Axonometric Projection 16

16.1 Definition. An axonometric projection may be defined as an orthographic projection upon a plane oblique to the three principal planes, as shown in Fig. 16.1. The object represented is usually assumed to have its principal faces parallel to the three principal planes of projection. Three types of views or projections may be obtained by varying the position of the axonometric plane. When this plane makes equal angles with the principal planes, an isometric projection results. The axes, or edges of the cube, are therefore equally foreshortened and make angles of 120° with each other.

When the axonometric plane is equally inclined to two of the principal planes, two of the axes project equally and the third is foreshortened by a different amount. In this case two of the angles between the axes are equal while the third is different.

When the plane is unequally inclined to all three principal planes a trimetric projection results. When this happens, the axes are all foreshortened by different amounts and the angles between the axes are all unequal. In no case can any of these angles be 90° or less.

Projections of this kind can be made in a variety of ways. For example, it will be noted that the body diagonal of the cube in Fig. 16.1 is perpendicular to the axonometric plane and the three edges will therefore make an angle of 120° with each other. Consequently an isometric projection may be made upon a plane which is set up perpendicular to this diagonal either by auxiliary projection, as shown in Fig. 16.2, or by revolving the cube until its body diagonal is perpendicular to the vertical plane, as in Fig. 16.3. These methods, however, are not practical for more complicated objects, but from them certain rules may be derived which make possible simple methods of construction. This scheme based upon simple rules of construction is called the conventional method.

16.2 Isometric projection compared with isometric drawing. In Fig. 16.3, it may be noted that the edges

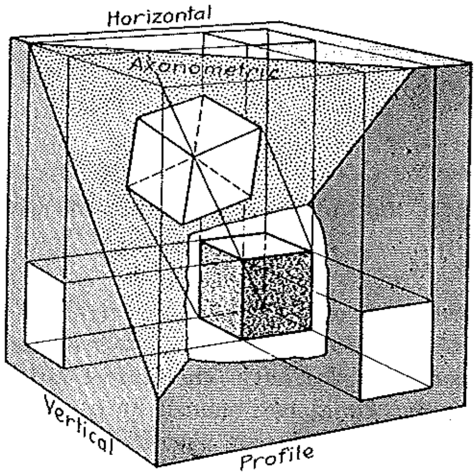


Fig. 16.1. Theory of isometric.

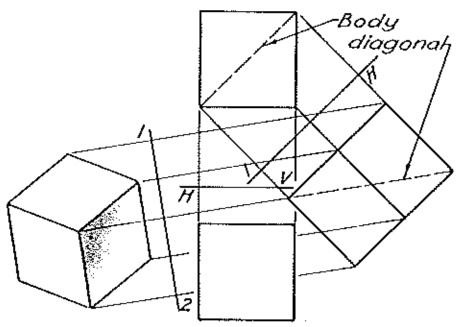


Fig. 16.2. Isometric view by auxiliary projection.

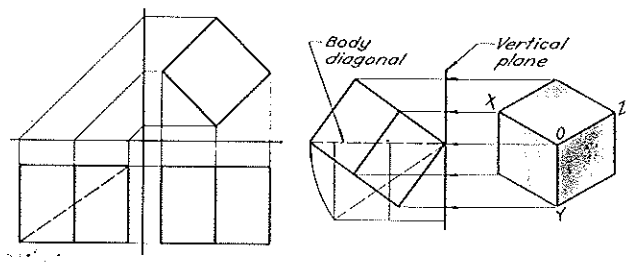


Fig. 16.3. Isometric view by turning cube.

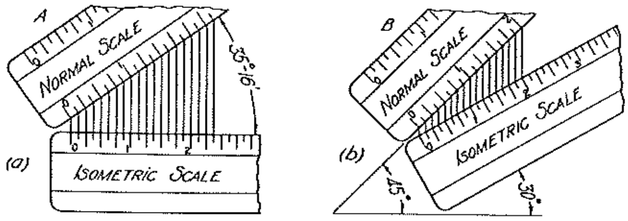


Fig. 16.4. Construction of isometric scales.

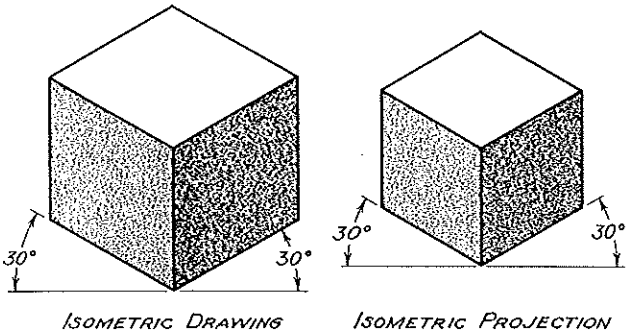


Fig. 16.5. Isometric projection and isometric drawing compared.

of the projection of the cube at the right are shorter than those of the cube itself as shown on the three-view drawing at the left. The correct ratio of this foreshortening could be obtained by constructing an isometric scale as shown in Fig. 16.4(*a*). A second method of construction is shown in Fig. 16.4(*b*). Scales of this type, however, are not on the market, and it would be tedious to make them and not worth while since an isometric drawing on which the regular normal scales are used has exactly the same appearance as a projection except for size. By making measurements along the three isometric axes with a normal scale the drawing becomes about 1¼ times as large as a true projection, as shown in Fig. 16.5.

A line parallel to any one of the isometric axes (edges of the cube in Fig. 16.5) is called an isometric line. All other lines are non-isometric.

16.3 Isometric of plane figures. *a. Straight-Line Figures.* The isometric drawing of a solid object consists mainly in representing three more or less irregular plane faces, which are parallel to the faces of the isometric cube. In these faces there may be any number of non-isometric lines. The outlines of the plane faces including the non-isometric lines in them constitute a series of plane geometrical figures which must be drawn in isometric. As a prelude to the drawing of more complicated solids the construction of plane figures in isometric will be considered.

In Fig. 16.6(*a*) an irregular seven-sided figure is shown. In Fig. 16.6(*b*), this figure has been enclosed in a rectangle and the coordinates of the corners of the figure relative to the box have been indicated. In Fig. 16.6(*c*) and (*d*), an isometric of the rectangle has been made in two different positions and the seven-sided figure constructed therein by making measurements as indicated.

b. Circles and Curves by Coordinate Method. A circle may be constructed in isometric by the coordinate method, as shown in Fig. 16.7. The procedure is as follows: (1) Divide the circle into 12 equal parts; (2) enclose it in a square, and draw coordinates through these points in two directions; (3) construct the isometric of the square and the coordinates, thus locating the 12 points in the isometric; (4) draw a smooth curve through the points.

Another very convenient method of drawing an ellipse which represents a circle in isometric or any kind of projection is illustrated in Fig. 16.7(*f*). First draw a parallelogram which is the projection of a square circumscribing the circle and then draw a semicircle, using one of the sides of the parallelogram as a diameter. Divide the semicircle into an even number of parts and project them perpendicularly to the side of the parallelogram. From these points draw lines in the parallelogram parallel to the other side. Draw a diagonal of the parallelogram. Draw lines from the points of intersection of the diagonal, parallel to the side of the parallelogram on which the circle is drawn. The intersections of those two sets of parallel lines give points on the isometric of the

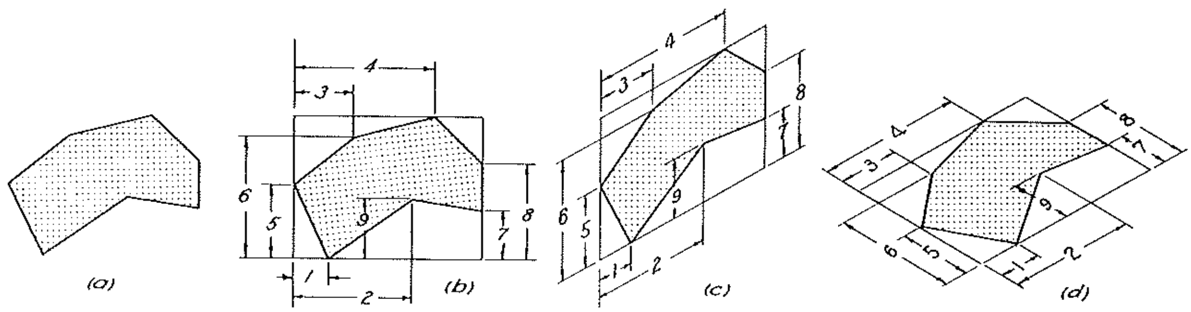


Fig. 16.6. Construction of plane figures in isometric.

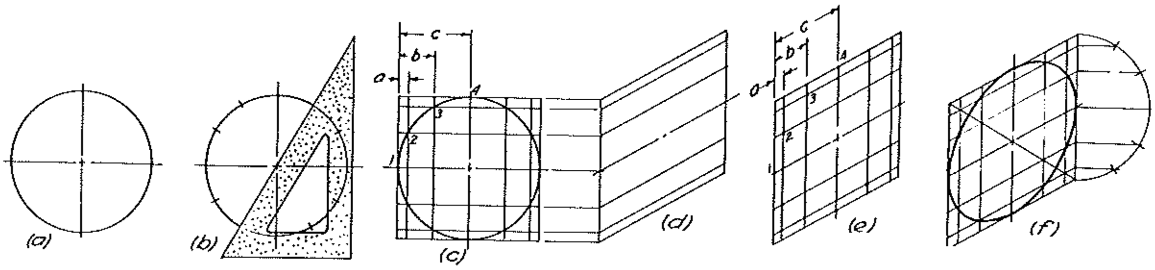


Fig. 16.7. Construction of circle in isometric.

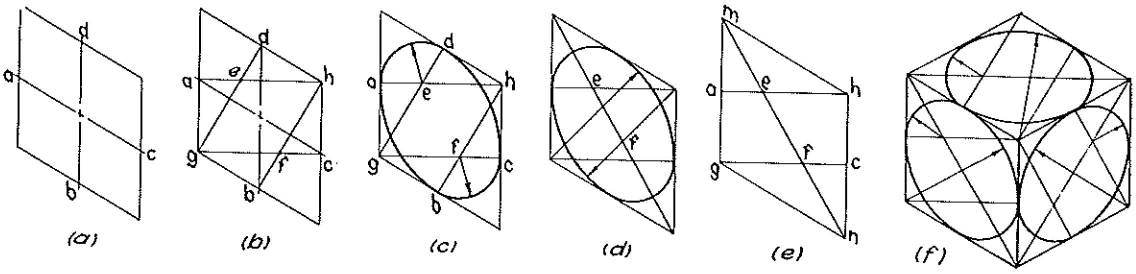


Fig. 16.8. Four-center method of representing a circle in isometric.

circle. This method may be used in any type of pictorial.

c. Circles by the Four-Center Approximate Method. An approximate isometric of a circle may be drawn by the method shown in Fig. 16.8. This construction depends upon the fact that the center of a circle which is tangent to a straight line lies on the perpendicular to the line at the point of tangency. Hence, if we erect perpendiculars at the midpoints *a*, *b*, *c*, and *d* of the sides of the isometric square, these perpendiculars will intersect in pairs, thus locating the centers of the four arcs, *e*, *f*, *g*, and *h*, which will approximate the correct ellipse. It will be noted that in isometric two of these centers lie on the corners of the square and the other two lie on the long diagonal. Use of these facts enables the draftsman to shorten the construction considerably by drawing only the lines *ah*, *gc*, and *mn*, as in Fig. 16.8(*e*). This construction can be used in any isometric face of a cube, as illustrated in Fig. 16.8(*f*). The method involves less labor than the coordinate method and is sufficiently accurate for most isometric work. This approximate ellipse has a shorter major axis and longer minor axis than the true ellipse as shown in Fig. 16.9.

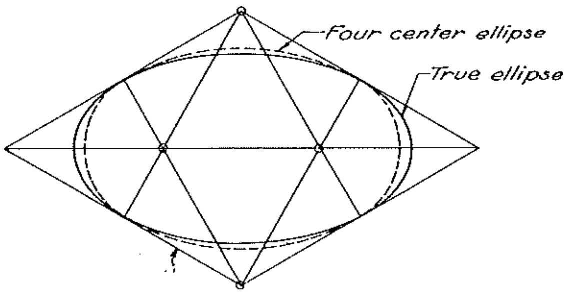


Fig. 16.9. True ellipse and four-center ellipse compared.

16.4 Isometric drawing of solids. Box method. From the drawing of plane figures to the drawing of solid objects in isometric is but a simple step, involving only the use of a third coordinate distance. The steps in the procedure are as follows:

a. Draw the orthographic views of the object to the same scale as that to be used on the isometric.

b. Enclose the views in the smallest enclosing rectangular box.

c. Draw the enclosing box in isometric in the position which will best reveal the shape of the object, making the three edges at 120° with each other.

d. Draw the simple parts of the object which lie in or adjacent to the faces of the box.

e. Plot the curves and interior points by the coordinate method.

f. It is the usual practice to omit all invisible lines in pictorial drawing.

16.5 Isometric of a block. Box method of construction. An isometric drawing of the block shown by three orthographic views in Fig. 16.10(*a*) may be readily constructed in the following manner. The first step as outlined above consists of enclosing the orthographic views of the object in the smallest rectangular box which will just enclose it as shown by the light lines of Fig. 16.10(*a*). This box serves as a reference frame from which dimensions can be measured in the orthographic views and plotted in the isometric.

The second step consists of drawing the isometric

of the enclosing box in the position desired, as shown in Fig. 16.10(*b*). Here the front orthographic view has been made the left face. The various parts which have been cut out of the block can now be cut from the isometric box in any order desired. Thus, in Fig. 16.10(*c*), the distance (a^H–*1*) on the top view has been measured on the same line, *AC*, in the isometric and the distance (a^H–*2*) along the line *AB*. The diagonal line *1–2* can now be drawn in the isometric view. From the points *1* and *2* in the isometric, vertical lines can be dropped to the bottom of the box and then the diagonal in the bottom face can be drawn.

In a similar manner the other cut-outs can be transferred by direct measurement from the orthographic to the isometric, as illustrated in the successive Figs. 16.10(*d*) and 16.10(*e*). It should be carefully noted that in all cases measurements are made on or parallel to the three isometric axes. They can be made in no other manner for no other lines are foreshortened in the same ratio as these lines.

As a second illustration, the construction of a truncated hexagonal pyramid is shown. In Fig. 16.11(*a*), the object is shown enclosed in a rectangular box, and, in Fig. 16.11(*b*), the box has been drawn in isometric and the hexagonal base shown in the bottom of the box. The measurements *a* and *b* for constructing this plane figure are obtained from the top view as shown in the figure.

Whenever an object has a plane of symmetry, advantage should be taken of this fact to speed construction. Hence, in Fig. 16.11(*c*), the central plane of symmetry has been established and the two points *2* and *9* located in it to give the center line of the truncated face (*2–9*). For example, the point *2* is located by measuring the coordinate *1–2* in the central plane as indicated. The point *9* is located by going up along the center line from *0* to *9*, using the distance *0–9* in the front view. Points *3*, *4*, and *5* are located by taking the measurements (*1–3*), (*1–4*), and (*1–5*) from the top and front views. By dropping perpendiculars from *3*, *4*, and *5* to the center line (*2–9*), the points *6*, *7*, and *8* are located as shown in Fig. 16.11(*c*). Isometric horizontal lines can then be drawn through points *6* and *7*. Points *10* and *11* can be located by stepping off from point *6* on these lines

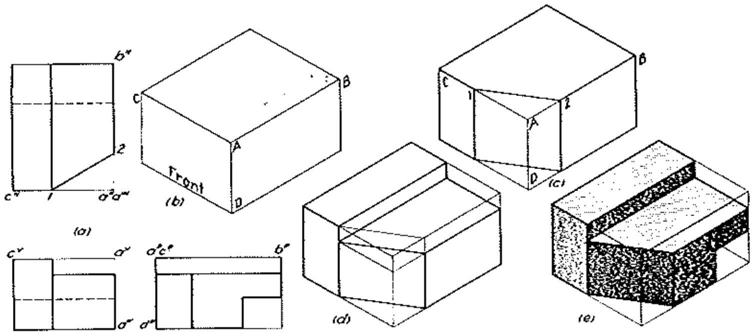


Fig. 16.10. Box method of drawing a solid in isometric.

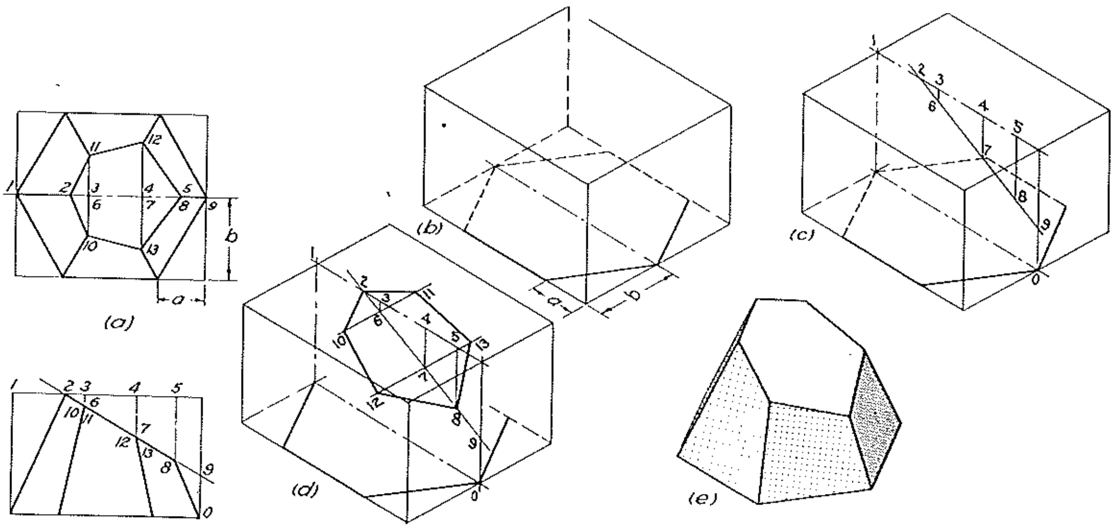


Fig. 16.11. Truncated pyramid in isometric.

the distances (*6–10*) and (*6–11*) which are equal. A similar procedure locates points *12* and *13* as shown in Fig. 16.11(*d*). All these measurements are taken from the top view. The six points in the truncated face are then connected to form the sloping truncated face. The corners of this face are then connected to the corresponding corners of the base, thus completing the isometric as shown in Fig. 16.11(*e*). It is customary in isometric drawing, as in all other pictorials, to omit hidden lines unless they are necessary to make clear the shape of the object. Note again that all measurements were taken on or parallel to isometric lines.

16.6 Solid objects involving circles. The objects illustrated thus far have been composed entirely of straight lines. Many objects, however, involve circles either singly or in groups. The following suggestions will assist in speeding up construction and in avoiding common errors.

16.6.1 PARALLEL CIRCLES OR OTHER CURVES. In actual drawing, circles nearly always occur in pairs. Since rapidity in construction is always important, the suggestions for speeding up the layout of circles parallel to each other, as shown in Fig. 16.12, are valuable.

In the four-center method the centers for the first circles are found in the usual way. Circles parallel to the first may be quickly found by drawing isometric lines from the original four centers and stepping off on them the distance between the circles, to locate the new centers, as shown in Fig. 16.12.

The same scheme may be used for a curve plotted by the coordinate method, as shown in Fig. 16.13, for a non-circular curve. One curve is drawn in the usual way, and isometric lines are drawn from the plotted points. Each successive curve may be stepped off with one setting of the divider.

16.6.2 TANGENT CIRCLES AND ARCS. The four-center method may be used for tangent circles or arcs only when they are tangent to each other at the mid-point of the sides of their enclosing rectangles, as shown in Fig. 16.14(*a*). If the tangency points occur at other places, the circles will overlap or miss, as shown in Fig. 16.14(*b*), because of their departure from the true ellipse. In such cases the coordinate method should be used or other approximations made.

16.6.3. COMMON ERRORS IN DRAWING CIRCLES. Two common errors are frequently made by the student in drawing circles on various objects. One of these consists of drawing the circle out of the proper isometric plane, as shown in Fig. 16.15(*a*). This can be avoided by making sure that the sides of the en-

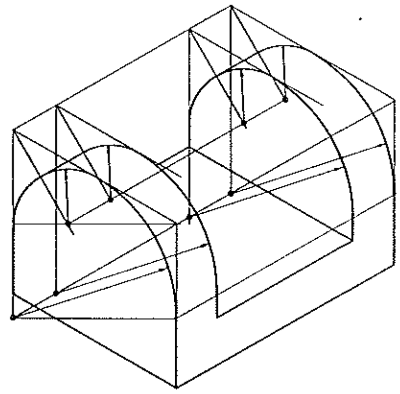


Fig. 16.12. Short cut in drawing parallel circles in isometric.

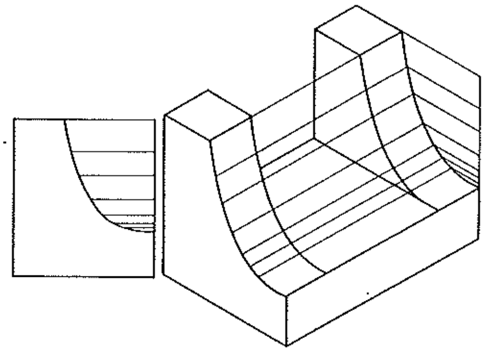


Fig. 16.13. Short cut in drawing parallel curves in isometric.

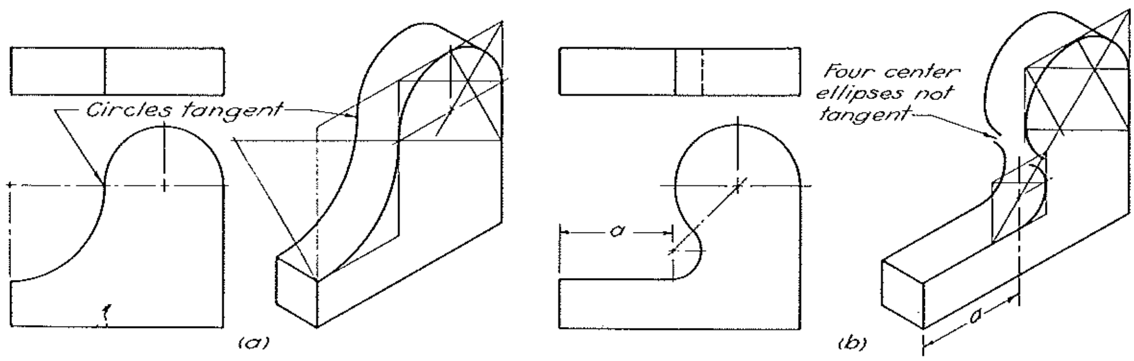


Fig. 16.14. Limitation of four-center method.

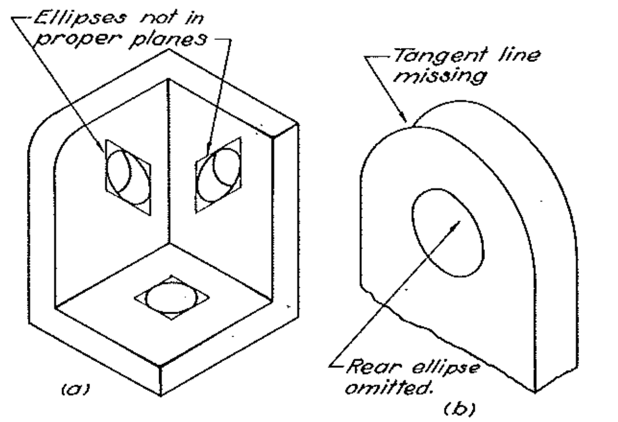


Fig. 16.15. Common errors made in drawing isometrics of circles.

closing parallelogram are parallel to the isometric lines of the plane in which the circle lies, as shown for the circle in the lower face of the object in Fig. 16.15(*a*).

A second error occurs in the drawing of short cylinders or cylindrical parts where the student fails to put in the isometric tangent line between the circles, as shown in Fig. 16.15(*b*). The far side of small holes is omitted many times.

16.7 Steps in construction illustrated. The simple bearing shown in Fig. 16.16 will serve to further illustrate the method of construction which has again been broken down into a series of successive steps, following the method previously suggested. Figure 16.16(*a*) shows the orthographic views enclosed in a box. Figure 16.16(*b*) shows the box in isometric with the base and cylindrical bearing partly completed. The circles are drawn in their proper planes by the four-center method based on the enclosing rectangles which are shown.

In an object of this kind, considerable time can be saved by using the plane of symmetry and noting that much of the construction falls naturally into isometric planes. To plot the vertical and sloping webs, a series of horizontal planes *d*, *e*, *f*, etc., are drawn in the orthographic views locating points *1 to 12* on the curves. In Fig. 16.16(*c*), the end view of the vertical web is drawn in the end of the isometric box, and on it the points *d*, *e*, *f*, etc., are located by measurements (*0–d*), (*0–c*), etc. From these points *d*, *e*, *f*, etc., isometric horizontal lines are drawn and measurements (*d–1*), (*e–2*), etc., made on them, thus locating points *1*, *2*, *3*, etc., on the curve which can then be drawn as in Fig. 16.16(*c*).

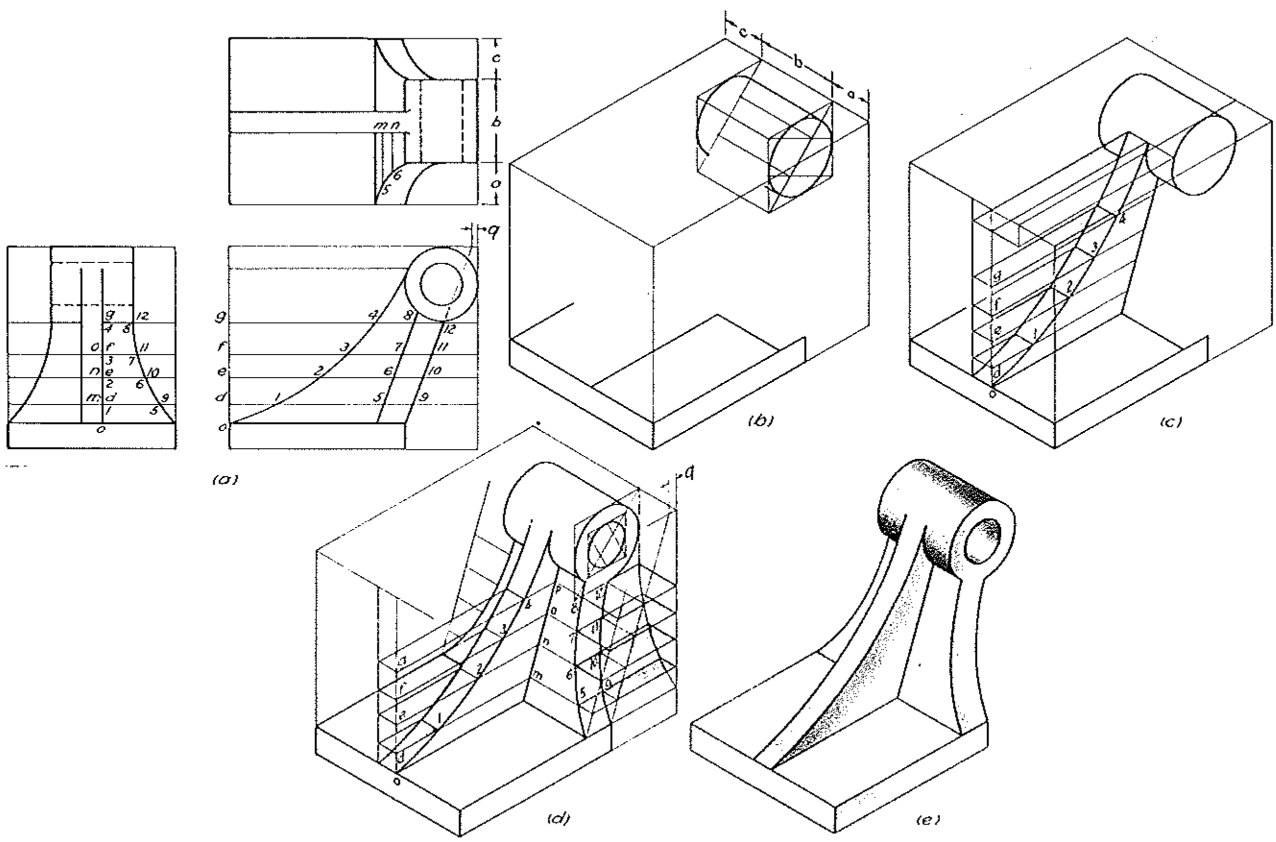


Fig. 16.16. Construction in isometric planes speeds drawing.

The front view of the sloping web is next constructed in the right face of the isometric box, as shown in Fig. 16.16(*d*). It is a simple matter to carry the *m*, *n*, *o*, *p* horizontal planes around the box from *d*, *e*, etc., to locate the points (*5*, *6*, *9*, and *10*), etc. From these points horizontal lines can be drawn in isometric, and the distances (*m*–*5*), (*n*–*6*), etc., obtained from the three-view drawing in Fig. 16.16(*a*), can be measured on them, thus establishing points 5, *6*, *7*, etc. The other curves may be found in a similar manner. The completed drawing with all construction removed is shown in Fig. 16.16(*e*).

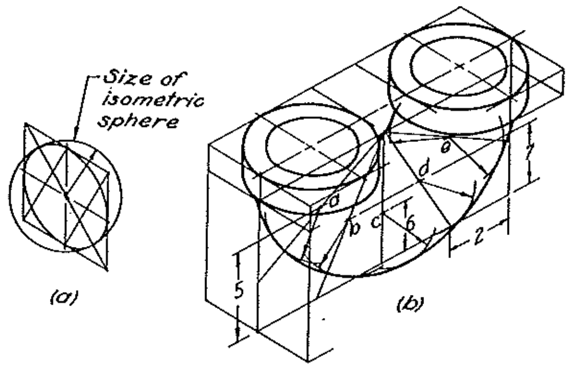


Fig. 16.17. Tangent sphere method of drawing a double-curved surface.

16.8 Isometric of a double-curved surface. On some objects such as the pipe return bend shown in Fig. 16.17, an enveloping curve representing the outstanding contour of the object must be drawn. This curve does not lie in a single plane and hence cannot be constructed by plotting points in the usual way.

Since a sphere projects as a sphere in isometric a simple method of making this, or any similar construction, is shown in Fig. 16.17. A series of spheres may be imagined lying in the bend just tangent to it. The centers of five or six of these spheres may be located on the isometric of the center-line circle, as shown in the illustration by points *a*, *b*, etc. Next the size of the isometric sphere is obtained, as shown in Fig. 16.17(*a*), by making the circle tangent to the isometric ellipse. Only the major axis of the ellipse needs to be drawn to determine the diameter of the spheres. With the radius thus determined the arcs may be drawn and a smooth curve drawn tangent to them.

16.9 Construction by the center-line layout. The box method of construction discussed in preceding paragraphs may be used for any type of object. When, however, the object consists of a number of circular parts lying in the same or parallel planes, the center-line layout shown in Fig. 16.18 is a convenient and rapid method of construction. In Fig. 16.18(*a*) the orthographic views are shown, and in Fig. 16.18(*b*) the isometric layout of the principal center lines are drawn. In Fig. 16.18(*b*) the parallelograms for some of the circles are drawn, and in Fig. 16.18(*c*) the drawing is completed.

16.10 Dimensioning. For shop purposes, other than assembly work, an isometric drawing must be dimensioned. The regular rules and suggestions for dimensioning two- or three-view working drawings hold for isometric drawing in a general way, but, in addition, the following rules must be observed.

16.10.1 Pictorial Plane Dimensioning. Dimensions on isometric drawings should be placed in such a way that they can be read from one point of view, which should be from the bottom of the sheet. This may be said to encompass all other rules in regard to the direction on which dimensions should read, and it is the only safe one to follow at all times. It is best to dimension the visible faces.

a. All dimension lines must be isometric lines and lie in isometric planes. This point must be carefully observed. Difficulty usually occurs in objects having

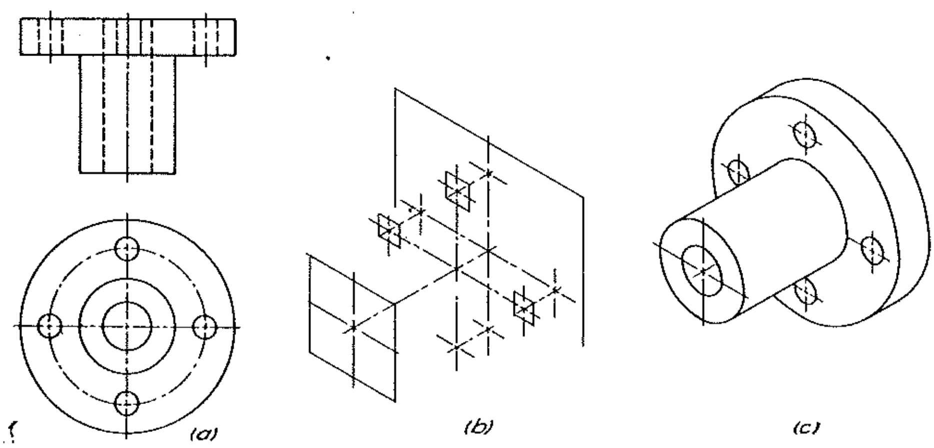


Fig. 16.18. Center-line method of constructing cylindrical objects.

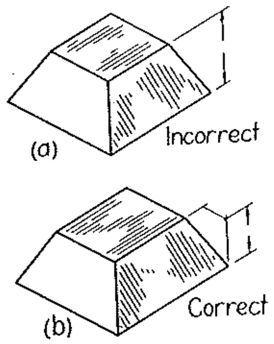


Fig. 16.19. Dimension lines in isometric planes.

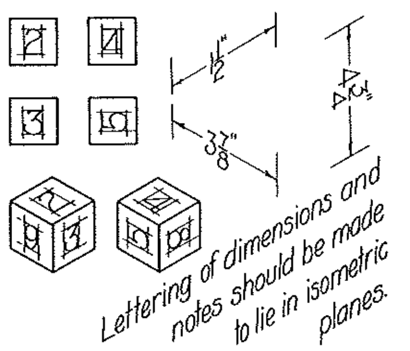


Fig. 16.20. Lettering and dimensions in isometric.

non-isometric lines. Figure 16.19(*a*) illustrates a very common error. The dimension line and the two witness lines do not lie in an isometric plane even though the dimension line is vertical. Figure 16.19(*b*) illustrates the correct method.

b. Figures and lettering of notes should be made to lie in isometric planes. Only vertical-style lettering should be used in isometric. Figure 16.20 shows how the parallelogram enclosing a letter or figure may be used as an aid in isometric lettering. The front views of the small cubes show the letters and their enclosing parallelograms orthographically; the two isometrics of the cubes show the six possible positions in which these parallelograms and figures may appear. Figure 16.21(*a*) illustrates the dimensioning of a rectangular object, placing the numerals in one or another of the positions shown in Fig. 16.20.

16.10.2 UNIDIRECTIONAL DIMENSIONING. The American Standards Association has recently approved the placing of all dimensions and notes in one plane as illustrated in Fig. 16.21(*b*). When using this system only vertical letters or numerals should be used. This method is simple and more rapid for production purposes.

16.11 Screw threads in isometric. Screw threads could be accurately drawn in isometric but the process is so laborious that a conventional scheme which is quite satisfactory has been adopted. Arcs of a series of parallel circles are used to represent the crest and root lines although the root lines need not be shown. Any method of drawing the circles may be used but the construction for the four-center method is illustrated in Fig. 16.22.

Because of symmetry of construction Square threads and Acme threads cannot be clearly shown in isometric. Dimetric or trimetric layouts are much more suitable for this purpose.

16.12 Section views. As in orthographic drawings, the interior construction of complicated objects is best shown by sectional views. Half and full sections may be made by removing one-fourth or one-half of the object, respectively. The cutting planes should always be isometric planes as shown in Fig. 16.23(*a*). In a half section the cross-hatching lines should be drawn

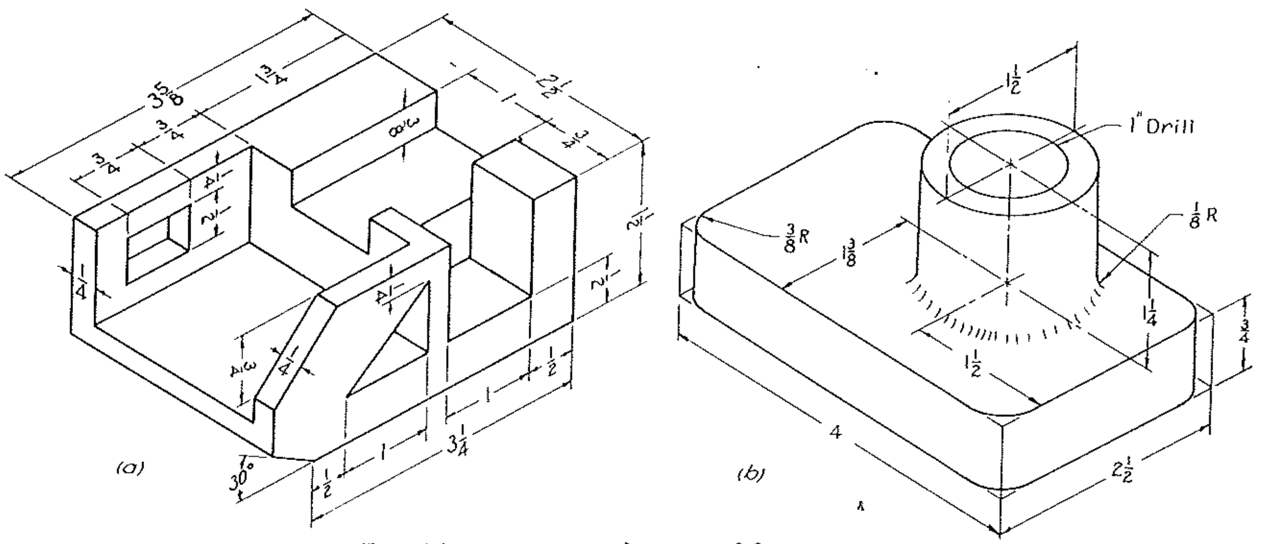


Fig. 16.21. Two approved systems of dimensioning.

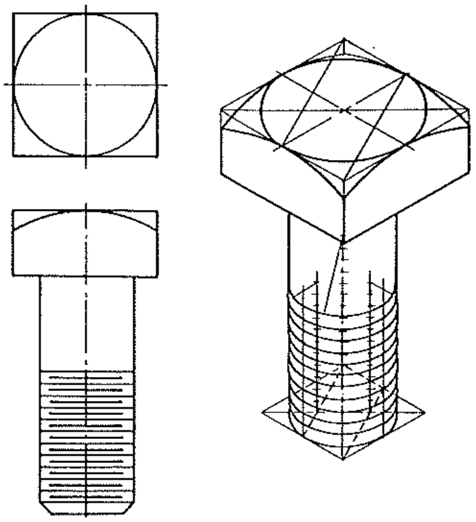


Fig. 16.22. Screw threads and square bolt head in isometric.

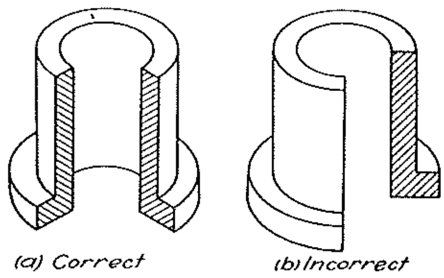


Fig. 16.23. Section cutting planes in isometric.

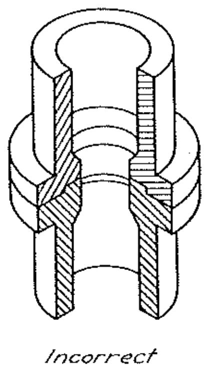


Fig. 16.24. Incorrect cross-hatching.

in a position to give the effect of coincidence if the two sectioned faces were revolved together. Correct and incorrect examples are given in Figs. 16.23 and 16.24 to illustrate this point. No new principles of construction are involved in making section views.

The step-by-step construction of a sectional view is shown in Fig. 16.25. By beginning with the sectioned parts, as shown in Fig. 16.25(*b*) and (*c*), a minimum number of construction lines need be used. Careful study of the figure will show the procedure. The finished sectional drawing is shown in Fig. 16.25(*f*).

16.13 Position of isometric axes. Thus far we have considered isometric drawing with the object always in one position. The three axes, however, may be drawn in an infinite number of positions so long as they always make equal angles with each other.

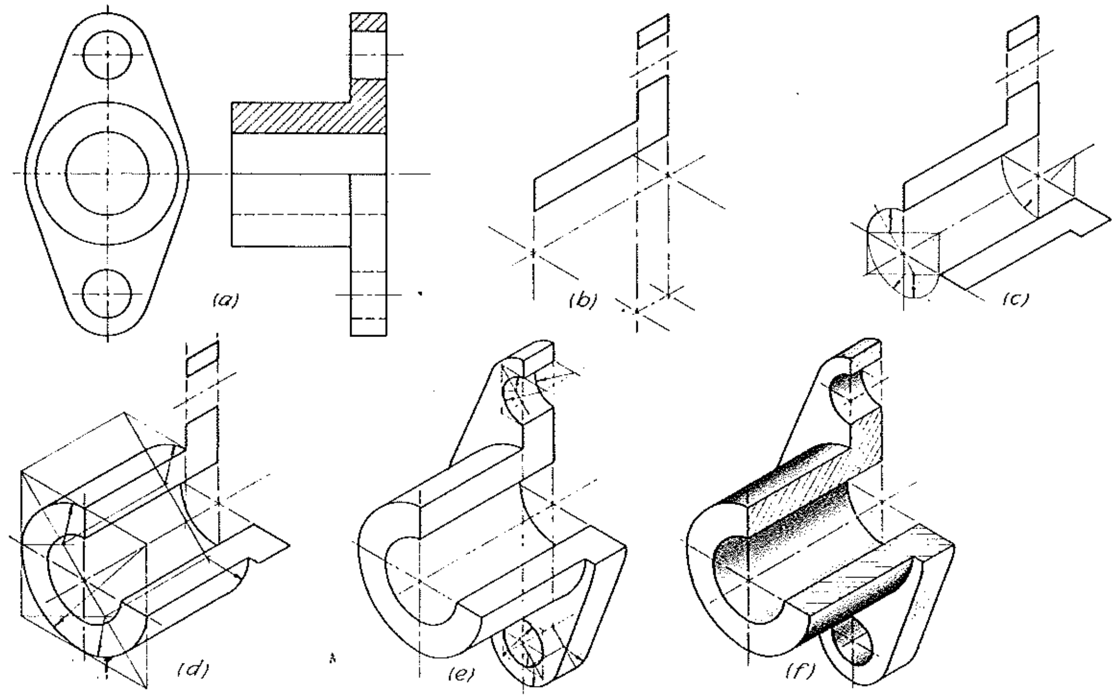


Fig. 16.25. Step-by-step construction of an isometric sectioned view.

Four easily drawn positions, as shown for the object and enclosing box, in Fig. 16.26, are most commonly used.

The choice of the position of these axes will depend upon the nature of the object. When the top and sides of the object contain most of the details, the position used thus far is best. If, on the other hand, the bottom contains the more important details, the position of Fig. 16.26(*b*) is by far the best. The object should, of course, be shown in the natural or normal position if it has one.

16.14 Spheres and other curved parts. Spherical parts occur on pieces of machinery and can readily be drawn in isometric. The sphere appears as a true circle. A simple lever involving spheres and curved handle is shown in Fig. 16.27.

In some objects such as gears and conveyors, it is desirable to divide a circle into a large number of equal parts. This must be accomplished first in the orthographic layout and then transferred to the isometric, using the outlines of the isometric square as shown in Fig. 16.28. Isometric protractors are on the market, and where such an instrument is available it may be used to make the divisions directly in the isometric.

16.15 Advantages of isometric. As compared with two- and three-view orthographic projections, isometric has the advantage of showing three sides of the object in one view, thus giving a more realistic picture of it.

As compared with other forms of pictorial drawing, isometric has the advantage of being easily constructed since the same scale is used on all sides. Circles can be readily approximated by the four-center method. It can be scaled and dimensioned. It is flexible in the position in which an object may be shown but not as flexible as other types, particularly oblique projection described in a later chapter. Circles are not distorted as in oblique and sometimes in perspective.

Against these advantages may be placed definite disadvantages which limit its usefulness in certain situations. Long objects with parallel sides show a disagreeable distortion since the eye is accustomed to the perspective effect of long parallel lines which appear to approach each other. There is also an exactness of symmetry causing an overlaying of lines in some symmetrical objects which makes the isometric difficult to read.

16.16 Dimetric drawing. Somewhat the same distinction exists between dimetric projection and

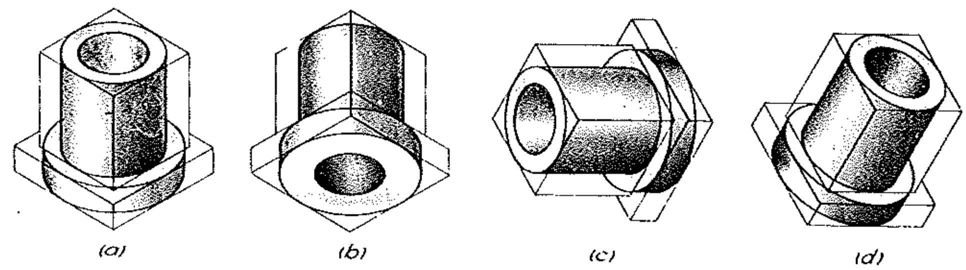


Fig. 16.26. Choice of position for isometric view.

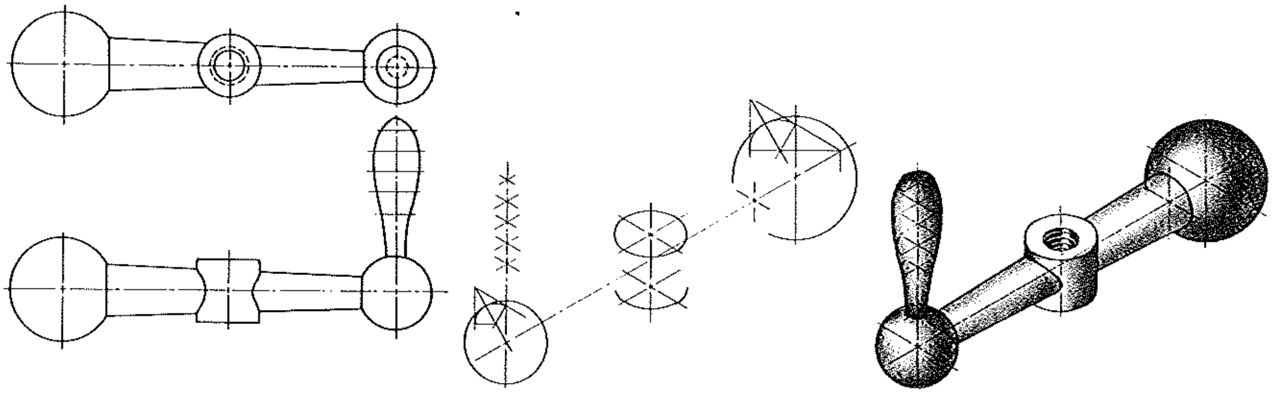


Fig. 16.27. Construction of object with curved surfaces.

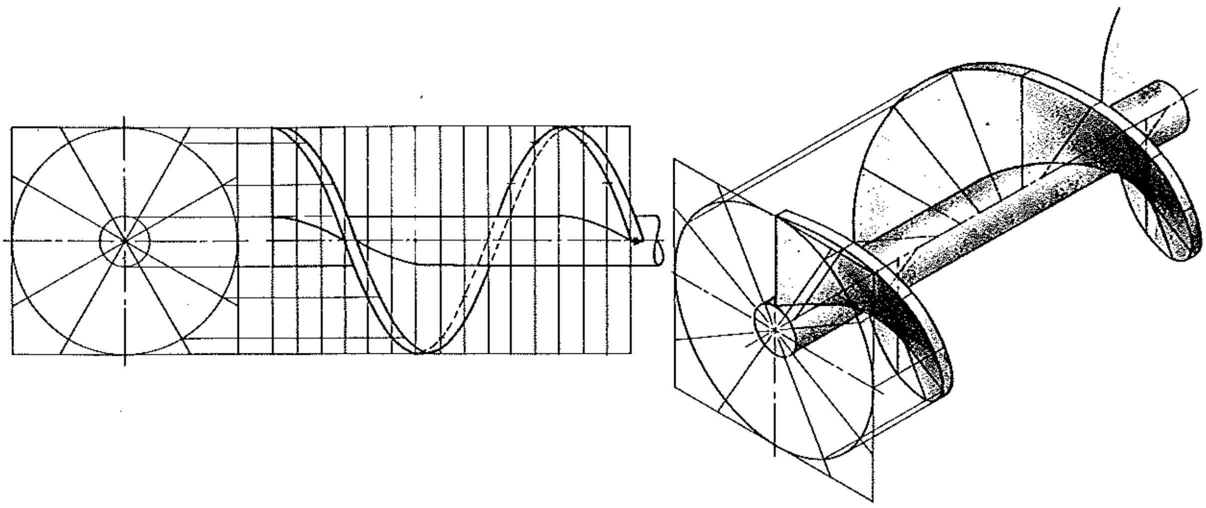


Fig. 16.28. Construction of a right helicoid in isometric.

dimetric drawing as obtained between isometric projection and isometric drawing, namely, that scales approximating the projected scales are used in making the drawing. In Fig. 16.29(a), the conventional cube has been shown rotated from the position for isometric projection to a convenient dimetric position. The dimetric projection is shown at (b).

In Fig. 16.30, four convenient positions for the dimetric axes are illustrated, with the approximate proportion of angles and scales for each axis indicated. The construction in conventional dimetric is carried on in the same manner as in isometric, except that on one axis the scale is changed. The simplest way of making a dimetric drawing is to proceed in the following manner:

a. Make the orthographic views to the scale desired for the two equal dimetric axes, and then enclose the views in the smallest possible rectangular box as shown in Fig. 16.31.

b. Draw the box in the desired dimetric position by transferring overall dimensions with dividers directly from the orthographic views for the equal axes and to the proper scale for the third axis. The scale to be used for this third axis is shown in Fig. 16.31 at the

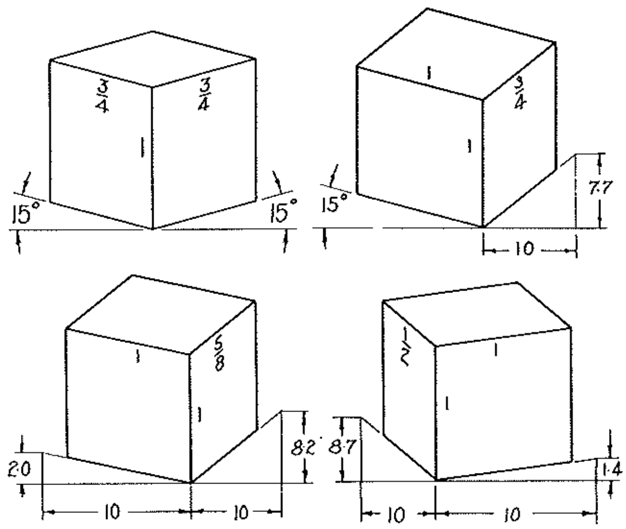


Fig. 16.30. Four convenient positions for dimetric drawing.

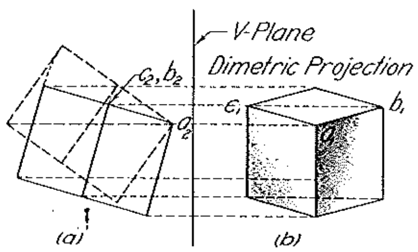


Fig. 16.29. Dimetric projection and drawing.

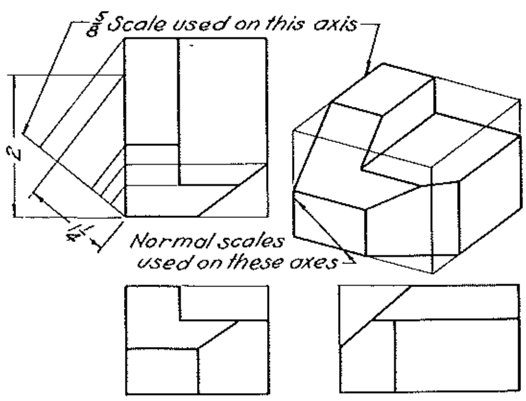


Fig. 16.31. Construction of a dimetric drawing.

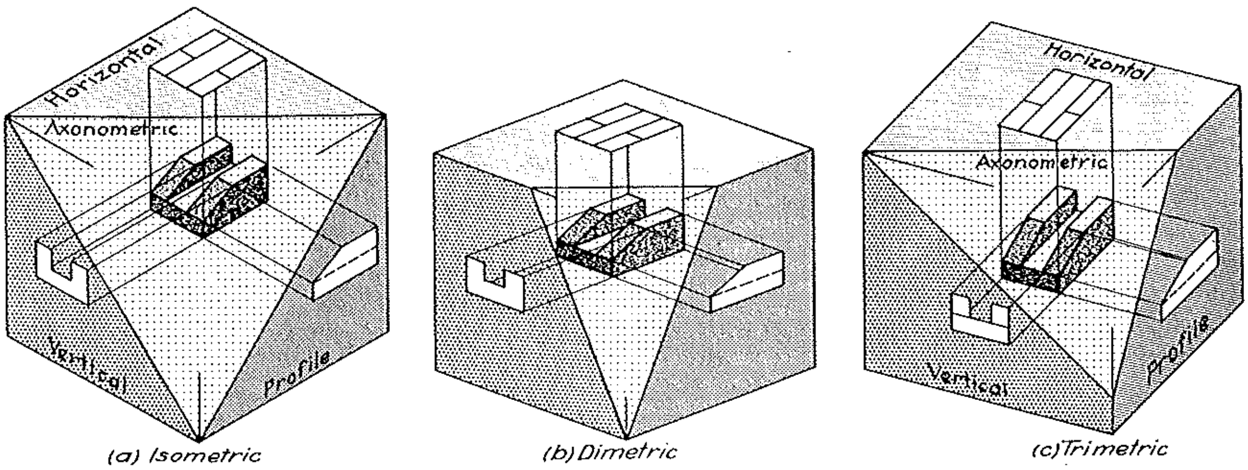


Fig. 16.32. Position of plane for isometric, dimetric, and trimetric projection.

left side of the top view. In this case the scale on the short axis was made ⅝ that of the other axes.

c. Plot points locating the corners and curves of the object just as in isometric, taking care to use the proper scale.

d. It should be noted that the four-center method of drawing circles can be used only in the face having equal scales on both sides.

16.17 True axonometric projections. A simple method of making true axonometric projections was devised by Professor L. Eckhart of Vienna, Austria, and published in 1937. This method was presented in the United States by the authors in 1942 and has since been widely used. The method is applicable to isometric, dimetric, and trimetric projections, and is particularly useful in the two latter types when orthographic views of an object are available. The question of scale on the various axes is automatically determined.

16.18 Theory of axonometric projections. In Fig. 16.32, the position of the axonometric plane relative to the three principal planes is shown pictorially for each of the three types of projection. The relative position of the three principal views and the axonometric view is also shown. It should be noted at the beginning that axonometric projection as here discussed is orthographic; i.e., the projecting lines are perpendicular to the plane of projection. The following principles of orthographic projection are involved in an understanding of axonometric projection.

a. If a point is projected orthographically upon any two inclined planes, as in Fig. 16.33, the two projections fall on a line which is perpendicular to the line of intersection of the planes, when the planes are revolved into coincidence. Thus, in Fig. 16.33, the projections O^A and O^P lie on the same perpendicular to AB. This principle has been again illustrated for all principal planes in Fig. 16.34.

In Fig. 16.35, the three principal planes together with the projections of an object on them have been successively revolved into the plane of the axonometric triangle. From Fig. 16.35(*c*), it can be clearly seen that the axonometric projection in the center could

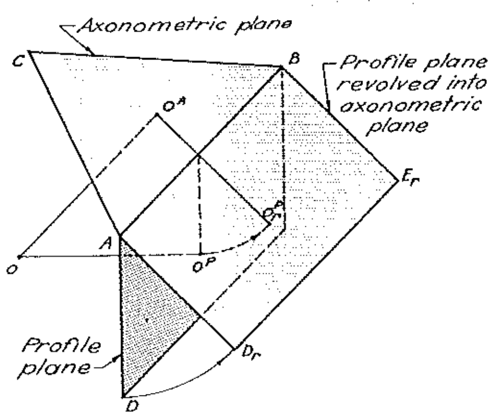


Fig. 16.33. Theory of axonometric projection.

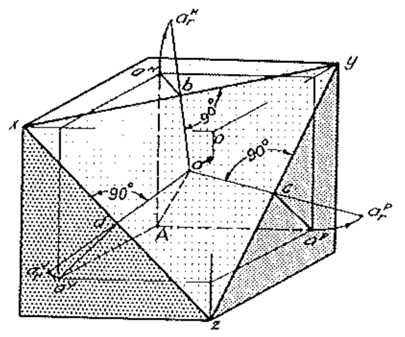


Fig. 16.34. *H*-, *V*-, and *P*-projections of a point revolved into axonometric plane.

be obtained by direct projection from any two of the three revolved orthographic views. The following things should be noted:

1. The projecting lines are always perpendicular to the axis of rotation.

2. In each case the revolved positions of the orthographic views have their principal edges parallel to the edges of the corresponding revolved plane.

b. One other geometric principle is involved. If three mutually perpendicular lines, as, for example, three intersecting edges of a cube, *ox*, *oy*, and *oz*, in Fig. 16.36(*a*), are made to pass through the three corners of a triangle, *xyz*, the projections of these lines on the triangle will be perpendicular to the side opposite the corner through which the line passes, as shown in Fig. 16.36(*a*).

c. Finally, in order to determine the position of right triangle *oyz*, of Fig. 16.36(*a*), when revolved into the plane *xyz*, it is necessary to use the geometric principle that any two lines drawn from the ends of a diameter of a circle to a point on the circumference make a right angle with each other. Then by hypothesis, when the triangle *oyz* is revolved about the line *yz* into the plane of the paper (*x*, *y*, *z*), the angle yo_rz will show as a right angle. Hence, if we construct a semicircle on *yz* as a diameter, as in Fig. 16.36(*b*), point *o* must move out along line *ox* to the point o_r on the semicircle. This construction enables the draftsman to determine the position of the orthographic views as shown in Fig. 16.35.

16.19 Constructing a trimetric projection. Having these principles in mind, a step-by-step construction for making a trimetric projection may be made as follows. See Fig. 16.37.

a. Select the position of the three axes as in Fig. 16.37(*a*). Note that the edges of the object in the finished drawing will be parallel to these lines. The angles between the lines may have any value greater than 90°.

b. Draw lines at right angles to the axes across the opposite angles as shown in Fig. 16.37(*b*). Only two are necessary.

c. Determine the revolved position of the axes as shown in Fig. 16.37(*c*) and (*d*). Note that this con-

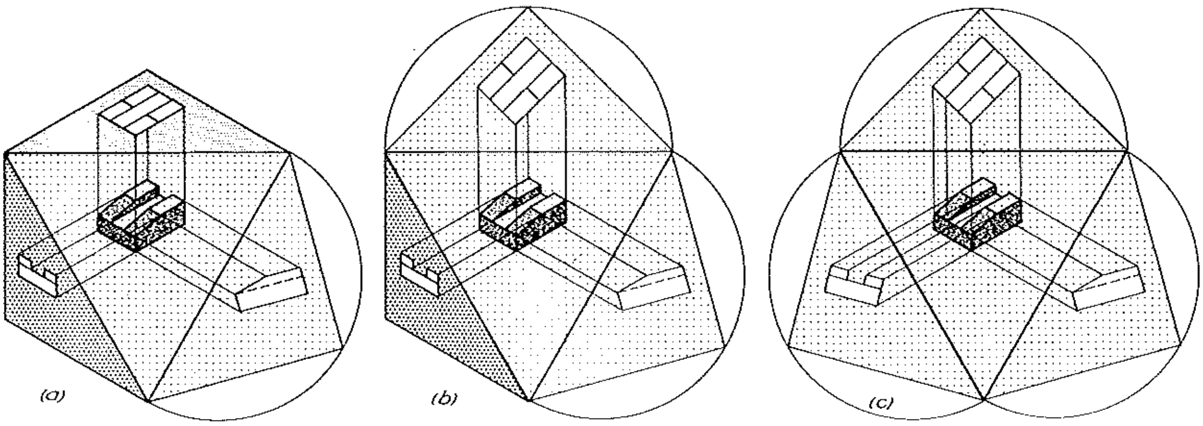


Fig. 16.35. Rotation of coordinate planes into axonometric plane.

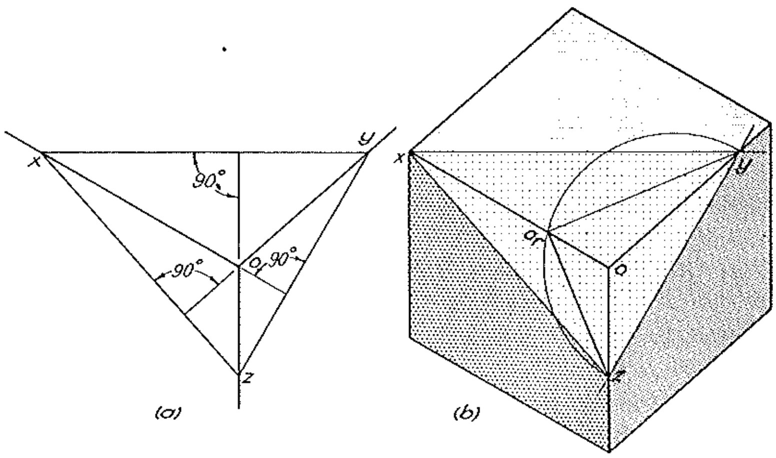


Fig. 16.36. Finding revolved position of the edges of coordinate planes.

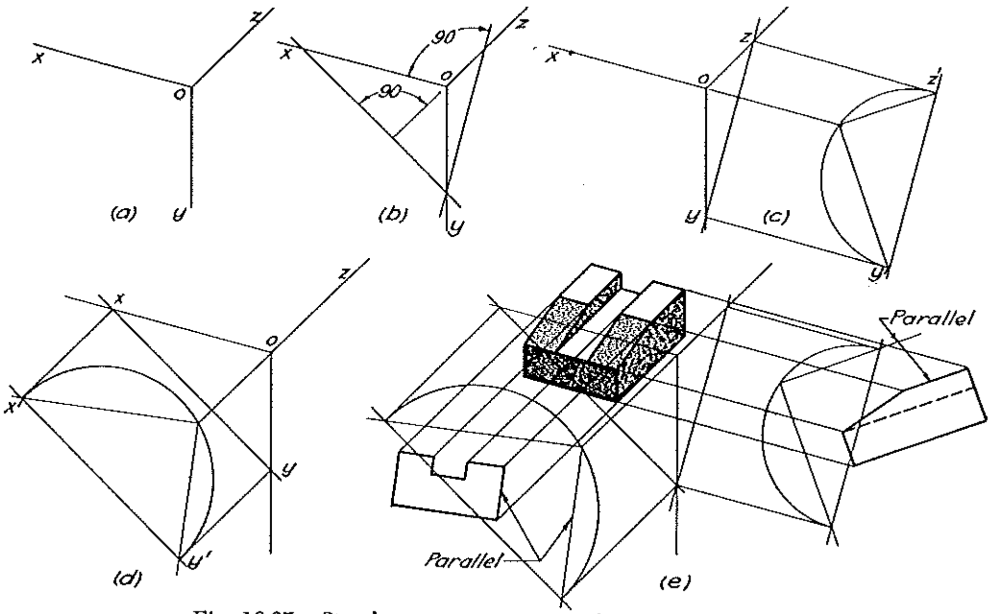


Fig. 16.37. Step-by-step construction of a trimetric projection.

struction has been translated to a parallel position in order to leave the central area free.

d. Place the front and side views parallel to the revolved position of the axes in the correct orientation thereto as shown in Fig. 16.37(*e*), and project from them to make the axonometric projection.

As a further illustration of this method the bearing bracket of Fig. 16.38 has been represented in Fig. 16.39. Details of projection have been omitted. In order to orient the orthographic views properly it is best to make a freehand thumbnail sketch of the axes and orthographic views as shown in this figure.

In Fig. 16.39 the top and front views have been used to make the construction. In drawing the circles with ellipse guides or by the trammel method, it is only necessary to find the location of the center in the pictorial and the major and minor axes. The major axis is equal to the diameter of the circle, and it will always

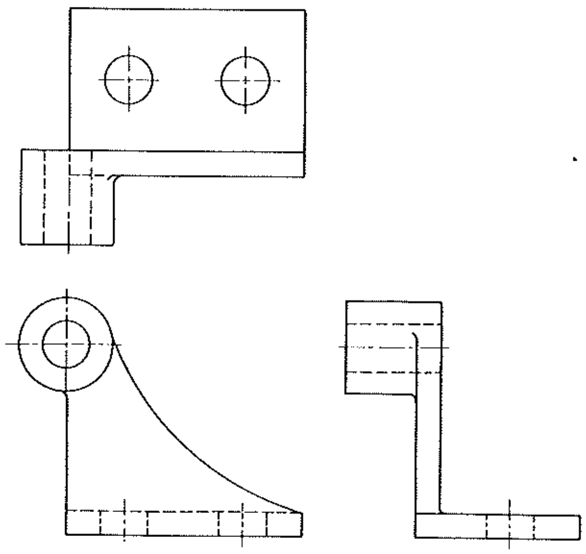


Fig. 16.38. Orthographic views of bracket.

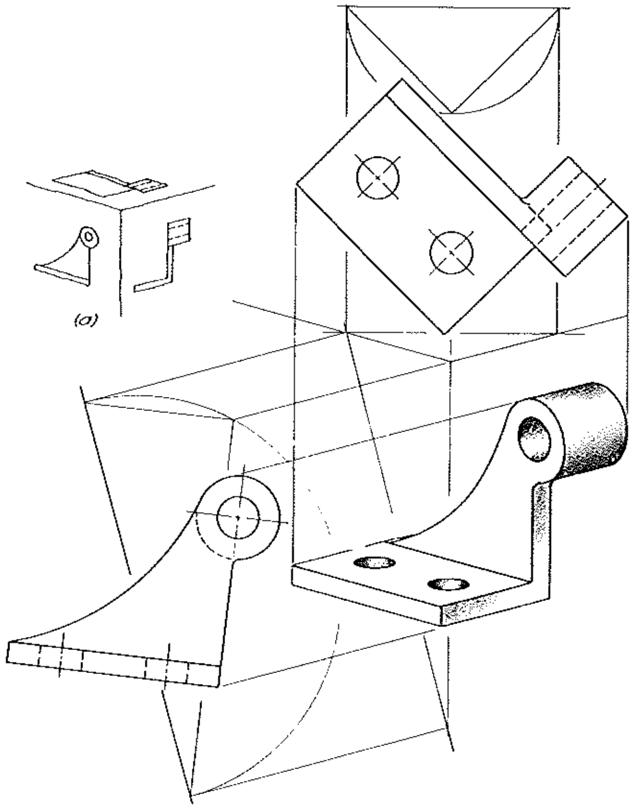


Fig. 16.39. Axonometric projection of bracket.

be perpendicular to the axis of the right cylinder of which the circle is the base.

Problems

The problems in the following group may be made as axonometric drawings by the conventional method or as true projections by the exact method.

The scales given under each figure are for the solution of isometrics on $8\frac{1}{2} \times 11$ inch paper by the conventional method. When dimetrics or trimetrics are made, the other scales should normally be smaller than the one given.

For exact projections the original orthographic views may be made at a slightly larger scale since the projected axonometric is foreshortened in all its dimensions. Thus, for example, a problem with scale specified as $\frac{3}{8}'' = 1''$ may have the orthographic views made at $\frac{1}{2}'' = 1''$ for the construction of true projections.

1. Make an isometric drawing by the conventional method of an object assigned from Figs. 16.40 to 16.51.
2. Make a true isometric projection of an object assigned from Figs. 16.40 to 16.51. Select axes as desired. Note that two correct orthographic views must first be made for this method.
3. Make a true dimetric projection of an object assigned from Figs. 16.40 to 16.51. Use axes as desired.
4. Make a true trimetric projection of an object assigned from Figs. 16.40 to 16.51. Use axes as desired.

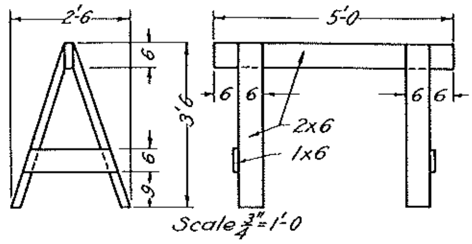


Fig. 16.42. Horse.

