet metal strips or sections are used for flashing material, but prepared-roofing strips can be used for cheap and one-season construction. Metal sheets or 5- x 7-inch shingles are commonly used around chimney and vent openings. Rolls of metal or asphalt roofing can be used for ridge, valley, and hip flashing.

b. Roofing Trim. Roofing trim signifies the gutters and downspouts, or leaders, used to collect and lead to the ground water draining from the roof. Roofing trim is not required for temporary buildings because drainage is diverted beyond building walls by eaves. An eave is the lower edge of a roof that overhangs the wall. Roofing trim is measured by the lineal foot.

(1) *Gutters.* A gutter usually is a semicircular or rectangular trough attached to the lower edge of the roof by hooks or hangers. It is made of galvanized steel or copper. Gutters are a minimum of 4 inches wide and have a minimum slope of 1 inch in 16 feet. For gutters larger than 4 inches, the width is determined by the roof area being drained.

(2) *Downspouts.* Downspouts must be large enough to accelerate the velocity of the water entering from the gutter. A sufficient number of downspouts must be provided to carry water away promptly.

295. Representation of Roofs

a. General Drawings. Roofing information is indicated in elevation views in general drawings and roof plan. Because all pitched roofs are inclined to two of the principal planes of projection, the principal dimensions are shown in a combination of elevation or sectional views.

(1) *Notes and symbols.* Roofing material is identified by exterior symbols and specific notes. Gutters are noted in the front view, downspouts in the side view. Chimney or smokejack material can be noted in addition to the type of ridge.

(2) *Pitch diagram.* If a set of drawings does not include a through section, the pitch diagram is placed above the ridgeline in the front elevation.

b. Construction Details. The details of roof construction and roofing material are shown in roof framing plans, typical wall details, and specific detail drawings showing elements such as the installation of flashing around roof penetrations.

(1) *Wall sections.* A wall section (fig. 102) includes a detail at the eaves showing the manner in which rafters are framed into the top plate. Section symbols indicate that sheathing, roofing paper or felt, and outside materials are used. Specific notes identify materials by title and size and give the spacing of rafters.

(2) *Specific details.* Figure 128 shows an isometric view of a detail of smokepipe installation and the flashing needed

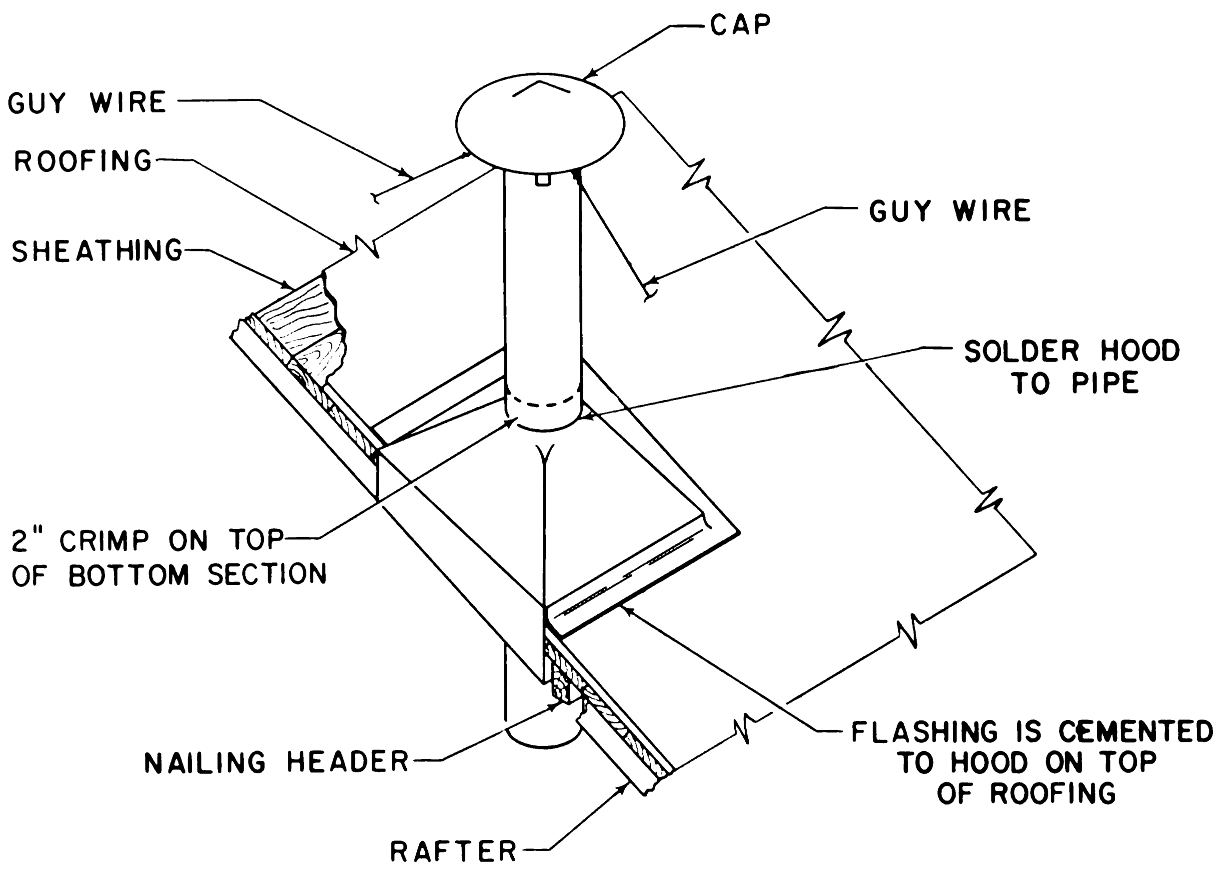


Figure 128. Smokepipe details.

around the roof penetration. In a construction drawing, this would be shown as a specific section in orthographic projection. Other specific details might be used to show sectional views of construction at ridge ventilators of flashing installation at ridges and valleys.

296. Timber Construction

a. Definition. Timber construction, or heavy wood framing, implies the use of framing members at least 6 inches in dimension. Members are connected with bolts, driftpins, or special timber connectors. Long, unsupported areas between walls are spanned by built-up roof trusses rather than rafters. Buildings with heavy timber framing and exterior walls of masonry or reinforced concrete are classified as mill construction. Heavy warehouses, trestle bridges, and towers are among other types of timber structures.

b. Connectors. Split rings, spikes, bolts, and driftpins are the connectors used most frequently for timber construction. Figure 129 illustrates some special connectors and lists the identifying symbols approved for use in military drawings. Symbols are compiled from MIL–STD–18A.

(1) *Split rings.* Split rings are available in 2½-, 4-, and 6-inch diameter sizes and are used for making wood-to-wood connections with medium and heavy loads. A hole must be drilled for the bolt and a groove made for the ring. If columns are built up of several pieces, for example, three 2 x 12-inch pieces to make a 6 x 12-inch column, the various pieces normally are fas-

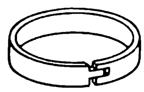
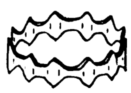
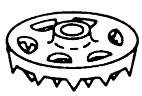
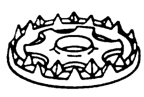
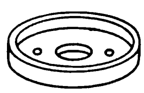
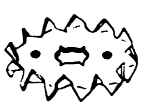
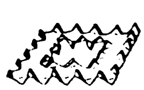
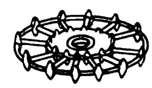
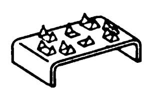
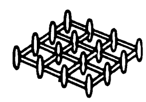
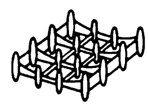
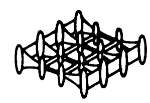
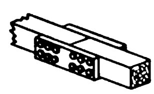
DESCRIPTION	SYMBOL	ILLUSTRATED USE	PICTORIAL
SPLIT RING	SR	$2\frac{1}{2}$ SR	
TOOTHED RING	TR	2TR	
CLAW PLATE, MALE	CPM	$2\frac{5}{8}$ CPM	
CLAW PLATE, FEMALE	CPF	$3\frac{1}{8}$ CPF	
SHEAR PLATE	SP	4SP	
BULLDOG, ROUND	BR	$3\frac{3}{4}$ BR	
BULLDOG, SQUARE	BS	5BS	
CIRCULAR SPIKE	CS	$3\frac{1}{8}$ CS	
CLAMPING PLATE, PLAIN	CPP	5x5CPP	
CLAMPING PLATE, FLANGED	CPFL	5x8CPFL	
SPIKE GRID, FLAT	SGF	$4\frac{1}{8}$x$4\frac{1}{8}$SGF	
SPIKE GRID, SINGLE CURVE	SGSC	$4\frac{1}{8}$x$4\frac{1}{8}$SGSC	
SPIKE GRID, DOUBLE CURVE	SGDC	$4\frac{1}{8}$x$4\frac{1}{8}$SGDC	
WOOD SPLICE PLATES			

Figure 129. Timber construction symbols and connectors.

tened together with 4-inch split ring connectors. A 3/4-inch bolt is used in combination with a 4-inch split ring after a high-strength, threaded rod assembly has forced the split ring to penetrate the wood.

(2) *Spikes.* Spikes are used for smaller sizes of lumber, as in timber trestle construction, to connect horizontal planking to stringers.

(3) *Bolts.* Bolts commonly used in timber construction vary in diameter from 1/4 to 1 1/4 inches. Measured from the underside of the head, lengths range from one inch to any length desired. Bolts are threaded and have square heads. They take square or hexagonal nuts. Bolts are placed through predrilled holes, with a washer at each end to increase the bearing area of the wood, and are fastened.

(4) *Driftpins.* Driftpins are large size spikes from 1/2 to 1 1/4 inch in diameter and from 8 to 24 inches long. They are driven in predrilled holes which are the same diameter or slightly smaller than the pin diameter.

297. Timber Trestles

Timber trestles are used frequently as bridges (fig. 130). A construction draftsman should be familiar with the nomenclature used in timber trestle construction, which differs from that used for heavy framing in buildings. The principal members of a timber trestle are a series of pile bents with a timber cap for each bent, wood stringers, and a wood deck. Other members include handrails and posts, headers, curbs, scupper blocks, bridging for the stringers, and cross bracing for the bents. Timber used for trestles usually is impregnated with a preservative such as creosote.

a. Bents. A bent is a single vertical framework consisting of vertical piles or posts and a horizontal timber cap. A trestle is supported by a series of bents that may be spaced from 10 to 20 feet on centers. Posts resting on mudsills or concrete piers may be used as vertical members. The vertical members in each bent are cross-braced for rigidity by bolting planks diagonally

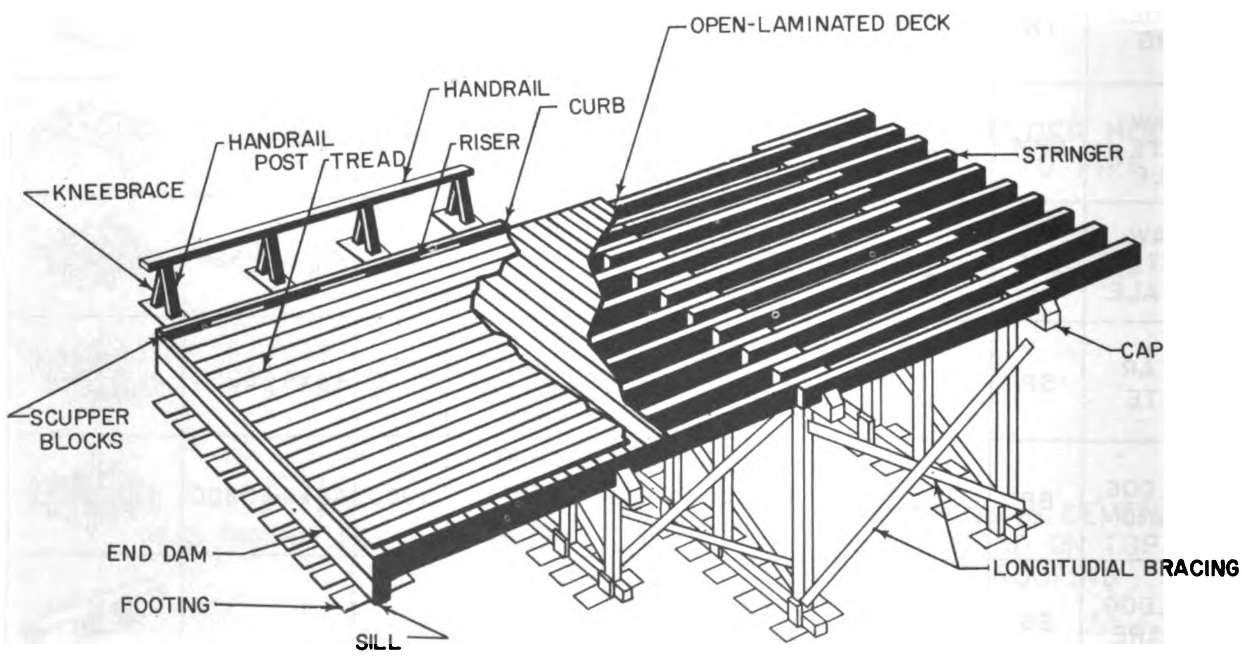


Figure 130. Timber trestle bridge.

across the bent on either side of the vertical members.

b. Timber Caps. Timber caps generally are from 12 x 12 inches to 12 x 16 inches in size. They are connected to the piles by driftpins, ½ to ¾ inch in diameter, driven approximately 14 inches into the piles. Piles are prepared for driftpins by drilling.

c. Stringers. Common stringer sizes are 4 x 16, 6 x 16, and 8 x 16 inches, the size depending on the span and load for which the trestle is designed. Stringers are placed on edge and fastened to the caps with driftpins. They should lap over bent caps at either end to permit successive stringers to be bolted together. Cross bridging, 2 x 6 or 3 x 8 inches in size, is nailed to stringers at third points between bents. Stringers usually are surfaced on one side to insure a base of uniform elevation for the deck.

d. Deck. Decks are made of planks installed perpendicularly to stringers, that is, parallel to bents. They may be nailed flat to the stringers or installed on edge to form a laminated deck. Adjacent planks forming the laminations are nailed together. Laminated decks may be surfaced with asphalt or concrete.

e. Header Boards. Header boards are installed flat (when a surfacing material is used) along either edge of the deck and connected to the deck by nailing. They run parallel to the stringers and their purpose is to contain the surfacing material and to support scupper blocks and curbs. Header boards may be up to 16 inches wide and as thick as the surfacing material.

(1) *Scupper blocks.* Scupper blocks may range in size from 2 x 8 to 3 x 12 inches. Blocks are approximately 8 to 10 feet long and are spaced about 12 inches apart to allow rainwater to drain from the trestle surface.

(2) *Curbs.* Curbs are made of timbers varying from 8 x 8 to 12 x 12 inches. Successive lengths are butted together to form a continuous barrier on either side of the trestle. Bolts passing through curbs, scupper blocks, and the decking fasten the first two in position.

f. Handrails and Posts. Handrail posts are vertical timbers fastened to stringers, the deck, and curbs with bolts. They are spaced on 8- to 12-foot centers and are grooved, or lapped, to receive handrails. Handrails are bolted to posts; joints usually are made at alternate posts to provide a continuous appearance.

298. Representation of Construction Trestles

The set of working drawings for building a trestle corresponds to that for building construction. Elevation, deck framing plan, section details, and a bill of material are needed. A cutting list also may be included.

a. Elevation. The elevation is drawn to small scale (¼″ = 1′-0″) and shows the trestle span relative to the existing terrain or grade. Spacing between bents can be given in this view.

b. Framing Plan. A deck framing plan corresponds to a floor framing plan. It shows the sizes and locations of stringers and bridging and indicates, through specific notes, the methods of connection.

c. Sections. Typical sections are drawn to show the sizes, bracing, and spacing of vertical members in a bent. The methods of connecting all members shown in a typical section are indicated graphically and with specific notes. Notes are used to give the sizes and functions of all members shown, for example, a 6 x 8-inch handrail. Notes are written in lowercase letters with the first letter of each word in uppercase. Location dimensions are used to show spacing and relative locations but the sizes of the individual members are given in specific notes.

d. Details. Details show methods of connection at large scale. A typical detail might show the method of bolting a handrail post to stringer, deck, and curb. The same detail also would show the bolt passing through curb, scupper board, header, and deck.

299. Water Tower

Figure 131 presents a simplified drawing of a tower for a 4,000-gallon water storage tank. Although minor location dimensions have been omitted for the sake of clarity, this is a typical working drawing of a timber structure and illustrates the manner in which members and methods of connection are drawn and identified.

a. Foundation Plan. The foundation plan gives the horizontal dimensions needed to lay

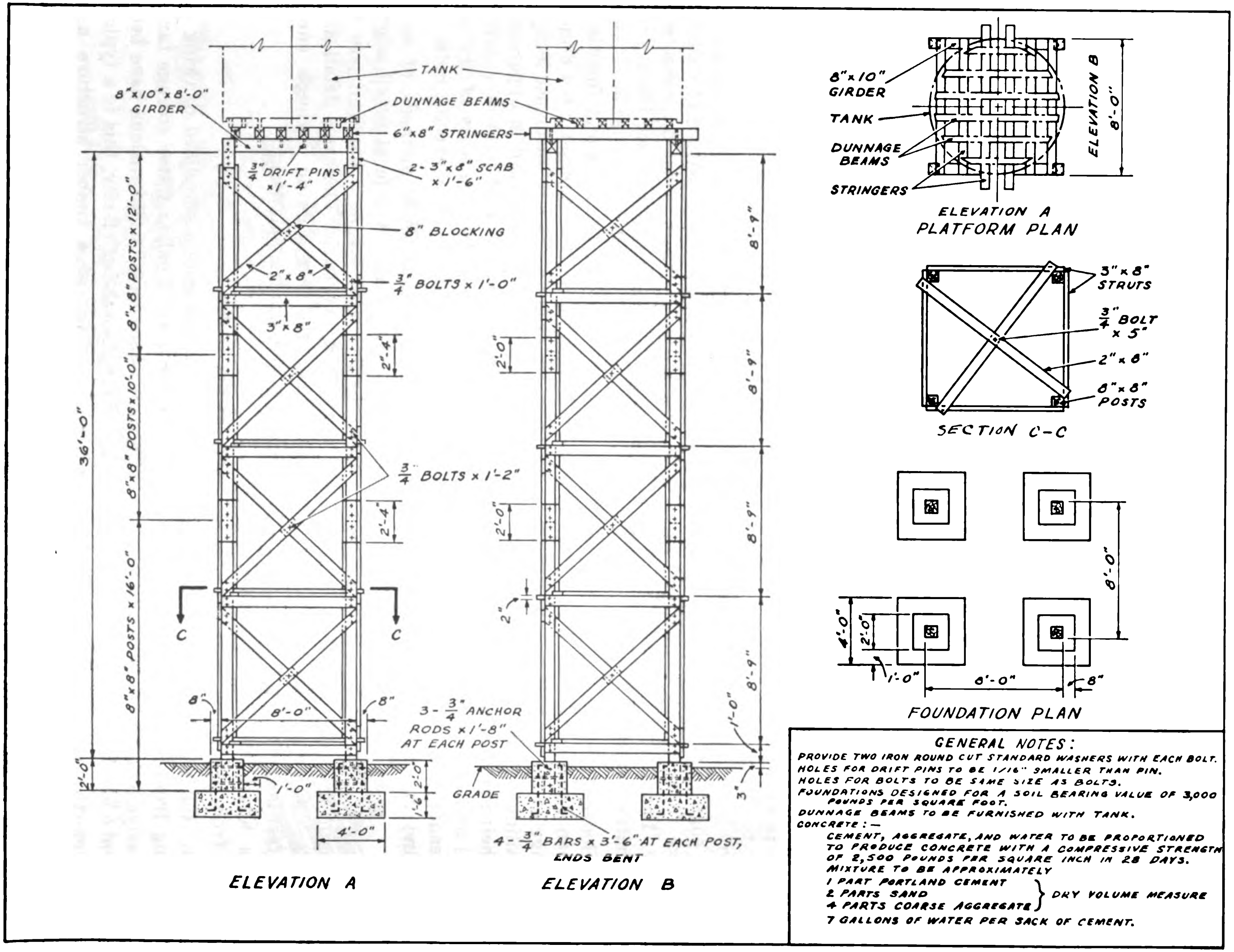


Figure 131. Water tower.

out the elevations. In addition to showing the spacing between columns, or posts, it shows the size dimensions of footings. Note the economy with which dimensions are presented.

b. Platform Plan. The platform plan shows that the same 8-foot spacing is maintained between the outside edges of the vertical posts. Like the deck plan of a trestle, it shows the spacing of stringers, although these location dimensions have been omitted in this drawing. Girder size is noted in this view and stringer sizes in the elevation views. Dunnage beam sizes are not noted because the general notes state that dunnage beams are supplied with the tank, meaning that they do not have to be fabricated on the job. Tank and dunnage beam locations are indicated with the phantom-like symbol because their erection is not part of this job. The platform plan also shows the relative locations of elevations *A* and *B*.

c. Elevations A and B. These show vertical members, location dimensions, and methods of connection. An examination of the elevations shows the tower to be composed basically of 4 posts supporting a platform on which a water storage tank can be placed at an elevation sufficient to supply water under the required pressure. Each column is composed of three 8 x 8-inch posts 16, 10, and 12 feet in length, respectively. Posts must be of sufficient size to prevent buckling under the load, foundations must be of the proper compressive strength to support the vertical loads, and the soil of sufficient bearing capacity to support foundations of the size shown. The posts are braced in three ways for rigidity. A draftsman should examine the ways in which the following connections are shown on the drawing.

(1) *Base.* Notes and drawings show that four 3/4-inch dowels have been bonded into each concrete footing base. The dowels are 42 inches long and are arranged in pairs on the opposite sides of each post. Posts and dowels are connected to each other with three 3/4-inch anchor rods, two anchor rods parallel to elevation *A* and one parallel to elevation *B*. Posts, anchor rods, and dowels are inclosed in 2 x 2 x 2-foot concrete piers. Note that the excavations required for footings are to be backfilled to 3 inches below the tops of the piers.

(2) *Splice plates.* Splice plates, are used to connect successive column sections. Location dimensions for bolts have not been included in this illustration because of the small scale, but they must be provided in working drawings. Splice plates are bolted to posts. A general note covers the number and kind of washers required per bolt.

(3) *Bracing.* Posts are bracd with horizontal 3- x 8-inch struts, and 2- x 8-inch cross bracing placed horiozntally (Section C–C) and vertically. Note that the vertical cross bracing is drawn with the hidden-line symbols for the ends of one of each pair of diagonals. This indicates that diagonals are placed on opposite sides of the 8- x 8-inch posts and explains why 8-inch blocking is required between diagonals at the point where they are bolted together.

(4) *Post-girder connection.* Elevations *A* and *B* show that 2 horizontal 8″ x 10″ x 8′-0″ girders span the posts and form a base for the tank platform. Girders are fastened to posts at either end with two 3″ x 8″ x 1′-6″ scabs. Six 6- x 8- inch stringers are fastened to the girders with driftpins. A general note covers the size holes to be drilled for driftpins.

d. Sections. A single cross sectional view, Section C–C, is required to show the arrangement of the horizontal bracing. Notice that no hidden-line symbol is used at the ends of the bracing, and no blocking is specified in notes.

e. Symbols. Note that the ends of framing timbers are indicated by intersecting diagonals. Timber in section, as shown in Section C–C and the foundation plan, is indicated by a different symbol. Note also the symbols used for concrete, dowels, and soil. Use of the phantom line to indicate tower and dunnage beam location has been described.

f. Notes. Draftsmen should study the use of specific notes, paying attention to the way in which mmbers are identified by size and function.

g. Dimensions. Note that horizontl dimensions are given in plan views and vertical dimensions in elevations. Study the manner in which dimensions are presented without repetition.

CHAPTER 13
MACHINE DRAWING

Section I. SCREWS, BOLTS, RIVETS AND WELDS

300. General Requirements

It would be impossible to build any structure or machine out of solid materials. It is necessary to build by joining component parts into larger parts or a complete assembly. In any case the draftsman must be familiar with the methods of fastening the parts together, either as permanent fastenings such as welds and rivets, or as removable connections requiring screws and bolts. The basic forms of such parts and the conventional method of their representation are inherently a part of the graphic language of the draftsman. A complete description of all types of fasteners in beyond the scope of this manual. Only a few of the more common types with their representations and some definitions of impbrtance to a draftsman are covered. The descriptions and methods of showing other fasteners can be found in military standard specifications, or in one of the numerous standards handbooks available.

301. Screw Threads

Screw threads are used to restrict or fix the relative motion of two parts or to transmit motion from one part to another. Threads may be right or left hand. *Right-hand* threads advance when turned clockwise; a *left-hand* thread advances when turned counterclockwise. Left-hand threads are always indicated by LH in the thread specification note; without this note all threads are considered as right-hand. The more common types of threads and their general use are shown in figure 132.

a. Terminology. Refer to figure 133 when studying the following definitions.

(1) *Axis.* The centerline of a screw thread running lengthwise.

(2) *Crest,* A flat surface on the major diameter of an external thread or on

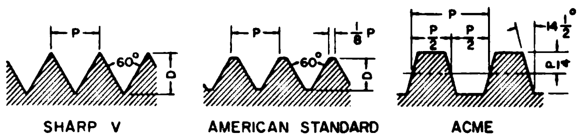


Figure 132. Types of screw threads.

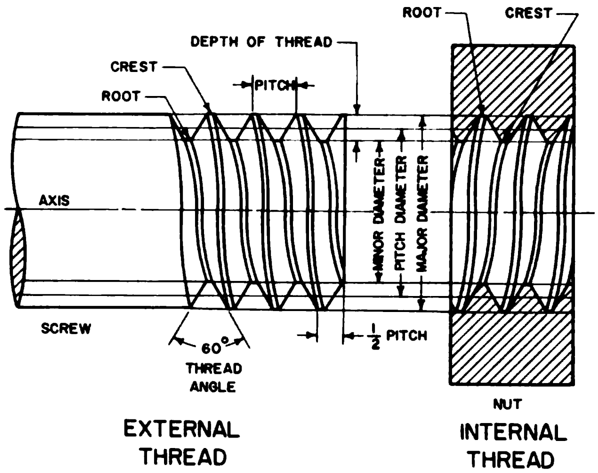


Figure 133. Screw thread definitions.

the minor diameter of an internal thread (top of the thread).

(3) *Depth.* Half the difference of the major and minor diameter or the distance from the crest to the root measured perpendicular to the axis.

(4) *External thread.* A thread on the outside of an object such as a rod or bolt.

(5) *Helix.* The "cork-screw" space curve on a cylindrical surface which marks the location of a point moving with

uniform angular velocity about the axis and at the same time with uniform linear velocity parallel to the axis.

(6) *Internal thread.* A thread on the inside of an object such as a nut.

(7) *Lead.* The distance a point on a helix or screw thread advances parallel to the axis while making one complete turn of the axis (the distance the screw advances in one turn). On a single-thread screw the lead and pitch are identical; on a double-thread screw the lead is twice the pitch; on a triple-thread screw the lead is three times the pitch.

(8) *Major diameter.* The largest diameter of an internal or external thread.

(9) *Minor diameter.* The smallest diameter of an internal or external thread.

(10) *Pitch.* The distance from a point on a screw thread or helix to a corresponding point on the next thread, measured parallel to the axis. On a double-thread screw the pitch is half the lead.

(11) *Root.* The surface of a thread on the minor diameter of an external thread or on the major diameter of an internal thread (bottom of the thread).

(12) *Threads per inch.* One inch divided by the pitch.

b. Thread Conventions. An accurate orthographic representation of any screw thread is impractical. In actual practice they are represented by drawing straight lines, and a note is added giving the designers specifications. Thread conventions are classified as semiconventional or symbolic.

(1) *Semiconventional representation.* Refer to figure 134 when studying the following procedure for drawing semiconventional threads.

(*a*) *Step 1.* Draw the centerline and lines parallel to it, which locate the major diameter of the threads.

(*b*) *Step 2.* Mark off pitch distances on upper (major diameter) line for the distance of all threads.

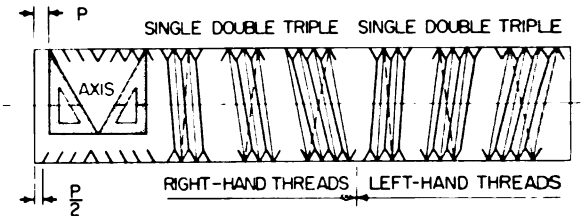


Figure 134. Drawing semiconventional threads.

(*c*) *Step 3.* On lower (major diameter) line mark *one measurement* of 1/2 pitch, then continue marking off pitch distances for the rest of the threads as above.

(*d*) *Step 4.* From each point marked on upper and lower lines draw short lines, sloping 60° to the right and left, which form crests and roots of the threads.

(*e*) *Step 5.* Connect crests and roots of the threads with solid straight lines to complete threads. Notice that crest lines are not parallel to root lines. Single and triple threads have a root opposite a crest. Double threads have a root opposite a root. The lines of step 5 slope to the left for right-hand external and left-hand internal threads; to the right for left-hand external or right-hand internal threads. The dotted lines of figure 134 which indicate the thread on the reverse side of the object are ommitted on the actual drawing.

(2) *Symbolic representation.* Threads of less than 1-inch diameter (drawing size) may be shown by *regular* or *simplified* thread symbols as shown in figure 135. Notice that both omit the V profile.

(*a*) The *regular symbol* shows the crest of the thread as long thin lines and the roots by shorter heavier lines. These lines are simply spaced, by eye or scale, to look well and need not be related to th actual pitch of the thread.

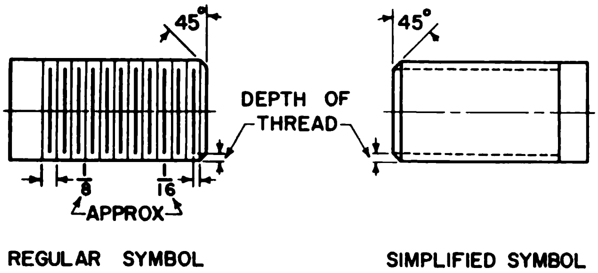


Figure 135. Drawing regular and simplified thread symbols.

(*b*) The *simplified symbol* omits the crest and root lines and shows the approximate depth of the thread by dotted lines indicating the threaded portion. Although not as descriptive as the regular symbol, it is preferred for detail drawings because it is easier to draw and so saves time.

c. Specification Note. As stated before, in addition to the thread conventions, the designer's specifications are given in a note. The format, or order of the specification note, is in accordance with accepted standards of which there are three: the American or National (designated as N), the Society of Automotive Engineers, SAE (designated as EF), and the International Organization for Standardization (designated as UN). Only the American standard is covered here; the others are described completely in military standard specifications or standards handbooks. The principal elements are thread series and screw thread fits.

(1) *Thread series.* The American standard lists five thread series: *coarse* (NC), recommended for general use, includes 12 numbered sizes below 1/4 inch; *fine* (NF), has more threads per inch and is used where ease of assembly and resistance to vibration are requisite, and includes 13 numbered sizes below 1/4 inch; *8-pitch* (8N), eight threads per inch, 1" to 6" dia, used primarily on bolts for high-pressure pipe flanges or cylinder and boiler heads, and similar fastenings against pressure; *12-pitch* (12N), 12 threads per inch, 1/2" to 6" dia, used widely in machine construction requiring thin parts; and *16-pitch* (16N), 16 threads per inch, 3/4" to 4" dia, used on such items as adjusting collars and bearings retainers. See table IX.

Table IX. American National Coarse (NC) and National Fine (NF) Series
Number of threads per inch

Size major diameter	NC series	NF series	Size major diameter	NC series	NF series
0	--	80	9/16	12	18
1	64	72	5/8	11	18
2	56	64	3/4	10	16
3	48	56	7/8	9	14
4	40	48	1	8	14
5	40	44	1 1/8	7	12
6	32	40	1 1/4	7	12
8	32	36	1 3/8	6	12
10	24	32	1 1/2	6	12
12	24	28	1 3/4	5	
1/4	20	28	2	4 1/2	
5/16	18	24	2 1/4	4 1/2	
3/8	16	24	2 1/2	4	
7/16	14	20	2 3/4	4	
1/2	13	20	3	4	
			3 1/4	4	
			3 1/2	4	
			3 3/4	4	
			4	4	

Note. Number 13 size NF series, not given.

(2) *Screw thread fits.* Four types of screw thread fits have been standardized:

(*a*) *Class I.* For rapid assembly and where some shake play is not objectionable.

(*b*) *Class II.* Standard commercial where interchangeability is essential.

(*c*) *Class III.* High quality commercial required for precision work.

(*d*) *Class IV* Where selected fit is required.

(3) *Figure 136* indicates the order of the specification note and explains its interpretation.

302. Bolts and Nuts

In general, data concerning bolt dimensions is obtained from standard tables. However, bolts and nuts are seldom shown on detail drawings, and on assembly drawings where they are encountered most frequently approximate dimensions are adequate.

a. Data and Terminology. Refer to figure 137 when studying the following information concerning bolts and nuts.

(1) *Series.* Bolts are classed in three series: *regular* — recommended for general use; *heavy*—designed to meet requirements for greater surface; and *light*—smaller across flats than the regular, they are designed to save material and weight.

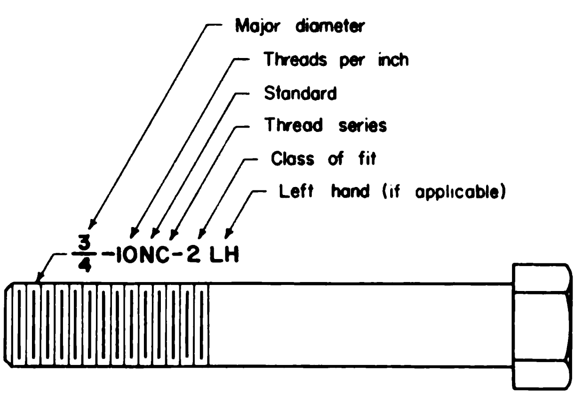


Figure 136. Thread specification note.

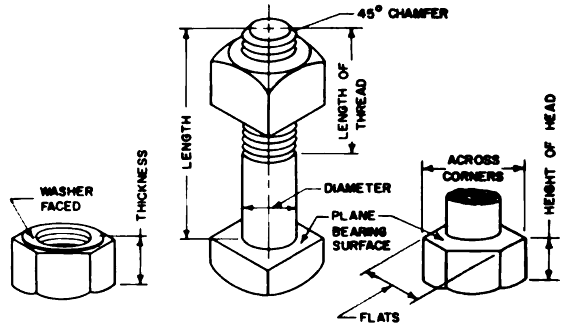


Figure 137. Bolt information.

(2) *Finish.* Bolts may be unfinished, semi-finished, or finished. Unfinished bolts, except for threads, are made by forging or rolling and are not machined on any surface. On semi-finished or finished bolts, the surface under the nut or bolt head may be machine finished to provide a washer-faced bearing surface. Finished bolts are machined all over for accuracy or to improve their appearance.

(3) *Diameter.* The shaft size.

(4) *Length.* Bolt lengths are dimensioned as the distance under the head to the end of the bolt.

(5) *Thread length.* This is related to the diameter and bolt length. In general, bolts are threaded a distance of $1\frac{1}{2}$ times the diameter plus $\frac{1}{8}$ inch. Short bolts, where the formula cannot apply, are threaded full length. On the thread end, bolts are chamfered at an angle of 45° to the depth of the thread.

(6) *Washer face.* The diameter of the machined surface forming the washer face is equal to the distance across flats. The thickness is $\frac{1}{64}$ inch for both bolt heads and nuts, and is always included in the height of the head or thickness of the nut.

(7) *Form.* The head on unfinished, regular- and heavy-series bolts and nuts may be square or hexagonal. On all others the head form is hexagonal.

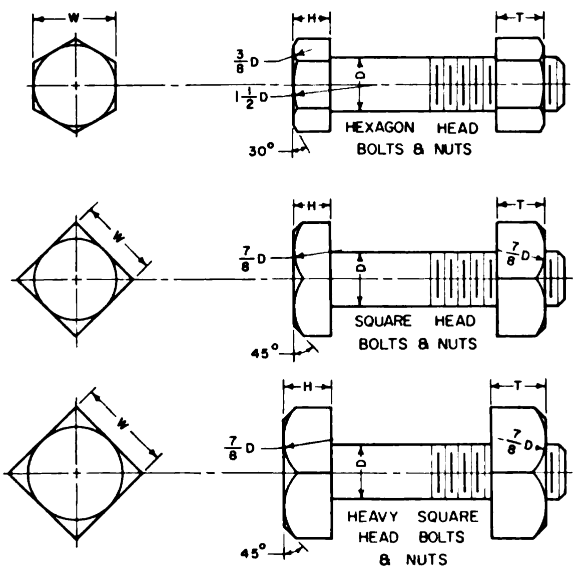
The corners are chamfered to form a flat circular top having a diameter equal to the distance across flats.

(8) *Chamfer.* The angle of chamfer with the flat top of bolts and nuts is drawn at 30° (45° for the heavy series).

(9) *Head height.* This is the overall height of the bolthead and for semifinished or finished bolts includes the washer-faced bearing surface (see *washer face,* above).

(10) *Thickness of nuts.* This is the overall thickness of the nut and for semifinished or finished nuts includes the washer-faced bearing surface (see *washer face,* above).

b. Approximate Procedure for Drawing Bolts and Nuts. This method is acceptable whenever drawing to exact sizes is not necessary to prescribe clearances. The only information required is: (1) diameter, (2) length, and (3) the type of head or nut. The width (W), height (H), or thickness (T) is then approximated in proportion to the diameter (D) of the bolt, thus



Semi-finished Regular	Unfinished Regular	Unfinished Heavy
$W = 1\frac{1}{2} D$ $H = \frac{3}{4} D$ $T = \frac{7}{8} D$	$W = 1\frac{1}{2} D$ $H = \frac{2}{3} D$ $T = \frac{7}{8} D$	$W = 1\frac{1}{2} D + \frac{1}{8}$ $H = \frac{W}{2}$ $T = D$

Figure 138. Bolt and nut formulas.

saving considerable drafting time. Figure 138 shows the formulas used to determine the dimensions for *W*, *H*, and *T* together with suggested radii for drawing arcs of boltheads and nuts. Figure 139 illustrates the procedure in drawing square and hexagonal bolts and nuts.

(1) *Step 1.* Draw centerline and lines representing the diameter (D).

(2) *Step 2.* On centerline, draw circle of radius ¾ D (diameter = 1½ D). For unfinished heavy series, diameter = 1½ D + ⅛ inch.

(3) *Step 3.* With triangles, circumscribe hexagon (or square) about circle of step 2, representing form of bolthead or nut with distance across corners presented at right angles to centerline of step 1. This completes end view of bolthead or nut.

(4) *Step 4.* From end view of step 3, project bolthead and nut to profile view.

(5) *Step 5.* Project arcs in bolthead and nut in accordance with radii as specified in figure 138.

(6) *Step 6.* Draw washer face on nut or bolthead, if required, and chamfers on nut, bolthead, and end of thread. Draw threads on bolt (regular symbol) as shown in figure 135. See thread length in *a*(5) above.

303. Rivets

Riveting is a method of making a permanent joint between two metal parts.

a. Forms of Rivet Heads. All holes for rivets are punched or drilled in the fabricating shop, whether the rivets are driven in the field or in the shop. Large rivets are usually heated to make the metal softer and easier to work. The rivet has a cylindrical body and its head may be conical, spherical, or flat. In assembly, the second head may be formed in the same shape. Clearance is always allowed between the rivet body and the prefabricated hole; the diameter of a rivet hole is usually made 1/16 inch larger than the rivet diameter. To provide for filling this clearance the rivet is extended (beyond the surface of the parts being joined) a length equal to ¾ of its diameter for a flat or countersunk head; 1.3 to 1.7 times the diameter for

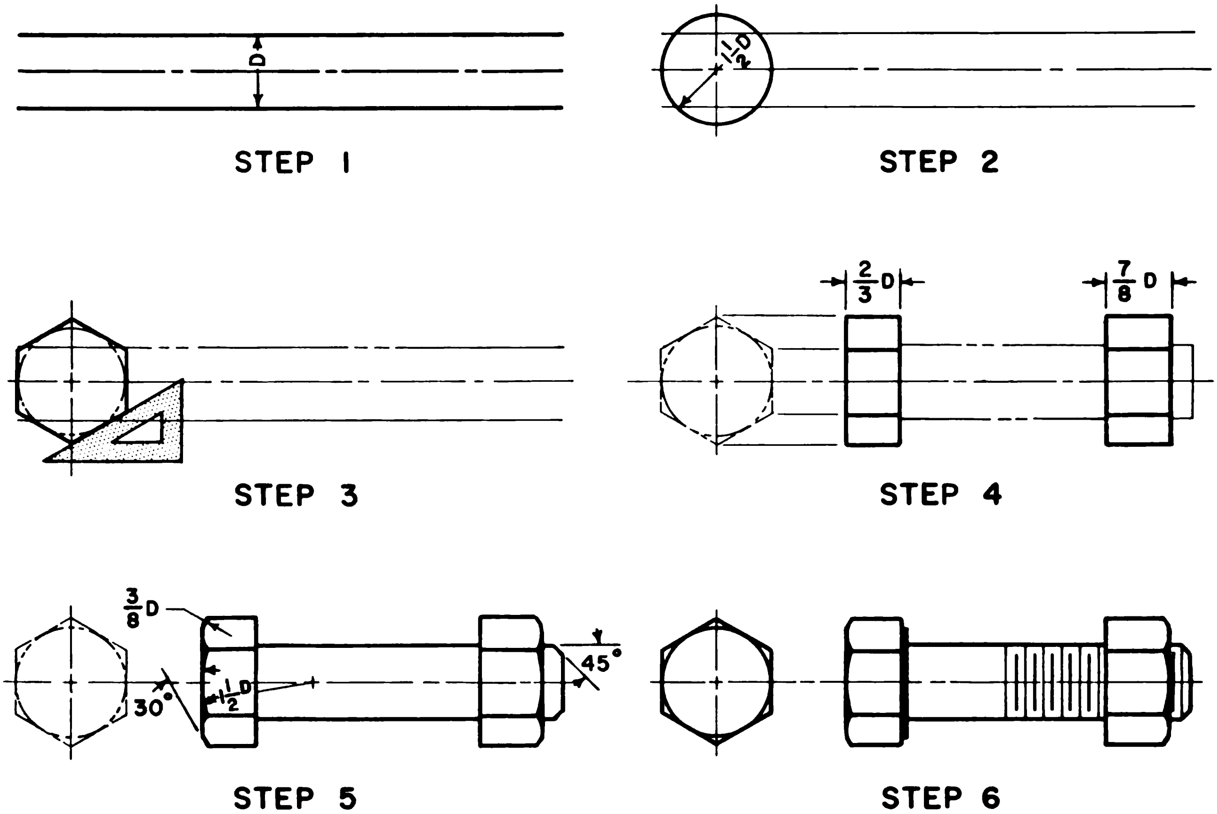


Figure 139. Steps in drawing bolts and nuts.

other type heads. Standard forms of rivet heads and the formulas for drawing them are shown in figure 140.

b. Symbols. Two different symbols are used to distinguish between shop and field rivets in detail drawings. Figure 141 shows the most common standard conventions. Notice that the rivet head diameter is used in drawing shop rivets, and the rivet body diameter is used for drawing field rivets. The blackened indication for field rivets indicates a hole in which rivets are placed later. Centerlines are used on detail drawings made to small scale, rivets being placed where the centerlines intersect. The centerlines represent the intersection of pitch and gage lines (fig. 168).

304. Welding

Welding is also a method of making a permanent joint between two metal parts, and its wide use has brought about a whole new language of symbols for use on drawings. The symbols and terms used are discussed in JAN–STD–19, Joint Army-Navy Standard for Welding Symbols. Figure 142 is a chart of various types of welding processes encountered most frequently.

a. Welding Symbol. The basic welding symbol (fig. 143) is simply a reference line forming an arrow, with one or more angle bends behind the arrowhead, which points to the location of the weld. All information required to indicate the welding process to be used, the location and type of weld, the size, finish, and so on, is located in specified positions on or near the welding symbol.

b. Arrow Side and Other Side. To provide for identification, welds are classified as *arrow side* (previously called near side) or *other side* (previously termed far side). A weld on the near side of the joint, parallel to the drawing

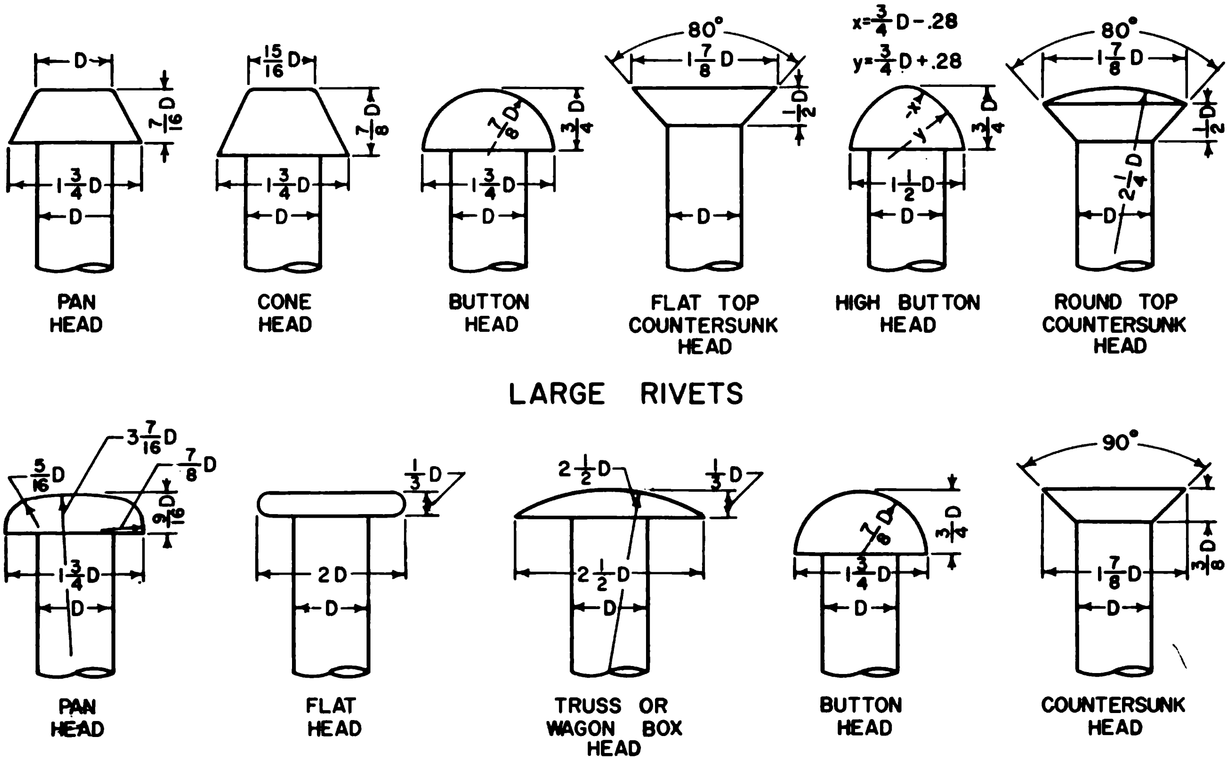


Figure 140. Forms of rivet heads.

Shop Rivets, Two Full Heads

Shop Rivets, Countersunk and Chipped, Near Side

Shop Rivets, Countersunk and Chipped, Far Side

Shop Rivets, Countersunk and Chipped, Both Sides

Shop Rivets, Countersunk but Not Chipped, Max. ⅛ in. High — Near Side

Shop Rivets, Countersunk but Not Chipped, Max. ⅛ in. High — Far Side

Shop Rivets, Countersunk but Not Chipped, Max. ⅛ in. High — Both Sides

Shop Rivets, Flattened to ¼ in. High for ½ in. and ⅝ in. Rivets — Near Side

Shop Rivets, Flattened to ¼ in. High for ½ in. and ⅝ in. Rivets — Far Side

Shop Rivets, Flattened to ¼ in. High for ½ in. and ⅝ in. Rivets — Both Sides

Shop Rivets, Flattened to ⅜ in. High for ¾, ⅞, and 1 in. Rivets — Near Side

Shop Rivets, Flattened to ⅜ in. High for ¾, ⅞, and 1 in. Rivets — Far Side

Shop Rivets, Flattened to ⅜ in. High for ¾, ⅞, and 1 in. Rivets — Both Sides

Field Rivets, Two Full Heads

Field Rivets, Countersunk and Chipped, Near Side

Field Rivets, Countersunk and Chipped, Far Side

Field Rivets, Countersunk and Chipped, Both Sides

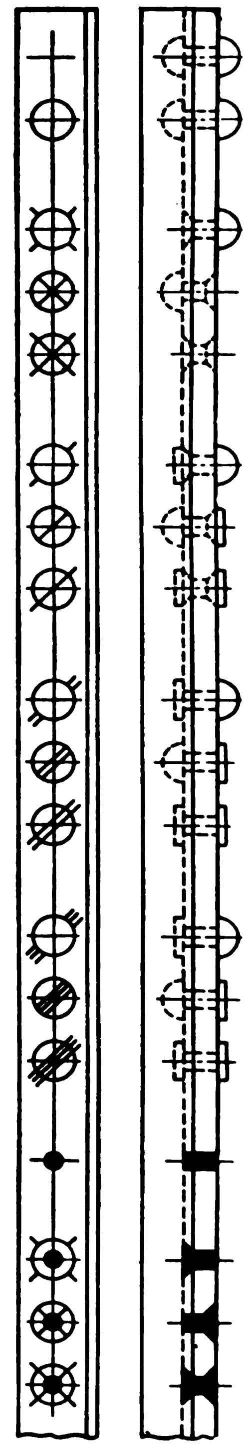


Figure 141. Rivet conventions.

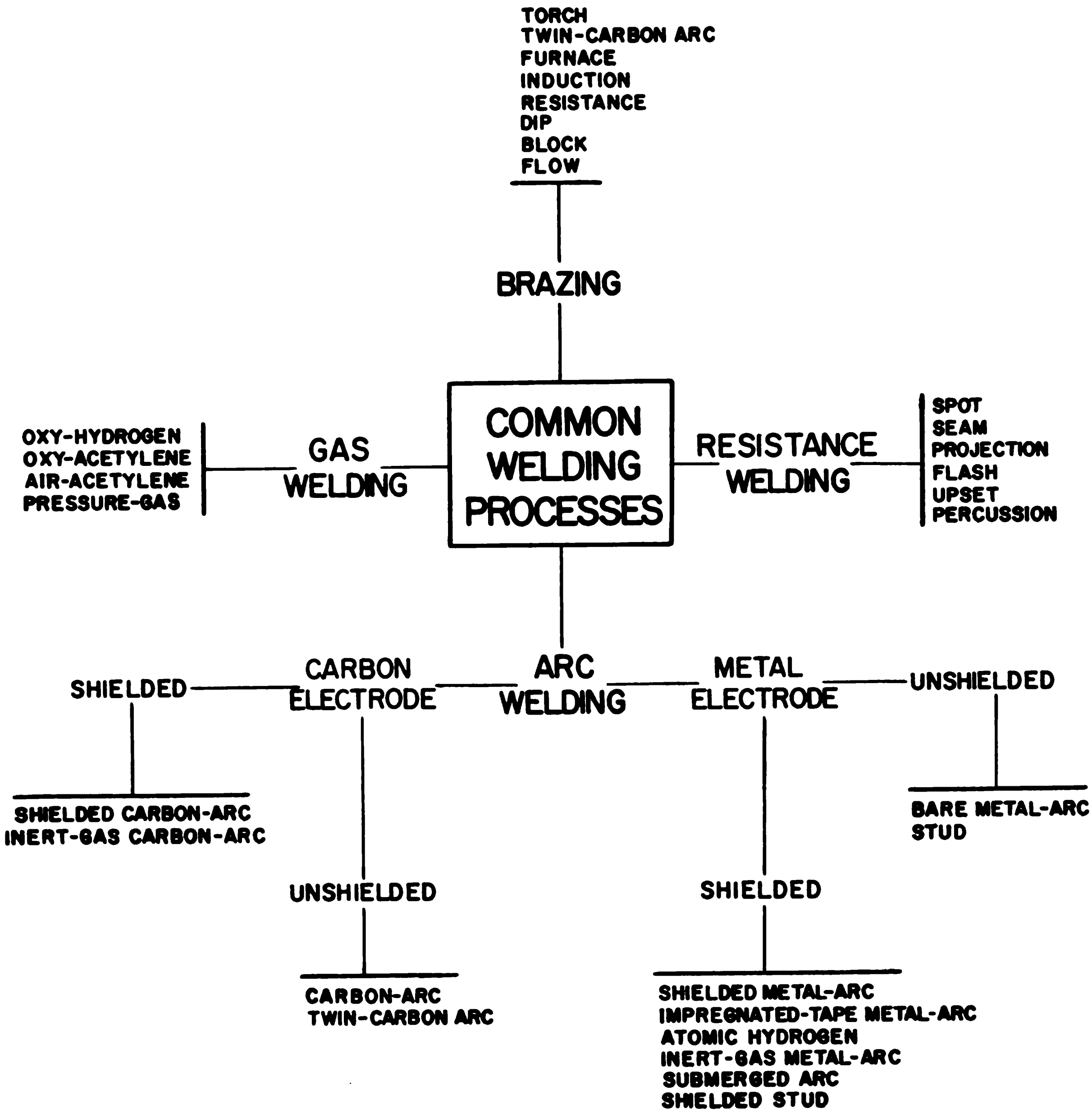


Figure 142. Common welding processes.

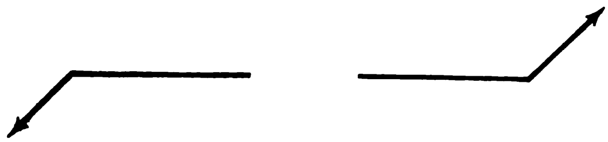


Figure 143. Basic welding symbol.

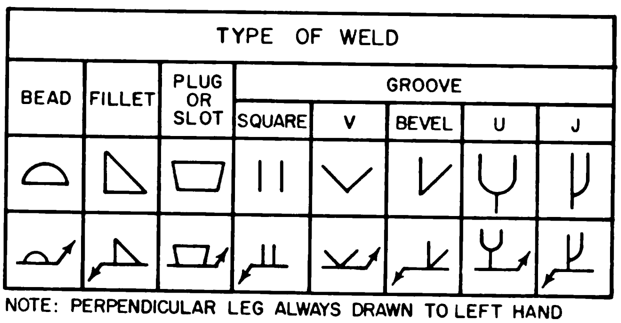


Figure 144. Basic arc and gas weld symbols.

sheet and toward the observer, is called the arrow side. It is on the same side as the symbol, and the arrow points to its face. The other side is on the opposite side of the joint away from the observer, and its face is away from the arrow.

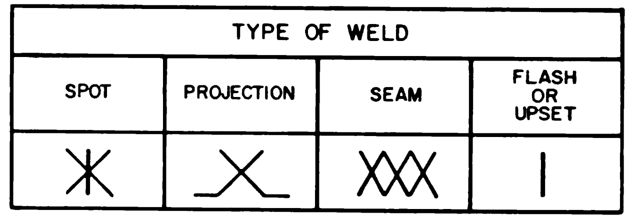


Figure 145. Basic resistance weld symbols.

c. Weld Symbols. Symbols used to indicate the type of weld are called basic weld symbols to differentiate them from the welding symbol, or arrow. Arc and gas weld symbols are shown in figure 144. Resistance weld symbols are shown in figure 145. Figure 146 shows some supplementary weld symbols and figure 147 shows the standard location of elements on the welding symbol. Figure 148 shows the types of welded joints and some applications of the welding symbol.

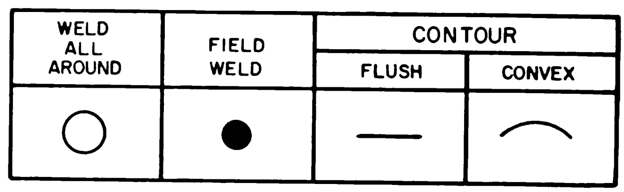


Figure 146. Supplementary symbols.

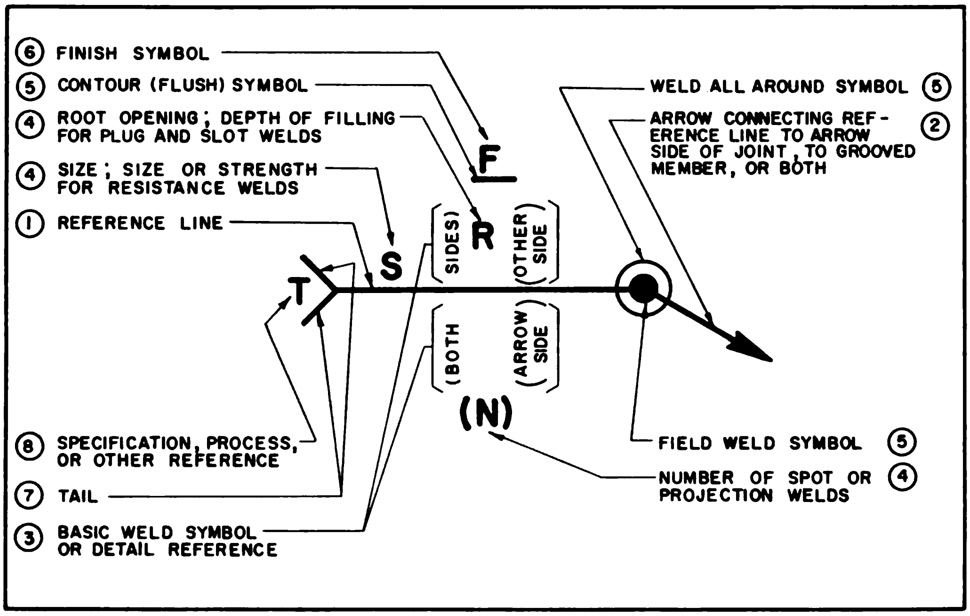


Figure 147. Standard location of elements on the welding symbol.

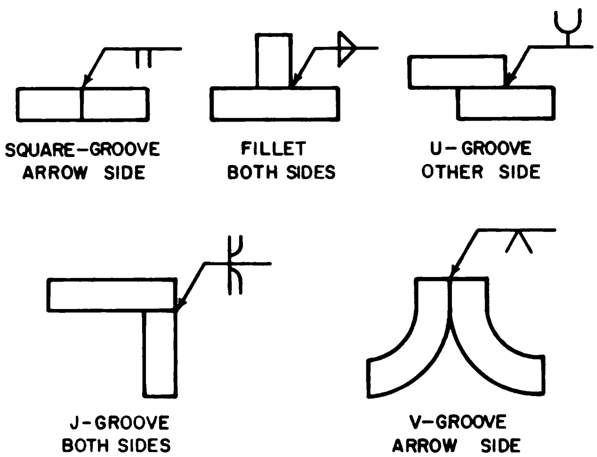


Figure 148. Application of the welding symbol.

Section II. MACHINE PARTS

305. Purpose

The purpose of this section is to present some of the basic mechanisms which are commonly used in elementary machine design. The draftsman must have a basic understanding of these mechanisms in order to make drawings of machine parts. The designer must know the mathematical relationships involved in the motion of the various parts, whereas the draftsman is more concerned with the instantaneous magnitude and direction of forces, their points of application, or the limits of travel of a moving part.

306. Introduction

A *machine* is an assembly of fixed and moving parts, so related and connected, that it can be used for the conversion of available energy into useful work. A *mechanism* is a subassembly of a machine which is designed to transmit an existing force and motion from one part into the force and motion desired in another part. In simple cases a single mechanism may comprise a machine. Some of the most common mechanisms are—

a. A *driver* is a mechanism which transmits its available force and motion to another mechanism called the *follower*.

b. The follower of one mechanism may be the driver of another.

c. When a driver and a follower are in direct contact it is called a *direct drive* mechanism. If the driver and follower are not in direct contact, the intermediate part is called a link or a band.

d. A *link* is a rigid part capable of transmitting tension or compression forces, such as a connecting rod.

e. A *band* is a flexible part which can transmit tension forces only, such as a belt or chain.

307. Linkages

A linkage is a system of links or bars joined together at pivot points which are fixed or constrained to move in a prescribed path. Only a few of the most elementary and most common linkages will be presented in this chapter.

a. Lever. A lever consisting of a single link is a rigid piece free to turn about one fixed point or fulcrum. Figure 149 shows two types of levers with the fixed point lettered *O*, the point *A* representing the point of application of the driving force F_A, and the point *B* representing the point of application of the balancing force of the follower F_B. The lever is used to multiply a small force through mechanical advantage or sometimes vice versa. The driving force times its distance from the fulcrum (lever arm) is equal to the balancing force times its lever arm.

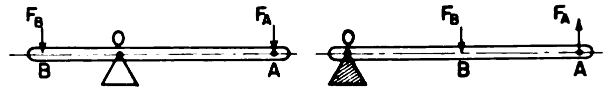


Figure 149. Levers.

Thus, referring to figure 149, $F_A \times OA = F_B \times OB$.

b. Rocker Arm. A rocker arm may be considered as a bent lever with its two arms making an obtuse angle (greater than 90°). Figure 150 shows a rocker arm with fixed pivot point *O* and arms *OA* and *OB* meeting in an obtuse angle. Effective lever arm is the perpendicular distance from the fulcrum to the line of action of the force acting (L_A or L_B). Thus, referring to figure 150, $F_A \times L_A = F_B \times L_B$.

c. Bell Crank. A bell crank may be considered as a bent lever with its two arms meeting in an acute angle (less than 90°). Figure 151 shows a bell crank with a fixed pivot point *O* and arms *OA* and *OB* meeting at an acute angle. In this case it is again necessary to use "effective lever arm" and the equation for the balanced forces is $F_A \times L_A = F_B \times L_B$.

d. Rotating Crank. If a link is subjected to a rotational force about a fixed point, the mechanism is called a rotating crank. Figure 152 shows a link *AB* which rotates counterclockwise about a fixed point *A*. The velocity of the point *B* at the *instant* shown is represented by a vector (arrow) R_B. The length of the vector represents the magnitude of the velocity, and the

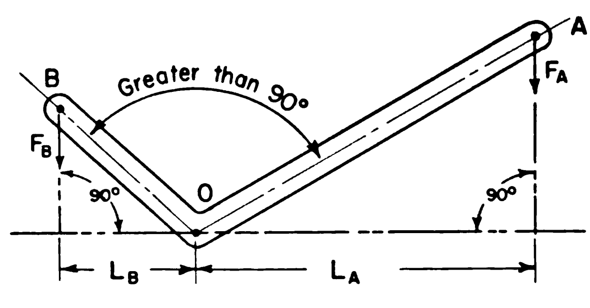


Figure 150. Rocker arm.

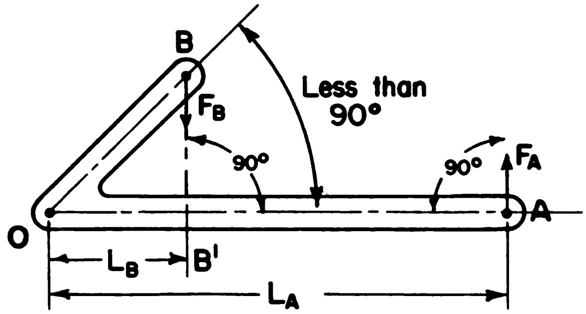


Figure 151. Bell crank.