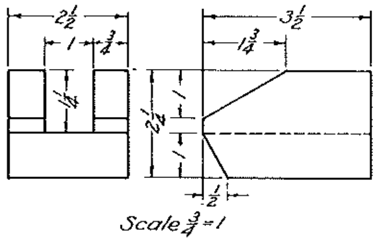


Fig. 16.43. Cut-block.

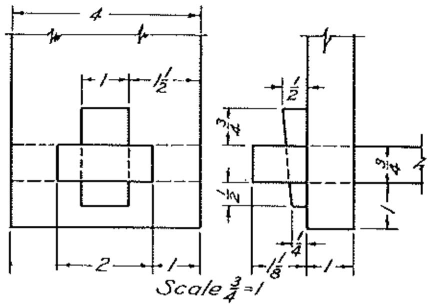


Fig. 16.40. Tenon joint.

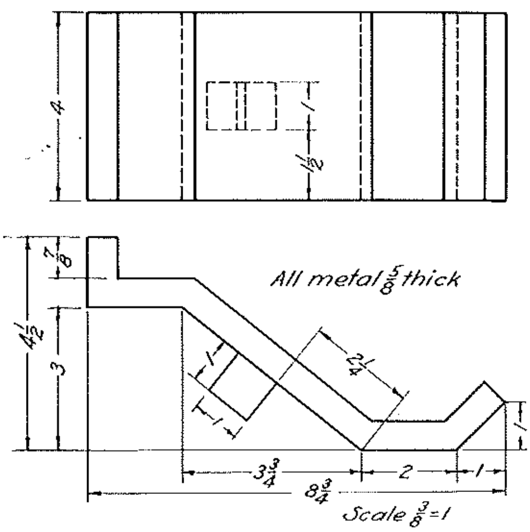


Fig. 16.44. Truss bearing strap.

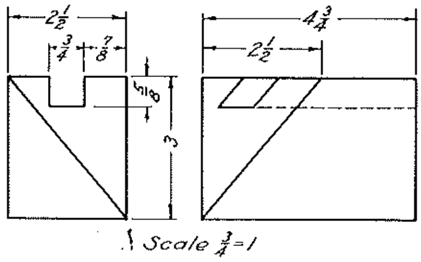


Fig. 16.41. Cut-block.

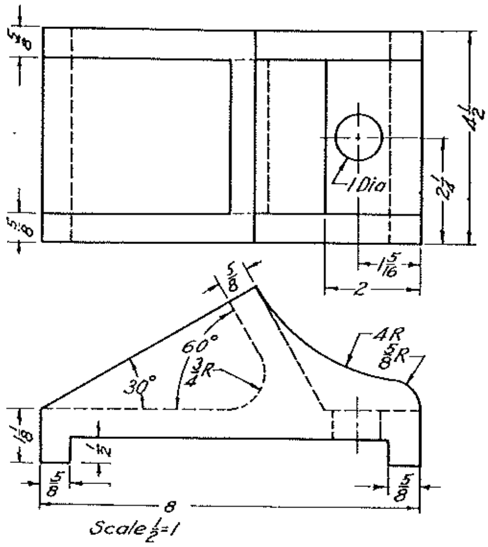


Fig. 16.45. Truss block.

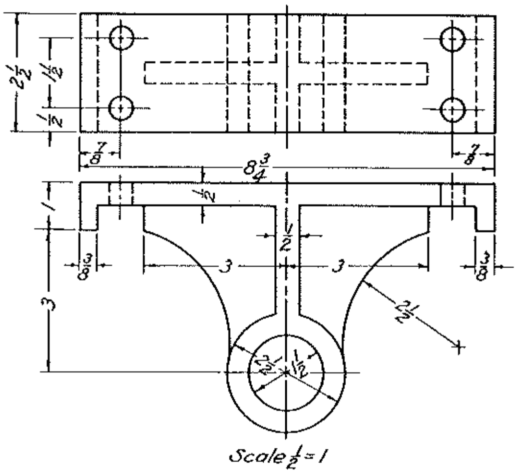


Fig. 16.46. Conveyor bearing support.

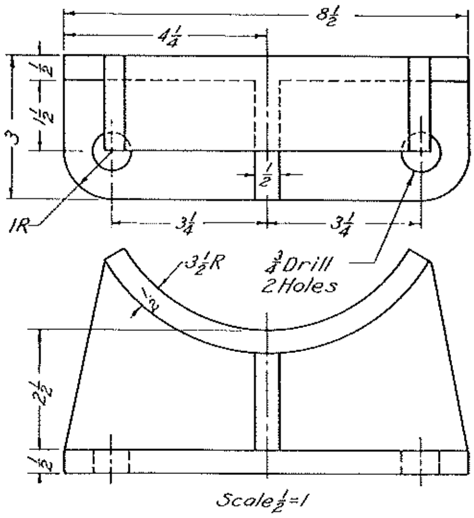


Fig. 16.47. Saddle.

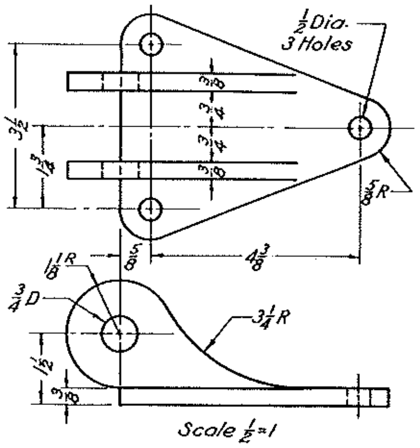


Fig. 16.48. Hinge.

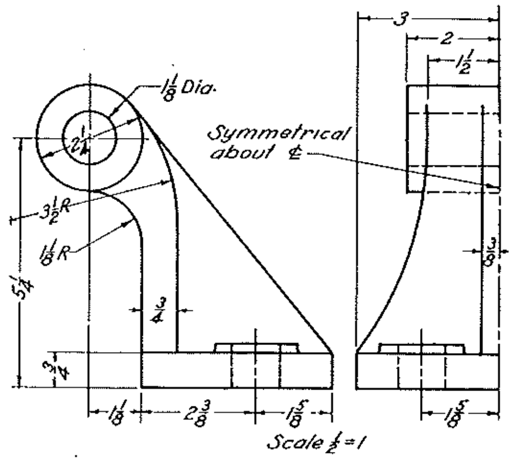


Fig. 16.49. Bearing bracket.

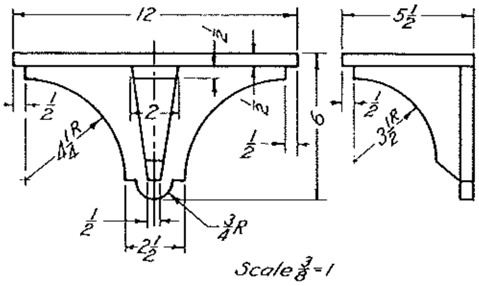


Fig. 16.50. Shelf.

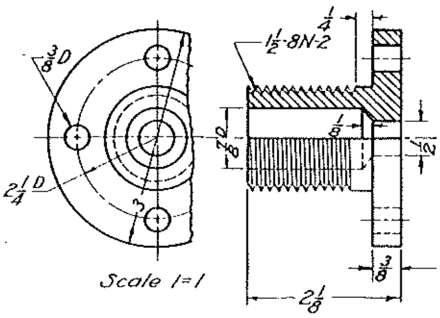


Fig. 16.51. Stuffing box body.

Oblique Projection

17

17.1 In both orthographic and axonometric drawing, already discussed in previous chapters, the projecting lines have been at right angles to the plane or planes of projection. We shall now consider a kind of drawing in which, as in axonometric, only one plane of projection is used, but in which the projecting lines, although parallel to each other, are oblique to the plane of projection. The object may be placed in any position, but, for convenience and to obtain the full advantage of this method of drawing, it is customary to have the front face of the object parallel to the vertical plane or picture plane as it is sometimes called.

17.2 Projecting lines. As noted above, the projecting lines may make any angle with the plane of projection except 90°. There are several types of oblique projection. They are distinguished from each other solely by the angle which the projecting line makes with the plane of projection as discussed in the following paragraphs. Because the projecting lines in any one drawing are always parallel to each other, the point of sight is said to be at infinity, since by definition parallel lines meet at infinity.

Because the projecting lines are parallel to each other, any line which is parallel to the picture plane will project in its true length. The projection will also be parallel to the original position of the line, as shown in Fig. 17.1.

This can readily be seen to be true if we remember that two parallel lines determine a plane. If we think of a plane through the lines *AB*, *BC*, etc., parallel to the plane of projection, then the plane of the projecting lines is a third plane intersecting these two, and from geometry we know that the intersections are parallel; hence *AB* is parallel to a_ob_o, and so on, for the other lines.

The line *AB* and its projection a_ob_o together with the projecting lines form a parallelogram, and again by geometry the opposite sides are equal. Hence *AB* is equal in length to a_ob_o.

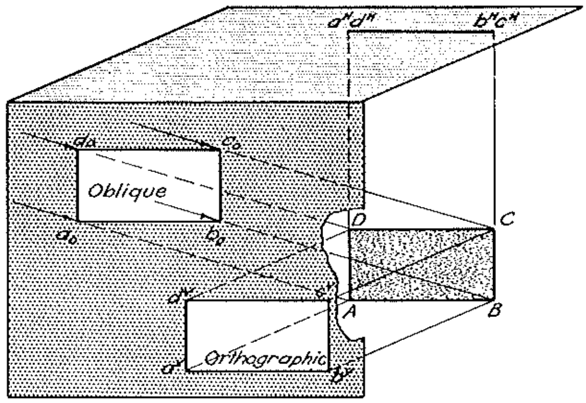


Fig. 17.1. Oblique projection of lines parallel to plane of projection.

Consequently, any face of an object which is parallel to the plane of projection will have exactly the same appearance in both oblique and orthographic projection. This feature is one of the chief advantages of oblique projections over other forms of pictorial drawing.

17.3 Cavalier projection. When the projecting lines make an angle of 45° with the plane of projection the drawing is called a Cavalier projection. This form of oblique drawing has one advantage not possessed by other types of oblique projection, namely, that lines which are perpendicular to the picture plane also project in their true length as well as those which are parallel to the plane.

In Fig. 17.2, the line *AB*, which is perpendicular to the plane, has its end *B* in the plane and the end *A* in front of the plane. The end *B* therefore coincides with its projection. When the end *A* is projected to the plane by a line making 45° with the plane in any direction, the projection of the line is exactly as long as the line itself. It should be definitely noted in this figure that, whereas the projecting lines Aa_1, Aa_2, Aa_3, etc., all make 45° with the plane of projection like the

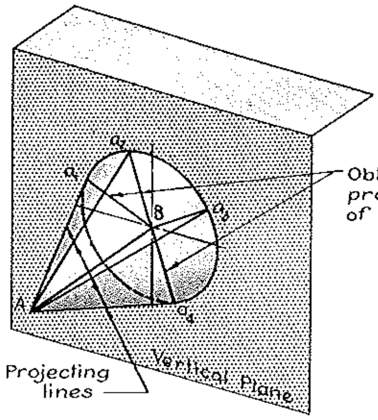


Fig. 17.2. Oblique projection of line perpendicular to plane of projection.

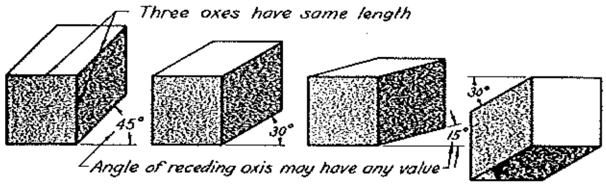


Fig. 17.3. A few positions of the receding axis.

elements of a cone, the projections Ba_1, Ba_2, Ba_3, etc., may make any angle with the horizontal.

Receding Axis. As in isometric the rectangular box furnishes an excellent reference frame for construction. The three edges of such a box, which meet at a corner, when represented in oblique drawing, are referred to as the axes of the drawing. Two of them are always in the front face at right angles to each other, and the third, which represents an edge perpendicular to the plane of projection, may be at any convenient angle. This inclined line is called the receding axis. In Cavalier projection all these three axes will project in their true length, and therefore the same scale may be used on all of them in making constructions. This is the distinguishing feature of Cavalier projection.

As noted above and as illustrated in Fig. 17.3, the receding axis may make any angle with the horizontal. This angle is not to be confused with the 45° angle which the projecting line makes with the plane of projection.

17.4 Theoretical construction. An oblique projection of an object may be constructed from its orthographic views by drawing the oblique projecting lines from these views and finding where they pierce the plane of projection, as shown in Fig. 17.4. Any two views could be used, but all three have been shown in the figure in order to illustrate the theory.

Since the vertical plane appears edgewise in both the side and top views, the piercing points of the projecting lines can be seen in these views by .nspection. Thus, in the pictorial top view of Fig. 17.4(a), the projecting line from a^H pierces the plane at $a_0{}^H$, and the front view of this piercing point must lie in the perpendicular from $a_0{}^H$. Likewise in the side view the projecting line from a^P pierces the picture plane at $a_0{}^P$, and the front view of this piercing point must lie horizontally across from $a_0{}^P$. The intersection of these two perpendiculars determines $a_0{}^V$, which is the

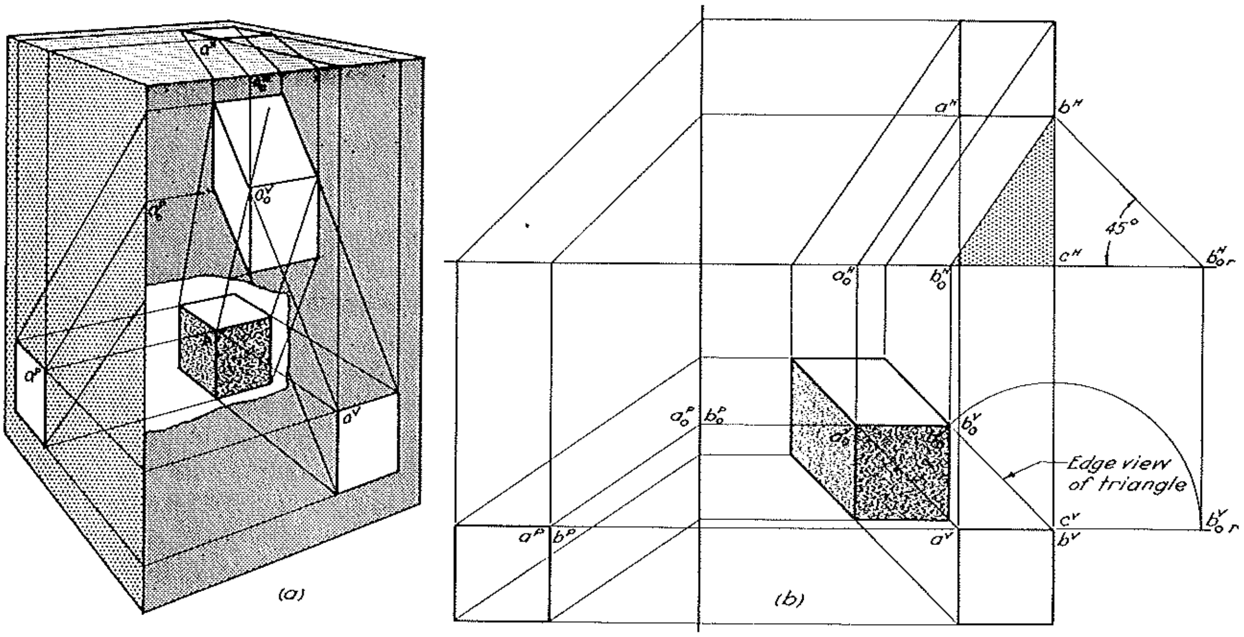


Fig. 17.4. Theory of oblique projection.

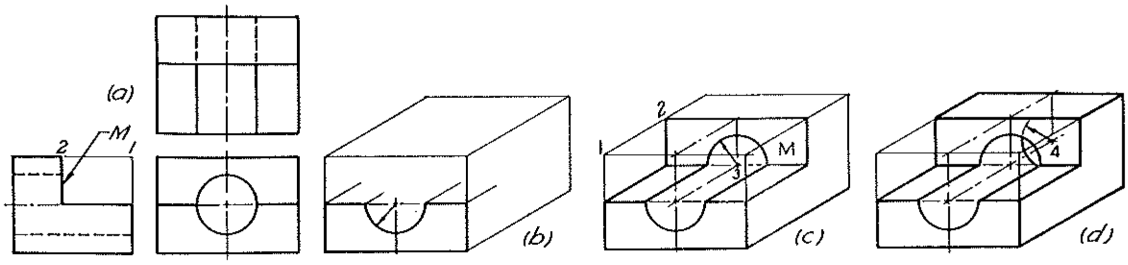


Fig. 17.5. Box method of constructing oblique projections.

oblique projection of point A on the object. The same procedure is used for all other points.

The orthographic construction of an oblique projection and the completed oblique projection are shown in heavy outline in Fig. 17.4(b). Although this theoretical method can be used for so simple an object as a cube, it would be too cumbersome for more complicated objects. A conventional method of construction similar to that used in isometric is explained in the following paragraphs.

It may be noted, in passing, that the true value of the angle which the projecting lines make with the V-plane does not show in any one of the three views of Fig. 17.4(b). It may be found, however, by dropping a perpendicular to the V-plane from B in Fig. 17.4(b) and revolving the shaded triangle to BCB_o around the line BC until it is parallel to the H-plane. The true value of the angle then shows in the H-projection at $b_{or}{}^H$.

17.5 Conventional construction of Cavalier projections. Since the same scale may be used on the three axes of a Cavalier projection, a method of construction similar to that used in isometric may be employed.

a. Plane Figures. One of the advantages of oblique projection is that plane figures in the front face of an object, or parallel thereto, project in their true shape just as shown in the orthographic views and hence require little further explanation.

The only difficulty experienced lies in getting the contours which lie behind the front face into their proper planes. Thus, in the block shown in Fig. 17.5(a), the circle, lying in the face M, while showing as a circle, must be located at the proper place. This is accomplished by measuring back a distance *1–2* and drawing a plane across the box, as indicated in Fig. 17.5(c). The center line of the front circle can now be carried back to this plane, thus locating the center of the required circle at *3*.

The center of the circle in the back face is formed by carrying the center line from *3* up over the top of the box and down the back until it intersects the receding center line through *3*, thus establishing the center *4*.

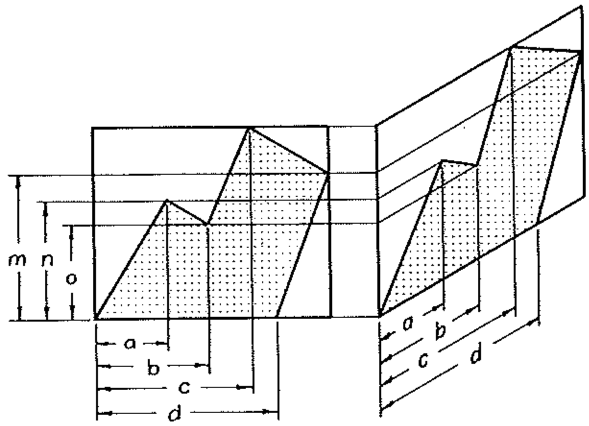


Fig. 17.6. Coordinate methods of construction.

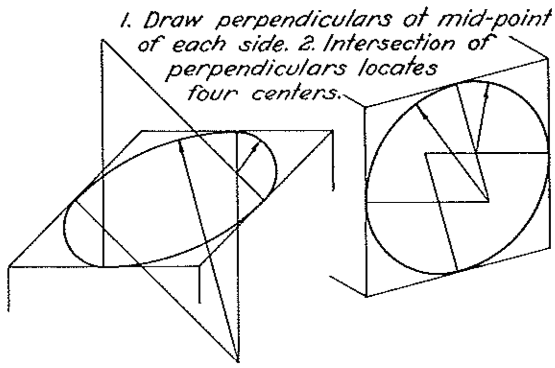


Fig. 17.7. Four-center approximate method of representing circles.

In the top and side receding planes, the coordinate method of construction may be used, as shown in Fig. 17.6. Circles may be plotted by the coordinate method in the same manner as for isometric, or they may be approximated by the four-center method of construction.

b. Four-Center Approximate Method of Representing Circles. A circle may be enclosed in a square, and, since it is always tangent to the square at the mid-point of the sides, the Cavalier projection will show an ellipse which is tangent to the mid-point of the sides of the enclosing rhombus. Hence, to find the centers of the four arcs, erect perpendiculars to

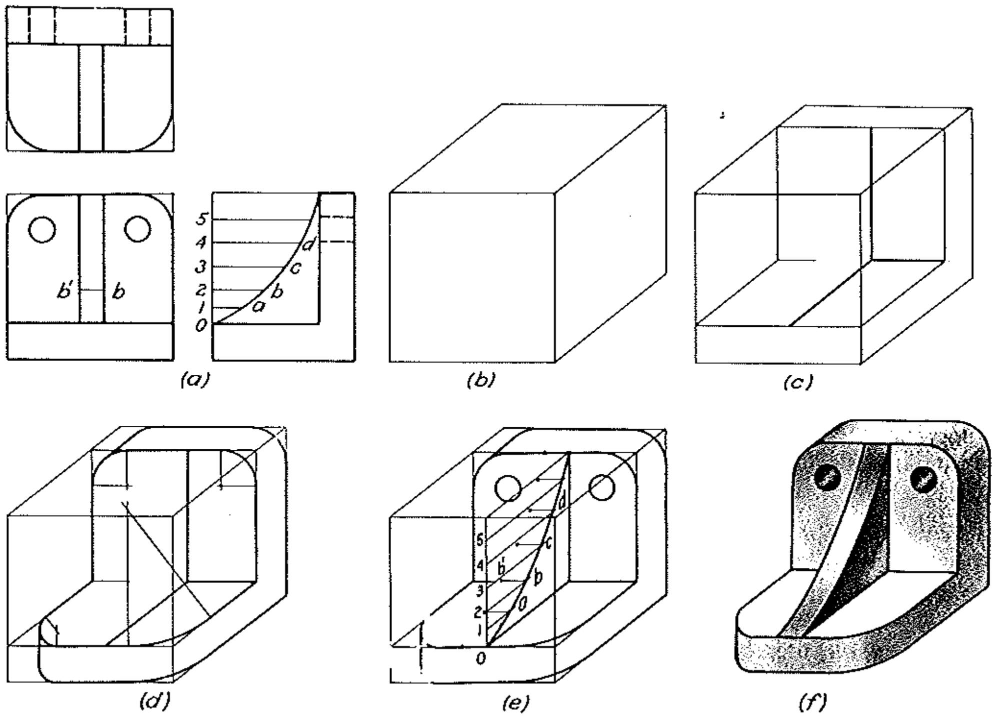


Fig. 17.8. Construction of curves in a receding plane.

the mid-points of the four sides of the rhombus, and find their intersections, as shown in Fig. 17.7. It should be noted that as the ratio of the major to the minor axis increases the approximation becomes less accurate.

c. Solid Objects. The steps in making a Cavalier projection of a solid or three-dimensioned object are illustrated in Fig. 17.8. They may be listed as follows:

1. Enclose the orthographic views of the object in the smallest possible rectangular box whose faces are parallel to the principal faces of the object. See Fig. 17.8(*a*).

2. Draw this enclosing box in Cavalier projection, making the front of the box like the orthographic front view and the receding axis to the same scale as the front and at an angle that will show the side and top to the best advantage. See Fig. 17.8(*b*).

3. Draw lightly all lines in the front face, and establish position of planes parallel to the front face. See Fig. 17.8(*c*).

4. Draw all lines in faces parallel to the front at the proper distances from the front face, as shown in Fig. 17.8(*d*).

5. Construct coordinates for curves not in the front face in the orthographic view as shown at *1–a*, *2–b*, *3–c*, etc., in Fig. 17.8(*a*), and then transfer these coordinates to the oblique as shown for one curve in Fig. 17.8(*e*). Since the second curve is parallel to the first, points on it may be located by stepping off the thickness of the web (see front view) as *bb′*, in Fig. 17.8(*e*).

6. Complete all lines, and erase construction. After erasure make heavy the visible outlines of the drawing, producing the finished drawing of Fig. 17.8(*f*).

17.6 Position of object. *a. For Simplicity of Construction.* Since any face of an object which is parallel to the picture plane appears in its true shape in an oblique projection, the construction of many draw-

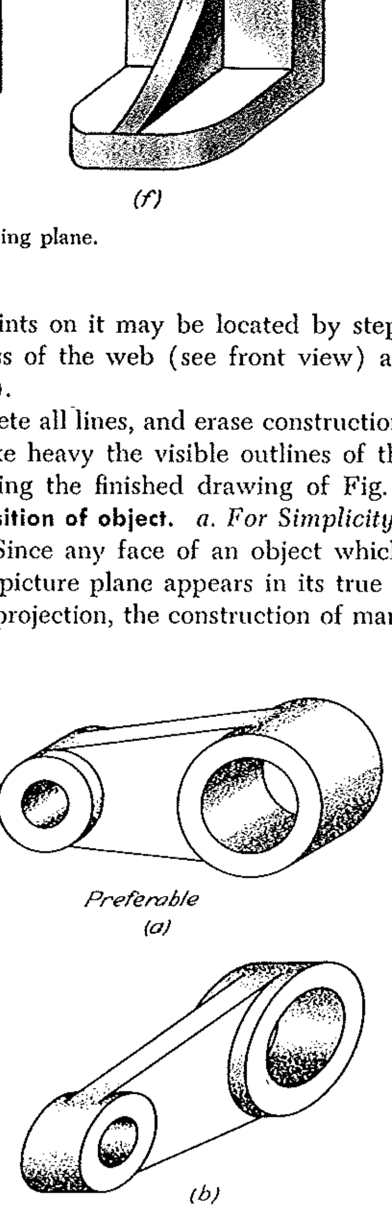


Fig. 17.9. Circles preferably parallel to front face.

ings can be kept quite simple by showing the face of the object which has the most circles, arcs, or other curves as the front face. This rule should be adhered to whenever possible for it can be readily seen that the object in the position of Fig. 17.9(*a*) is not only easier to draw but also looks much better than the same object as represented in Fig. 17.9(*b*).

b. To Reduce Distortion. Unpleasant distortion in Cavalier projection frequently can be reduced by placing an object which has one dimension much greater than the others with this long dimension parallel to the picture plane, as shown in Fig. 17.10. Some discrimination must be exercised, however, for this may not work so well with some objects as with others. A better method to reduce distortion is to reduce the scale on the receding axis.

17.7. Cabinet drawing. A second type of oblique projection which has been specifically named is produced when the angle which the projecting line makes with the plane of projection is 63°-26′. The tangent of this angle is 2, which means that a line perpendicular to the vertical plane is just twice as long as its projection, or stated in another way the projection is one-half as long as the line. This result will be produced automatically if the scale used on the receding axis is just one-half that used on the front face. A drawing made in this way is called a Cabinet drawing. Again it should be mentioned that the angle which the receding axis makes with the horizontal may have any value just as in Cavalier projection.

a. Construction of a Cabinet Drawing. A Cabinet drawing may be made in the same manner as a Cavalier projection with the exception that the scale on

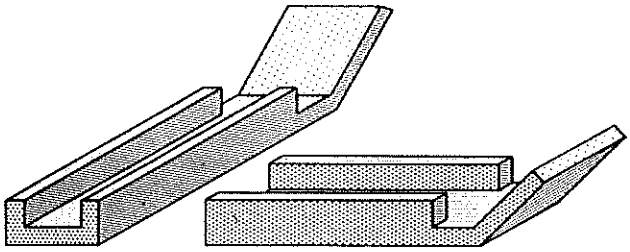


Fig. 17.10. Long dimensions parallel to plane of projection.

the receding axis must be reduced one-half. The steps in this procedure are shown in Fig. 17.11, which, though not a Cabinet drawing, illustrates the method of construction. Where curves are involved in the receding faces a convenient scheme for obtaining the foreshortened or one-half-scale dimensions from the orthographic views is shown in Fig. 17.11.

Thus, for a Cabinet drawing, if the total length *ab* on the receding axis is 3 inches, the line *ac* will be 1½ inches long. This line may be laid out in any convenient direction from either end of line *ab*, as illustrated. The point *c* is then connected with *b*, and all other points to be plotted are transferred to line *ac* by lines parallel to *bc*. This device for making proportional divisions of any line should be thoroughly understood by the student.

The four-center approximate method of drawing circles cannot be used in Cabinet drawing since the sides of the enclosing parallelogram are not equal. A circle can be plotted, however, without referring to the original orthographic projections except to get the dimensions and position of the enclosing parallelogram. The method of plotting coordinates by means

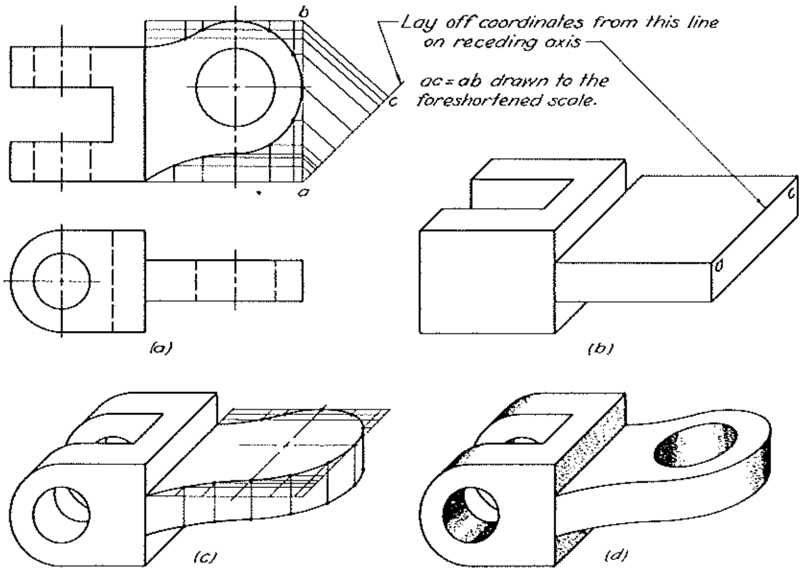


Fig. 17.11. Method of foreshortening the scale on the receding axis.

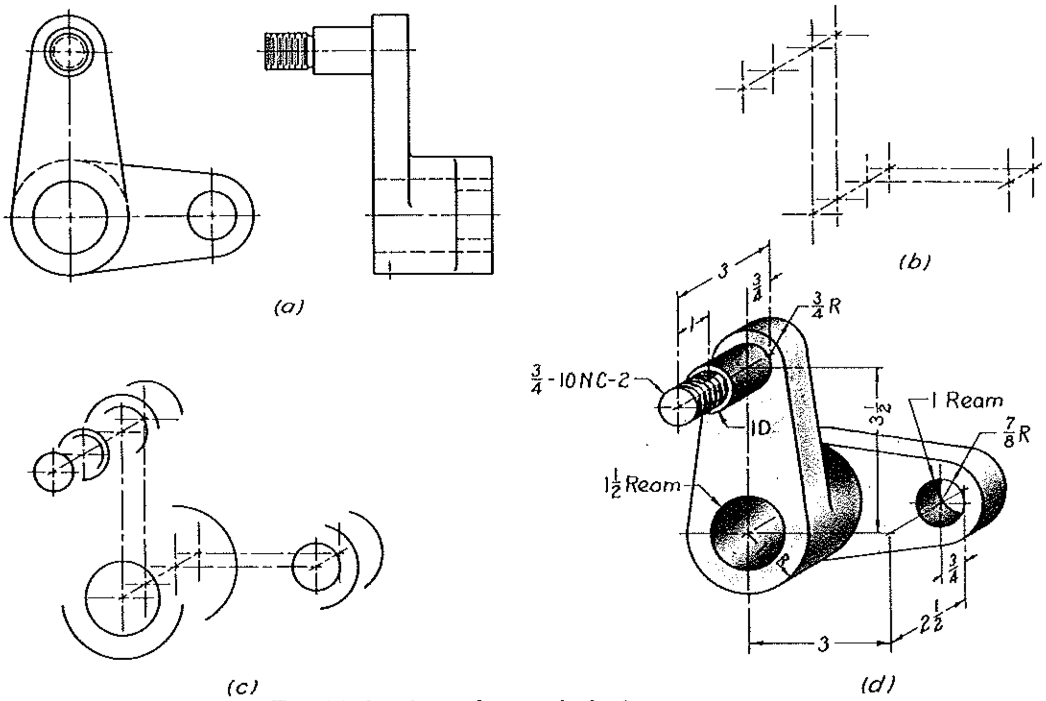


Fig. 17.12. Center-line method of construction.

of a semicircle and a diagonal of the parallelogram is shown in Fig. 16.7.

17.8 General oblique. Obviously, other scales than those mentioned could be used on the receding axis. For example, if the scale on the front face is 1″ = 1″, a scale of ¾″ = 1″ could be used on the receding axis. A drawing made in this manner is neither a Cavalier projection nor a Cabinet drawing and is simply referred to as an oblique projection. The angle which the projecting lines make with the plane of projection can be determined by comparing the length of a perpendicular with the length of its projection. Thus, in Fig. 17.11, a perpendicular 1 inch long would project ¾ inch long. Hence the tangent of the angle which the projecting line makes with the plane of projection would be $1 \div \frac{3}{4}$ or 1.333. This angle is 53°-8′. Its value, of course, is of theoretical interest only since it does not enter into the actual construction of the drawing.

The construction of any oblique drawing follows the same pattern as the construction of a Cavalier projection, with the exception that the scale on the receding axis is changed to suit the conditions.

17.9 Center-line layout. When an object is composed of more or less cylindrical parts like the rocker arm in Fig. 17.12(*a*), the construction can be based upon a center-line framework instead of the box construction previously explained. With the direction of the three axes chosen, the centers of all circular parts can be laid out as illustrated in Fig. 17.12(*b*), using the proper scale on all axes. At each center, circles of the proper size can be drawn, as shown in Fig. 17.12(*c*). The straight lines tangent to them can be drawn quickly, giving the final result shown in Fig. 17.12(*d*).

17.10 Sectioning oblique drawings. As in all pictorial drawing, hidden lines are not shown since it is very difficult to interpret them. Interior construction is best shown by making sectional views with either one-fourth or one-half the object removed. The cutting planes, in general, should be parallel to the oblique

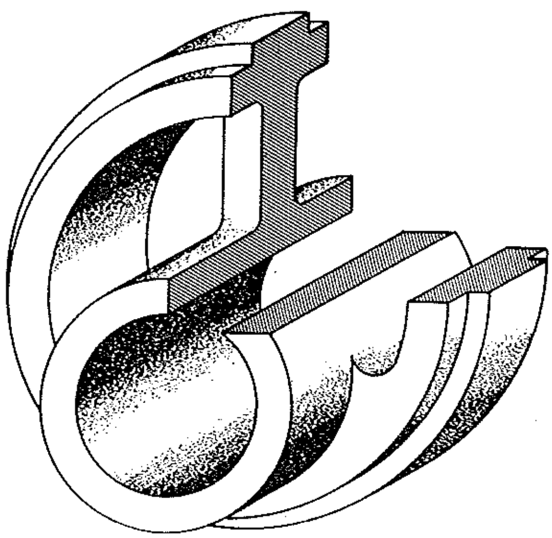


Fig. 17.13. Sectional view in oblique projection.

planes or faces of the enclosing box, as shown in Fig. 17.13. Other illustrations may be found in the problem sections of various chapters.

The cross-hatching lines lying in two planes which are at right angles to each other should be sloped in such a way that they would seem to coincide if the planes were rotated together. Correct section lining is shown in Fig. 17.13.

17.11 Dimensioning oblique drawings. The principles of dimensioning studied in connection with working drawings apply in general to oblique projections, with the following additions:

a. Dimensions should be made to read from the bottom and right-hand side of the sheet so far as possible. See Figs. 17.12 and 17.14(*b*).

b. Dimension lines and witness or extension lines must lie in the same oblique plane. See Figs. 17.14 and 17.15.

c. Dimensions must lie in the oblique plane determined by the dimension lines and extension lines.

d. Only vertical lettering and numerals should be used. Numerals and letters may be made to lie in oblique planes in the same manner as shown for isometric. The unidirectional system is also approved.

e. As far as possible, dimensions should be placed in the front face or parallel thereto since this makes the dimensioning similar to that in the orthographic views.

f. When notes are extensive and are not on the figure, they may be lettered neatly in slant style. In general, however, vertical lettering is preferred.

17.12 Screw threads in oblique projection. Since circles which are parallel to the plane of projection show as true circles in oblique projection, screw threads may be easily represented by a conventionalized scheme, if the axis of the thread is made parallel to the receding axis of the drawing. The axis of the bolt or nut, as in Fig. 17.16, becomes the line of centers for a series of circles representing the crests of the threads. The root line does not show. The spacing of the circles is made the same as the pitch of the thread until the pitch becomes too fine, in which case the smallest convenient spacing is used.

Whenever possible, bolts, screws, or nuts should be drawn in the position shown in Fig. 17.16. When placed with the axis parallel to the picture plane, the circles representing the thread crests must be plotted as ellipses and drawn with an irregular curve or ellipse guide, which is a slow process.

17.13 Three-dimensional curves. Three-dimensional curves, such as the conveyor shown in Fig. 17.17, can be drawn with comparative ease if the axis of the conveyor is placed on the receding axis of the drawing. The method is illustrated in the figure.

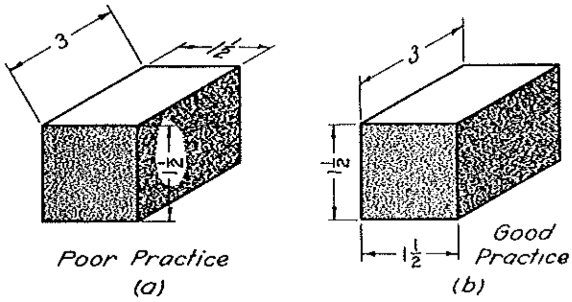


Fig. 17.14. Dimensioning in oblique projection.

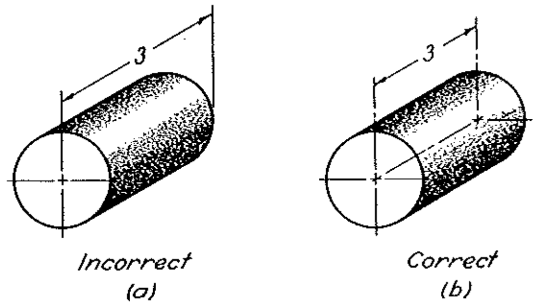


Fig. 17.15. Dimensions in oblique plane.

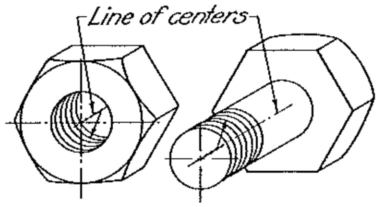


Fig. 17.16. Screw threads in oblique projection.

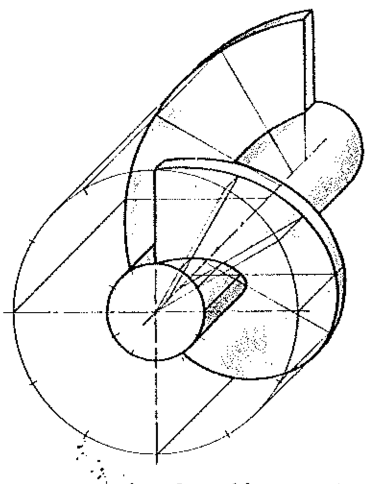


Fig. 17.17. Helicoid in oblique projection.

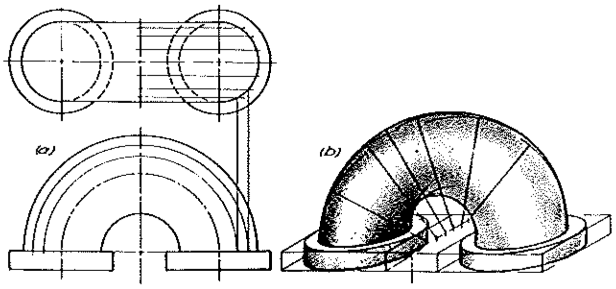


Fig. 17.18. A double-curved surface in oblique projection.

The circles are first divided into 12 equal parts, and the pitch is likewise divided into the same number of parts. On the center line, step off intervals equal to one-twelfth the pitch. From these points radial lines can be drawn parallel to those used in dividing the circles. The construction is shown for the first four points on the curve. After the first turn has been completed, successive turns can be made by stepping off distances equal to the pitch from the previous curve. The thickness of the blade can also be stepped off at equal intervals from the first curve. In cases of this kind the orthographic views are not required to make the construction.

If, on the other hand, the three-dimensional curve is irregular in shape, it may be necessary to resort to the box construction and plot three rectangular coordinates.

17.14 Double-curved surfaces. The outline of a double-curved surface is represented by an enveloping curve tangent to imaginary curves in the surface. Thus a return pipe bend can have a series of semicircles drawn on its surface, as shown in Fig. 17.18(*a*). These curves are then drawn in oblique and the enveloping curve drawn tangent to them.

17.15 Advantages of oblique drawing. From the foregoing paragraphs it is quite clear that oblique drawings have several distinct advantages over other pictorial forms.

a. The front face of an object or any face parallel to it may be drawn like its true orthographic projection, and hence circles may be drawn as true circles.

b. Distortion may be largely overcome by a careful foreshortening of the scale on the receding axis.

c. Dimensioning is simpler since only one set of dimensions need be made in an oblique plane.

d. There is a greater range of choice of positions of the axes than in the other forms except trimetric. See Fig. 17.3.

To offset these advantages it should be noted that oblique projections even though foreshortened on the receding axis have an unpleasing distortion. This is particularly true when circles must be shown in the receding faces.

Problems

Problems in the following group may be assigned as Cavalier projections (note: this does not mean that the receding axis must slope at an angle of 45°), Cabinet drawing, or general oblique projection. The student should note that the only practical difference in drawing the different types of projection lies in the scale used on the receding axis.

For general obliques, it is recommended that the scale on the receding axis be in the ratio ¾ to 1 of that used for the front face. The most convenient slope for the receding axis is 30° up to the right, but any other direction may be used.

The selection of all scales and the slope of the receding axis has been left to the student unless specifically directed by the instructor.

1. Make a Cavalier projection of an object assigned from Figs. 17.19 to 17.29.

2. Make a Cabinet drawing of an object assigned from Figs. 17.19 to 17.29.

3. Make a general oblique projection of an object assigned from Figs. 17.19 to 17.29.

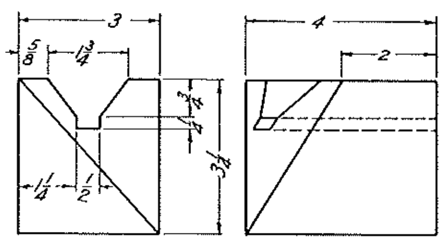


Fig. 17.19. Cut block.

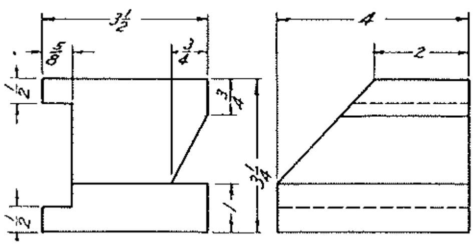


Fig. 17.20. Cut block.

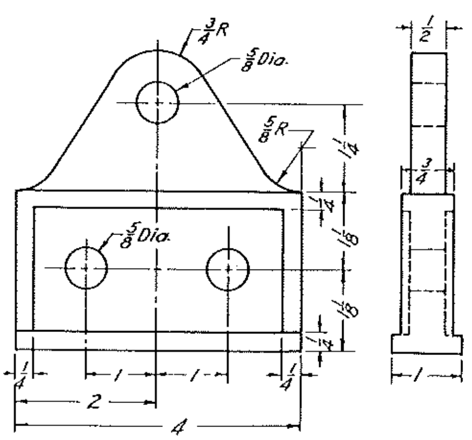


Fig. 17.21. Conveyor attachment.

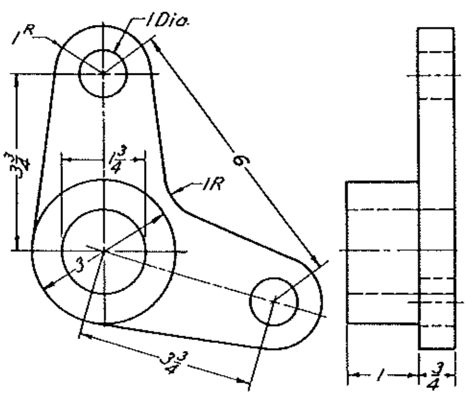


Fig. 17.22. Rocker arm.

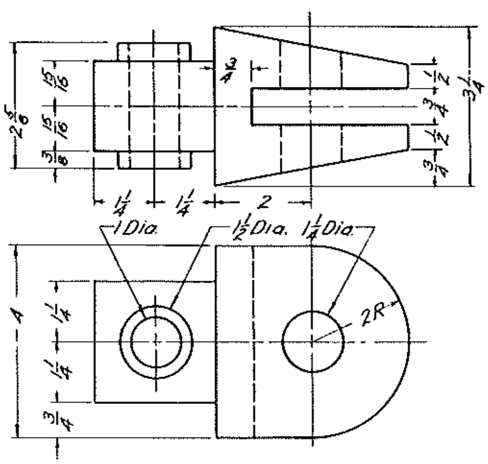


Fig. 17.23. Link.

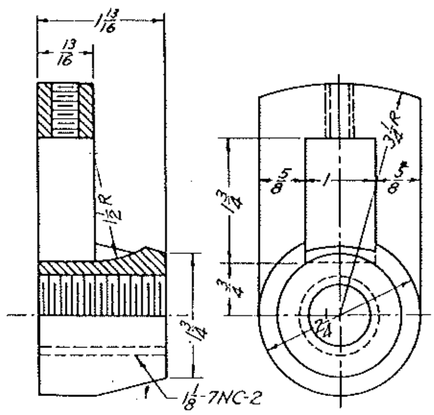


Fig. 17.24. Flue hole cutter holder.

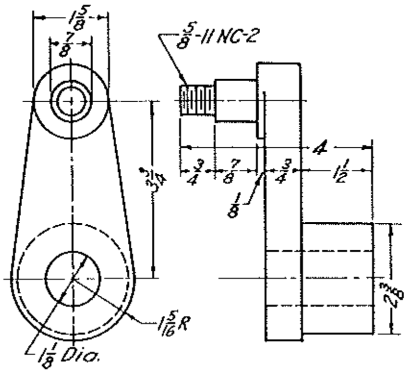


Fig. 17.25. Bell crank.

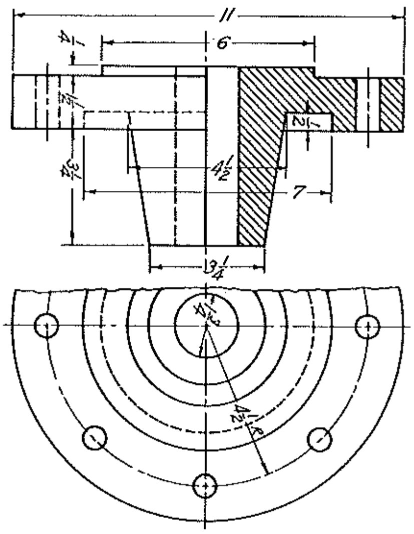


Fig. 17.26. Cylinder end.

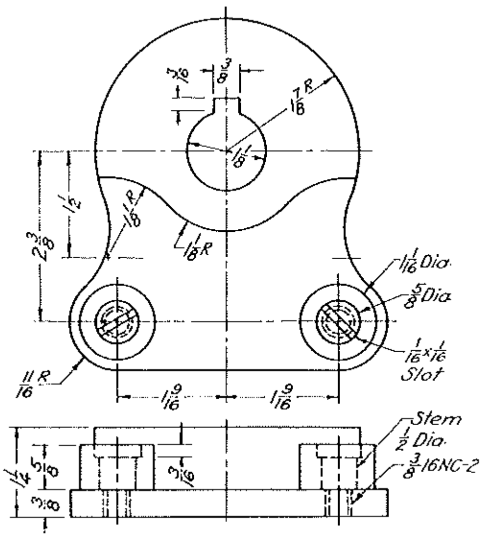


Fig. 17.27. Cam follower.

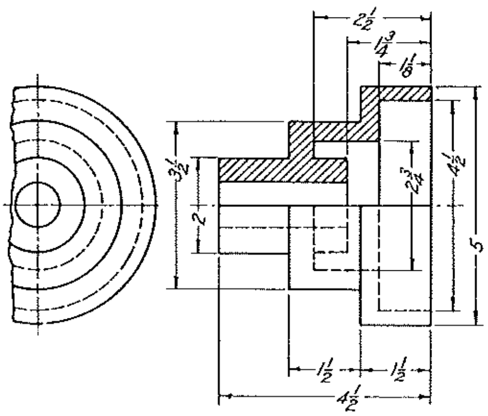


Fig. 17.28. Step pulley.

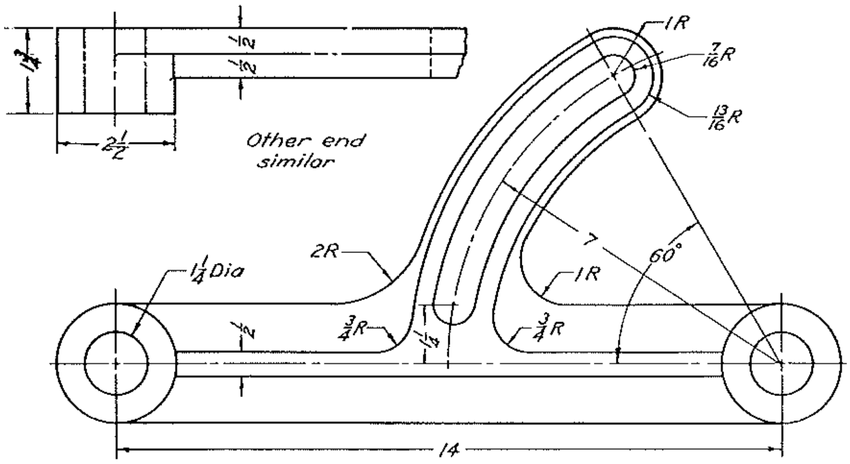


Fig. 17.29. Belt tightener.

Perspective 18

18.1 When a person looks at an object, the light rays (visual rays) from the object are focused by the eye so that the picture is formed on the spherical rear surface of the eye known as the retina. Perspective is the form of pictorial drawing which most nearly approaches the picture as seen by the eye. Thus, if we imagine a vertical plane between the eye and the cube, in Fig. 18.1, the visual rays from the cube to the eye, if intercepted by the vertical or picture plane, will form an image which exactly coincides with the edges of the cube. This produces the same image as the cube itself if viewed from this one particular position.

It will be observed that the major difference between perspective projection and the forms studied heretofore lies in the fact that the point of sight is at a finite distance from the object. The visual rays or projecting lines from the object therefore converge to the point of sight instead of being parallel to each other as in other forms of projection. This type of drawing is sometimes called scenographic projection or central projection since the lines of sight converge to a single point or center.

The picture or perspective obtained will depend upon the relative position of the object, picture plane, and point of sight.

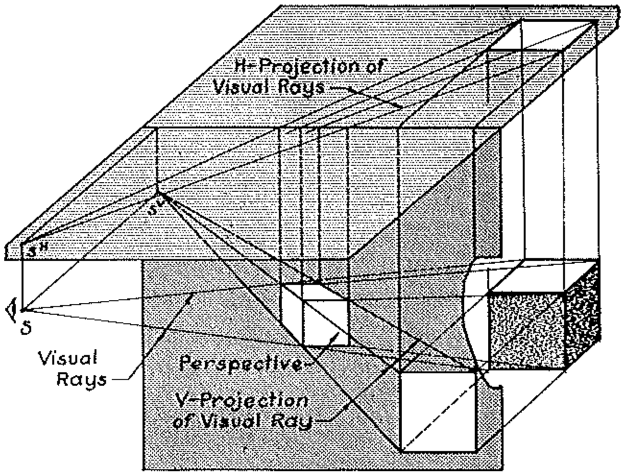


Fig. 18.1. Theory of perspective.

18.2 Location of the picture plane. Normally the picture plane is placed between the object and the point of sight, as in Figs. 18.2(*b*) and (*c*). In these positions all the lines of the drawing are shorter than their true length on the object.

By comparing Figs. 18.2(*b*) and (*c*) it can be seen that the picture becomes smaller as the picture plane

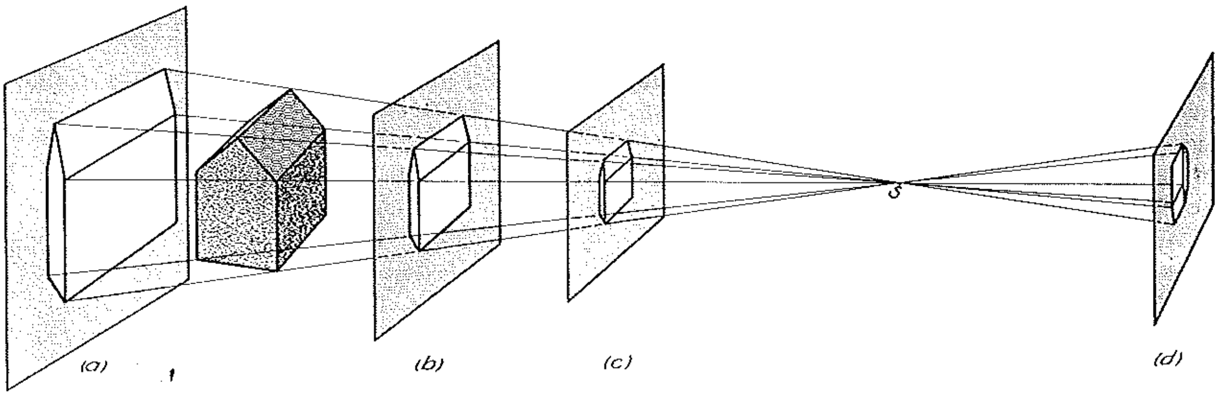


Fig. 18.2. Relationship of object, picture plane, and point of sight.

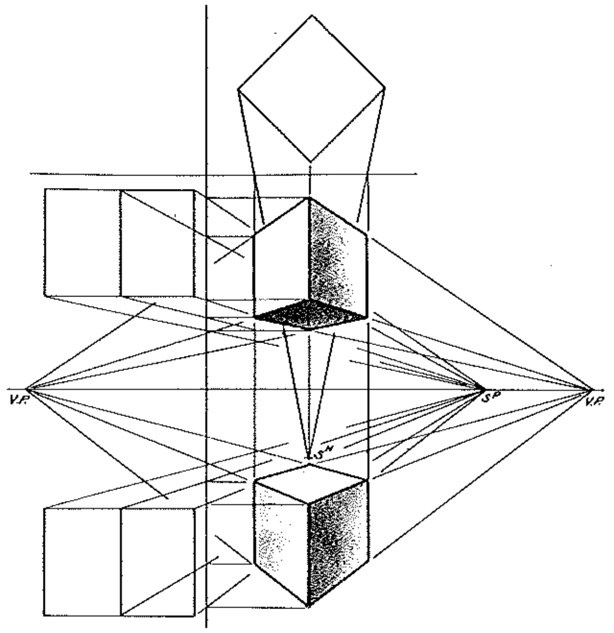


Fig. 18.3. Object above and below point of sight.

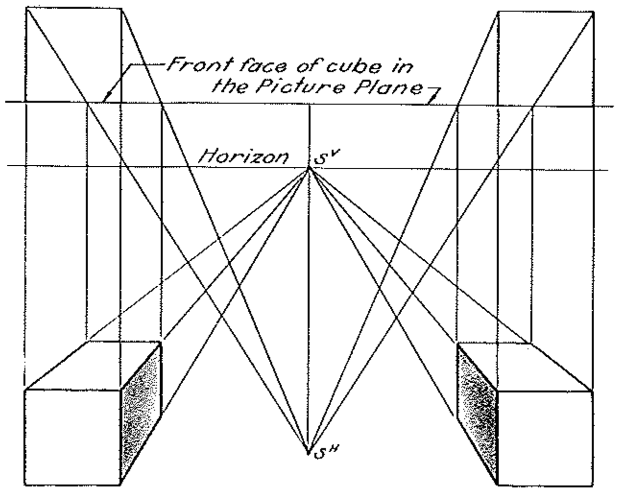


Fig. 18.4. Object right and left of point of sight.

is moved away from the object and closer to the point of sight.

If the object is between the observer and the picture plane, as in Fig. 18.2(*a*), the image will be larger than the object. Finally, if the point of sight is between the object and the plane, as in Fig. 18.2(*d*), the image is inverted and reversed. This is what takes place in a camera where the lens is the point of sight.

18.3 Location of the point of sight. With the picture plane and object in a definite relationship to each other the perspective can be greatly altered by a change in position of the point of sight. For example, the point of sight could be chosen above the object to show the top, or below the object to show the bottom, as in Fig. 18.3. Likewise it could be chosen to the right or left of the object to reveal either side, as in Fig. 18.4. A proper choice of the point of sight is therefore very important in making an attractive perspective.

It has been observed from experience that when the eye is focused on a certain point the eye will see clearly all the picture contained within a right circular cone having its apex at the eye and an interior angle at the apex of approximately 30°. This condition is satisfied when the point of sight is placed at a distance from the object at least twice the longest dimension of the object, as shown in Fig. 18.5.

18.4 Position of object. The angular position of the object relative to the plane of projection will also make a great difference in the appearance of the finished perspective, as can be noted from an examination of Figs. 18.3 and 18.4. The position of the object gives rise to three types of perspective, as follows:

a. Parallel Perspective. When the principal face of the object is parallel to the picture plane, as in Fig. 18.4, we have what is termed a parallel or one-point perspective. The term one-point refers to the fact that such perspectives have only one principal vanishing point.

b. Angular Perspective. When two faces of the object are inclined to the picture plane, as in Fig. 18.3, we have an angular or two-point perspective. There are two principal vanishing points.

c. Oblique Perspective. When all faces of the object are oblique to the picture plane, we have an

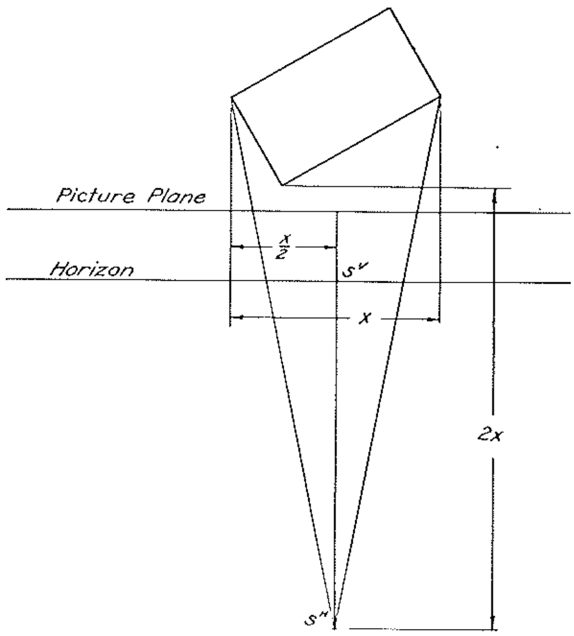


Fig. 18.5. Location of point of sight.

oblique or three-point perspective. There are three principal vanishing points, as shown in Fig. 18.6.

18.5 Visual-ray method. Perspective may be constructed in a number of ways. The simplest method, though not the most practical for complicated objects, is the visual-ray method which is based on the definition of Art. 18.1. By this method it is only necessary to draw the visual rays from the object to the point of sight and find where they pierce the picture plane. This method has been used in Fig. 18.7(*a*) where visual rays from *A* to the point of sight, S, have been drawn in the top and front views. The vertical projection A_p, of the point where this line pierces the vertical plane is the perspective of *A*. In Fig. 18.7(*b*), the piercing point is found by using the top and side views of the point *A*, and the point of sight. A vertical line through v^H intersects a horizontal line through v^P to locate v^V, which is the perspective, A_p, of point *A*.

The perspectives of the other corners of the cube have been located in the same manner. Since the perspective tends to overlap the front view in Fig. 18.7(*a*), the method used in Fig. 18.7(*b*) is preferable.

18.6 Vanishing points. It will be observed in a number of the preceding figures that lines which are not parallel to the picture plane converge to a point. By definition parallel lines meet at infinity. The perspective of this meeting place is called the vanishing point of the lines.

To find the vanishing point of any group of parallel lines it is necessary to draw a line through the point of sight parallel to the group of lines and then find where this line pierces the picture plane. In a step-by-step procedure the method is as follows:

a. Through the point of sight, draw a line parallel to the group of lines. It should be recalled that to draw one line parallel to another the corresponding projections are made parallel and that at least two projections are required.

b. Find the *V*-piercing point of this line.

This method of finding the vanishing points is shown pictorially in Fig. 18.8, where an object, the picture

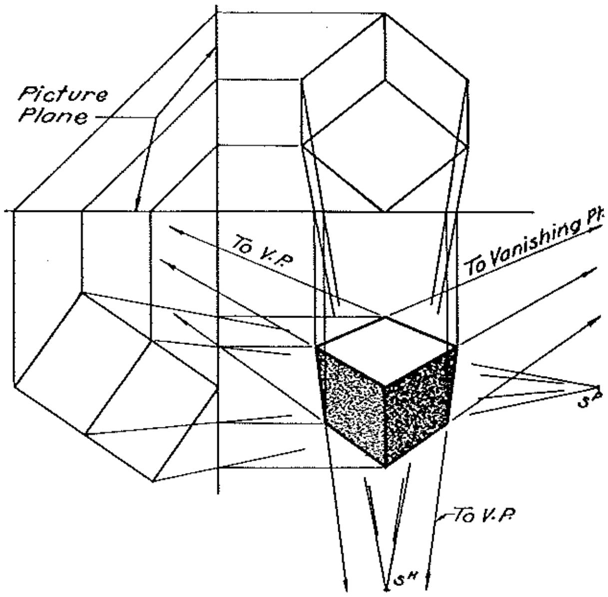


Fig. 18.6. Three-point perspective.

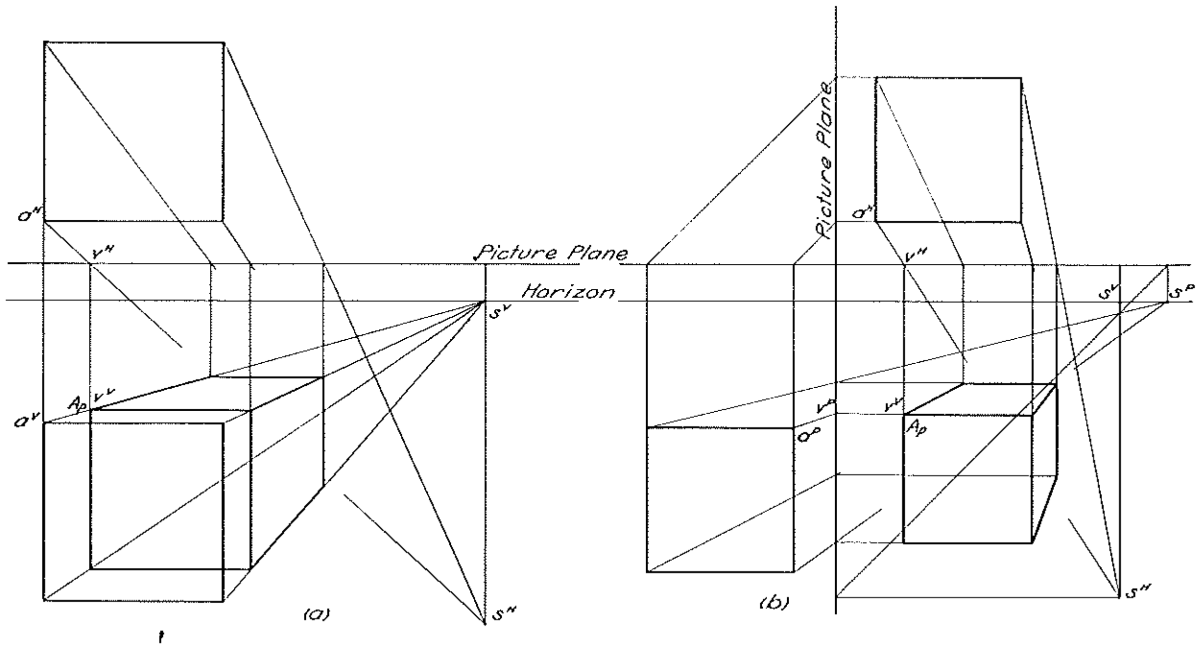


Fig. 18.7. Perspective of cube. Visual-ray method.

plane, the point of sight, the vanishing points, and the final perspective are represented. Lines have been drawn from S, parallel to several sets of parallel lines on the object to locate the vanishing points of these lines. The perspectives of these lines are then shown to vanish at the points thus found. From this figure it can be seen that horizontal lines vanish at a point on the horizon, lines sloping up to the rear vanish above the horizon, and lines sloping down to the rear vanish below the horizon.

In Fig. 18.9, the construction is shown for finding vanishing points as the draftsman does it. In Fig. 18.9(*a*), the line is parallel to the horizontal, and consequently the vanishing point falls on the horizon because the vertical projection is parallel to the reference line. In Fig. 18.9(*b*), the line slopes up to the rear, and so the V.P. is above the reference line.

18.7 Perspective of a line. To find the perspective of a line, it is necessary to find the perspective of two points on the line. Those two points may be corners of an object or any other points, real or imaginary, on the line. When two complete projections of the object, in its desired position, are given, as in Fig. 18.4, the perspective of two points can be found by the visual-ray method. However, when the front face is not parallel to the picture plane, it requires considerable time to rotate the object and obtain the desired views. To avoid this difficulty, two other points

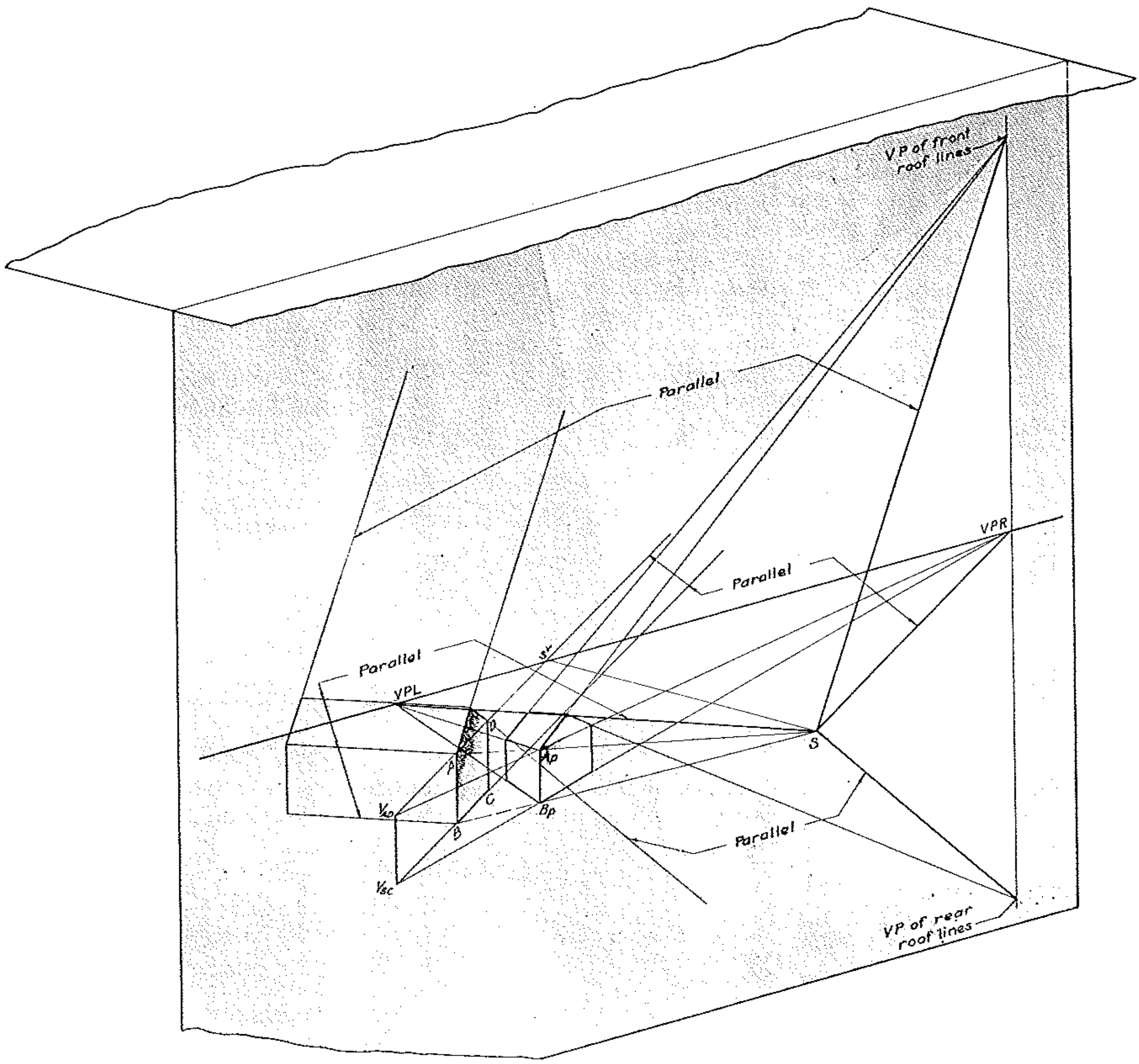


Fig. 18.8. Theory of vanishing points.

on the lines are commonly used. They are the vanishing point of the line and the point where the line pierces the picture plane. Since the vanishing point is the perspective of a point at the infinite end of the line, it may always be used as one point on the perspective of the line. The point where the line pierces the picture plane must lie in the picture plane, and consequently the vertical projection of this point must be its own perspective. For purposes of explanation, the horizontal and vertical projections of an inclined line *AB* are given in Fig. 18.10. The vanishing point, *VP*, is found as explained in Art. 18.6. The vertical piercing point, v^V, of the line *AB* is found as shown in Fig. 18.10(*a*). The perspective of the complete line extending from the picture plane to infinity will be the line joining v^V and *VP*.