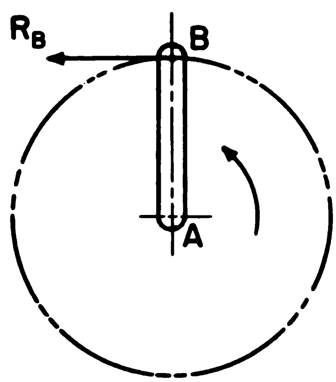


Figure 152. Rotating crank.

direction of the vector represents the direction of motion of the point *B* at that instant.

e. Four-Bar Linkage. Figure 153 is a schematic diagram of a four-bar linkage showing all links in a zero or starting position. If the driver moves alternately to the left and right through *equal* angles 1, and 2, the point B_0 will move first to B_1 and then to B_2. The follower will move through angles 3 and 4 in the same periods of time; however, careful construction and measurement will show that angles 3 and 4 are *unequal.* Thus if the driver moves with uniform angular speed, the follower will move with a variable angular speed. Therefore, values of the angular speeds of the driver and follower, and the linear speeds of the moving points B and C for any given arrangement of the linkage, apply only for that instant. When the links have moved to any other position, the quantities involved will have changed to new instantaneous values.

f. Crank and Connecting Rod. Figure 154 is a diagram of the values of the instantaneous forces for a crank and connecting rod. In this mechanism the reciprocating straight line motion of a sliding block *B* is converted into the rotary motion of the crankshaft about a fixed center *O*. The true instantaneous velocities of the points A and B are represented by the vectors R_A and R_B.

g. Resultant Motion of a Point. A point on the link of a mechanism may be constrained to move in a definite direction, or it may move in a direction which is determined by the action of two or more forces acting on that point. Thus referring to figure 155, the instantaneous motion of a point *O*, acted on by two forces F_A and F_B, is represented by a vector F_R which is the vector sum of the two components. The resultant force F_R is found by constructing a parallelogram with the two components F_A and F_B as sides, and drawing the diagonal to find F_R.

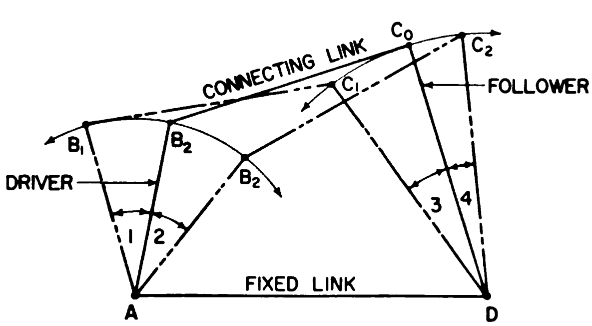


Figure 153. Four-bar linkage.

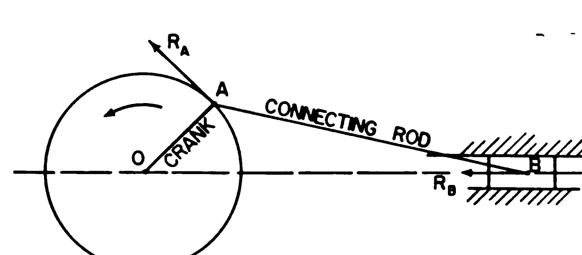


Figure 154. Crank and connecting rod.

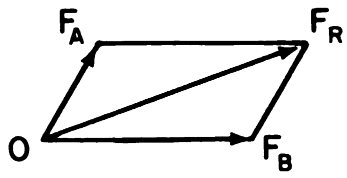


Figure 155. Resultant of two forces.

308. Straight-Line Mechanisms

A straight-line mechanism (fig. 156) is a linkage which will produce rectilinear motion of a point by constraining it to move in a straight line because of the relative prooprtions of the links. There are many types of straight-line mechanism, but only the most elementary types will be presented.

a. Straight-Line Motion. The linkage shown in figure 156 consists of a link DB pivoted at fixed point *D*, and pinned at the point *B* on the link AC, so that lengths AB:BC = BC:BD. If the point *C* is attached to a sliding block constrained to move along the straight line through DC, the point *A* will trace an approximate straight line AA′ as the link DB swings about D. If AB = BC = BD the point A will trace an exact straight line. Algebraically then AB/BC = BC/BD or, AB x BD = $(BC)^2$.

Example 1: In figure 156 given A = 3.6″, and DB = 2.5″, find the length of BC in inches.

Solution: AB x BD = $(BC)^2$ = 3.6 x 2.5 = 9
BC = $\sqrt{9}$ = 3″

Example 2: In the figure 156 how far from O should the point D of example 1 be located?

Solution: Let the point C move until point A coincides with O. In this position it can be seen that OD = AB — DB. Therefore, OD should be 3.6 — 2.5 = 1.1″

b. Parallel Motion. Parallel-motion mechanisms are not straight-line mechanisms, but are closely related mechanisms. Parallel rulers and the drafting machine are examples. These mechanisms are four bar linkages (par. 307*e*) with each pair of opposite sides equal, thus forming a parallelogram. If one side is fixed, the opposite side always moves parallel to the fixed side.

c. Pantograph. The pantograph is essentially a four bar linkage connected to form a parallelogram with two extended sides, and so designed as to make two points move in parallel paths at a predetermined distance ratio. It is used to enlarge or reduce the size of drawings. Figure 157 shows one arangement of the links of a pantograph. The general requirements for the setting of the pantograph links are:

(1) The four bars must be connected to form a parallelogram (ABFC) with two sides extended (ABP and ACT).

(2) The tracing point *T*, the follower point *F*, and a fixed pivot *P* must be on sepa-

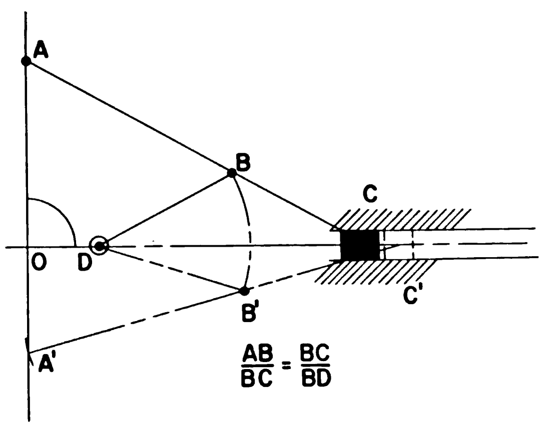


Figure 156. Straight-line mechanism.

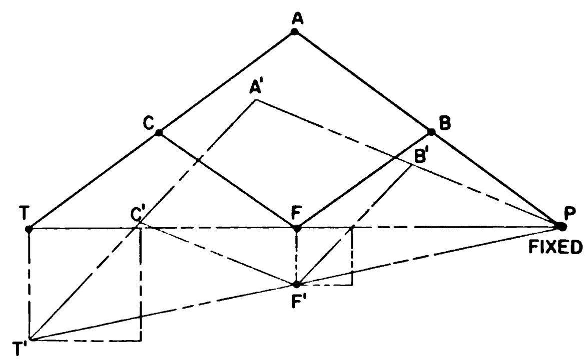


Figure 157. Pantograph.

rate links, and lie in a straight line *PFT*.

(3) The ratio of the distance moved by the tracing point to the distance moved by the follower point is equal to the ratio of their respective distances from the pivot point *P*.

Example: On figure 157 the distance *TF* equals the distance *FP*. If the follower point moves ½" downward, how does point *T* move?

Solution: By reconstructing linkage as shown by phantom lines, the point *T* has moved downward 1" because *TP* = 2 x *FP*.

309. Cams

A *cam* is a plate, cylinder, or solid piece, with a curved outline or groove, which rotates about an axis and transmits its rotary motion to the reciprocating (up and down) motion of another piece called the *follower*. The follower may have a pointed, rolling, or flat contact with the cam, as illustrated in figure 158. The (up and down) motion of the follower may be irregular or regular. *Irregular* motion conforms to no definite law. *Regular* motion conforms to some physical law, and may be uniform, harmonic, uniformly accelerated, or uniformly retarded with reference to *time*. The different kinds of regular motion are best illustrated by plotting the up and down motion (or rise and fall) of the follower for each interval of time, thus making a *motion diagram* (fig. 159).

Note. In this chapter it is assumed that the cam and camshaft are turning at a constant speed in revolutions per minute so that equal angles about the center of the cam represent equal periods of time. It is also assumed that the follower is constrained to move in an *up and down line of motion only*.

a. Uniform Motion. If the point of a follower moves equal distances in equal periods of time, the follower has uniform motion. Referring to diagram 1, figure 159, the total rise of the follower, represented by AB, is divided into three equal parts. The follower must rise to points 1,

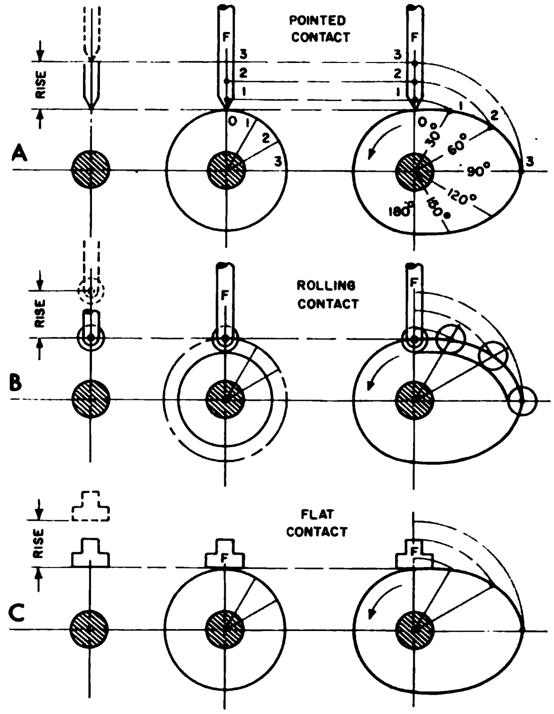


Figure 158. Cams and followers.

2, and 3 in the time it takes the cam to turn in equal intervals of time to 30°, 60°, and 90° respectively. The follower may have uniform fall as shown on the right side of diagram 1.

b. Harmonic Motion. Diagram 2, figure 159, is the motion diagram for harmonic motion of the follower. The line AB represents the total rise of the follower. Points on the motion diagram are found by dividing a semicircle into 30° sectors, intersecting the semicircle in points numbered from 1 to 6. The numbered points are projected horizontally to the ordinates drawn for equal time intervals of rotation of the cam. The solid curve shows the harmonic "rise" for 180° rotation of the cam, and the dotted curve shows the harmonic "fall" of the follower to its original position. A cam with this motion is useful for high speed operation.

c. Uniformly Accelerated and Retarded Motion. Diagram 3, figure 159, represents uniformly accelerated and uniformly retarded motion. The line AB represents the total "rise" of the follower as before. The line AB is halved,

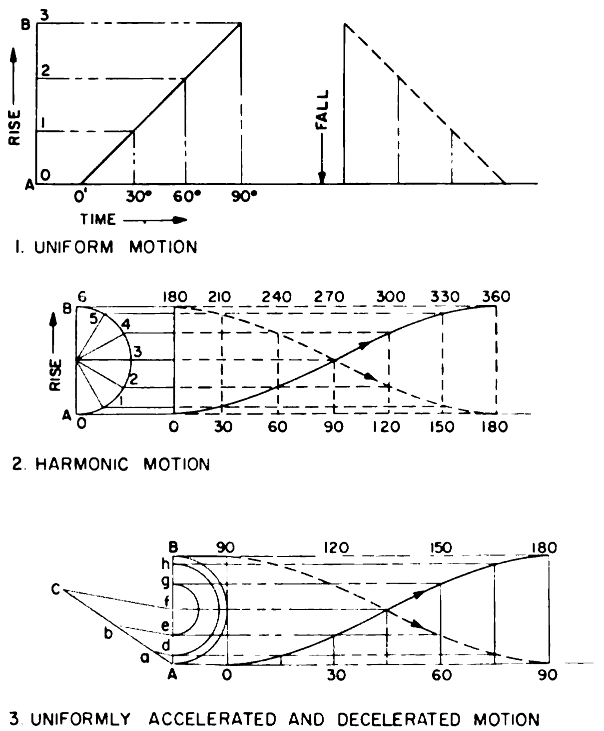


Figure 159. Motion diagrams.

and the lower half is divided into three parts in the ratios of 1:3:5. This is done graphically so that $\frac{Ad}{1} = \frac{de}{3} = \frac{ef}{5}$. The upper half of the line AB is divided by using dividers so that $\frac{fg}{5} = \frac{gh}{3} = \frac{hB}{1}$. The solid curve shows the "rise" of the follower by uniform acceleration to the midpoint of travel and its continued rise by uniformly retarded motion. The dotted curve shows the "fall" of the follower to its midpoint of travel, by uniformly accelerated motion and its continued fall by uniformly retarded motion to its original position. Uniformly accelerated motion is the motion of a freely falling body, and it gives the easiest motion to a cam.

d. Construction of a Cam. To develop the design for a cam it is necessary to know the initial position of the follower with respect to the camshaft, the type of contact, the motion required of the follower and the direction of rotation of the camshaft.

Example: Construct a plate cam with a pointed follower to turn counterclockwise. The follower is to move in a vertical line above the center of the cam. In the initial position the follower point is 1 inch above the center of the cam. The follower is required to have the following motions.

0°–120°, rise 1 inch with simple harmonic motion 120°–210°, dwell or rest with no motion at 210°, drop ¼ inch instantly 210° –360°, fall ¾ inch with uniform motion.

Solution: Refer to figure 160 and study each step.

(1) Draw baselines of motion diagram and mark off 12 equal spaces along baseline, and number points of 12 equal spaces to represent each 30° interval rotation of the cam.

(2) Draw semicircle at left end of baseline with diameter equal to 1 inch rise and tangent to baseline. Divide semicircle into four equal arcs (at 45° intervals) numbered 1, 2, 3, and 4. The semicircle is divided into four equal arcs because there are four 30° intervals from 0°–120°. Points 1, 2, 3, and 4 are projected horizontally with T-square to locate points 1, 2, 3, and 4 on the motion diagram. Points 4, 5, 6, and 7 are all on the line 1 inch above baseline because follower rests from 120°–210°. The point 8 is ¼ inch below point 7 because the follower drops ¼ inch instantly at 210°. From 210°–360° the follower falls ¾ inch to starting position with uniform motion, and a straight line is drawn from point 8 to the end of the diagram.

(3) Draw base circle with radius of 1 inch and mark the initial point of the follower at 0° position of the cam. Extend all 30° lines outside base circle.

(4) Locate points on cam by transferring distances of each point above baseline in motion diagram with dividers to same distance outside base circle.

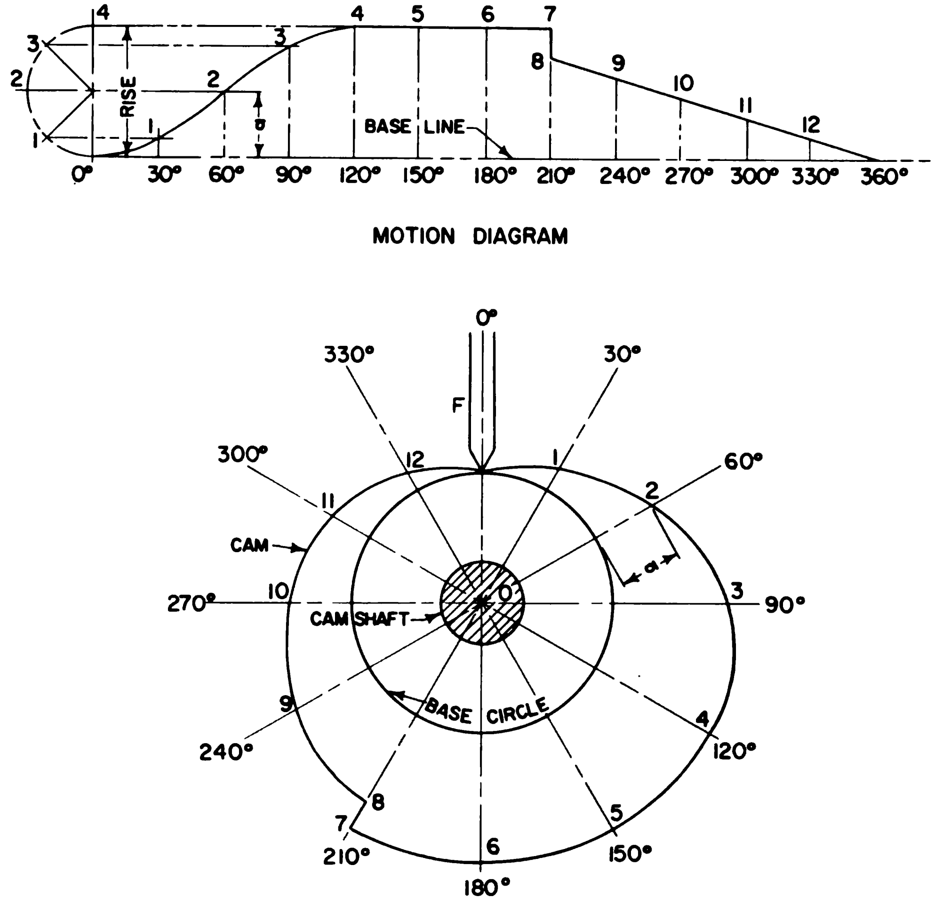


Figure 160. Construction of a cam.

See distance "*a*" for point No. 2 on 60° line.

(5) Connect points 0–1–2–3–4 and 8–9–10–11–12–0 with a French curve. Points 4 through 7 are connected with a curve of 2-inch radius.

310. Gears

To understand the operation and drawing of gears, first consider two shafts, connected through the rolling contact of two wheels or cylindrical pulleys of equal or different diameters. If one shaft is turned, and there is no slippage at the point of rolling contact of the two wheels, the other shaft will turn in the opposite direction. The speeds of the two shafts will be inversely proportional to the diameters of the two wheels through which they are connected. To prevent slippage when large forces are transmitted, it becomes necessary to cut teeth in each wheel thus forming two gears with meshing teeth. A complete coverage of gears is beyind the scope of this manual. Only a few necessary definitions and the steps in drawing spur gear teeth by the appoximate circular arc method are presented herewith.

a. Definitions. Figure 161 illustrates some of the terminology used in connection with the drawing of gears.

(1) *Pitch circle* is the projection of an equivalent cylinder on a plane perpendicular to the axis of the gear. The pitch circles of two meshing gears are tangent at the *pitch point,* which is on their line of centers.

(2) *Pitch diameter* is the diameter of the pitch circle. Gear teeth are designed

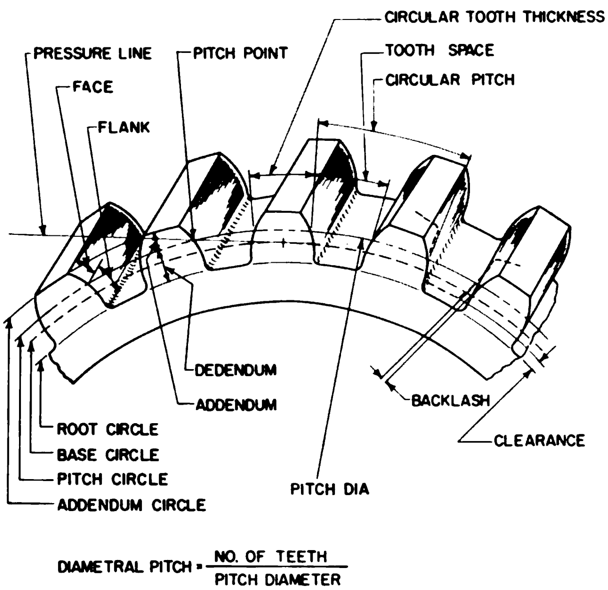


Figure 161. Gear terminology.

to the size of equal subdivisions stepped off on the pitch circle.

(3) *Circular pitch* is the linear distance between corresponding points on two adjacent teeth measured along the pitch circle. The circular pitches of two meshing gears are equal.

(4) *Diametrical pitch* is the number of teeth on the gear wheel per inch of pitch diameter.

(5) *Addendum circle,* or outside circle, is the circle which passes through the outer extremities of the teeth.

(6) *Root circle* is the circle which passes through the bottoms of the grooves between the teeth.
the addendum circle and the root circle are concentric with the pitch circle.

(7) The *addendum distance* of a gear is equal to the radius of the addendum circle minus the radius of the pitch circle.

(8) The *dedendum distance* of a gear is equal to the radius of the pitch circle minus the radius of the root circle.

(9) *Clearance* is the difference between the addendum distance of one gear and the dedendum distance of another gear in mesh with it.

(10) The *face* of a tooth is the portion of the contact surface between the pitch circle and the addendum circle.

(11) The *flank* of a tooth is the portion of the contact surface between the pitch circle and the root circle.

(12) The *circular thickness* of a tooth is its thickness measured along the arc of the pitch circle.

(13) *Tooth space* is the space between two teeth measured on the arc of the pitch circle.

(14) *Backlash* is the difference between the tooth thickness of a gear and the tooth space of another gear in mesh with it.
Note that the circular thickness of a tooth is equal to the tooth space and that circular pitch is equal to the sum of circular tooth thickness and tooth space.

b. Gear proportions. In order for two gears to mesh, the teeth of each gear must fit the space between the teeth of the other. The opposing teeth contact each other along a common "pressure line." The pressure angle between the pressure line and the line of centers of the two gears, determines the shape of the tooth face. The American Standards Association has standardized two pressure angles, 14½° and 20°. The draftsman uses 15° (or 75° tangent to base circle) as a close approximation for the pressure angle. The dimensions necessary to draw an American standard 14½° gear are related according to the following mathematical equations.

Name	Symbol	Relationship
Number of teeth	N	
Diametral pitch	P_d	$P_d = N/D$
Pitch diameter	D	
Addendum	a	$a = 1/P_d$
Dedendum	b	$b = 1.157/P_d$
Outside diameter	D_o	$D_o = (N + 2)/P_d = D + 2a$
Root diameter	D_R	$D_R = D - 2b = (N - 2.314)/P_d$
Circular pitch	p	$p = \pi/P_d = \frac{\pi D}{N}$
Circular tooth thickness	t	$t = p/2 = \frac{\pi D}{2n} = \frac{\pi}{2P_d}$

c. Steps in Drawing a Spur Gear. Figure 162 illustrates the steps in drawing a spur gear by the approximate circular arc method as follows:

(1) Draw pitch circle, addendum circle, and root circle.

(2) Mark pitch point, and divide pitch circle into as many divisions as the number of teeth and subdivide each space in half to represent one tooth plus one tooth space.

(3) Through pitch point draw a line at 75° to the radius of the pitch circle extended. This line represents the *pressure line* or *line of action* of force transmitted to another gear in mesh. Use 30° angle plus 4° angle of triangles to obtain 75° pressure line.

(4) Draw base circle tangent to pressure line. The radius of the base circle is found by sliding one leg of a 90° triangle along the pressure line until the other leg meets the center of the gear. The base circle contains the centers of arcs of tooth faces.

(5) Divide pitch radius into four parts and with compass set to ¼ pitch radius draw faces of teeth through points laid off on pitch circle, keeping centers of arcs on the base circle.

(6) Retrace portions of addendum circle for top of each tooth.

(7) Retrace portions of root circle for bottom of groove between teeth.

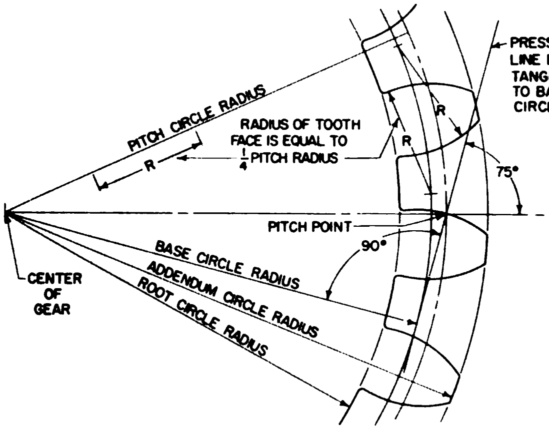


Figure 162. Drawing a spur gear.

Section III. DETAIL AND ASSEMBLY PRACTICES

311. Detail and Assembly Drawing Synonymous With Working Drawings

Detail and assembly drawings are components of a set of working drawings. Each detail drawing and assembly drawing, separately or in combination, constitutes a working drawing. The same general procedure for making working drawings should be followed in making detail and assembly drawings. These include sheet layout, selection of views, selection of scales, application of centerlines, and dimensioning. Remember the detail drawing gives all necessary shop information for the production of individual items, and an assembly drawing shows the location of each item in relation to one another.

312. Detail Drawing

In addition to being familiar with the general procedures for making working drawings, the draftsman must understand the requirements governing detail practices. These vary according to their intended use. In general, the draftsman is concerned with two main categories, mechanical and construction drawing. Only a few significant elements, pertinent to the treatment of details in general, are dealt with in this chapter.

313. Mechanical Practice

In machine drawing, two systems are employed. Both follow the practice of drawing the details of each piece individually on a separate sheet; when the end item is small and consists of only a few parts, the details may be shown on the same sheet with the assembly drawing, as in figure 163.

a. Multiple-Drawing System. Some manufacturers use the multiple-drawing system, in which different drawings are made for the pattern shop, the foundry, and machine shop. In this case, each drawing presents only that information required by the shop for which the drawing is intended. Figures 164 and 165 are multiple drawings. Figure 164 is for the foundry, and figure 165 is for the machine shop.

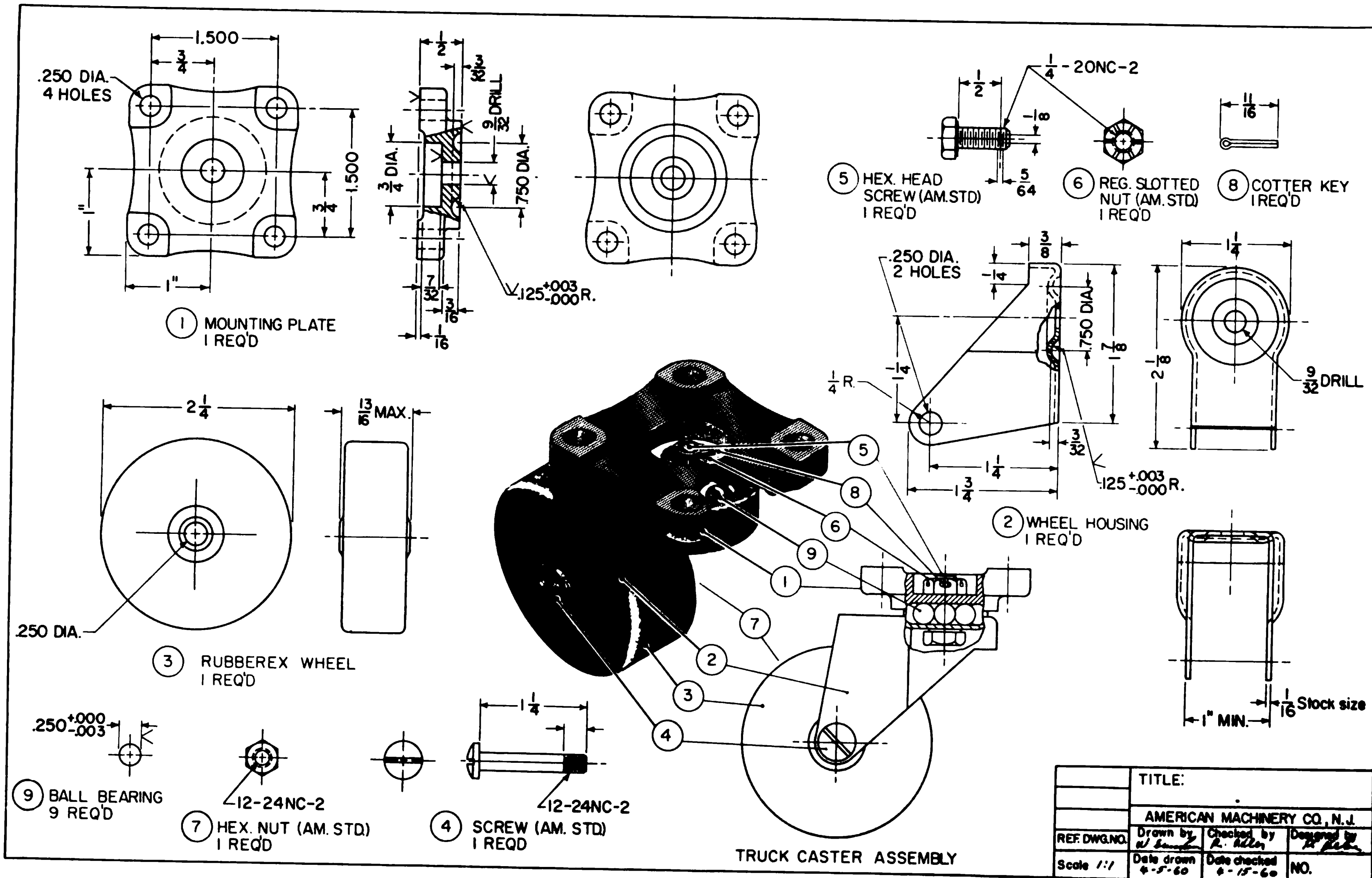


Figure 163. Relation of details versus assembly.

Notice how each drawing gives only that information required by the using shop; on the other hand, notice that both drawings are cross-referenced to each other.

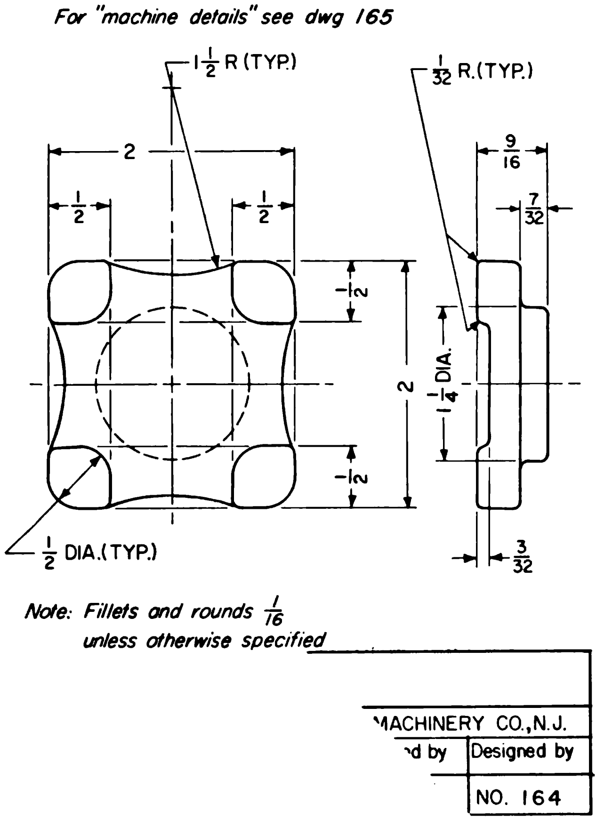


Figure 164. Detail drawing for the foundry.

b. Single-Drawing System. The practice most commonly followed employs the single-drawing system, in which all information necessary for the completion of the finished piece is made to be used by all shops involved in its production. Figure 166 is a single drawing to be used by both the foundry and the machine shop. Notice how the information required by each shop is given separately so that one set of dimensions and data is not dependent on the other; also note that the need for cross-reference is eliminated.

c. Finish Marks. In dimensioning a machine detail, the draftsman should mark all surfaces of a casting or forging that are to be machined. Such marking not only indicates the machining operation but also suggests to the pattern maker where to provide extra metal on the rough casting or forging to allow for machine finishing. Figure 167 shows the two types of finish marks in use and illustrates the method of their construction and placement. The standard mark recommended by the American Standards Association (ASA) is a 60° *V* with its point touching the surface to be machined while the wings are in the air (away from the object). Figures 165 and 166 show the application of the standard mark. Finish marks should be placed on all views in which the surface to be finished appears as a line, even if the line is a dotted line. If the part is to be finished on all surfaces, it is treated by the general note "Finish All Over."