To find the desired points *A* and *B* on this line, the horizontal projections of visual rays from S to *A* and from S to *B* may be constructed as shown in Fig. 18.10(*b*). From the points where these visual rays pierce the picture plane, projecting lines may be drawn vertically to locate A_p and B_p on the perspective v^V–*VP*.

The greatest advantage of this method in practical applications is obtained when the lines are horizontal. In that case the vertical projection of the line is not necessary since it is known to be parallel to the reference line, and the vanishing point must therefore lie on the horizon. Any elevation of the object will give the height of the vertical projection of any horizontal line and consequently the height of the *V*-piercing point. This is illustrated in Fig. 18.11, where the perspective of the line *AB*, the upper line of the rectangle, is found without actually drawing its vertical projection. This method is particularly convenient since many of the lines of an object are horizontal.

Even when such horizontal lines do not exist on the object it is possible and convenient to assume such imaginary lines for purposes of construction as shown for points on the circle in Fig. 18.16.

18.8 Parallel or one-point perspective. When the object is placed so that one face is parallel to the picture plane and the others perpendicular to it, the resulting picture is known as parallel or one-point perspective. Except for interior views this is not usually the most desirable position for the object because it tends to move the point of sight over to one side in order to show two exterior sides of an object.

Either the visual-ray or the vanishing-point method or a combination of the two may be used to find the perspective. The visual-ray method has been illustrated in Fig. 18.4. Consequently, the more practical method involving the use of vanishing points will be discussed here. For this method it is necessary to

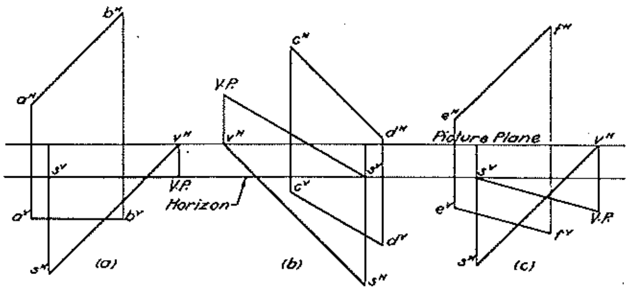


Fig. 18.9. Method of finding vanishing points.

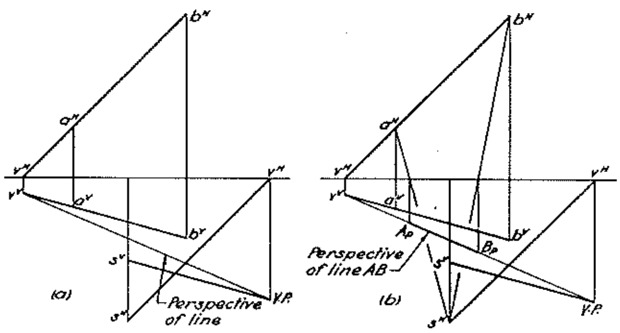


Fig. 18.10. Perspective of an inclined line. Vanishing-point and visual-ray method.

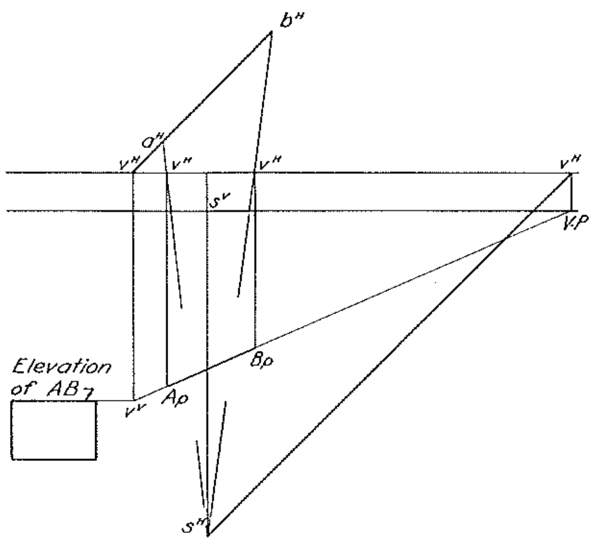


Fig. 18.11. Perspective of a horizontal line. Vanishing-point and visual-ray method.

have the horizontal projection drawn in the proper relation to the reference or picture plane and any elevation in its proper relation to the horizon. The horizontal and vertical projection of the point of sight must also be given. This information for a small house is shown in Fig. 18.12(a).

The first step in the solution is always to find the vanishing points of the principal lines of the figure. In this case the lines parallel to the picture plane will have vanishing points at infinity, which means that any face parallel to the picture plane will show in the perspective in true shape but reduced in size, depending on the distance of the object behind the picture plane. The lines perpendicular to the picture plane will have a vanishing point which may be found by the method explained in Art. 18.6. In this case the lines drawn through S parallel to the given line must pierce the picture plane at a point whose vertical projection is at s^V, which therefore becomes the vanishing point for all lines perpendicular to the picture plane, as in Fig. 18.12(b). In other words, the vertical projection of the point of sight is always the vanishing point for lines perpendicular to the picture plane.

The next step is to extend one of these lines until it pierces the picture plane. Since this is a horizontal line the piercing point will be at the level of the line as shown in the given elevation. This piercing point is marked v^V in Fig. 18.12(b). By joining the piercing point to the vanishing point the perspective of the complete line is formed. By visual rays the required points A_p and B_p on the line may be found to give one line on the building, as shown in Fig. 18.12(b). Other lines on the building may be found in the same manner, as illustrated in Fig. 18.12(c). It should be noticed that the front face of the building is true shape but not true size.

An architectural drawing in parallel perspective is shown in Fig. 18.13.

18.9 Angular or two-point perspective by the combination method. When one of the principal axes of the object is parallel, and the other two inclined to the picture plane, the resulting picture is called two-point perspective. In this case the required information, which is the same as for parallel perspective, is shown in Fig. 18.14(a). Note that a true profile projection is not required.

To find the perspective of any point it is necessary to find the perspective of a line through the point and then locate the point on the line by a visual ray. Any two points on the line will determine the line but the best ones are the vanishing point and the V-piercing point.

The first step is to find the vanishing points of both sets of inclined lines that are parallel respectively to AB and AC. These vanishing points have been located at VPR and VPL in Fig. 18.14(b). Then any line of the drawing such as AB in Fig. 18.14(b) may be extended to find its V-piercing point at v^V. By connecting v^V with VPL, the vanishing point of AB, the perspective of the entire line is found. Visual rays drawn to points A and B will serve to locate points A_p and B_p on the perspective of the line. These will be the perspectives of two corners of the building. Another corner of the building, such as C in Fig. 18.14(c), may be located by connecting A_p with VPR, which is the vanishing point of line AC, and drawing the visual ray through C, thereby locating C_p on the

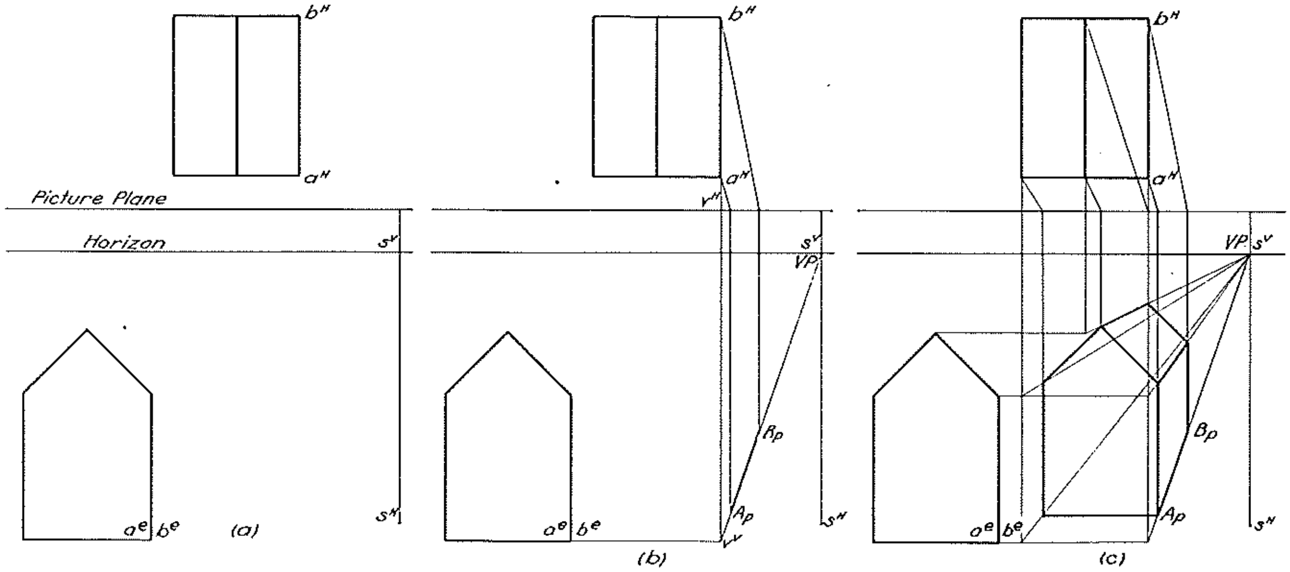


Fig. 18.12. Perspective of building. Vanishing-point and visual-ray method.

line *AC*. Corner *D* of the building must be located exactly as was done for point *A*.

18.10 Two-point perspective by the vanishing-point method. It is possible to find the perspective of an object without the use of visual rays. To do this two lines are constructed through each point so that the intersection of these lines determines the point. Thus, in Fig. 18.15, the perspective of the line *AB* may be found as explained in the previous paragraph by joining v^V with *VPL*. The perspective of *AC* may be found in a similar manner. The intersection of these two lines will locate the perspective of *A* at A_p in Fig. 18.15. All other points on the object may be located similarly. The entire construction is shown in Fig. 18.15. This construction is used exclusively in the measuring-point method which is explained in Art. 18.13.

18.11 Perspective of a circle or curve. To find the perspective of any circle or curve it is necessary to have a series of points on the plan view and the

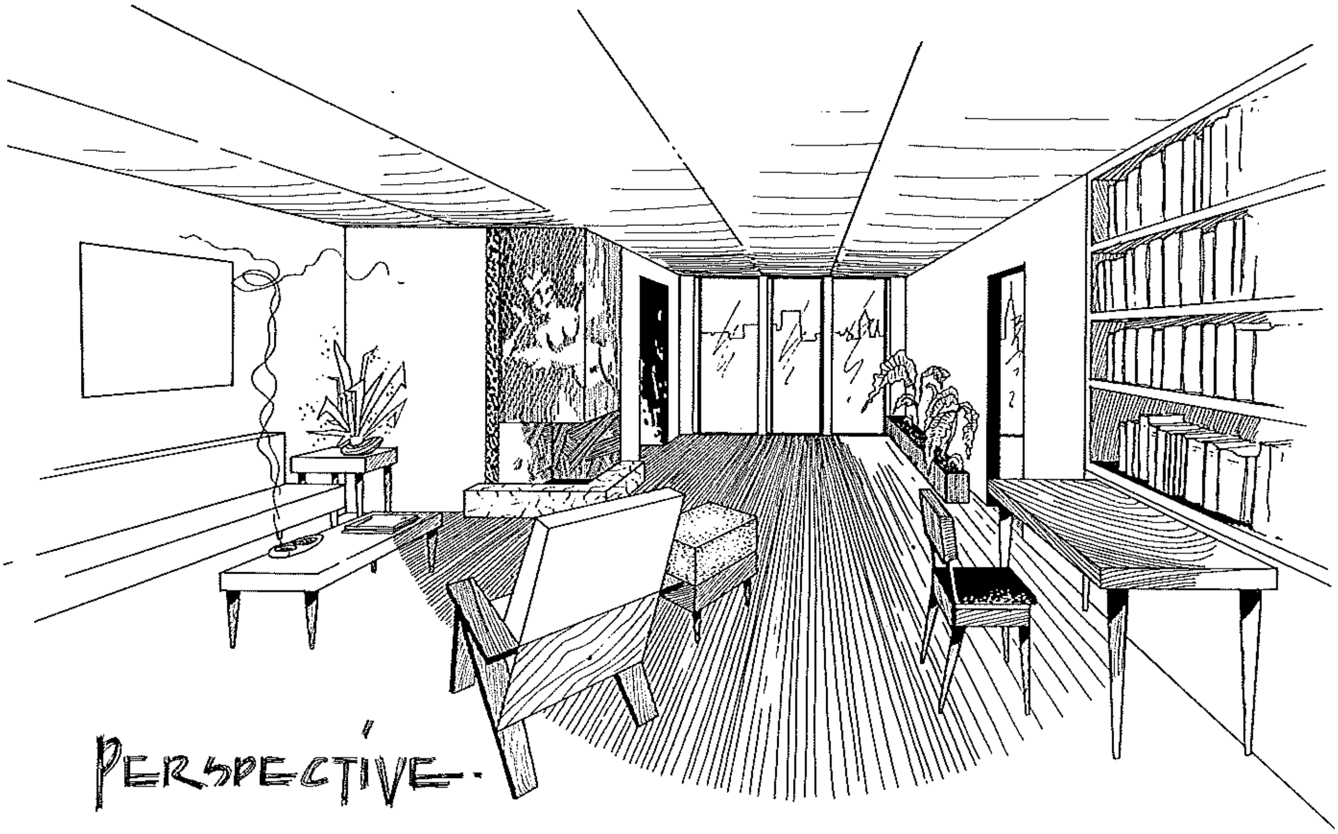


Fig. 18.13. Parallel perspective of an interior. Courtesy Don R. Brown.

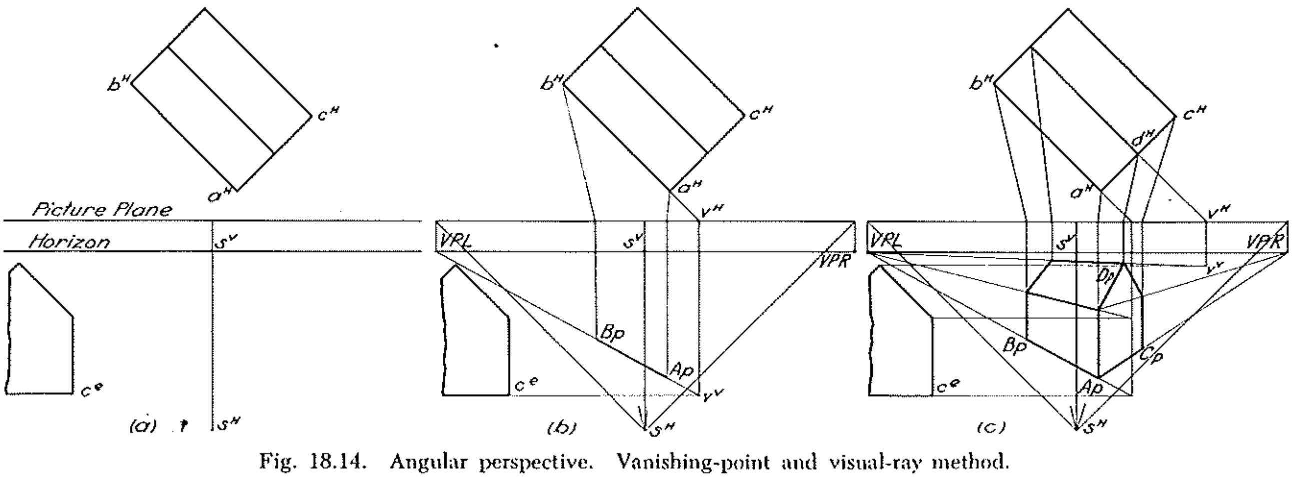


Fig. 18.14. Angular perspective. Vanishing-point and visual-ray method.

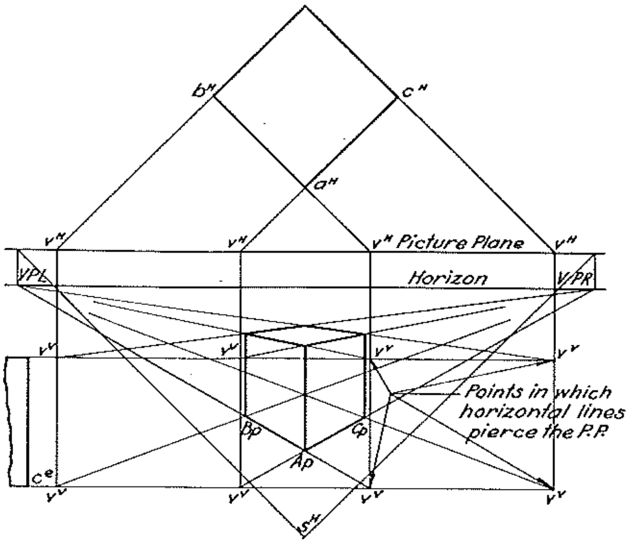


Fig. 18.15. Perspective by the vanishing-point method.

same points located on any elevation. Figure 18.16 shows a circle in two positions, one of which has been solved by the combination visual-ray and vanishing-point method and the second by the vanishing-point method only. A series of points is first numbered in either view, and the position of each point is marked in the other view by the same number. Horizontal lines are assumed through these points. These lines may be in the plane of the circle, or they may be perpendicular or inclined to it, so long as they pass through the points on the circle. The perspective of these lines is determined in the usual manner. The points on these lines can then be found either by visual rays, as in Fig. 18.16(*a*), or by intersecting lines, as in Fig. 18.16(*b*), to determine the perspective of the curve.

18.12 Measuring points and lines. When a vertical face that is inclined to the picture plane, such as face *ABCD* in Fig. 18.17, is rotated until it lies in the picture plane, the vertical projection of this face in the revolved position $a^V{}_r b^V{}_r c^V{}_r d^V{}_r$ is coincident with the perspective of the revolved position. If the vanishing point of the line joining b^H to $b^H{}_r$ in Fig. 18.17 is found, the perspective of this line can be used to carry points from the revolved position to their correct position in the perspective. The vanishing point *MPR*, of the line $b^H b^H{}_r$ is therefore called a measuring point. Since the vertical projection of the revolved position $a^V{}_r b^V{}_r c^V{}_r d^V{}_r$ is in true size, the horizontal lines $a^V{}_r b^V{}_r$ and $c^V{}_r d^V{}_r$ are true length and any desired distances from *A* or *D* can be laid off along these projections. The projection $a^V{}_r b^V{}_r$ is therefore called a measuring line. The projection $c^V{}_r d^V{}_r$ could have been used equally well as a measuring line. In fact, a horizontal line can be drawn through any point that lies in the picture plane and used as a measuring line.

A simpler method for finding the measuring point *MPR* is illustrated in Fig. 18.17. If, through v^H, the *H*-projection of *VPR*, an arc having a radius $v^H s^H$ is drawn from s^H to the picture plane, this point on the picture plane may be projected straight down to *MPR* on the horizon.

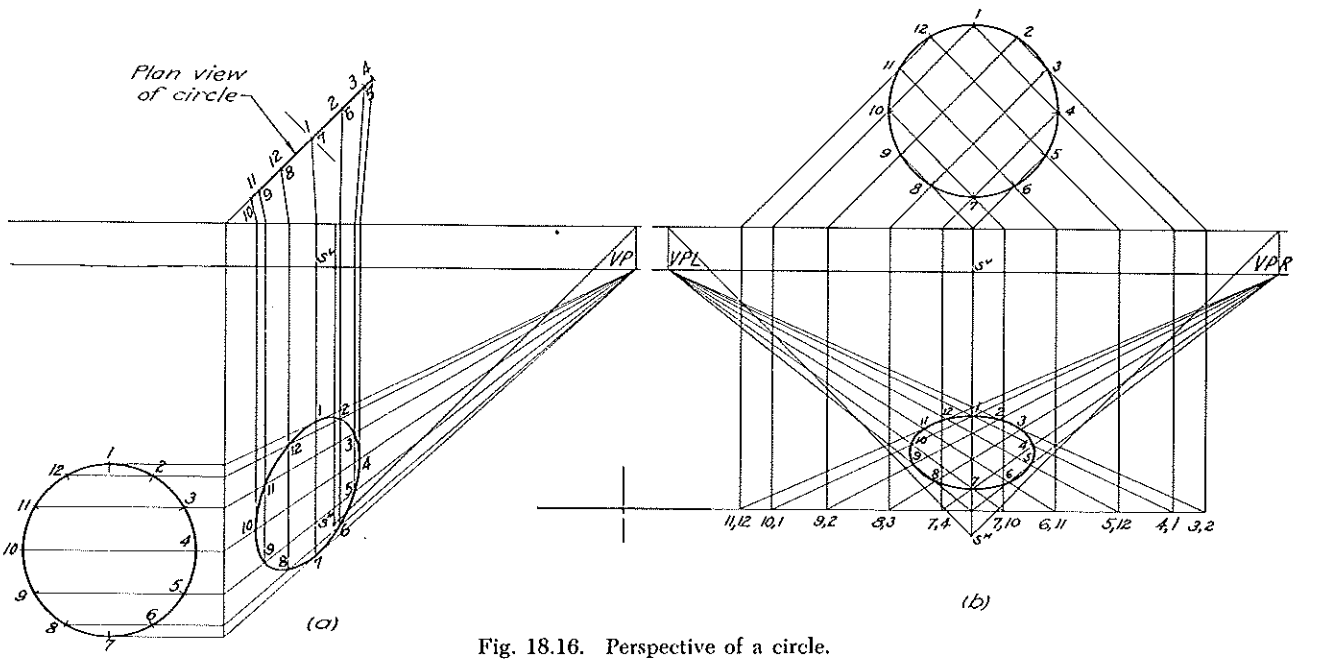


Fig. 18.16. Perspective of a circle.

Proof. Since $a^H b^H b^H_r$ was constructed as an isosceles triangle and since $v^H s^H v_1^H$ has its sides respectively parallel to $a^H b^H b^H_r$, the triangle $v^H s^H v_1^H$ is similar and also an isosceles triangle. Therefore $v^H s^H$ is equal to $v^H v_1^H$, and v_1^H may be located by constructing the arc shown on the figure.

18.13 Construction of a perspective by the measuring-point method. The great advantage of this method over all other methods of perspective is that it is not necessary to set up the projections in any particular position and work from them by projection or visual rays. The vanishing points right and left are usually taken as far apart as convenient, the picture plane and horizon are made to coincide, the angles that the sides of the object make with the picture plane are chosen, and a front corner of the object is selected at a certain place on the picture plane. If the vanishing points are chosen first, then s^H is located by drawing lines from the vanishing points parallel to the sides of the object, which are usually at right angles to each other.

In Fig. 18.18(*a*), the projections of an object are given. The problem is to draw the perspective so that the corner marked *A* will be in the picture plane 6 inches below the horizon and 1 inch right of the point of sight. The side *AB* is to make an angle of 60° with the picture plane, and the vanishing points are to be 18″ apart. The construction will then proceed in the following steps:

a. Figure 18.18(*b*). Draw a horizontal line near the top of the sheet, and mark off the vanishing points 18″ apart.

b. Figure 18.18(*b*). Through *VPR* construct a line at 60° with the picture plane and through *VPL* a line making 30° with the picture plane. The intersection of these two lines will locate s^H. The vertical projection s^V will be on the horizon. This assures that the faces of the block will form the specified angles with the picture plane.

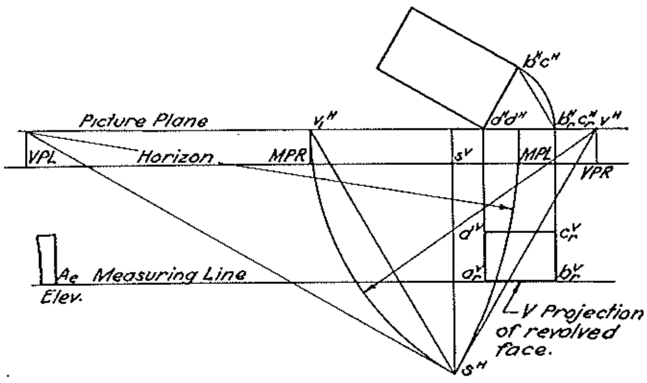


Fig. 18.17. Finding measuring points.

c. Figure 18.18(*c*). Using *VPR* as a center, swing an arc through s^H to the picture plane to locate *MPR*. Using *VPL* as a center, swing an arc through s^H to the picture plane to locate *MPL*.

d. Figure 18.18(*d*). Measure 6″ below the horizon and 1″ right of the point of sight to locate the perspective of point *A*. Through this point draw a horizontal line which is the measuring line for horizontal distances.

e. Figure 18.18(*e*). On a vertical line through A_p, lay out the height of the object *AD* to locate D_p. Draw lines from these points to *VPR* and *VPL*.

f. Figure 18.18(*f*). Lay out the distance *AB* on the horizontal measuring line to the right of A_p. From this point, draw a line to *MPR* to intersect the line from A_p to *VPR*, thus locating B_p. Erect a vertical line through B_p to give the right edge of the object.

g. Figure 18.18(*g*). Lay out the distance *AC* on the horizontal measuring line to the left of A_p. From this point, draw a line to *MPL* to intersect the line

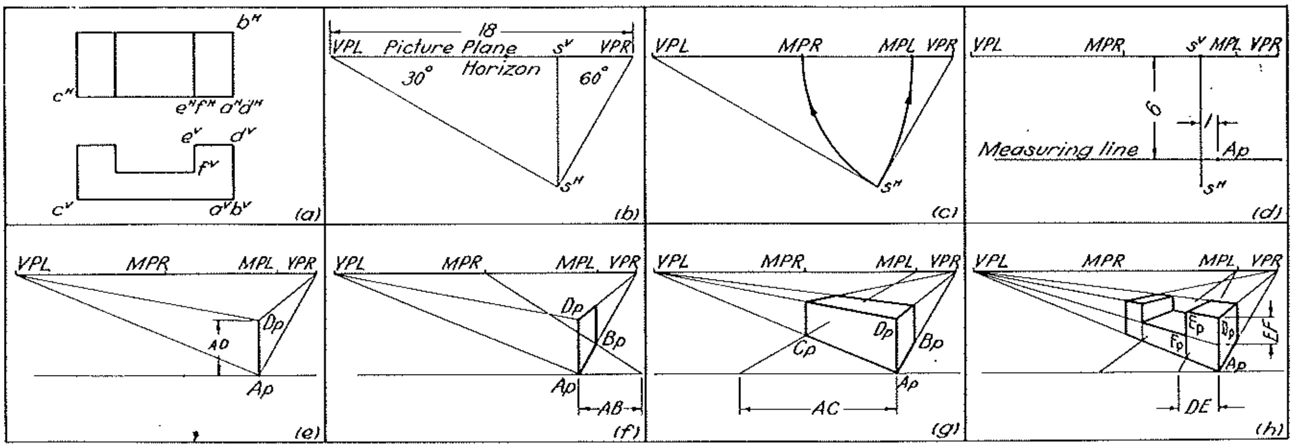


Fig. 18.18. Perspective by the measuring-point method.

from A_p to *VPL*. This locates C_p. Erect a vertical line through C_p to give the left edge of the object. Complete the outline of the figure by drawing to the proper vanishing points.

h. Figure 18.18(*h*). From D_p, lay out on the vertical line the distance *FE*, which is the depth of the slot. From this point, draw a line to *VPL*. From A_p, lay out the distance *DE* on the horizontal measuring line to the left of A_p. Connect this point to *MPL* to intersect the line from A_p to *VPL*. Erect a perpendicular to locate points E_p and F_p, which establishes the right side of the slot. In a similar manner locate the left side of the slot.

i. Connect these points to the proper vanishing points to complete the picture.

18.14 Perspective of a circle by the measuring-point method. By taking measurements from the orthographic projections, points on a circle may be located in perspective by the use of coordinates, but this is a tedious process and should be avoided if possible.

The better method is to find the perspective of a square circumscribing the circle and then obtain the ellipse by the diagonal method. For a circle lying in a vertical face the procedure is illustrated in Fig. 18.19, and the steps are listed below.

a. Figure 18.19(*b*). Find the perspective of the front face of the object shown in Fig. 18.19(*a*) by the method given in the preceding paragraph.

b. Figure 18.19(*c*). On the measuring line through A_p, lay out the horizontal distance *A*–*2*, from *A* to the center line of the circle, to the left of A_p. On either side of this point, lay out the radius of the circle to locate points *1* and *3*. Carry those three points back into the picture by drawing lines to *MPL*.

c. Figure 18.19(*d*). From A_p, lay out the vertical distance *A*–*7*, from *A* to the center line of the circle, on the front corner of the object. On either side of this point, lay out the radius of the circle to locate points *6* and *8*. From those three points, draw to *VPL* to form the perspective of the square circumscribing the circle.

d. Figure 18.19(*e*). On either of the vertical lines, construct a semicircle as shown. Divide the semicircle into 6 equal parts, and project these points horizontally to the vertical line that was used as the diameter of the construction circle. From these points on the vertical line, draw lines to *VPL*.

e. Figure 18.19(*f*). Construct the diagonal of the square, complete the grid, and mark the points.

When the circle lies in a horizontal plane, the procedure is similar except that the semicircle must be drawn on the measuring line, as illustrated in Fig. 18.20. When the points have been carried back into the perspective by means of the measuring points and vanishing points, the grid is constructed by means of the diagonal as previously explained.

18.15 Three-point perspective. When all three of the principal axes of an object are oblique to the picture plane, the resulting picture is called a three-point perspective. The theory of perspective as it has been developed for one- and two-point perspective can be extended to three-point. However, the actual construction is more complicated because the picture plane does not appear edgewise in the top view. It is possible to solve the problem by visual rays, as

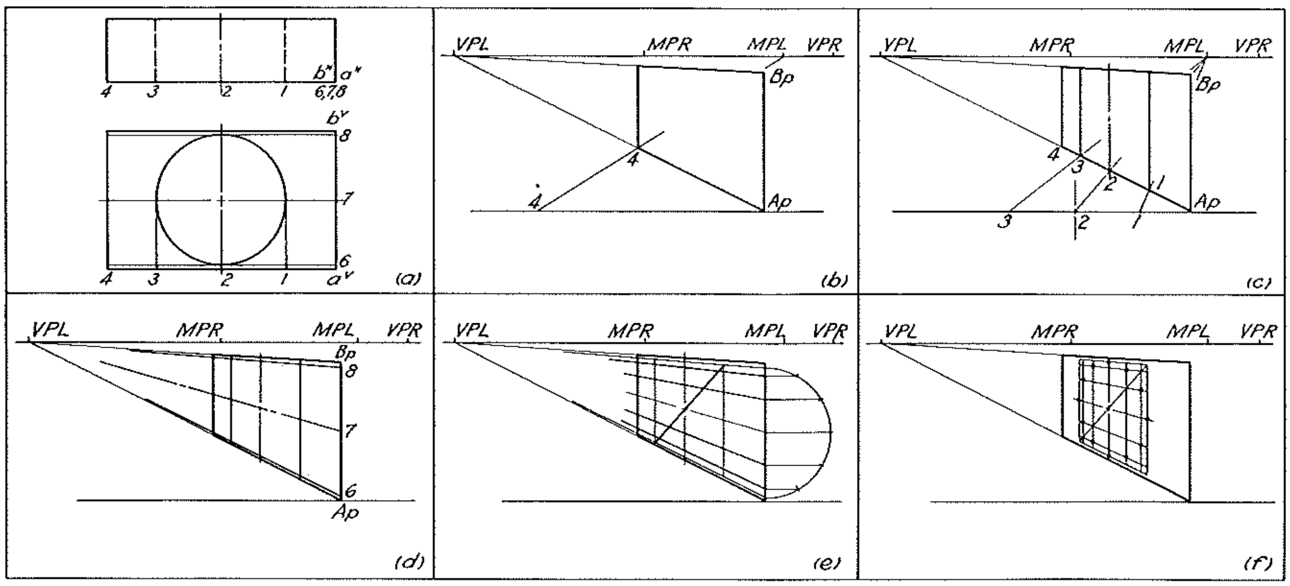


Fig. 18.19. Circle by the measuring-point method.

shown in Fig. 18.6, but the solution is tedious and will not be discussed here. If it is desired to specify the angle of tilt of the picture plane and the angle of rotation of the object, the reader should refer to the texts: ***Industrial Production Illustration*** by Hoelscher, Springer, and Pohle or *Perspective* by Moorehead.

The customary procedure is to select the three vanishing points as far apart as convenient and work from these points in the manner illustrated in Fig. 18.21 and as explained below.

a. Figure 18.21(*a*). Select the three vanishing points, and draw the triangle connecting them. Through each corner construct a line perpendicular to the opposite side of the triangle. These three lines intersect at point S, which is the projection of the point of sight as determined by the selected vanishing points.

b. Figure 18.21(*b*). Revolve the top plane into the picture plane as explained in Art. 16.18 for axonometric. With *VPR* as a center and $VPR\text{–}S_r$ as a radius, swing an arc to locate *MPR*. With *VPL* as a center and $VPL\text{–}S_r$ as a radius, swing an arc to locate MPL.

c. Figure 18.21(*c*). Revolve the right side plane S, *VPR*, *VPV* into the picture plane as explained in Art. 16.18. With *VPV* as a center and $VPV\text{–}S_r$ as a radius, swing an arc to locate *MPV*. If desired, another *MPR* may be located but this is not necessary since one has already been found.

d. Figure 18.21(*d*). Select A_p as a point in the picture plane in such a position that the center of the picture will come approximately at S.

Through A_p, draw a line parallel to *VPL–VPR*. This is a measuring line, and distances may be laid out for right or left distances and front or back distances just as explained for two-point perspective in Art. 18.13. The top of the box is obtained as shown in Fig. 15.21(*d*).

e. Figure 18.21(*e*). Construct a line through A_p parallel to *VPR–VPV*, and on this line lay out the height of the box from A_p. From the point, draw to *MPV* to intersect the line from A_p to *VPH*. This determines the height of the box in the perspective.

f. Figure 18.21(*f*). From the points already located, draw to the proper vanishing point to complete the perspective of the box.

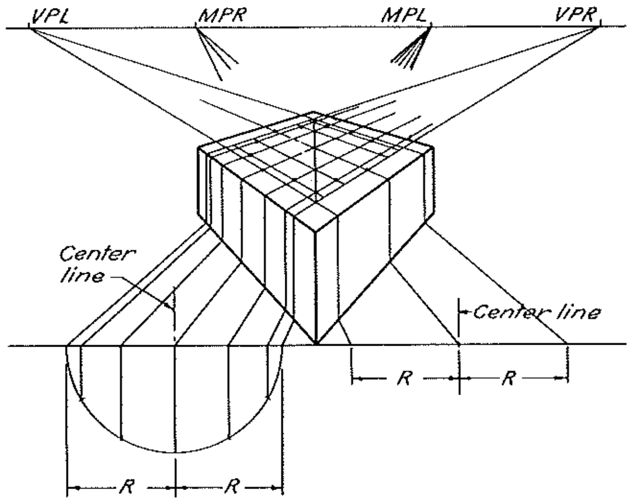


Fig. 18.20. Horizontal circle by the measuring-point method.

18.16 Isometric three-point perspective.° For the special case of three-point perspective in which the three principal vanishing points lie on the corners of an equilateral triangle, an easy construction has been developed that has the same relation to the theoretical three-point perspective that isometric drawing has to isometric projection.

The construction is as follows:

a. Figure 18.22(*a*). Lay out an equilateral triangle of the size desired, usually the maximum a drawing board will accommodate, and let the corners be the three vanishing points.

b. Figure 18.22 (*b*). Select a point A_p in the picture plane and through this point construct two measuring lines, one parallel to *VPL–VPR* and the other parallel to *VPR–VPV* (or *VPL–VPV*).

c. Figure 18.22(*c*). On the horizontal line, lay out the right and left or length dimension of the box to the left of A_p. Lay out the front and back dimensions or depth of the box to the right of A_p. Draw to the vanishing point as shown. This determines the top of the enclosing box for any object.

° This method was developed by Professor Wayne Schick of the University of Illinois and is reproduced by his permission.

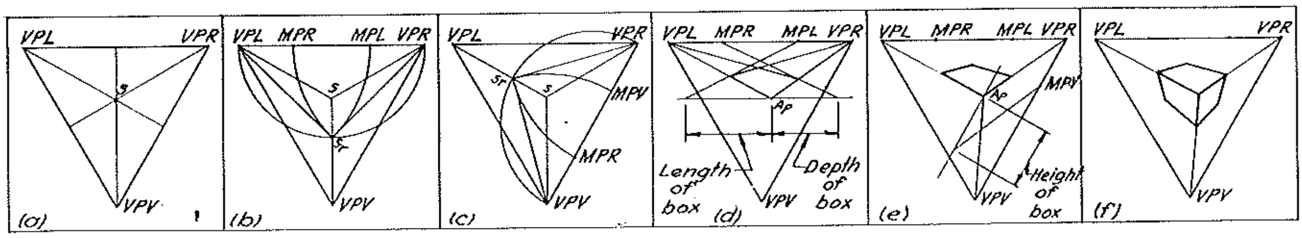


Fig. 18.21. Three-point perspective projection.

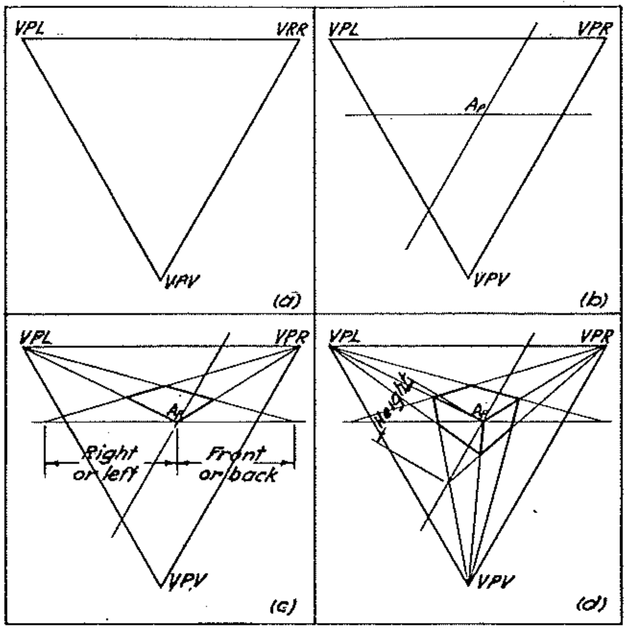


Fig. 18.22. Three-point perspective drawing.

d. Figure 18.22(*d*). On the measuring line parallel to *VPR–VPV*, lay out the height of the box, and draw to the vanishing point *VPR* as shown. The lower corner of the box is located at the point where this line crosses the line from A_p to *VPV*. Complete the box by drawing to the proper vanishing points. Other dimensions of an object may be laid out in the same manner.

18.17 Shades and shadows in perspective. When light shines on an object a part of the surface will be lighted and the remaining part will be dark. That part of the surface on which no light shines is said to be in shade. The lines on the object that separate the light areas from the shaded areas are called shade lines. When the object rests on or is adjacent to some other object, it casts a shadow which may be outlined by finding the shadow of the shade lines. To find the shadow of an object, therefore, two things are necessary: first, to pick out the shade lines; and second, to find the shadow of these lines on the surfaces on which the shadow falls.

To recognize the shade line requires a knowledge of the direction of the light ray and the ability to visualize the object as it stands in space. In case of doubt it is possible to find the shadow of every line on the object, after which the largest area outlined by these shadows will be the shadow of the object.

When the light rays are tangent to any surface, that surface is said to be in shade.

18.18 Shadow of a vertical line. A vertical line resting on a horizontal plane is used as the basic line in determining shadows. One reason for this is that, since the horizontal projection of a vertical line is a point, the horizontal projection of the shadow of the line must coincide with the horizontal projection of a light ray. When the direction of the light ray is specified by two projections of one ray, as *MN* in Fig. 18.23, the shadow of the line *AB* in the horizontal projection must be a line through a^Hb^H parallel to m^Hn^H. Since that shadow is a horizontal line, it must have its vanishing point on the horizon. That vanishing point may be found at *VPS* in the usual manner, as shown in Fig. 18.23. Then the shadow of *AB* on the horizontal plane must vanish at *VPS*, and, since *B* is on the horizontal plane, the shadow must start at B_p. By joining B_p to *VPS*, the shadow of a vertical line of infinite height is obtained. To find the shadow of *A*, it is then necessary to draw the perspective of the light ray through *A* and find the point where it intersects the shadow line. The vanishing point of the light ray *MN*, found as explained in Art. 18.6, is located at the point marked *VPLR*. Then, by joining A_p to *VPLR*, the point A_{sp} is located, and the actual shadow of the line lies between B_p and A_{sp}.

In finding shades and shadows in perspective, it is always necessary to locate first the vanishing points *VPS* and *VPLR*. Always remember that *VPS* is the vanishing point of the shadow of the vertical line on a horizontal plane and nothing more.

When the vertical line casts a shadow on a vertical plane, the shadow must be parallel to the line and in two-point perspective will show as a vertical line. The best way to find this shadow is to find the shadow of the line on the horizontal base plane until it crosses

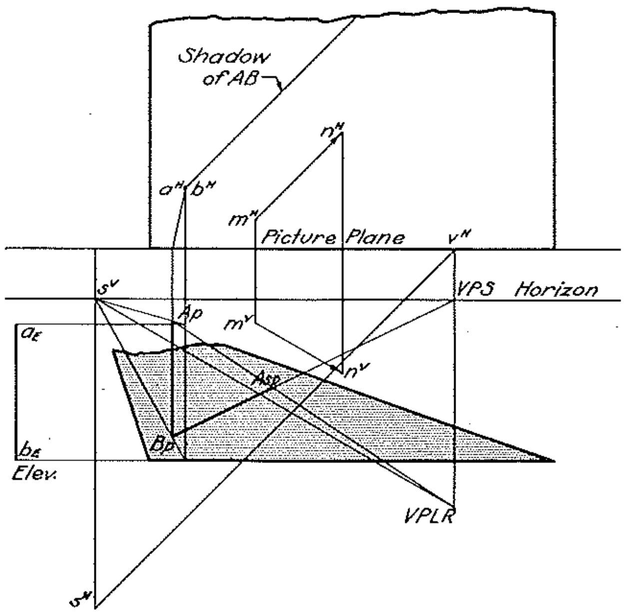


Fig. 18.23. Shadow of a vertical line on a horizontal plane.

the base line of the vertical plane. From there the shadow will be vertical, as illustrated by the shadow of the flag pole in Fig. 18.24. The location of this vertical shadow can also be found by means of a visual ray from the plan or top view, as indicated in the figure.

When the shadow falls on an inclined surface such as the roof of the building in Fig. 18.24, it is necessary to locate two points on the shadow of the line or the line extended. One point on the eave line has already been located, and another can easily be located on the ridge line. One method is by visual ray, as shown in Fig. 18.24. The other method, which is better since it can also be used when working by measuring-point method, involves cutting a vertical plane through the center of the building, as indicated by the dotted line. Then by imagining the front of the building removed the shadow on the section plane can be found, which will locate the desired point on the ridge line. This construction is shown in dashed lines in Fig. 18.24. The shadow of the flag pole on the roof will be the line joining the point on the eave line to the point on the ridge line, and a light ray through the top of the flag pole to *VPLR* will locate the end of the shadow.

18.19 Shadow of a horizontal line. When a horizontal line casts a shadow on a horizontal plane, the shadow will be parallel to the line itself. In perspective this means that the two lines will have the same vanishing point. Thus, in Fig. 18.25, the line *AB* vanishes at *VPR*, and consequently its shadow must also vanish at *VPR*. *BC* vanishes at *VPL*, and its shadow also vanishes at *VPL*.

When a horizontal line casts a shadow on a vertical or inclined plane, the shadow of two points on the line, or one point and the direction, must be found

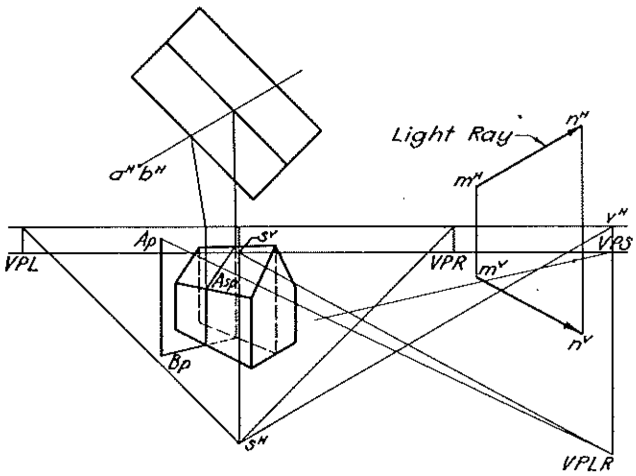


Fig. 18.24. Shadow of a vertical line on a vertical and inclined surface.

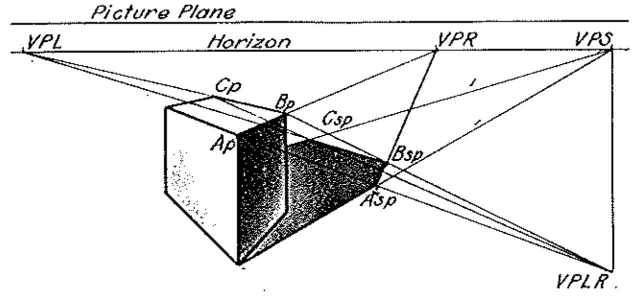


Fig. 18.25. Shadow of a horizontal line.

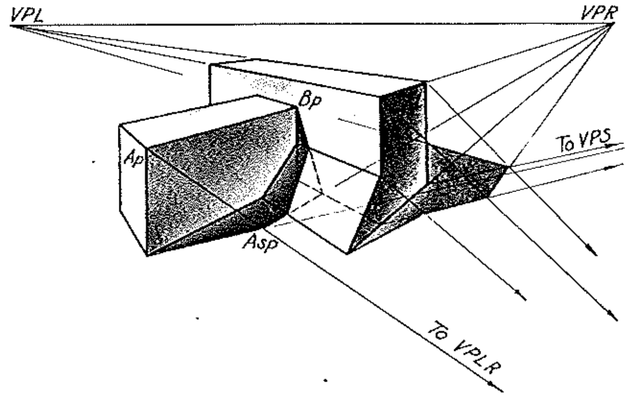


Fig. 18.26. Shadow of a horizontal line on various planes.

on the given plane. Thus, in Fig. 18.26, the line *AB* casts a shadow on the horizontal, inclined, and vertical planes. The shadow on the horizontal plane vanishes at *VPR*, and if the inclined plane were removed it would continue to the base of the vertical plane and from there would go to B_p because *B* is actually on the vertical face. The intersection of this shadow on the vertical face with the top line of the inclined face gives a second point on the inclined plane to determine the shadow of the horizontal line on the inclined plane.

18.20 Shadow of an inclined line on any surface. To find the shadow of an inclined line it is usually best to assume as many vertical lines as necessary through points on the line and find the shadows of these vertical lines. For example, in Fig. 18.27, a vertical line was assumed through B_p. By means of this vertical line, the shadow of B_p on the ground was found at B_{sp}. Note that the vertical line through B_p is an imaginary line.

18.21 Shadow of a curved line. The shadow of a curved line may be found by assuming a series of vertical lines through points on the curve. The shadow of these vertical lines may be found in the usual manner and the shadow of the point located on the shadow of the line. This is illustrated in Fig. 18.28.

18.22 Reflections. Whenever water appears in the foreground of a perspective, the building or structure

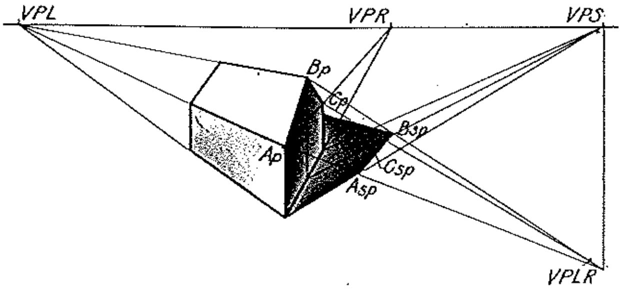


Fig. 18.27. Shadow of an inclined line.

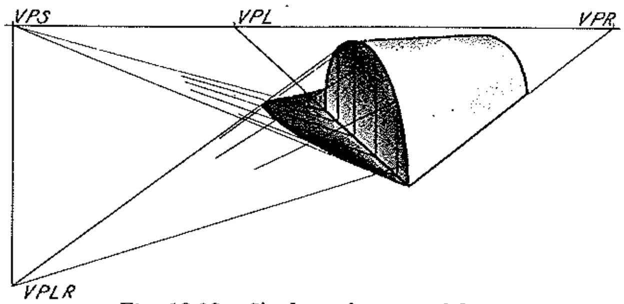


Fig. 18.28. Shadow of a curved line.

shown in the picture will also show in the water as a reflection. To obtain the perspective of the reflection, the elevation of the structure being shown may be reversed about the water line, and the complete perspective of this inverted object constructed in the same manner as the original perspective. Figure 18.29 shows the elevation of the corner of a building standing on the bank of a body of water, with the picture plane and water surface shown edgewise. Point C is the corner of a building, C_w is the projection of C on the surface of the water, and C_R is the position of C in the reversed elevation.

Point S is the point of sight for the perspective, and, therefore, the piercing points of the visual rays in the picture plane will locate the perspectives of C, C_w, and C_R at C_p, C_{wp}, and C_{Rp}, respectively. By plane geometry it can be shown that, since the two distances, y, were constructed equal, the three angles marked α must be equal. Then the perspective of C_R must coincide with the perspective of the reflection of C on the water surface, thus proving that the reflection of an object may be obtained in this manner.

By geometry it can also be shown that, since the two distances marked y were constructed equal, then the two distances marked y' must also be equal. Since these distances are measured directly in the perspective, it then becomes possible to locate the reflection of any point in a two-point perspective by measuring the distance, y', from the perspective of the point, C_p, to the perspective of its projection on the water surface, C_{wp}, and laying that distance below C_{wp} on the water surface to locate C_{Rp}, which is the reflection of point C. This gives a rapid method of finding the reflection of any point, without drawing the reversed elevation. In a three-point perspective, the reversed elevation must be drawn and the reflection found in the same manner as the real perspective.

The lines in the reflection should be made irregular and broken to represent wave action. The surface of the water can be indicated by a series of irregular horizontal lines whose spacing increases toward the

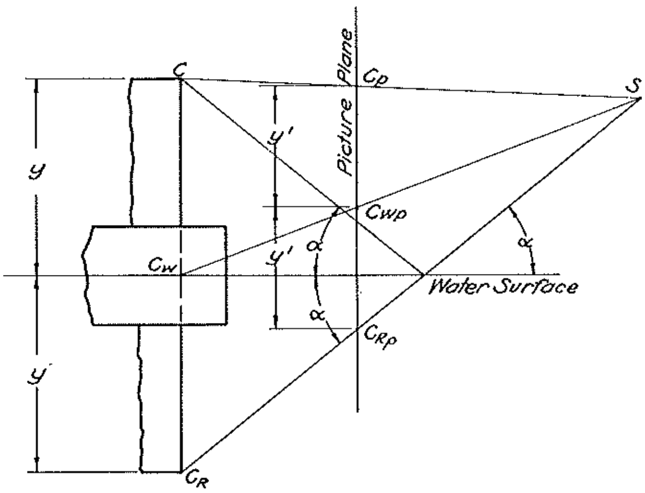


Fig. 18.29. Theory of reflections.

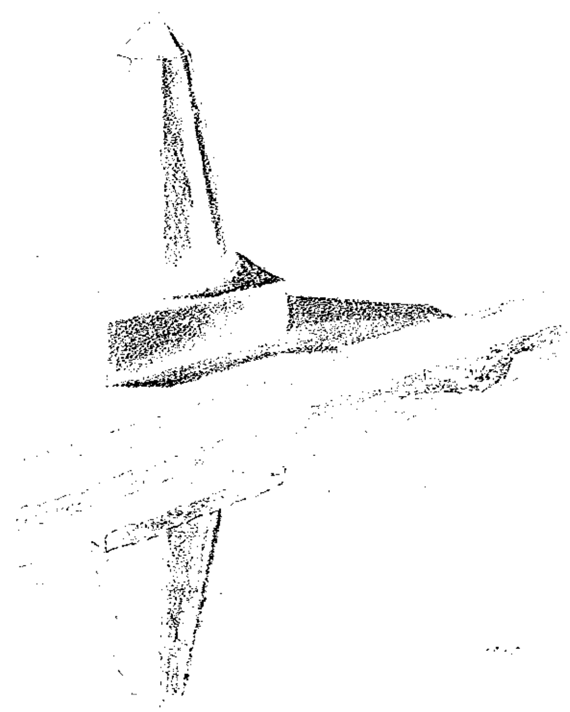


Fig. 18.30. Shades, shadows, and reflections in perspective.

front of the drawing. Figure 18.30 shows a perspective with shades, shadows, and reflections.

Problems

The problems in the following group may be solved by any method discussed in this chapter. The layouts have been made for angular perspective. These can be drawn most rapidly by the combination vanishing-point and visual-ray method.

Dimensions for the location of the plan view have been given to the borderlines of standard sheets, and the scale for each size of sheet has been specified. This arrangement will normally bring the point of sight (s^H) and the vanishing points on the sheet.

For parallel perspectives, notes have been added on each of the simpler drawings specifying the location and position of the plan view. In all cases the elevation should be placed out of the range of the perspective at the left or right.

For shades and shadows in perspective, the direction of the light ray has been specified verbally for some of the simpler objects.

1. Make an angular perspective of the outdoor fireplace shown in Fig. 18.31 by the combination visual-ray and vanishing-point method.
2. Same as Problem 1, using vanishing-point method only.
3. Make a parallel perspective of the outdoor fireplace shown in Fig. 18.31. See note in the figure for position of object relative to the picture plane and the point of sight.
4. Make the perspective specified in Problem 1, and then find the shades and shadows, assuming the light ray to be parallel to the vertical plane and to make an angle of 45° with the horizontal plane, down to the right.
5. Make an angular perspective of the cube shown in Fig. 18.32 by any assigned method.
6. Make a parallel perspective of the cube shown in Fig. 18.32. See note in the figure for the relative position of the object and point of sight.
7. Make a perspective of the monument shown in Fig. 18.33 by the visual-ray method only.
8. Make a perspective of the monument shown in Fig. 18.33 by the combination visual-ray and vanishing-point method.
9. Make the perspective assigned in Problem 8, and then find the shades and shadows, assuming the light ray to have the following position. Horizontal projection 30° with ground line, up to the right. Vertical projection 45° with ground line, down to the right.
10. Make an angular perspective of the memorial fountain shown in Fig. 18.34 by the combination vanishing-point and visual-ray method.
11. Make a parallel perspective of the memorial fountain shown in Fig. 18.34. See note in the figure for the relative position of object and point of sight.
12. Make an angular perspective of the arch shown in Fig. 18.35 by the combination vanishing-point and visual-ray method.
13. Make an angular perspective of the garage shown in Fig. 18.36 by the combination vanishing-point and visual-ray method. Find and use the vanishing points for the rafters.

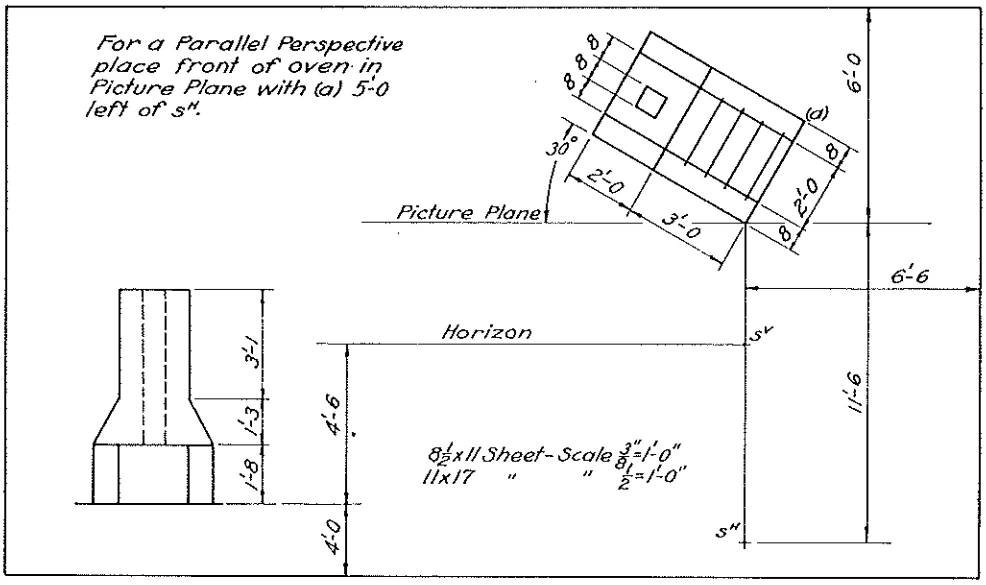


Fig. 18.31. Outdoor fireplace.

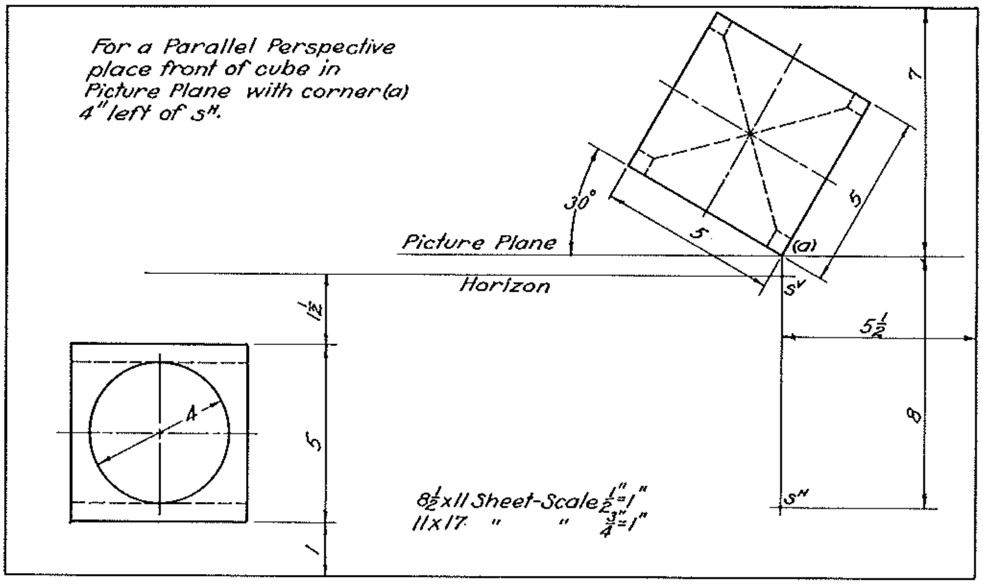


Fig. 18.32. Drilled cube.

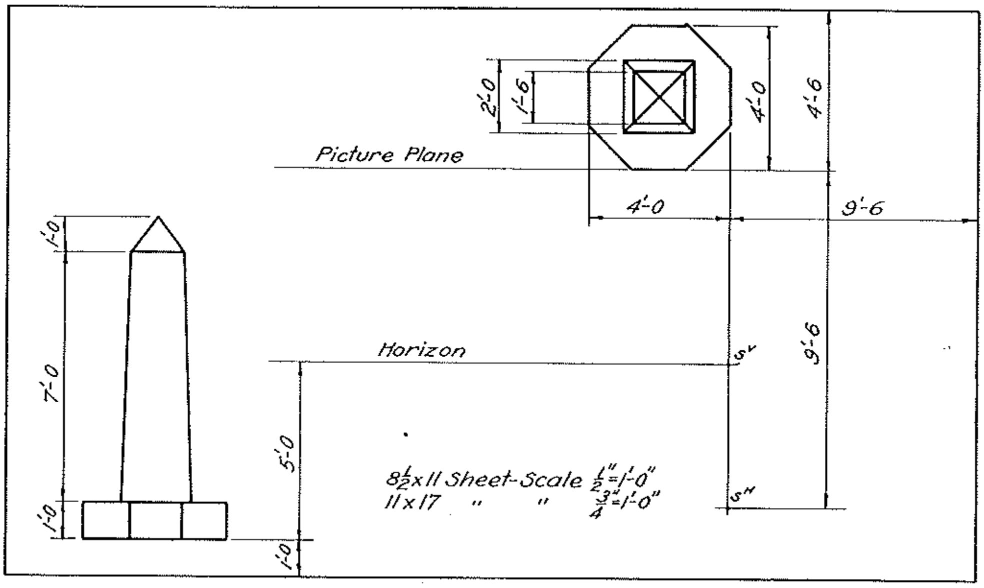


Fig. 18.33. Monument.

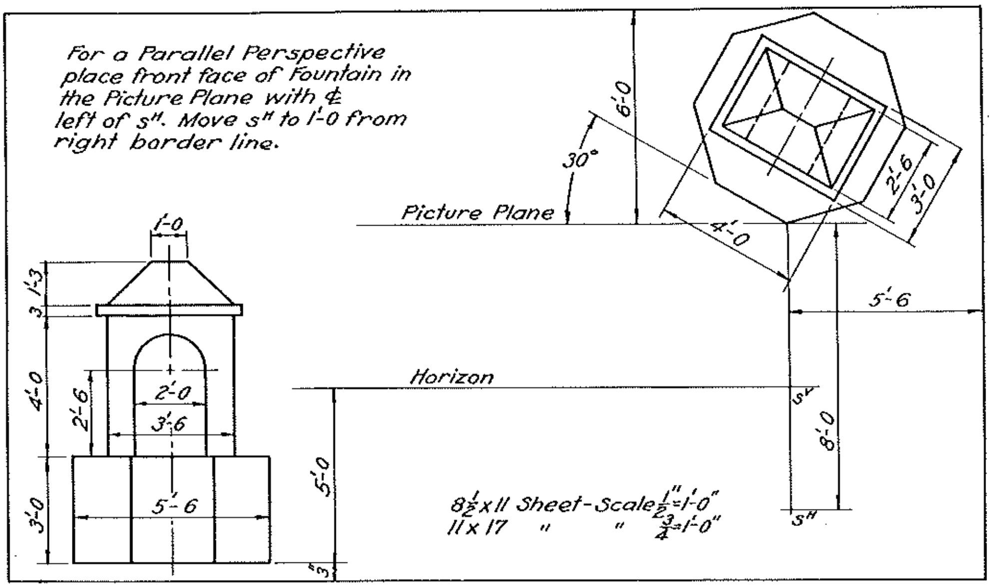


Fig. 18.34. Memorial fountain.

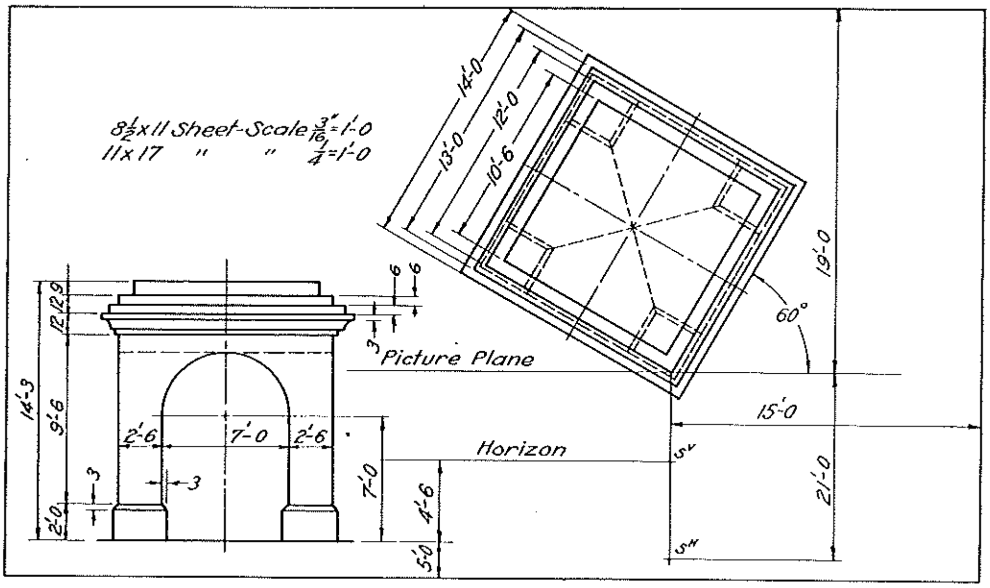


Fig. 18.35. Memorial arch.

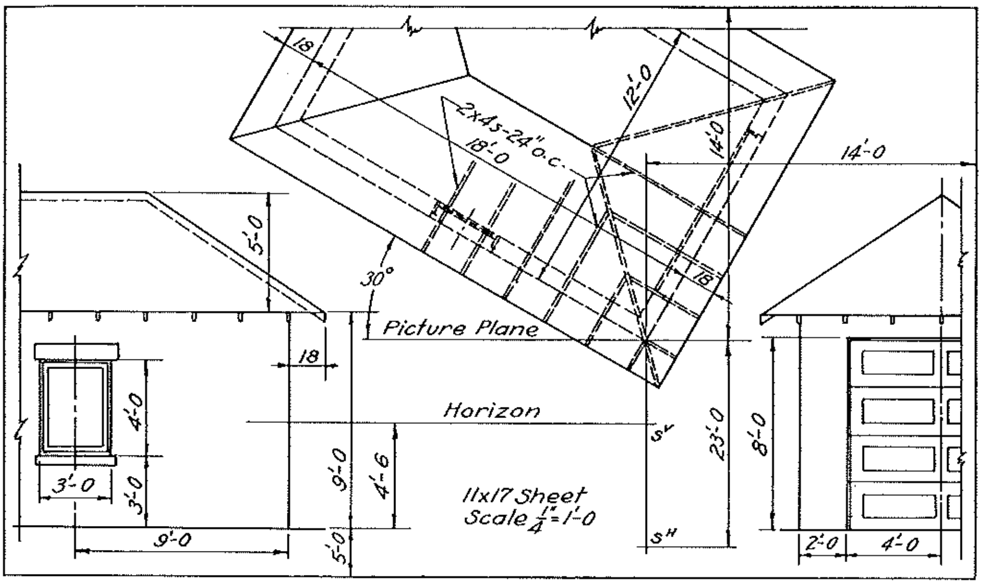


Fig. 18.36. Garage.

Charts and Diagrams 19

19.1 Uses of charts. The purpose of charts and diagrams is to present facts and their significance in a more easily interpreted form than could be done with words or tabular data. A technical or business publication scarcely appears today without charts of some kind. Some of the more common uses of charts are as follows:

a. To present results of test data obtained in experiments.

b. To correlate the observations of natural phenomena.

c. To present business statistics.

d. To determine trends in business.

e. To present equations graphically for computation uses.

f. To derive empirical equations.

19.2 Classification of charts. According to the method of presentation or drawing, with which this chapter is primarily concerned, charts may be readily classified in the following form:

a. Plane curves on rectangular coordinates, logarithmic, semilogarithmic, trilinear, polar coordinates, and others.

b. Bar charts of all kinds.

c. Pie or sector charts.

d. Computation charts, vector diagrams, and nomographs.

e. Flow charts and distribution diagrams.

f. Three-dimensional charts.

g. Map or distribution diagrams.

All of these are illustrated in the various figures of this chapter.

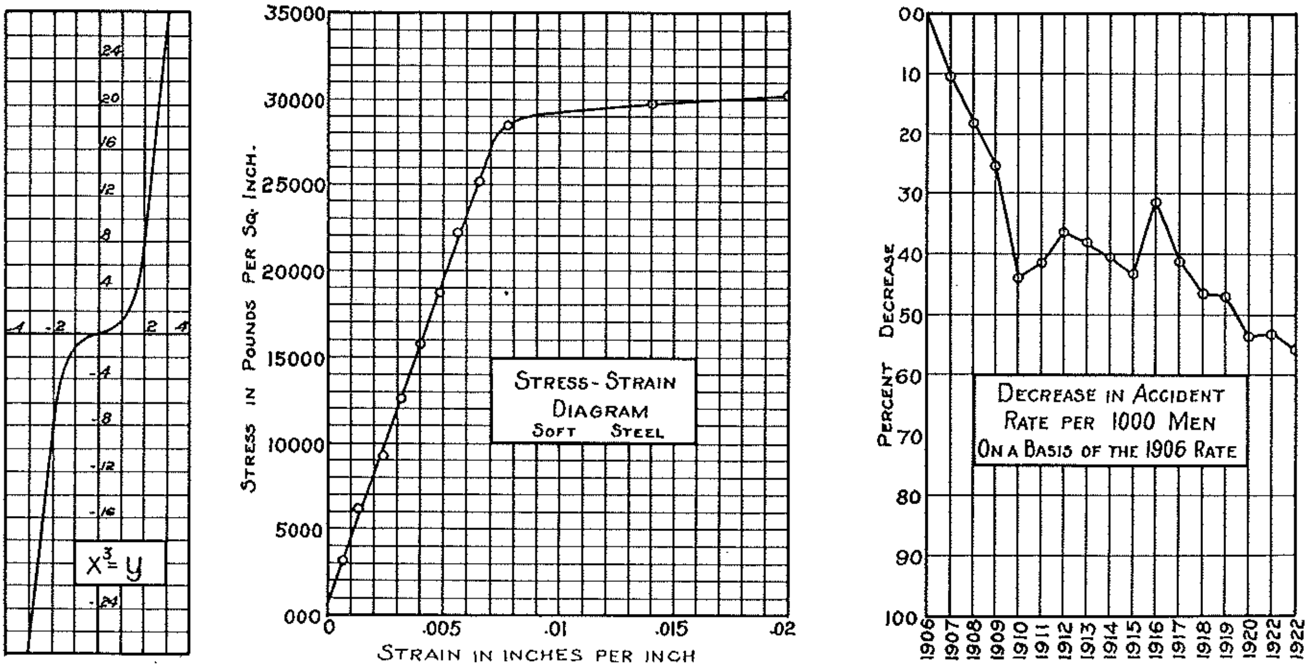


Fig. 19.1. Types of plane curves.

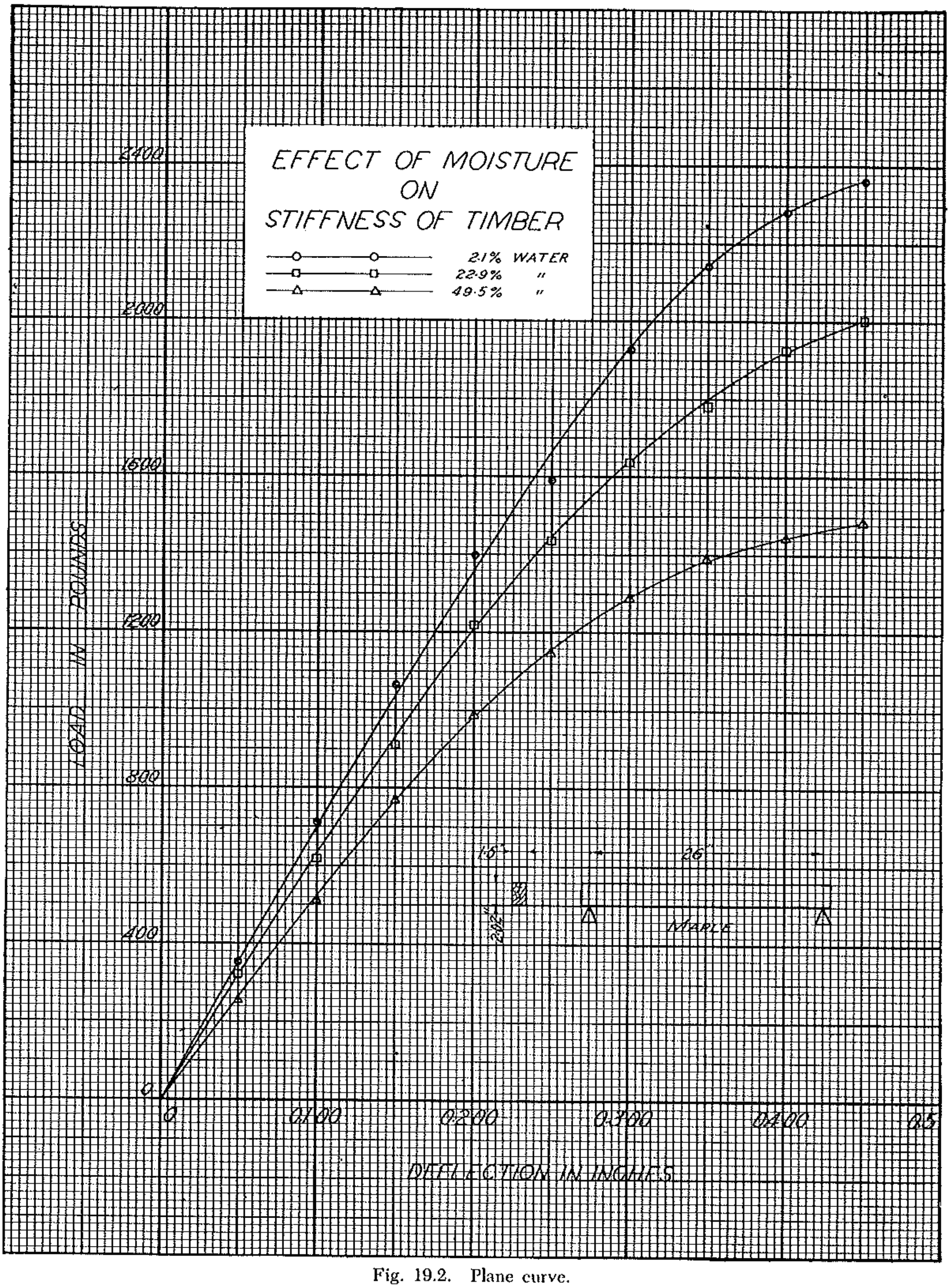


Fig. 19.2. Plane curve.

19.3 Charts on rectangular coordinates. Charts are more commonly made on rectangular coordinates than on the other forms, as illustrated in Fig. 19.1. They are used to compare quantities. The impression given by such charts will depend upon the scales selected for each of the coordinates.

19.4 How to draw the chart. Having the data for a chart given or collected in tabular form, the steps outlined in the following paragraphs must be taken to produce a chart which will give the desired effect. Two forms of presentation are possible, depending upon the purpose of the chart. One form is the test or laboratory report; the other is designed for publication.

In this book we are concerned primarily with those prepared directly on commercially available printed coordinate papers.

a. Selection of Axes. Two variables are usually involved in a chart. It is therefore necessary to decide which variable will be placed on the vertical or *Y*-axis and which on the horizontal or *X*-axis. It is the general practice to place the independent or controlled variable on the horizontal axis. One exception to this rule, established by custom, is the so-called stress-strain curve. When time is one of the variables this is usually placed on the *X*-axis.

The location of the zero point or intersection of the axes must be so chosen that all values of the variables can be plotted. When only positive values are involved, this point is placed in the lower left corner of the chart about 1 inch in from the printed border, as shown in Fig. 19.2.

b. Choice of Scales. The choice of scales materially affects the impression given by the chart. See Fig. 19.3. The scales on the two axes should be chosen to take maximum advantage of the space available. If the chart is to be made upon printed coordinate paper, the scale units should be chosen to come upon the heavy printed lines. These units should be multiples of 1, 2, 4, or 5. Interpolation of the smaller divisions on the paper should be easy to make. If the chart is to be made for formal publication, coordinates are usually ruled upon blank paper. For this type of work the reader should consult the ASA publication Y-15.3 (formerly Z-15.3) "Engineering and Scientific Graphs for Publications."

c. Marking Coordinates. Unit values of the coordinates should be marked on each axis, as shown in Fig. 19.2. A legend should indicate what the units are and the unit of measurement, as, for example, inches, feet, etc., or time in days, hours, or minutes. Note in Fig. 19.2 that the smaller ruled divisions have been used as guide lines for the lettering.

d. Showing Plotted Points. The plotted points are indicated by open circles about $\frac{1}{10}$ inch or a little less in diameter. If more than one curve is shown on a single chart, squares and triangles may be used for the points on the other curves, as shown in Fig. 19.2. If more curves are needed solid circles, squares, and triangles may be used. They should be smaller than the open ones. If a curve is to be drawn to represent a mathematical equation, plotted points should not be shown on the finished chart.

e. Drawing the Curve. The nature of the curve to be drawn between plotted points will depend upon the data involved. If there is no direct relationship between the variables, as, for example, time and rainfall, straight lines will be drawn from point to point, as shown in Fig. 19.4. When there is a direct relationship, as in Fig. 19.2, a smooth curve will be drawn through the average of the points. The curve should touch but not pass through the circles of the plotted points.

f. Titles. Every chart must have a well-thought-out title stating specifically what is represented. This should be placed to make the total effect a well-balanced sheet.

g. Sketches. If a small sketch will make the chart more intelligible, this may be placed on the sheet but

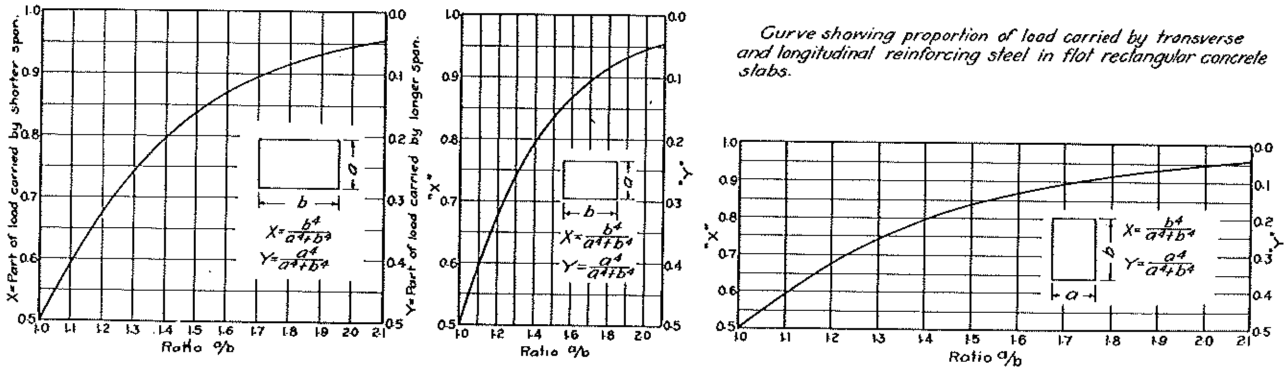


Fig. 19.3. Effect of scale on apparent slope of curve.

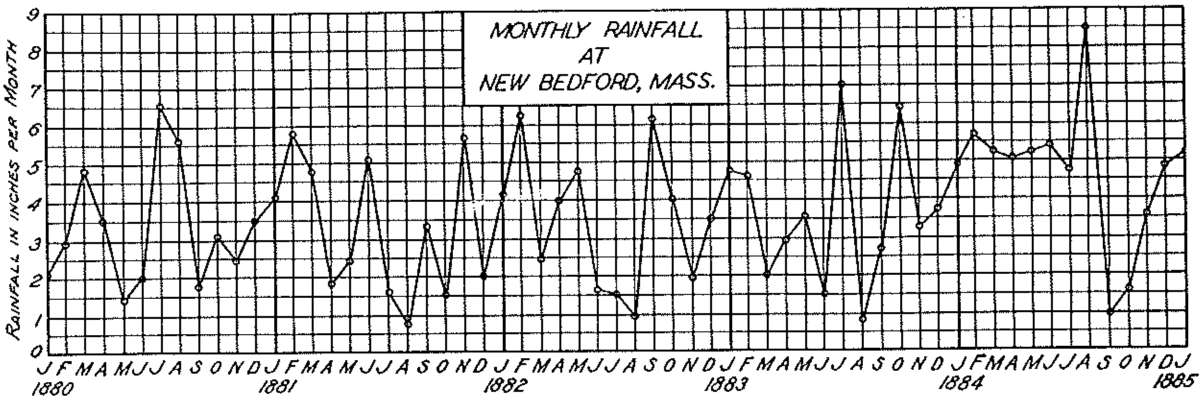


Fig. 19.4. Rainfall curve.

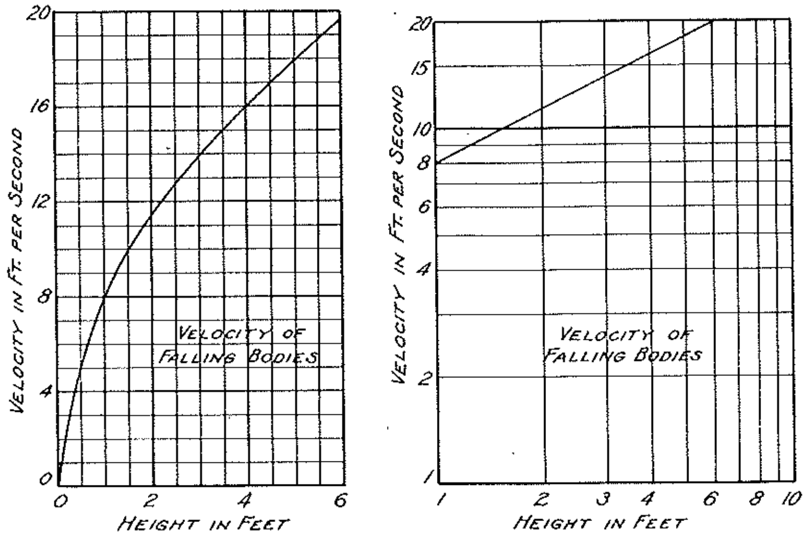


Fig. 19.5. Same curve on rectangular and logarithmic paper.

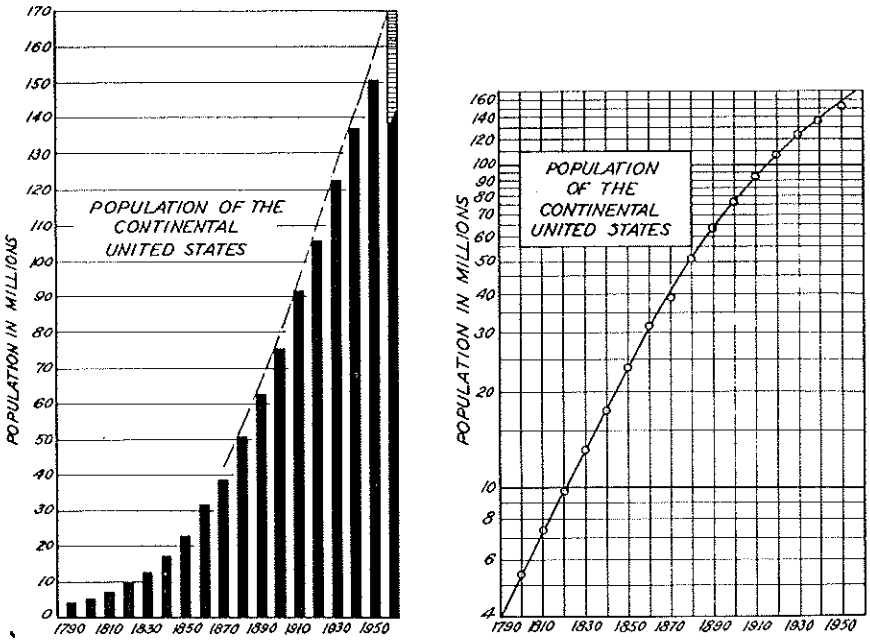


Fig. 19.6. Bargraph and semilog chart of same data.

tables of data and extensive explanatory matter should not be placed within the chart.

19.5 Logarithmic charts. These charts are most useful in engineering work where the relationship of the variables is more complex, as, for example, a product, quotient, or exponential form of the variables. In such cases the chart becomes a straight line on logarithmic paper, as illustrated in Fig. 19.5. By the use of logarithmic charts empirical equations to represent test data can frequently be derived, as discussed in Art. 19.13(*b*). The ruled lines of this type of paper are spaced according to the logarithms of numbers. Such paper is commonly available with one, two, or three cycles, in each direction.

19.6 Semilogarithmic charts. When the rate of change in two variables is more important than the quantitative change, semilogarithmic paper is used since the slope of the tangent to the curve at any point gives the rate of change at that point and the whole chart indicates a trend in the rate more accurately than does the same data plotted on rectangular coordinates, as may be seen by comparing the two charts of Fig. 19.6. Semilogarithmic paper has a logarithmic scale in one direction and an arithmetic scale in the other. Equations of the general form $y = a10^{MX}$ will plot as straight lines on this paper. Empirical equations can frequently be determined by plotting data on this type of paper.

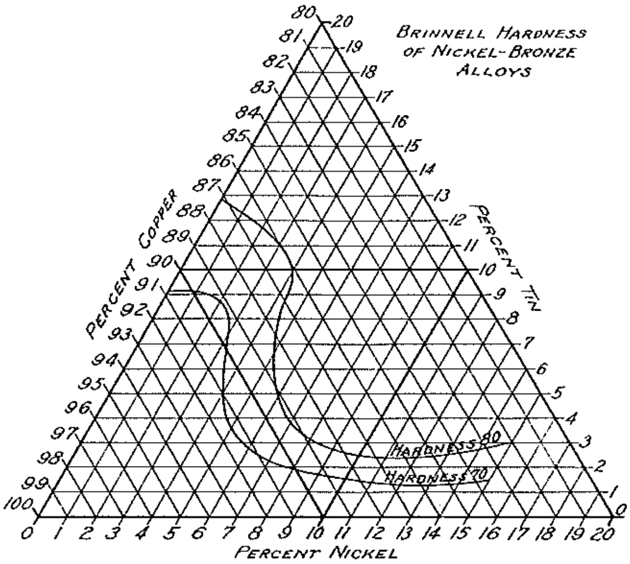


Fig. 19.7. Trilinear curve.

19.7 Trilinear charts. Trilinear charts are in the form of an equilateral triangle. The coordinates are ruled parallel to the sides, and the altitude perpendicular to any side represents 100. These charts are

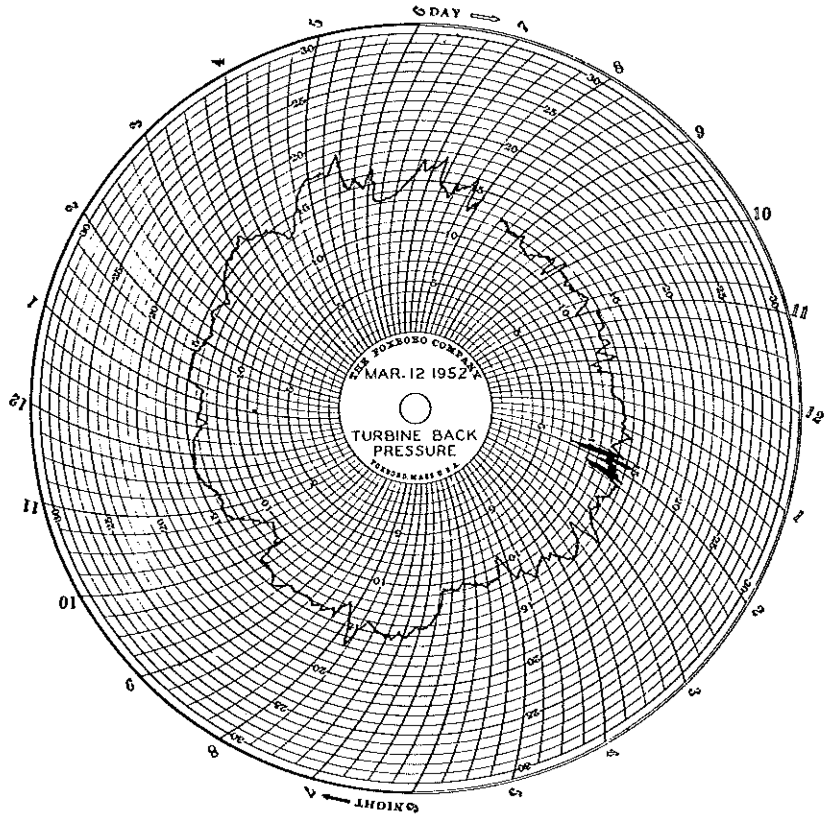


Fig. 19.8. Polar coordinate chart.

useful in comparing properties of chemicals or alloys composed of three substances, as shown in Fig. 19.7. The equilateral triangle has the property that the sum of the perpendiculars to the three sides from any point inside is equal to the altitude of the triangle. It will be noted in Fig. 19.7 that only a portion of the complete triangle has been drawn since the curves lie in one corner and it would be a waste of space to show the remainder of the blank chart.

19.8 Polar charts. These charts are useful when equations are given in polar coordinate form or when quantities radiating from a center are involved, as, for example, illumination charts. They are also used in modified form upon continuous recording devices, as illustrated in Fig. 19.8. The radiating lines are curved in this case because the recording stylus is pivoted at a fixed center.

19.9 Pie diagrams or sector charts. These charts, circular in form, are used to show the relative distribution of the parts of a whole, as illustrated in Fig. 19.9. Other common examples are the distribution of the tax dollar, or the costs of production in an industry. They are quite effective and simple to make. If the sector areas are shaded, Zip-A-Tone may be used.

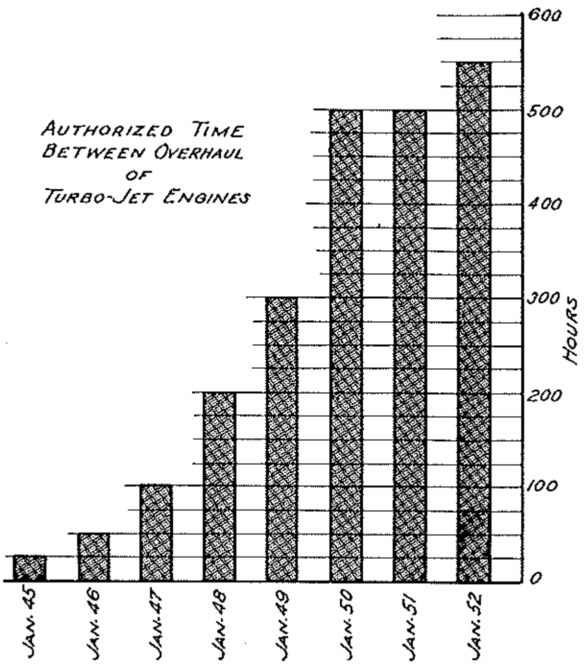


Fig. 19.10. Bar diagram.

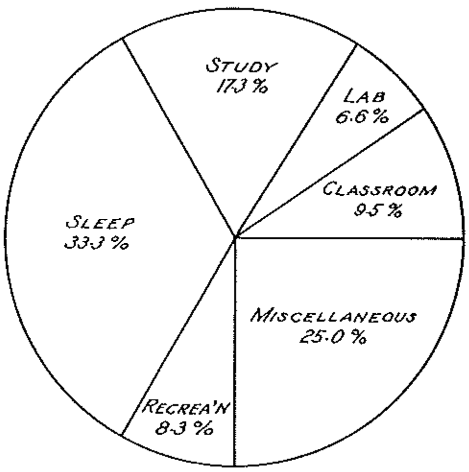


Fig. 19.9. Pie diagram.

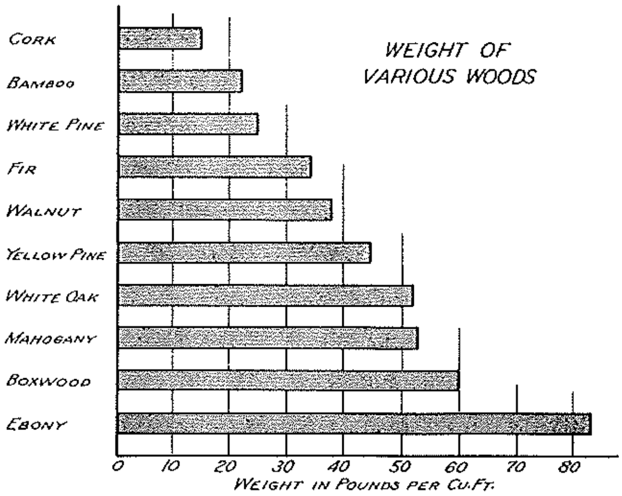


Fig. 19.11. Horizontal bars.

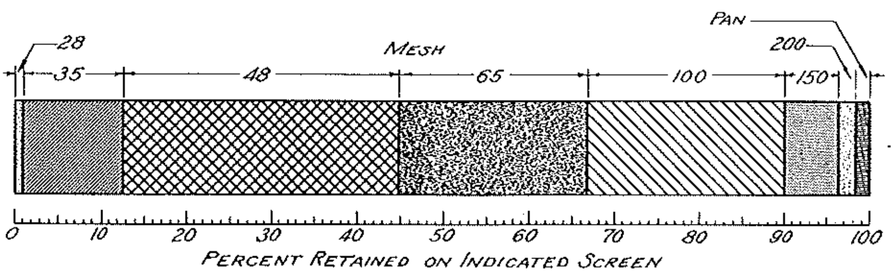


Fig. 19.12. A 100 per cent bar chart.

19.10 Bar charts. Bar charts are more commonly used for the popular presentation of facts since they are easy for the average layman to interpret. Bar charts may have the bars either vertical or horizontal, as shown in Figs. 19.10 and 19.11. They may be additive, as in Fig. 19.12, or comparative, as in Fig. 19.13. The same general rules used for rectangular coordinate charts apply here with only slight modification. Shading of the bars can be done most economically with Zip-A-Tone, a commercial product available from The Para-Tone Company, Chicago, Illinois.

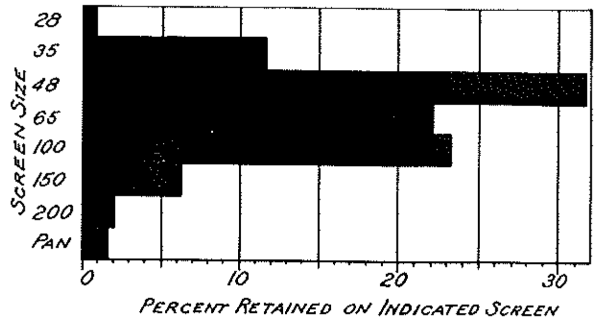


Fig. 19.13. Histogram.

19.11 Flow and organization charts. In the process industries it is often desirable to trace the raw material through the various stages of handling to the finished product. This is readily accomplished by a flow chart, as illustrated in Fig. 19.14.

Charts showing the lines of authority or responsibility from chief executive to the minor departments can also be shown in this type of chart, which is then called an organization chart. For formal presentation, the lettering on such charts is usually done mechanically with Wrico or Leroy lettering guides.

19.12 Distribution diagrams. These diagrams usually take the form of maps and may show a wide variety of information useful in business operations, such as distribution of sales, density of population, etc. A good map of the area under consideration is a basic

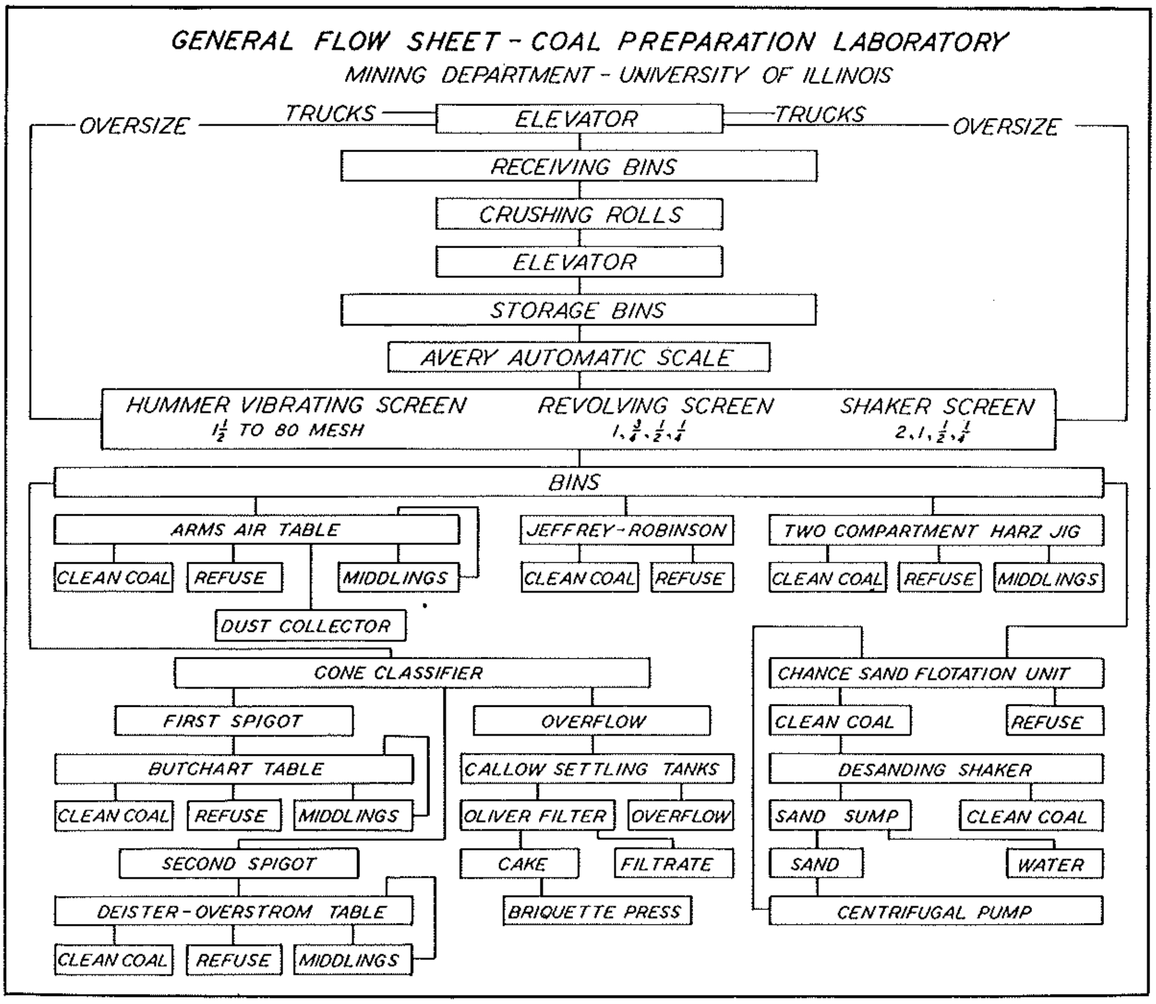


Fig. 19.14. Flow chart.

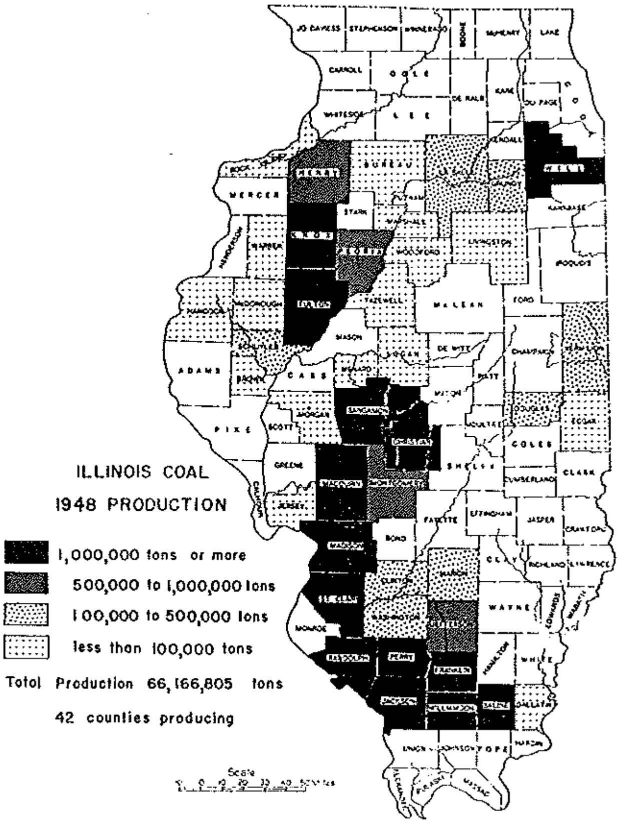


Fig. 19.15. Distribution chart.

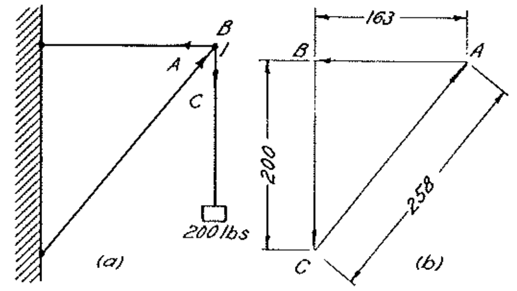


Fig. 19.16. Vector diagram.

requirement. These are usually traced from existing maps in atlases or the like. A typical example is shown in Fig. 19.15. In addition to location, quantitative values are usually involved. These values are shown by different types of shading.

19.13 Computation charts. Though many of the foregoing charts can be used to simplify calculations, a number of charts are designed specifically for that purpose.

a. Vector Diagrams. These diagrams may be used to solve problems involving quantities which have both magnitude and direction, such as forces, velocities, and accelerations. The only geometry involved is the ability to draw one line parallel to another and to use a scale.

Thus, in Fig. 19.16, a wall crane is shown supporting a load of 200 lb. Bow's system of notation is used. Any line is designated by the letters on opposite sides of it. Thus the known force of 200 lb is noted as *BC* in Fig. 19.16(*b*) and is drawn in a downward direction at a scale of 100 lb = 1 inch, or 2 inches long. From *C*, a line is drawn parallel to the sloping member of the crane of random length. A second line is drawn from *B* parallel to the horizontal member of the crane until it intersects the sloping line from *C*. The lines in Fig. 19.16(*b*) may now be scaled to give the magnitude of the stresses in the two members of the crane. The arrows are drawn in a continuous direction around the triangle and indicate the direction in which the forces act at joint *1*. Thus the member *CA* is in compression, and the member *AB* is in tension.

A more complicated stress (vector) diagram for a truss is shown in Fig. 19.17. For other illustrations, see Arts. 14.13.2 and 14.49.

b. Derivation of Empirical Equations. It is sometimes desirable to find the equation which expresses mathematically the results of test data. The method may be described briefly as follows:

1. Plot the data from the test on various types of coordinate paper until a straight line is secured.

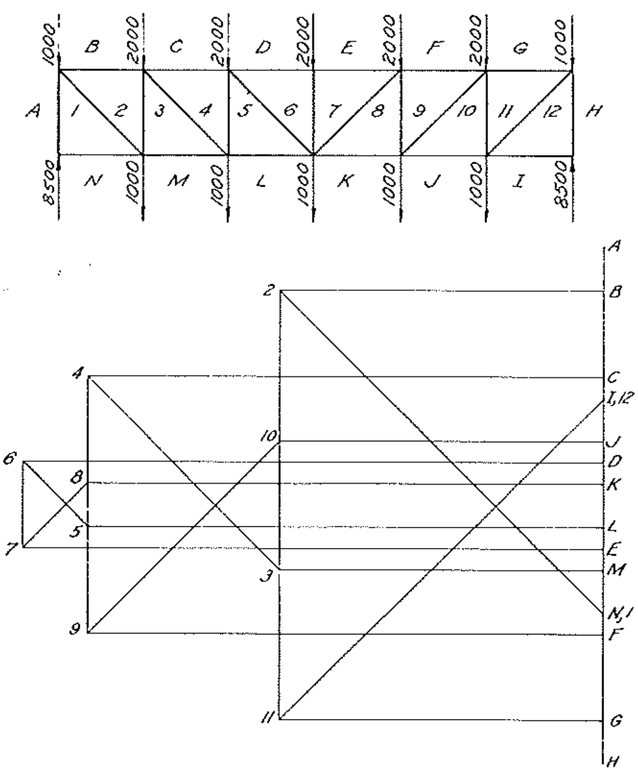


Fig. 19.17. Vector diagram.

2. By the methods of analytical geometry, determine the equation of the straight line. Several methods are available as follows.

(*a*) Slope and intercept.

(*b*) Two points.

(*c*) Method of averages.

(*d*) Method of least squares.

The second method will be used for a simple illustration, assuming that the data of Fig. 19.18 are plotted on logarithmic paper as a straight line.

When the equation assumes the form of $y = ax^m$, it will plot as a straight line on log-log paper. This equation may also be written $\log y = \log a + m \log x$, and in this form it is not difficult to find the equation of the line by the two-point method.

First assume two points near the ends of the line, such as *A* and *B* in Fig. 19.18, and read the coordinates from the graph as accurately as possible.

Point	Loss in Watts	Volts
A	800	128
B	4340	300

By substituting these values in the equation $\log y = \log a + m \log x$, the following equations are obtained.

$$\log 800 = \log a + \log 128m \qquad (1)$$

$$\log 4340 = \log a + \log 300m \qquad (2)$$

These equations then become

$$2.903 = \log a + 2.107m \qquad (3)$$

$$3.637 = \log a + 2.477m \qquad (4)$$

Subtract to eliminate $\log a$

$$0.37m = 0.734$$

$$m = 1.984$$

The value of m may be substituted in equation 3 or 4 to determine the value of $\log a$, or an independent calculation may be made as follows: Multiply equation 3 by 2.477/2.107

$$3.413 = 1.176 \log a + 2.477m \qquad (5)$$

$$3.637 = \log a + 2.477m \qquad (6)$$

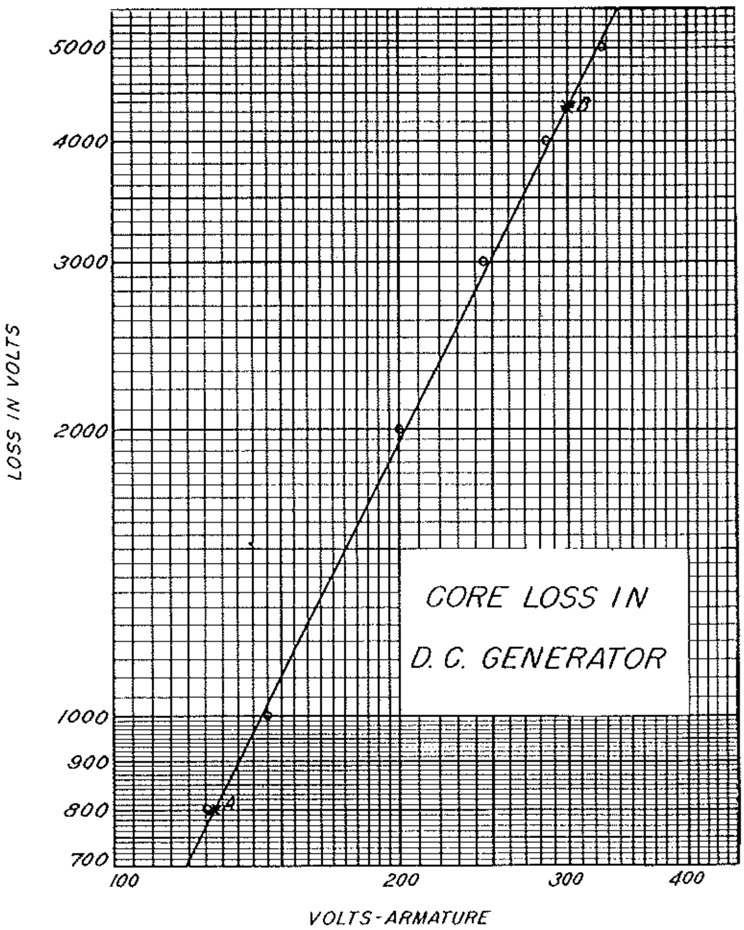


Fig. 19.18. Derivation of empirical equation.

Subtract equation 6 from equation 5

$$-0.224 = 0.176 \log a$$

$$\log a = -1.273$$

$$a = 0.053$$

The equation of the curve is therefore $y = 0.053x^{1.084}$ or

$$\text{Loss in watts} = 0.053E^{1.084}$$

where E equals volts.

c. Functional Scales. The following terms should be understood by the student from his previous mathematics courses.

A constant is any quantity which has only one value in any equation.

A variable is a quantity which may have any value between certain limits.

A function of a variable is any quantity which involves the variable. Thus if X is a variable, X^2, $\sin X$, $(1 + X)$, and $1/X$ are functions of the variable.

To prepare a scale for any function, the following steps are necessary.

1. Assign values to the variable at suitable intervals over the range desired for the scale.
2. Compute the value of the function for these values of the variable.
3. To some convenient scale, plot the values of the function on a straight line.
4. Number the plotted points with the values of the variable (not the function).

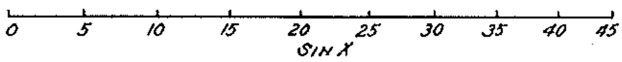


Fig. 19.19. Functional scale for sin X.

As an illustration, let it be required to make a functional scale for the function sin X from 0° to 45°.

1. Values of the variable.

5° 10° 15° 20° 25° 30° 35° 40° 45°

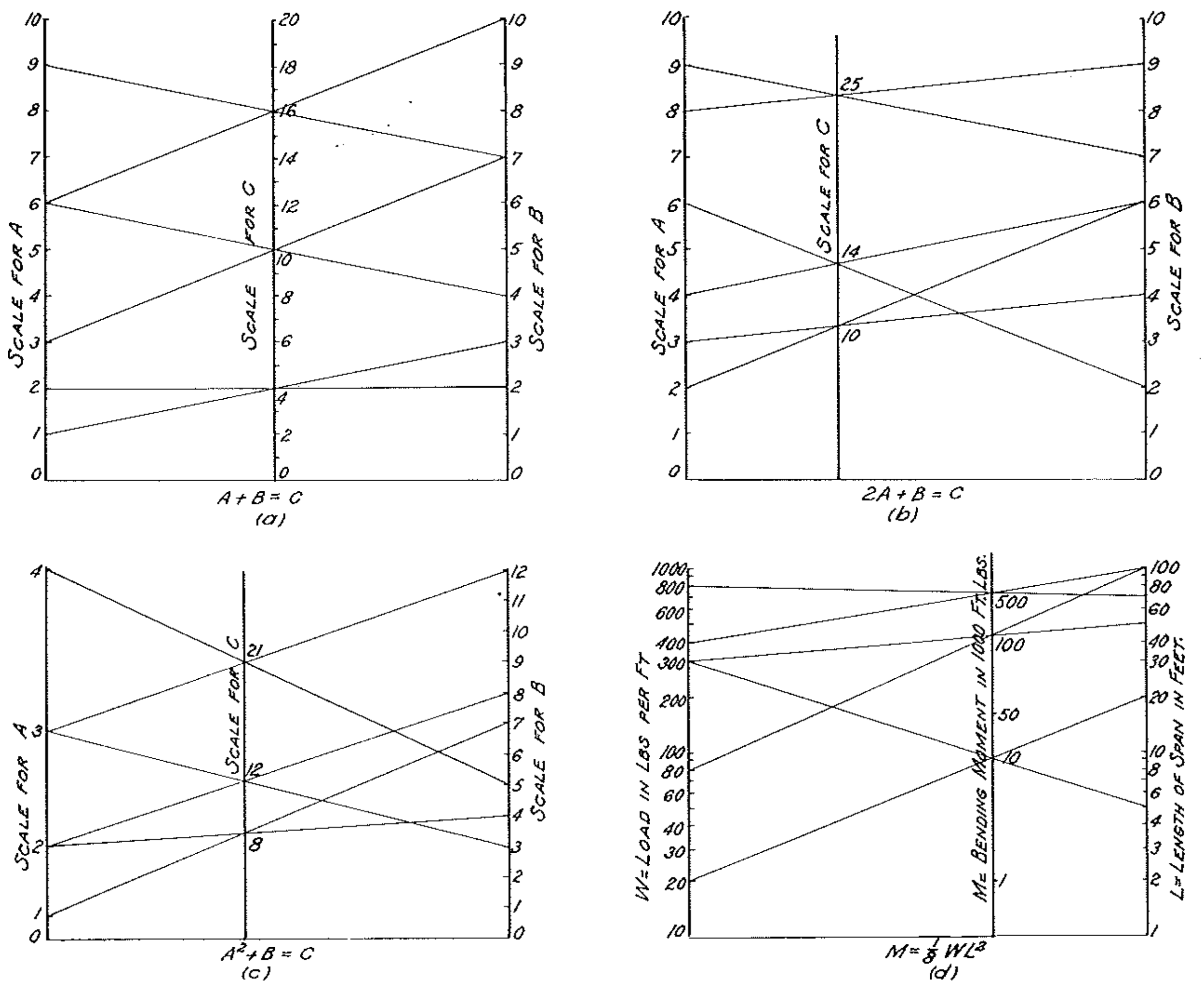


Fig. 19.20. Nomographs.

2. Computed values of the functions.

.087 .174 .259 .342 .423 .500 .574 .643 .707

3. Plot the values in (2) above as in Fig. 19.19, using a scale of 4.5″ = 1 unit. Other scales could be used to obtain greater or lesser length.

4. Mark the scale with the values listed in (1) above. See Fig. 19.19.

d. Nomographs. Nomographs, sometimes called alignment charts, are very useful in engineering offices when it is necessary to solve the same equation repeatedly by using different values of the variables.

The difficulty of making a suitable nomograph will depend upon the complexity of the equation. Only a few simple illustrations can be given here. For a more complete treatment of the subject, see *Graphic Aids in Engineering Computation* by Hoelscher, Arnold, and Pierce, McGraw-Hill Book Co., New York.

Let it be required to make a nomograph for a simple sum like $A + B = C$, between the limits 1 and 10 for both A and B.

This chart will have three parallel scales, and the term that appears on one side of the equation by itself is the middle scale. The procedure is as follows: (1) lay out functional scales for A and B at a convenient distance apart, as shown in Fig. 19.20(*a*); (2) assume a convenient value of C. Then choose two values of A, and solve the equation twice for the corresponding values of B. Thus, for example, assume a value for C equal to 4 and for A equal to 2 and then 3. The corresponding values of B will be 2 and 1. Draw two lines across the chart connecting the corresponding values of A and B. These will intersect at a point whose value on the C scale is 4, as shown in Fig. 19.20(*a*).

Repeat this process to locate as many values of C as desired. These will normally be integral values. Subdivide the spaces on the C scale as desired.

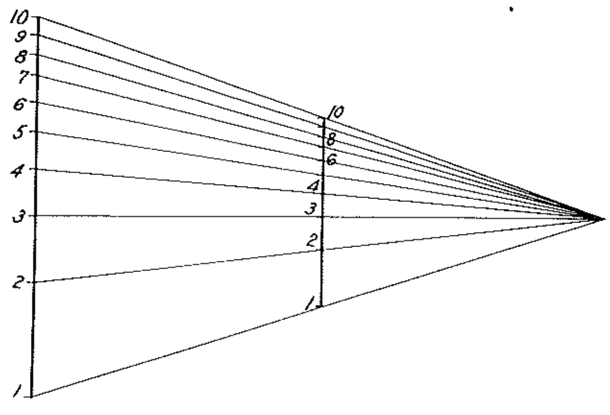


Fig. 19.21. Construction of logarithmic scale.

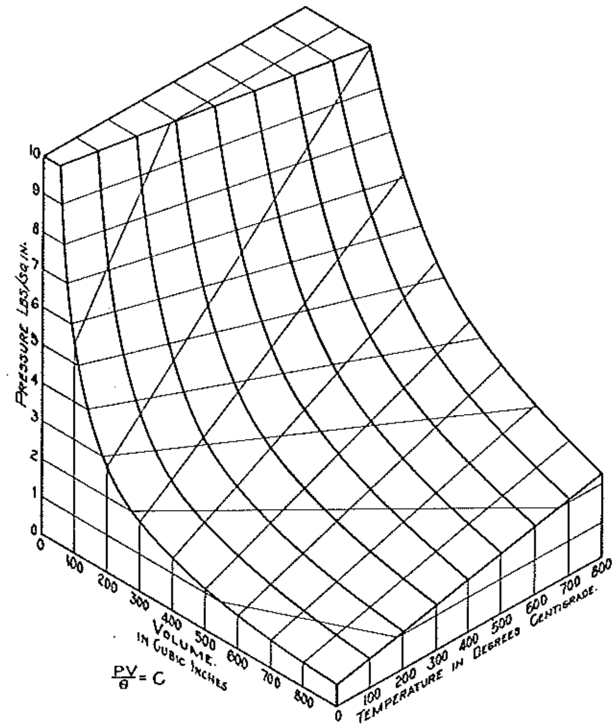


Fig. 19.22. Three-dimensional chart.

In Fig. 19.20(*b*), it will be noted that the scale used for plotting the function $2A$ is only one-half that for the B scale. As a consequence, the C scale is shifted to one side. In Fig. 19.20(*c*), the A scale is a squared scale. Note that the values of the variable A not the function A^2 are marked on the scale.

In Fig. 19.20(*d*), the equation for the bending moment in beams, $M = \frac{1}{8}WL^2$, is solved. The first step in preparing a nomograph for this equation is to change the equation into a suitable form as a sum or difference of the variables. This can be done by taking logarithms of both sides of the equation. It may then be written:

$$\log 8 + \log M = \log W + 2 \log L$$

Let the span (L) range from 1 to 100 ft and the load (W) from 10 to 1000 lb per ft.

Logarithmic scales may then be laid out for L and W, and the scale for moments M may be located as before. In cases of this kind it is best to choose values of M such as 10 and 100 or 100 and 1000, which will determine the length of one logarithmic cycle.

A logarithmic functional scale of any convenient length can be laid out by plotting accurately one large scale from logarithmic tables and then drawing lines from this scale to a point, as shown in Fig. 19.21. A line can be drawn across this triangle parallel to the

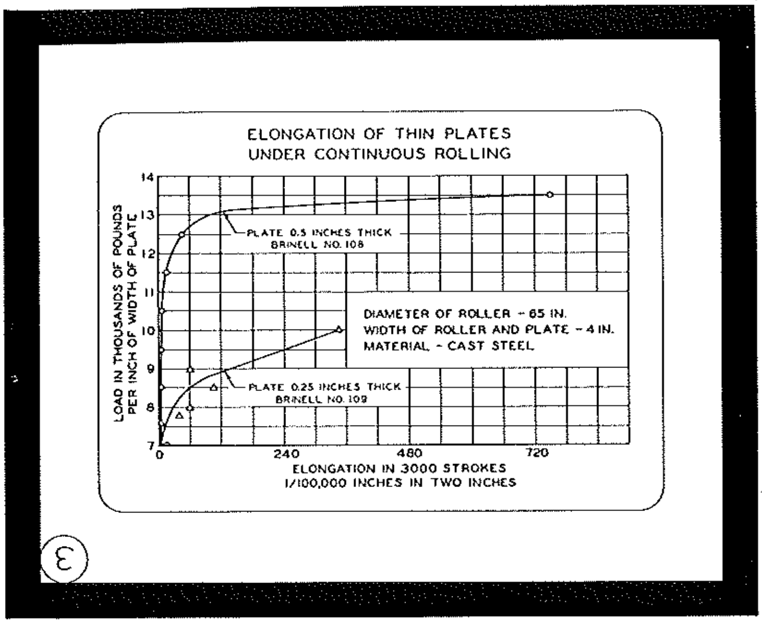


Fig. 19.23. Lantern slide.

original scale to give a logarithmic scale of any desired length within limits of the triangle.

19.14 Three-dimensional charts. Three-dimensional charts are based upon one of the pictorial forms of projection discussed in Chapters 16, 17, and 18 of this book. They are useful for illustrating in a popular way the relationship between three variables. Figure 19.22 shows a chart of this type.

19.15 Charts and diagrams for publication or lantern slides. Many times in teaching or in public discussion it is desirable to have charts prepared for reproduction as lantern slides, as illustrated in Fig. 19.23. For those who have occasion to make drawings for this purpose it is recommended that a copy of ASA Y–15.1 (formerly Z–15.1) "Engineering and Scientific Charts for Lantern Slides" be procured and followed as a guide.

Problems

The information contained in the following problems should be shown in chart form according to specifications in the book or from the instructor. If these are not given, the student should select the best form of presentation for any particular data.

Each chart should be complete with proper titles, coordinate markings, and any other necessary information. It is recommended that $8\frac{1}{2} \times 11$ inch paper be used for these charts, and commercial coordinate papers should be used when available.

Coordinates are not specified. The student should select his own values to give the best results.

Plane Curves—Rectangular Coordinate Paper

1. Plot a curve for the areas of circles, $A = \pi r^2$, of radii varying from 0 to 14′.

2. Plot a curve for the areas of spheres, $A = 4\pi r^2$, of radii varying from 0 to 14′.

3. Plot a curve for the volume of spheres, $V = .5236d^3$, for diameters from 0 to 10′.

4. Plot a curve for computing the volume of a liquid at different depths in a segment of a hemisphere 20′ in diameter. $V = \pi h(c^2/8 + h^2/6)$, where h = depth of liquid and c = diameter of liquid surface. Show a sketch in your chart to explain the terms in the equation.

5. Plot a curve for computing the volume of a liquid at different depths in a cylindrical tank whose axis is horizontal, and whose diameter is 10′. Carry the curve from zero to a full tank by 1′ intervals. Make a diagram showing the meaning of terms in your equation. Consult a handbook for necessary equations.

6. The equation for the bending moment of a beam is $M = \frac{1}{8}WL^2$, where M = the bending moment in foot-pounds, W = the uniform load in pounds per foot of beam, and L = the span in feet. Compute and plot three curves for these values of W, namely, 100, 200, and 300 lb per ft, for all spans from 5 to 35′.

7. Plot a curve for wind pressures on a flat surface normal to the wind as given by Marvin's formula, $P = .004V^2$, where P is the pressure in pounds per square foot and V is the velocity of the wind in miles per hour. Use values of V from 0 to 100 miles per hour.

8. Plot a curve showing the growth in population of your state. Data from U. S. Census.

9. Plot a smooth curve showing the maximum rainfall to be expected for any period of time from the following data. Note: The curve will pass along the upper boundary of the plotted points. One or two extreme points may be outside of the curve.

Storm Intensity Data

Column A: Duration of storm in minutes.
Column B: Rainfall in inches per hour.

A	B	A	B	A	B
121	0.78	27	3.52	63	2.06
122	1.18	18	4.31	15	3.10
25	1.21	32	2.70	15	3.62
56	1.26	26	2.92	15	4.51
103	2.10	180	0.90	60	1.20
63	1.32	82	0.70	56	2.20
32	2.11	70	1.10	22	3.93
38	1.82	72	1.77	12	4.88
34	2.80	70	1.90	7	5.92
4	5.92	45	1.30	11	2.30
10	5.10	24	1.61	16	3.87
10	4.15	8	1.46		

10. Draw stress-strain diagram for mild steel from the data given below. Plot strain on the horizontal axis.

Mild Steel

Unit Stress	Unit Strain	Unit Stress	Unit Strain
0	0	32,800	0.0022
4,080	0.00012	33,500	0.0030
7,670	0.00025	34,400	0.0052
11,100	0.00037	37,000	0.0250
15,400	0.00050	47,000	0.0625
18,700	0.00063	52,000	0.1000
23,200	0.00075	53,400	0.1250
26,700	0.00087	54,100	0.1500
30,100	0.0010	54,800	0.1875
32,800	0.00113	55,100	0.2375
33,800	0.00119	54,700	0.2625
32,700	0.0015	47,500	0.3125

11. Draw a stress-strain curve for mild steel from the data above. Plot only as far as the 37,000-lb load. Plot strains horizontally, and select coordinates so that the curve goes well across the sheet.

12. Same as Problem 10. Use data for duralumin.

Duralumin

Unit Stress	Unit Strain	Unit Stress	Unit Strain
0	0	35,700	0.0087
4,520	0.0004	36,300	0.0107
9,100	0.0008	37,300	0.0130
15,820	0.00143	41,300	0.0250
20,300	0.00186	46,100	0.0500
24,900	0.0023	48,000	0.0625
29,400	0.0030	50,100	0.0750
32,000	0.0044	51,500	0.1000
33,500	0.0057	53,300	0.1250
34,500	0.0069	53,500	0.1600

13. Same as Problem 10. Use data for brass.

Free-Cutting Brass

Unit Stress	Unit Strain	Unit Stress	Unit Strain
0	0	34,900	0.0083
5,750	0.00033	35,200	0.0100
10,600	0.00066	36,600	0.0133
16,800	0.00122	37,500	0.0208
21,600	0.00166	39,100	0.0333
26,300	0.0023	40,800	0.0667
29,200	0.0030	44,200	0.1000
32,200	0.0039	47,500	0.1500
32,200	0.0051	49,400	0.2000
34,000	0.0059	50,500	0.2333

14. Same as Problem 1. Plot on logarithmic paper.
15. Same as Problem 2. Plot on logarithmic paper.
16. Same as Problem 3. Plot on logarithmic paper.
17. Same as Problem 6. Plot on logarithmic paper.
18. Same as Problem 7. Plot on logarithmic paper.

Semilogarithmic Chart

19. Same as Problem 8. Use semilogarithmic paper.

Bar Charts

20. Make a bar chart comparing the loss of weight of various metals in different solutions as given in the table below. Group the three bars for each metal together.

Action of One-Half Liter of 0.2 N Salt Solutions, Renewed Daily for 7 Days, on Metals at 17° to 20° C

Loss in grams per square meter per hour

Metal	$MgCl_2$	$CaCl_2$	NaCl
Zinc	0.57	0.21	0.06
Cast iron	0.51	0.12	0.06
Wrought iron	0.51	0.18	0.15
Aluminum	0.10	0.03	0.00
Lead	0.33	0.24	0.01
Copper	0.15	0.12	0.01
Tin	0.10	0.08	0.00
Nickel	0.03	0.05	0.00

21. Plot the following information in the form of:
a. A barograph.
b. A pie diagram.
c. A 100% bar chart.
d. A histogram.

Distribution of the Operating Money of a State University

Item	Amount	Per Cent
Instruction	15,200,000	36
Related activities	2,900,000	7
Organized research	8,400,000	20
Extension and public service	4,200,000	10
Libraries	1,300,000	3
Physical plant	5,830,000	14
Administration	3,002,000	7
Retirement, etc.	1,093,000	3

22. Plot the following information in the form of:
a. Plane curve.
b. Barograph.
c. 100% Bar.
d. Histogram.

Screen Analysis of Medium Sand

Screen	Size of Opening	Amount Passing in Pounds
#100	0.0055	0.75
#50	0.011	3.00
#40	0.015	5.75
#30	0.022	10.00
#20	0.034	14.25
#10	0.073	20.50
1/8 in.	1/8	21.75
3/16 in.	3/16	23.25
1/4 in.	1/4	25.00

23. A weight of 150 lb is suspended by two ropes, one of which makes 75° with the ceiling and the other 60°. Find the stress in each rope.

Trilinear Chart

24. Make a trilinear chart for the data shown in the table below. Let the upper vertex represent 100% volatile matter, the left vertex 100% moisture. Plot a smooth "coalification curve" through the points. A coalification curve shows the changes from peat to anthracite due to geologic forces. The left wing of the curve shows the loss of moisture due to vertical pressure, the right wing the loss of volatile matter due to lateral pressure.

Analysis of Fuel on Ash-Free Basis

Type	Per Cent Moisture	Per Cent Volatile Matter	Per Cent Fixed C
Anthracite	4.1	4.8	91.1
Semianthracite	4.0	11.2	84.8
Bituminous A	2.8	20.2	77.0
Bituminous B	3.2	36.3	60.5
Bituminous C	12.0	39.1	48.9
Bituminous D	19.8	35.7	44.5
Lignite	37.6	29.6	32.8
Peat	81.6	12.4	6.0

Sector Diagrams

25. Make a sector diagram showing the distribution of the various items entering into the cost of government in the island of Puerto Rico.

Items	Per Cent
General government	14.4
Protection	9.6
Education	29.4
Social welfare	9.7
Highways and streets	13.7
Economic development	5.8
Public utilities	10.2
Debt service	7.2

26. Secure data and make a chart showing the distribution of the tax dollar in your community.

Map Drawing 20

20.1 For the planning and construction of many engineering undertakings, it is necessary to have representations of the earth's surface. Such representations are called maps. When the area to be shown is small, a map is essentially a one-view orthographic projection, and hence only two dimensions can be shown. This is frequently sufficient. Where the third dimension, namely, the difference in elevation of the earth's surface, is essential, symbols are used to give this information. If the area to be shown is large or if extreme accuracy is desired, then other types of projection are used. Such projections are beyond the scope of this book.

20.2 Classification of maps. Maps are conveniently classified upon the basis of their purpose or intended use. On this basis, Professor E. R. Stuart divides maps * into four classes which he calls geographic, topographic, cadastral, and engineering. Although no hard and fast lines can be drawn between the various classes of maps, the distinctions are usually quite clear, as may be noted from the descriptions in the following paragraphs.

20.3 Geographic maps. Maps of this group show a comparatively large area, and must, therefore, be drawn to very small scales, which means, of course, that only the more important features of the earth's surface can be shown, such as the larger rivers and lakes, mountains, cities, and railroads. On these maps, the cities are located by small circles, and only the larger curves in streams and the principal changes of direction of the railroads are shown. Examples of such maps are to be found in any atlas or geography textbook, and hence are familiar to everyone. The scales vary from a few miles to the inch to several hundred miles to the inch. Relief, or difference of elevation, is shown in a very general way, usually by hachures or shading.

* *Topographical Drawing*, by Edwin R. Stuart, U. S. Military Academy.

20.4 Topographic maps. The term topography means the configuration or shape of the land surface of any area. Because of the details which must be shown, the area covered by such maps is quite small as compared to geographic maps. The most widely known maps of this class are those prepared by the United States Geological Survey. A small portion of such a map is shown in Fig. 20.1. Figure 20.1 is taken from the Urbana Quadrangle in Illinois in flat country.

U. S. Geological maps are made to the following scales, determined by the needs in the economic development of the area shown. These maps are always bounded by meridians of longitude and parallels of latitude.

The larger scales shown below are used in the more highly developed areas and the smaller ones in more sparsely settled or desert regions. The arc of latitude and longitude covered is the same in both directions. A scale of 1:24,000, 1″ = 2000 ft, covers $7\frac{1}{2}$ minutes of latitude and longitude.

1:62,500, 1″ = nearly 1 mile.
1:125,000, 1″ = nearly 2 miles.
1:250,000, 1″ = nearly 4 miles.

Index maps and circulars of each state, Alaska, Hawaii, and Puerto Rico showing the areas covered by topographic and planimetric maps are available without charge from the United States Geological Survey, Washington 25, D. C. The charge for individual maps is given in the circulars.

The large-scale maps show all the natural features down to little streams which run dry in the summer. City streets, country roads and trails, tunnels, aqueducts, pipelines underground, bridges, houses, and all the works of man together with permanent vegetation such as forest areas are shown. A portion of a privately made topographic map is shown in Fig. 20.2.

20.5 Cadastral maps. Maps of this class are used primarily for showing political and civil boundaries, together with property lines, and are used for the pur-

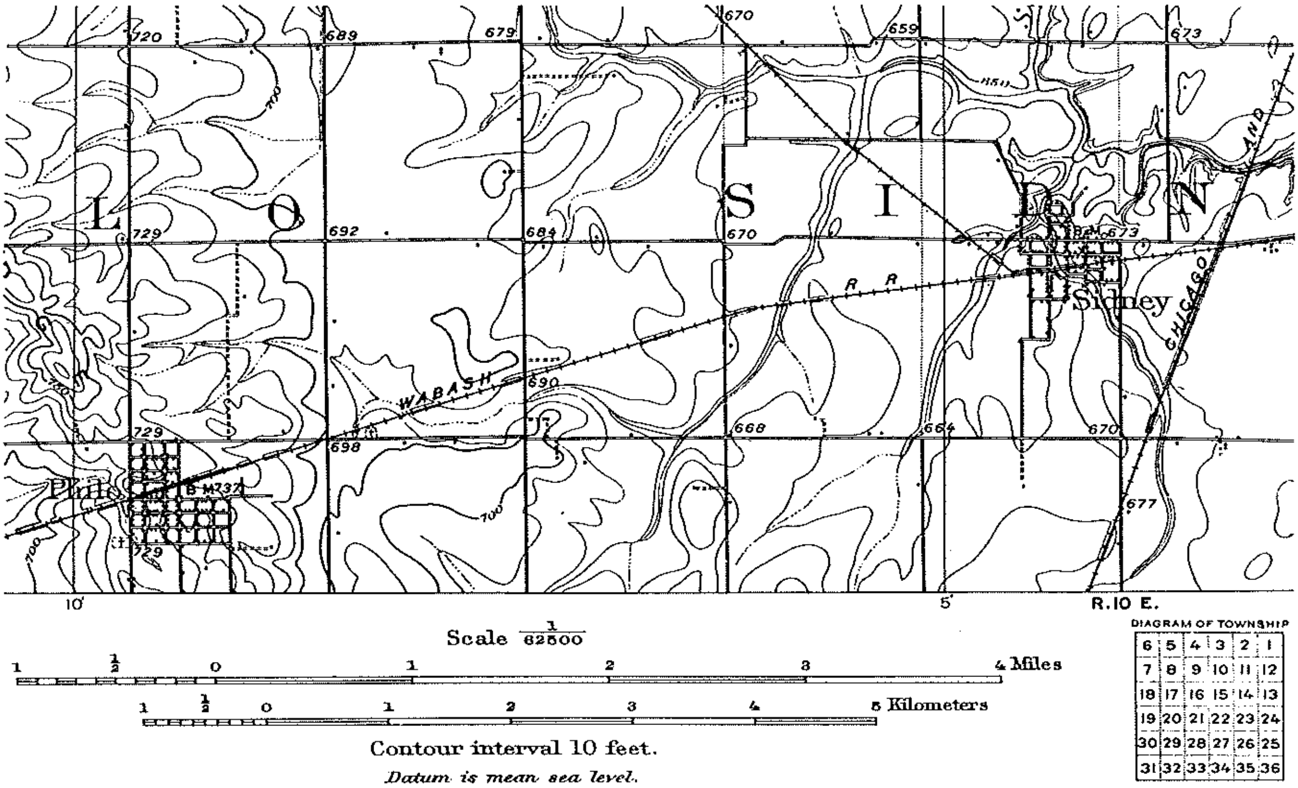


Fig. 20.1. Topographic map. Part of Urbana, Illinois, Quadrangle.

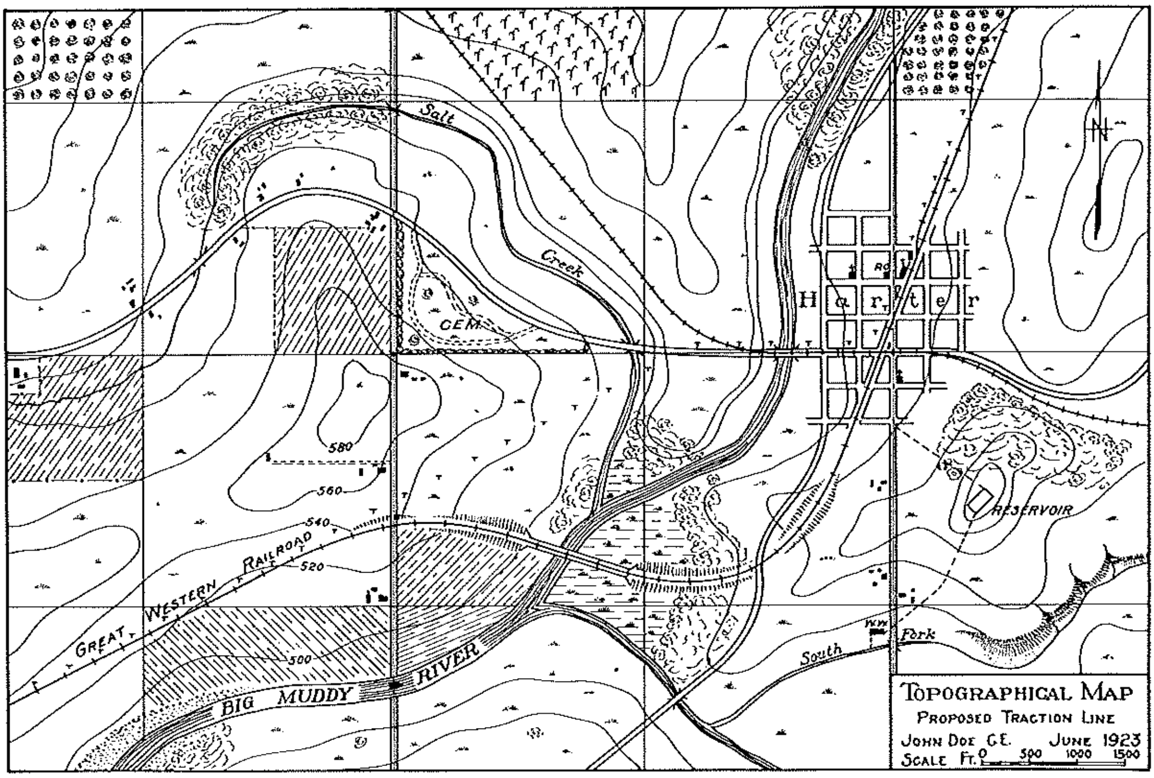


Fig. 20.2. Topographic map.

poses of taxation and the transfer of property. Hence, because of the accuracy required, such maps must be drawn on a still larger scale than either of the preceding classes. They contain, besides the property lines, only enough of the natural features, such as streams and roads, to enable one to locate the corresponding lines on the ground. Plats of city additions, mineral rights, farm surveys, and the like fall in this group. The scale for such maps is usually greater than 6 inches to 1 mile.