For "casting details" see dwg 164

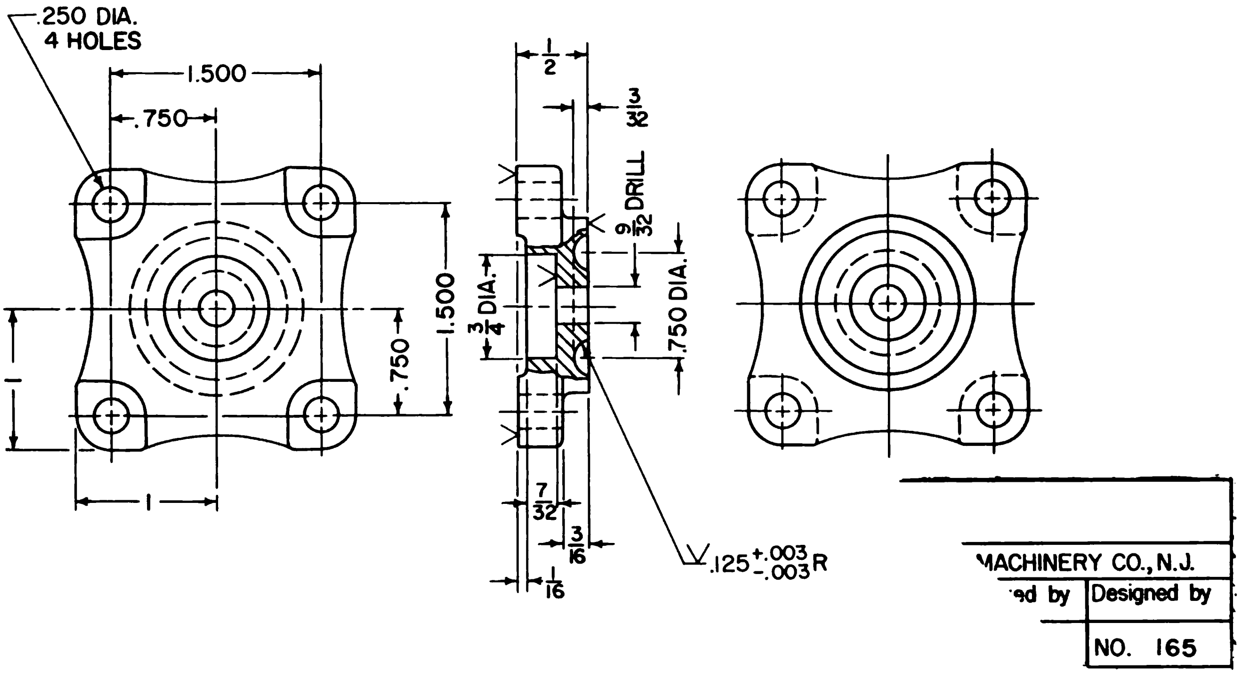


Figure 165. Detail drawing for the machine shop.

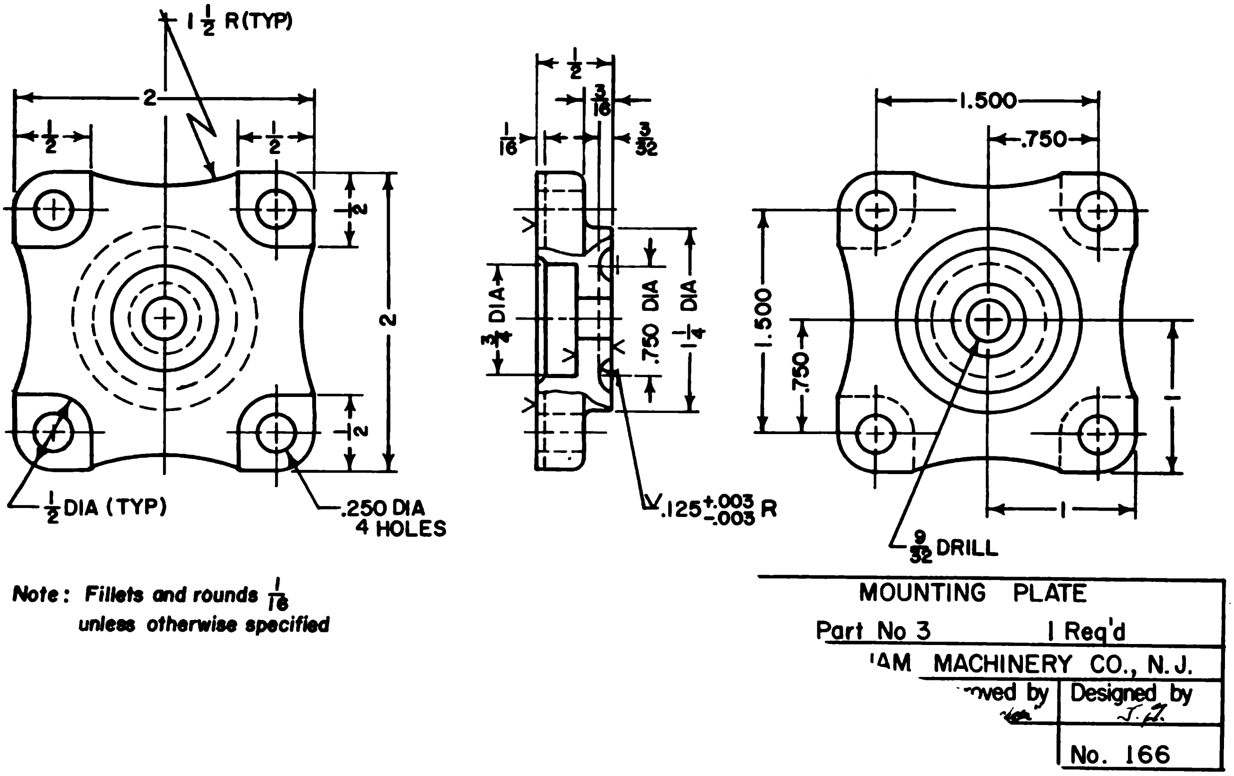


Figure 166. Single drawing for use by all shops.

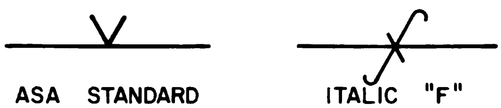


Figure 167. Finish marks.

d. Other Notes. Rounds and fillets occurring a number of times on a drawing are only identified once for each variation in size. The note *"TYP"* (abbreviation for typical) is then added to indicate that the dimension is typical for all other similar rounds and fillets (fig. 164). This same note may be applied to similar dimensions on a drawing.

CHAPTER 14

STEEL FRAME CONSTRUCTION

314. Structural Steel Details

Steel structures are composed of rolled-steel shapes used either singly or built up to form members. Figure 168 shows sections of the common shapes together with the symbols used to identify them in notes, dimensions, and bills of materials. Dimensions for detailing these and other less used shapes are described completely in the Americal Institute of Steel Construction (AISC) handbook or military standard specifications. Abbreviations and order of specifications for some of the shapes given in figure 168 are as follows:

a. Equal Angles. L3 x 3 x ¼ x 8′-0 (size of legs x thickness x length).

b. Unequal Angles. L7 x 4 x ½ x 6′0 (size of long leg x size of short leg x thickness x length).

c. Channels. 9 ⊔ 13.4 x 9′8 (depth x weight/foot x length).

d. I Beams. 15 I 42.9 x 12′6 (depth x weight/foot x length).

e. Wide Flangle Shapes. 24 W- 76 x 18′-3 (nominal depth x weight/foot x length).

f. Zees. Z6 x 3½ x 15.7 (depth x flange width x weight/foot x length).

g. Plates. Pl 18 x ½ x 2′-6 (width x thickness x length).

315. Actual Size and Weight Versus Nominal Size Classification

The process for rolling structural-steel shapes permits a wide range of actual sizes and weights within a single nominal size classification. Although a beginning construction draftsman may not be required to prepare steel detail drawings, he should be aware of the reasons for specifying members in the manner described above. Steel details cannot be prepared without a structural steel handbook that specifies the actual dimensions for the various weights. Examples of such data are given in tables X, XI, XII.

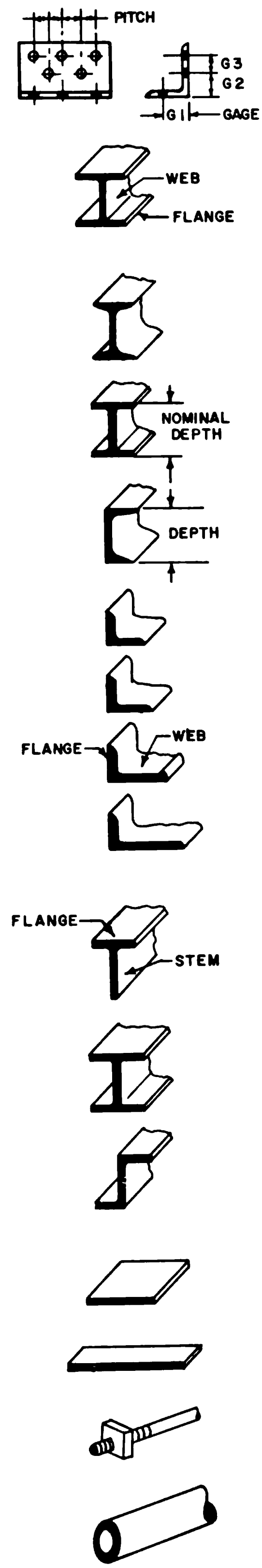
316. Shop Drawings

Steel structural members are prepared in special fabricating shops, and the drawings showing the required fabrication of parts and methods of assembly are called shop detail drawings or simply *shop drawings.* Figure 169 is a shop drawing of a structural steel member made from a single rolled shape. Figures 170, 171, and 172 are shop drawings of members built up of a combination of rolled shapes. The practices for detailing structural steel, as illustrated by these figures, include the following:

a. Working Lines and Working Points. Shop drawings are made about light *working lines* laid out first along the centerlines or rivet gage lines to form a skeleton of the assembled member. The intersections of these working lines are called *working points* from which all dimensions are given. This skeleton is usually the same as, or taken from, the designer's stress diagram. Generally, the skeleton diagram is drawn to a small scale on the shop drawing (fig. 170).

b. Relative Position of Parts. Parts to be riveted or welded together in the shop are shown in the same relative position (vertical, horizontal, or inclined, as in fig. 170) which they will occupy in their assembled position in the structure, instead of being detailed individually, as is the practice for machine drawing. Note in figure 170 that due to the truss being symmetrical about each side of the center, only half of the truss need be shown. In such cases, it is always the left end which is drawn.

c. Long Vertical or Inclined Members. Long vertical (columns) or inclined (braces) members are sometimes drawn in a horizontal position on the drawing. When thus drawn, a vertical member is drawn with the bottom at the left (fig. 171), and an inclined member is drawn in the direction it would fall.



DESCRIPTION	SYMBOL	ILLUSTRATED USE
GAGE	g	g = $3\frac{1}{2}$
PITCH OF RIVETS	p	p = $2\frac{1}{2}$
WIDE FLANGE SHAPE	WF	24WF76
BEAMS		
AMERICAN STANDARD	I	15I42.9
LIGHT BEAMS & JOISTS	B	6B12
STANDARD MILL	M	8M17
JUNIOR	Jr	7Jr5.5
LIGHT COLUMNS	M	8x8M34.3
CHANNELS		
AMERICAN STANDARD	⊔	9⊔13.4
CAR & SHIP	⊔	12x4⊔44.5
JUNIOR	Jr⊔	10Jr⊔8.4
ANGLES		
EQUAL LEG	L	L3x3x$\frac{1}{4}$
UNEQUAL LEG	L	L7x4x$\frac{1}{2}$
BULB	BULB L	BULB L6x$3\frac{1}{2}$x17.4
SERRATED	$\overset{X}{L}$	$\overset{X}{L}$(3+1)⊔4.1
TEES		
STRUCTURAL	ST	ST5WF10.5
ROLLED	T	T4x3x9.2
BUILT UP	T	T BAR 3x$\frac{1}{2}$ BAR 4x$\frac{1}{4}$
SERRATED	$\overset{X}{T}$	$\overset{X}{T}$(4+1)WF10
BEARING PILE	BP	14BP73
ZEE	Z	Z6x$3\frac{1}{2}$x15.7
PLATE	Pl	Pl 18x$\frac{1}{2}$x2'-6
PLATE (ALTERNATE USE)	Pl	10.2 # Pl
CHECKERED PLATE	CK Pl	CK Pl $\frac{1}{2}$
FLAT BAR	Bar	Bar $2\frac{1}{2}$x$\frac{1}{4}$
TIE ROD	TR	$\frac{3}{4}$ϕ TR
PIPE COLUMN	○	○6ϕ

Figure 168. Symbols for single structural shapes.

Table X. American Standard Channels

Dimensions for detailing

Depth of section	Weight per foot	Flange		Web
		Width	Mean thickness	Thickness
in.	lb	in.	in.	in.
6	13.0	2 1/8	3/8	7/16
	10.5	2	3/8	5/16
	8.2	1 7/8	3/8	3/16

Table XI. American Standard Beams

Dimensions for detailing

Depth of section	Weight per foot	Flange		Web
		Width	Mean thickness	Thickness
in.	lb	in.	in.	in.
10	35.0	5	1/2	5/8
	25.4	4 5/8	1/2	5/16

Table XII. Wide Flange Shapes

Dimensions for detailing

Nominal size	Weight per foot	Depth	Flange		Web
			Width	Thickness	Thickness
in.	lb	in.	in.	in.	in.
16 x 11 1/2	96	16 3/8	11 1/2	7/8	9/16
	88	16 1/8	11 1/2	13/16	1/2
16 x 8 1/2	78	16 3/8	8 5/8	7/8	9/16
	71	16 1/8	8 1/2	13/16	1/2
	64	16	8 1/2	11/16	7/16
	58	15 7/8	8 1/2	5/8	7/16
16 x 7	50	16 1/4	7 1/8	5/8	3/8
	45	16 1/8	7	9/16	3/8
	40	16	7	1/2	5/16
	36	15 7/8	7	7/16	5/16

d. Scales. Scales of shop drawings vary from 1/4″ = 1′-0″ to 1″ = 1′-0″ depending on the size of the drawing sheet as compared with the size of the structural member. Usually two scales are used in the same view, one denoting length and the other showing the cross section a a larger scale than the length, as in figure 170. Often, it is expendient to disregard scaled length and draw the member as if there were breaks in the length (although not shown on the drawing, as in fig. 171) so that details of intermediate connections and rivet spacings at the ends can be drawn at the same scale as the cross section.

e. Dimensions. Dimensions are always placed above the dimension line. Remember on construction drawings, the dimensions lines are unbroken. Dimensions are given to centerlines and working lines, never to the outer edges of rolled shapes (except for length dimensions),

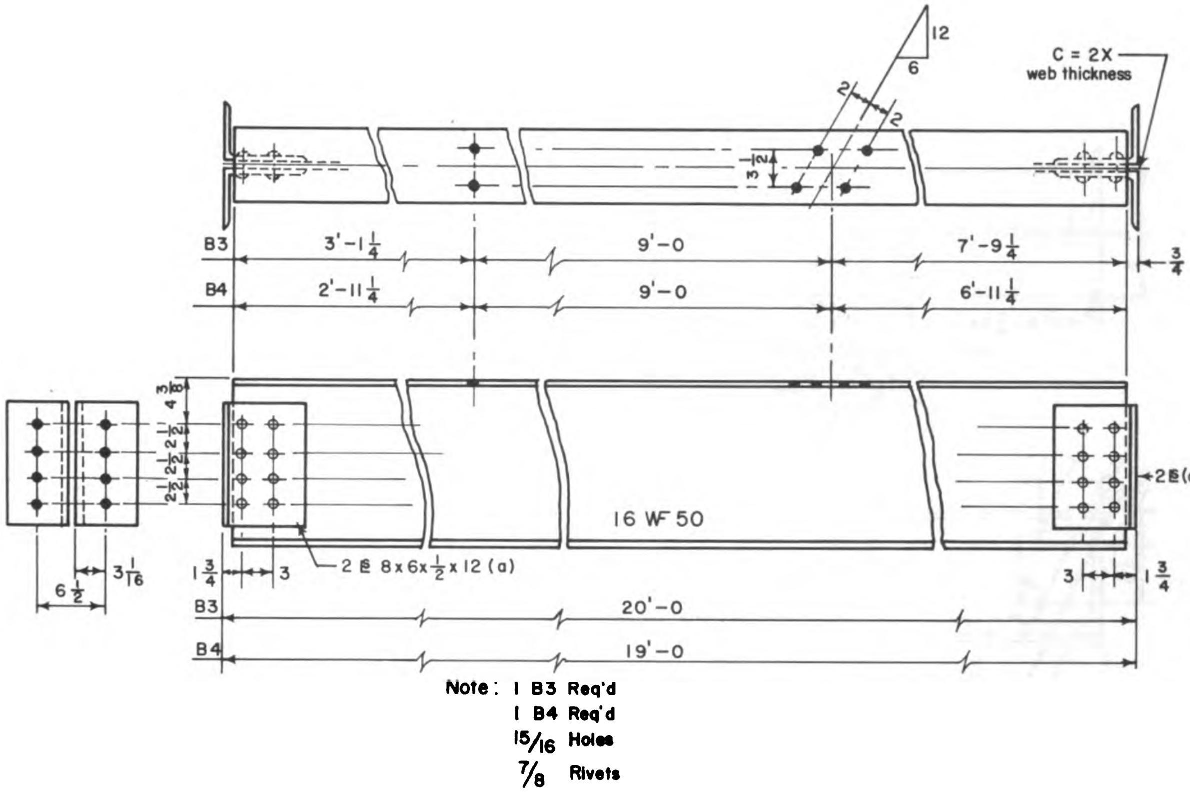


Figure 169. Shop drawing of a beam.

and extension lines are drawn in accordance with routine drawing practice. When members differ in length only, they may be shown by a single drawing. When thus drawn, the different lengths are given separately and are identified by erection marks at the left end of each dimensions line. Figure 169 shows two beams detailed on the same drawing. All inch symbols are omitted (unless there is a possibility of misunderstanding), even though the dimensions are in feet and inches and should be hyphenated as 5′-0, 5′-0¼, and so on (par. 314 and figs. 169–172).

f. Sizes of Rolled Shapes. Sizes of rolled shapes are specified by abbreviated notes as described in paragraph 314. The specification note may be given along with the length dimension (fig. 171) or is placed near and parallel to the part as in figures 169 and 170. In some cases, it is advantageous to place the specification right on the front view of the shape (fig. 172).

g. Slopes. Slopes of members and inclined centerlines, cuts, and so on, are indicated by their tangents. The value of the angle is given by constructing a small right triangle (not necessarily to scale) with its hypotenuse on or parallel to the skewed line. The long leg of the triangle is always labeled 12, meaning 12 inches. Figures 169 and 170 illustrate the manner in which the slope triangle is used.

h. Erection Marks. Erection Marks facilitate the identification of members. Like index marks on a road map, they consist of capital letters (B for beam, C for column, T for truss, and so on) indicating the type of member and a number giving the specific member in an assembly or its location in the structure. They are indicated in subtitles of shop drawings (fig. 169) and on erection diagrams as in figure 172.

i. Assembly Marks. Assembly marks identify the use of the same shape in more than one place. The member is completely specified once and then given an assembly mark (lower case letter, to avoid confusing it with the erection mark). It is not necessary to repeat the complete specification in identifying similar mem-

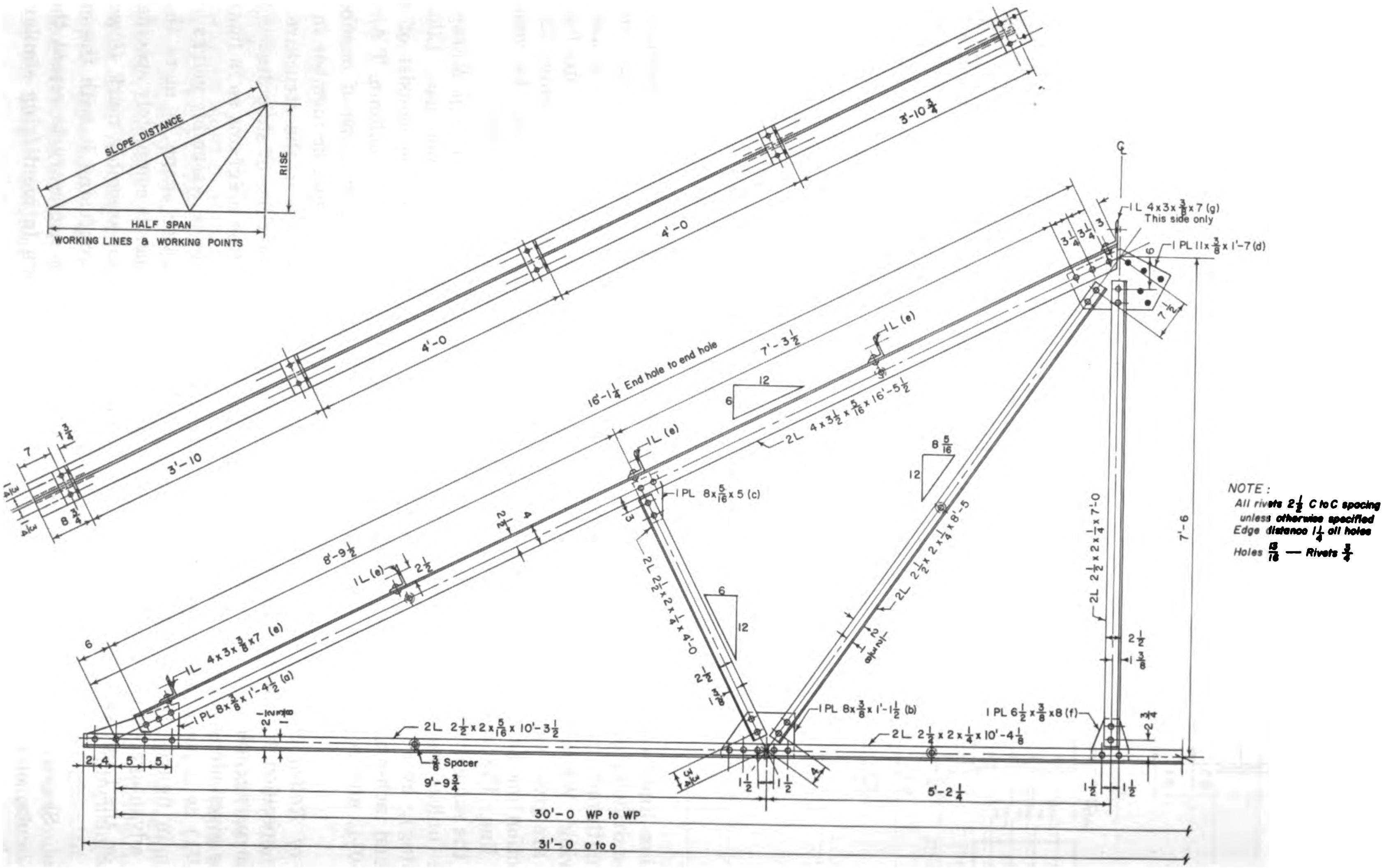


Figure 170. Shop drawing of a typical steel truss.

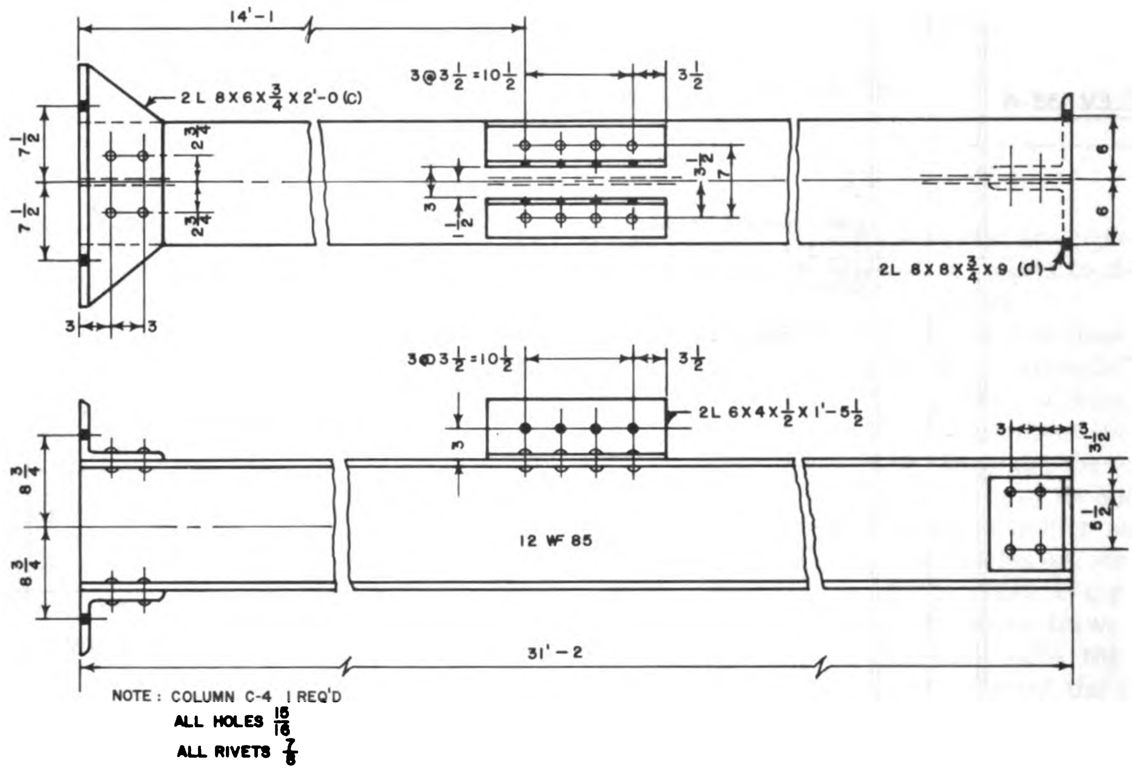


Figure 171. Shop drawing of a column.

bers. For example, see the specification "2s 8 x 6 x ½ x 12 (a)" in figure 169.

317. Plans for Steel Framing Systems

a. Erection Plans. An erection plan shows the relative location of every part of a structure, assembly marks for the various members, all main dimensions, the number of pieces in a member, packing of pins, size and grip of pins, and any special features or information that will assist the erector in the field. However, erection plans are not required unless the structure is difficult or intricate. Diagrammatic design drawings can be used as erection plans if the assembly numbers of the various members have been noted.

b. Falsework Plans. Falsework is a temporary support, usually timber, for a steel structure such as a truss bridge that cannot be self-supporting until completed. Falsework plans are used only in a complex construction.

318. Bill of Material

A complete list of materials, showing all the different parts of the structure with identifying marks and shipping weights, should be included in the plans. This is necessary for checking, to insure that all parts will be on hand prior to erection, and to compute the weights of fabricated sections for erection equipment.

319. Rivet Lists

A rivet list may be shown in the bill of material or elsewhere in the plans. It shows the dimension and number of all field rivets, field bolts, and spikes used in the erection of a structure.

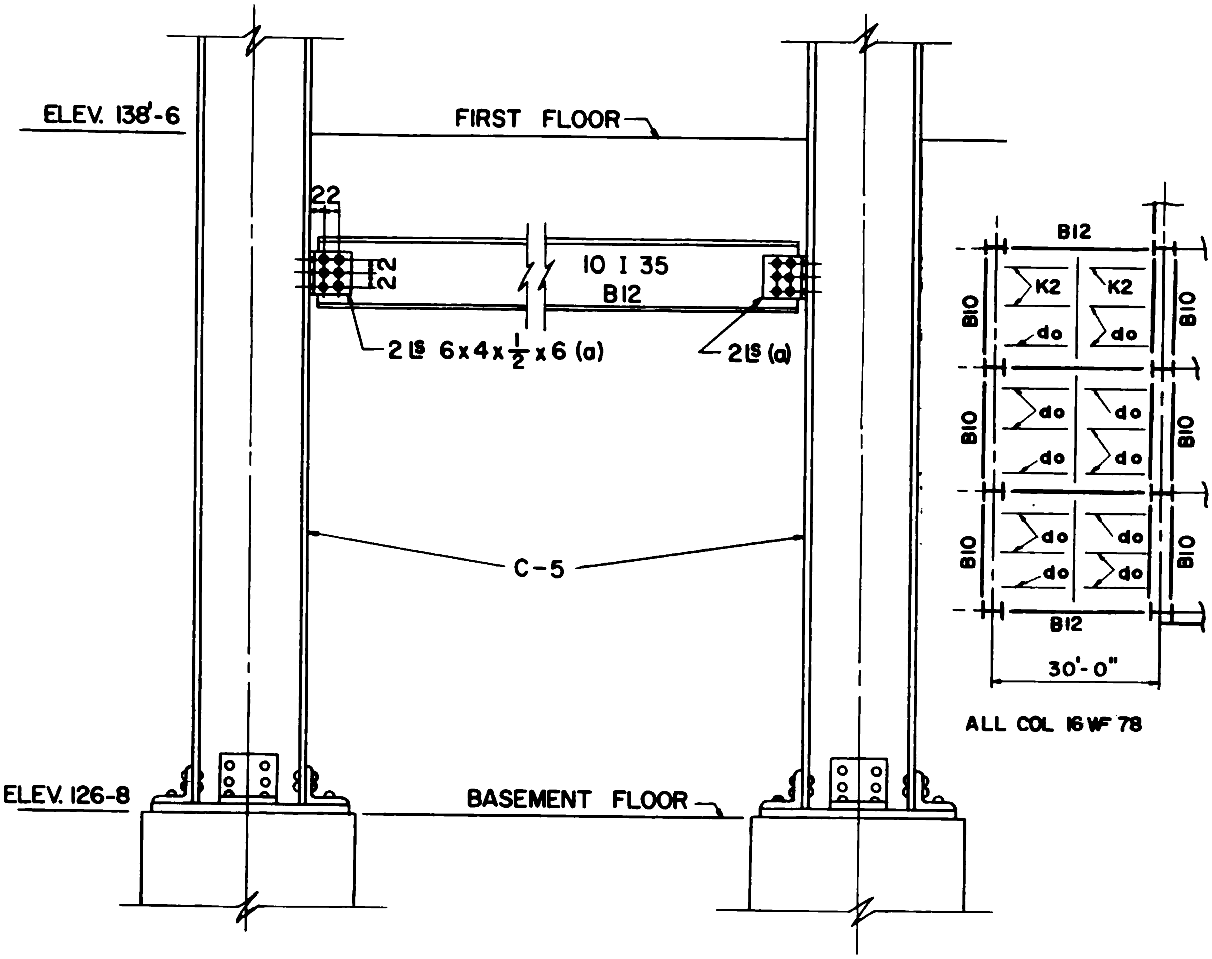


Figure 172. Typical steel frame construction.

CHAPTER 15

PLUMBING, HEATING, AND ELECTRICAL WIRING

Section I. PLUMBING

320. Water Distribution Systems

The water distribution system of a building is the inside plumbing installation that supplies water to the fixtures. The water-supply main entering the building branches out in reduced-diameter pipes that connect to each individual fixture and supply it with its water requirements.

a. Definition. All piping, apparatus, and fixtures for waste disposal and water distribution systems in a building are called plumbing.

b. Piping Systems. Piping systems are composed of pipes, fittings, unions, and valves.

(1) *Piping.* Up to 12 inches in diameter, standard piping of steel or wrought iron is classified by its nominal inside diameter, which differs slightly from its actual inside diameter. The actual inside diameter varies for a given nominal size depending on whether the pipe weight is standard, heavy, or extra heavy. The external diameter is the same for all three weights. For 2-inch steel piping, the actual inside diameter of standard is 2.067 inches, heavy is 1.939 inches, extra heavy is 1.503 inches. External diameter for the three weights is 2.375 inches. Above 12 inches, pipe is called OD (outside diameter) because it is classified by its actual diameter. Copper and brass piping are classified by the same nominal sizes as iron pipe. There are two weights for each size, regular and extra strong. Pipe is supplied in straight lengths in sections from 12 to 20 feet long.