20.6 Engineering maps. Maps drawn for reconnaissance, construction, or maintenance purposes are called engineering maps. The scale is seldom smaller than 1 inch equals 400 feet, and it may approach the architectural scales as the other limit, as for example, ⅛ inch equals 1 foot. Maps for railroad, highway, canal, or hydroelectric construction are excellent examples of this class of maps. Such maps frequently have the character of topographic maps in that they include the contour lines, the natural features, and works of man. Being on a larger scale, they are, of course, much more accurate in detail than the usual topographic map. A portion of a highway construction map is shown in Fig. 20.3.

Public utility companies use what are in effect large-scale cadastral maps to show the location of their lines and connections thereto. Figure 20.4 is a portion of a water company map showing the location of the water mains, fire hydrants, and connections to private property.

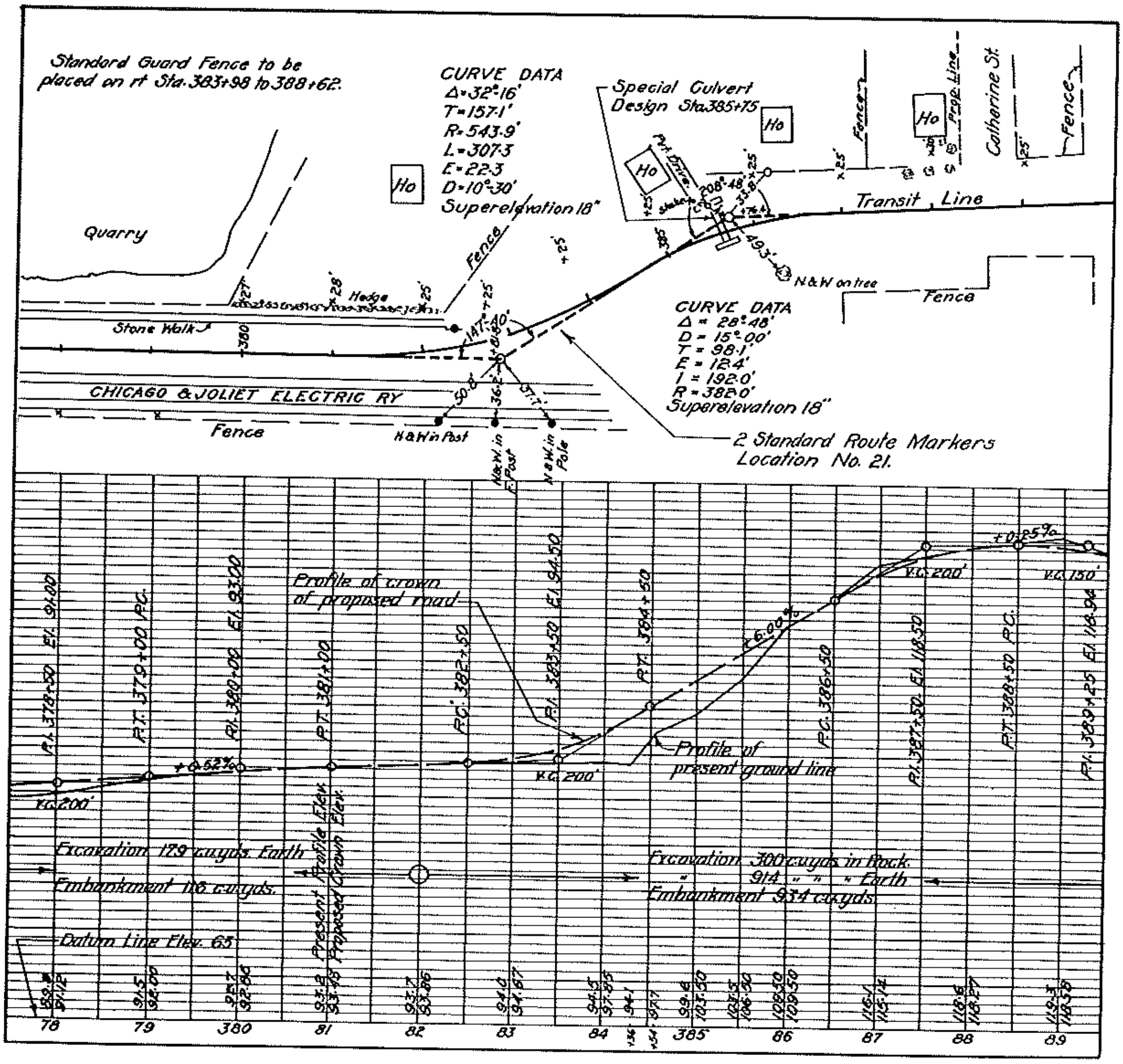


Fig. 20.3. Highway map and profile.

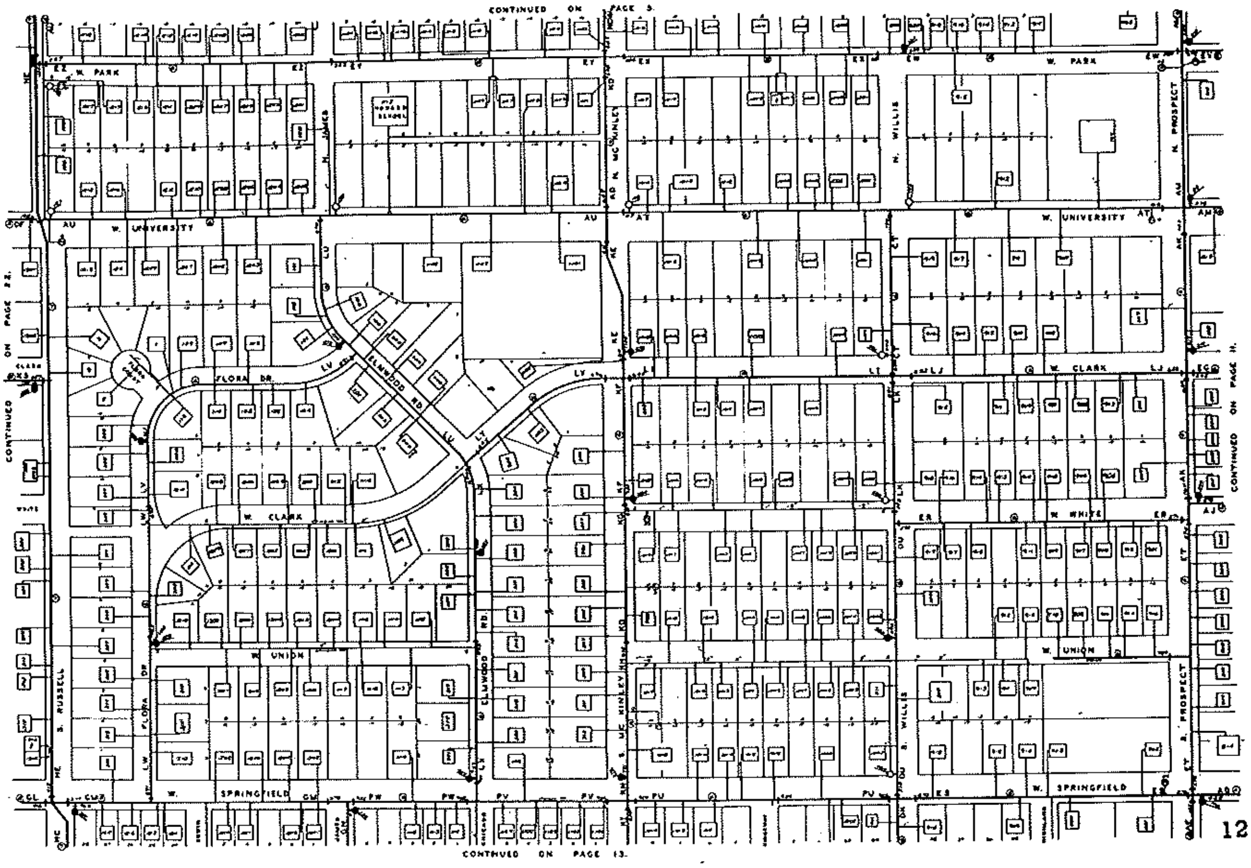


Fig. 20.4. Map of city water supply system. Courtesy Northern Illinois Water Corp.

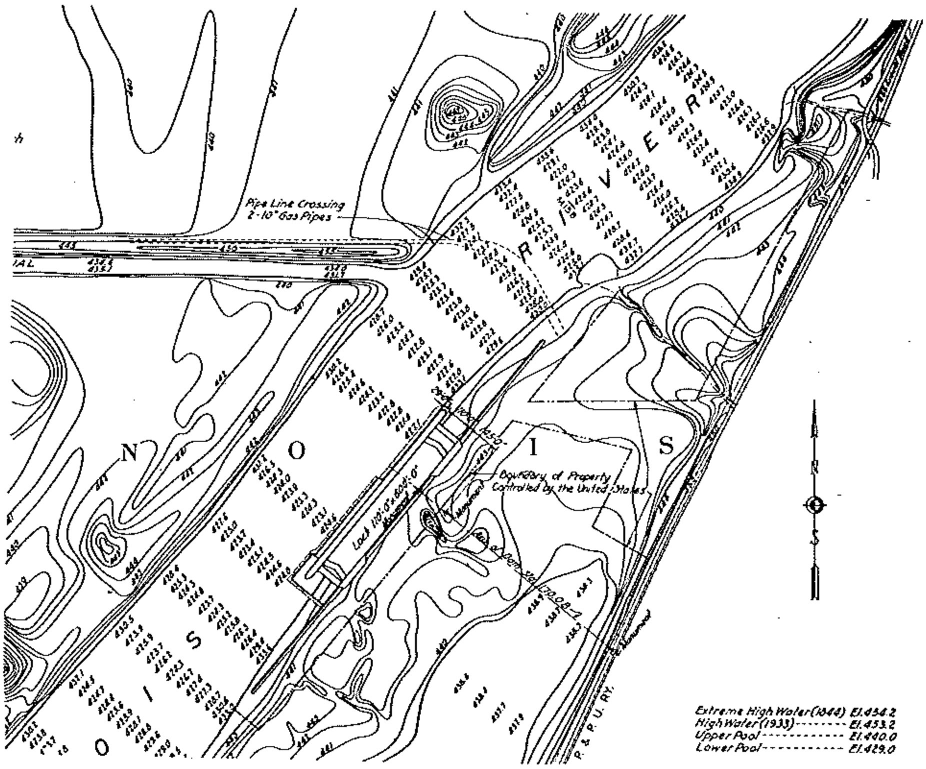


Fig. 20.5. Contour map for construction.

Contour maps, showing principally the elevation of the land, are used for location, estimating costs, and construction. A map of this type is shown in Fig. 20.5. Further details concerning the use of contour maps are discussed in Arts. 20.26 and 20.27.

20.7 Military maps. This book is concerned primarily with engineering maps for civilian use but there is a close connection between topographic maps for this use and military maps. Military maps may be classified according to the scale, which definitely determines the area that can be represented and the use of the map.

Small-scale maps with scales ranging from 1:1,000,000 to 1:7,000,000 are used for strategical planning by commanders of large forces.

Intermediate scale maps with scales varying from 1:200,000 to 1:500,000 are used for planning operations, troop movements, concentrations, and supply.

Medium-scale maps with scales running from 1:50,000 to 1:125,000 are required for tactical and administrative studies for units of the size of regiments. U. S. Geological maps (1:62,500) are suitable for this purpose.

Large-scale maps of about 1:20,000 are used for tactical and technical battle needs.

Symbols for military maps are quite extensive and may be found in a booklet called *Military Symbols,* see next column.

20.8 Map scales. From the foregoing classification of maps, it will be noted that scales are used ranging from .1 inch equals 1 foot as the largest to 1 inch equals several hundred miles as the smallest. The scale of a map is shown both graphically and numerically at some place near the title or as a part of it, as shown in Fig. 20.1. Sometimes the numerical scale is stated as a ratio. Thus, a scale of 1 inch to the mile is expressed as 1:63,360.

Survey measurements are made in feet and fractions of feet, which are expressed in feet and decimals of a foot instead of in feet and inches; hence the engineer's scales on the boxwod rules are in the decimal system, and have 10, 20, 30, etc., divisions to the inch. These units may also represent 1, 2, or 3 feet to the inch, 10, 20, or 30 feet to the inch, or 100, 200, or 300 feet to the inch. All these scales occur frequently in engineering work.

The selection of a scale for a map will be influenced by many factors, chief among which are: the size and character of the area to be shown, the form in which the map is to be presented, and the purpose for which it is to be used. Cost of preparation and length of service must sometimes be considered.

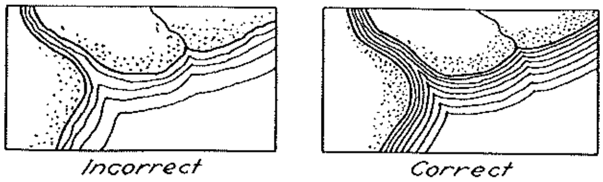


Fig. 20.6. Symbol for water lining.

20.9 Map symbols. Since the scale of any map is small, relatively speaking, the representation of objects upon it must be highly conventionalized. Upon all but the largest-scale engineering maps, even the largest objects must be shown by symbols rather than by plan views of them. The purpose of a map is, after all, not to show the exact appearance from above, but, rather, to show the comparative size of objects and their position relative to one another. Hence, conventional symbols have been devised which bear some resemblance, where possible, to the objects themselves. The purpose of having this resemblance is for convenience in interpretation.

A well-standardized system of symbols, used by practically all map-making departments of the government, is published in a small booklet called *Military Symbols* published by the Departments of the Army and the Air Force as Document FM 21–30.

20.10 Size and prominence of symbols. The size of symbols should vary only slightly with the scale of the map, since, to almost any scale, most symbols are exaggerations, no matter how small they are made. The symbols shown in Figs. 20.6 to 20.17 are the proper size for the usual engineering maps.

Since the variation in size of symbols is quite limited, prominence may be secured by a variation in the weight of lines used. The purpose of the map will determine which symbols are to be made most prominent. On an oil property map, for example, flowing wells, dry wells, railroads, roads, and property lines are the important features. In practically all cases, the vegetable symbols are least important (military maps excepted) and, therefore, should be drawn lightly and not too close together.

20.11 How to draw symbols. There are two distinct steps in learning how to draw symbols, the first of which is a careful examination of a correct model or sample of the symbol, and the second, an endeavor to reproduce it. The more important of these steps is the examination of the sample, for upon the keenness and accuracy of the observation depends the effort at reproduction. For example, an examination of the water lining at the right in Fig. 20.6 will make clear that the first lines are drawn very near to the shoreline and follow it around very closely, whereas the lines become farther apart and less irregular as we

approach the center of the body of water. Examples of both correct and incorrect water lining are shown in Fig. 20.6.

Similarly, a careful examination of the symbol for grass in Fig. 20.7 will show that it consists of about seven short strokes, ranging in length from almost a dot at the ends to about 3/32 inch at the center. It will also be observed that these strokes are slightly curved and seem to meet in a common center. The individual symbols are arranged at random and not in rows. The careless observer would fail to note many of these essential points, and consequently his attempts at imitation would lack the things which he overlooked. Common errors in making the symbols for grass are shown in Fig. 20.7, in contrast with a correct execution. Likewise, the result of poor observation of the tree symbol is shown in Fig. 20.8.

A large variety of map symbols, printed on cellophane for pasting on a drawing, may be obtained from Para-Tone Co.

20.12 Colors of symbols. On a finished map, the symbols should be shown in colors. The color for each symbol in Figs. 20.10 to 20.17 is indicated in the figure title. These colors may be readily remembered by four simple groupings, thus: the artificial features, or works of man, are made in black; water features in

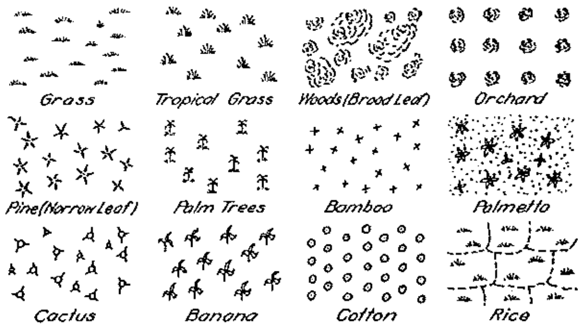


Fig. 20.10. Vegetation symbols (green).

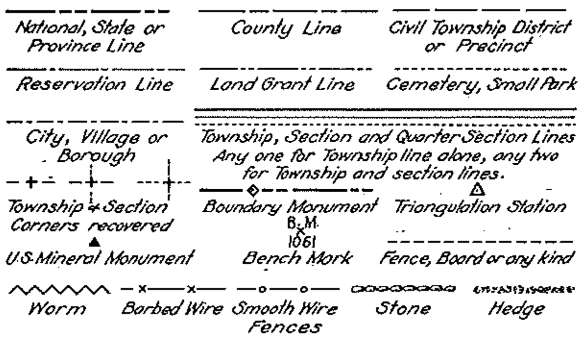


Fig. 20.11. Civil boundaries (black).

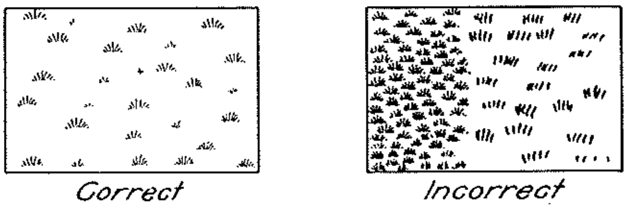


Fig. 20.7. Grass.

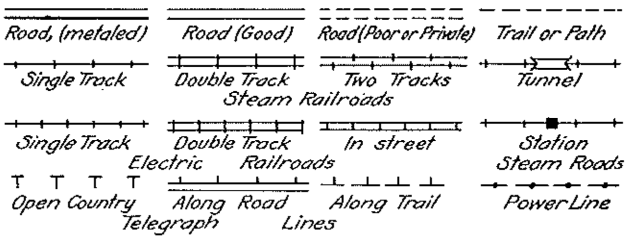


Fig. 20.12. Roads and communication symbols (black).

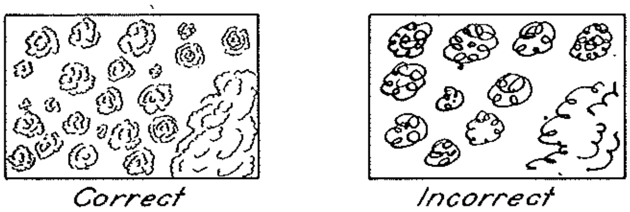


Fig. 20.8. Deciduous trees.

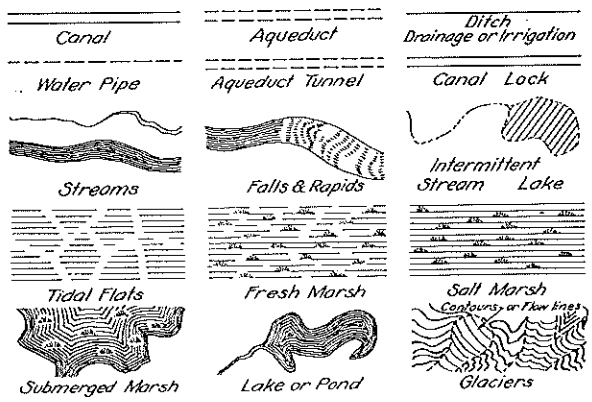


Fig. 20.13. Hydrographic symbols (blue).

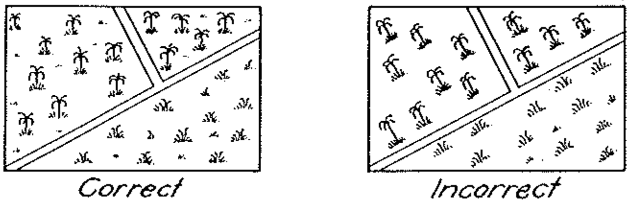


Fig. 20.9. Palm trees and tropical grass.

blue; contours, sand, washes, etc., in brown; and vegetation in green. In printing maps, each color requires a separate printing, therefore a reduction in the number of colors used reduces the cost. Since vegetation, except very large forests, is not permanent, the green is usually omitted.

20.13 Spacing of symbols. One of the greatest difficulties in drawing symbols is to learn how to space those which do not have plotted locations. The general tendency is to cover the sheet too thickly. The draftsman must constantly be on his guard against this practice, for two reasons. First, the more symbols drawn the longer it takes and the more it costs to produce the map. Second, it is more difficult to produce uniformity of texture when the symbols are crowded. The heavy and light areas on the map are disagreeably noticeable when symbols are placed too close together. When there are large areas to be covered with symbols involving the use of parallel lines, as for example in the case of marsh lands, a section liner should be used.

20.14 Position of symbols. Another very important point is the position of the symbols on the sheet. All symbols which have a definite base, as for example, grass, marsh, palm trees, and corn, should be drawn with the base parallel to the bottom of the sheet, so that the symbols appear in a natural upright position. They should never be placed with their bases parallel to roadways or property lines which run diagonally across the sheet. An illustration of this point is shown in Fig. 20.9. Symbols for vegetation which occur in rows, however, may have the rows running in any direction.

20.15 Special symbols. For some purposes, special symbols must be devised. Thus, for purposes of aerial navigation, a map must show clearly the landing fields of various kinds, beacon, and other aids to navigation, as well as those objects which project up into the air and may be obstructions to flight. Some of these symbols are shown in Fig. 20.16. Such objects as roads, railroads, railway stations, rivers, lakes, woods, and telegraph lines, which will not interfere with flight, are shown by the usual symbols.

Property maps of various industries may also require the engineer to devise symbols to show certain features which are not included among the standard symbols. It should be the engineer's purpose always to make such symbols unmistakable as to meaning and easy to interpret.

20.16 Definition of terms. The following terms are commonly used in surveying and map drafting.

a. Azimuth. The azimuth of a line is the angle the line makes with a north and south line measured clockwise from the north. See Fig. 20.18. In older

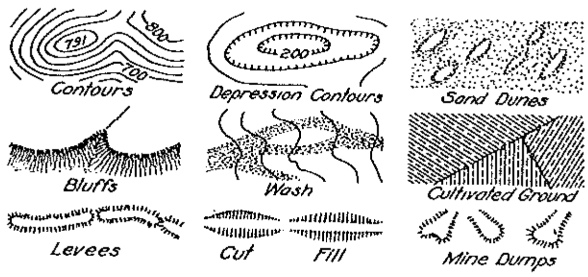


Fig. 20.14. Relief symbols (brown).

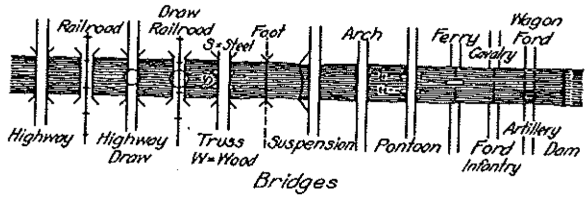


Fig. 20.15. Bridges and fords (black).

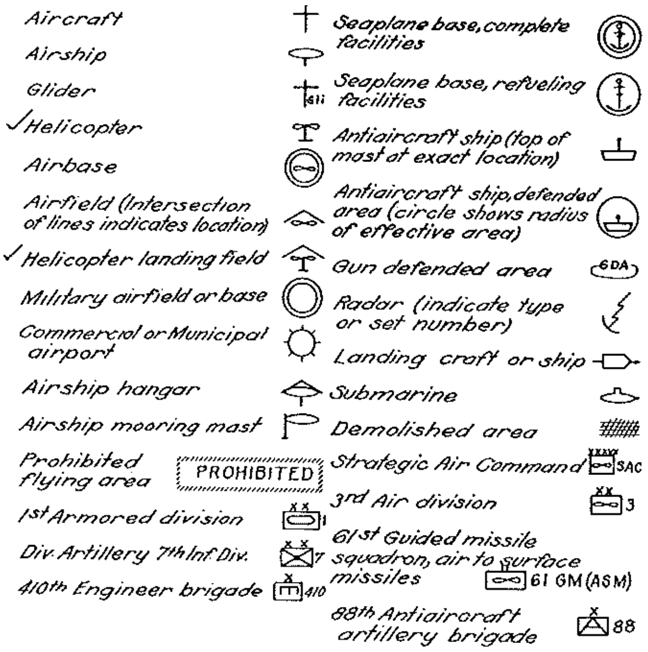


Fig. 20.16. Aeronautical symbols, Departments of the Army and Air Force (black—friendly, single line; enemy, double line) (color—friendly, blue; enemy, red).

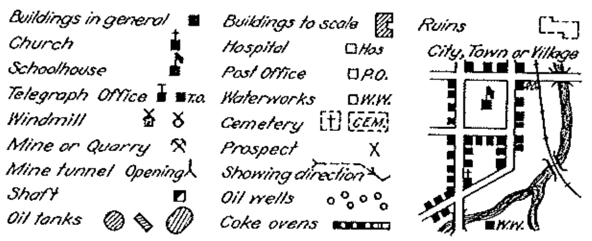


Fig. 20.17. Building symbols (black).

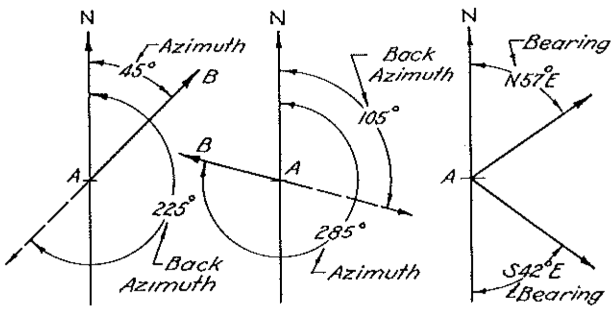


Fig. 20.18. Azimuth and bearing of a line.

survey notes the azimuth angle is frequently given from the south. See problems at the end of this chapter.

b. Back Azimuth. The angle measured to the line running in the opposite direction from the azimuth measurement. The back azimuth is therefore equal to the azimuth plus or minus 180°. See Fig. 20.18.

c. Bearing. The angle which a line makes with a north and south line measured either from the north or south. It is always less than 90°. The bearing of a line making 57° to the east of north would be specified as North 57° East or N 57° E. See Fig. 20.18.

d. Backsight. A sight looking back to the last point or station previously occupied. It is 180° from the foresight. See Fig. 20.19.

e. Foresight. In occupying a new point the surveyor orients his transit by sighting back on the point previously occupied. This is the backsight. The telescope of the transit is then plunged 180° to give the foresight. See Fig. 20.19.

f. Deflection Angle. The angle of a line in a survey measured to the right or left of the foresight. See Fig. 20.19.

g. Magnetic North. The north point as indicated by the needle of a magnetic compass which points toward the magnetic North Pole. This varies from place to place.

h. True North. A north line established by observations on Polaris, the North Star.

i. Traverse. A broken line measured by observation of angles and distances in the field. In property surveys it is usually the boundary line. A traverse may be open or closed. See Fig. 20.19. It is said to be closed when it ends upon the point of beginning or upon a point whose location has been previously determined.

j. Stations. The turning points of a traverse. In railroad and highway surveys points on the center line at 100-foot intervals are also called stations and are identified during the survey and construction by stakes with the station numbers on them. Points between stations are given the last station number with the distance from that station as a plus quantity.

The following abbreviations are commonly used on maps and map notes:

P.C. Point of curvature: the point at which the tangent ends and the curve begins on a highway or railroad.

P.T. Point of tangency: the point where the curve ends and the tangent begins.

P.I. Point of intersection: the point where the tangents to a curve intersect.

P.S. Point of switch: the point at which a switch diverges from the main line of a railroad.

P.R.C. Point of reverse curve: the point at which one curve ends and another of opposite curvature begins.

20.17 Plotting a map traverse. The method of plotting map notes depends upon the method of making the survey and upon the accuracy required. In general, the plotting on a map indicates or duplicates in miniature the work carried out in the field. Thus, an angle measured in the field with a transit may be measured on the map with a protractor, and a distance measured by tape or stadia in the field is measured on the map with a boxwood scale.

The three most common methods of plotting transit surveys, in an ascending order of accuracy, are: (1) protractor and scale method; (2) tangent method; and (3) rectangular coordinate method.

20.18 Protractor and scale method. Where great accuracy is not required, the survey notes may be plotted by means of the protractor and scale. The degree of accuracy depends both upon the kind of instruments used and upon the skill of the draftsman. Any errors made are, of course, carried forward, but are not necessarily cumulative, since the possibility of error in either direction is the same, and in a large number of measurements these errors will to some extent balance each other, unless the errors are due to a personal and constant tendency of the draftsman to overestimate or to underestimate in plotting angles or distances.

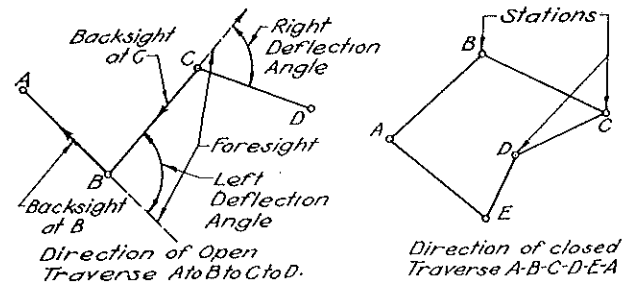


Fig. 20.19. Traverse stations.

For ordinary work, nothing less than a 6-inch celluloid protractor should be used, and this should be tested to see that the 180- and 90-degree angles, at least, are correct. Steel protractors, with straight edge and vernier attached, are, of course, much more desirable.

A portion of a page of survey notes is shown in Fig. 20.20. Let it be required to lay out the angle at Sta. *2* to locate Sta. *3* from these notes. Assume the point *B* in Fig. 20.21 to be Sta. *2* and the line *BA* the "backsight." The first step, then, in laying out the angle is to extend the line *AB* so far past *B* that both ends of the protractor may be on the line when the center is at *B*. Deflection angles are measured to the right and left of the sight line produced; that is, a deflection angle marked right should be laid off to the right of the extended line *AB* when looking forward along that line in the direction *C*. Hence, the protractor must be laid on the right or left side of the line from which the angle is measured, according as the notes describe the angle, as measured in the field, to the right or left of the line. Having the protractor set as described above, mark off the angle of 59°-40′ as accurately as possible, with a very sharp pencil, at the point *D*. With a straight edge and pencil, draw the line through the point *B* and the new point just located, and on this line scale off the proper length, namely, 652 feet to locate Sta. *3*.

20.19 Tangent method. This method is more accurate for the plotting of angles, but requires more time; hence, it is generally used for plotting traverses; the protractor method may be used for plotting in the details. The tangent method requires a table of natural tangents and is, in brief, simply the plotting of an angle on the basis of the definition of the tangent. Again assuming the same angle as in the previous case, draw the line *AB* (see Fig. 20.22), extend it beyond *B*, and lay off on it ten units with any one of the engineer's scales. The larger the scale the greater the accuracy. At the end of these ten units, erect a perpendicular to the right of the line, since the deflection is marked right, and on it scale off the natural tangent of the angle multiplied by 10, which is 17.0901. Then through the point thus located and the point *B*, draw the line required, and on it scale off the distance 652 feet.

If the deflection angle is much greater than 45°, greater accuracy may be obtained by first erecting a perpendicular at *B* and laying off on it ten units, and then at the end of this ten-unit line erecting another perpendicular on which may be laid off a distance equal to ten times the tangent of the complement of the angle, as shown in Fig. 20.23.

℄ of R.R. bridge	79°40′L	603′
℄ of Park Road bridge	138°50′L	231′
Shore of island at fork	171°20′L	220′
⊙ 3	59°40′R	652′
℄ of Park Road No. 1 on curve	151°45′R	119′
North corner of boat house	121°25′R	575′
⊙ 2		

Fig. 20.20. Survey notes.

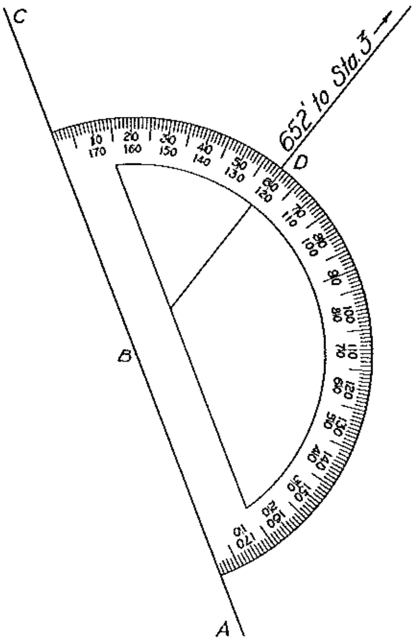


Fig. 20.21. Plotting angles by the protractor method.

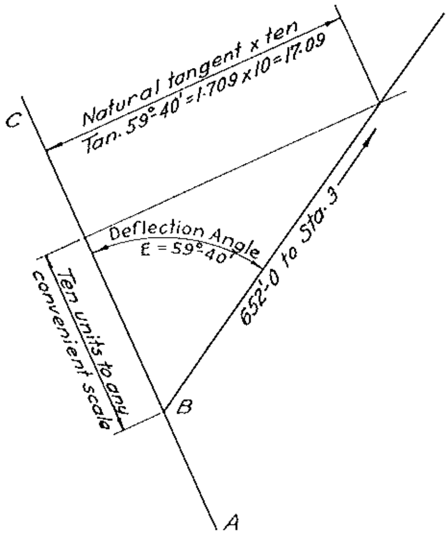


Fig. 20.22. Plotting angles by the tangent method.

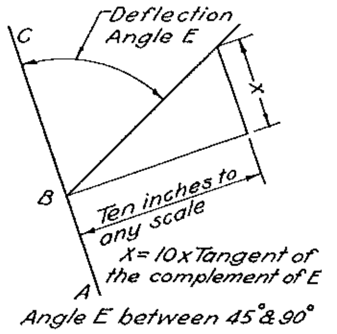


Fig. 20.23. Plotting angles from 45 to 90° by the tangent method.

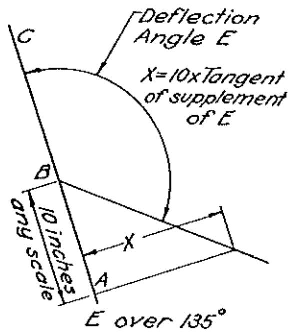


Fig. 20.24. Plotting large angles by the tangent method.

If the deflection angle is greater than 135°, the ten-unit line should be laid off between *B* and *E*, as shown in Fig. 20.24, and the tangent of the supplementary angle must be used.

20.20 Rectangular coordinate method. Inasmuch as this method requires considerable trigonometric calculation and is used only when great accuracy is required, it will not be discussed in this book. Complete information concerning this method may be found in surveying texts.

20.21 Representation of elevation on maps. A one-plane projection can show only two dimensions, but for many purposes it is highly desirable that a map shall show three dimensions, namely, length, breadth, and difference of elevation. This object may be attained by two conventional schemes, that is, by the use of hachures or contours.

20.22 Hachures. If only a general idea of the elevation of the country is desired, the method of hachures is satisfactory, since it gives the effect of relief and is readily understood by the average person. Differences in elevation between any two points, however, can be shown only in a very relative manner. An example of this method of representation is shown in Fig. 20.25, from an examination of which it will be noted that the strokes are short, heavy, and close together where the slope is steep, becoming gradually longer, lighter, and farther apart as the slope becomes more gentle and approaches the horizontal. The direction of the stroke should be the same as that in which water would flow on the slope. Care should be exercised not to have a continuous white line between the several rows of short strokes.

20.23 Contour lines. A contour line on a map is the projection of an imaginary line on the earth's surface which passes through all points of the same elevation. The meaning of a contour line may perhaps become a little clearer from an examination of Fig. 20.26, the lower part of which shows a landscape in perspective, and the upper part of which shows the same landscape in map form with elevations indicated by contour lines at intervals of 20 feet. The shoreline is in reality a contour line. The first contour line above the shore represents what the shoreline would be if the water rose vertically 20 feet. To put it in other words, if a man could walk along such a line on the ground, he would go neither up nor down but proceed always on a level and eventually he would return to the place from which he started.

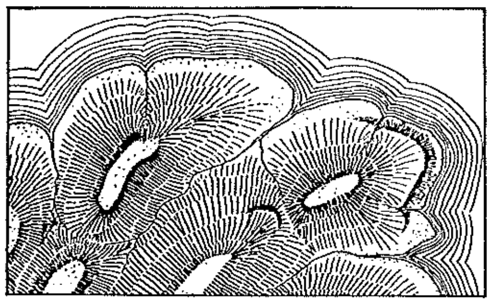


Fig. 20.25. Hachures.

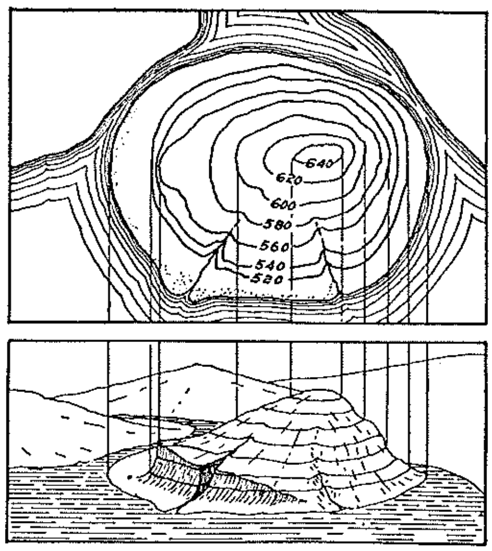


Fig. 20.26. Meaning of contour lines.

With a little reflection the following rules will be observed to be true, both of imaginary contour lines on the ground and of their projection on a map. The rules are stated as applied to a map.

a. Every contour line must either close upon itself or extend to the edge of the map.

b. When a contour line closes, it usually indicates a summit but it may indicate a depression. When it indicates a depression, this is made clear by the symbol shown in Figs. 20.14 and 20.27.

c. Contour lines never cross.

d. Where contour lines are close together the surface is steep, and where they are far apart the surface is gently sloping.

e. When contour lines are close together, they are in a sense parallel to each other (not parallel in a strictly mathematical sense). When they are far apart they need not necessarily be parallel.

f. Contour lines approaching a stream go upstream before reaching the water's edge, where they stop at points directly opposite each other at right angles to the stream. If the stream is shown by a single line they cross it at right angles; if shown by two lines, they do not cross.

g. Contour lines cannot run into the shore of a lake or other still body of water, since the water surface is at the same level at all points.

h. The first contour lines from the water's edge, on opposite sides of a still body of water, must be of the same number or elevation.

i. It is customary to make every fifth contour line heavier than the rest. This line is broken at some convenient place, and the number representing its elevation is inserted in the break in ink of the same color as the line. Where the contour lines are far apart each one may be numbered.

The numbers indicating the elevation of the contour lines are lettered parallel to the contour line, and, where possible, the numbers for consecutive lines are placed in rows, as shown in Fig. 20.26. If it is possible, these numbers should read from the bottom of the sheet. Contour lines may be drawn with a lettering pen or with a pen designed especially for the purpose and called a contour pen. The point of this pen is on a swivel which allows it to turn freely in any direction.

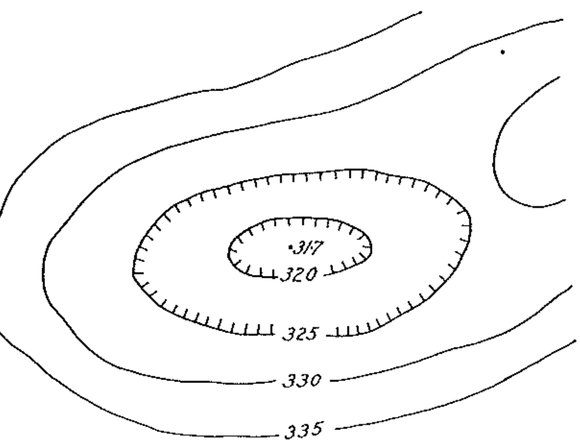


Fig. 20.27. Depression contours.

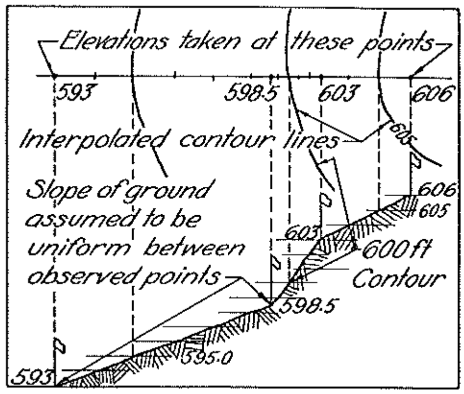


Fig. 20.28. Plotting contour lines by interpolation.

The contour interval may be any desired value, from 1 foot in very flat country up to 200 feet in rough mountainous country. By contour interval is meant the vertical distance between the planes of consecutive contour lines; 5, 10, 20, 100, and 200 feet are the intervals most frequently used.

On a summit or depression, the last contour line is numbered, or the elevation of the high or low point within the contour is given. See Figs. 20.26 and 20.27.

20.24 Plotting contour lines. The data for making a contour map may be obtained in the field by obtaining the horizontal location and the elevation of a series of points sufficiently close together so that reasonable interpolations may be made between them. These points may be taken in a rectangular pattern at intervals suitable to the terrain. They may also be taken in radial patterns from traverse points. In the latter case it is usual to choose points on the surface where there is a change in slope. Thus, in Fig. 20.28, elevations were obtained at four points as indicated at the top of the figure. A sectional view shows the slope of the ground surface, and the light horizontal lines are contour planes at 1-foot intervals. A sectional view, of course, is not necessary since the horizontal distance between points can be divided proportionately. Thus in Fig. 20.28 the 605 contour is two-thirds the distance from 603 to 606.

With this explanation, the actual work of plotting contour lines from survey data is illustrated in Fig. 20.29. Here the traverse stations *1*, *2*, and *3* have been shown with the observations of elevations on

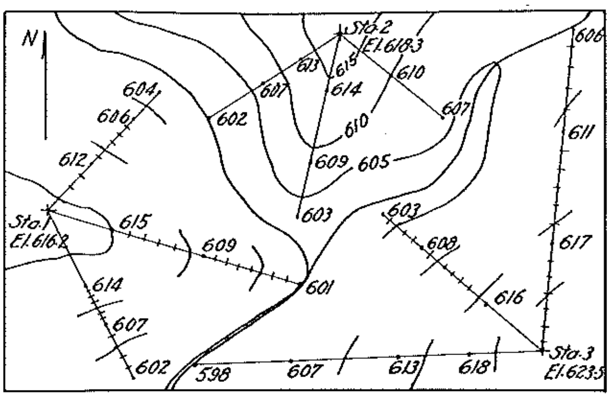


Fig. 20.29. Plotting contours.

the earth's surface plotted from each station in the usual radial pattern. Assuming the ground slope to be uniform between plotted points, the space between points can be divided into a number of spaces equal to the difference in elevation between points as indicated for a number of spaces in Fig. 20.29.

In the upper portion of the map completed contours have been shown, and in the other portions the lines are sketched in only between plotted elevations. In general, it will be noted that between the radial lines of plotted points the contour lines follow the stream pattern.

20.25 Use of contour maps. Contour maps are used in engineering work to make preliminary estimates of excavations for structures, in locating dams and computing the volumes of water stored behind them, in computing the area of watersheds, and in many other kinds of work. Figure 20.1 shows a portion of a topographic map taken from a United States Geological map of the Urbana Quadrangle in Illinois.

20.26 Outcrop from contour maps. Contour maps also are used extensively in geology and mining. Figure 20.30 illustrates the use of a contour map to determine data concerning a stratum of limestone. The upper surface of the layer was observed to outcrop on the 500-foot contour at point *A*. At other places the stratum was covered by overlying material. Borings were made at *B* and *C* at elevations shown on the map. At *B* the top surface was encountered at elevation 580 and the bottom at 465. At *C* these values were, respectively, 420 and 305.

Using the map, an elevation view was made of the three points a^V, b^V, and c^V at the known elevations of the top surface of the stratum. A horizontal line drawn across this triangle from a^V to d^V determines the strike line $a^H d^H$ which upon measurement from the North line shows the strike to be S 52 E. By making an endwise view of the strike line and again plotting the known points as at (*b*) the stratum is shown edgewise and its thickness and slope or dip can be determined as shown in Fig. 20.30(*b*). The dip is shown on the map by drawing an arrow perpendicular to the strike line pointing in the downward direction with the value of the dip lettered on it.

Having the edgewise view of the stratum the outcrop can be determined by finding where the top and bottom surfaces of the limestone bed cross the 400–700-foot contour planes in the edge view and projecting these back to the corresponding contour lines. These are shown by the small circles at the edge of the shaded area for the top surface and the black dots for the bottom.

If, on the other hand, an outcrop of a bed is shown on a contour map, the strike can be determined at once by connecting the points where any one contour line crosses the upper line of the outcrop. Having the strike line, an edge view of the bed or layer may be obtained and from this the dip and thickness.

20.27 Cut and fill from contour maps. Contour maps are also used to determine the cut and fill required in the construction of a railroad or highway, as illustrated in Figs. 20.31 and 20.32. Since the sides of a cut or fill are plane surfaces, contour lines on them will be parallel and equally spaced. Finding the outline of a cut or fill therefore is simply a problem in the intersection of surfaces. Having the contours on the map, it is only necessary to draw the contours in the cut or fill at the same levels as the map contours and find where these lines intersect.

If the road bed is level, the contour lines in cut or fill are parallel to the edge of the road bed. The spacing of these contour lines depends upon the slope of the cut or fill. If the slope is 45° or 1:1 the spacing will be the same as the contour interval of the map

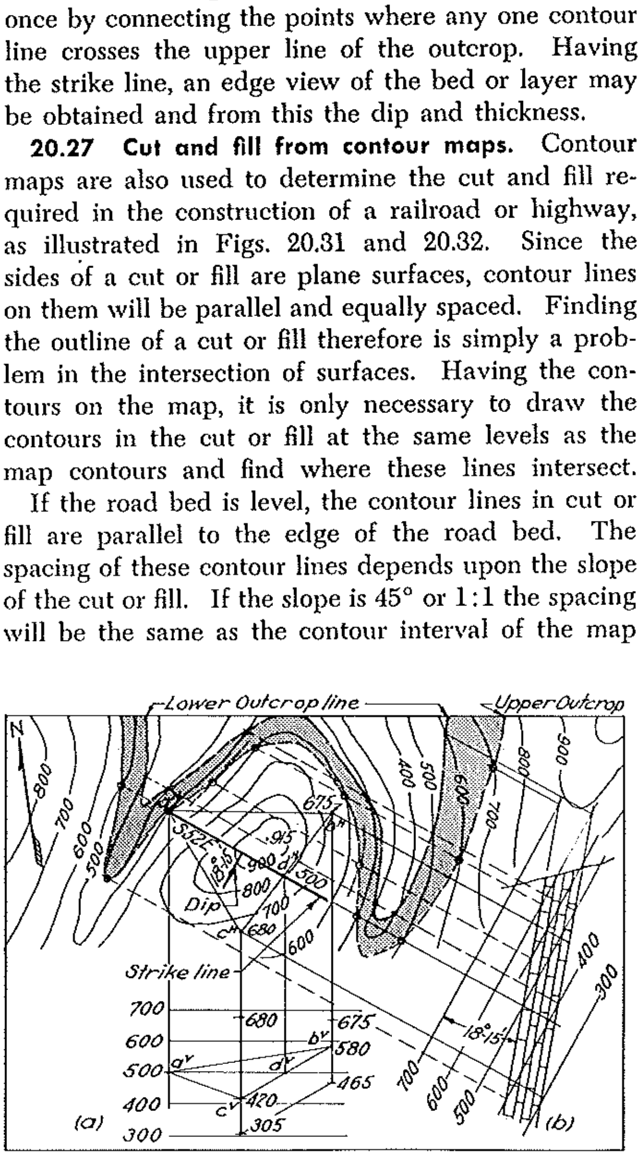


Fig. 20.30. Finding strike and dip from an outcrop.

whereas if it is 1½:1, the spacing will be 1½ times the contour interval. The solution of a problem of this type is shown in Fig. 20.31(*a*).

In hilly country, however, level road beds seldom occur. There is usually a definite slope, and this slope or grade is expressed in per cent. Thus a slope or rise of 1 foot in 100 feet of horizontal distance is called a 1% grade. A rise of 2 feet in 100 feet is a 2% grade, and so on. An ascending grade is marked plus and a descending grade minus.

When the road bed is on a grade, the contour lines of the cut and fill are not parallel to the edge of the road bed, as can be seen in Fig. 20.31(*b*). On an up grade, the contour lines in a cut converge toward the edge of the road bed and those on a fill diverge. The rate of divergence depends upon the grade and the slope of the cut. On a 1:1 slope the divergence will be equal to the grade. Thus in a 1% grade and a 1:1 slope the contour line will diverge 10 feet from the edge of the road bed in 1000 feet. With the same grade and a 1½:1 slope the divergence in 1000 feet would be 15 feet. On curves, the divergence must be plotted at each station and a smooth curve drawn. This has been done on one side of the line shown in Fig. 20.32. Theoretically cut and fill will meet at the edge of the road bed on each side. In order not to complicate the illustration, the culvert necessary for drainage was omitted.

Where necessary, additional contours may be interpolated on the map as well as on cut and fill.

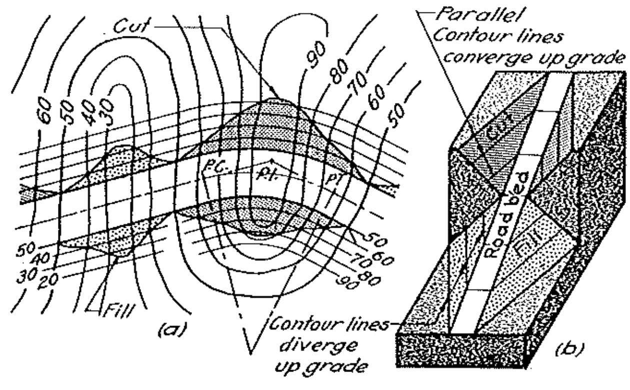


Fig. 20.31. Plotting cut and fill on a level grade.

A more customary method for determining the outline of the cut and fill is by taking cross sections in the field. This is done by establishing a line perpendicular to the center line at each station and obtaining elevations at selected points on this perpendicular line. These cross sections are then plotted on paper and the roadway placed in its proper position, as shown for the two sections in Fig. 20.32. These sections can be used to determine the edge of the cut or fill and to calculate the quantities of earth to be moved.

20.28 Profiles. A profile is a line showing the elevations of the ground along some one particular line on the earth's surface. Although a profile represents something entirely different from a contour, yet the

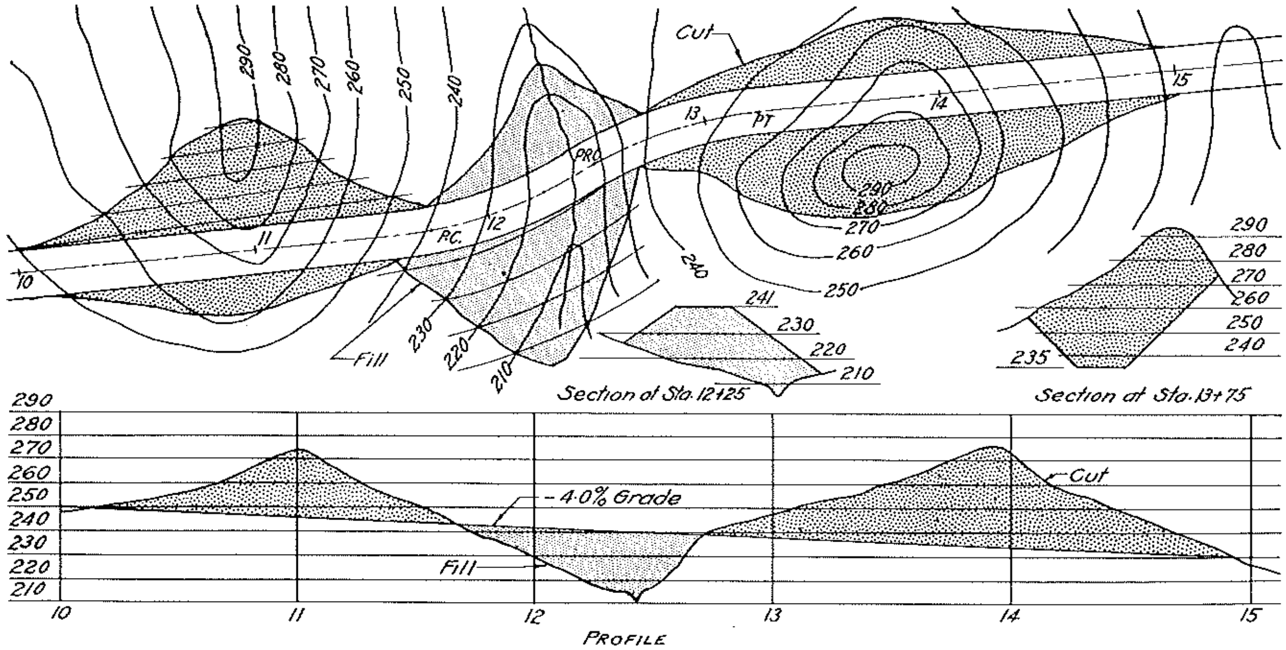


Fig. 20.32. Plotting cut and fill on an inclined grade line.

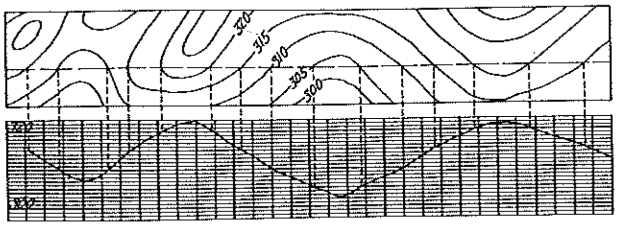


Fig. 20.33. Profile determined from a contour map.

two are related in such a manner that one may be obtained from the other. A profile usually accompanies a map showing a road, railroad, sewer, water-supply line, or canal location. If the profile is to be made very accurately, the elevation of points on the line should be obtained by means of a level in the field. However, a profile for preliminary purposes may be obtained from a contour map as shown in Fig. 20.33.

When elevations are obtained with an instrument in the field, readings are taken every 100 feet in flat country, and at closer intervals of 50, 25, or 10 feet in rough country, depending upon the ruggedness of the slope. These readings are then plotted on a special coordinate paper called profile paper, in which the spacing of coordinates is different in the two directions.

When the elevations are obtained from a contour map, the proposed line is drawn on the map and the intersections of this line with the contour lines give the elevations of points whose distances apart are obtained by scaling the map. These points are then plotted on the profile paper.

Profiles, as indicated in a preceding paragraph, are usually plotted to two different scales, the larger of which is used on the vertical axis. The purpose of the two scales is to show the variations of elevation more clearly. Since a profile is usually thousands of feet or several miles in length, whereas the difference of elevation varies only over a few hundred feet, the scale which would bring the horizontal length within workable limits would make the vertical distances so small as to be insignificant.

20.29 Profile on curves. When a profile is made of a line a portion of which is curved, like a railroad line, for example, the developed length of the curve is shown in profile and not the projected length. In other words, the length of the profile is the same as the true length of the line. The beginning and ending

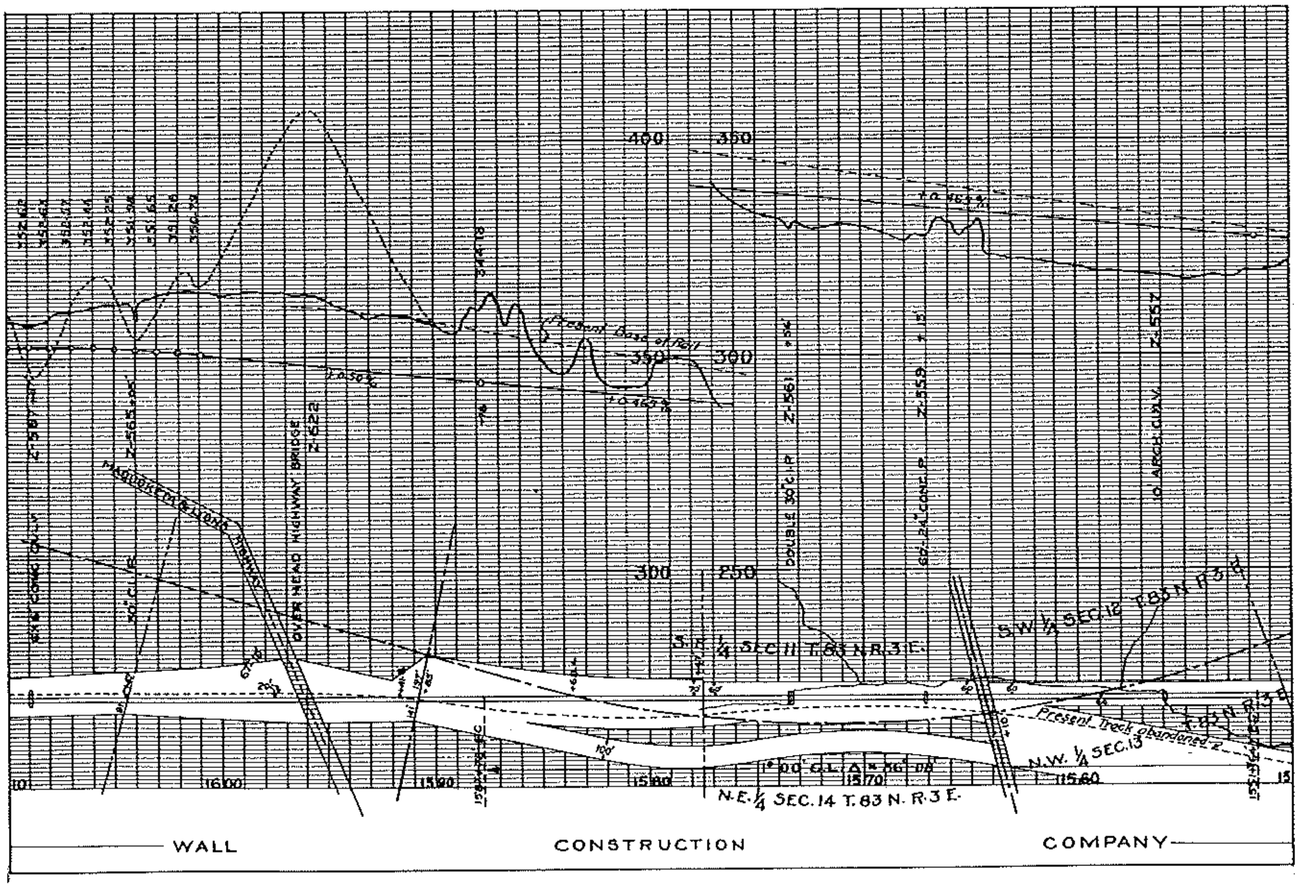


Fig. 20.34. Railway profile.

of the curve are shown, and the degree of curvature is indicated, as in Fig. 20.34.

20.30 Grade lines. In engineering work, where maps are used, a profile is seldom drawn except for the purpose of establishing the grade line of some such structure as a railroad, highway, sewer, or other engineering project. The grade line is the controlling line in construction of the types of structures mentioned. It establishes the slope or deviation from the horizontal. The grades of lines are specified in percentages, and represent the number of feet of vertical rise or fall in 100 feet horizontal distance. Grades are specified as plus when the slope is upward, and minus when the slope is downward, in the direction in which the line is laid out. See Fig. 20.32. Thus a +5% grade means a rise of 5 feet in 100 feet horizontal distance.

20.31 Vertical curves. In lines of any considerable length a uniform grade cannot be maintained from end to end. Although two grade lines of different slope will intersect in a point, in actual construction they must be joined by a vertical curve in order to smooth out the otherwise abrupt change of direction which would be disastrous on highways and railroads. These vertical curves are usually laid out as parabolas in the following manner, and as indicated in Fig. 20.35. Lay out on opposite sides of the point of intersection of the grade lines the same number of 10-, 25-, or 50-foot spaces. In practice both the length and number of these spaces are arbitrarily selected to suit the length of the curve and the nature of the work. The elevation of the end points *E* and *D* of the curve, Fig. 20.35, may be determined from the grade lines, and the elevation of the mid-point *C* of the line *ED* computed. The parabola passes halfway between *A* and *C* at *B*. With this point established, other points on the parabola may be determined by the fact that the offset from the tangent to a parabola varies as the square of the distance along the tangent. The value of the offset at *B* being known, offsets at the other points may be computed as shown in Fig. 20.35.

20.32 Horizontal curves. When railroads and highways change direction, the change is accomplished by means of circular curves that join the straight parts of the line which are called tangents. The curvature is specified in degrees, as for example, a 3-degree curve. A 3-degree curve is one on which a chord of 100 feet subtends an angle of 3 degrees at the center. Circular curves are joined to the tangent by an easement or spiral curve, but this spiral portion is not shown in the usual map. The radii of curves for various degrees is given in the Appendix.

20.33 Lettering. Engineering maps, particularly those drawn to a large scale for the purpose of construction, are usually lettered in single-stroke Reinhardt letters, either slant or vertical, except the titles, which may be made in a more ornamental style. On Geographic and United States Government maps, the lettering is in modern roman with certain variations designed for special purposes. A competent map draftsman must be a master of this style of lettering.

Although the lettering is about the last thing to be inked on a map, the placing of it must receive attention during the preliminary pencil work; otherwise, there will often be no place to put some very essential information when the work is nearing completion. As in all other types of drawing, lettering should be placed, as far as conditions will permit, so that it may be readable from the bottom and right-hand side of a drawing.

20.34 Titles. The title of a map is usually placed in the lower right-hand corner, if possible. It should contain a statement of what the map is, i.e., Plat of Jones Subdivision, the location of the ground, the name of the person or company for whom the map was made, the date of the survey, the scale, the north point, and the name or initials of the draftsman. The name of the surveyor may be in the title or it may

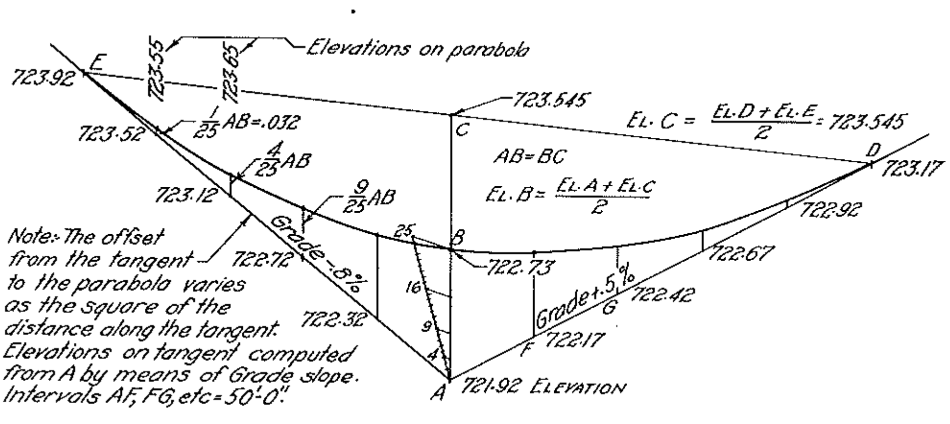


Fig. 20.35. Plotting vertical curves.

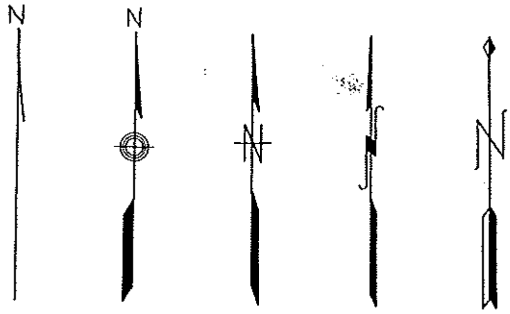


Fig. 20.36. North points.

occur only in a statement which certifies that the survey and map are correct. This statement and signature must be written. They are usually placed near the title but are not a part of it. The scale is frequently represented graphically below the title. In no case should the title be enclosed in a box.

On engineering maps Gothic letters are used; on the more highly finished maps the roman style is preferred.

20.35 North points. Every map should have the direction of the meridian indicated by means of a suitable arrow. Unless otherwise specified, this arrow points true north. The south portion of the arrow should be somewhat longer than the north portion to give it a balanced appearance. The barb and tail should be narrow and graceful, thus avoiding an arrow that is too bold or conspicuous. Sample arrows are shown in Fig. 20.36.

Problems

In the following problems which have been selected to fit 8½ × 11 and 11 × 17 inch paper, great care should be exercised in the layout of the traverses and in plotting the artificial features and contour lines. With few exceptions, all plotted points fall within the borderlines of the sheets specified. Since these are from older maps the azimuth, when used, has been plotted from the south instead of north as is the case in more recent practice.

Without being specified it is assumed that the student will put in all necessary lettering in the proper size and style. Notes and dimensions given in the sketches are not to appear on the finished map except the size of city lots. Symbols of proper size and color are to be used in all cases.

1. From the survey notes of Figs. 20.37 and 20.38, plot Map A. (Notes in these two figures read up the page.) Plot the traverse by the tangent method, and have it checked by your instructor. When approved, plot the details by the protractor and scale method, using all information given in the sketches.

Plot the data for the contours from Figs. 20.39 and 20.40. (Note that these read down the page.) Draw the contour lines, interpolating where necessary. After the map has been checked, ink it in the proper colors.

2. Same as Problem 1. Use Figs. 20.41 to 20.44 for Map B. Scale, 1″ = 400′.

3. On an A-size sheet (8½ × 11 or 9 × 12), draw a map from the notes and sketches in Fig. 20.45. Observe again that the notes read up the page and that the azimuths are plotted from the south instead of north. Scale, 1″ = 400′.

4. On an A-size sheet (8½ × 11 or 9 × 12), draw the contour map from Fig. 20.46. The elevations have been given on a large grid for rapid plotting. Parts of a few contour lines have been sketched in as an aid. This contour map may be plotted on the map of Fig. 20.45 by properly locating the grid with reference to the section corner at the left in this figure.

5. On an A-size sheet, draw the map from the notes and sketch of Fig. 20.47. Azimuths are again given from the south. Scale, 1″ = 400′.

6. On an A-size sheet, draw a topographic map from the data given in Fig. 20.48. Parts of a few contour lines have been shown as an aid in beginning. These contours may be plotted on the map of Fig. 20.47 by properly aligning the section corners at the right of the figure.

7. From the contour map of Problem 1, Map A, draw the profile along the railroad or highway center line as specified by your instructor. Use a piece of profile paper 5 inches wide and 15 inches long. Rule a border ¾ inch from the narrow left-hand end and ½ inch from the other three edges. Horizontal scale same as map scale. Vertical scale to be selected by the student. This scale should be in units such as 5, 10 or 20 feet to the inch. Make the intersection of the left end of the railroad or highway line with the borderline of your sheet Station No. 1. Stations are marked at 100-foot intervals.

8. Same as Problem 7, using Map B, Figs. 20.41 to 20.44.

9. Same as Problem 7, using Map C, Figs. 20.45 and 20.46. The length of profile paper required is 5 × 12 inches.

10. Same as Problem 7, using Map D, Figs. 20.47 and 20.48. Size of profile paper required 5 × 12 inches.

11. On the profile made as assigned from Problems 7 to 10, draw a grade line that will balance cut and fill as nearly as possible.

12. On an A-size sheet (8½ × 11 or 9 × 12) make a study of six assigned map symbols from Figs. 20.6 to 20.17. Enclose them in neatly balanced rectangles, and letter under each the name of the symbol.

Station	Defl. ls	Distance
℄ of east bridge on Washington St.	122°00'L	675'
North bank of stream (average width 15 feet)	127°00'L	420'
North bank of stream	148°30'L	340'
℄ of bridge on Cherry St.	175°50'L	380'
North bank of stream	156°00'R	535'
℄ of bridge on Gum St.	138°00'R	687'
⊙2	44°05'L	1618'
East bank of stream	144°00'L	1055'
Northeast corner of barn	134°30'L	758'
South end of 100' bridge on ℄	130°20'L	1160'
Northwest corner of house	125°30'L	910'
P.T. on switch 6° curve (955' radius)	85°55'L	830'
P.S. (=Point of switch)	61°40'L	395'
P.T. on R.R. Main line 3° curve (1910' radius)	48°10'L	354'
P.C. on R.R. Main line	24°45'R	1032'
Intersection Washington & Walnut St. ℄s. (℄=center line)	41°20'R	665'

Locate Station No. 1 780' from right border line and 1200' from upper border line of 12"x18" sheet. Foresight due North along St. ℄. These notes read up the page.

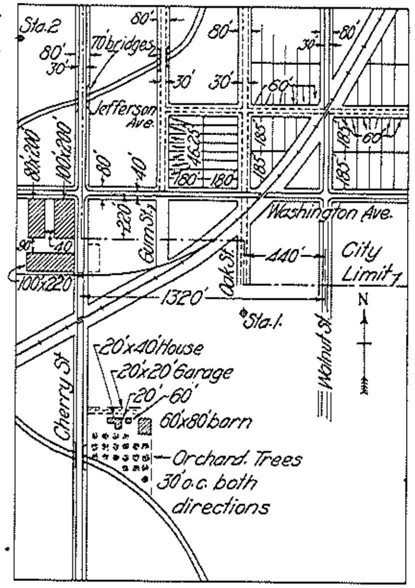


Fig. 20.37. Survey notes, Map A.

Station	Defl. ls	Distance
Scale of map 1"=200'		
⊙1	126°30'L	1898'
West bank of stream	180°00'L	775'
End of R.R. Switch	161°00'L	563'
Northwest corner Bldg No. 3.	152°00'L	862'
West bank of stream	166°30'L	514'
West bank of stream	136°30'L	417'
Center of R.R. bridge	113°05'L	556'
West bank of stream	97°15'L	844'
West bank of stream	93°25'L	1318'
℄ of R.R. Main line	5°00'L	480'
⊙3	109°20'L	1669'
West shore of lake	45°00'L	955'
East shore of lake	45°00'L	438'
West shore of lake	51°32'L	722'
East shore of lake	51°32'L	480'
West bank of stream	60°00'L	600'
East bank of stream	60°00'L	555'
East bank of stream	89°15'L	565'
℄ of west bridge on Washington St.	105°15'L	762'
North bank of confluence of streams	113°05'L	940'

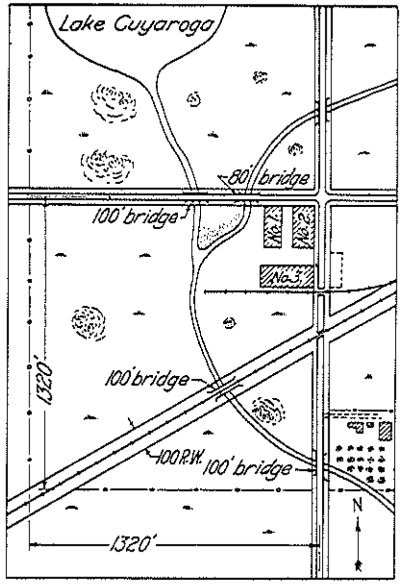


Fig. 20.38. Survey notes, Map A.

Station	Azimuth	Obs. Dist.	Cor. Dist.	Vert. Angle	Diff. of Elev.	Elev.
At Sta. 1.	Elev. 698.8	H.I. 4.6			K=100	
Shot 1	30°30'		1130			690.2
2	" "		1025			693.1
3	" "		608			694.5
4	64°25'		1140			693.3
5	" "		845			693.9
6	" "		534			694.7
7	90°00'		1383			693.5
8	" "		1010			693.8
9	" "		490			696.4
10	119°15'		1308			693.6
11	" "		851			694.5
12	142°05'		1035			693.6
13	" "		570			696.0
14	165°10'		1196			693.8
15	" "		720			698.2
16	" "		267			700.7
17	194°45'		1198			704.2
18	" "		793			705.3
19	221°00'		1115			711.9
20	" "		742			705.6
21	240°00'		838			705.6
22	" "		687			702.1
23	303°00'		720			697.2
△ 2	135°55'	H.I. 4.7	1618			706.8

These notes to be read down the page.

The data in these columns have not been reproduced since they are not essential to plotting the map.

All stations on this traverse are the same as those in the previous survey.

Note:- The azimuth of any line is the angle which the line makes with a north and south line measured in a clockwise direction from the south.

H.I. means height of instrument

K is the stadia constant, a factor used in computations

Fig. 20.39. Topography notes, Map A.

Station	Azimuth	Obs. Dist.	Cor. Dist.	Vert. Angle	Diff. of Elev.	Elev.
At Sta. 2						
Shot 1	22°45'		940'			691.0
2	" "		642'			692.7
3	31°30'		500'			696.2
4	46°40'		250'			701.1
5	90°00'		358'			693.9
6	" "		157'			701.3
7	270°00'		617'			693.6
8	" "		310'			700.8
9	335°00'		251'			694.6
10	" "		148'			698.9
△3	26°25'		1669'			697.2
Shot 1	10°00'		520'			699.2
2	66°50'		530'			706.2
3	" "		259'			701.4
4	137°45'		710'			700.6
5	154°32'		1150'			694.6
6	" "		512'			698.8
7	171°05'		1122'			694.5
8	182°09'		768'			696.0
9	208°00'		597'			693.6
10	249°03'		330'			693.4
11	289°15'		629'			693.2
12	305°55'		905'			696.1
13	305°55'		468'			694.0

Water level of lake 692.3

Fig. 20.40. Topography notes, Map A.

Station			Defl. ∠s	Distance
West bank of confluence of north & south branches			128°30'R	1375'
North bank of south branch			83°45'R	730'
Center of highway bridge			58°30'R	680'
North bank of south branch			26°45'R	905'
West bank of north branch			140°30'L	1560'
South bank of north branch			120°30'L	2290'
North bank of south branch			8°30'R	1170'
⊙2			48°45'R	2700'
P.C. on R.R. line			137°40'R	2420'
P.C. on ℄ of highway			118°15'R	1495'
P.T. on R.R. line			85°00'R	1535'
℄ of R.R. line			7°20'L	1915'
⊙1			50°30'R	3040'
Center of highway bridge			180°00'R	250'
P.S. on R.R.			159°30'R	490'
P.T. on R.R. switch			128°45'R	940'
Southwest corner Bldg No. 1			124°30'R	1005'
Northeast corner Bldg No. 2			111°15'R	1365'
North bank of stream			107°00'R	550'
North bank of stream			94°45'R	940'
North bank of stream			139°00'L	400'

Locate Station 0, 400' from left and 1100' from top border line. Foresight north along section line which makes 30° with the left border line. Read notes up the page.

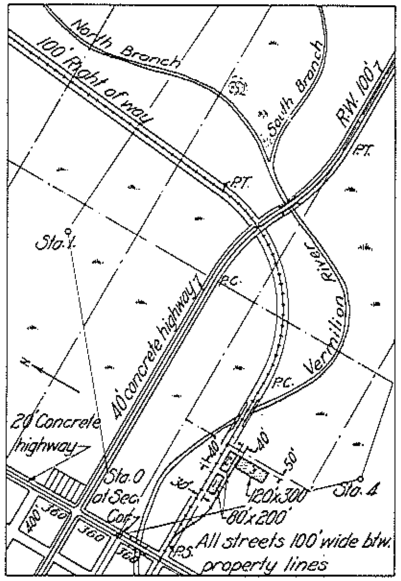


Fig. 20.41. Survey notes, Map B.

Station			Defl. ∠s	Distance
Scale of map 1" = 400'				
⊙0			66°00'R	2380'
Southeast cor. bldg No. 3			83°00'R	870'
Northeast cor. bldg No. 3			90°00'R	1150'
South bank of river			97°00'R	1460'
Center of R.R. bridge			109°00'R	1235'
South bank of river			135°20'R	1022'
South bank of river			163°30'R	1314'
⊙4			56°15'R	3040'
South bank of river			78°00'R	1370'
South bank of river			101°00'R	1185'
Center of highway bridge			118°30'R	1220'
P.T. on ℄ of highway			160°30'R	625'
Section corner			142°40'L	985'
⊙3			94°15'R	2190'

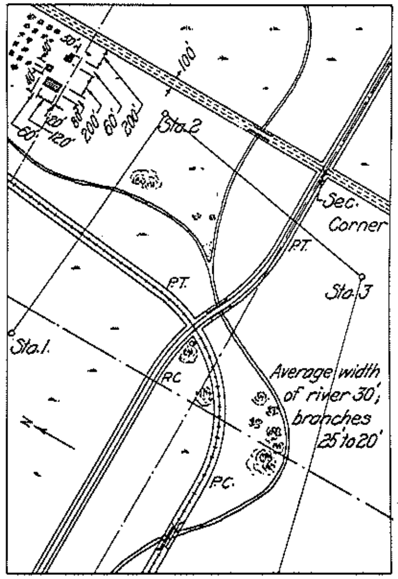


Fig. 20.42. Survey notes, Map B.

Station	Azimuth	Obs. Dist.	Cor. Dist.	Vert. Angle	Diff. of Elev.	Elevation
At Sta. 0	Elev.	448.7	H.I. 4.7		K = 98	
Shot 1	135°40'		720			452.1
2	194°30'		564			452.6
3	" "		1430			460.0
4	230°30'		898			455.0
5	" "		1462			461.2
6	" "		1690			469.1
7	" "		2356			474.3
8	331°30'		712			450.0
9	" "		1344			459.1
Δ1	230°30'	H.I. 4.3	3040			478.2
10	16°45'		1200			470.0
11	" "		2000			457.5
12	156°15'		520			481.3
13	230°20'		410			477.5
14	" "		1420			470.0
15	" "		2182			460.3
16	254°15'		1955			462.5
17	" "		2456			470.0
18	296°45'		984			473.9
19	" "		1714			460.0
20	337°50'		720			475.0
21	" "		1440			471.8
22	" "		1749			465.0
Δ2	279°15'	H.I. 4.6	2700			467.6

These notes read down the page.

Note:—The azimuth of a line is the angle which the line makes with a north and south line measured in a clockwise direction from the south.

Elevation at water line under highway bridge 447.4

Elevation at water line under railway bridge 452.5

The traverse of this survey is the same as that used in the preceding survey.

Fig. 20.43. Topographic notes, Map B.

Station	Azimuth	Obs. Dist.	Cor. Dist.	Vert. Angle	Diff. of Elev.	Elevation
Shot 23	00°00'		361			463.7
24	" "		1280			470.0
25	58°30'		775			460.0
26	175°00'		1889			472.0
27	201°00'		508			472.4
28	" "		1020			480.0
29	243°00'		750			473.8
30	264°45'		834			466.2
31	284°15'		1100			460.0
Δ3	13°30'	H.I. 4.8	2190			472.8
32	58°35'		1770			462.9
33	69°15'		1715			457.1
34	121°30'		320			468.6
35	" "		760			463.2
36	173°40'		978			462.0
Δ4	69°45'	H.I. 4.3	3040			462.1
37	16°30'		354			465.0
38	" "		775			468.9
39	" "		1120			472.0
40	69°20'		682			460.2
41	162°30'		450			457.3
42	" "		1370			455.0
43	210°00'		1835			458.4
44	221°30'		1526			454.7
45	233°00'		631			457.1

The data belonging in the empty columns have not been reproduced since they are not needed in plotting the map.

Elevation at water line under highway bridge 455.4

Fig. 20.44. Topographic notes, Map B.

Station	Azimuth	Distance
⊙1 (check back for ∠ & distance	266°-0'	3485'-0"
West bank of stream	325°-30'	940'-0"
P.C. on highway ℄ (Rad. 1000')	265°-30'	1245'-0"
℄ of 150' highway bridge	255°-50'	1020'-0"
Southeast corner of barn	197°-45'	1245'-0"
Southeast corner of house	188°-30'	1170'-0"
Intersection of highway ℄s	171°-50'	900'-0"
Northeast corner of house	135°-15'	534'-0"
Southwest corner of barn	108°-45'	610'-0"
O3	40°-30'	2945'-0"
Intersection of highway & R.R. ℄s	91°-50'	2040'-0"
Northeast corner Bldg. No. 1.	38°-0'	810'-0"
Southeast corner Bldg. No. 2.	30°-30'	975'-0"
P.T. on R.R. switch (Rad. 820')	28°-0'	836'-0"
P.R.C. on R.R. switch	359°-0'	635'-0"
P.S. on R.R. (Rad. 820')	312°-45'	815'-0"
⊙2	142°-0'	2530'-0"
East bank of stream	168°-45'	1700'-0"
Intersection of highway & R.R. ℄	168°-45'	1305'-0"
℄ of R.R. bridge (200' span)	155°-0'	1510'-0"
East bank of stream	142°-0'	1250'-0"
South bank of stream	104°-15'	1430'-0"
P.T. on ℄ of highway (Rad. 1000')	104°-15'	895'-0"
⊙1 Locate Sta. No. 1 100 ft from right border line & 900 ft from lower border line.		

These notes read up the page

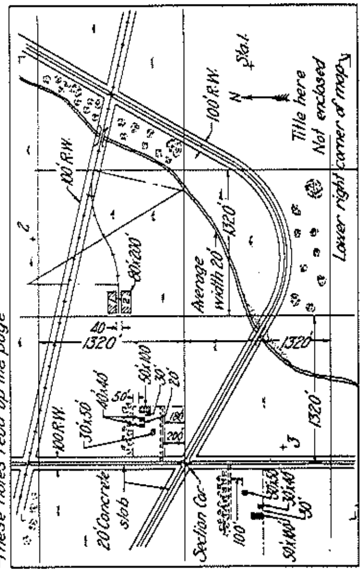


Fig. 20.45. Survey notes, Map C.

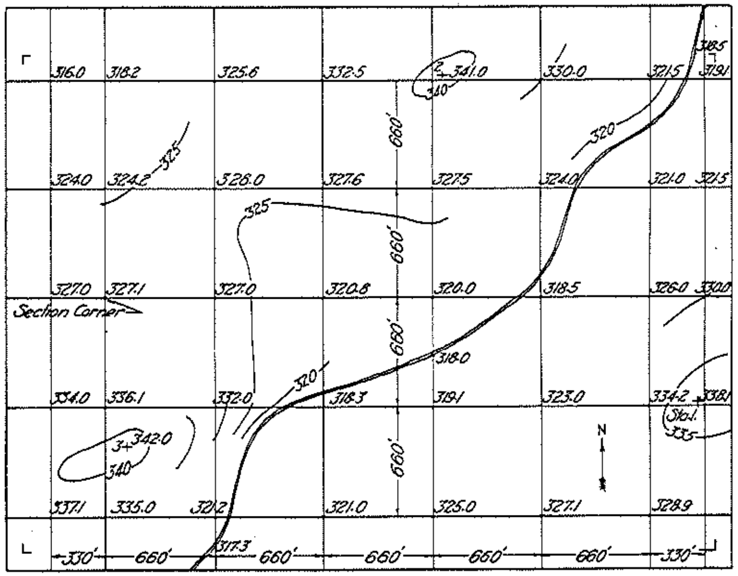


Fig. 20.46. Topography, Map C.

Station	Azimuth	Distance
⊙1 (check back ∠ & distance)	91°-0'	3020'-0"
Section Corner	223°-0'	575'-0"
P.T. on highway ℄ (1000' Rad)	192°-0'	432'-0"
P.C. on highway ℄	110°-0'	569'-0"
℄ of 200' highway bridge	84°-0'	900'-0"
P.T. on highway ℄	67°-30'	1775'-0"
East bank of stream	34°-0'	1051'-0"
⊙3	348°-30'	1640'-0"
Northwest corner of barn	298°-30'	1215'-0"
Northwest corner Bldg. No. 2	310°-45'	564'-0"
Southwest corner Bldg. No. 1.	322°-15'	695'-0"
R.R. ℄	110°-0'	545'-0"
P.T. on R.R. switch	70°-35'	1390'-0"
P.S. on R.R. switch (1200' Rad)	72°-05'	2010'-0"
North bank of stream	47°-0'	1620'-0"
East bank of stream	30°-0'	1580'-0"
⊙2	240°-0'	3105'-0"
P.C. on highway ℄ (1000' Rad)	321°-0'	1230'-0"
Northwest corner of barn	311°-10'	502'-0"
Northeast corner of barn	295°-15'	780'-0"
South bank of stream	236°-0'	985'-0"
℄ of 150' R.R. bridge	214°-0'	970'-0"
West bank of stream	180°-0'	1060'-0"
West bank of stream	168°-0'	1550'-0"
⊙1 Locate Sta. No. 1. 200'-0" from left border line & 1200'-0" from the lower border line.		

These notes read up the page.

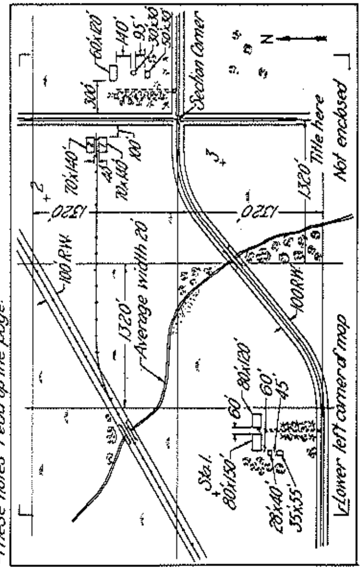


Fig. 20.47. Survey notes, Map D.

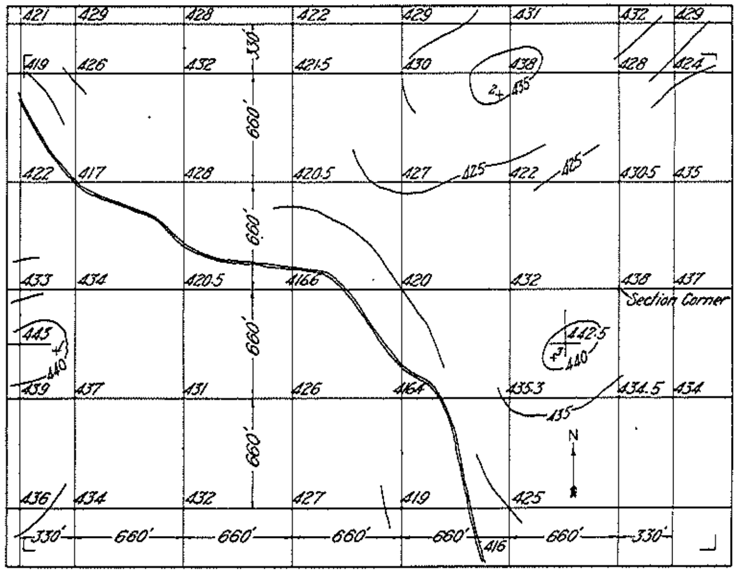


Fig. 20.48. Topography, Map D.

Architectural Drawing* 21

21.1 Introduction. Architecture is the art and science of building, and involves diverse types of structures. Many phases of engineering are integrated in building, construction, and design. These include electrical engineering for power, illumination, and communications; mechanical engineering for elevators, escalators, machinery, and power; and civil engineering for structural design, site planning, and services. Other fields of engineering must be considered for materials and methods, plumbing, heating, and ventilating. Every engineer will have occasion to use architectural drawings. An engineer may draw plans or write specifications for a building or some part of a building. Engineers have designed and built industrial buildings, multi-storied structures, bridges, and power projects, whose architecture is good because of the forthright engineered solution of the building's purpose and structure. Architecture constantly changes and advances with progress in science and engineering.

A building is essentially a structural frame which meets certain space requirements, and which will endure certain loading conditions. The designer of a building must understand human needs, space requirements, structural elements, form, scale, and proportion. This chapter is concerned with the working drawings or "plans" by which the architect conveys to the builder or contractor the necessary information to erect the complete structure. Building design, specifications, aesthetics, and other aspects of architecture are beyond the scope of this book.

As stated elsewhere in this book, the fundamental principles underlying all projection drawing are the same. In general, architectural drawing is third-angle projection, although there are occasions when the first angle is used. Owing to the size of the building, practical sheet size, and the fact that a plan must be made for each floor, the architect cannot relate his views on one sheet as in a machine drawing in third-angle projection. Instead, he uses one plane at a time, placing it parallel to that part of the building which he wishes to show, and then projects upon it. Rather than project directly from view to view as in machine drawing, the architect must resort to measurements which are made according to the rules of projection.

An architect's drawings may be divided into two general classes, namely, those which are used for study and consultation with clients, and those by means of which the building is actually erected. The latter are called working drawings. The former are further subdivided into two classes called preliminary sketches and display drawings. The preliminary sketches are made by the architect for his own study of the problem and to use in discussion with his client; the display drawings represent the completed solution which the architect submits in competition or for public display.

21.2 Preliminary sketches. The draftsman begins his study of a problem by making freehand sketches embodying different ideas which occur to him. From these he selects what appears to be the best, and works up a preliminary sketch in pencil to a small scale, say 1/16 or 1/8 inch to the foot, for presentation to his client. These sketches may include the main floor plans, an elevation, and a perspective. They are dimensioned for general sizes only and are sometimes embellished in such a way as to make them more attractive to the client. It is essential that they shall be easily understood, since frequently the person who is to inspect and approve them is not proficient at reading drawings. To this end, only the material which will show the general arrangement is included, and the details of construction are omitted. These drawings are often made on tracing paper so that com-

* This chapter was prepared by Prof. Wayne L. Shick, Registered Architect.

parison of different floor plans can be readily made by placing one over the other.

21.3 Display drawings. In some respects display drawings serve the same purpose as the preliminary sketches, since they make clear to others the general arrangement and appearance of the building. They are made to small scale, the exact choice depending upon the size of the building and the desired size of the finished drawing. They usually include a front elevation, the main floor plans, and a perspective. They are rendered in pencil, ink, or water colors, or in a combination of these, and include, besides the building itself, some imaginary background, such as trees, shrubbery, gardens, and clouds, the whole drawing being a problem in art, designed to secure the most pleasing effect and to show the building to the best advantage.

An ordinary front elevation may be made quite realistic by projecting the shades and shadows on the building, by material indication, colors in various tones, and by putting in a foreground in parallel perspective.

Display drawings are not dimensioned, but the scale is represented graphically. They contain very little information that could be used by the builder.

21.4 Working drawings. The working drawings developed from the architect's sketches and display drawings are the ones in which the engineer is particularly interested. The purpose of such drawings is to provide information from which, with the written specifications, accurate estimates of cost can be made and the building constructed. They must, therefore, be accurately drawn to scale and include all necessary details and dimensions.

A complete set of working drawings, or set of plans, as they are sometimes called, will include the following six or more sheets: plot plan; basement or foundation plan; floor plans in order—first, second, third, and so on, not duplicating, of course, where the floors are exactly alike; four elevations, if all views of the building are different; sections, as many as may be required; and details, as many as may be required. In addition, large buildings frequently require separate sets of plans for the structural framing, whether it be of timber, steel, or reinforced concrete, and separate plans for the mechanical, electrical, plumbing, heating, and ventilating work.

21.5 Plot plans. The first sheet of a complete set of plans is the plot plan. It shows the property lines and the relation of the proposed building to them. See Fig. 21.1. The building is sometimes represented by a cross-hatched area whose shape is that of the outside of the structure at the grade line. In addition, there should be shown the drainage sewers and water mains, utilities, walks and driveways, and any outbuildings to be constructed. If the building site is hilly, the elevations are shown by contour lines, and any grading which may be necessary is indicated. This sheet, like the others, contains in the lower right-hand corner the architect's standard title and, at some convenient place on the sheet, an arrow indicating the north point.

21.6 Floor plans. The floor plan of a building, instead of being a top view as in machine drawing, is in reality a horizontal section as seen from above. The horizontal cutting plane is passed so that it will show the most detail; it need not be a single continuous plane, but may be offset to different heights above the floor at various places. The plan will, therefore, show all openings in the walls in the story through which it is passed. See Fig. 21.2 and Fig. 21.11. It will show interior walls and built-in features such as the plumbing fixtures, special cases, and cabinets. The location of heat outlets or ventilating ducts may also be shown, as well as the location of steam or hot-water radiators and their connecting lines where space must be provided for them by someone other than the heating contractor. The exact location of the water and drainage pipes for the plumbing is usually not shown on small jobs unless their location presents a problem the solution of which must be provided for in advance.

Stairways are indicated by showing approximately one-half of the full flight to the floors above and below, and by marking upon the drawing the full number of risers. An illustration is shown in the floor plans in Fig. 21.2. Two consecutive floor plans show completely the stairway connecting them. Stairways are frequently worked out to a large scale in order to make sure that they will properly fit in the space allowed. A common rule for proportioning the risers and treads is to make the sum of one riser and one tread approximately 17 inches. Seven to eight inches is a maximum height for a comfortable riser.

In addition to the items discussed above, which would actually appear in a projection made strictly according to theory, it is customary to indicate certain features which would not appear by the rules of projection. For example, beams and ornamental features, which appear in the ceiling above the floor shown, are indicated on the floor plan. The lintels over wall openings are also indicated, although they are above the cutting plane. In small buildings not requiring separate framing plans, the supporting members for the floor above are shown on the plan of the floor below. Thus, the beams or joists supporting the second floor would be indicated on the first-floor plan. This, of course, does not apply where a special set of framing plans is prepared. Ceiling lights and out-

lets are indicated in the same way, by locating them on the plan of the floor below. The precise location of the wiring is not given, unless openings must be allowed for it by others than those who do the wiring. In reinforced concrete and steel work, for example, holes must be provided where wiring conduits and pipes pass through floors or beams, as the cutting of holes after the concrete is poured and set might damage its structural value. For reasons of economy also, space for conduits, piping, and ventilating ducts must be provided in advance.

It has become an established practice to draw the floor plans so that the front of the building is toward the bottom or right edge of the sheet, depending upon the shape and size of the building. Elevations should read from the bottom of the sheet, or the right-hand edge in some instances.

In making the floor plans of a building that has several stories, time may be saved by tracing from the first-floor plan the outside walls and interior columns which run through from floor to floor. This also avoids the possibility of error in the location of columns or piers, elevator shafts, and the like, which must line up from story to story.

21.7 Elevations. The elevation of a building is a projection of the building upon a vertical plane perpendicular to the direction from which the elevation is seen, and shows the story heights, all openings in the outside walls, and the nature of the outside finish, such as wood, stone, brick, metal, and glass. Unless the sides of a building are identical, each elevation should be drawn, see Figs. 21.3, 21.4, and 21.5. Where the wall material is erected in a certain pattern, the size, arrangement, and location of the material are shown on the elevation, and the exact construction is shown in a large-scale detail drawing. The outline of the building below the grade line is shown by invisible lines, as seen in Fig. 21.13, as are also roof lines which may be concealed behind parapet walls. On elevations of small buildings, stairways are sometimes drawn in invisible lines in order to save drawing a section. With these exceptions, the invisible line is not used on the elevation unless absolutely necessary. Dimensions on an elevation are practically limited to

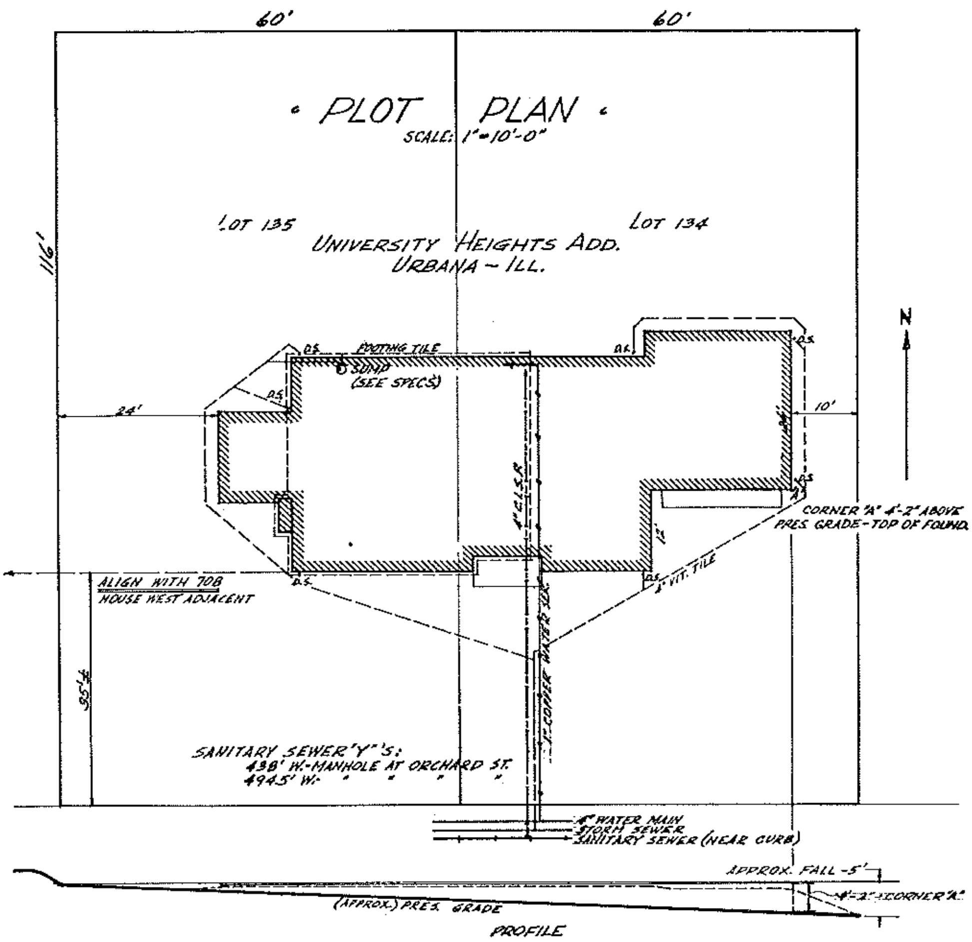


Fig. 21.1. Plot plan.

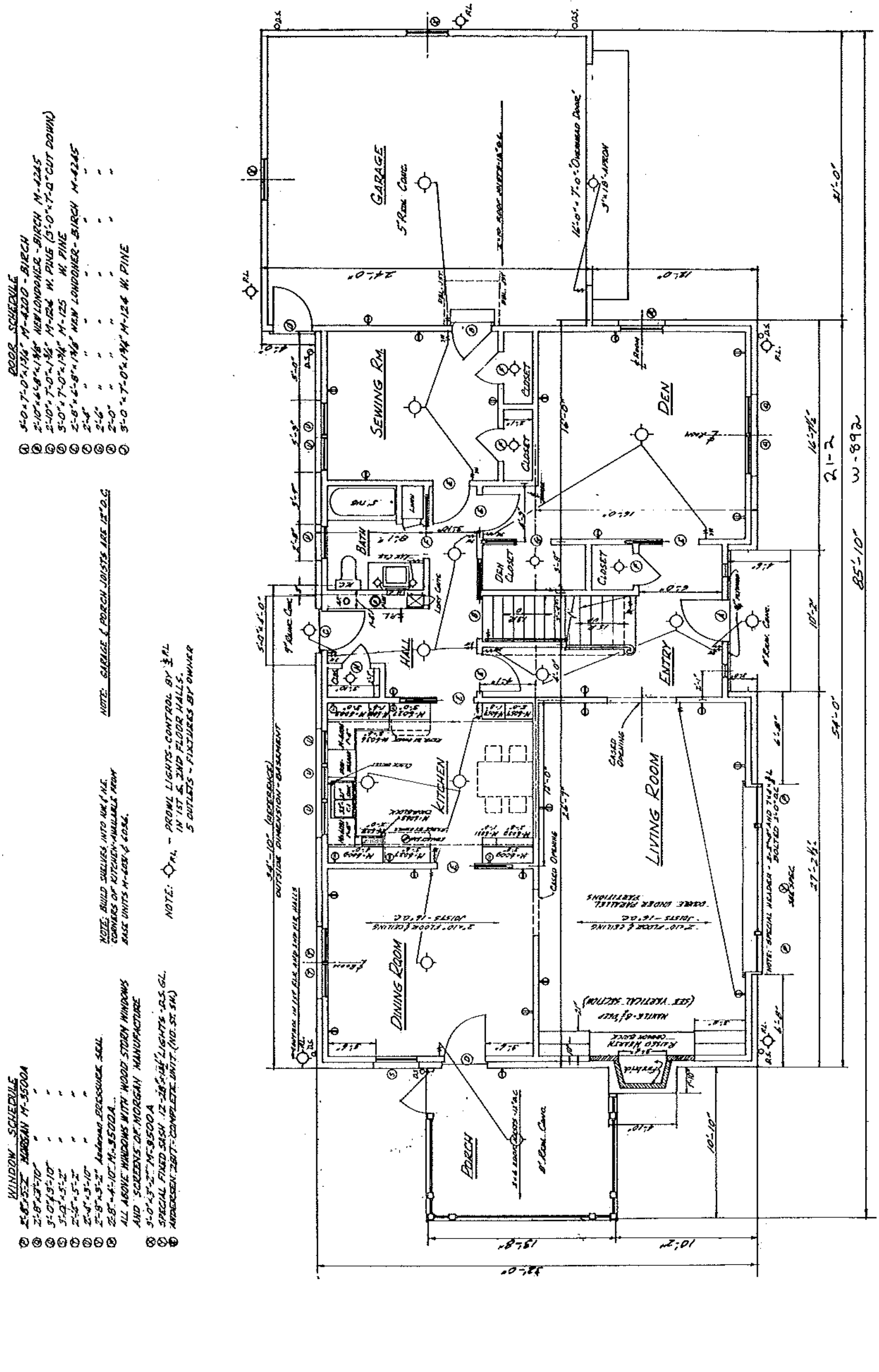


Fig. 21.2. First-floor plan.

those in a vertical direction. See Fig. 21.12. Other dimensions belong on the floor plans and should not be placed on the elevation unless it is impossible to show them on the plans. The elevations are given life and snap by accented lines and touches of ruled-line rendering to suggest the texture of the surface. This ruled-line rendering must be soft and subdued, and not an attempt at a rigid representation, as in machine drawing.

In making elevations, the plan sheet is taped in proper projection position, either beneath the tracing paper on which the elevation is to be drawn or at the top of the sheet, whichever is more convenient. Sometimes the elevation is drawn by reading the principal dimensions from the plan view, locating approximate window positions, and then drawing the windows in the best size, style, and arrangement on the elevation. The best fenestration is worked out by a coordinated study of the plan, elevations, and section. This coordinated study applies to the design and detailing of the entire building and its many parts.

21.8 Sections. The exact details of construction, different kinds of material, and the exact size and integrated placement of the materials are shown in cutaway drawings or sections. Sections cut across the narrow way of a building are called transverse sections, as shown in Fig. 21.6; those cutting lengthwise are called longitudinal sections. Other sections may be taken of parts of the building, showing with exactness the construction of the individual part and how it relates to the building. These sections are called detail sections, i.e., a section of a foundation, a doorway, a fireplace, or stairway. The cutting plane for a section may be offset to take in the important features which it is desirable to show. The cutting plane may be shown edgewise on the floor plan by a heavy dash-and-dot line with arrows at the ends indicating the direction in which the view is taken. All parts cut by the plane are shown cross-hatched in some characteristic way to represent the material, as shown in Fig. 21.13. All parts behind the cutting plane are shown in the usual way. Invisible lines are avoided.

21.9 Standard details. Many of the details and materials and methods used in building construction have been standardized. An entire building could be erected of materials which are standard, uniformly manufactured and specified by the manufacturer, and erected by standard practices. Such things as brick, tile, structural steel, windows, and doors are furnished in certain standard sizes and fabrications.

The most common uses of brick are as a structural load-bearing wall or partition, or as an outer screen wall or veneer facing to a building which has some other structural framing. The brick may be used in a

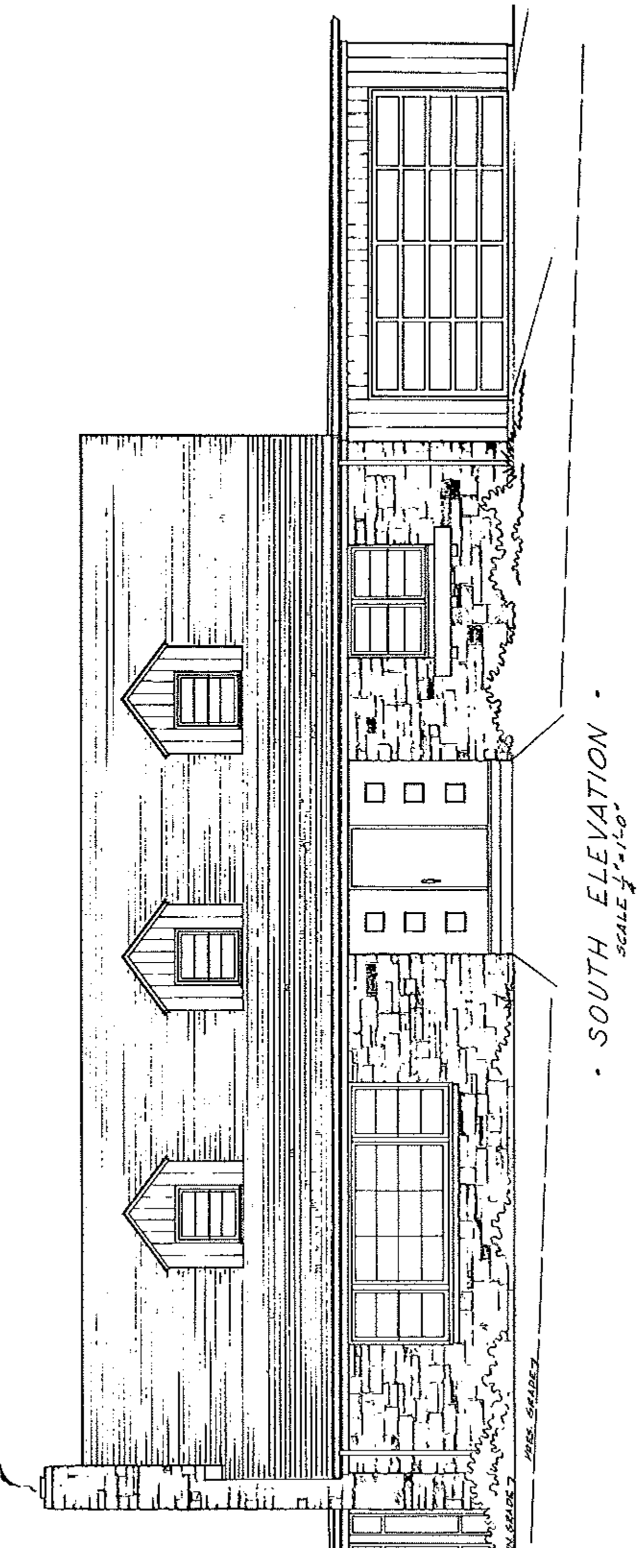


Fig. 21.3. Front elevation.

variety of patterns and bonds, and the brick wall may be united with the structure by metal anchors, lintels, and other connectors. Precast concrete slabs, stone, metal sheets, and other materials are also used to "skin" a building over a structural frame, using metal connectors of various kinds.

a. Brick. Bricks may be obtained in several sizes, colors, and textures. Figure 21.7 illustrates two common types of bond, and some types of brick joints. Joints vary from ¼" to 1" thick usually by ⅛-inch increments.

b. Tile. The word tile applies to two distinct classes of material, namely, the large hollow blocks or building tile, and the smaller solid units used for floors and the covering of walls which are subject to moisture, acid, or other abusive conditions, particularly in kitchens and bathrooms. Tile is also widely used in schools, industrial plants, public buildings, etc. Both kinds may be obtained in standardized dimensions. Figure 21.8 illustrates common building tile sizes.

c. Structural Steel. A few of the common sizes and dimensions of standard steel beams, channels, and angles are given in tables in the Appendix. For complete information, consult the American Institute of Steel Construction (AISC) handbook.

d. Metal Sash. Metal windows are made in stock sizes and are specified by numbers which have the

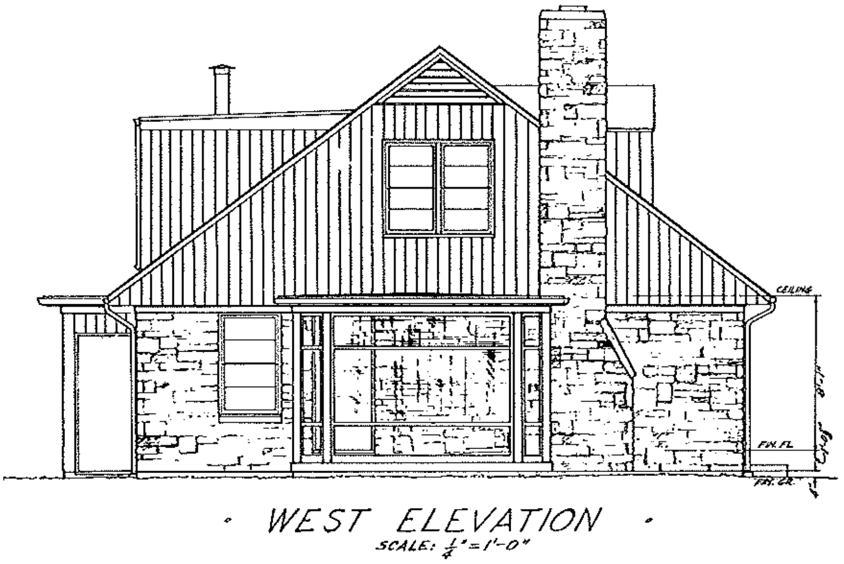


Fig. 21.4. End elevation.

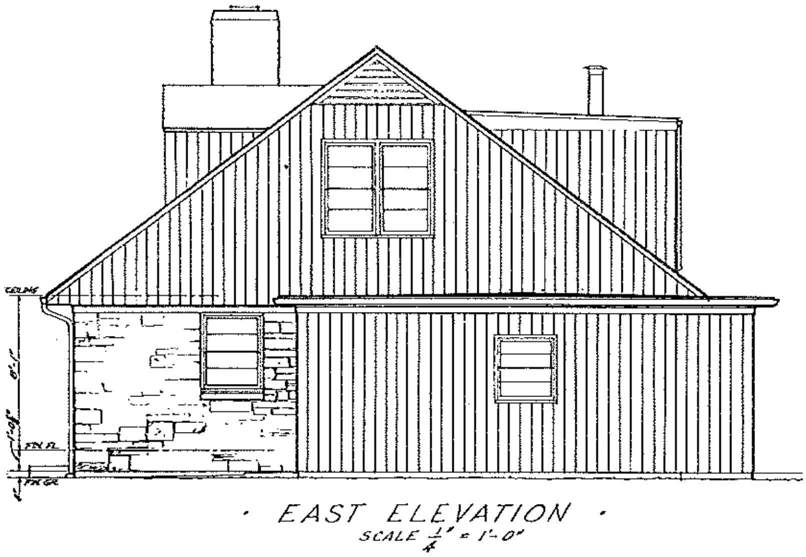


Fig. 21.5. End elevation.

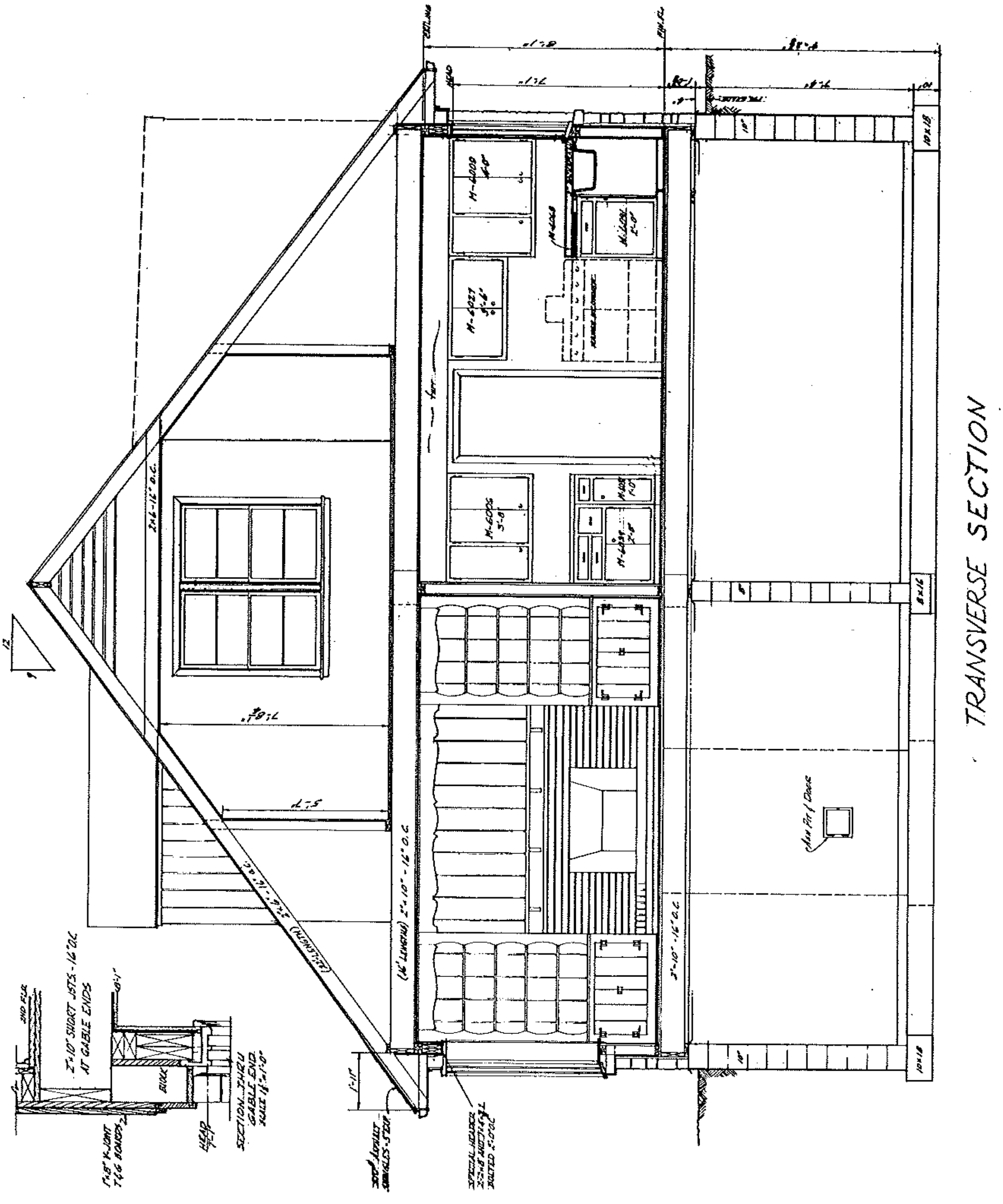


Fig. 21.6. Transverse section.

meanings indicated in Fig. 21.9. The details of construction of one type of sash are shown at the left of this figure. See the Metal Window Institute for a complete listing of standard metal window sizes and types.

e. Wood Sash. Wood windows and metal windows are manufactured in the same types, namely, the projecting or awning types, casement—that is, vertically pivoted; double-hung—that is, sliding up and down and horizontal sliding. Windows can be had in any size of fixed sash. A millwork manufacturer or lumber yard should be consulted for a catalogue of standard types and dimensions of wood sash. For large window openings, the opening is broken up into two, three, or more sashes, separated by a slender vertical member called a mullion. Figure 21.10 gives standard sizes for three types of wood windows.

f. Doors. Doors may be obtained in wood, metal, or flexible material types. Common metal and wood doors are manufactured in stock sizes from 1'-8" to 3'-0" wide by increments of 2", and in 6'-6", 6'-8", and 7'-0" heights. The thickness may be 1⅜", 1¾", or

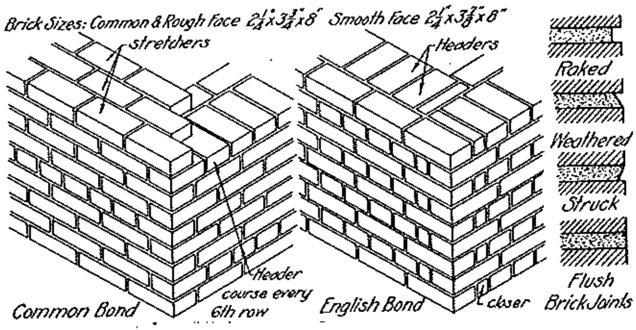


Fig. 21.7. Brick bond and joints.

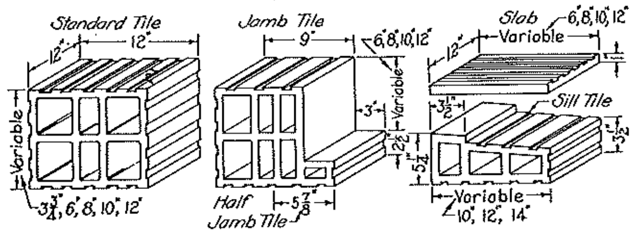
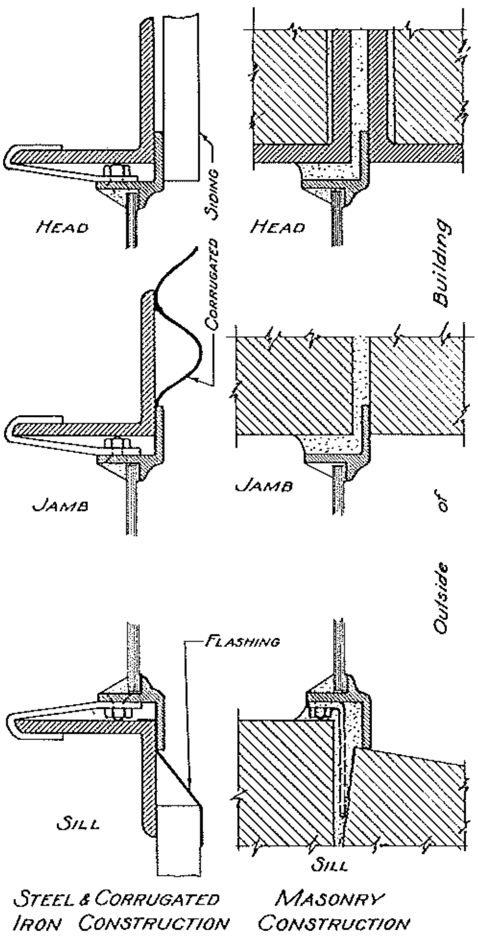


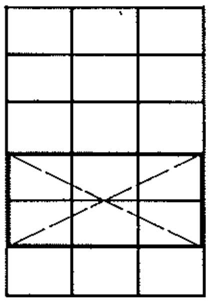
Fig. 21.8. Typical tile blocks.



DIMENSIONS - METAL SASH
A TYPE - 20 × 16 BAR CENTERS
B TYPE - 22 × 16 BAR CENTERS

HEIGHT	WIDTH			
	1'-8 7/8"	3'-8 7/8"	5'-0 7/8"	6'-8 7/8"
2'-9"	A12	B22	A32	A42
4'-1"	A13	B23	A33	A43
5'-5"	A14	B24	A34	A44
6'-9"	A15	B25	A35	A45
8'-1"		B26	A36	A46
9'-5"		B27	A37	A47
10'-9"		B28	A38	A48
12'-1"		B29	A39	A49

MULTIPLE UNITS — OPENING WIDTHS: BAR CENTER DIMENSION (1'-8", 3'-8", 5'-0", 6'-8") TIMES NUMBER OF EACH UNIT, PLUS 4" FOR EACH MULLION, PLUS ONE BRICK JOINT



A36161
CODE FOR SASH NUMBERS
A-20×16
3-LIGHTS WIDE
6-LIGHTS HIGH
1-NO. VENTS.
6-LIGHTS IN VENT
1-LIGHTS UP TO VENT

Fig. 21.9. Steel sash details and dimensions.

for very large doors 2¼″. Flush-panel doors having smooth flat faces are most commonly used, although doors panelled in various designs are available. Doors for large openings may be made up of several doors either hinged together or sliding on tracks, or they may be of a flexible folding type.

g. Wood. Wood is used in buildings in two ways, as a structural material and as a finish material. Structural lumber comes in several grades, the number 1 and number 2 grades being most commonly used. Lumber is available in lengths varying from 8-foot to 24-foot lengths by 2-foot increments. On special order longer boards can be obtained. The cross-sectional dimensions in greatest demand are 2″ × 4″, 2″ × 6″, 2″ × 8″, 2″ × 10″, and 2″ × 12″. These are nominal dimensions, the exact dimensions of lumber being ⅜″ less than the nominal dimensions up to 5″, and, for 6″ and larger, ½″ less than the nominal. For example: a 2″ × 4″ is actually 1⅝″ × 3⅝″ in cross section, and a 6″ × 8″ is 5½″ × 7½″. One exception is the 1″ board which is about 13/16″ in thickness. As a finish material, wood is usually employed as boards 1″ (13/16″) thick, of various widths and lengths, and in several qualities from nearly perfect boards with no knots, checks, or other defects to the most imperfect of boards which may be used for some decorative effect. Wood can be processed into several other types of finish material such as plywood which comes in many thicknesses and sheet sizes.

21.10 Details. Because of the small scale, it is impossible to show the exact construction of all parts of a building on any of the drawings just discussed. It is necessary, therefore, to draw typical details of all intricate parts of the building for which the construction is not self-evident or in accordance with standard practice. These details are made to a larger scale than the rest of the drawing and may vary from ½ inch to the foot up to full size, as shown in Fig. 21.13. It is quite evident that an architect cannot include everything that may need explanation, but his plans and specifications should embrace enough details to permit the making of an explicit contract. It would be manifestly unfair for him to insist upon some type of construction not fully shown in the plans and specifications, when the contractor had perhaps figured on some cheaper scheme. As the building operations proceed, however, the architect is required, from time to time, to furnish additional detail drawings, which must always be given a title showing clearly to what part of the building they apply.

The architect does not devise all the details which are shown in his plans, but depends upon the manufacturers of the different products which go to make up a building to supply him with information concerning their products. Such information has been collected in a set of volumes, called *Sweet's Architectural File,* published annually. A similar file for engineers is also on the market. The progressive architect or engineer also keeps a file of the catalogues of all the manufacturers of materials in which he is interested.

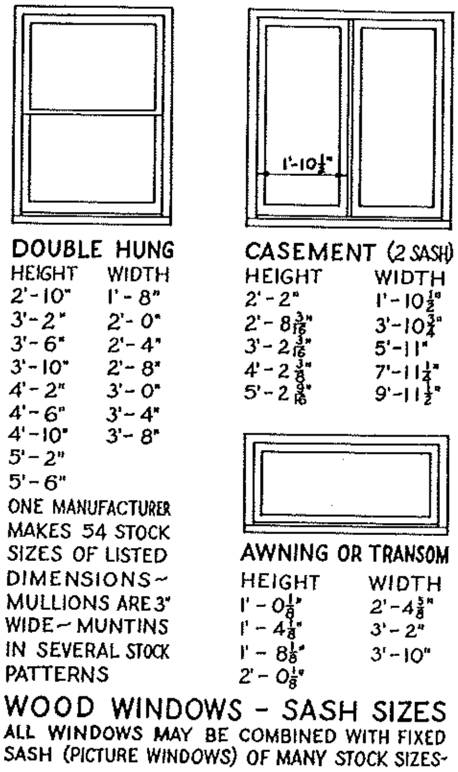


Fig. 21.10. Wood window details and dimensions.

21.11 Dimensioning. The common rules which apply to machine drawing hold in general for architectural drawing. However, it is more difficult to tell what to dimension, as it is only by experience that one can learn which dimensions, of the many that might be given on a building plan, are of any value to the workman. The dimensions given must be clear, definite, and unmistakable. Moreover, they must check with one another from place to place and from plan to elevation. The inevitable variation in commercial sizes of material must be taken into consideration. This does not lessen the requirements for accuracy but demands an expert knowledge of building operations on the part of the architect. Several points to be observed in dimensioning are as follows:

a. Keep all outside dimension lines well away from the building lines. The nearest line should be about an inch away from the building line.

b. Dimension to center lines of interior walls or to the outside of walls, and then give the thickness also. Whenever possible, make a series of inside dimensions in one straight line clear across the building.

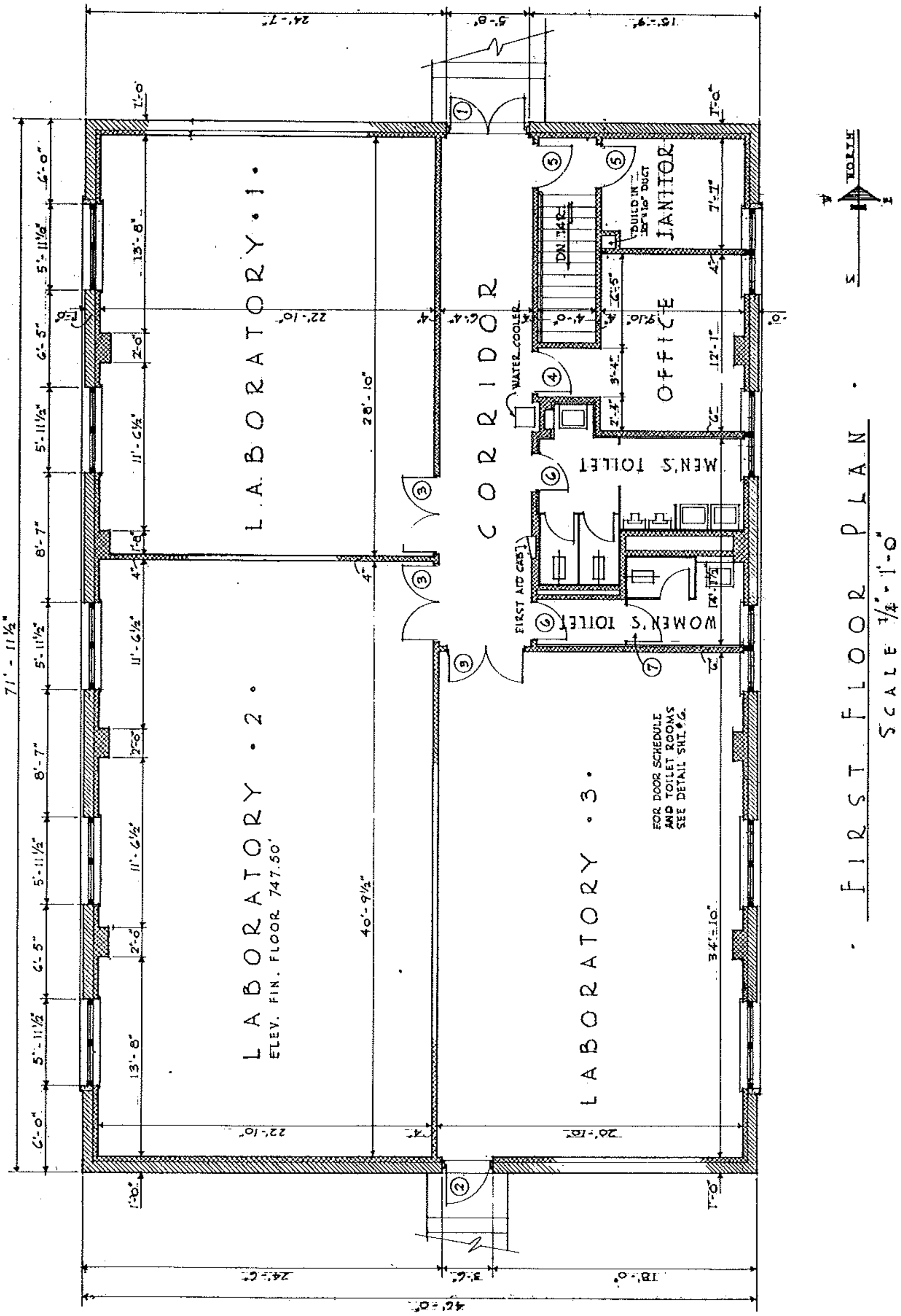


Fig. 21.11. First-floor plan.

c. Dimension to the center lines of columns in both directions.

d. Dimension to the center lines of openings in outside walls, or to the sides of the opening, as required by the structural framing.

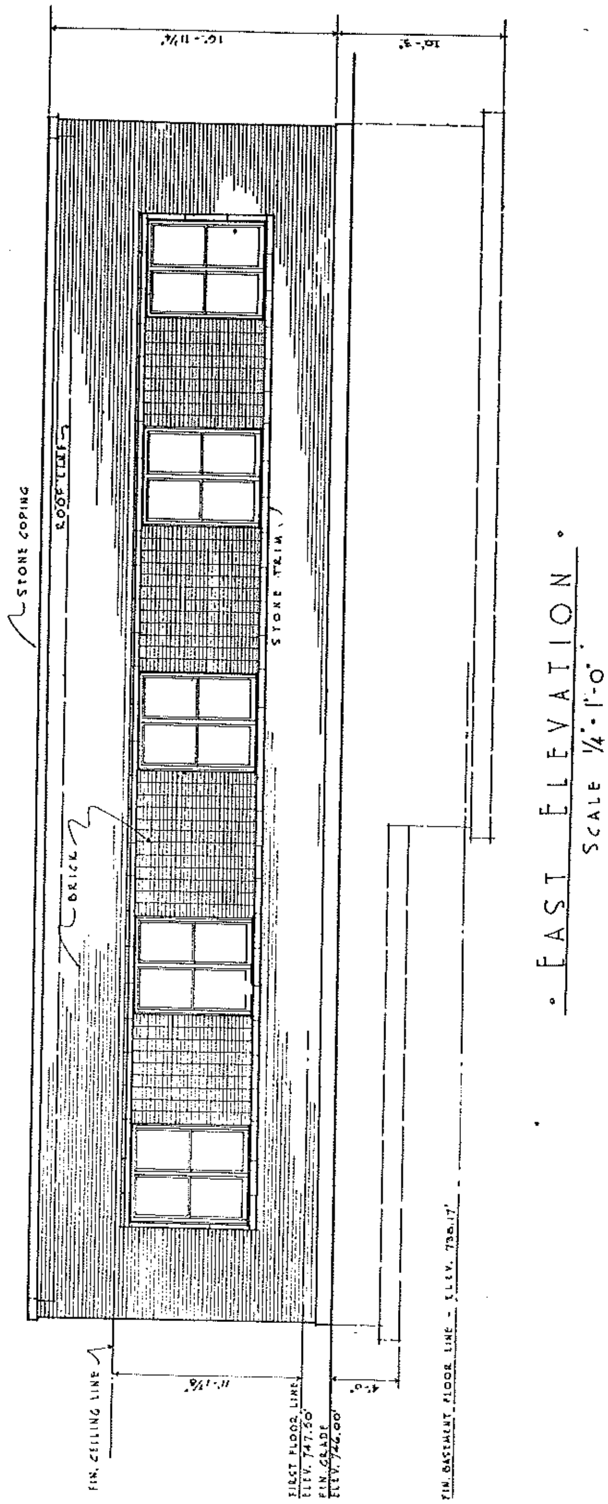


Fig. 21.12. Elevation.

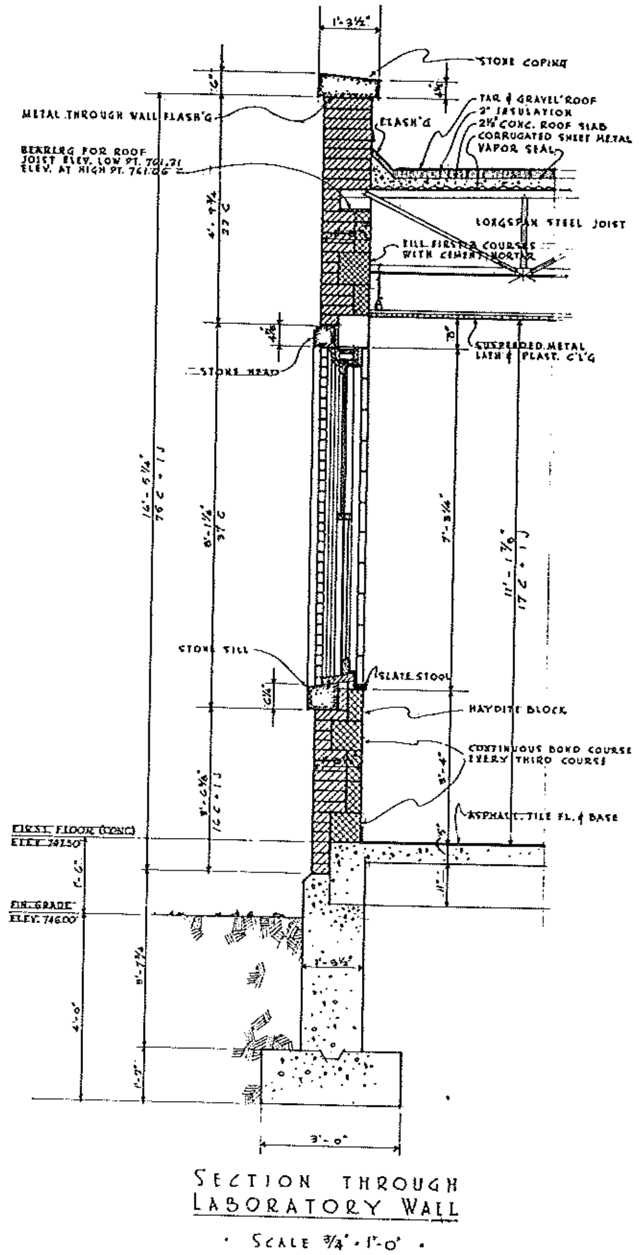


Fig. 21.13. Typical section through wall of building shown in Fig. 21.12.

21.12 Notes. More notes are used in architectural drawing than in any other branch of engineering drawing. If the meaning of a symbol is doubtful, it should be made clear by a note. When a part is detailed, a brief note, such as "See detail on sheet No. 11," should be placed on the floor or elevation drawings near the part detailed. Then under the detail itself there should be a title stating what it is, and a note referring back to the place where the parts may be found in the drawings. In addition to these notes, the sizes of doors, windows, beams, girders,

lintels, columns, etc., must be given. These might be classified as dimensions, but since they do not appear in dimension lines it is better to call them notes.

21.13 Specifications. The contract documents in any architectural project are the agreement, the general conditions of the contract, the drawings, and specifications. The architect prepares specifications to accompany each set of plans. Specifications begin with general statements and conditions, and proceed in a systematic way to consider the work of various trades and materials involved in the construction of the building. The specifications cover those points of construction which cannot be shown in a drawing, namely, kind and quality of materials, manufacturer, type of finish, methods of construction, and in addition reemphasize such points as might be overlooked if the drawings alone were used.

The Federal Housing Authority has prepared a booklet on residential construction, *Minimum Property Requirements,* and a short-form type of specifications which are quite good for small-house work. *Architectural Specifications* by Sleeper, John Wiley & Sons, is a most comprehensive book on the subject, and the American Institute of Architects has prepared Specification Sheets as an aid in their writing. The specifications of individual manufacturers of building products and *Sweet's Architectural File* provide specific information.

21.14 Symbols. Since the plans and elevations of working drawings are made to a scale of $\frac{1}{4}$ or $\frac{1}{8}$ inch to the foot, certain conventional representations are employed. These conventions have been generally standardized, and the parts of the building represented by given symbols are specifically described either by detail drawings, notes, or specifications. Windows are commonly indicated by an opening in the wall the width of the sash, and lines representing the glass and sill. Swinging doors are shown by breaking the wall the width of the door, and drawing the door ajar with an arc for the swing of the door. See Fig. 21.2 and Fig. 21.14. Windows and doors are usually coded by a letter in a circle, each window or door of the same kind and size having the same letter as shown in Fig. 21.2. A chart or schedule of doors and of windows is then prepared describing each kind and size used in the building.

It is clear that the smaller the scale the simpler the symbol must become. A common fault of beginners is to make the symbol too large and cumbersome in proportion to the rest of the drawing. See Ramsey and Sleeper, *Architectural Graphic Standards,* for a comprehensive table of architectural indications. Equipment or material which is not standard or for which there is no definite symbol should be identified on the drawing by a noted circle or rectangle, and be explicitly described by note, detail, or specification in the drawings and specifications.

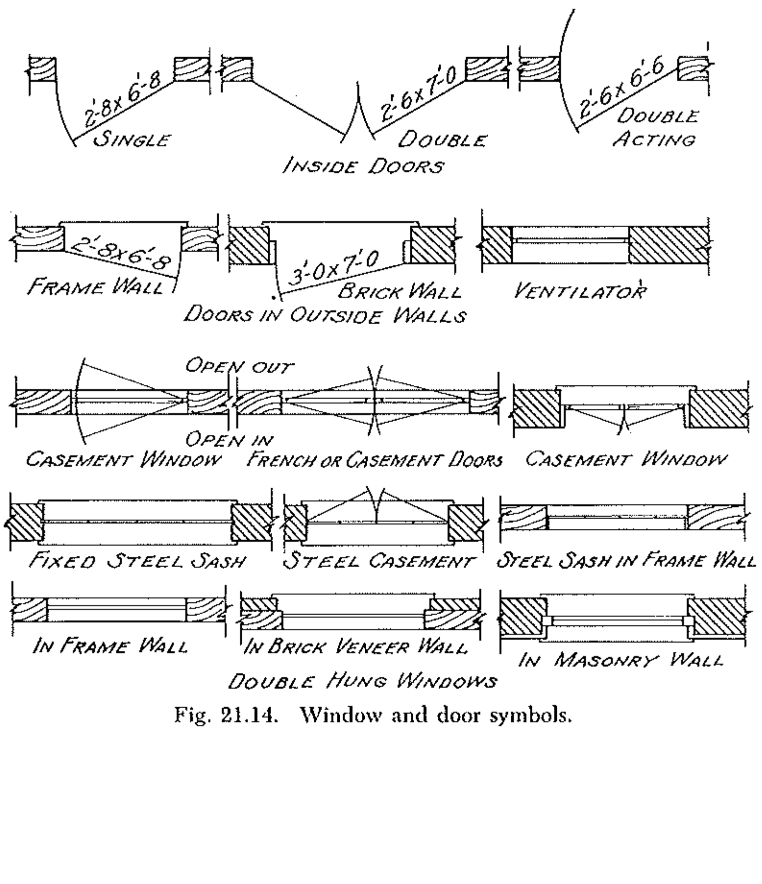


Fig. 21.14. Window and door symbols.