(2) *Fittings.* Pipe fittings are used to connect lengths of pipe and to provide continuity, and for changes in direction. For the pipe materials described above, screwed fittings, butt-welded fittings, and soldered-joint fittings are used. Pipe sections also are connected by being screwed or welded to flanges that are bolted together.

(3) *Unions.* Unions are three-piece connections designed to be "unmade" conveniently. For screwed unions, one piece is threaded internally on one end and externally on the other; the second piece is threaded internally on one end and has an external shoulder on the other. The first two pieces are screwed to the ends of the pipes being connected and the third piece draws them together by screwing onto the first piece while bearing against the shoulder of the second. Unions are also designed for connection to pipe by welding and soldering.

(4) *Valves.* Valves are used to regulate flow in a piping system. Globe and gate valves usually are used as shut-off valves. Check valves insure that fluid does not back up against the direction of flow. Valves are specified by type, material, size and working pressures, for example, ½-inch globe valve, brass, 125 pounds working pressure.

c. Fixtures. Many different fixtures are required for plumbing systems. Appendix V shows symbols for those in common use.

321. Materials

Water distribution piping for interior installations is made of galvanized steel, wrought iron, copper, plastic, or brass. Nickel, silver, and chrome piping are used in locations where pipes are exposed to view. Galvanized wrought iron is the material most frequently used in theater of operations construction. Fittings normally are of the same material as the piping and are made with screw or flange connections; screw connections are normally used only for pipe up to 4 inches in diameter. Valves usually are made of brass. The material types to be used for the systems are designated in the specifications; sizes and special instructions are noted in the drawings.

322. Building Waste Systems

Waste systems include all piping from sinks, water closets, urinals, showers, baths, and other fixtures that carry liquids and sewage outside of the building. A system consists of a main building drain, branch mains, and soil and vent stacks. Water, soil, and vent piping specifications include the materials of manufacture for each type of piping, such as cast iron, galvanized steel, wrought iron, copper, brass, lead, or acid-resistant cast-iron pipe. Fittings or traps normally are specified to be of the same material as the pipe. Pipe types may be included in a pipe schedule in the drawings.

a. Vitrified Clay Piping and Fittings. Vitrified clay piping fittings are used for underground house drains and sewers and normally are noted in the plans as VCP or VP. VCP is sometimes used for soil and vent stacks in theater of operations construction. Pipes and fittings are made with bell-and-spigot ends. Joints are made by inserting the spigot end into the ball and calking with cement mortar.

b. Cast-Iron Pipes and Fittings. Cast-iron pipes and fittings are used for building drains and for soil, waste, and vent piping. These pipes can be laid in unstable soil without danger of sagging. Pipes and fittings are made with bell-and-spigot and flange ends. Bell-and-spigot joints are calked with oakum and lead or a calking compound; flanged fittings are bolted together to make a joint.

c. Galvanized Steel and Iron Piping. Galvanized steel and iron pipes and fittings are the materials most commonly specified for plumbing installations. Pipe ends have standard pipe threads and all pipes and fittings of this type are joined by standard pipe threads. Such piping is manufactured in three different weights and in diameters from 1/8 up to 12 inches to any one of several specifications. The fittings are manufactured in all shapes required to change or intersect flow.

d. Miscellaneous Piping. Brass, lead, or copper piping is used in better class, or more expensive, systems of waste plumbing. Brass or lead is used when excessive acids or corrosive liquids are present. Such acids and liquids are seldom present in the flow of theater of operations sewage. Brass pipes and fittings are joined by standard pipe threads, and the fitting shapes are identical to those used for galvanized steel or wrought iron pipe. Lead pipe is very ductile, a feature that is advantageous in speed of installation, but it must be well supported because it deteriorates rapidly if permitted to sag. Copper pipe is not commonly specified for use as waste and vent piping because of the excessive cost of the larger sizes. For making connections, the pipe is out to the desired length and sweat-soldered to the applicable type of the several fittings available.

323. Building Waste Systems Layout and Nomenclature

a. House Sewers. The first component of waste and sewage piping is the house sewer, which is that part of the waste plumbing system beginning just outside the foundation and terminating at a street sewer branch or a septic tank. Usually, it is the bell-and-spigot type and is made of vitrified clay or cast iron. For distances of 5 feet or greater from the foundation wall, a house sewer should be made of cast iron.

b. House Drains. A house drain is that part of the plumbing system receiving the discharge of all soil and waste stacks within the building. It is constructed of cast iron with lead joints and should have a slope of at least 1/4 inch per foot. The house drain should connect directly into the house sewer. It may be installed underground or suspended from the first-floor joists. A house drain system is also referred to as the collection lines; it includes appliances such as house traps, backflow valves, cleanouts, and area drains. A cleanout consisting of a branch pipe projecting through the floor is connected to the drain just inside the basement wall to permit cleaning the house sewer. A house trap is connected to the house drain inside the basement wall just beyond the sewer cleanout. A fresh-air inlet is placed next on the building side of the house trap. No traps are placed at the foot of the stacks where they join the house drain. In general, house drains fall into one of four classes in any set of specific building plans.

(1) *Combination drains.* Combination drains receive the discharge of sani-

tary wastes from the building plus the storm water from the roof and other exterior sources.

(2) *Sanitary drains.* Sanitary drains receive the discharge of sanitary and domestic wastes only.

(3) *Storm drains.* Storm drains receive storm-, clear-water, and surface-water wastes only.

(4) *Industrial drains.* Industrial drains receive liquid waste from industrial equipment or processes and consequently receive little attention in theater of operations construction.

c. Soil Pipes. Soil pipe is that portion of the plumbing system that receives the discharge of water closets, with or without additional fixtures, and conveys it to the house drain.

d. Waste Pipes. Waste pipe is that part of the drainage system conveying to the soil pipe the discharge of fixtures other than water closets, such as sinks, lavoratories, urinals, and bathtubs. Soil and waste pipes usually are made of extra-heavy cast iron.

e. Vent Stacks. Vent stacks are the vertical pipes that do not carry any sewage. Usually, they are made of cast iron and may be combined or cross-connected with the soil and waste stacks to save on piping and to maintain a continuous flow of air from the roof to the house drain. By venting and allowing the free circulation of air throughout the system, the growth of harmful bacteria is retarded, poisonous gases are diluted, pipe scaling is delayed, disagreeable odors are removed, and a balanced atmospheric pressure is maintained.

f. Fixture Branches. Fixture branches connect the fixtures with the stacks and must be made of cast iron, brass, or copper. Waste and soil branches are connected to the trap of each fixture and should have a slope of ⅛ to ½ inch per foot. The length of a horizontal branch, measured from the inlet of the trap to the vent opening, should not be over 5 feet.

g. Traps. Traps provide a water seal that prevents disagreeable odors from escaping through the fixtures. They are classed as running traps, Y-traps, S-traps, and P-traps and are made of steel, cast iron, or brass. Water closets and urinals have traps of vitreous china that are a part of the fixtures. All traps should be self-cleaning and capable of being completely flushed each time the trap operates so that no sediment remains inside to decompose.

324. Plumbing Drawings

Plumbing plans for large installations usually are drawn separately because of the volume of detail in drawings. Those for smaller systems normally are shown in drawings in combination with other utilities, it being assumed that each trade can identify the applicable symbols to make its installations from the combined plans. Theater of operations building drawings normally show all the utilities of a building in one drawing. The overlay method is used to prepare separate plumbing plans for large installations.

a. Plumbing Plans. An overlay is begun by fastening a sheet of tracing paper over the plan view of the floor for which plumbing is to be shown; exterior walls and partitions are traced. To prevent confusion the drawing is kept as simple as possible. Wall thicknesses are shown but no material symbols are used. It is common construction practice for walls on which water closets and lavatories are hung to be double-studded to allow room for concealing piping. Door and window openings are shown but no door swings are indicated. The primary purpose of the drawing is to show the location of piping and fixtures relative to wall and partition lines. Pencil lines must be sharp and opaque because the overlay is reproduced to make working prints.

(1) *Fixtures.* Fixtures are represented symbolically and are drawn to scale in their relative locations. Appendix V shows military standard plumbing symbols compiled from MIL–STD–17. Fixture symbols are the first items to be drawn in the layout after wall and partition lines have been traced. No dimensions are shown. Waste outlet and water supply connections must be located so that the piping layout can be shown.

(*a*) *Wall lines.* Note that many symbols are drawn touching the wall line. Corner bath, wall lavatory, and low-tank water closet symbols are examples.

(b) *Letter symbols.* Many plumbing symbols must be accompanied by identifying initials when drawn in the plumbing plan, such as SS, accompanying the service sink symbol; DF, accompanying the drinking fountain symbol; and D, accompanying the drain symbol. All symbols with identifying initials must be identified in the same way in plumbing drawings.

(2) *Piping.* Appendix V also shows symbols for piping fittings. Pipe is shown in a single-line symbol. Valve and fitting symbols are used in plumbing plans only for supply piping; they are not used for waste. Types of joints are designated in the specifications. A single-line pipe symbol is drawn between fixtures to give mechanics an idea of the approximate location. The exact length of runs is determined in the field. All runs of pipe must be identified by nominal size. The size is printed as a figure (¾″) next to the pipe with an arrowhead and leader extending to the pipe from the dimension; the nominal size is all that is printed. A dimension must be given wherever pipe size changes.

(a) *Hot water.* A hot-water pipe (system) is indicated by a single heavy dashed line consisting of one long dash and two short dashes.

(b) *Cold water.* A cold-water pipe (system) is indicated by a heavy dashed line consisting of alternate long and short dashes.

(c) *Waste piping.* Waste or sewage piping is indicated by a heavy solid line. Although no fittings are shown, waste branches always intersect with a short 45° segment indicating a Y-connection.

(d) *Vent stacks.* Vertical vent stacks appear in section in a plumbing plan and are shown as circles drawn to scale.

(e) *Legends.* Pipeline symbols should be organized under the heading *Legend* and identified in all piping plans unless the drawing contains only a single system. The legend is located at a convenient place in the drawing area.

(f) *Intersections and crossovers.* When fitting symbols are not used in the diagrammatic representations, the intersection (joining) of any two piping runs will be represented by actual contact between the lines. Crossovers (no connection between piping) will be represented by a break in one of the lines.

b. *Vertical Views.* Vertical views of piping, such as sections and elevations, are used only to clarify complicated layouts. Finished floor lines and elevations should be shown, and the height of the piping runs should be located by dimensions from finished floor lines.

(1) *Riser diagrams.* A riser diagram is an elevation or perspective view of a waste system showing the stacks and risers; fixtures may or may not be shown. Generally, soil and vent stacks, traps, cleanouts, and main runs are shown with indicated sizes. Riser diagrams are not shown in plumbing plans for small buildings but are normal for large-system installations.

(2) *Isometric views.* Isometric drawings are the only perspective views used for piping drawings. Figure 173 shows an elevation and an isometric view of the piping for a heating installation. The same drawing principles apply to the plumbing drawings.

c. *Details.* Installation details generally are not required for plumbing drawings. Piping and fixtures are installed by mechanics according to standard plumbing practices.

325. Plumbing Takeoff

A plumbing quantity survey involves listing all the components necessary to complete the work. Lines are followed in sequence from source to fixture. Because plumbing drawings do not generally show an exact piping layout, a takeoff man must visualize the piping design as he lists material; in this way, he will be better able to account for all the material required.

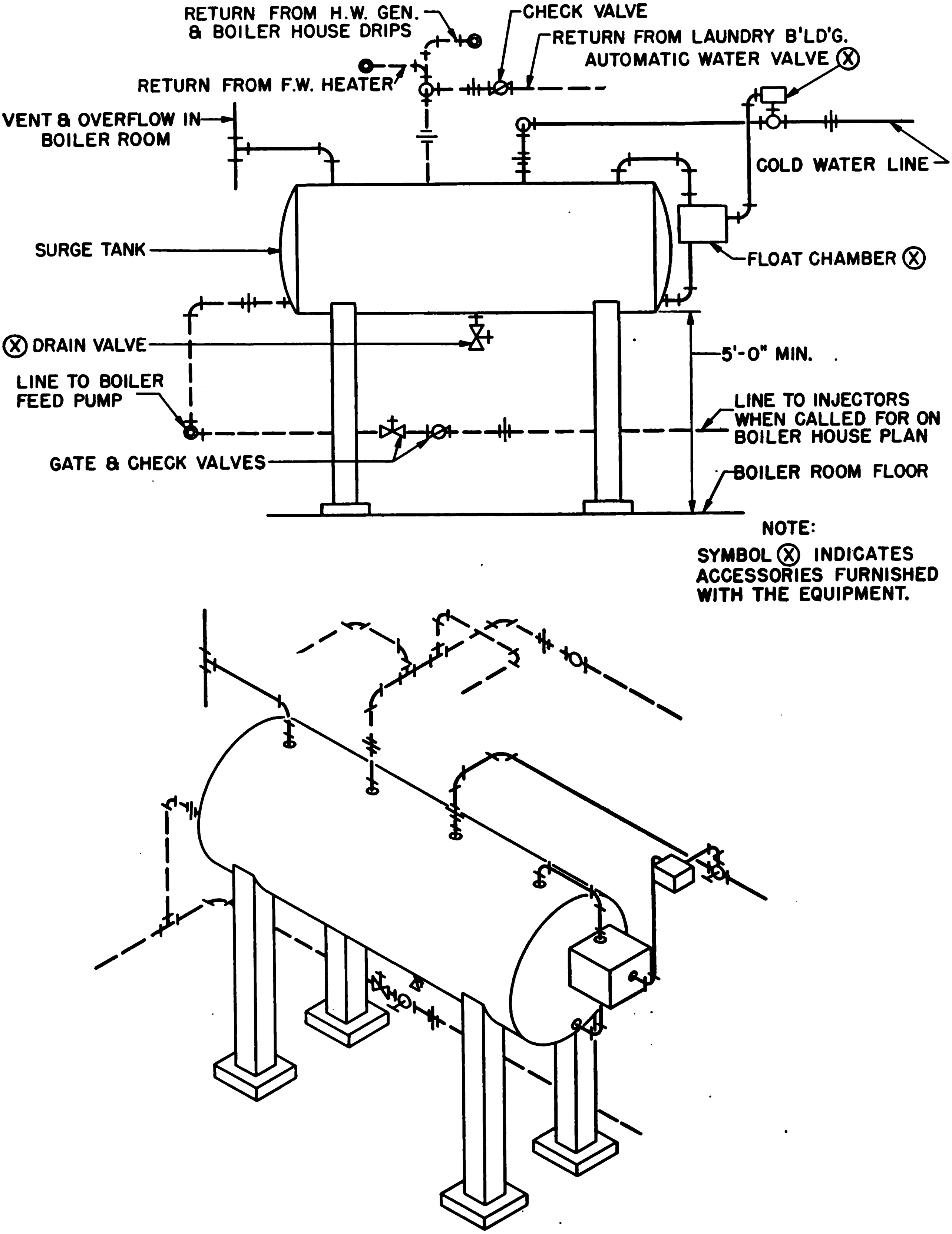


Figure 173. Single-line piping, elevation and isometric.

a. Piping. Piping is listed by size, material, stock number, and the total number of lineal feet. When pipes of different material are listed, different sizes are listed under their respective material headings. Soil piping is listed separately. A typical listing is as follows:

½" galvanized-steel pipe ____Stock No. __ 100 lf
¾" galvanized-steel pipe ___ Stock No.__ _ 150 lf
½" red brass pipe _________Stock No. _ 75 lf

b. Fittings. Fittings are listed by size, material, classification, stock number, and quantity. *For example:*

½" galvanized cast-iron elbows,
90° ______________________Stock No. __ 25 ea
¾" galvanized cast-iron elbows,
90° ______________________Stock No.__ _ 35 ea

c. Fixtures. Fixtures are listed by name, stock number, and quantity.

d. Soil Piping. Soil piping is listed by size, material, strength, and the number of 5-foot lengths. Fittings are listed by size, material, classification, strength, and quantity. Fitting classifications differ from those of brass and iron. A 90° elbow is called a quarter bend, a 45° elbow is called an eighth bend, a laterial is called a Y. The plumbing takeoff would, for example, list piping as follows:

4" extra heavy cast-iron soil pipe
(5 ft lengths) _________________5 lengths
4" quarter bend extra heavy CI ____ 4 each

e. Wastage Estimates. In compiling a bill of material from a plumbing takeoff, allowances must be made for piping wastage; extra quantities must be added to make up for the losses in cutting and fitting.

Section II. HEATING

326. Definition of Heating

Heating is the operation of a system to transmit heat from a point of generation to the place or places of use. A construction draftsman's job is not to design, but to draw, from notes and sketches supplied by the designer, the plan of a heating system. To do this, the draftsman must be familiar with the basic elements of heating systems and their graphic representation in a finished layout.

327. Heating Systems

a. Basic Principles. The basic principle of heating is that any fluid—gas, water, or air, for example—tends to rise when heated. In a system allowing free circulation heated fluid is replaced by cooler fluid that, being denser, tends to fall. There are many familiar examples of this. In a closed or semiclosed room, the temperature at the ceiling will be from 2 to 4 degrees warmer than at floor level. In a small lake on a warm day, the water at the top is noticeably warmer than that at deeper levels.

b. Classification. Though all heating systems make use of the basic principles described above, different circulation mediums may be used. Heating systems are classified according to the medium used to carry heat from the point of generation to the point of use.

328. Hot-Water Systems

Hot-water heating is one of the most common systems. Panel heating and radiator installations make use of this medium. Hot-water systems are used extensively by the Army and are classified according to piping arrangement.

a. One-Pipe System. The one-pipe system is the simplest hot-water installation. Heat is applied to the water by the heating unit, which may be coal-, oil-, or gas-fired. The combustion chamber is surrounded by the boiler jacket in which the water is heated. Gravity takes effect as the water heats. The lighter, warmer water rises and circulates up and out of the boiler into the radiators. A single pipe serves as the supply and return main. Visualize a one-pipe system with three radiators. A portion of the hot water from the main enters the first radiator and circulates through it, giving off heat to the room. Then the water, having cooled, empties back into the main. Water entering the second radiator is cooler than its original boiler temperature; therefore, to obtain the same amount of heat, the second radiator must be larger than the first. The same heat loss occurs in the third radiator which means that this radiator, the last in the system, must be the largest of all. It is apparent that a one-pipe system has many disadvantages. It is impractical to increase the size of the radiators in large heating systems, thus a one-pipe system is adequate only for very small installations.

b. Two-Pipe System. The disadvantages described above are largely offset in a two-pipe system. Separate supply and return mains are provided so that cooler water emptying from a radiator is not recirculated through other radiators in the circuit. All radiators can be the same size because all use the same water temperature. This system is the better hot-water installation. In comparison of radiator size in the one-pipe and two-pipe system it is assumed that each radiator is to supply the same amount of heat.

329. Warm-Air Heating Systems

Warm-air heating is used in almost all Army semipermanent construction and is found in most barracks; therefore, it is the type most familiar to a construction draftsman.

a. Elements. A warm-air heating system is composed of a heating plant, bonnet, warm-air ducts, warm-air registers, return air registers, cold-air return ducts, and a fan or blower for forced circulation. The plant includes the heating unit, a combustion chamber, and a jacket around the chamber in which the air is heated. The bonnet or plenum chamber, in which the heated air is collected for room distribution, is placed above the plant. The warm air is distributed through sheetmetal ducts and discharged into the room through warm-air registers or grilles. After the air has circulated through the room and lost its heat, it is returned to the plant through return air registers and ducts. In gravity warm-air systems, circulation is attained by application of the basic principle that warm air is lighter than cold air, but, in most systems, a fan or blower is installed to increase circulation.

b. Design. Many design principles have been advanced regarding the placement of registers and ducts in a building, but only one will be used in this discussion. All heating design stems from the basic concept of a comfort zone, which is defined as the horizontal area from the top of an average man's head to his knees. Because the air used in warm-air heating is discharged from registers at a temperature of 175° F., it is apparent that it would be very uncomfortable if it were blown directly on a person. Therefore, registers are placed, either above or below the comfort zone so that no direct drafts of hot air are blown directly on room occupants.

(1) *Warm-air registers.* Exterior walls, in heating design, are thought of as cold walls because of the disagreeable drafts that occur in their immediate area. Warm-air systems, for this reason, usually are designed to blanket cold walls with a layer of warm air. Warm-air registers are placed on interior walls (ceiling, high wall, or baseboard to satisfy comfort zone requirements) to diffuse the warm air toward the cold exterior walls.

(2) *Cold-air registers.* Cold-air registers are always located at baseboard height regardless of other design theories. The reason for this is apparent: the heavy cool air collects in layers just above the floor. Cold-air return registers located in the baseboard act as collectors and return the air to the heating plant through return ducts for reheating and recirculation.

(3) *Furnaces.* The location of the furnace or heater room also is of great importance to warm-air heating design. It is good design policy to locate the furnace room centrally in the building plan to equalize duct lengths. Good design also dictates that main (trunk) ducts run above a central corridor to equalize branch duct lengths to individual rooms.

c. Ducts. Warm-air heating ducts are built of sheet metal in rectangular or round sections. Many combinations and shapes are possible, however, some of the most common rectangular combinations and connections are shown in figure 174.

(1) *Bonnets.* 1, figure 174 shows a typical warm-air bonnet with two main (trunk) supply ducts.

(2) *Elbow connections.* 2, figure 174 illustrates two possible elbow-duct connections, one vertical and the other horizontal.

(3) *Tee connections.* 3, figure 174 shows two possible tee-duct connections. Be-

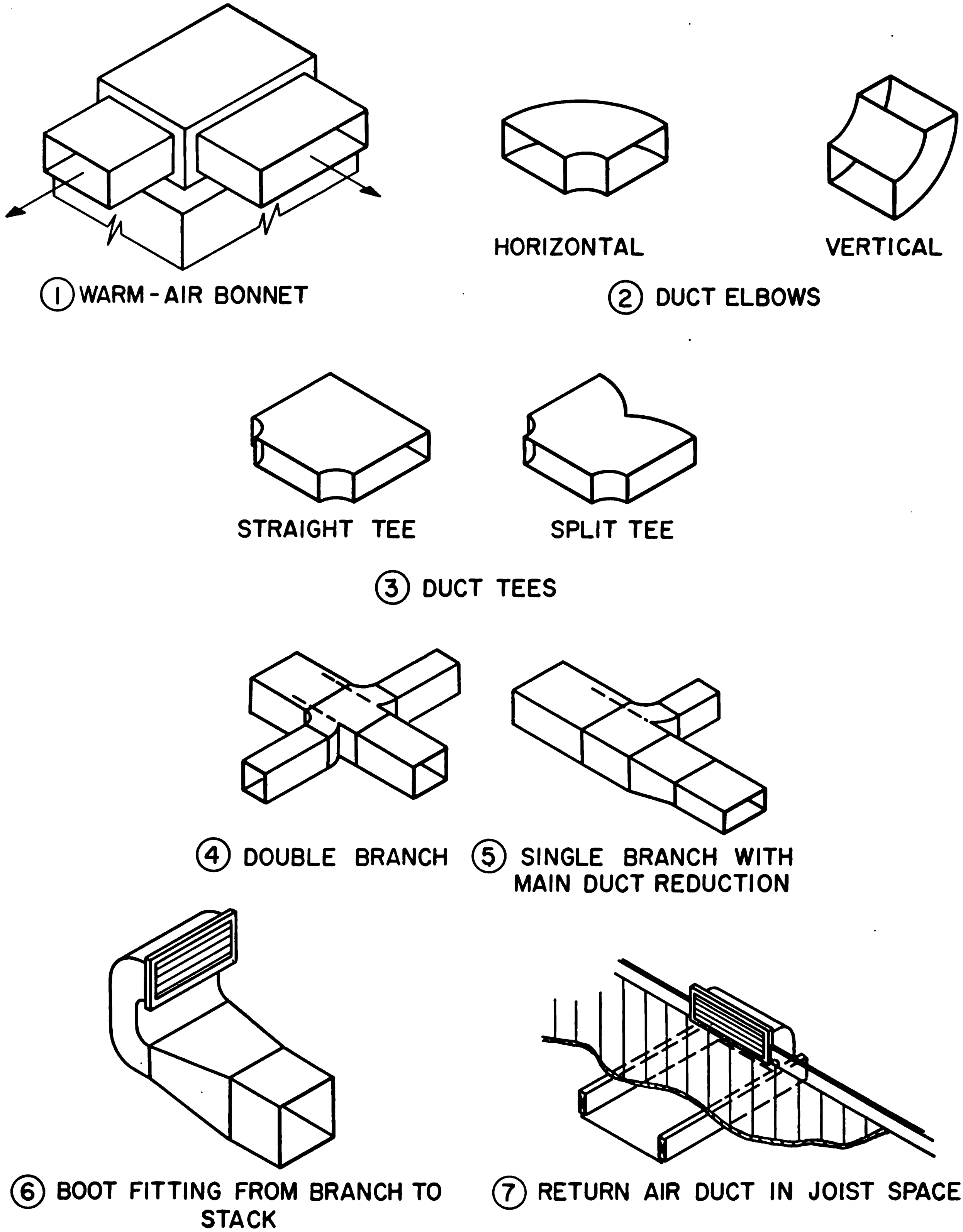


Figure 174. Duct connections.

cause it is desirable to direct the flow of air on the warm side of the system as much as possible, a split tee is used. However, on the cold-air return ducts, a straight tee may be used because direction of air flow is not so paramount. From the diagram, it will be noted that a straight tee would obviously be considerably less expensive to form than a split tee.

(4) *Trunk takeoffs.* Trunk duct takeoffs are shown in 4 and 5, figure 174. In the double branch connection, less air is present in the main duct after some of the air has been channeled into branch ducts. Therefore, the size can be reduced after the connection. The single branch connection shows two methods of reduction. The first occurs at the connection in a horizontal direction; the second is effected by a vertical reduction in depth. It will be noted that in both double and single branch takeoffs the branch connections form a natural air scoop to encourage airflow in the desired direction.

(5) *Boots.* 6, figure 174 illustrates a boot fitting from branch to stack, the stack terminating at a warm-air register. This figure also illustrates one method of changing the shape of a duct without changing its equivalent cross section area or constricting the flow of air.

(6) *Joist spaces.* 7, figure 174 shows an inclosed joist space used as a return duct. It is not advisable to use this method in warm-air duct work because there is too much costly air leakage.

330. Space Heating Systems

Space heaters are used in theater of operations temporary buildings. A space heater is not a heating system, but it must be discussed because of its universal application in theater of operations construction. The Army authorizes three types of space heaters, the Cannon Stove, the U. S. Army Space Heater No. 1, and the U. S. Army Space Heater No. 4. The U. S. Army Space Heater No. 1 is the heater used almost exclusively in theater operations construction.

331. Heating Drawings

The same general rules apply in preparing heating drawings as in preparing plumbing drawings. For small buildings, the location of radiators or registers and of the heating plant is shown in the general plan drawings. For large or complicated installations, separate heating drawings are prepared for reproduction. Walls and partition lines are located first by tracing from the architectural plan view, then the symbols for heating equipment and fixtures are located and drawn.

a. Symbols. Appendix VI presents the heating symbols most commonly used in preparing military drawings. Additional symbols can be found in MIL–STD–17.

b. Space Heater Systems. Separate plans are not required to represent space heating systems because this kind of installation is simple enough to be included in a general plan view. The symbol for a space heater is a circle, which is identified by a specific note. When indicating a space heater, also show the hearth. Fireproof wall covering should be indicated by a note.

c. Warm-Air Systems. Actual duct, register, blower, and furnace sizes for warm-air systems are designed by a heating engineer, who also furnishes the sizes for the draftsman together with a rough sketch of the duct layout. The draftsman draws the heating plan in finished form, using standard symbols and notations.

(1) *Supply ducts.* Warm-air supply ducts are indicated in the heating plan by solid lines. In giving duct sizes, the standard method is to list first the horizontal dimension, which is the one the draftsman will scale in the heating plan. The second dimension gives the depth of the duct. The duct symbol in appendix VI is dimensioned as 12 x 20. When drawing this size duct in a heating plan, the 12-inch dimension is drawn to scale; the 20-inch dimension, or depth, is not shown.

(2) *Return ducts.* Cold-air return ducts are indicated in the heating plan with dashed lines. The same rules of duct dimensions apply, dimensions being noted as described above.

(3) *Supply registers.* Warm-air registers are located and scaled in a drawing to the actual size given. Two intersecting diagonal lines are drawn between corners. Appendix VI shows combined register and damper symbols. If ceiling registers are used, face dimensions are shown in the plan with the proper warm-air register symbols. If wall or baseboard registers are installed, one face dimension and one stack thickness are shown. Stack dimensions depend on stud dimensions, but are usually from 3 to 6 inches thick. Whether ceiling, wall, or baseboard registers are used, face dimensions are noted adjacent to the symbol. Heights of wall registers above the finished floor line should be included in notes.

(4) *Return registers.* Return air registers are located in a drawing from the design sketch and the symbols drawn. The horizontal face dimension is scaled outside the wall line as a solid line, and the stack thickness is drawn inside the wall line as a rectangle with a diagonal extending from the upper right corner to the lower left-hand corner of the symbol. Stack dimensions are from 3 to 6 inches in depth, depending on stud thickness. Face dimensions are noted adjacent to the symbol.

(5) *Ducts.* When drawing ducts in the plan, a draftsman should remember the direction of airflow, appearance, and economy. *For example,* when drawing two branch ducts coming off the main duct at 90°, an equal reduction in size on either side of the main supply duct would be conducive to airflow. Double-line duct layouts are drawn first by laying out a centerline for the duct runs. Duct symbol lines are drawn equidistant from layout centerlines. The inside radius of duct connections is 6 inches; the outside radius is concentric to the inside radius and tangent to the edge of the smaller branch duct.

332. Steam Heating

Steam heating is seldom used in Army construction but is rather common in civilian work. Its components are, in many ways, identical to hot-water systems. Because steam heat is not used extensively by the Army, however, it is merely mentioned as the fourth main type of heating system.

333. Heating Takeoff

Except for duct work, takeoff sheets for heating are compiled similarly to those for plumbing; they represent a complete listing of all equipment and material. Duct work is listed differently. Except in the smallest installations, where only several duct sizes and few special fittings are required, it is awkard to list all sizes of ducts, transition pieces, and special fittings. Sheet metal normally is fabricated in a shop and transported to the job so, to facilitate the work of sheet metal fabrication, a listing of the total quantities of sheet metal by gages should be provided. The list can also be used for procurement and cost estimating.

Section III. ELECTRICAL WIRING

334. Definition of Electrical Wiring Systems

The electrical wiring system distributes electrical energy in a building. It is frequently called the interior wiring system to distinguish it from the electrical distribution system generally used to indicate outside power lines and appurtenances for multi-building installations. Although a draftsman is not required to design the interior wiring system for a building, he must be familiar with electrical symbols and nomenclature and have a basic knowledge of interior distribution systems, types of wires, and circuit hookups to draw an electrical layout intelligently. And he must be able to apply that knowledge in drawing wiring plans for a building.

335. Theory of Electrical Distribution

Electrical distribution can be explained most easily by comparing it to waterflow. Water is forced through a piping system under pressure, the pipe must be large enough to allow water passage without undue friction, and pressure must be sufficient to move water from the pumping source to the points of use. In electrical distribution, the pressure developed by an electric generator must be sufficient to cause electricity to flow through conductors to the points of use and, as with pipe, the conductor must be large enough to permit flow without undue resistance. Pressure in an electrical wiring system is measured in volts, rate-of-current flow in amperes, and resistance in ohms. The unit of electrical power is the watt.

336. Bulding Feeders and Subfeeders

A building feeder is a set of conductors supplying electricity to the building. A subfeeder is an extension of the feeder through a output, or switch, from one interior distribution center to another without branch circuits between.

a. Building Service. Conductors that supply electricity to a building from an exterior distribution system also are known as building service; when run overhead from poles they are called aerial service. The point where the wires enter the building is called the service entrance. If the service or electricity is to be metered, the meter is installed at the service entrance.

b. Main Switch. The service entrance on the inside of a building is connected to the service switch, or main breaker switch, which is used to connect and disconnect the power supply to the interior wiring system. From this point, the power is carried to secondary points of distribution, or panel boxes.

c. Panel Boxes. Panel boxes also are called safety boxes because the panels house the two safety components of the wiring system, a circuit breaker and fuse.