Various kinds of cross-hatching indicate different materials as shown in Fig. 21.15. A key, showing the cross-hatching and materials represented, may be placed on the drawing, particularly if the materials are uncommon and not generally recognizable. However, to one familiar with building plans and construction, cross-hatchings commonly used are readily understood without such a key.

21.15 Electrical wiring. The electric outlets and switches which control outlets are shown either on the floor plan, or upon a simplified tracing of the floor plan, in their approximate locations. A line between an outlet and a switch indicates control of the outlet by that switch, as shown in Fig. 21.2. This simplified type of electrical layout is generally used by architects. The type of service, method of wiring, number of circuits, types of fixtures, and other details are exactly described in the specifications. The precise location of outlets, routing of wire and conduit, and the grouping of outlets into circuits can best be accomplished after the structural shell of the building has been erected. This on-the-job location is worked out by the electrical contractor under the supervision of the architect. Such procedure is economic of drafting time and costs, avoids conflicts between the drawing and the practical installation, and gives the contractor a clear picture of the outlets to be installed which with the specifications enables him to figure the contract cost. The National Electrical Code governs the method of wiring and circuit design. Electrical symbols used in building construction are shown in Table 34 in the Appendix.

For buildings which are repeated many times, such as identical units in a housing project or prefabricated houses, or for very large structures in which duct and pipe spaces must be provided for wiring, the electrical layout problem should be integrated with the plan and the structural drawings. In such cases, it may be economical to predetermine the exact location of outlets, wiring, and the grouping of outlets into circuits. Even so, under practical installation difficulties, and unforeseen conditions, changes or deviations from the electrical layout will be made. A meticulous electrical design and layout could be made for any building, but this should be done only when it is a practical and economical procedure.

21.16 Titles. Architectural titles are usually placed in the lower right-hand corner of the sheet, although occasionally one will find a drawing whose title has been put in some other place. The style of lettering usually employed is a single-stroke, free imitation of the roman. The title generally displays the name of the architect, or firm of architects, rather prominently. The name of the building, if public, or the

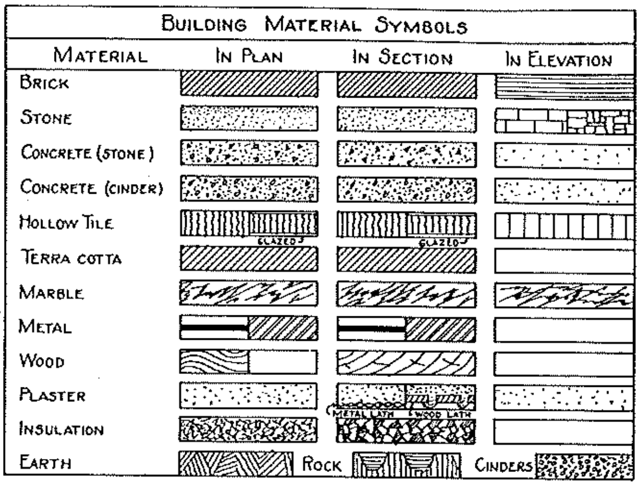


Fig. 21.15. Standard material symbols.

name of the owner, is also given prominence in the title. The contract number, the sheet number, the scale, and the names of the draftsman, tracer, and checker, and the approval signature of the architect are also included. The same general title is placed on each sheet, with a change, of course, in the sheet number and other details where necessary. Other information concerning the drawing on the sheet is placed below the views, as, for example, First-Floor Plan, East Elevation, etc., and not in the title space itself.

21.17 Technique. The technique of architectural drawing is similar in many respects to that of machine drawing. Visible outlines, such as walls, beams, and columns, are made heavier than center lines, dimension lines, and cross-hatching. All lines should be lighter than those generally used in a first-class machine drawing, in order to show adequately the many small details. Contrast between the weights of lines will give the drawings a vigorous and workmanlike appearance.

There is, however, a little greater freedom in the architect's technique, by which he gives expression and life to the drawing, than is permissible in other fields of drawing, although greater freedom does not mean less accuracy. The overrunning of corners is a common practice not found in other engineering drawings, and, though it may speed up the work somewhat, care should be exercised not to overrun where confusion might result.

On elevations, accent lines and ruled-line rendering are used for embellishment of the drawing. There are also many details which the architect must put in freehand. These give character to the work, and produce an effect which is entirely different from the hard and rigid appearance of machine drawings.

These elements, together with the greater freedom in the style of lettering, constitute the chief differences between the technique of architectural and machine drawing.

21.18 Lettering. The architect must employ his knowledge of lettering in two ways; first, in the lettering of his drawings, titles, and the like; and second, in the design of inscriptions and display or sign lettering. Such lettering constitutes a problem in design with which the engineer is not concerned. On working drawings, single-stroke modification of the roman alphabet is used for titles and subtitles; the single-stroke Gothic is most frequently employed for notes.

Problems

The plans shown in Figs. 21.17 and 21.19 to 21.29 show all walls, door openings, and rooms (some windows and prominent elements are also shown). Other plans may be selected from magazines and books, or a plan may be originally designed. Some variations have been suggested, and the student may develop and modify any particular plan to suit individual needs. Locate and determine the size of windows, built-in features, and other details. Select materials for construction, walls, and partitions. Determine the type of roof, whether flat, shed, gable, or hip. Locate electric outlets, plumbing fixtures, heating, etc., as required. Some details of construction can be worked out by inspection of the building shown in this chapter, and by information from reference books. Select the scale and sheet size to be used for each problem.

Each of the following problems may be applied to any one of the buildings shown in Figs. 21.16 to 21.29 or to the buildings shown in Figs. 21.1 to 21.6 and 21.11 to 21.13.

1. Draw the floor plan (or plans).
2. Draw the foundation or basement plan.
3. Draw a vertical section through the outside wall, roof, and foundation.
4. Draw one to four elevations, as assigned.
5. Draw four interior elevations and a plan of a selected room.
6. Draw a detail of some part of the building, such as fireplace, doorway, stairway, or counter. Sections and elevations as needed.
7. Draw a transverse section through the entire building.
8. Draw the plot plan for the building.

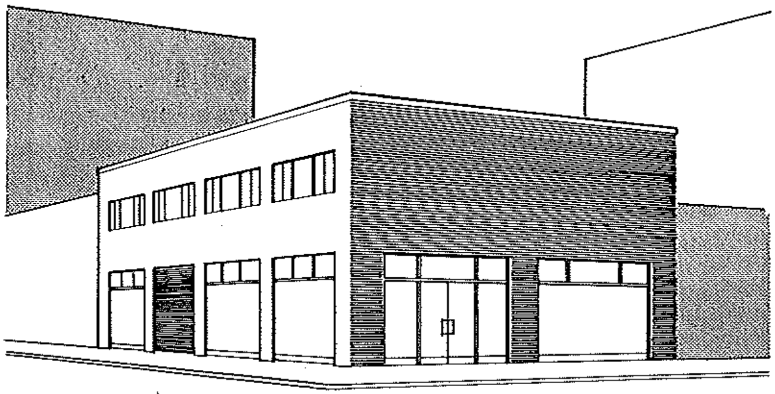


Fig. 21.16. Perspective of store. The building may be modified by different arrangements of interior partitions, and by changing display space, counters, windows, and doors. The plan will vary with the type of store. From first to second floor is 12'-0"; second-floor ceiling height is 9'-0". The first floor is 4" reinforced concrete on 12" fill. The second floor will support 80 lb per sq ft. Outside walls are 13" thick. See Fig. 22.47 for truss and roof details. Heat is supplied from outside source.

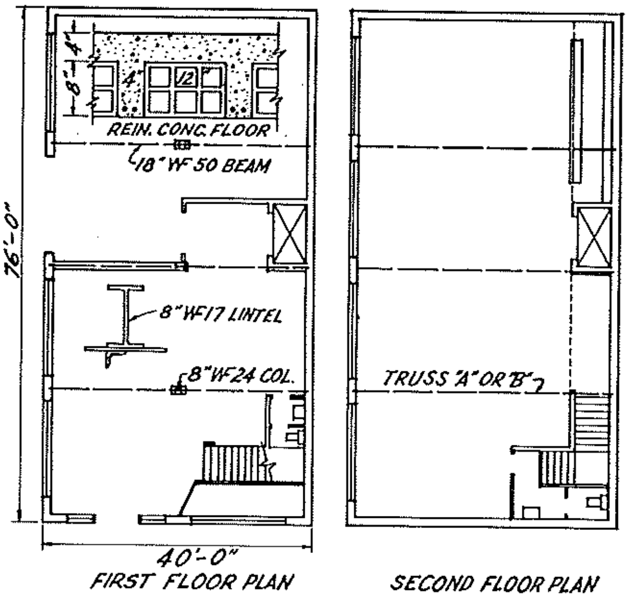


Fig. 21.17 First- and second-floor plans of store shown in Fig. 21.16. The interior of the building may be divided by non-bearing partitions into desired spaces, i.e, washroom, office, stock room, sales room, etc.

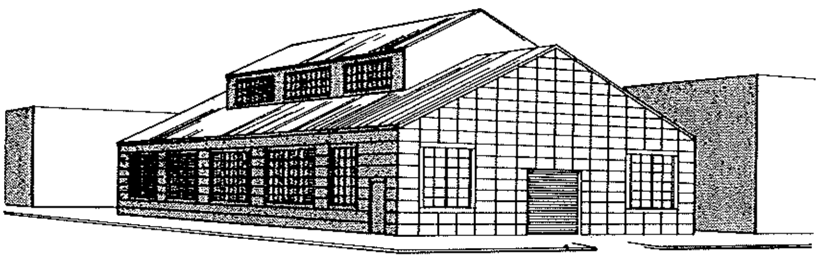


Fig. 21.18. Perspective of factory. Walls of masonry, concrete, or metal panels over masonry. Wall footings are reinforced concrete 2'-0" wide and 12" deep. Column footings are 3'-0" square and 15" deep. The gable end may have truck doors on each side with a large window in the middle. The monitor on top of the building may be extended the full length, or be omitted. See Fig. 22.48 for steel framing.

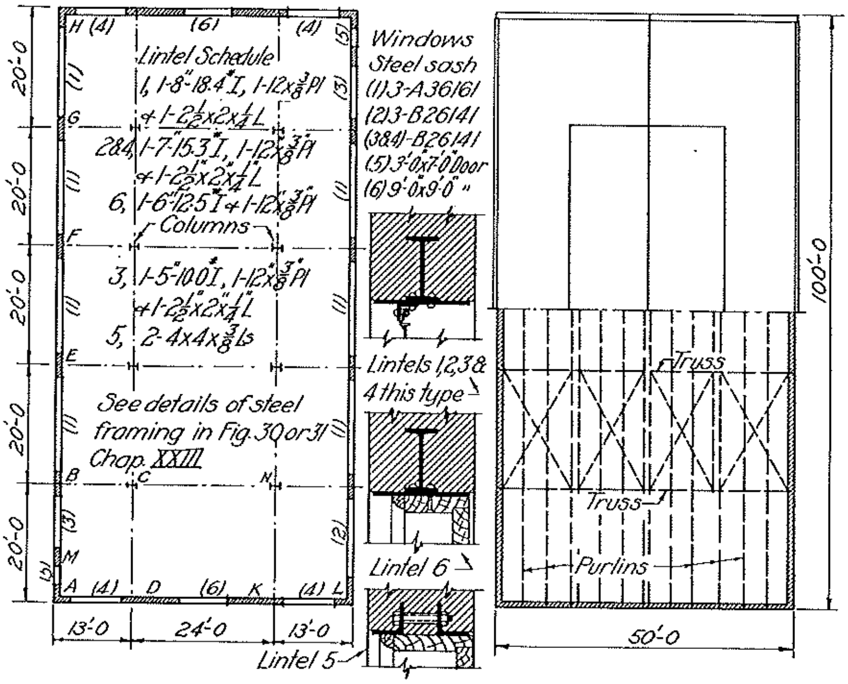


Fig. 21.19. Floor plans of factory shown in Fig. 21.18.

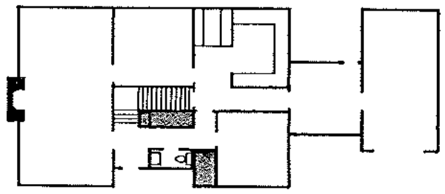


Fig. 21.20. First-floor plan of a two-story residence with basement. 30'-0" × 72'-0".

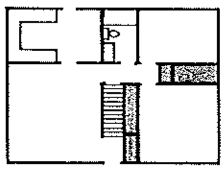


Fig. 21.23. Floor plan of a one and one-half or two-story house with basement. 26'-0" × 36'-0".

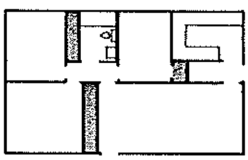


Fig. 21.21. Floor plan of a one-story development house. 24'-0" × 40'-0".

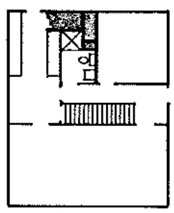


Fig. 21.24. Floor plan of a two-story house with basement. 27'-0" × 33'-0".

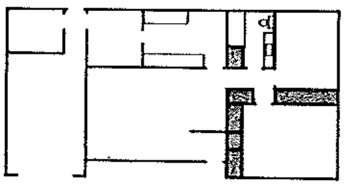


Fig. 21.22. Floor plan of a two-bedroom house. 28'-0" × 56'-0".

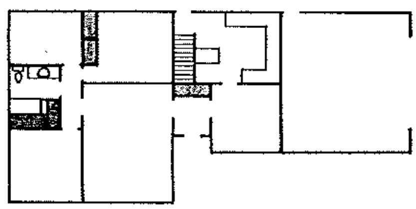


Fig. 21.25. Floor plan of a six-room house with basement. 32'-0" × 68'-0". Furniture and interior decoration should be considered. Minimum ceiling height is 10'-0".

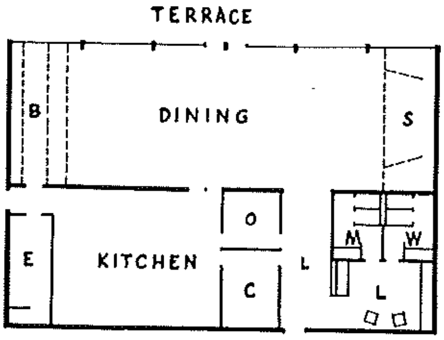


Fig. 21.26. Floor plan of a restaurant or cafe. The building may serve various types of business. Ceiling height is 12'-0" for larger spaces.

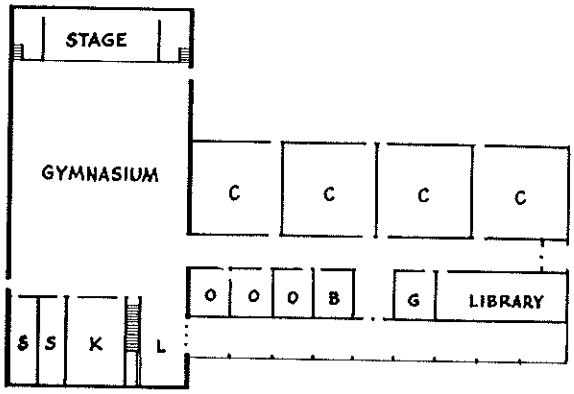


Fig. 21.28. Floor plan of a school. 128'-0" × 188'-0". The gymnasium truss is 6'-0" deep and clears the floor by 24'-0". Roof structure over classrooms is 2'-0" deep. Ceiling height in all rooms but gymnasium is minimum of 10'-0".

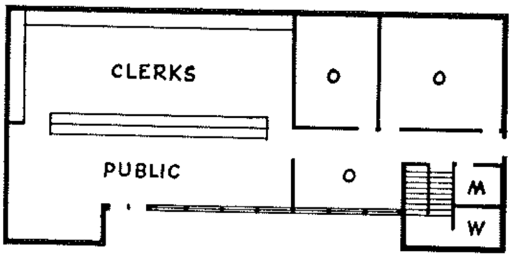


Fig. 21.27. Floor plan of a small office building. 40'-0" × 84'-0".

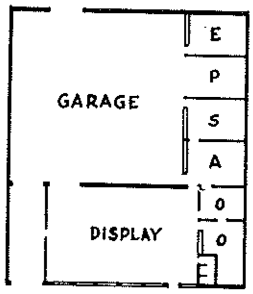


Fig. 21.29. Floor plan of a garage with sales room. Ceiling height in garage and sales room is 14'-0" minimum. Smaller spaces have 9'-0" ceilings. Trusses in garage portion average 6'-0" deep.

Structural Drawing 22

22.1 Introduction. Structural drawing includes all layout and detail drawings connected with the design and construction of buildings, bridges, viaducts, and similar structures in which structural steel, timber, concrete, and other building materials are used. Certain standard practices and conventions have been developed in this field of drafting quite unlike those prevailing in machine drawing, although merging somewhat with those found in architectural drawing.

Steel and reinforced-concrete structures are treated here from the drafting viewpoint only. No attempt is made to deal with engineering design of any structure but the information gained in studying methods of framing, clearances required, and the technical terminology forms an excellent basis for later design courses.

Although a sufficient number of tables are given in the Appendix to solve the problems of this chapter, it is desirable that the student have access to the *Steel Construction Manual* of the American Institute of Steel Construction.

22.2 Definition of terms. In order that the meaning of certain terms used in the later portions of this chapter may be clear, a glossary of the more common terms used in structural work is given below. Where the term member is used in these definitions, a unit part of some larger structure is meant. This unit part itself may be constructed of numerous pieces of steel, but it functions as a single piece and is designated as such. Thus, any part of a structural framework, such as a floor beam or post in a steel bridge, may be spoken of as a member.

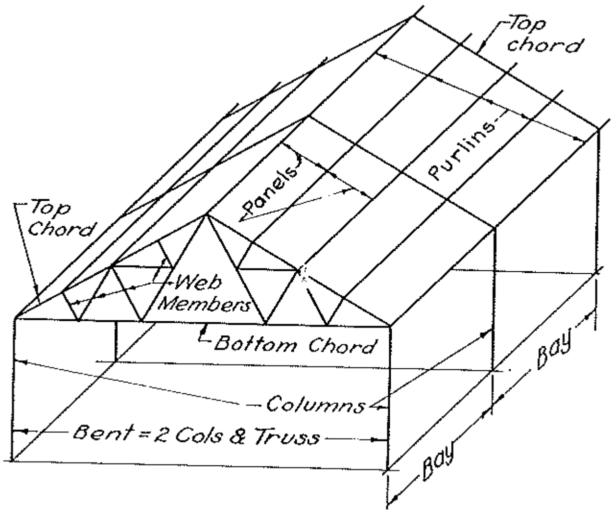


Fig. 22.2. Line diagram, mill building.

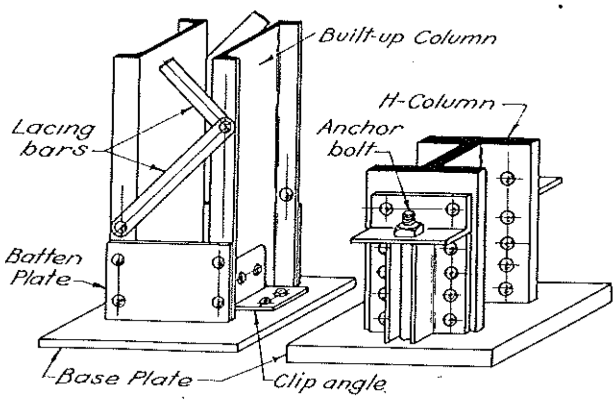


Fig. 22.1. Column bases.

DEFINITION OF COMMON TERMS USED IN STRUCTURAL DRAFTING ROOMS AND FABRICATING PLANTS

Batten Plate. A small plate used near the ends of built-up members to hold two parts of any member in their proper position. See Fig. 22.1.

Bay. The space between two consecutive sets or tiers of columns and beams, or columns and trusses. See Fig. 22.2.

Bent. A vertical framework, usually columns and beams supporting other members. In Fig. 22.2, the truss and two columns supporting it constitute a bent. Figure 22.3 shows a bent as used in railroad trestles or on viaducts.

Cantilever. A beam, girder, or truss in which one end or both ends project beyond the supports.

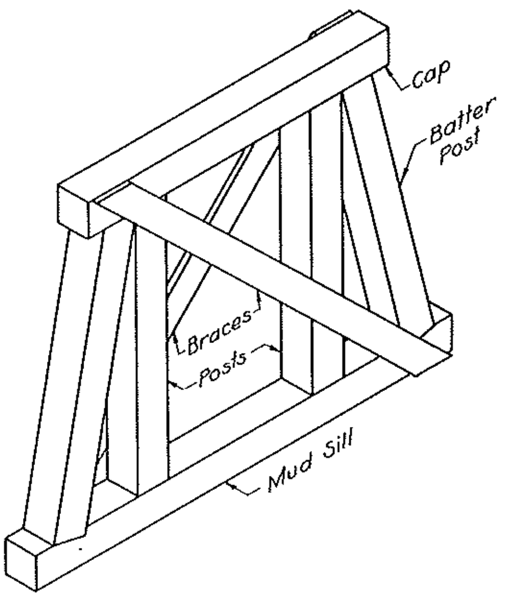


Fig. 22.3. Railroad trestle bent.

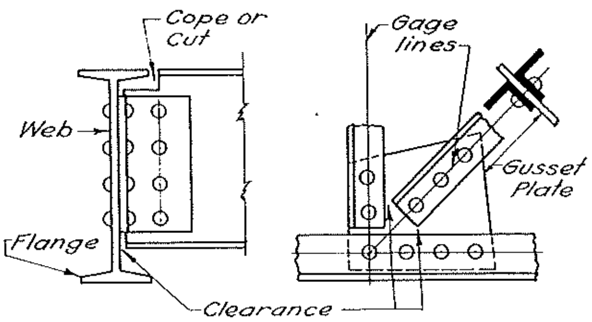


Fig. 22.4. Structural riveted connections.

Chord. The top or bottom members of a truss. See Fig. 22.2.

Clearance. The space left between members to allow for the slight inaccuracies of cutting, and also to facilitate erection. See Fig. 22.4.

Clip Angle. A small angle used to fasten light connections. See angles on top chord of truss in Fig. 22.33.

Column. A vertical compression member, usually supporting beams and girders. See Fig. 22.2.

Cope. To cut out a part of the top or bottom flange of a beam or channel so that it may fit another. See Fig. 22.4.

Cover Plate. A plate riveted to the flanges of a compression member to give it greater area. The plates on the top flange of a plate girder are perhaps the most common examples. See Fig. 22.5.

Filler Plate. A plate used to fill in empty spaces through which rivets must pass, as, for example, under stiffeners on a plate girder. See Fig. 22.5.

Flange. The top and bottom projection or outstanding parts of a beam, channel, or girder. See Figs. 22.4 and 22.5.

Gage Line. The line along which rivet holes are punched in structural members. See Fig. 22.4.

Girder. A member designed to carry bending stress, usually supporting other members. Figure 22.5 shows one end and a section of a girder.

Gusset Plate. A plate connecting the several members of a truss or other structural framework. See Fig. 22.4.

Lattice Bar or Lacing Bar. One of a series of short diagonal bars used to connect the several parts of a member. See Fig. 22.1.

Lintel. A structural member designed to carry the wall over a window, door, or other opening. See Fig. 22.6.

Panel. The space between two purlins in a roof or between two vertical members in a bridge truss. See Fig. 22.2.

Pitch. The ratio of the height of a gabled roof to its width.

Purlin. The horizontal members spanning from truss to truss, upon which the roof is carried. See Fig. 22.2.

Stiffener. An angle riveted to a plate to prevent it from buckling. See Fig. 22.5.

Truss. A steel framework whose members take only tension or compression stresses. See Figs. 22.2 and 22.33.

Web. The portion of an I-beam, channel, or girder, between the upper and lower flanges. See Figs. 22.4 and 22.5.

Web Member. The members of a truss between the top and bottom chords. See Fig. 22.2.

22.3 Number and location of views. As in machine drawing, third-quadrant projections are used entirely, and two or three views of an object are drawn, as may be required. The top view appears above the front view, and the end view to the right or left of the front view. If the top member is inclined, the top view will be an auxiliary projection, rather than a projection on the horizontal plane, as, for example, the top chord of the truss in Fig. 22.33. Frequently,

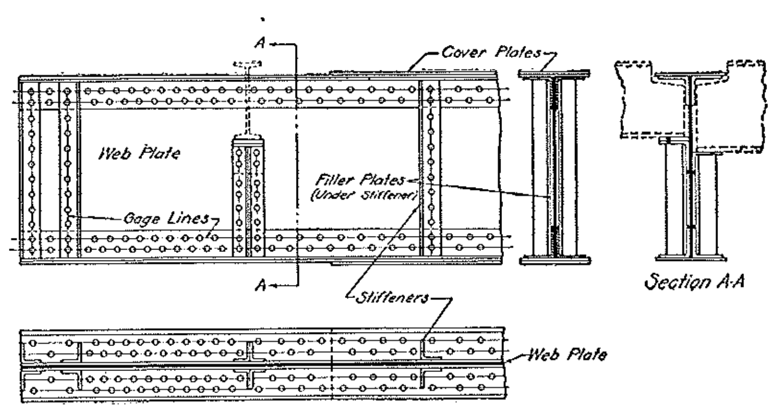


Fig. 22.5. Plate girder.

however, for very simple pieces, only one view is necessary, since the shapes of the pieces in the other direction are known to have a certain standard form. In blocking out the views, care should be taken to allow ample space for dimensions, more space being required between views for this purpose than is ordinarily necessary in machine drawing.

22.4 Bottom view. In addition to the usual three views, it is frequently necessary to show a bottom view of structural members. In structural drafting, such a bottom view is made as a horizontal section looking down, instead of the regular bottom view, such as would be made in machine drawing. The horizontal cutting plane is passed to show as little other detail beside the bottom members as possible. An illustration of this practice is shown in Figs. 22.5 and 22.33. The purpose of this practice is to show the front and back details of a girder, for instance, on the same side of the horizontal center lines in both the top and bottom views. This arrangement shows their actual relation to each other better than if a theoretical bottom view were taken.

22.5 Details. In machine drawing it is customary, in making a detail working drawing, to separate the parts of a machine and detail them individually, whereas in structural drafting the opposite may be said to be the common practice. In other words, all the parts of a member are detailed as far as possible in the place they occupy in the structure. For example, the members of an ordinary roof truss are detailed in their proper places in the truss, as are the parts of a plate girder, or the large posts and chords of a bridge. That is to say, beams and girders are detailed horizontally on the sheet, and columns are detailed vertically, unless they are too long to be placed in that position, in which case the bottom end is placed at the left of the sheet and the column detailed horizontally. Inclined or sloping members are sometimes detailed in the position which they occupy, as indicated in Fig. 22.7. When they cannot be conveniently detailed in this manner, they are placed

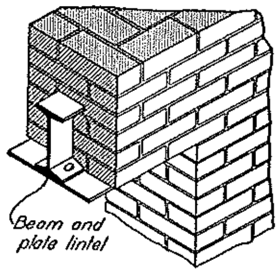


Fig. 22.6. Steel lintel.

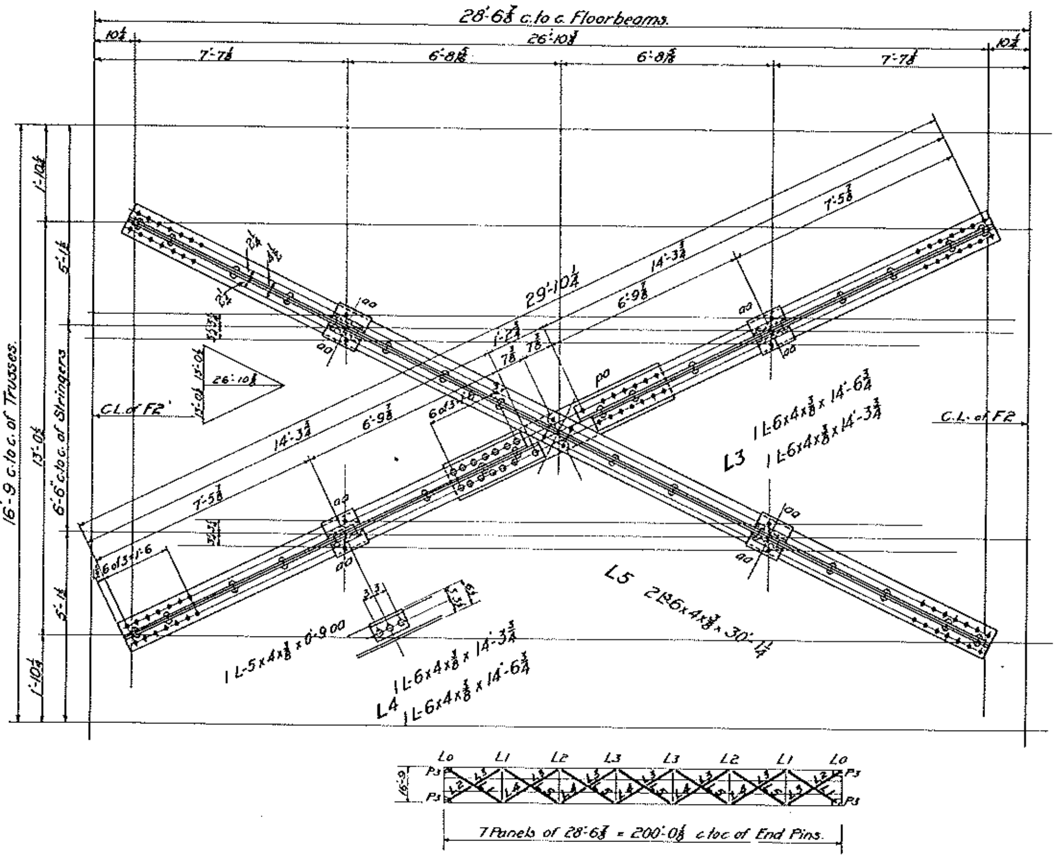


Fig. 22.7. Wind bracing and erection diagram.

horizontally in the position in which they would fall.

If the member detailed is a part of a larger structure, its position in the completed structure is shown by a heavy line in a small sketch on the sheet, as shown in Fig. 22.7. This holds true for all except plain building work. When connections occur in building work upon the detailing of which other framing depends, sketches are made showing the member connecting with the one detailed, in order to work out dimensions. Connecting members are not shown on the final shop drawing.

22.6 Scales. Structural drawing differs from machine drawing again, in that on simple pieces the drawing is not scaled in one direction. Thus, in Fig. 22.8, the end view is made to scale in both directions and the other view is likewise to scale in all dimensions except the overall length. The details at the ends are made to scale lengthwise, but the total length is not. In machine drawing a break is indicated across a figure which is shortened in this manner, but in structural drawing it is not customary to do this. See Fig. 22.8.

When beams are of the same size and vary only in lengthwise dimensions, the same drawing may be used for several beams by putting on a set of dimensions for each beam as shown in Fig. 22.8. Many companies have printed forms showing the front, top, bottom, and end views of a beam, or any combination of these views which best suits their purpose. On these sheets it is only necessary for the draftsman to put in the details and dimensions.

In structural drawing the architect's scales are the only ones employed. They range from ¼″ = 1′-0″ for framing plans, to 3″ = 1′-0″ for the layout of joints. Almost any combination between these limits may be used. The more common ones, however, are ¾″ = 1′-0″ and 1″ = 1′-0″.

22.7 Symmetrical members. If large members such as trusses and plate girders are symmetrical about a center line perpendicular to their longest dimension, only one-half is detailed. It is the standard practice to show the left half when looking toward the side having the principal connections. For a railroad plate girder, this requires that the inside left end of the far girder be shown as the front view. Figure 22.33 illustrates this for a roof truss. As may be noted, the detail should be carried far enough past the center line to show any variation that may occur at the center. In no case should the detail be stopped exactly on the center line, even though there may be no variation beyond. The member should be broken off beyond the center by a ragged or wavy line, or the lines of the drawing may be simply stopped at the same place. The wavy line should be drawn only where there are members actually broken off, and not through the space between members.

22.8 Sectional views. Sections are frequently necessary in structural drawing and may be made in the positions occupied by end views or interpolated sections in machine drawing. When several sections of the same piece are necessary, these may be put in convenient places on the sheet and noted as sections taken at some particular plane, as, for example, Section *AA*. The place where this section is taken is then indicated on the drawing by a line *AA*, with arrows on the end of it to indicate the direction of sight, as in Fig. 22.5. Standard practice as regards cross-hatching is also shown in Fig. 22.5. The main part of the member cut is usually made solid black, although cross-section lines may be used. Filler plates, stiffeners, etc., need not be cross-sectioned.

22.9 Standard details. Through long years of practice and experience, certain details of steel construction have become standardized. The draftsman and detailer should adhere to these standard details unless it is impossible to do so, or unless some particular advantage is to be gained by departing therefrom. Some of the more important and common standards are discussed in the following paragraphs.

22.10 Standard structural shapes. The shape, dimensions, and consequently the weight of structural sections are thoroughly standardized, and the general dimensions of the more common pieces should be familiar to the draftsman. Figure 22.9 shows cross sections of the more common shapes, the sizes of which vary through a wide range although the general proportions remain about the same. Thus, I-beams may be obtained in sizes from 3 to 36 inches in height, and for each height there are a number of standard weights. The *Steel Construction Manual* lists all of these completely, and the student is referred to it for further information. A list of the

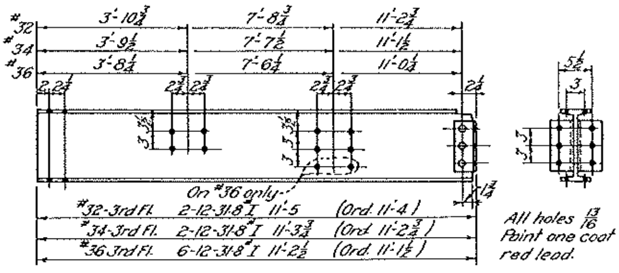


Fig. 22.8. Detail for a series of beams.

standard light sections is given in Tables 24 to 26 in the Appendix.

22.11 Gage lines. The lines along which rivets should be placed in the flanges of I-beams, channels, angles, and other structural shapes have become standardized through long usage. These lines are called gage lines. In angles, the gage line is measured from the back of the angle. The gage line in the flange of a channel is also measured from the back of the channel, but in the flanges of an I-beam the gage lines are measured from the center. Edge distances are not given because they vary along the same beam, and they also vary in shapes of different weight, whereas the distance measured from the back or center line always keeps the gage lines in the same relative position. Standard gages for I-beams, channels, and angles are given in Tables 23 to 26 in the Appendix.

22.12 Rivet size and spacing. Maximum and minimum distances for rivet spacing along the gage lines have also been established. Data on these spacings are given in Table 27 in the Appendix.

Since a certain clearance is required in driving rivets, there is a limit to the size of rivets which may be driven in the standard shapes. Figure 22.10 shows the shape and size of the dies used in driving rivets. The minimum-size rivet is governed by the following rule: the diameter of the rivet should never be less than the thickness of metal to be punched. That is to say, a hole for a ½-inch rivet should not be punched through ¾-inch metal.

The end and edge distance of rivets from sheared or rolled edges of members, together with the maximum and minimum pitches allowed, are given in Table 27 in the Appendix. When drawing rivet heads the diameter is made equal to $1\frac{1}{2}D + \frac{1}{8}$ inch where D is the rivet diameter.

22.13 Beam connections. The angles for connecting beams to columns or girders have been standardized in six series designated as A, H, HH, B, K and KK to accommodate different loadings and rivet sizes. A portion of the B series for ¾ rivets is shown in Table 28 in the Appendix. The rivet spacings shown should be adhered to.

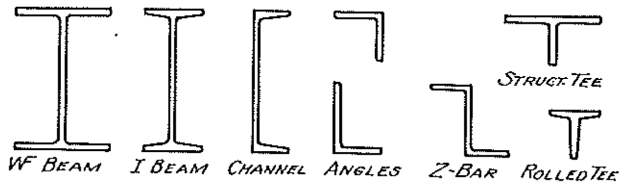


Fig. 22.9. Structural rolled sections.

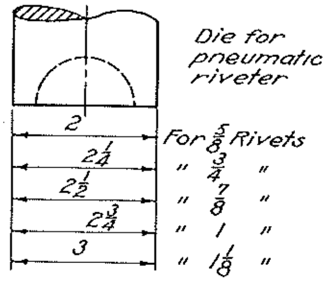


Fig. 22.10. Rivet die.

22.14 Conventional symbols. The use of conventional signs and symbols is limited almost entirely to the representation of rivets. The standard symbols and their meaning are shown in Fig. 22.11. It will be noted that, where the operation is to be performed on the near side or outside of the piece, the designating marks are on the outside of the circle, whereas, to indicate the same operation on the far side or inside, the marks are on the inside of the circle.

When there is a long line of rivets uniformly spaced, not all the rivets need be drawn in. Usually only those at the beginning and end of a series of uniform spaces need be indicated. The side view of a rivet is not shown except when it will add to the clearness of the drawing.

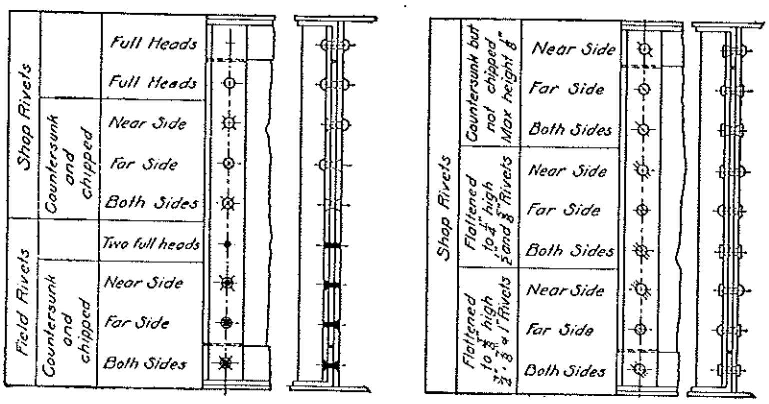


Fig. 22.11. Conventional symbols for rivets.

A departure from the above rule must be observed with field rivets. All field rivets must be shown. They are also shown in the side view unless this will confuse the drawing.

2-∠s-3$\frac{1}{2}$x3$\frac{1}{2}$x$\frac{3}{8}$ x 6'-10	5-10 ⊔ 15·3 x 13'-4
3-∠s-6x4x$\frac{1}{2}$ x 8'-6	2-T 5x3$\frac{1}{2}$x13·6x 7'-2
1-15 I 42·9 x 17'-2$\frac{1}{2}$	1-Z 5x3$\frac{1}{4}$x17·9x 5'-4$\frac{3}{4}$
4-12 ⊐ 10 x 12'-0	2-℔ 12x$\frac{1}{2}$x 1'-6
1-27 WF 94x27'-0$\frac{1}{2}$	20-112# A·R·E·A Railsx33'-0

Fig. 22.12. Method of specifying standard shapes.

22.15 Billing materials. In making a bill of material or in notes, the following symbols are used as abbreviations: the wide-flanged beams are indicated by WF; I-beam is indicated by the capital letter I; the channel by a symbol similar to the cross section of a channel lying on its back, to prevent confusion with the symbol for the I-beam if carelessly made; and angle, T-bar, and Z-bar are indicated in the same way by symbols representing their cross section. The proper method of billing the various shapes is shown in Fig. 22.12. The weight per foot, or thickness in the case of the angle, must always be given, as all the structural shapes are made in several weights for the same general dimensions.

22.16 Dimensions. Since a single detail may be sufficient for the fabrication of several tons of steel, it is quite evident that a single error in dimensions may spoil tons of steel, not to mention the waste in labor and time and the loss of a reputation for reliability. Placing of the dimensions is perhaps the most difficult single problem. An examination of the illustrations in this chapter will give a basis upon which judgment can be formed as to the best placing of dimensions. The rules given apply particularly to drawings which are completely detailed in all respects. The following rules should be observed and applied with common sense and judgment.

22.17 Techniques. *a.* Dimension lines should be light, solid, black lines terminating in arrows.

b. The figures should be placed above the dimension lines at or near the center of the space between arrows. Note: This differs from the standard practice in machine drawing.

c. Dimensions should be given as shown in *A*, Fig. 22.13.

d. Where a dimension line runs through a rivet whose location it does not give, the dimension line should be broken and an arc drawn around the rivet, as shown in *B*, Fig. 22.13. Avoid this situation whenever possible.

e. The division line in fractions should always be made parallel to the dimension line.

f. When the space between the arrow heads is very limited, the dimension may be put in as shown in *C*, Fig. 22.13.

22.18 Placing dimensions. *a.* On truss members, detail dimensions should be placed in a continuous row from end to end of the member, no dimension being omitted.

b. An overall dimension should accompany each set of detail dimensions.

c. Where two or more lines of dimensions are given for the same piece, they should not be placed closer together than 5/16 inch, and the first line should not be closer to the piece than double this distance. It may be farther away when circumstances demand. Above all things, dimensions should not be crowded upon one another or upon the object drawn.

d. The lettered figures of a dimension should not fall upon the outline of any member, since this makes it almost impossible to read. When other methods fail, a leader should be used and the dimension placed in the clear, where it will be legible.

22.19 Fabricating dimensions. *a.* Dimensions should be calculated to the nearest sixteenth of an inch, except for bevels when it is frequently advisable to work to the nearest thirty-second of an inch.

b. The detail dimensions should always be added to see that they check with the overall dimension.

c. The work is completely detailed only when it is unnecessary for the workman to add, subtract, multiply, or perform any other mathematical operation to obtain an essential dimension.

d. The slope of all members should be given in run and rise and not by angles. One of the dimensions of the run and rise should always be 12 inches. The run is the horizontal distance and the rise the vertical distance. See Figs. 22.32 and 22.33.

e. Before the work is submitted to the checker, it should be examined from the point of view of the shop man. All the dimensions and other information needed to lay out the work should be checked.

f. On beams and girders, the position of successive and independent details may be dimensioned consecutively from the left end in one line of dimensions as in Figs. 22.8 and 22.14. Chain dimensioning may be used when the details are continuous from end to end as in Fig. 22.23.

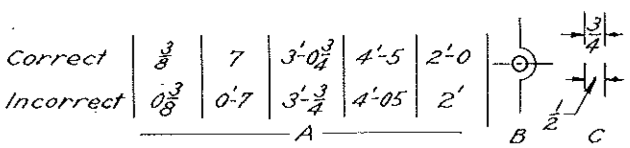


Fig. 22.13. Method of dimensioning.

g. End distances and edge distances are usually given by note on light truss members. They are dimensioned on beams, columns, and girders. Gage lines should be dimensioned even though they are standard.

h. Field rivets should be dimensioned independently even though they are located with a series of detail dimensions.

i. The size of each piece is given close to the piece itself.

In dimensioning, as with standard details, many fabricating companies have adopted certain standard practices for their draftsmen to observe, which have been developed through experience in the shop. These vary somewhat in different shops.

22.20 Rectangular framed structures. Structural steel fabrication may be roughly divided into two major categories, namely, rectangular framed structures such as tall buildings and those involving triangular framework such as roof trusses and bridges. The framing of buildings consists mainly of vertical and horizontal members which are connected at right angles to each other.

22.21 Design drawings or layouts. The structural draftsman usually works from design layouts or framing plans which show the arrangement of columns, girders, and beams for each floor of a building. This layout gives the size of each member and its location relative to others both horizontally and vertically. The horizontal distances are shown by dimensions and the vertical distances by elevations as shown in Fig. 22.15. A note indicates the distance of the major portion of the framing below the finished floor line. Departure from this general level will be called out as plus or minus distances above or below the finished floor level as noted for beam *K3* in Fig. 22.15.

22.22 Marking. In order to provide a systematic procedure for detailing, fabricating, and erection, each member of a structure is given a mark on the design drawing. This mark on the layout is placed on the detail drawing of the piece, painted on the piece in the shop, and used by the erector in the field to place the member in the structure.

In addition to these marks, which can be called erection marks, and which must appear on the final finished piece, other marks must be placed upon each piece of steel used to make the composite. These latter marks are for the purpose of assembling the member in the shop and may be called assembly marks.

Each company has its own system in both categories. A common method is to assign capital letters as erection marks to the horizontal members. The letter is followed by a number. This number may refer to the sheet or drawing number on which the member is detailed or it may refer to a floor number.

Columns may be numbered in consecutive order in some systematic arrangement on the plan, or the rows of columns may be given letters in one direction and numbers in the direction at right angles to the first as shown in Fig. 22.15. Any column is then designated by the intersection of the lettered and numbered rows, as for example, *B-2*, *C-3*, etc., in Fig. 22.15. Since a column will have the same number throughout its entire height, but must be erected in sections, each section must be given a distinguishing mark, as for example, *B-2* Tier One or *B-2* (*0-2*). Tier one would be the mark of the first columns to be

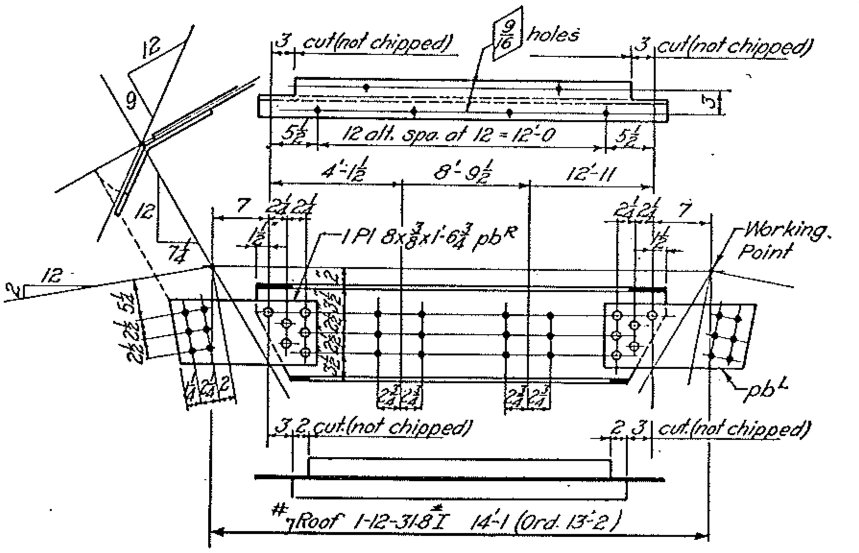


Fig. 22.14. Roof purlin detail.

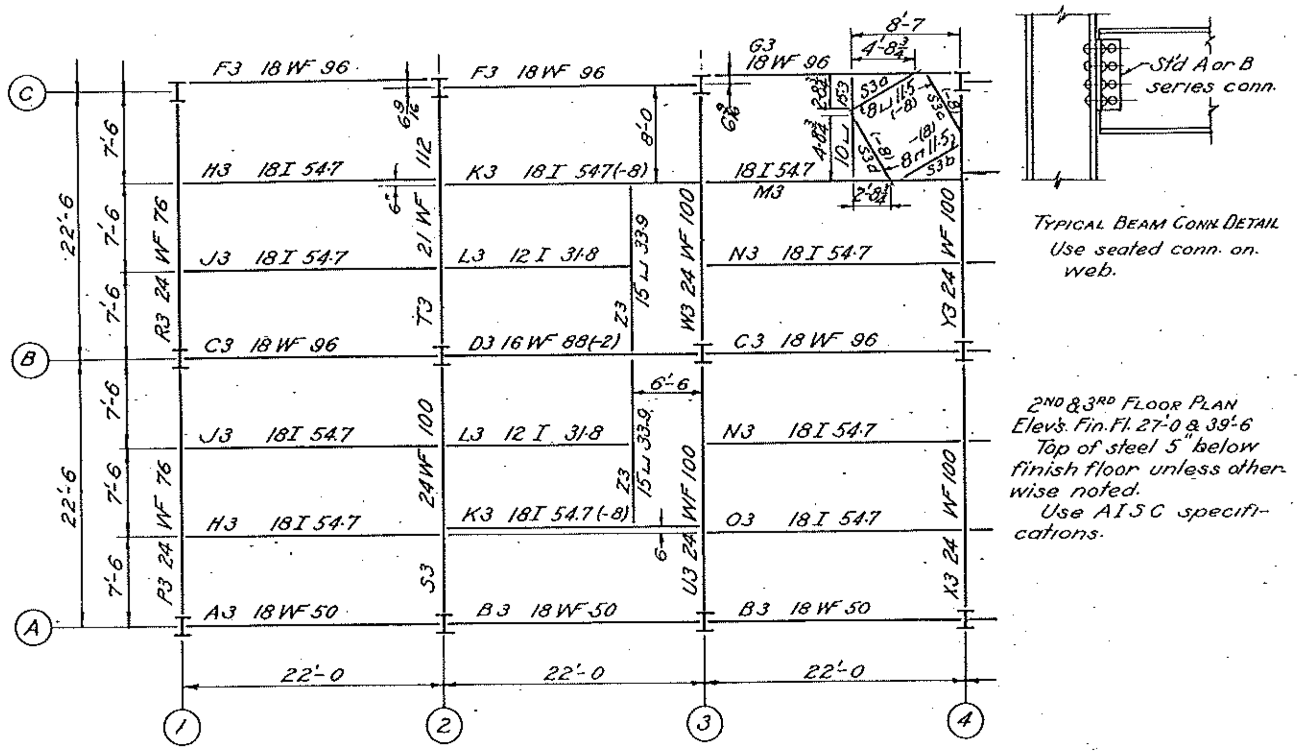


Fig. 22.15. Design layout of floor framing.

erected, usually through two stories. The mark (0-2) would indicate the same thing, namely, that the column extended from the footing through story two.

It is customary in many shops to use small letters for assembly marks. The assembly marks originate with the detailer whereas the erection marks are placed on the layout by the designer. The detailer should observe the following rules.

a. Each separate piece should be given a mark.

b. When two or more pieces are identical, they should be given the same mark and need to be detailed only once.

c. When two pieces are similar in all respects except that one is left and the other right, they may be given the same mark with the suffix *R* and *L*. The one drawn is usually marked *R*.

d. The letters *i* and *l* should be avoided since it is difficult to distinguish them on a drawing or in the shop. The prime mark should not be used.

22.23 Detail sketches. Before beginning the detail of a member, except perhaps the simplest, it is advisable to make a sketch with straight edge and pencil, or freehand, to work out the connections to other members. The controlling dimensions such as elevations above or below floor levels, line-up with other members, and actual rather than nominal member sizes form the basis for working out these sketches. Use standard beam connections wherever possible.

Thus for the left end of the beam in Fig. 22.16, which is a sketch of beam *H*-3 in Fig. 22.15, a sketch is hardly necessary. But for the right end it is essential to work out the connection very carefully so that beams *H*-3 and *K*-3 may be erected without difficulty. Note that the top of *K*-3 is below *H*-3 and also offset horizontally. Such connections may tax the ingenuity of the detailer.

In beginning this sketch, the engineer would first select a standard beam connection. From page 190 of the *AISC Manual*, the load that the beam *H*-3 will carry on a span of 22 feet is 54,000 pounds. One-half of this load is supported at each end. From the table on page 257, *AISC Manual*, connection *B*-4 will be more than ample since it will carry an end reaction of 53,000 pounds, almost double that required. A *B*-3

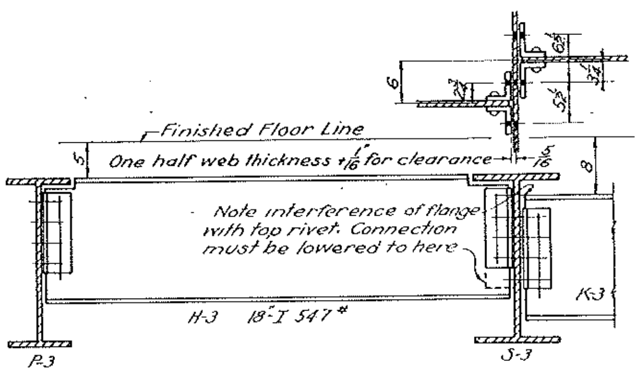


Fig. 22.16. Sketch for detailing beam.

connection would have the necessary strength, but the detailer will normally use the standard for the beam size unless the designer has authorized lighter connections.

The location of this connection on beam *H-3* depends upon the size of the beam and type of supporting member. From Table 23 in the Appendix we find that the first rivet cannot be closer than 2¾ inches to the top of the support beam. When possible this distance is made 3 inches to facilitate the use of multiple punches. Since the top of the flange is usually at a specified height, it is customary to dimension rivets from the top flange. This line of dimensions should not be tied in to the bottom flange. The completed shop drawing of beam *H-3* is shown in Fig. 22.17.

A second detail sketch for a seated connection on a column is shown in Fig. 22.18. This is a detail of beam *C-3* in Fig. 22.15. When a beam must fit between the flanges of a column, standard beam connections are usually not practicable. For the inexperienced draftsman it is a satisfactory rule to make the number of rivets in the seat equal to the number in the outstanding flanges of a standard connection for the size of beam involved. Actually the number of rivets must be carefully computed in design.

The clip angle at the top of the left end of the beam in Fig. 22.18 is used for stability only. On the right end the clip was placed on the web to avoid interference with the connecting beam on the opposite side of the column. The shop drawing of beam *C-3* is shown in Fig. 22.19. Note the −⅝ at each end of the overall dimension. This is the distance from the center line of the column to the end of the beam and gives a check on the center-to-center distance of columns. The 1¹³⁄₁₆″ end distance to rivet holes is obtained as shown in the sketch at the right in Fig. 22.18. The actual clearance is approximately 7⁄16 inch instead of ½ inch.

The ± ⅛ inch shown opposite the ends of the beam in Fig. 22.19 indicates that the length of beam may be allowed to vary by this amount. In other words, a beam with a minimum length of 21′-10½″ or a maximum of 21′-11″ could be used. The shop would adjust the 1¹³⁄₁₆″ dimension to suit. The net distance between holes as shown on the drawing cannot be varied.

22.24 Non-rectangular connections. Structural members may be skewed, i.e., at an angle of other than 90° with each other, as, for example, the 8″ channels in the upper right-hand part of Fig. 22.15. Members may also have a slope with the horizontal, as, for example, the roof rafters *D* and *E* in Fig. 22.22. The hip rafters *C* in this figure have both skew and

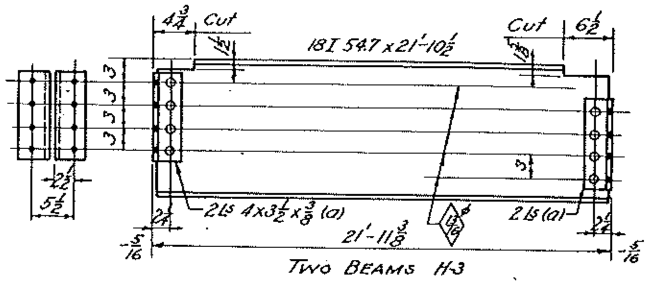


Fig. 22.17. Floor beam detail of Fig. 22.16.

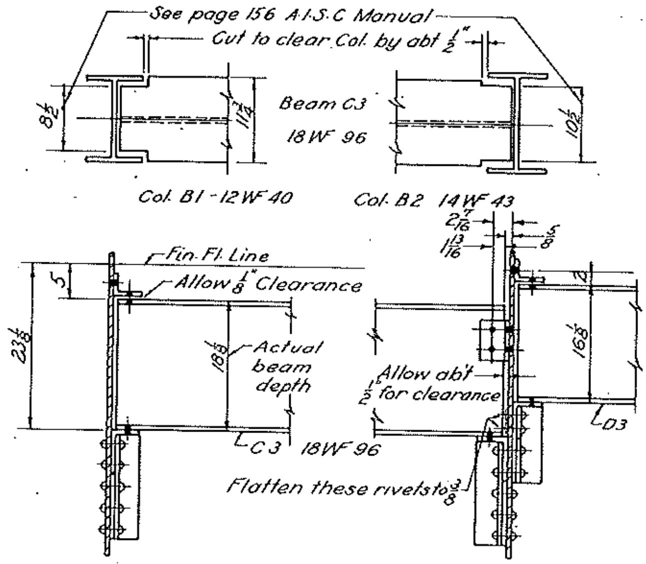


Fig. 22.18. Sketch of beam and column connections.

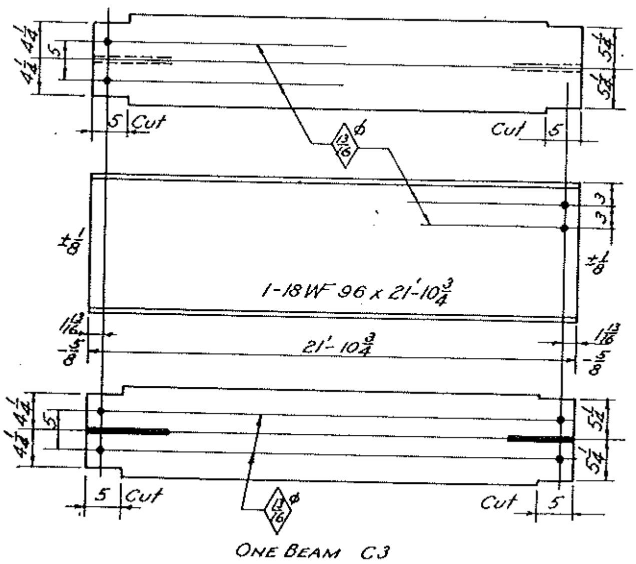


Fig. 22.19. Beam detail of Fig. 22.18.

slope. If the purlins *P1*, *P2*, etc., had their webs in in a vertical plane they would be canted relative to their supporting members.

Non-rectangular connections usually require some trigonometric calculations in making the layout. In order that these computations may be accurately controlled, working points are established.

22.25 Working points. Working points are commonly taken at the intersection of the center lines of members or in the case of trusses at the intersection of gage lines. See Fig. 22.33. It is not necessary that center lines be used. The lines used, however, must be parallel to the center lines. Thus in Fig. 22.20, which is a detail sketch of the channel *S3a* in Fig. 22.15, the center line of the 18 WF 96 beam, and the back of the channels were used to establish the working points. In Fig. 22.22, the intersection of the center lines of the ridge and side beams with the top of the sloping beam were used.

22.26 Detailing skewed members. Using the channel *S3a* of Fig. 22.15 as an illustration, the sketch of Fig. 22.20 can be made. The diagonal length between working points is obtained by taking the square root of the sum of the squares of the two legs of the right-angle triangle, as shown at the bottom of the figure. The squares were obtained from Inskip Table of Squares. Using the same tables, the bevel of the member is found to be *12* to *6* $^{15}/_{16}$ as shown in the computations in the figure. Minimum bends and rivet distances have been standardized as given in Table 29 in the Appendix. With these data the shop drawing of the channel was made as in Fig. 22.21.

22.27 Detailing sloping members. A roof framing plan together with a sketch of the end connections of a rafter is shown in Fig. 22.22. From consideration of the architect's plans the working points were chosen in the plane of the top of the rafter, as shown. The ridge rafter was then located 1½ inches below the working point so that its edge would lie approximately in the plane of the top of the rafter. In a similar manner the top of the side beam and top of the corner column were located to give a reasonable connection. From this sketch the shop detail shown in Fig. 22.23 was prepared.

In some shops sloping members are detailed in the position they occupy. Likewise the elevation of working points rather than the vertical distance between them is sometimes given. The slope of the member is given by the usual right-angle triangle shown on the member.

In other shops the member is drawn horizontally, in which case the slope or bevel would be given on the end connections as shown in Fig. 22.24. In this figure the purlins have been shown canted for pur-

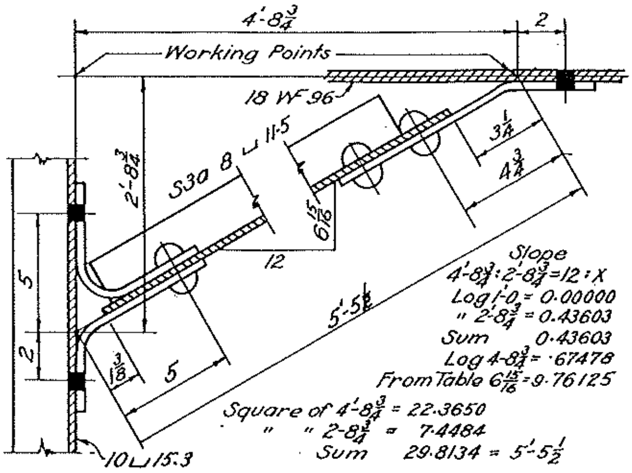


Fig. 22.20. Sketch of skewed connection.

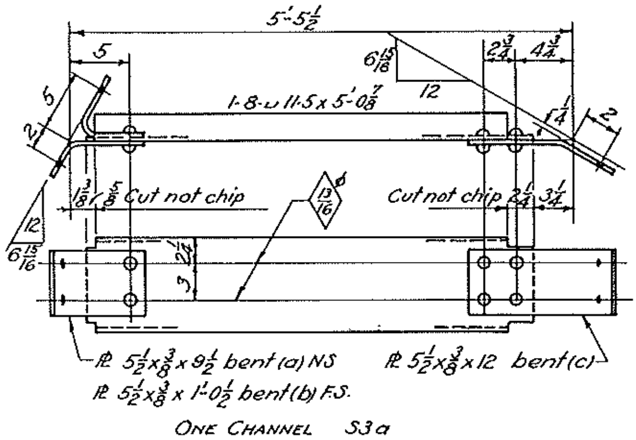


Fig. 22.21. Detail of skewed beam of Fig. 22.20.

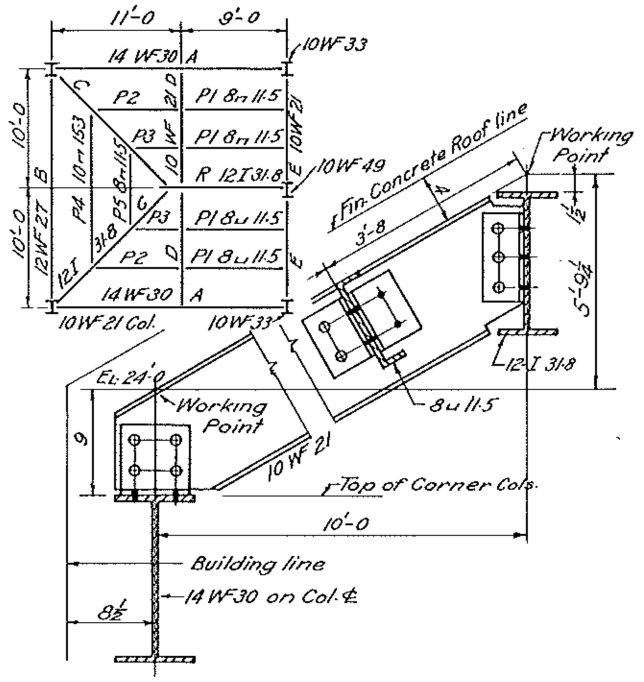


Fig. 22.22. Roof framing plan and sketch of sloping rafter *D*.

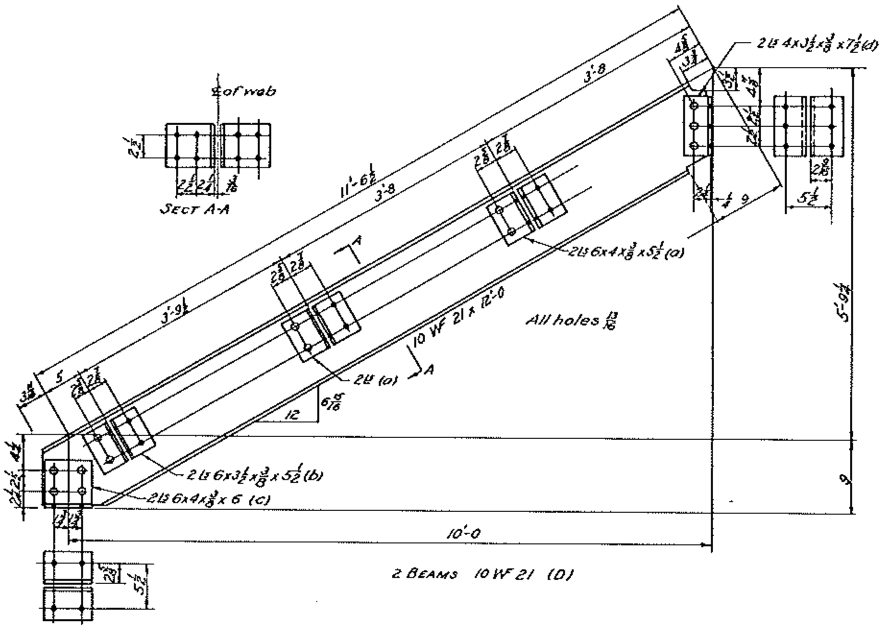


Fig. 22.23. Detail of roof rafter of Fig. 22.22.

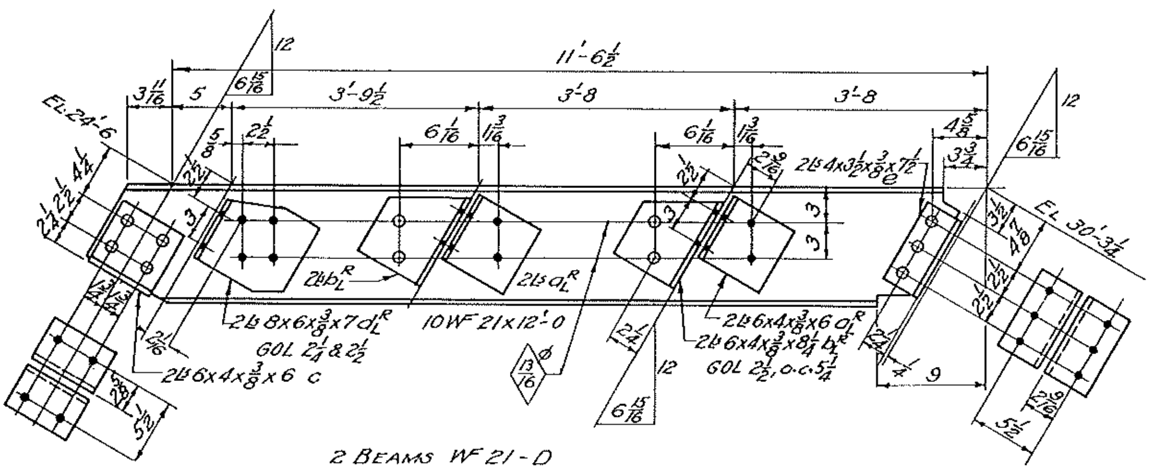


Fig. 22.24. Detail of Fig. 22.23 drawn horizontally.

pose of illustration. Note that the holes for the purlin connections have been kept in lines parallel and perpendicular to the length of the member. This is desirable in multiple-punch operations. Figure 22.25 shows the purlin detail for this situation.

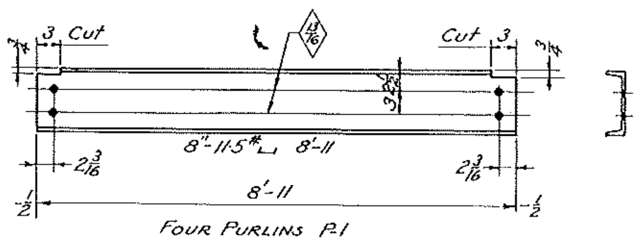


Fig. 22.25. Purlin detail.

22.28 Column details. Since the lower-story columns are the first structural pieces to be erected and footings with anchor bolts and base plates must be in position before erection can begin, it is necessary to detail columns first. In order to facilitate detailing, the designer makes a column schedule as illustrated in Fig. 22.26. This schedule shows the elevation of each floor, the size and composition of each column, the point at which the columns are spliced, the elevation of the base plate, and the size of the base plate.

When base plates are shipped loose, as is usually the case, these are detailed separately with proper provision for anchor bolt holes, grouting holes if necessary, and planed surfaces on heavy plates to

give full bearing to the milled end of the column. Two typical column bases are shown in Fig. 22.27.

22.29 Column splices. Since the load which columns carry increases from the top downward the size of columns must be increased accordingly. This is usually done at intervals of two stories, beginning at the bottom. In buildings with an odd number of stories the top section may be either one or three stories in height. Column splices are usually placed far enough above the floor level to clear all beam connections. Two typical splices are shown in Fig. 22.28. Further details are shown in *Structural Shop Drafting*, Vol. I, AISC.

22.30 Right- and left-hand columns. Situations sometimes occur in which columns and other members are similar in detail except that they are in right- and left-hand arrangement as shown for Columns *A2* and *B2* in the upper part of Fig. 22.29. Right- and left-hand arrangements are always relative to a vertical plane, never a horizontal plane.

In situations of this kind considerable drafting time can be saved by detailing one column and calling it out as shown and then by note calling out the second column as opposite hand, as indicated in the lower part of Fig. 22.29.

In the shop it is customary to mark the faces of a column by the letters *A*, *B*, *C*, and *D* in counterclockwise order, looking down on the column and always beginning with the letter *A* on a flange face as shown in Fig. 22.29. Shop details should show the faces so marked. The direction of one face, as for example, the north side, should be so marked.