(1) *Circuit breakers.* A circuit breaker is a protective switch designed to open a current-carrying circuit under overload, high or low voltage, or short-circuit conditions without injury to itself. It is used principally to protect motors and generators and is sometimes substituted for the entrance switch in small buildings. No fuses are used in the circuit breaker, which generally is operated automatically, although manual operation is provided for. As a rule, no detailed wiring diagram for a circuit breaker is shown in construction prints because such diagrams are found on the inside of the circuit-breaker box cover. A detail of a circuit-breaker wiring connection is shown in figure 175.

(2) *Fuses.* A fuse is a protective device used in an electrical circuit. It has a small piece of soft metal, inclosed in a protective case or tube. When too much current flows through it, the metal melts, breaking the circuit and preventing an overload. Types and capacities of fuses to be installed are given in drawing notes or specifications.

(3) *Circuit amperages.* Panel boxes are made in different circuit amperages, the most common being 15- and 20-ampere circuit ratings. Panels also are available with different numbers of circuits inclosed—2, 4, 8, 12, 16, 20, 24, and 32 circuits. It is usual practice, especially when future electrical expansion is considered, to leave some of the circuits unused for the present.

337. Branch Circuits

A branch circuit is a set of conductors feeding through an automatic cutout, or fuse, and supplying one or more energy-consuming devices such as lights or motors. Branch circuits can be wired in two ways: in series or in parallel.

a. Series Wiring. Series circuits are not applicable to interior wiring because if one light fails all the lights in the circuit fail.

b. Parallel Wiring. If one bulb burns out in a parallel circuit the rest of the fixtures function as before. This system permits the current to bypass the fixture that has failed.

c. Home Run. The expression home run, as used in wiring, denotes the wires running from the fixtures on a circuit to the panel box or power supply.

338. Materials and Fittings of Electrical Systems

A great variety of materials and fittings are used in the installation of electrical wiring.

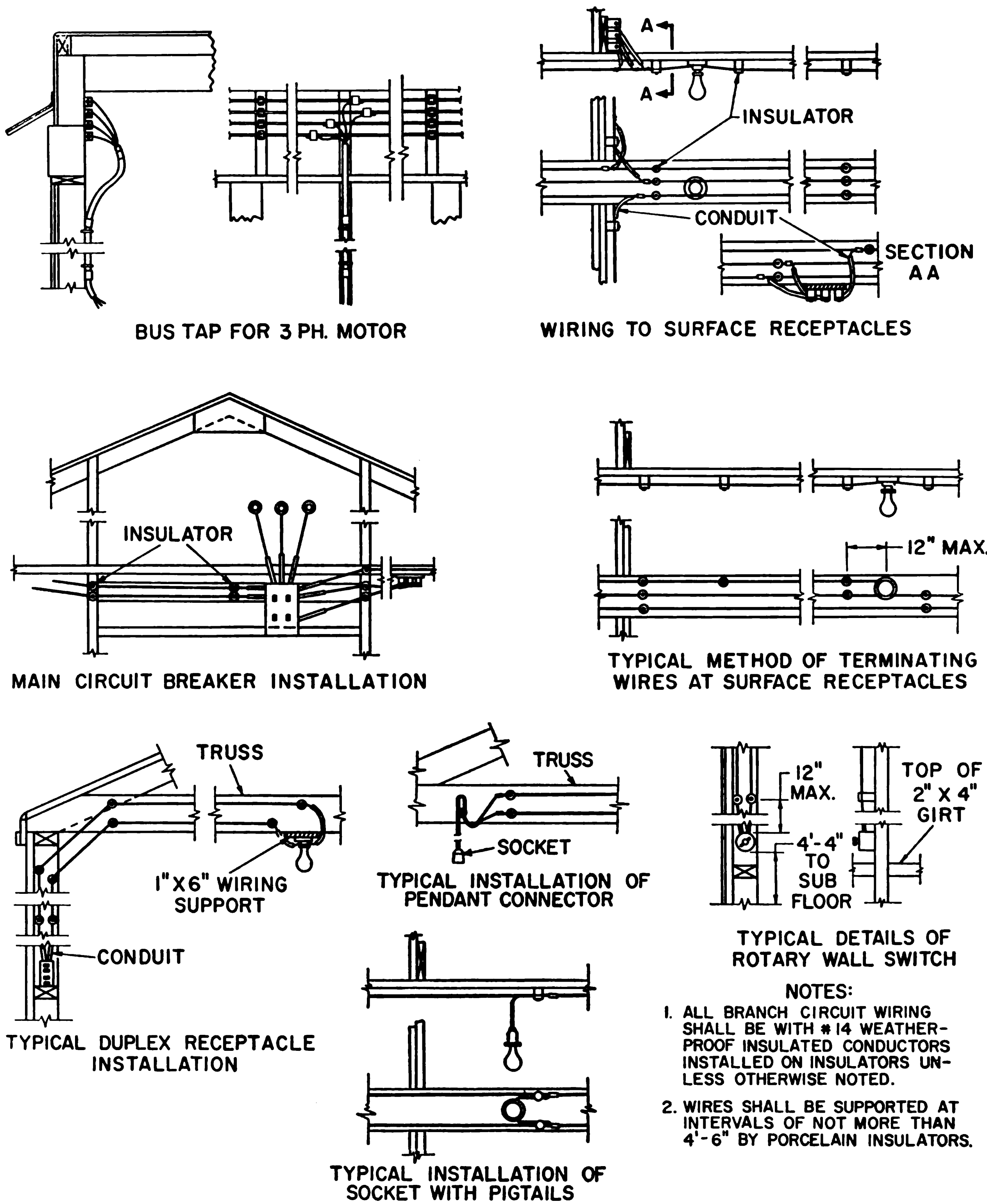


Figure 175. Typical electrical details.

The more common items used in theater of operations construction are listed below.

a. Conductors. A conductor is any wire, bar, or ribbon with or without insulation. Usually, it is made of copper because of the good current- and voltage-carrying characteristics of that metal.

b. Conduits and Fittings. Conduits are of two kinds, rigid and thin-walled. Rigid conduits have threaded ends and matching threaded fittings for installation, and changes of direction usually are made with the fittings rather than by bending. Thin-walled conduits are lightweight steel tubing without threads and can be bent as desired. Threaded adapters and connectors are used for joining thin-walled conduits to outlet boxes and other appliances. The number of insulated wires than can be carried in various sizes of conduit can be found in table XIII.

Table XIII. Number of Wires Allowable in Various Sizes of Steel Conduit

Size of wire	Number of wires in one conduit [1]								
	1	2	3	4	5	6	7	8	9
18	½	½	½	½	½	½	½	½	¾
16	½	½	½	½	½	½	¾	¾	¾
14	½	½	½	½	¾	¾	¾	1	1
12	½	½	½	¾	¾	1	1	1	1¼
10	½	¾	¾	¾	1	1	1¼	1¼	1¼
8	½	¾	1	1	1¼	1¼	1¼	1¼	1¼
6	½	1	1¼	1¼	1½	1½	2	2	2
4	¾	1¼	1¼	1½	2	2	2	2	2½
2	¾	1¼	1½	1½	2	2	2½	2½	2½
1	¾	1½	1½	2	2	2½	2½	3	3
1/0	1	1½	2	2	2½	2½	3	3	3
2/0	1	2	2	2½	2½	3	3	3	3
3/0	1	2	2	2½	3	3	3	3½	3½
4/0	1¼	2	2½	2½	3	3	3½	3½	4

[1] Rubber-covered or weatherproof wire.

c. Outlet Boxes and Fittings. When a conduit is used, it usually is ended in one of several types of steel outlet boxes, which are then finished with plain covers or receptables and appropriate covers. Also, some receptacles attach directly to the outlet boxes without the use of an auxiliary cover.

d. Insulators. Porcelain insulators are used widely for open wiring and concealed knob-and-tube installations. They consist of a porcelain knob, cleats, a tube, and wire supports. Fabric insulation tubing, or loom, is used as slip-on insulation where wires cross in contact at exposed fixture connections and as additional protective insulation where weatherproof wiring enters outlets or switchboxes.

e. Connectors and Clamps. Connectors are connected to each other and to panel boards, appliances, or devices with various types of connectors, clamps, terminals, lugs, or slips.

f. Lamp Sockets. Lamp sockets generally are screw-base units placed in circuits as holders for incandescent lamps. Fluorescent lamps have prong contacts fitting into special holders.

g. Wall Receptacles and Appliance Plugs. Portable appliances and devices are connected to an electrical supply circuit with outlets called receptacles. The appliance cord terminates in a plug that fits into the energized receptacle and can be inserted or withdrawn as desired.

h. Electrical Energy Devices. Electrical energy is produced two ways, chemically or mechanically. The chemical device is called a battery and is either the rechargeable (storage) or nonrechargeable type. The main source of electric power is engine-driven generators. A transformer is not a source in itself but is a device for changing alternating-current voltages to high voltages for efficient transmission between points or down to low voltages for lamps, electrical devices, and machines.

339. Electrical Installation

A building is wired by installing copper wires or conducting cables insulated by rubber and/or fabric. The conductors are supported by porcelain insulators of various shapes or are carried in metal conduits. Lights and appliances are connected to the wiring system by metal or porcelain outlet boxes. Switches are installed to control the flow of current. The location of fixtures and receptales is shown in the construction prints. Materials and devices usually are described in specifications.

a. Wire Splices and Taps. The continuity of electrical wiring is maintained with splices. Takeoffs for branch circuits or single appliances and outlets can be made with taps (fig. 175). When bare conductors are spliced or tapped, it is necessary to reinsulate, to prevent short circuiting, with either rubber of friction tape or a combination of both.

b. Porcelain Insulators and Fittings. Porcelain knobs and cleats are the principal wire supports for open wiring, as shown in figure 175. If concealed knob-and-tube wiring is called for, the conductors are run along the hollow spaces of the walls or in floors and ceilings. Wires running parallel to studs or joists are supported by knobs; wires running perpendicularly to such members are supported and insulated by porcelain tubes that pass through holes bored in those members. Connections for fixtures and appliance outlets and switches must be made through outlet boxes.

c. Armored Cable and Nonmetallic Sheathed Cable. Armored cable and nonmetallic sheathed cable may be run exposed on walls, ceilings, or roof structures, or concealed in walls and floors. It is held in place by anchor staples or metal clips fastened to the wood members.

d. Conduits. Thin-walled conduits, rather than rigid, are favored because they can be bent readily to conform to changes of direction. They are fastened to walls and building members by metal clips or are imbedded in concrete. Rubber-insulated wires are pulled through the conduit system before its installation to complete the wiring scheme.

340. Wiring Plans

Wiring plans either are combined with the architectural plan or are shown in separate drawings. The plans generally are schematic and composed of conventions and symbols. In combination with notes, specifications, and schedules they give all the information needed for installation. As with plumbing and heating plans, the complexity of the architectural plan and the installation determine whether a separate drawing is required; if required, separate wiring plans are prepared by the overlay method. The same conditions apply as in preparing heating and plumbing overlays. Wall locations and thicknesses, but no material indications, are shown. Conventional window symbols are shown and door openings are indicated, but not door swings.

a. Symbols. Appendix VII lists the line symbols and conventions used in wiring plans for military use; more symbols for electrical equipment in buildings and building distribution systems can be found in MIL–STD–15A.

b. Schematic Wiring Diagrams. A schematic wiring diagram is the form of wiring plan used most frequently for construction drawings. It is also the form used for the design sketches given to draftsmen. The first step in drawing a schematic diagram is to trace door openings and window and wall symbols from an architectural plan of the appropriate floor; next, locate equipment and fixtures, using wall lines as datum lines. Draw the appropriate symbols and connect them by a single line of medium weight representing the wiring circuit. Line symbols for different types of wiring circuits are shown in appendix VII. Letter the notes after all fixtures have been connected by appropriate single-line circuit symbols.

(1) *Line symbols.* Two wires are indicated in a schematic diagram by a single line. If there are more than two wires, draw short perpendicular lines through the line symbols to indicate the number of inclosed wires. The three lines drawn through the line symbols in the schematic diagram of figure 176 indicate three inclosed wires.

(*a*) *Connections and crossovers.* Connecting wires are indicated by placing a dot at the point of intersection. No dot is used where wires cross without connecting.

(*b*) *Home runs.* Home runs are indicated by the appropriate line sym-

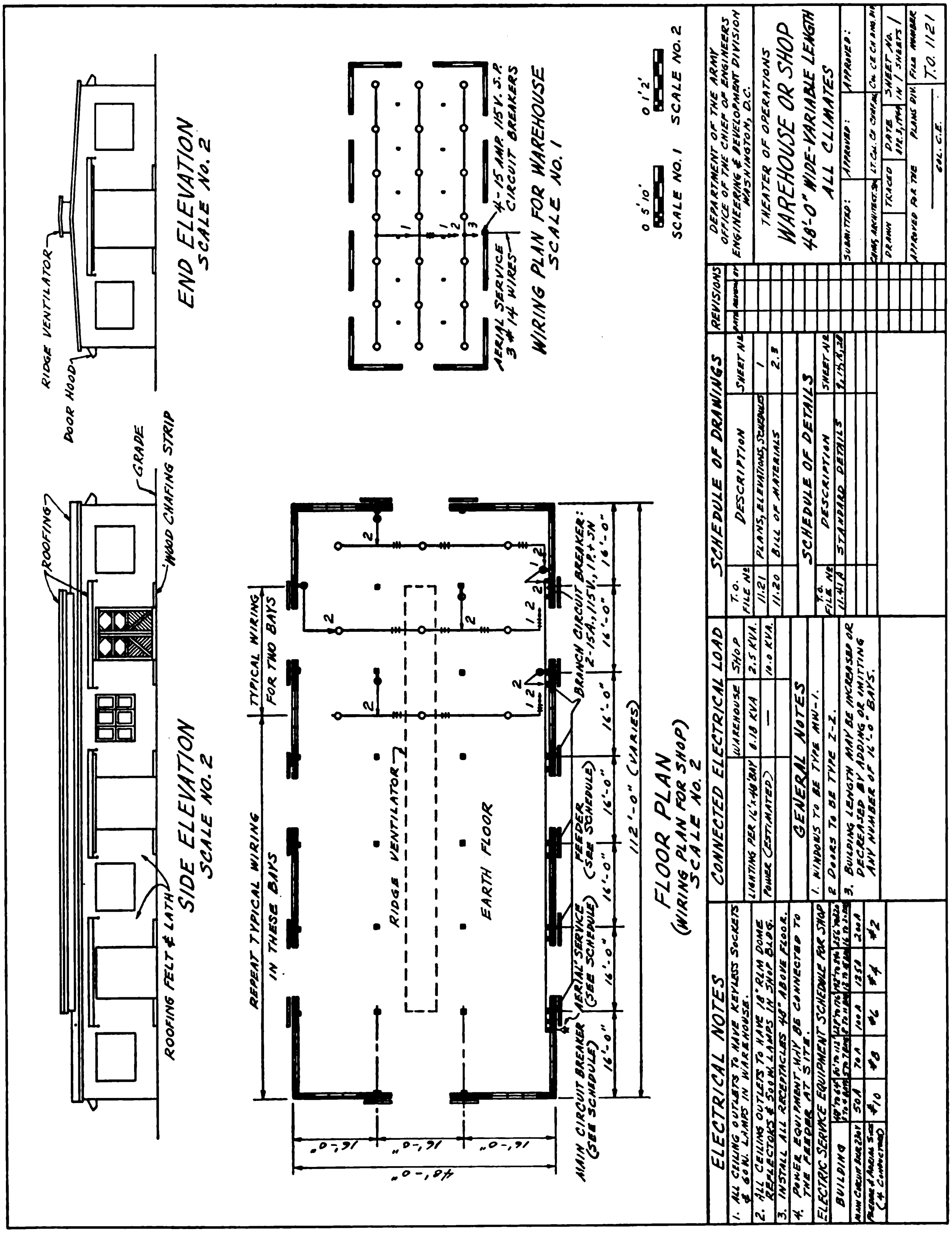


Figure 176. Wiring plan.

bols for showing two or three wires. Arrowheads drawn on the line show the number of circuits included. As in figure 176 a note is placed near the arrowheads giving the identification number of each circuit. In the wiring plan in figure 176 circuits 1, 2, and 3 are identified.

(*c*) *Aerial-service.* Aerial-service is indicated with the line symbols in figure 176. A note placed adjacent to the symbol identifies the service by title and gives the number and size of the wires making up the service. The note in figure 176 reads Aerial Service, 3 No. 14 Wires.

(2) *Fixtures.*

(*a*) *Panel boxes.* A panel box symbol is a rectangle drawn with the long dimension parallel to the wall line. The inside area of the rectangle is divided by closely spaced lines paralleling the long dimension. In figure 176 the main switch and panel box are identified as main and branch circuit breakers. The branch circuit breaker is identified by title and is accompanied by a note giving the number, amperages, and phase of the circuits. Information about the main circuit breaker is given in a schedule placed in the electrical notes.

(*b*) *Convenience outlet.* A convenience outlet symbol is always drawn perpendicular to a wall or column (fig. 176).

(*c*) *Ceiling outlets.* Ceiling outlets are shown in a circle about $\frac{3}{16}$ inch in diameter, depending on the scale of the drawing.

c. Detailed Wiring Plans. Detailed wiring plans show the way in which the wires of a circuit connect electrical fixtures to the source of supply or main switch. Instead of a single-line symbol of a schematic drawing, detail drawings show the individual wires of two- and three-wire circuits. Symbols are used in detailed wiring plans, which are not drawn to scale and must be prepared by draftsmen specializing in electrical drawings.

d. Notes and Dimensioning. No actual dimensions or dimension lines are shown in electrical drawings. Location dimensions and spacing requirements are given in the form of notes or follow installation principles; *for example,* light fixtures are spaced according to a rule stating that the distance between fixtures is twice the distance between the wall and the first fixture. In figure 176, note 3 of the electrical notes states that all receptacles are to be installed 48 inches above the floor. Wall switches usually are located 4 feet above the finished floor line, and convenience outlets are placed either 1 or 4 feet above the finished floor line. Note that the electric notes include an equipment schedule showing the increase in wire sizes and current as more bays are added to the basic building. The statement of connected electrical load expresses power in terms of kva, or kilovolt-amperes.

341. Electrical Wiring Takeoff

To prepare a quantity survey for electrical work, a takeoff man must be familiar with electric circuits and wiring installation practices because drawings are schematic. As in other crafts, all material is listed.

a. Conduits. Conduits are first classified as rigid, flexible, flexible tubing, or armored cable and are listed by the total number of lineal feet required for each diameter of a particular classification. Rigid conduits come in two weights, heavy and light. Heavy conduits cannot be bent and are installed with threaded fittings, which are listed by the quantity of each size and classification. Light, rigid conduits can be bent; no fittings are required.

b. Wires. Wire measurements are expressed in feet for length; gage number or mills for diameter; and circular mils for area. In preparing a takeoff, wire is first classified by insulation and type of conductor (solid or stranded) and is then listed in order by gage sizes and the number of feet given for each size.

c. Fixtures. Fixtures are described by title and other pertinent specifications are added. "Switches, toggle, three- and four-way", followed by the quantity, is the correct listing for this type of switch. Other fixtures are identified and listed similarly.

APPENDIX I

REFERENCES

AR 320–5	Dictionary of United States Army Terms
AR 320–50	Authorized Abbreviations and Brevity Codes
AR 611–201	Personnel Selection and Classification—Manual of Enlisted Military Occupational Specialties
DA Pam 108–1	Index of Army Motion Pictures, Film Strips, Slides, and Phonorecordings
Da Pam 310–1	Index of Administrative Publications
DA Pam 310–3	Index of Training Publications
DA Pam 310–4	Index of Technical Manuals, Technical Bulletins, Supply Bulletins, Lubrication Orders, and Modification Work Orders
DA Pam 310–5	Index of Graphic Training Aids and Devices
DA Pam 310–8	Index of Army Personnel Tests
FM 5–34	Engineer Field Data
FM 21–5	Military Training
FM 21–6	Techniques of Military Instruction
FM 21–30	Military Symbols
FM 21–31	Topographic Symbols
TM 5–233	Construction Surveying
TM 5–240	A Guide To The Compilation and Revision of Maps
TM 5–302	Construction in The Theater of Operations
TM 5–460	Carpentry and Building Construction
TM 5–704	Construction Print Reading in The Field
TM 5–742	Concrete and Masonry
TM 5–744	Structural Steelwork
TM 5–745	Heating, Ventilating, and Sheet Metal Work
TM 5–760	Electrical Wiring
MIL–STD–1A	General Drawing Practice
MIL–STD–2B	Engineering Drawing Sizes and Format
MIL–STD–7	Types and Definitions of Engineering Drawings
MIL–STD–8B	Dimensioning and Tolerancing
MIL–STD–9A	Screw Thread Conventions and Methods of Specifying
MIL–STD–12B	Abbreviations for Use on Drawings and in Technical-Type Publications
MIL–STD–14A	Architectural Symbols
MIL–STD–15A	Electrical and Electronic Symbols
MIL–STD–16B	Electrical and Electronic Reference Designations
MIL–STD–17	Mechanical Symbols
MIL–STD–18A	Structural Symbols
JAN–STD–19	Welding Symbols
DOD	Industrial Security Manual for Safeguarding Classified Information

APPENDIX II

ABBREVIATIONS*

American Wire Gage	AWG
Appendix	APPX
Asbestos	ASB
Asphalt	ASPH
Asphalt-tile floor	ATF
Assembly	ASSY
Atomic	AT
Automatic	AUTO
Average	AVG
Axial flow	AX FL
Azimuth	AZ
Barracks	BKS
Base	B
Bevel	BEV
Bill of exchange	B/E
Bill of material	B/M
Bill of sales	B/S
Blueprint	BP
Board feet	FBM
Both faces	BF
Both sides	BS
Both ways	BW
Brick	BRK
Building	BLDG
By (used between dimensions)	X
Cast iron	CI
Cast-iron pipe	CIP
Cast steel	CS
Ceiling	CLG
Cement base	CB
Cement floor	CF
Center	CTR
Center line	CL or ¢
Center matched	CM
Center of pillar	CPLR
Center tap	CT
Center to center	C TO C
Check	CHK
Chief	CH
Chief of Engineers	C OF ENGRS
Chief of Staff	C OF S
Circuit	CKT
Circuit breaker	CKT BKR
Circumference	CIRC
Class	CL
Classification	CLASS.
Clay pipe	CP
Coaxial	COAX.
Cold-drawn steel	CDS
Cold-rolled	CR
Column	COL
Concrete	CONC
Confidential	CONF
Construction joint	CJ
Copper	COP
Cork	CK
Corps of Engineers	CE
Corrugate	CORR
Counterbore	CBORE
Counterdrill	CDRILL
Countersink	CSK
Coupling	CPLG
Cubic	CU
Cubic feet	CU FT
Cubic meter	CU M
Cubic millimeter	CU MM
Datum	D
Department of Defense	D D
Detail	DET
Diagonal	DIAG
Diameter	DIA
Dimension	DIM.
District Engineer	DE
Ditto	DO.
Division Engineer	DIV E
Down	DN
Draft	DFT
Drain	DR
Drawing	DWG
Dressed and matched	D&M
Drill	DR
Each	EA
Edge thickness	ET
Elevation	EL
Entrance	ENT
Exterior	EXT
Federal Specification	FS
Federal stock number	FSN
Feet-board measure	FBM
Fillet	FIL
Finish	FIN.
Finish all over	FAO
Finish one side	FIS
Fire alarm box	FABX
Fire extinguisher	FE
Fire-hose cabinet	FHC
Fire-hydrant	FHY
Fire main	FM
Floor	FL
Foot or feet	FT or ′

* These abbreviations are from MIL-STD-12B, Abbreviations for Use on Drawings and in Technical-Type Publications.

Forged steel ---------------------------------- FST
Frame ---------------------------------- FR
Full size details ---------------------------------- FSD
Gage ---------------------------------- GA
Gallon ---------------------------------- GAL
Galvanize ---------------------------------- GALV
Galvanized iron ---------------------------------- GI
General ---------------------------------- GEN
Glass ---------------------------------- GL
Height ---------------------------------- HGT
Hexagon ---------------------------------- HEX.
Hexagonal head ---------------------------------- HEX HD
High-carbon steel ---------------------------------- HCS
Horizontal center line ---------------------------------- HCL
Horizontal reference line ---------------------------------- HRL
Hot-rolled steel ---------------------------------- HRS
Inch ---------------------------------- IN. or "
Inside diameter ---------------------------------- ID
Iron (abbreviate only in conjunction with other materials) ---------------------------------- I or Fe
Iron (Ferrum) ---------------------------------- Fe
Iron pipe ---------------------------------- IP
Joint Chiefs of Staff ---------------------------------- JCS
Keyway ---------------------------------- KWY
Kilowatt ---------------------------------- KW
Kilowatt hour ---------------------------------- KWH
Lawn faucet ---------------------------------- LF
Linear or Lineal ---------------------------------- LIN
Lintel ---------------------------------- LINTL
Liquid ---------------------------------- LIQ
Locus of radius ---------------------------------- L/R
Lumber ---------------------------------- LBR
Machine screw ---------------------------------- MS
Machine steel ---------------------------------- MS
Maximum ---------------------------------- MAX
Meter ---------------------------------- M
Mile ---------------------------------- MI
Mixture ---------------------------------- MIX.
Not to scale ---------------------------------- NTS
Number ---------------------------------- NO.
Page ---------------------------------- p
Penny (nail size) ---------------------------------- d
Phillips head ---------------------------------- PHL H
Piling ---------------------------------- PLG
Plate glass ---------------------------------- PLGL
Plus or minus ---------------------------------- ±
Plywood ---------------------------------- PLYWD
Point of curve ---------------------------------- PC
Point of intersection ---------------------------------- PI
Pound ---------------------------------- LB
Radius ---------------------------------- R or RAD.
Reference ---------------------------------- REF
Reference line ---------------------------------- REF L
Rough ---------------------------------- RGH
Round ---------------------------------- RD
Section ---------------------------------- SECT.
Sliding expansion joint ---------------------------------- SEJ
Slip joint ---------------------------------- SJ
Space heater ---------------------------------- SPH
Specification ---------------------------------- SPEC
Spot face ---------------------------------- SF
Spot weld ---------------------------------- SW
Standpipe ---------------------------------- SP
Stove bolt ---------------------------------- SB
Subsoil drain ---------------------------------- SSD
Tee ---------------------------------- T
Terra cotta ---------------------------------- TC
That is ---------------------------------- i. e.
Thread ---------------------------------- THD
Timber ---------------------------------- TMBR
Title block ---------------------------------- T/B
Ton ---------------------------------- T
Tongue and groove ---------------------------------- T&G
Tread ---------------------------------- TRD
Typical ---------------------------------- TYP
Vent hole ---------------------------------- VH
Vertical center line ---------------------------------- VCL
Waste pipe ---------------------------------- WP
Water closet ---------------------------------- WC
Wide or width ---------------------------------- W
Wood ---------------------------------- WD
Zone of Interior ---------------------------------- ZI

APPENDIX III

MATERIAL SYMBOLS

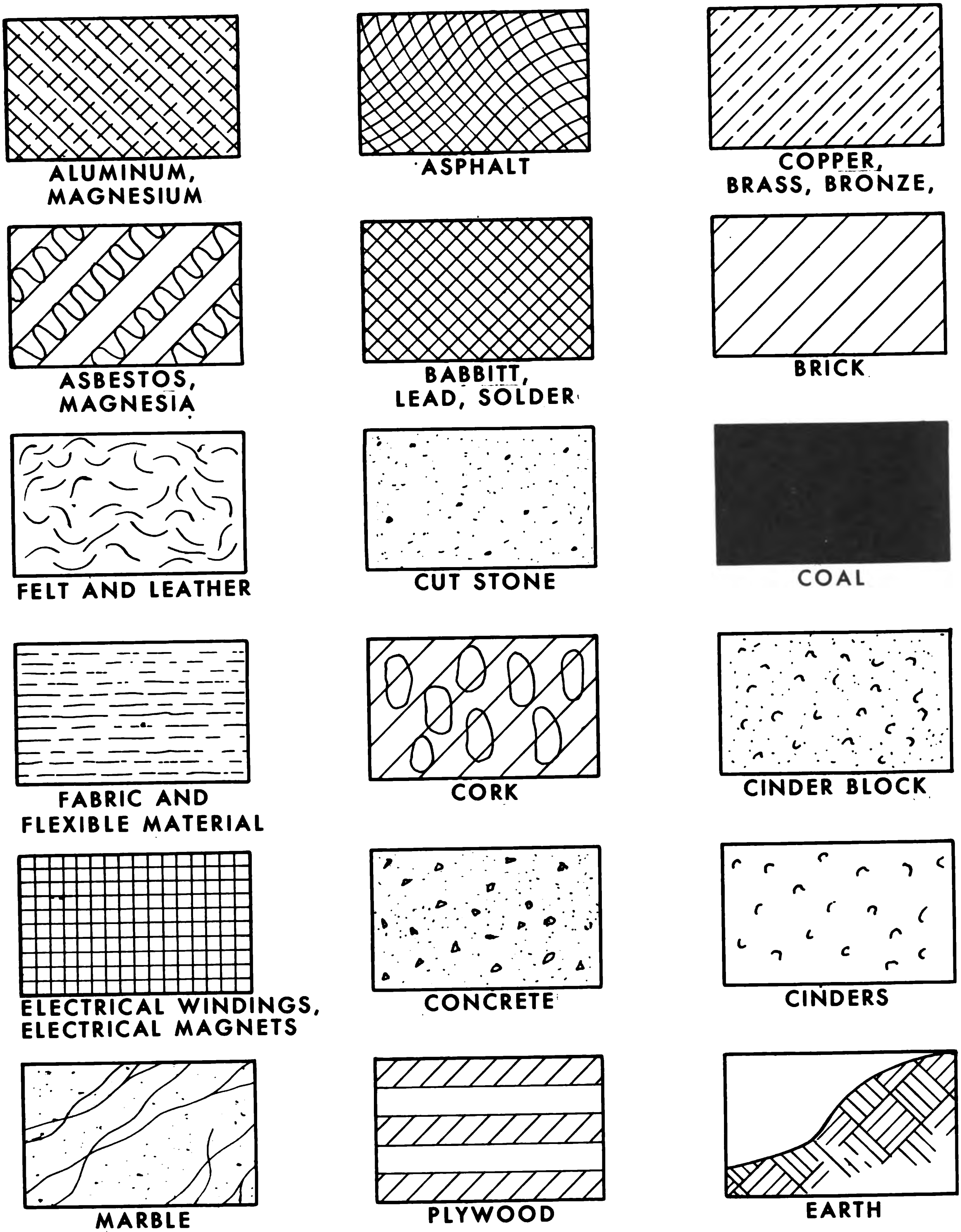


Figure 177. Material symbols.

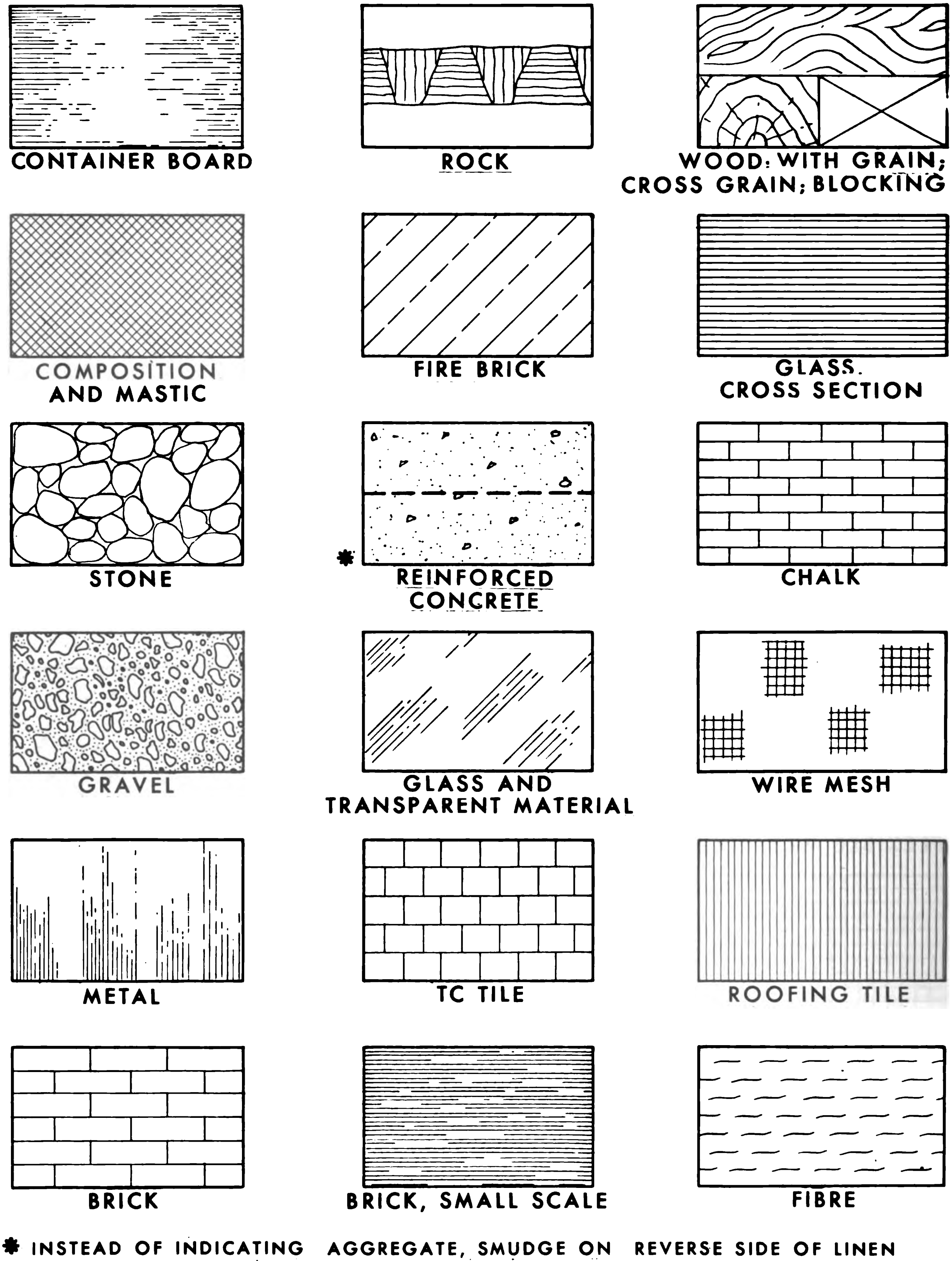
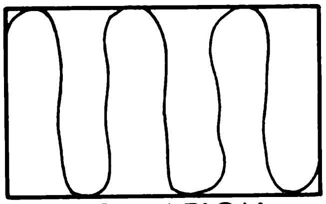
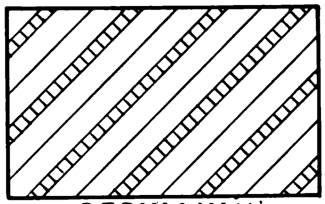


Figure 177—Continued.


INSULATION, THERMAL ACOUSTICS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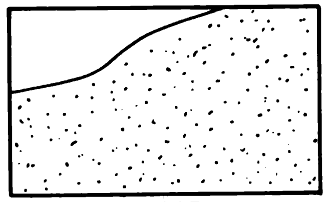
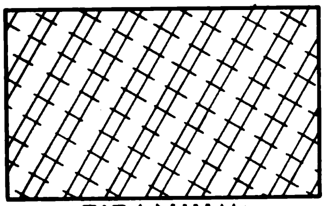
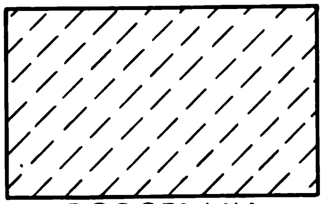
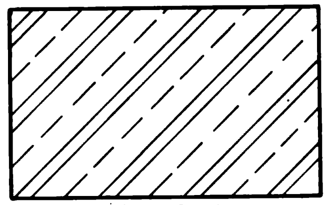
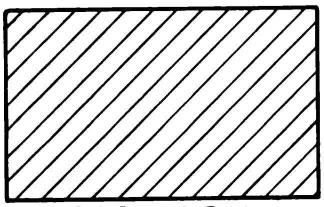
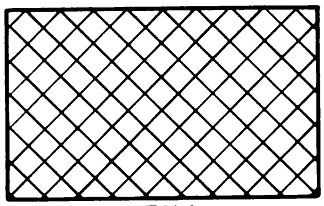

SAND

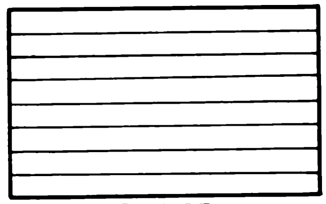

TITANIUM

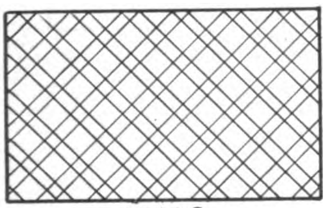

PORCELAIN

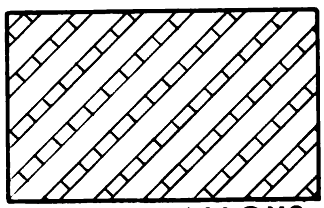

MATERIAL FISSIONABLE

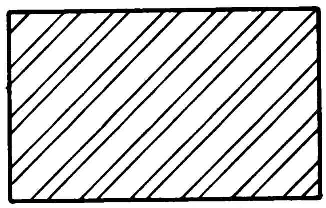

CAST IRON. MALLEABLE IRON

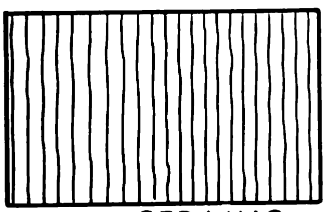

TIN

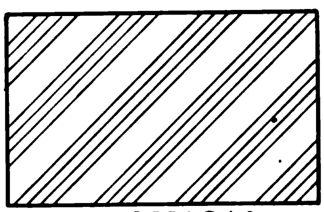

SLATE

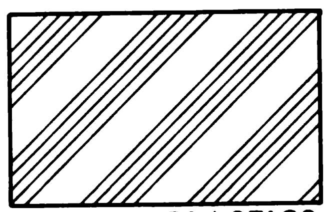

ZINC

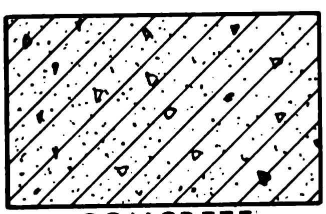

SPECIAL ALLOYS

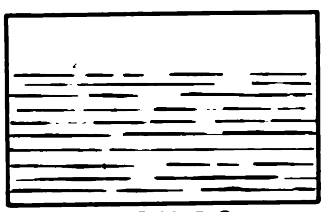

STEEL AND WROUGHT IRON


TILE, CERAMIC STRUCTURAL; FACING


ELECTRICAL INSULATION


RUBBER & PLASTICS


CONCRETE MASONRY UNITS


LIQUIDS

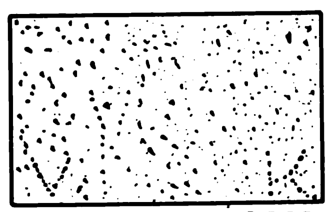

STUCCO, PLASTER

Figure 177—Continued.

APPENDIX IV

ARCHITECTURAL SYMBOLS

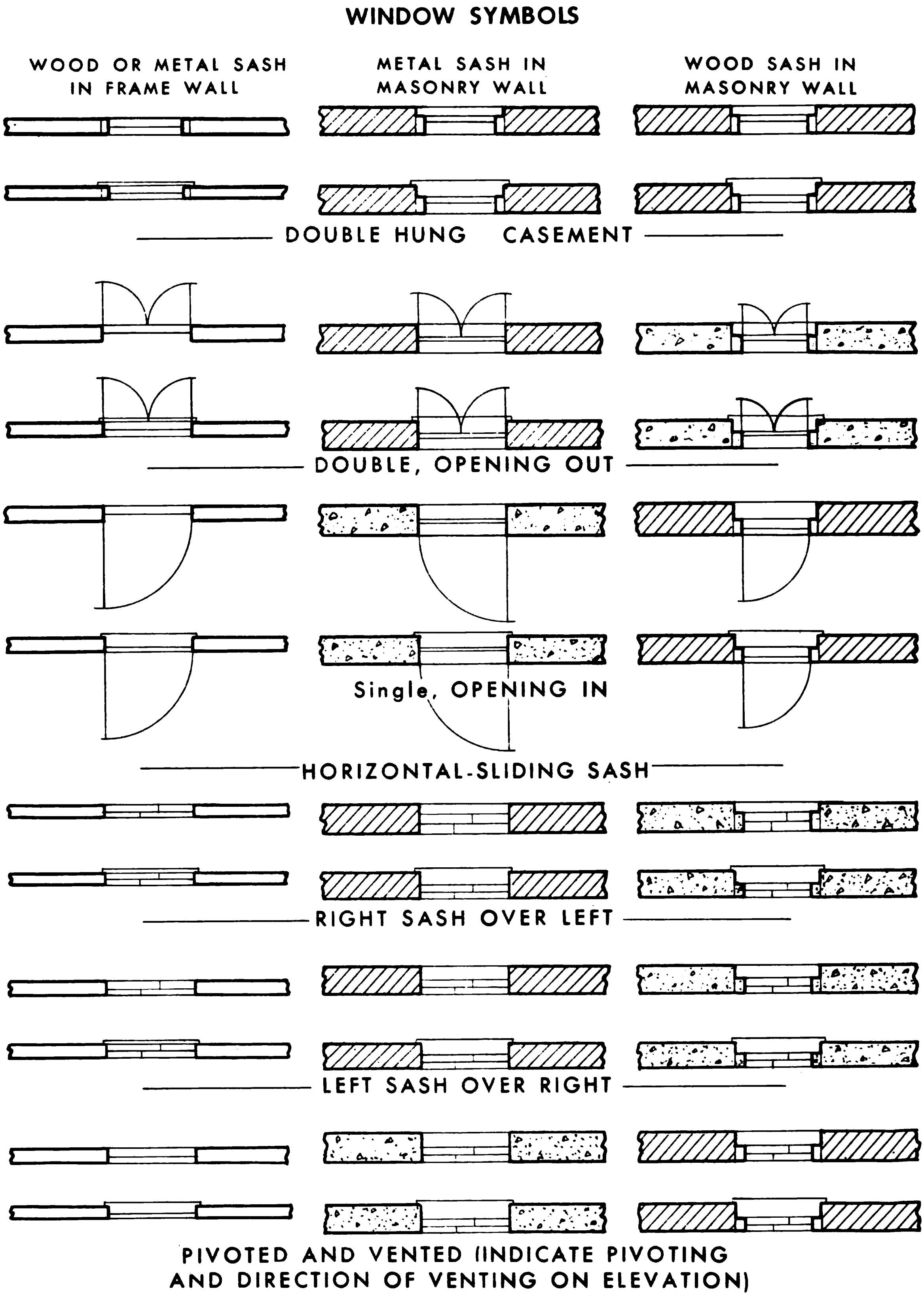


Figure 178. Architectural symbols.

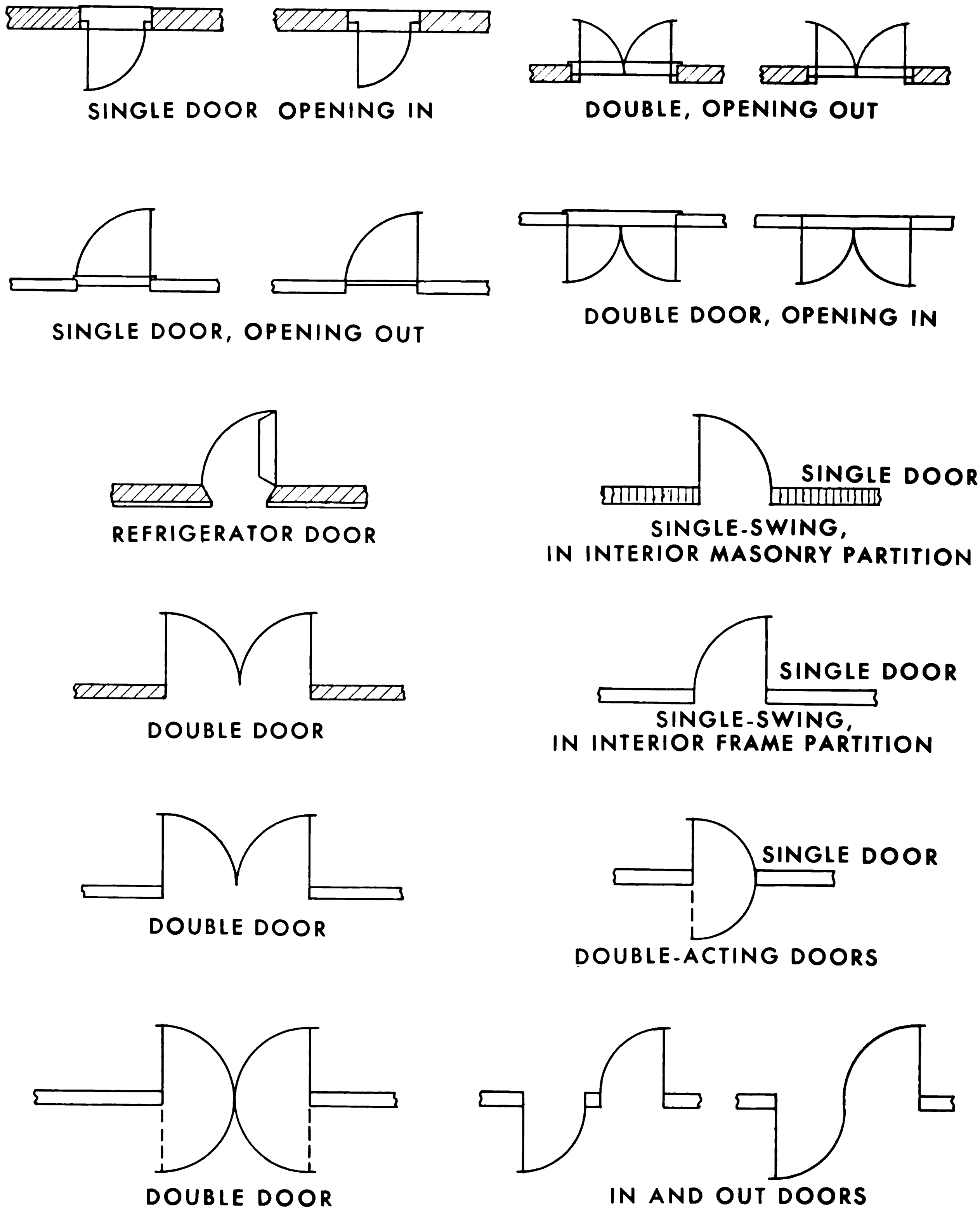


Figure 178—Continued.

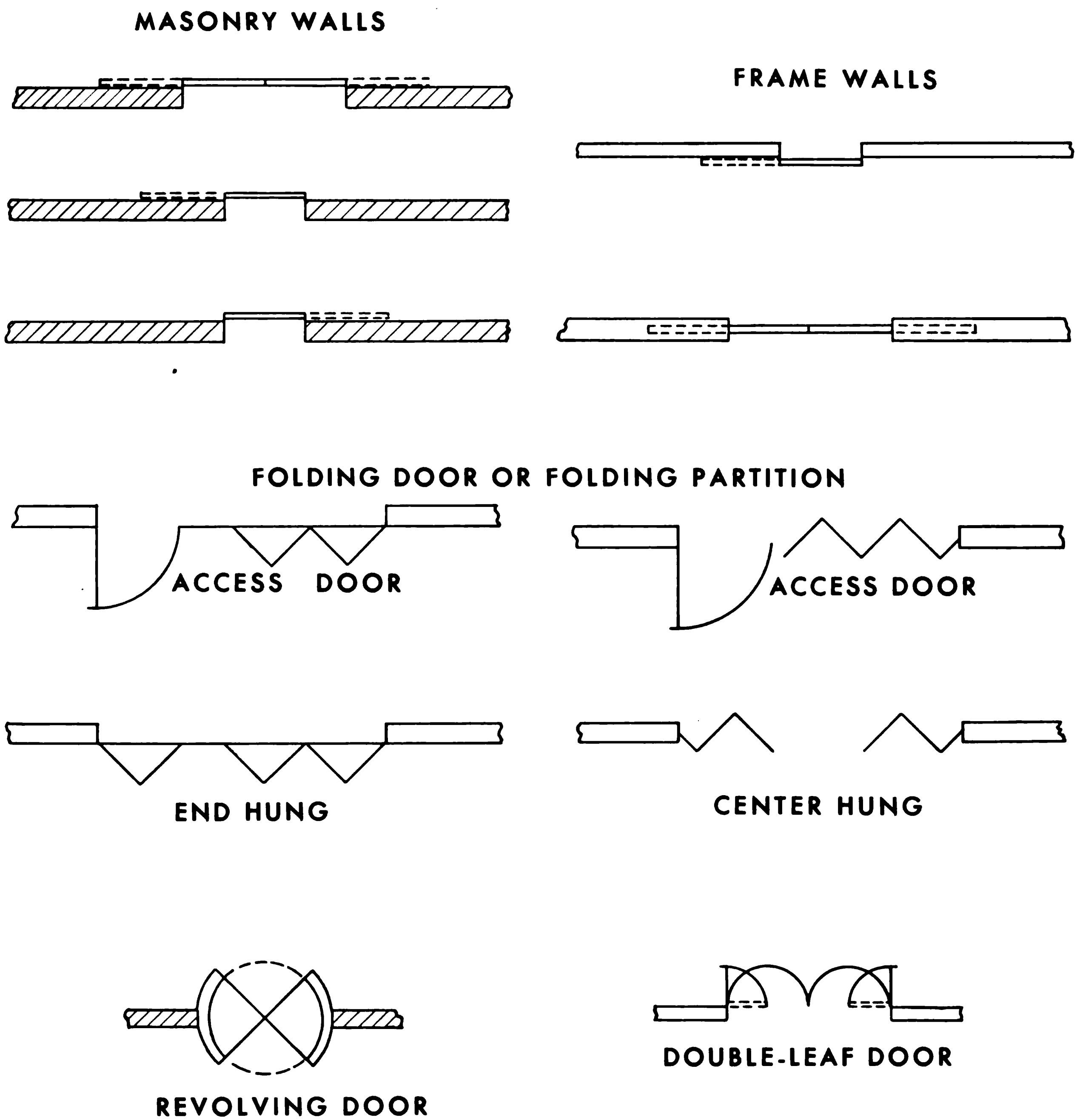


Figure 178—Continued.

APPENDIX V
PLUMBING SYMBOLS

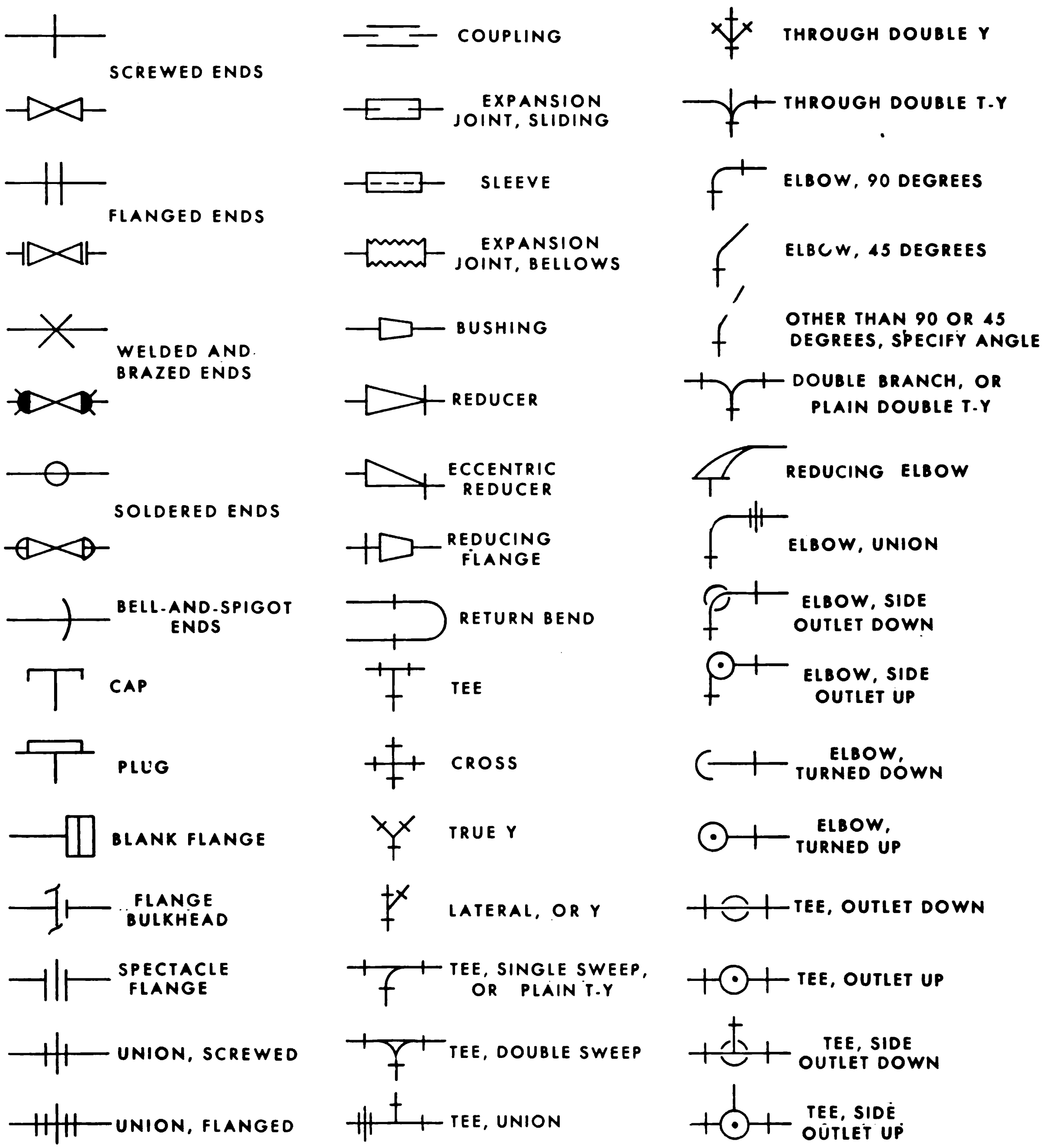


Figure 179. Plumbing symbols.

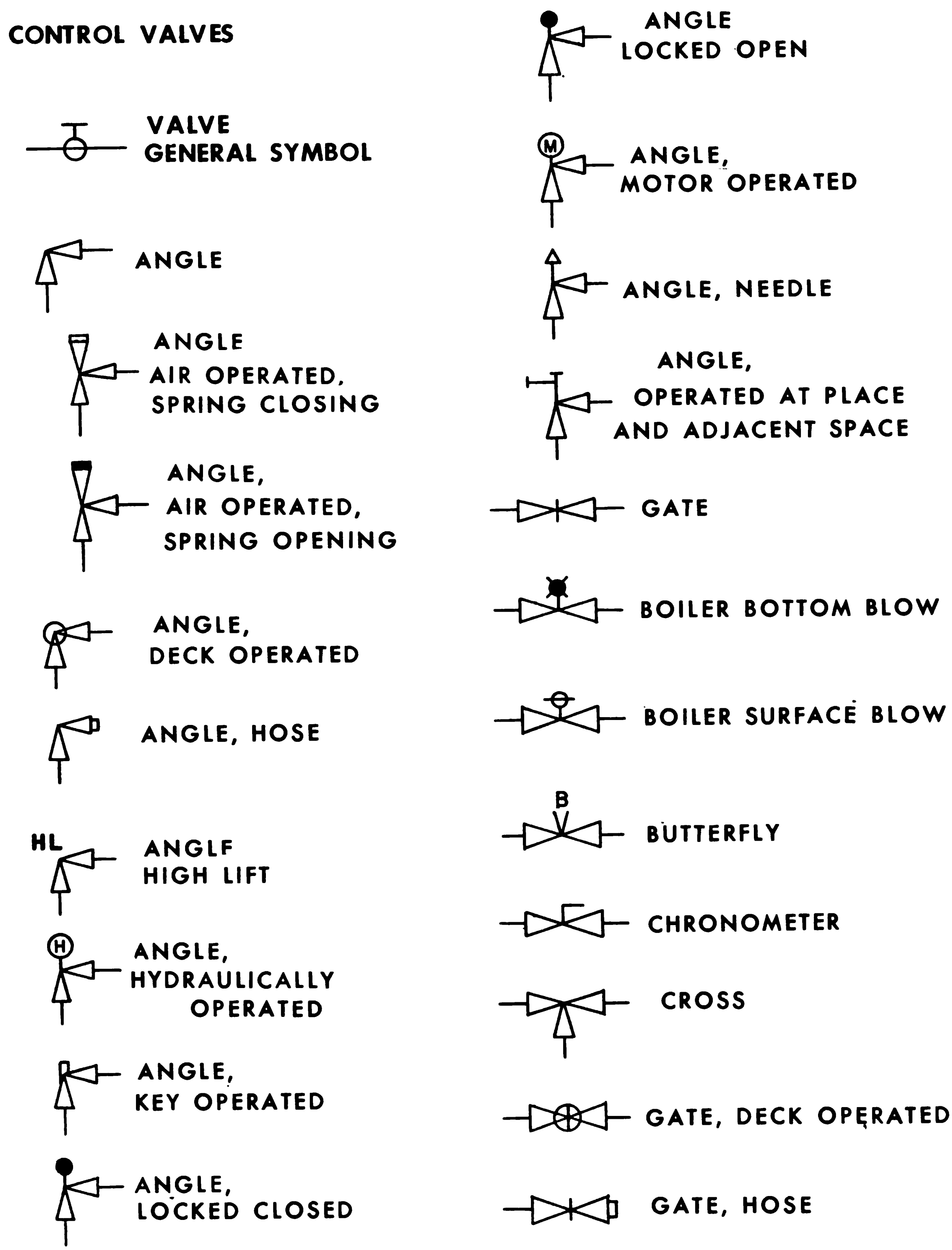


Figure 179—Continued.

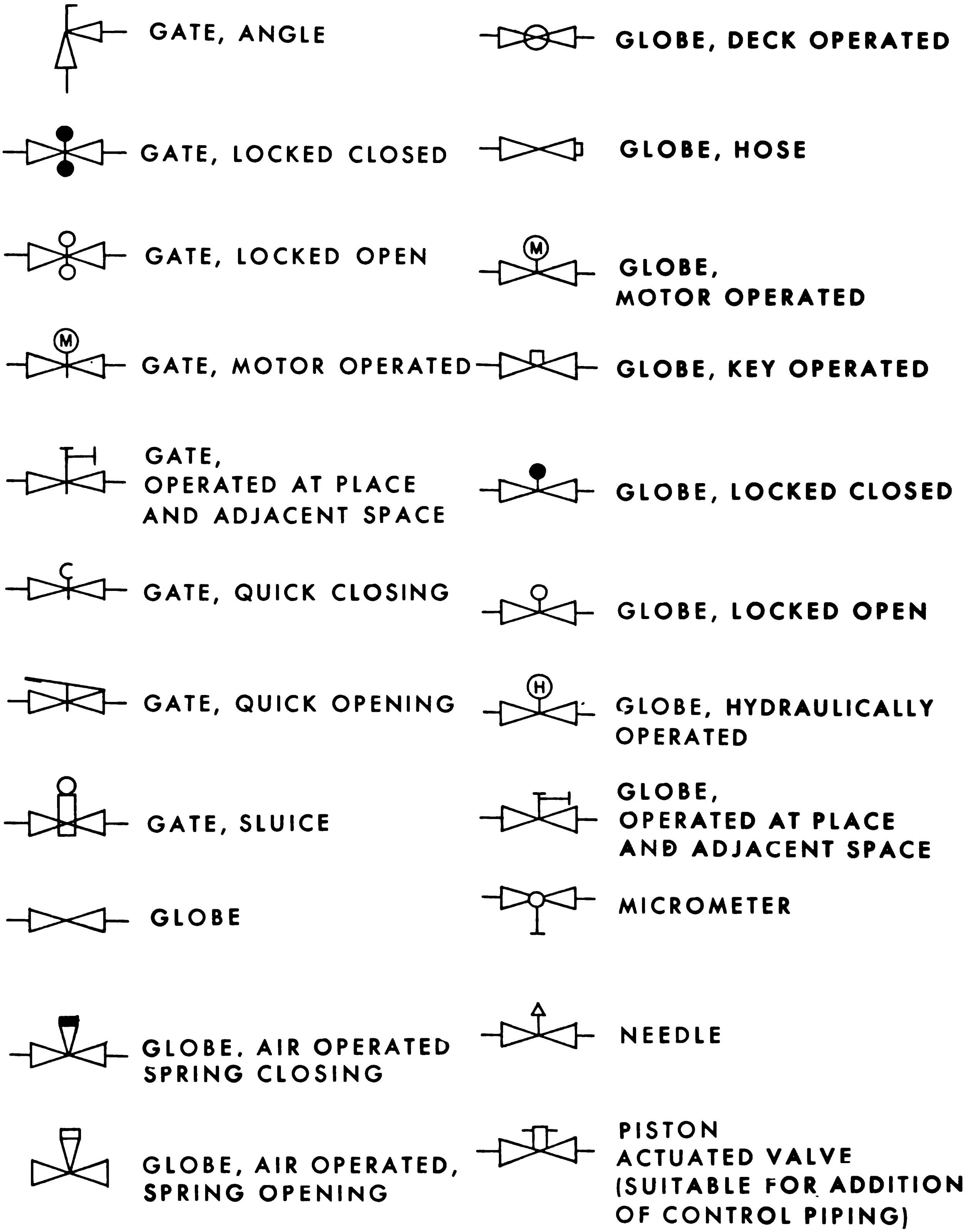


Figure 179—Continued.

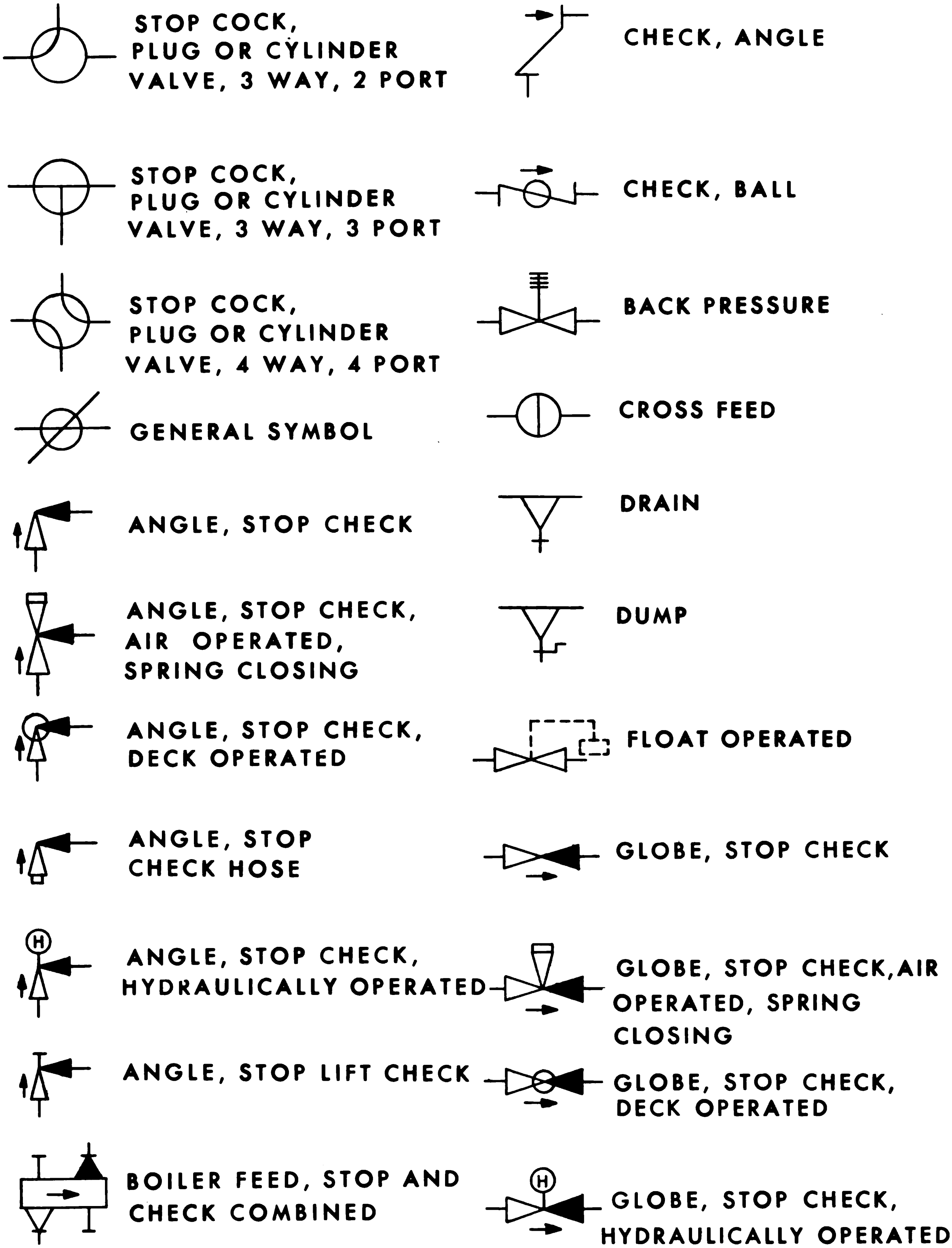


Figure 179—Continued.

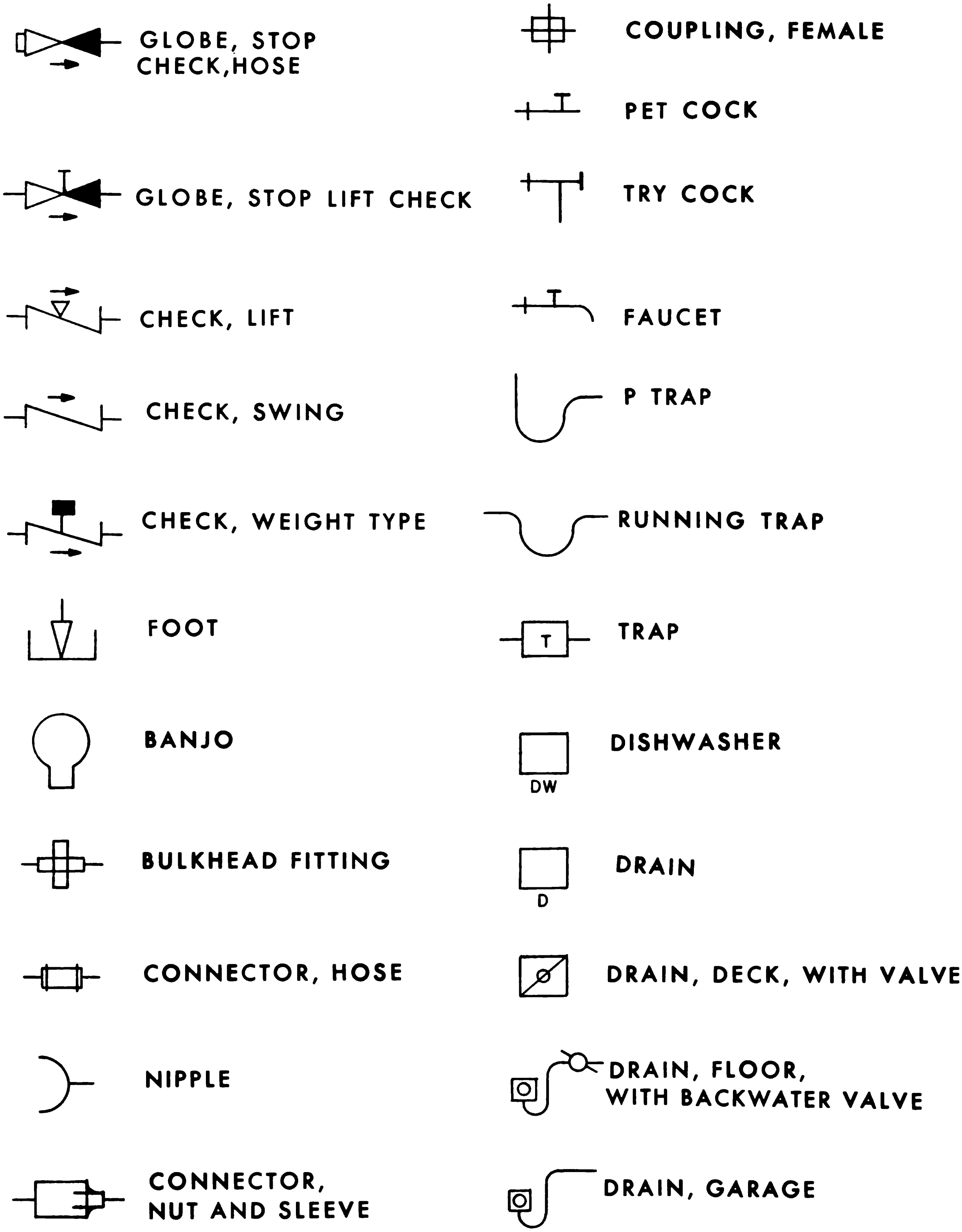


Figure 179—Continued.

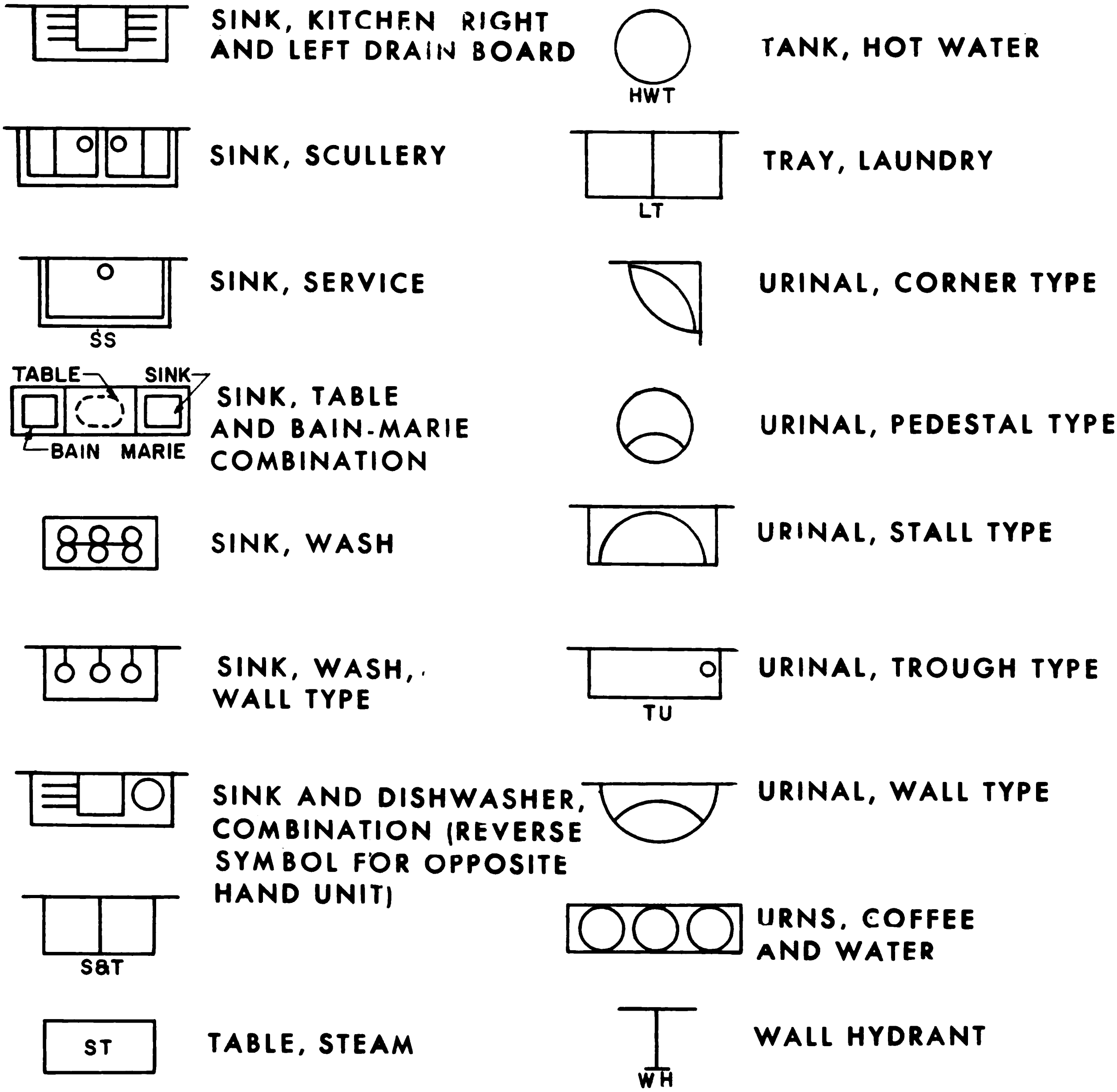


Figure 179—Continued.

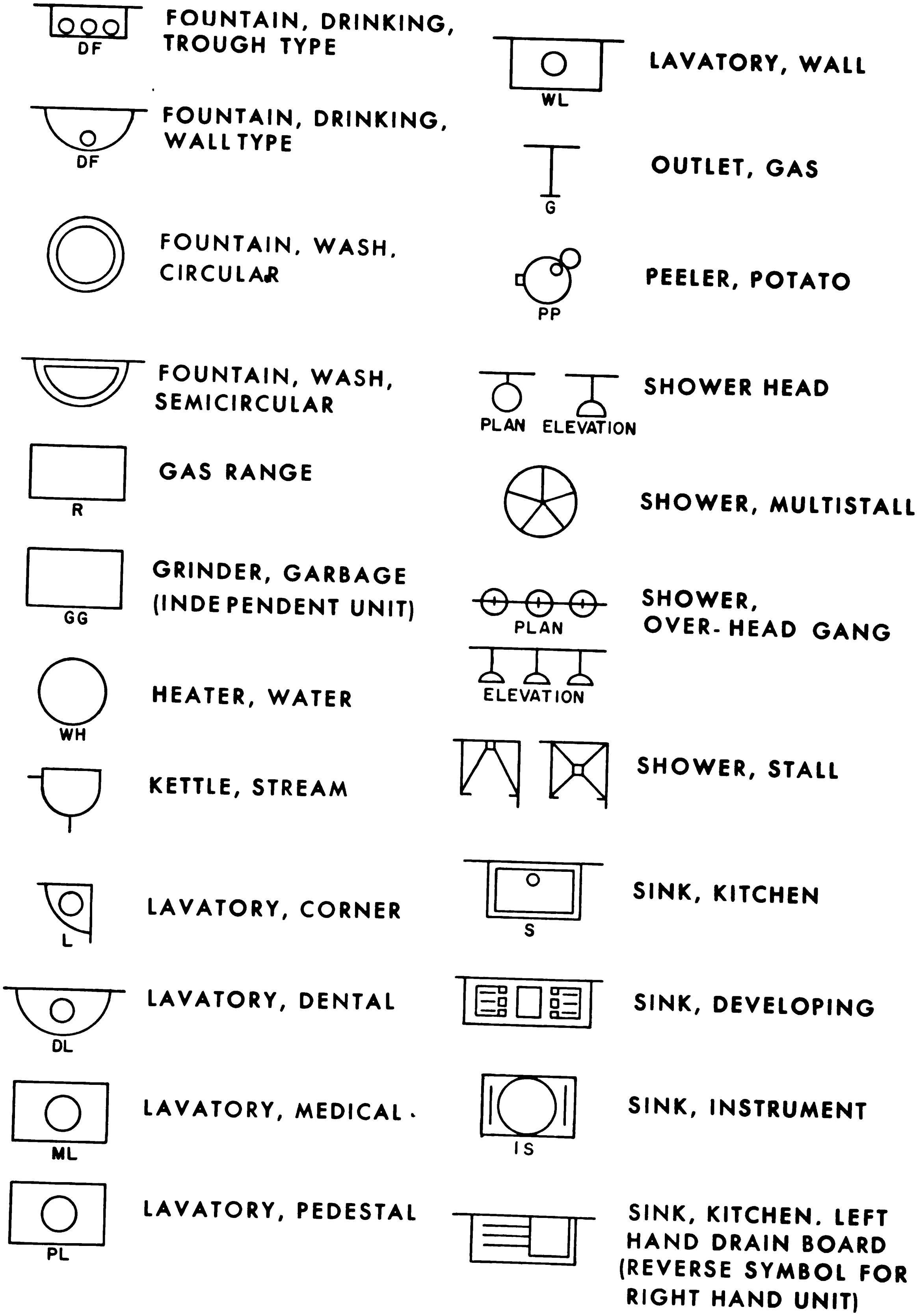


Figure 179—Continued.

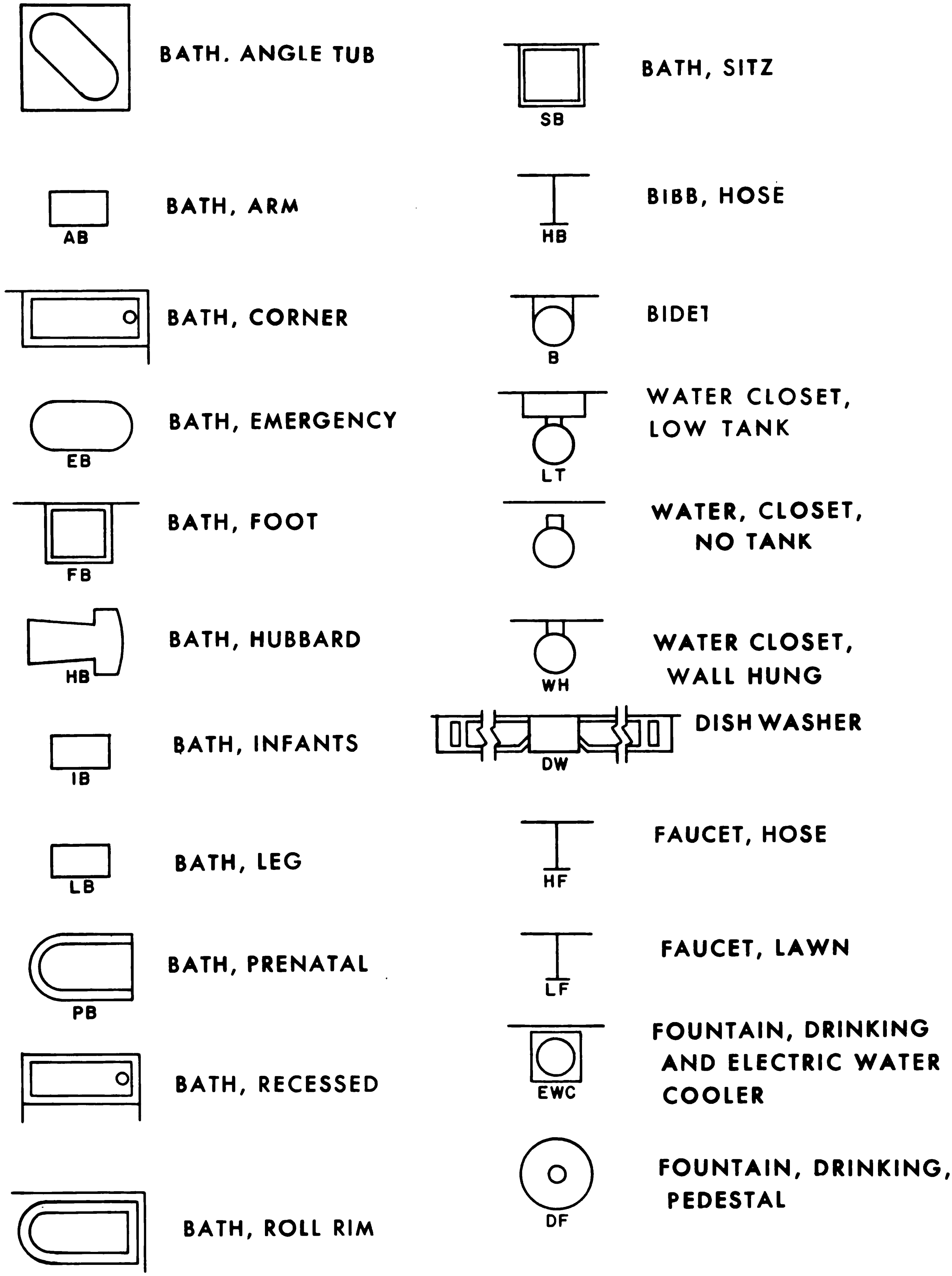


Figure 179—Continued.

APPENDIX VI

HEATING SYMBOLS

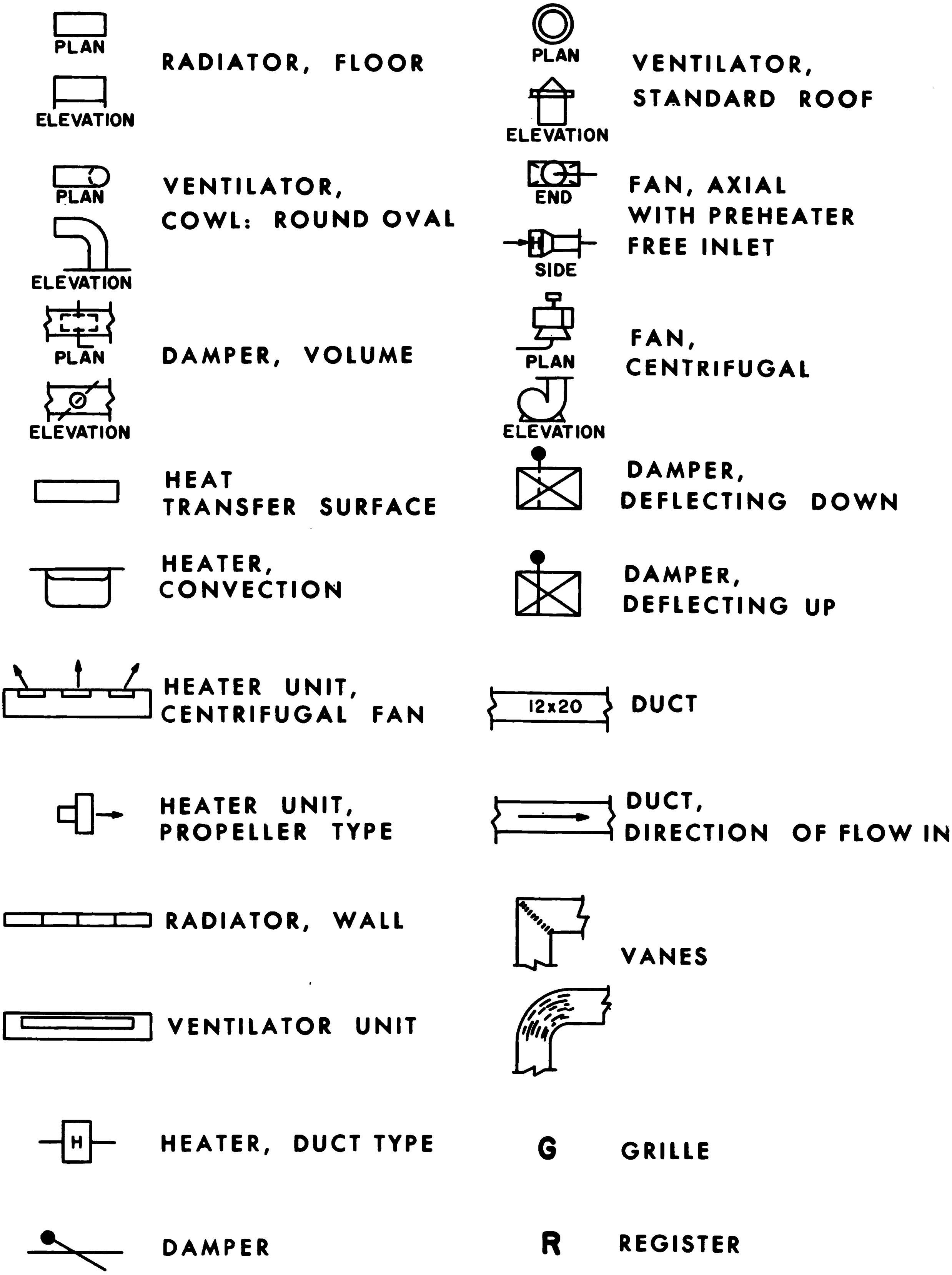


Figure 180. Heating symbols.

APPENDIX VII

ELECTRICAL SYMBOLS

APPENDIX VII
ELECTRICAL SYMBOLS

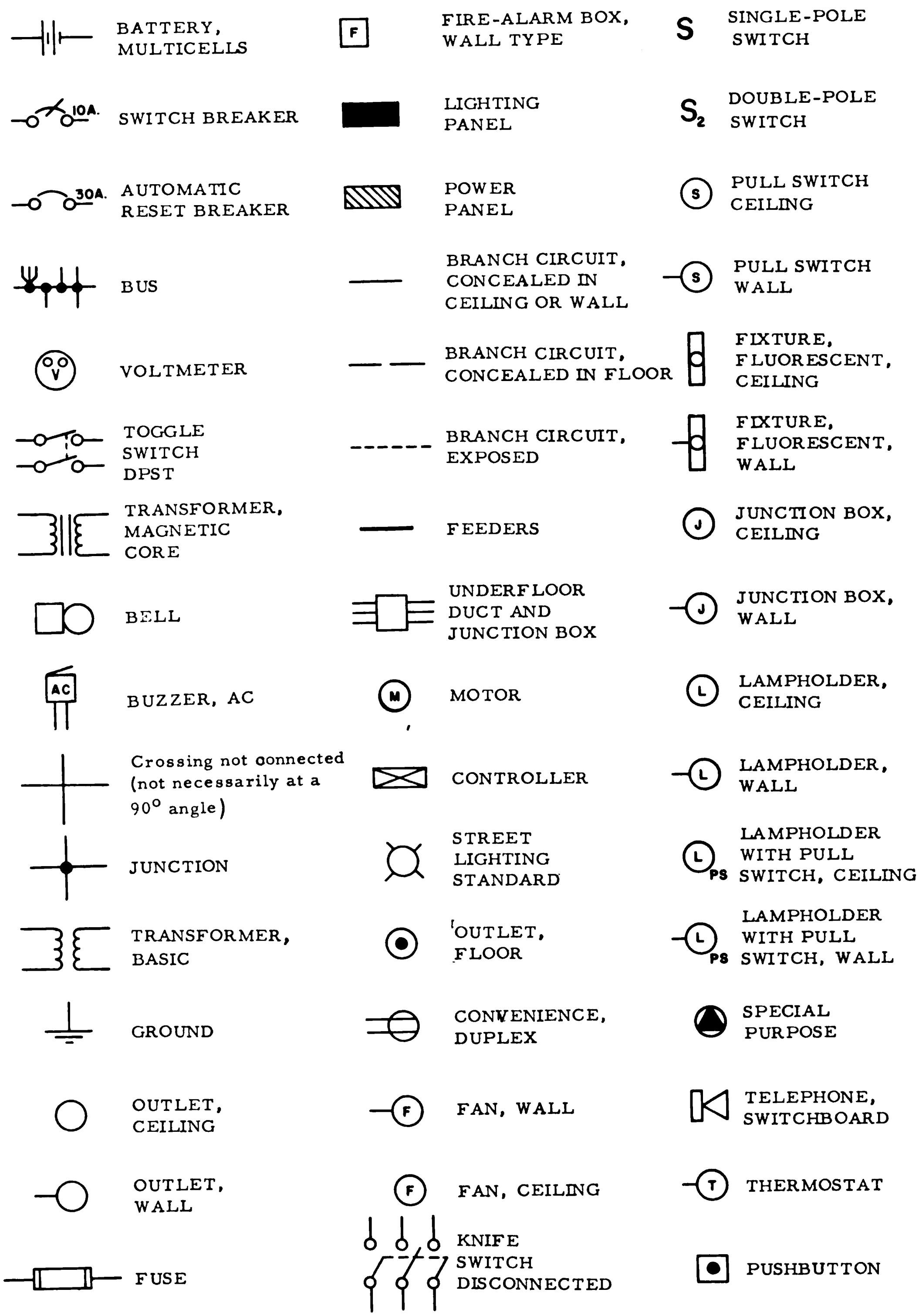


Figure 181. Electrical symbols.

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For explanation of abbreviations used, see AR 320-50.

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	01	FRAME																					
		LUMBER																					
1		2x 6-14 FT	PCS	13	10	10	10	27	16	16	16	29	19	19	19	41	24	24	24	48	28	28	28
2		2x 6-16 FT	PCS	33	33	33	33	47	47	47	47	65	65	65	65	77	77	77	77	97	97	97	97
3		2x 8- 8 FT	PCS	16	16	16	16	21	21	21	21	25	25	25	25	31	31	31	31	36	36	36	36
4		2x 8-16 FT	PCS	2	2	2	2	---	---	---	---	2	2	2	2	3	---	---	---	2	2	2	2
5		2x10-16 FT	PCS	---	---	---	---	2	2	2	2	---	---	---	---	---	2	2	2	---	---	---	---
6		2x12-16 FT	PCS	9	9	9	9	14	14	14	14	18	18	18	18	23	23	23	23	27	27	27	27
7		4x 6-12 FT	PCS	2	2	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4
8		6x 6-16 FT	PCS	10	10	10	10	14	14	14	14	17	17	17	17	21	21	21	21	24	24	24	24
		NAILS																					
9		10D COMMON	LB	14	14	14	14	21	21	21	21	28	28	28	28	35	35	35	35	42	42	42	42
10		20D COMMON	LB	5	5	5	5	9	9	9	9	12	12	12	12	15	15	15	15	19	19	19	19
		BOLTS AND SCREWS																					
11		MACHINE BOLT 1/2" x 12"	EA	24	24	24	24	30	30	30	30	36	36	36	36	42	42	42	42	48	48	48	48
12		MACHINE BOLT 5/8" x 10"	EA	72	20	20	48	76	20	20	46	120	40	40	92	142	50	50	102	164	60	60	112
13		WASHER 1/2" x 1 3/8"	LB	1.5	1.5	1.25	1.25	1.5	1.5	1.5	1.5	2	2	2	2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
14		WASHER 5-8" x 1 3/4"	LB	10	3	3	7	10	3	3	6.5	16	6	6	12.5	20	7	7	14	22	8	8	15
		MISCELLANEOUS																					
15		FLAT SHEET STEEL 11 GA 48" x 96"	SH	.05	.05	.05	.05	.08	.08	.08	.08	.1	.1	.1	.1	.13	.13	.13	.13	.15	.15	.15	.15
	02	ROOF																					
		LUMBER																					
1		1x6-8 FT	PCS	294	294	294	294	441	441	441	441	463	463	463	463	735	735	735	735	857	857	857	857
		NAILS																					
2		8D COMMON	LB	10	10	10	10	15	15	15	15	20	20	20	20	25	25	25	25	30	30	30	30
3		7/8" ROOFING	LB	5	5	5	5	7.5	7.5	7.5	7.5	10	10	10	10	12.5	12.5	12.5	12.5	15	15	15	15
		MISCELLANEOUS																					
4		ASPHALT PETROLEUM 5 GAL	CN	3.2	3.2	3.2	3.2	6	6	6	6	6.4	6.4	6.4	6.4	10	10	10	10	12	12	12	12
5		ROOFING FELT 45 LB 36" WD	RO	6	6	6	6	8.9	8.9	8.9	8.9	11.9	11.9	11.9	11.9	14.8	14.8	14.8	14.8	17.8	17.8	17.8	17.8
	03	CLADDING																					
		LUMBER																					
1		LATH WOOD #2	BDL	---	8	8	8	---	10	10	10	---	12	12	12	---	14	14	14	---	16	16	16
2		1x 3-14 FT	PCS	---	17	17	17	---	35	35	35	---	35	35	35	---	43	43	43	---	51	51	51
3		1x 6- 8 FT	PCS	---	534	534	534	---	625	625	625	---	773	773	773	---	892	892	892	---	1012	1012	1012
4		2x 4- 8 FT	PCS	---	71	63	50	---	81	73	59	---	110	94	68	---	123	107	81	---	135	120	95
5		2x 4-12 FT	PCS	---	11	20	20	---	16	24	24	---	16	32	32	---	20	37	37	---	24	41	41
6		2x 6-12 FT	PCS	---	16	12	12	---	20	15	15	---	24	16	16	---	28	20	20	---	32	24	24
7		2x 6-16 FT	PCS	---	8	8	6	---	12	12	8	---	12	12	8	---	14	14	10	---	16	16	12
8		2x10-12 FT	PCS	---	---	---	12	---	---	---	12	---	---	---	24	---	---	---	24	---	---	---	24
		NAILS																					
9		3D COMMON	LB	---	1.4	1.25	1.25	---	2.4	2.2	2.2	---	2.6	2.2	2.2	---	3.2	3	3	---	3.5	3.3	3.3
10		8D COMMON	LB	---	56	56	56	---	70	70	70	---	84	84	84	---	98	98	98	---	112	112	112
11		10D COMMON	LB	---	14	14	14	---	17.5	17.5	17.5	---	21	21	21	---	24.5	24.5	24.5	---	28	28	28
12		7/8" ROOFING	LB	---	12	12	12	---	15	15	15	---	18	18	18	---	21	21	21	---	24	24	24
		MISCELLANEOUS																					
13		GLASS SUBSTITUTE 48" WIDE	RO	---	.5	.5	.5	---	1	1	1	---	1	1	1	---	1.25	1.25	1.25	---	1.5	1.5	1.5
14		BUILDING PAPER 15 LB 36" WIDE	RO	---	5.6	5.6	5.6	---	6.5	6.5	6.5	---	8.2	8.2	8.2	---	9	9	9	---	9.45	9.45	9.45
15		HANGERS AND TRACKS 12'x12"	EA	---	---	---	2	---	---	---	2	---	---	---	4	---	---	---	4	---	---	---	4
16		WIRE CLOTH 16 MESHES/IN	FT	---	92	64	64	---	156	128	128	---	184	128	128	---	216	160	160	---	248	192	192
17		WIRE CLOTH 2x2 MESH	FT	---	12	---	---	---	12	---	---	---	24	---	---	---	24	---	---	---	24	---	---
18		JOINT FASTENER 5/8"	BX	---	10	8	8	---	18	16	16	---	20	16	16	---	24	20	20	---	28	24	24
		HARDWARE																					
19		SURFACE BOLT 6"	EA	---	4	4	---	---	4	4	---	---	8	8	---	---	8	8	---	---	8	8	---
20		T HINGE 6"	PR	---	4	---	---	---	4	---	---	---	8	---	---	---	8	---	---	---	8	---	---
21		T HINGE 10"	PR	---	---	6	---	---	---	6	---	---	---	12	---	---	---	12	---	---	---	12	---
22		THUMB LATCH	EA	---	2	2	---	---	2	2	---	---	4	4	---	---	4	4	---	---	4	4	---
23		TACK 7/16" #9	LB	---	.5	.5	.5	---	1	1	1	---	1	1	1	---	1.2	1.2	1.2	---	1.4	1.4	1.4
24		DOOR SPRING 16 1/2"	EA	---	4	---	---	---	4	---	---	---	8	---	---	---	8	---	---	---	8	---	---

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