A shop detail of Column *B2* in the framing plan of Fig. 22.15 and the column schedule of Fig. 22.26 is shown in Fig. 22.30.

	COLUMN SCHEDULE				
	A1	B1 to F1	A2 to A6	B2 to B6	C2 to C6
High Roof line 64'-9					
Fin. Third Floor +39'-6	10 WF 21	12 WF 27 (1'-3)	12 WF 27 (1'-6)	12 WF 40	12 WF 40
Fin-Second Floor +27'-0					
Fin. First Floor +14'-6	10 WF 33	12 WF 40	12 WF 40	14 WF 43	14 WF 43
Fin. Bsmt Floor +0.0	12"		1'-6		
COL. BASE PLATE	16x1½x18	16x1½x20	16x1½x20	16x1½x22	16x1½x22

Fig. 22.26. Column schedule.

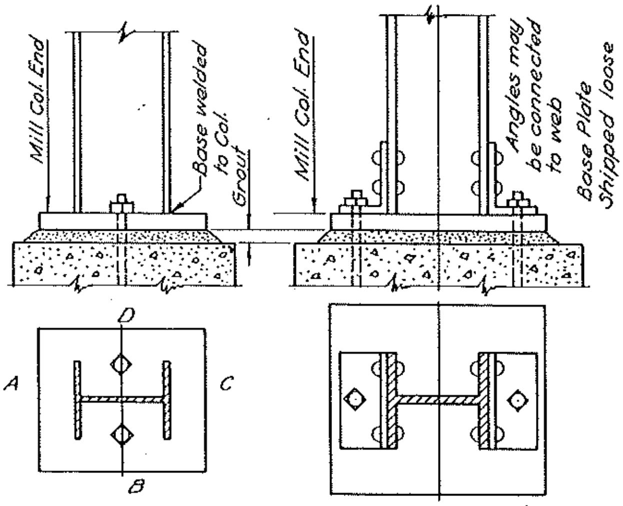


Fig. 22.27. Column-base connections.

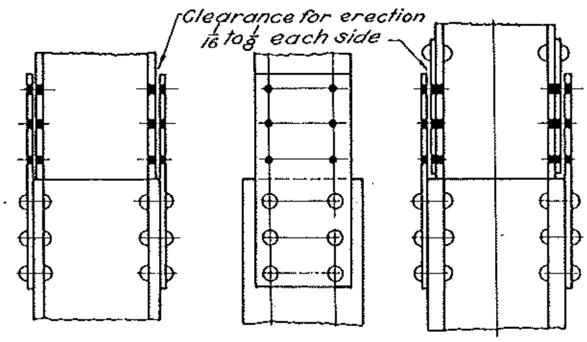


Fig. 22.28. Column splices.

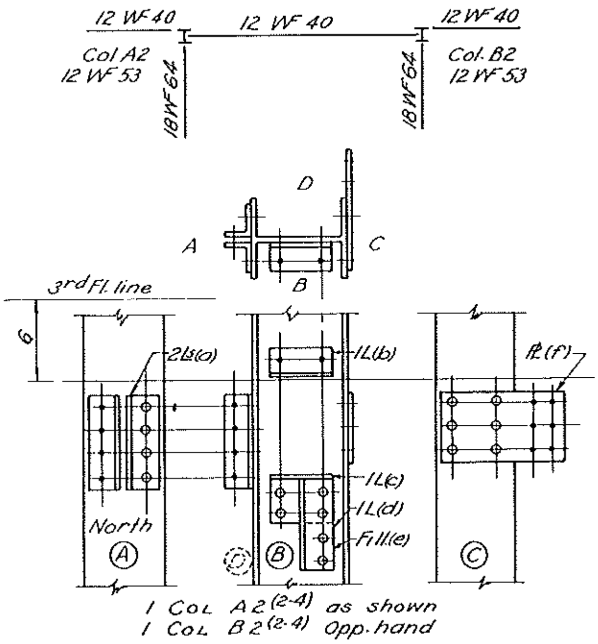


Fig. 22.29. Right- and left-hand details.

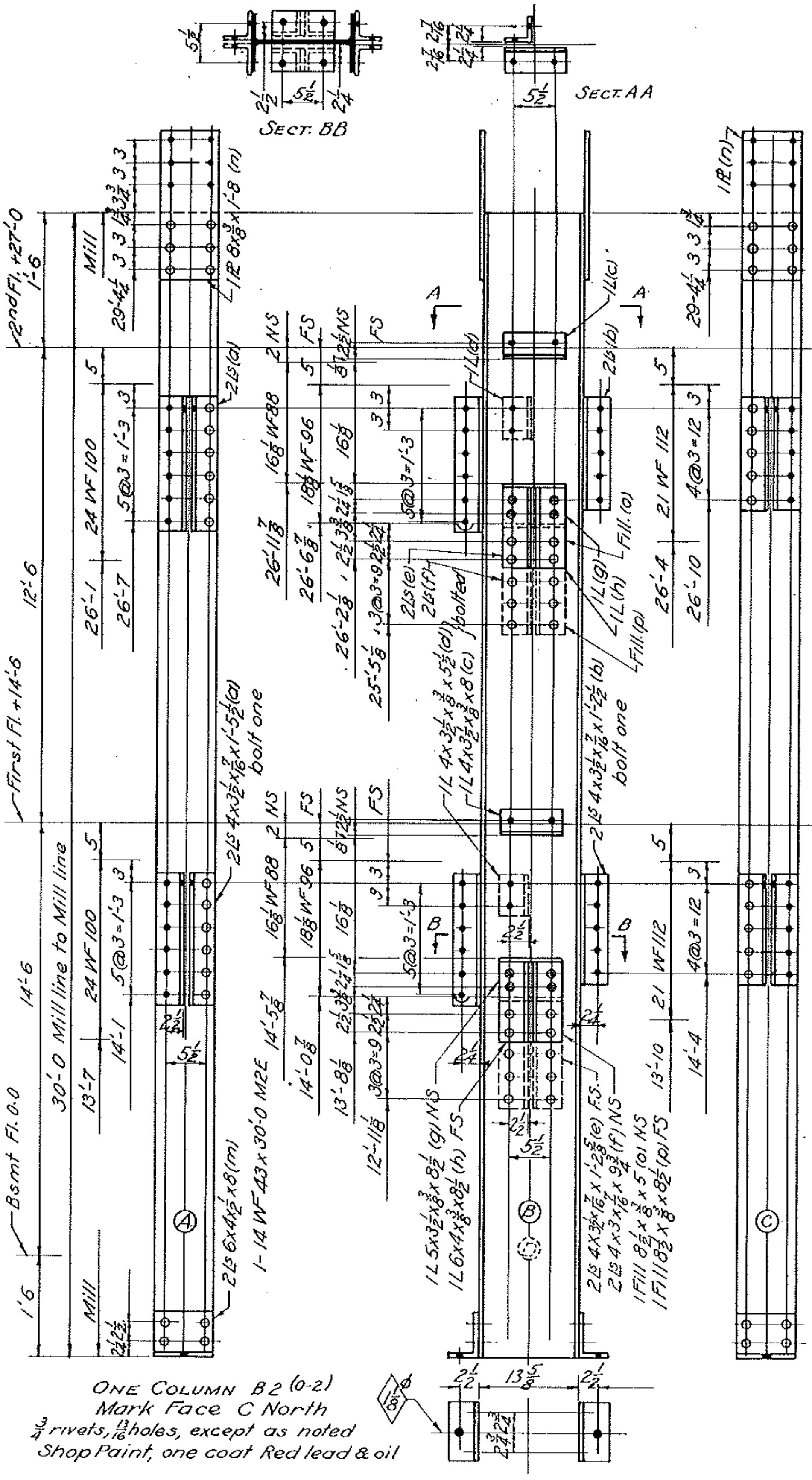


Fig. 22.30. Column detail.

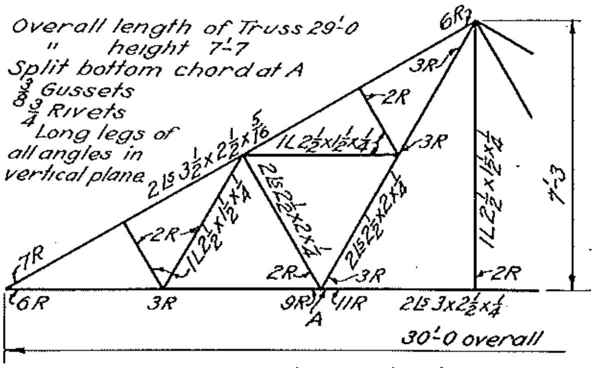


Fig. 22.31. Design diagram of steel truss.

The columns having been detailed, the beams framing into them must be detailed to fit.

22.31 Detailing a truss. In designing trusses, line diagrams similar to the one shown in Fig. 22.31 are used as the bases for the computation of stresses. The intersections of these lines give the working points used in detailing the truss.

Two general schemes for making roof truss details are in use. In one of these only the dimensions between working points are given along with the size of members, the slopes of members, and the number of rivets in each member, as shown in Fig. 22.32. The working out of the details of the joints is left to the template maker.

In the second method which is more commonly used, all details are worked out and dimensioned on the shop drawing as shown in Fig. 22.33. This method has the advantage of permitting the template maker and the men in the shop to proceed at once to cut, punch, and assemble the work. It also gives a permanent record of the work.

The procedure in making a complete shop drawing is explained in the following paragraphs.

Assume that complete information is given the draftsman in the design sketch, as shown in Fig. 22.31. Since the truss is symmetrical, it will be necessary to show only the left half, up to and including the center points.

The first step, after deciding upon the number and arrangement of views and selecting a scale to fit the requirements, is to lay out the working lines. These working lines correspond to the gage lines shown in Fig. 22.33, which form a group of triangular figures the dimensions of which can be readily computed. It will be noted that all dimensions in Fig. 22.33 are based on the working points. After the working lines are laid out, the members of the truss may be laid out around these lines as gage lines to the same scale, or to a slightly larger one if desired. For example, the bottom chord is composed of two 3″ × 2½″ × ¼″ angles placed back to back with the long legs vertical. The standard gage for a 3″ angle, as obtained from the tables, is 1¾″. Hence, we scale down from the working line for the bottom chord a distance of 1¾″, and draw a line parallel to the working line which represents the bottom of the angles. A second line, drawn just a little above the first, represents the thickness of the angle. From the bottom line, we may now scale upward a distance of 3″, and draw a line which will represent the top edge of the vertical leg of the angle. These three lines, which together repre-

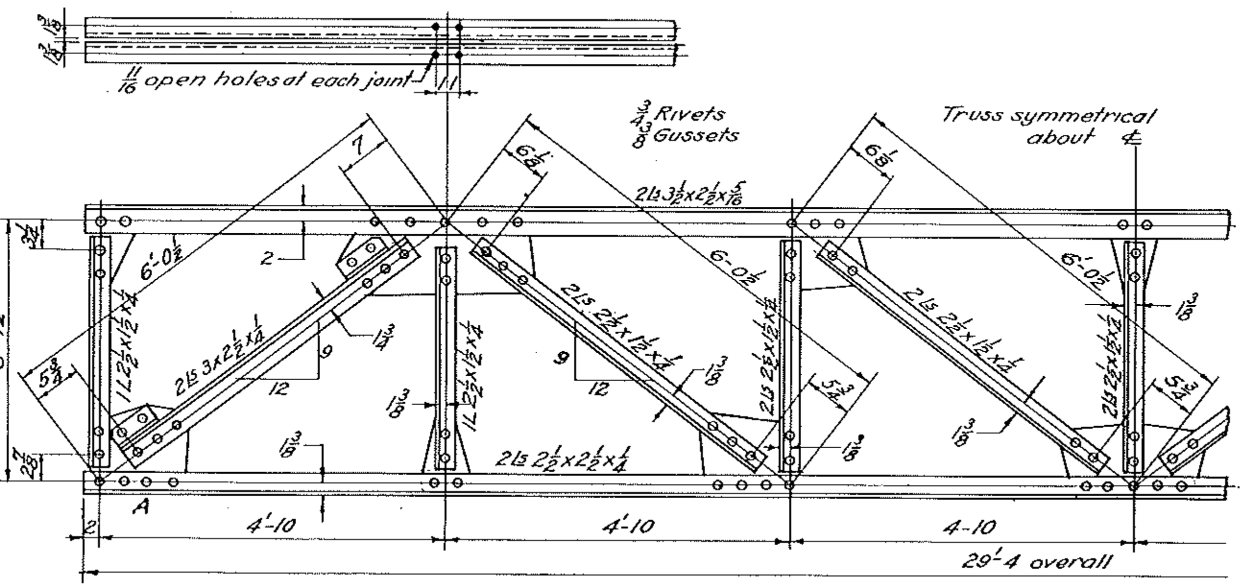


Fig. 22.32. Sketch detail of flat truss.

sent the angle, can be marked off with one setting of the scale and then drawn in very quickly.

In the same way the other angles may be drawn around their corresponding working lines. The ends of the angles should usually be shown cut off at right angles to their length as a matter of economy. When all the angles have been drawn, the proper number of rivets may be put in at each point to the same scale as that used in laying out the angles. The rivet spacings may be scaled from the end of the angles, using the standard end distance and standard spacing called for by the design. After all the rivets have been properly located, the gusset plates may be drawn in to scale, care being taken to provide the proper edge distance from the last rivets. This is done by drawing a circle of the proper radius—equal to the specified edge distance—around the outstanding rivets in each member and then drawing the lines representing the edges of the gusset plate tangent to these circles. Gusset plates must be cut from rectangular pieces, and hence it is desirable to make as few cuts as possible to obtain the proper shape for the plates. In no case may reentrant angles be used. When the gusset plates have been drawn, the truss is ready for dimensioning. The rules for dimensioning are given in Arts. 22.16 to 22.18.

22.32 Layout of a joint. Where structural members meet at an angle other than 90°, the distance from the working point to the first rivet in the sloping member is determined by making a large-scale layout right on the truss detail, as illustrated for one joint in Fig. 22.34, which represents joint *A* on Fig. 22.32. The truss detail is usually made to a scale of 1″ = 1′-0″, and the joint layout to a scale of 3″ = 1′-0″. The needed dimensions are then scaled off. Although all lines of the large-scale layout have been shown in Fig. 22.34, only those which are useful in obtaining the desired dimensions need be drawn.

To make such a layout, the principal working lines of the joint, as indicated by the lines marked *1*, *2*, and *3*, are used. These are the gage lines of the members which form the joint. Around these lines

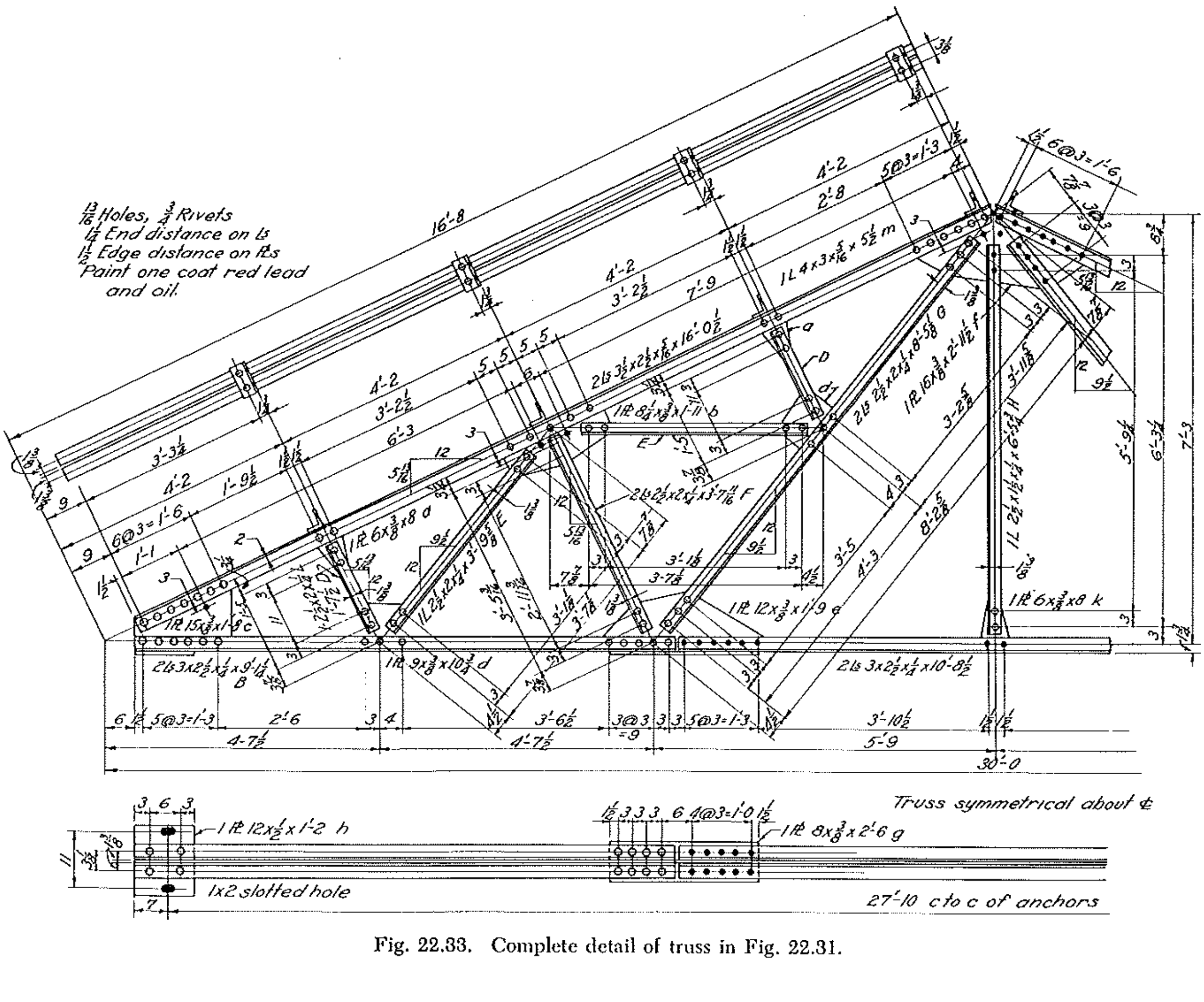


Fig. 22.33. Complete detail of truss in Fig. 22.31.

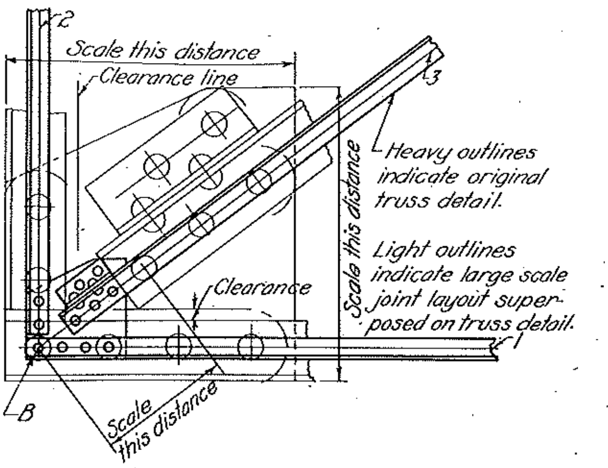


Fig. 22.34. Large-scale joint layout for obtaining detail dimensions.

the members are then drawn in to large scale, beginning with the member which runs through the joint, as, for example, the bottom member in Fig. 22.34. The bottom chord, which is composed of two $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$ angles, is laid out around line *1* by measuring down at right angles to the line a distance of $1\frac{3}{8}''$, which is the standard gage for the $2\frac{1}{2}''$ leg. With the bottom line of the angle thus determined, the whole angle may now be drawn in. Then, to scale, $\frac{1}{2}$ inch above the top edge, draw a line for clearance. Draw the angles around the working lines 2 and 3. The sloping member on line *3* is composed of two $3'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$ angles, and the standard gage for the 3″ leg is $1\frac{3}{4}''$ The angle may then be laid out around the working line as a gage line in the same manner as the bottom chord. The line representing the lower edge of the angle is extended until it intersects the clearance line of the bottom chord, and at the intersection a line is drawn at right angles to line *3*. This last line represents the end of the angle. The first rivet may be put in $1\frac{1}{4}''$ from this line, and then its distance to the working point *B* may be scaled and put down on the detail drawing. From the first rivet, the location of the last one may be scaled off, and a circle with a radius equal to the standard edge distance for gusset plates drawn around it. In a similar manner, the rivets farthest from the working point *B* in each member may be drawn, and then the edges of the gusset plate may be drawn tangent to the edge distance circles around these rivets. Any required distance may now be scaled from this layout, and the size of the gusset plate determined. Such a layout must be made for each different joint, and, although the type of connection may be quite different from the one shown, the general principle is just the same.

22.33 Welding. In some structures welding is being used in lieu of rivets for fastening members together. As with riveted structures, some of the welding is done in the shop and other portions upon erection in the field. For the correct use of welding symbols and the dimensioning thereof the reader is referred to Chapter 26, Welding Drawing.

22.34 Reinforced concrete. Only the general principles of detailing reinforced-concrete structures can be covered in this brief treatment, since reinforced concrete is used for such a wide variety of structures each of which involves details not covered in others. The following paragraphs cover items which must always be included. All data, symbols, abbreviations, etc., shown in this section are approved and shown in the *Manual of Standard Practice for Detailing Reinforced Concrete Structures* published by the American Concrete Institute.

22.35 Symbols and abbreviations. The following symbols and abbreviations are recommended by the ACI.

#	To indicate size of deformed bar member
∅	Round—mainly for plain round bars
□	Square
←→	Direction in which bars extend
Pl	Plain bar
Bt	Bent
St	Straight
Stir	Stirrup
Sp	Spiral
CT	Column tie
IF	Inside face
OF	Outside face
NF	Near face
FF	Far face
EF	Each face
Bot	Bottom
E.W.	Each way
T	Top

Round deformed bars are specified by number from #2 to #8. The number corresponds to the diameter in eighths of an inch. Thus a #3 bar is $\frac{3}{8}$ inch in diameter approximately. The nominal diameter of a deformed bar is the same as a plain bar having the same weight per foot.

22.36 Engineering drawings. These are the general plans of the structure. They must give all information necessary to build the forms, detail the reinforcing steel, and make the steel placement drawings. Beside the general floor plan showing the location and size of girders, beams, joists, columns, etc., this will require some details, usually sectional views, and typical bar diagrams as shown in Fig. 22.35. In

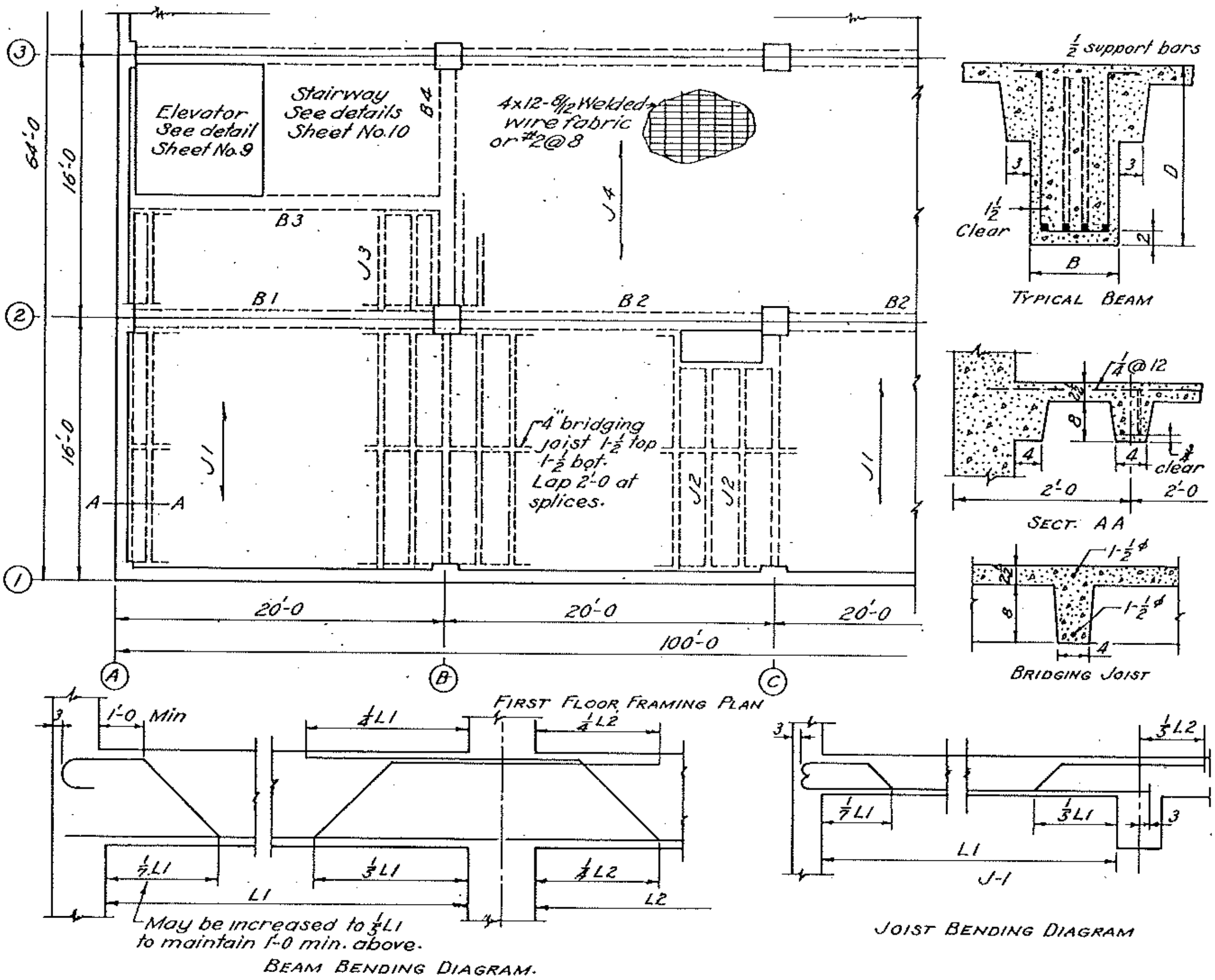


Fig. 22.35. Reinforced-concrete framing plan.

BEAM SCHEDULE

Mark	B×D	Tee	Reinforcing		Stirrups			Stirrup support
			Bent	Str	No.	Size	Spacing each end	bar at top
B1	12x25	2 sides	2-7/8	2-7/8	10	1/2	6, 2@8, 10, 12	2-1/2
B2	12x25	2 sides	2-7/8	2-7/8	12	1/2	5, 2@7, 9, 12, 12	
B3	10x17	1 side	2-3/4	2-3/4	8	3/8	6, 8, 10, 12	
B4	12x20	2 sides	2-7/8	2-7/8	10	3/8	6, 2@8, 10, 12	
B5	14x25	2 sides	2-1φ	2-1φ	14	1/2	5, 2@7, 2@9, 2@12	

B = Breadth of beam and D = Depth overall.

JOIST SCHEDULE

Mark	B	D	Reinforcing	
			Bent	Str.
J-1	4	8+2 1/2	1-3/4	1-3/4
J-2	4	8+2 1/2	1-3/4	1-3/4
J-3	4	8+2 1/2	1-5/8	1-1/2
J-4	4	8+2 1/2	1-3/4	1-3/4

Fig. 22.36. Beam and joist schedules.

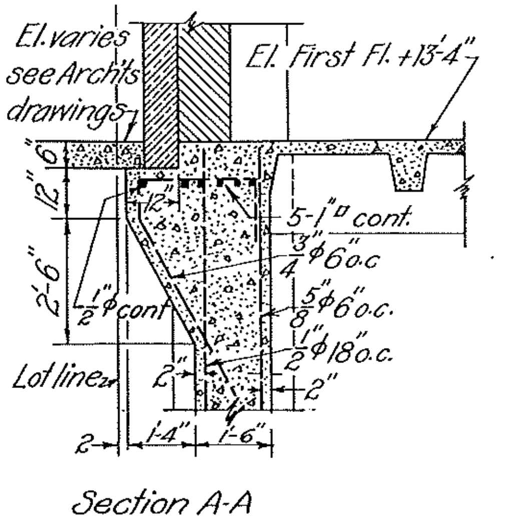
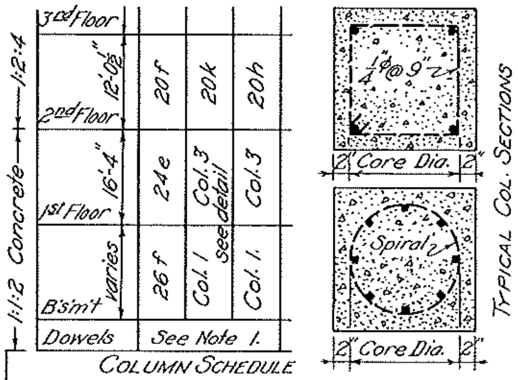


Fig. 22.37. Special reinforcing detail.



KEY TO COLUMN SCHEDULE				
Vert. Steel \ Column Size	16"x16" 1/4"φ@9"-12"x12"	20"x20" 3/8"φ 1 7/8"p 16"d	24"x24" 7/16"φ 2"p 20"d	26"x26" 1/2"φ 2 3/8"p 22"d
4-5/8"φ	16a			
4-7/8"φ	16b			
8-7/8"φ		20e	24e	
8-1"φ		20f	24f	26f
8-1"□			24g	26g

Fig. 22.38. Column schedule.

buildings of this type, beam and joist schedules are also required as illustrated in Fig. 22.36. Note that, although these schedules give all necessary information, they are not adequate for bending the steel.

Reinforcement for walls and slabs must be shown either in schedules or on the plans or elevations. A special detail of this type is shown in Fig. 22.37.

The steel for columns is usually shown in schedules together with sufficient detail views to show the typical arrangement of steel, as illustrated in Figs. 22.38 and 22.39.

Typical column splices are shown in Fig. 22.40.

Footings are shown on the general plans as illustrated in Fig. 22.41 and detailed as in Fig. 22.42.

Accessories such as beam bolsters, chairs, etc., which support the reinforcing may be shown on the drawing but are usually given by note referring to some standard covering the placement of such items.

Anchors for architectural work, such as suspended ceilings, and elevators, which require placement before pouring the concrete, must be shown or noted as well as all openings to be provided for plumbing, heating, ventilating, and the like.

22.37 Placement drawings. The instructions in this article are quoted, by permission, from the *ACI Manual of Standard Practice* with such modifications as are necessary to make them fit the illustrations of this text.

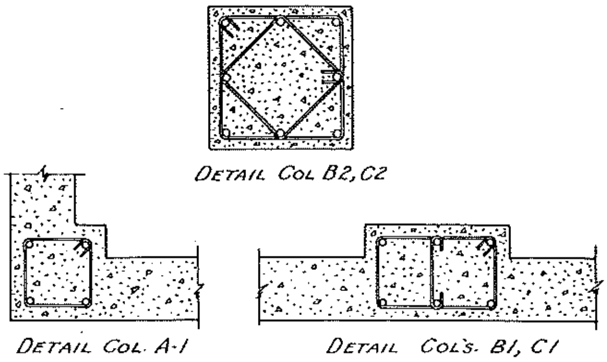


Fig. 22.39. Detail of column reinforcing.

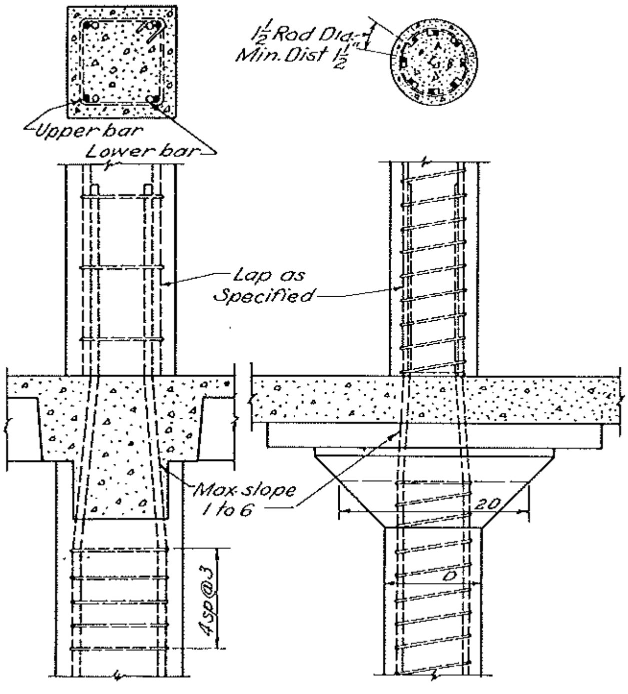


Fig. 22.40. Column reinforcing splices.

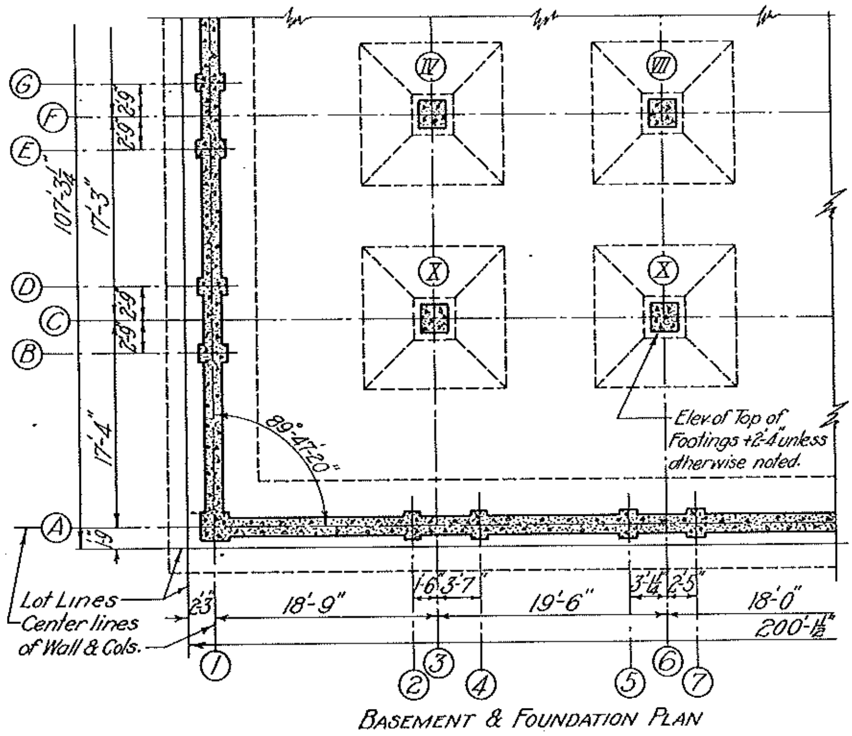
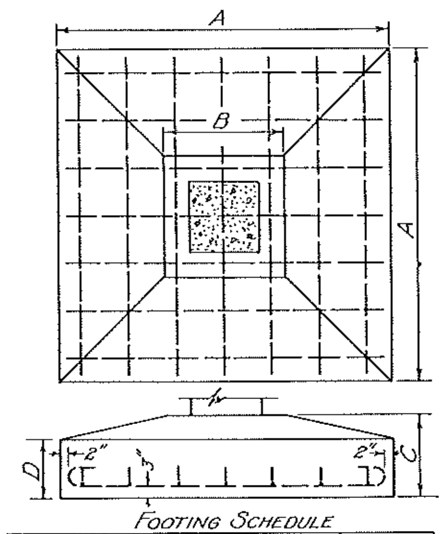


Fig. 22.41. Column and wall footing plan.

a. Outline Drawing. The detailer should first draw the outline of the floor, which can usually be done by tracing from the engineering drawing. Dimensions are optional on the placing drawings, but, in the case of joist construction, it will be found desirable to show them for convenience and time saving in spacing the joists. Beam and column designations are then added, using the same designations as on the engineering drawing. If there is any variation in beams of the same engineering designation, a letter suffix can be added to differentiate it. On the drawing in Fig. 22.43, the designer has foreseen the reinforcing steel requirements and the detailer is able to use the identical beam designations.



FOOTING SCHEDULE

Mark	A	B	C	D	Bars No.	Bars Size	Remarks
I	7'-0"		1'-6"		42	¾"φ	Flat
II	11'-0"	3'-2"	2'-3"	1'-6"	48	¾"φ	
III	11'-6"	3'-4"	2'-5"	1'-4"	54	¾"φ	

Fig. 22.42. Column footing schedule.

b. Metal Forms. The next step is the spacing and arrangement of metal forms and concrete joists. It is necessary to draw a few more joists than are shown on the engineering drawing in order to show definitely their location. Joists are generally located directly in line with those in adjacent spans. The 20-in.-wide forms are used wherever possible, but a few 10-in. and 15-in. forms are used to fill out the spaces adjacent to beams and double joists or wherever necessary to adjust the joist spacing to provide continuity. Only these two narrow widths should be used, and, where a space is not sufficient to permit the use of the 10-in. forms, a solid slab the full depth of the floor system must be used. Tapered forms are not furnished in 10-in. and 15-in. widths.

c. Beam Schedule. Since beam bars are the first ones required on a floor, the preparation of a beam schedule is the next logical step. The form of schedule to use is shown in Fig. 22.44. The horizontal type of schedule was chosen because the simplicity in re-

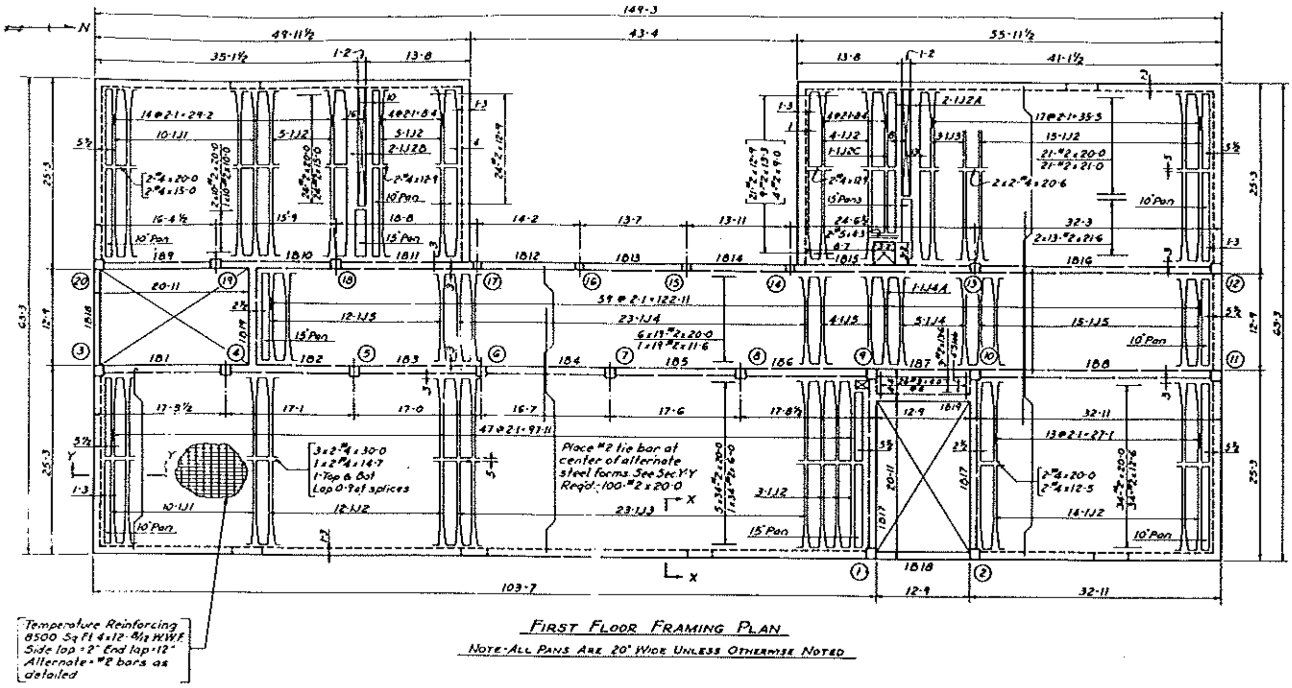


Fig. 22.43. Steel placement drawing. Courtesy American Concrete Institute.

BEAM SCHEDULE

Beam				Straight			Bent					Hook	O					Hook	H	O	Stirrups							Support Bars			2" Chairs	
Mark	No	B	D	No	Size	Lgth	No	Size	Lgth	Mark	Type				H						No	Size	Lgth	Mark	Dim	Type	Spacing Each End	No	Size	Lgth	No	Type
1B1	1	12	25	2	#6	16-8	2	#6	24-3	1B600		8	2-2	2-5½	9-9	2-5½	6-9		1-9		13	#4	4-11	U400	9/22		4,2@6, 2@10,12 Col-3 5,2@8, 2@10,12,15 Col-4	2	#4	15-8	4	BB
1B2	1	12	25	2	#7	16-7	2	#7	27-9	1B700			7-6	2-5½	7-10	2-5½	7-6		1-9		7 6	#4 #4	4-11 4-11	U400 U401	9/22 9/22		5,2@8, 2@10,12,15 Col-4 6,2@8, 10,12,15 Col-5	2		15-7	4	BB
1B3	1	12	23	2	#6	16-6	2	#6	27-8	1B601			7-8	2-3	7-10	2-3	7-8		1-7		16	#3	4-7	U301	9/20		4,3@6, 2@8,10,12	2		15-6	4	BB
1B4	1	12	23	2	#6	16-1	2	#6	27-5	1B602			7-8	2-3	7-7	2-3	7-8		1-7		16	#3	4-7	U301	9/20		Do.	2		15-1	4	BB
1B5	1	12	23	2	#6	17-0	2	#6	28-4	1B603			7-11	2-3	8-0	2-3	7-11		1-7		16	#3	4-7	U301	9/20		Do.	2		16-0	4	BB
1B6	1	12	23	2	#7	16-6	2	#7	27-0	1B701			7-9	2-3	7-10	2-3	6-11		1-7		16	#3	4-7	U301	9/20		Do.	2		15-6	4	BB
1B7	1	12	23	2 2	#6 #7	13-9 27-6		Bot In	Top	Extend	7-8	Into	Beam	1B8							10	#3	4-7	U301	9/20		5, 2@7, 10,12				3	BB
*1B8	1	12	33	3	#8	30-8	3	#8	38-8	1B800			8-7	3-2	19-6	3-2	3-2	1-1	2-3		20	#4	6-3	U402	9/30		6,3@8, 2@12, 2@15, 2@18	2		29-9	4 6	BBU-1 BB
1B9	1	12	25	2	#6	15-4	2	#6	22-7	1B604		8	2-1	2-5½	8-9	2-5½	6-2		1-9		12	#4	4-11	U400	9/22		5,2@7, 2@10,13	2		14-4	3	BB

JOIST SCHEDULE

Joist				Straight			Bent					Hook	O					Hook	H	O	3/4" Chairs
Mark	No.	B	D	No	Size	Lgth	No	Size	Lgth.	Mark	Type				H						
1J1	20	5	8+2½	1	#7	24-0	1	#6	26-2	1J600		8	3-4	1-0½	16-6	1-0½	3-7		9	24-11	5
1J2	58	5		1	#6	24-0	1	#6	44-11	1J603			3-7	1-0½	15-2	1-0½	24-1		9		5
1J2A	2	Var.		2	#6	24-0	2	#6	31-6	1J607			3-7	1-0½	15-2	1-0½	10-8		9		10
1J2B	2	Var.		2	#6	24-0	1	#6	44-11	1J603			3-7	1-0½	15-2	1-0½	24-1		9		10
1J2C	1	5		1	#6	20-2	1	#6	22-0	1J606		8	2-6	1-0½	13-8	1-0½	3-1		9	20-9	4
1J3	26	5		1	#6	24-0	1	#6	31-6	1J607			3-7	1-0½	15-2	1-0½	10-8		9		5
1J4	28	5		1	#6	13-9	1	#6	21-4	1J604			8-4	1-0½	8-4	1-0½	1-11	8	9		3
1J4A	1	5		1	#6	13-9	1	#6	16-4	1J605		8	1-11	1-0½	9-1	1-0½	1-11	8	9	14-5	3
1J5	31	5	8+2½	1	#5	13-9															

Fig. 22.44. Beam and joist schedules for Fig. 22.43. Courtesy American Concrete Institute.

inforcing steel and the available space on the drawing make this type best suited for the purpose.

d. Beam Reinforcement. Beam reinforcement consists of straight bars, trussed bars, and stirrups. The length for the straight bars is usually the same as the center-to-center distance between columns for interior spans, and the distance from the center line of the first interior column to a minimum embedment of 6 in. into the exterior column or wall for end spans; or, if this embedment cannot be obtained, extend to within 3 in. of the outside face and terminate with a hook. This is shown in the typical beam-bending diagram on the engineering drawing in Fig. 22.35. Bending dimensions for truss bars are calculated from information given on the engineering drawing.

Consider beam *1B9* in Fig. 22.43 as an example. The detailer should draw a simple line detail to show the width of supports and clear span for the beam, as shown in Fig. 22.45, filling in the other dimensions as they are determined.

The various dimensions of the bars are then calculated according to the typical beam-bending diagram and inserted on the line detail. These dimensions are then added up and inserted in the proper space provided in the beam schedule. The height of bend is obtained by deducting the top and bottom concrete protection from the beam depth, in this case, 25 in. less 4 in. (2 in. at bottom for fireproofing and 2 in. at top for fireproofing and joist bars) or 21 in. The slope dimension is then computed or selected from a table.

e. Stirrups. Dimensions for stirrups are obtained from the size of the beam by deducting the concrete protection, in this case, 1½ in. from the top, bottom, and sides of the beam. Thus 3 in. is deducted from both the width and depth of the beam. For beam *1B9* which is a 12 × 25 beam, the stirrup dimensions become 9 × 22. The detailer must also determine the direction in which hooks are to extend and indicate this in his schedule. It is usually desirable to turn hooks out into a slab unless prevented from doing so by openings; when used in spandrel beams, one hook is turned in and the other out. In this case, the length of stirrup support bars are specified as approximately the length of the clear span. These support bars are frequently specified as covering the stirrup spacing only.

f. Joists. When spacing the joists, it is best to select a principal panel of the floor, then align all other joists in adjoining panels by the use of narrow-width forms where necessary. It is obvious that on the floor shown in Fig. 22.43 the detailer would select the panel bounded by columns *3*, *9*, and *1*.

The general procedure for calculating lengths and bending diagrams for joist bars is the same as for

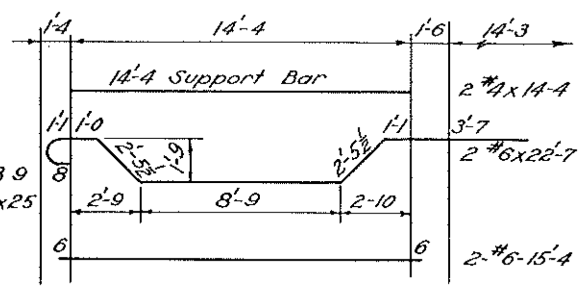


Fig. 22.45. Bending computation diagram. Courtesy American Concrete Institute.

beams except that the typical bending diagrams for joists, as shown on the engineering drawings, are to be followed. The joist schedule is similar to the beam schedule except that stirrups and stirrup support bars are not usually required. Variations in the typical joists shown on the engineering drawings are indicated by suffixes such as *J2*, *J2A*, *J2B*, and *J2C*.

g. Temperature Reinforcement. The temperature reinforcement, and reinforcement for bridging joists, and around openings, is detailed on the plan view. For ease in handling, and for economy, temperature bars are detailed in 20-ft lengths, using only one odd length in any run with an allowance made for splices. Some fabricators and erectors prefer to have all #2 temperature reinforcement furnished in 20-ft lengths and cut on the job where necessary. Bridging joist bars are detailed in the same manner, except that the bars, being of a larger size, make it more economical to specify greater lengths. In determining the number of lines of temperature steel, the lines adjacent to beams or walls are located about one-half the standard spacing away from the beam or wall.

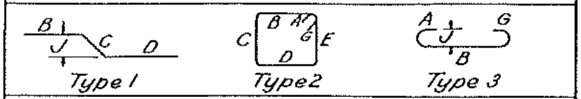
Frequently wire mesh is used for temperature reinforcement instead of straight bars, as the ease of placing often compensates for any difference in cost. The method of indicating the areas to be covered is plainly shown on the placing drawing in Fig. 22.43. Similar methods of detailing can be used wherever wire-mesh temperature reinforcement is required.

22.38 Column-placement schedules. The placement of steel for columns is usually shown in schedules, and bar-bending lists as shown in Fig. 22.46. The straight bars are ordered directly from the schedule, and all bent bars, ties, spirals, etc., are shown in the bar-bending lists. Bent bars are numbered in both schedules to correspond.

22.39 Other types of construction. The foregoing discussion has applied directly to the beam and joist type of construction. The general principles are the same in all construction, but for specific cases involving other types such as flat slab construction the reader

Floor / Height	Column Schedule: Col. Mark	A1	A2, A3, B1, C1	B2, B3, C2, C3
Roof				
4th Fl.				
10'-0	Size	12x12	12x14	15x15
	Core			
	Vert. Steel	4-5/8 x 12'-0	2-3/4 x 12'-0 4-C601	8-C602 10 T312
3rd Fl.	Ties or Spirals	10 T301	16 T306 16 T307	10 T313
11'-0	Size	12x12	12x16	18x18
	Core			
	Vert. Steel	4-3/4 ϕ x 13'-0	2-1 ◻ x 13'-8 4-C802	8-C803 11 T310
2nd Fl.	Ties or Spirals	11 T301	17 T304 17 T305	11 T311
12'-0	Size	14x14	14x18	21x21
	Core			
	Vert. Steel	1-1 ϕ x 15'-2 3-C801	1-1¼ ◻ x 16-4 3-C1001 2-C1002	8-C1003 14-T308
1st Fl.	Ties or Spirals	18 T300	20 T302 20 T303	14 T309
	Top of Footing	6	12	9

Bar Bends



All Dimensions are Out to Out

Size	Length	Mark	Type	A	B	C	D	E	G	J
3/8	4'-4	T300	2	4	11	11	11	11	4	
	3'-8	T301	2	4	9	9	9	9	4	
	5'-0	T302	2	4	15	11	15	11	4	
	1'-7	T303	3	4	11				4	2¾
	4'-2	T311	2	4	10½	10½	10½	10½	4	
	4'-8	T312	2	4	12	12	12	12	4	
3/8	3'-6	T313	2	4	8½	8½	8½	8½	4	
3/4	12-0	C601	1		8'-6	1-6	2-0			2½
3/4	12-0	C602	1		8'-6	1-6	2-0			2½
1ϕ	15-2	C801	1		11'-0	1'-6	2'-8			2½
1ϕ	13-8	C802	1		9'-9	1'-3	2'-8			2
1ϕ	12-8	C803	1		8'-6	1'-6	2'-8			3
1¼ ◻	16'-4	C1001	1		11-10½	1'-1½	3'-4			2¼
1¼ ◻	16'-4	C1002	1		11-7½	1-4½	3'-4			2¾

Fig. 22.46. Column reinforcing schedule.

is referred to the *Manual of Standard Practice for Detailing Reinforced Concrete Structures* ACI 315–51.

Problems

The problems for rectangular framed parts and skewed and sloping members are referred to Figs. 22.15 and 22.26 which are to be used together. The truss problem in Figs. 22.47 to 22.48 are for building shown in Figs. 21.16 and 21.18 of the preceding chapter. These should be referred to where necessary.

Beam problems can normally be detailed on an A-size sheet (8½ × 11). Column details will require the B-size sheet (11 × 17), and truss details require the C-size sheet (17 × 22). A scale of 1″ = 1′-0″ should normally be used.

Although only a few problems have been stated verbally, the selection of beams and columns available make it possible to assign each student in a class of 25 a different problem if desired.

Standard connections can be found in the Appendix.

Where a sketch is called for in the following problems, a pencil layout made with instruments but omitting unessential elements is meant.

Square Framed Beams

1. Make a detail sketch of the connections required for a beam assigned from Fig. 22.15. Refer to Fig. 22.26 for column sizes. Standard beam connections are shown in the Appendix. Study your problem carefully to see that the connection you make can be assembled in the shop and erected in the field.

2. Make a complete detail of the beam assigned and sketched in Problem 1.

Skewed Beams

3. Make a sketch of the connections required in an assigned skewed channel in the upper right corner of Fig. 22.15.

4. Make a complete detail of the channel sketched in Problem 3.

Sloping Beams

5. Make a sketch of the connections for the sloping rafter E in Fig. 22.22.

6. Make a complete detail of rafter E sketched in Problem 5.

7. Make a sketch of connections required for the hip rafter C in Fig. 22.22. Note that a double auxiliary layout is required to obtain the angle of bend of the connections.

8. Make a complete detail of the hip rafter C sketched in Problem 7.

Purlins

9. Make a complete detail of a purlin assigned from Fig. 22.22. Notes should cover number required which are exactly alike.

Trusses

10. Make a complete detail of the truss shown in Fig. 22.47 at the top of the figure. This is an architect's drawing. You are not to copy it but to make a detail for fabrication in the shop.

11. Same as Problem 10, using lower truss of Fig. 22.47.

12. Make a complete detail of the truss shown in Fig. 22.48. Scale ¾″ = 1′-0″.

Columns

13. Make a complete detail of a column assigned from Fig. 22.26. For beam connections to these columns, see Fig. 22.15. Assume first-floor beams to be the same as second-floor beams.

Reinforced Concrete

The following data supplements that given in Figs. 22.49, 22.50, and 22.51.

Columns *C-3*, *C-6*, *F-3*, and *F-6* are 24 inches square. The reinforcing consists of 8 1-inch square bars with proper ties.

Column *A-1* is 30 inches square and has 8 ¾-inch bars.

Columns *A-2*, *A-4*, *A-5*, *A-7*, *B-1*, *D-1*, *E-1*, and *G-1* are 18×30 inches in cross section, and each has 6 ⅞-inch bars.

The first-story height floor to floor is 14 feet. The columns above the second floor are 4 inches smaller on each dimension. Except for Column *A-1* they are centered over the column below. Column *A-1* has its outside faces flush for the entire height. Reinforcing rods in the second story are ⅛ inch less in diameter than in the first story.

14. Make a typical cross section of any assigned column.

15. Make a typical detail of second-story splice for any assigned column.

16. Make a bar-bending schedule for beams *B-101* and *B-102*. See Figs. 22.49 and 22.50.

17. Make a bar-bending schedule for joists *J-101*, *J-103*, *J-104*, and *J-105*. See Figs. 22.49 and 22.51.

18. Make an engineering drawing (floor framing plan) for the second floor of the building shown in Figs. 21.16 and 21.17. Use 20-inch metal pans instead of tile to form joists. Each joist shall have 2 ⅝-diameter rods, one bent and one straight. See *ACI Manual* for details of framing concrete to steel beams.

19. Make a typical detail of the joists of Problem 18.

20. Make a typical cross-section detail through the 18″-WF 50# beam, showing the placing of joist reinforcing rods. See *ACI Manual* for suggestions.

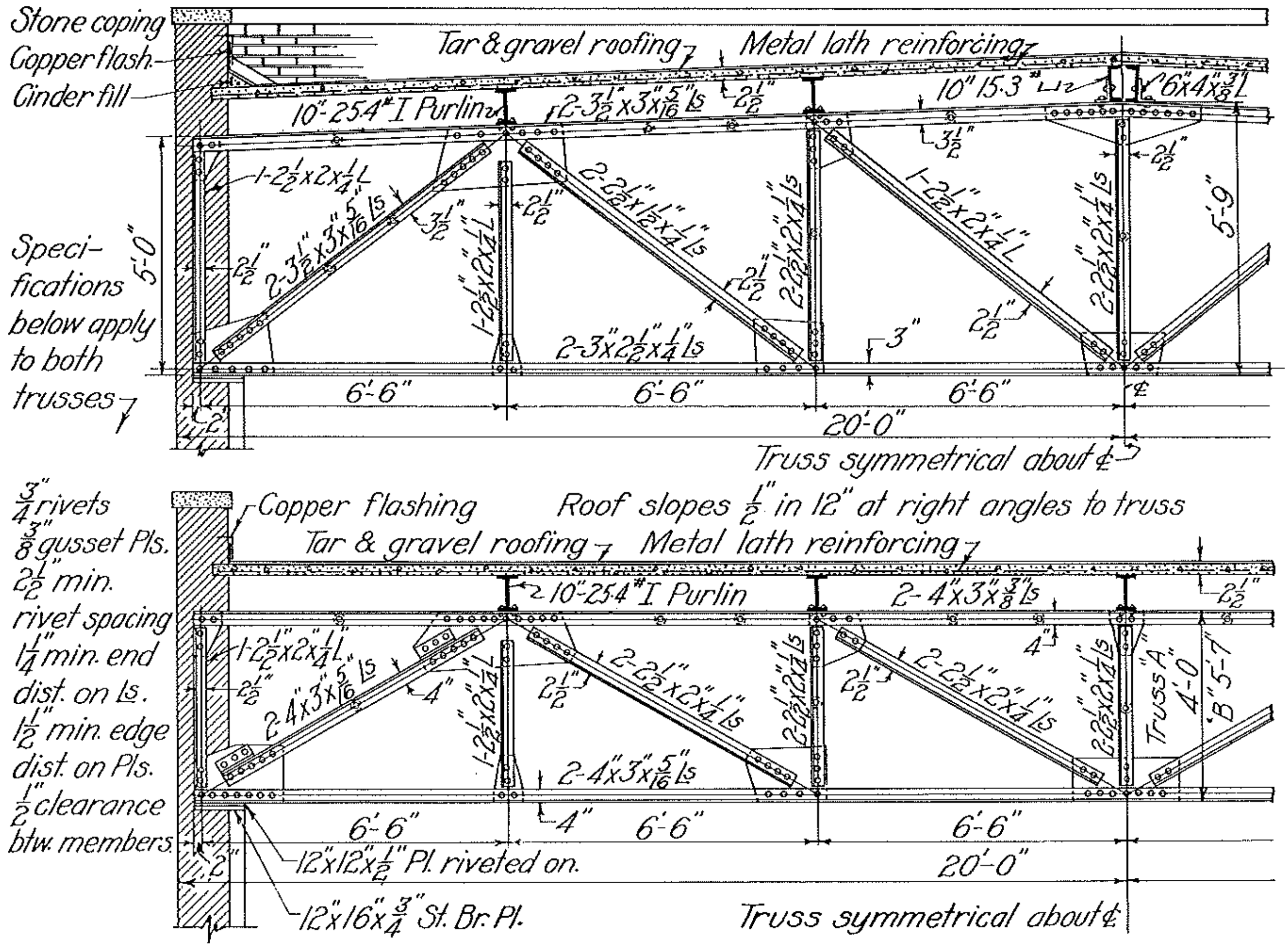


Fig. 22.47. Truss detail for building shown in Figs. 21.16 and 21.17.

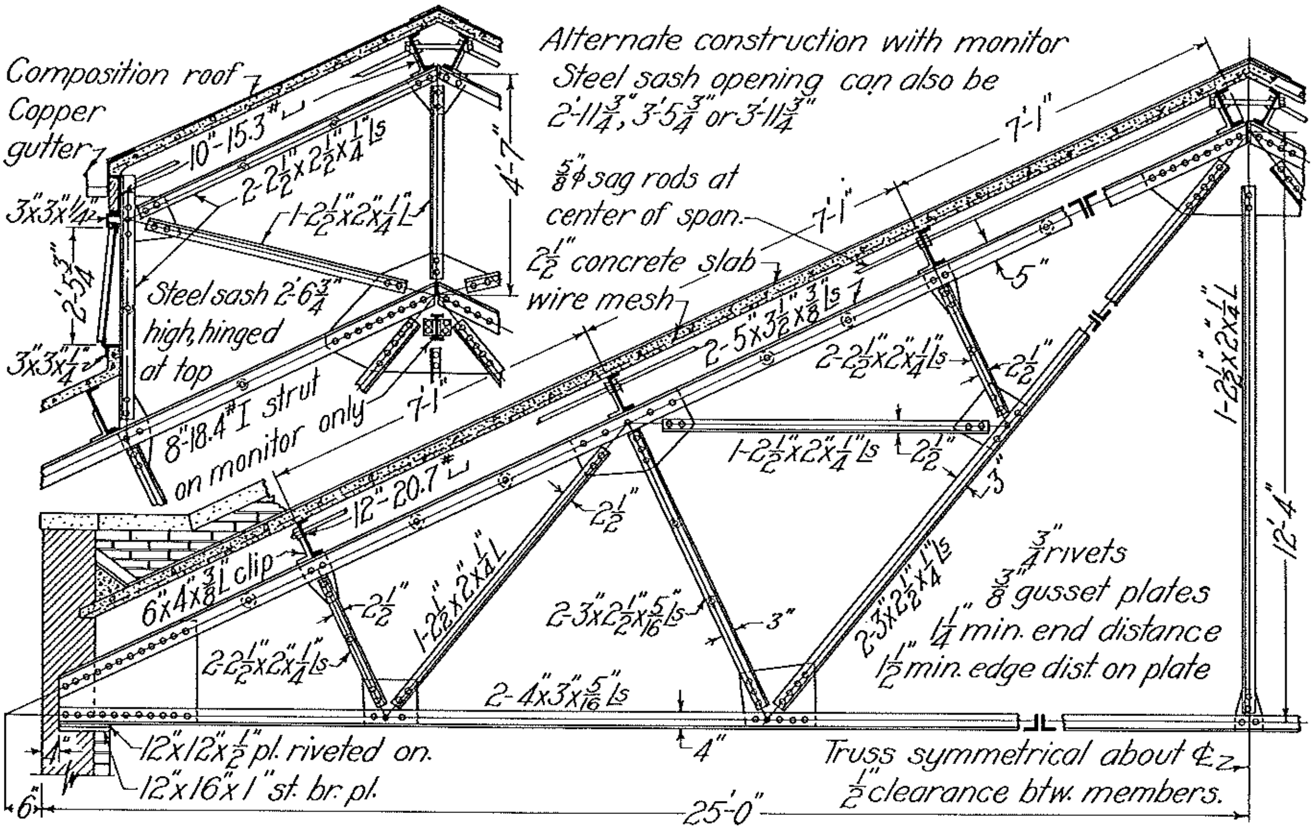


Fig. 22.48. Truss detail for building shown in Figs. 21.18 and 21.19.

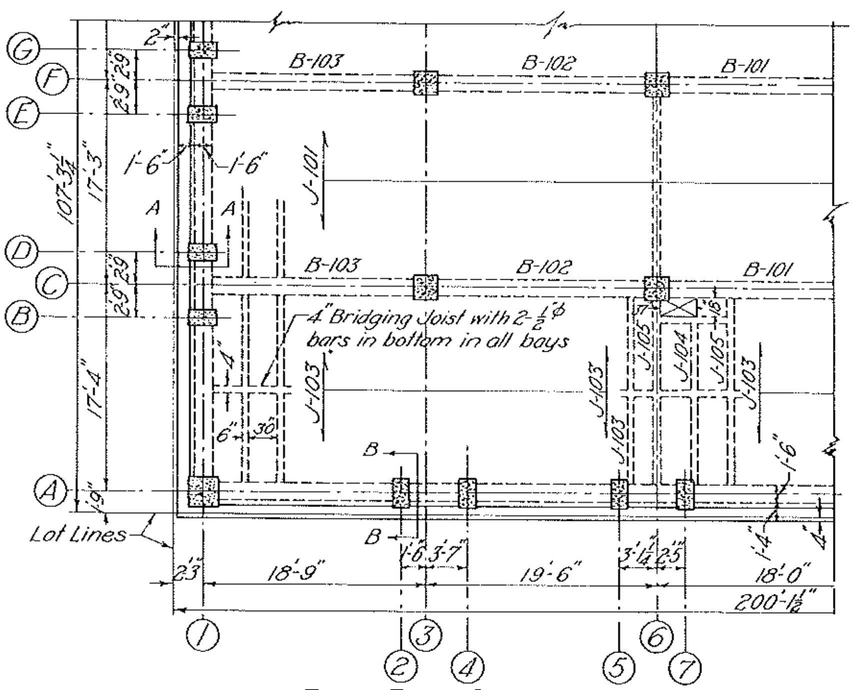
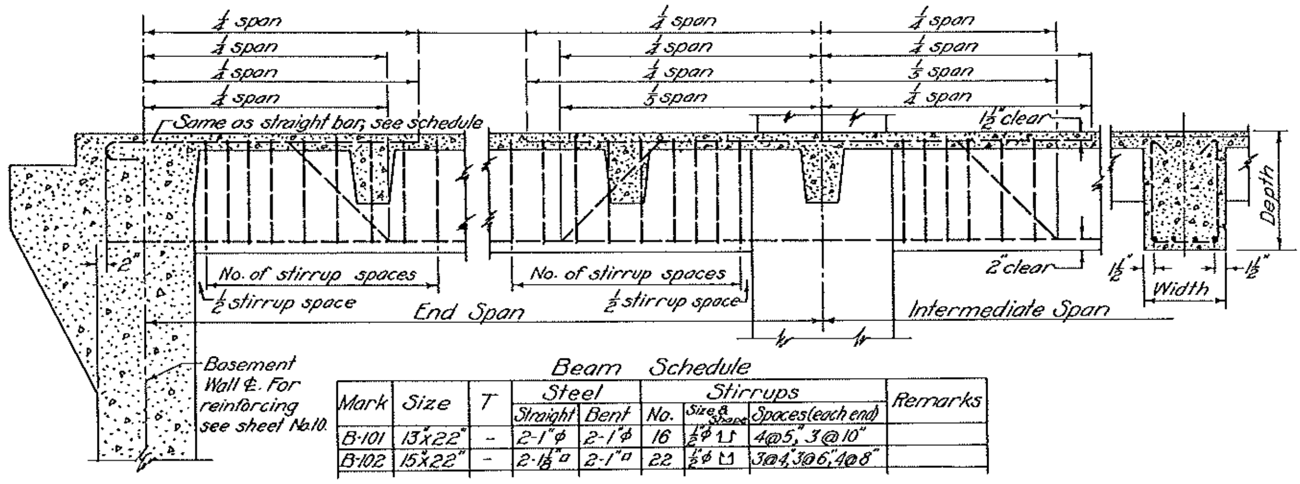


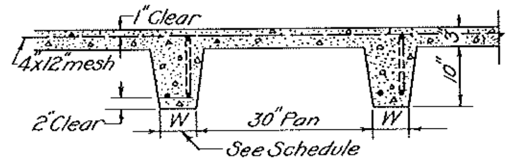
Fig. 22.49. Concrete floor framing plan.



Beam Schedule

Mark	Size	T	Steel		Stirrups			Remarks
			Straight	Bent	No.	Size & Shape	Spaces (each end)	
B-101	13"x22"	-	2-1"φ	2-1"φ	16	½"φ ⊔	4@5", 3@10"	
B-102	15"x22"	-	2-1⅛"□	2-1"□	22	½"φ ⊔	3@4", 3@6", 4@8"	

Fig. 22.50. Beam detail.



Joist Schedule

Mark	Size		Steel		Stirrups			Remarks
	Width	Depth	Str'ght	Bent	No.	Size + Shape	Spacing	
J-101	6"	10"+3"	1-⅞"φ	1-¾"φ	20	¼"φ ⊔	3@3", 6@6"	
J-102	6"	10"+3"	1-1"φ	1-⅞"φ	18	¼"φ ⊔	3@3, 5@6"	
J-103	6"	10"+3"	1-⅞"φ	1-⅞"φ	18	¼"φ ⊔	3@3, 5@6"	
J-109	5"	10"+3	1-⅝"φ	1-½"φ	4	¼"φ ⊔	3@5"	
All straight bars to extend 1'-0" past ℄ of support								
Bent bars shall extend to the ¼" point of the next span.								

Fig. 22.51. Joist detail.

Pipe Drawing* 23

23.1 Introduction. Some form of piping is used in most projects with which the engineer is concerned. For that reason he should understand the general functions and characteristics of piping systems. He should also know the proper methods of representation and location of pipes and pipe fittings.

Pipes are normally used for conveying liquids, gases, and solids such as water, oil, steam, air, and minerals. They are sometimes used as structural elements, such as columns and beams.

The material of which pipes are made covers a wide range. In general, they are round but other shapes are frequently used. Sizes range from very small to very large and thickness of walls ranges from very thin to very thick.

The material, shape, size, and wall thickness are not necessarily dependent one upon the other but each depends upon the purpose for which the pipe is used.

In general, a piping system of any extent consists of a succession of individual pieces connected in such a manner as to maintain continuity of flow. Volume of flow is controlled by various devices developed to meet the specific need. Fixtures used to control direction and volume of flow are generally classified as fittings and valves. Fittings and valves may or may not be made of the same material as the pipes to which they are attached.

23.2 Pipe material. In ancient times pipe material was limited to bamboo, wood, and stone. As civilization progressed metals came into common use. At the present time such a wide variety of materials and methods is available that pipes are now made from iron, steel, brass, copper, lead, aluminum, and metal alloys. They are also made from wood, concrete, clay, glass, plastics, and rubber. Insulated, lined, and reinforced pipes are also in common use.

* This chapter was prepared by Prof. L. D. Walker of the University of Illinois.

Pipes of special materials for special purposes continue to be developed.

It is the purpose of this chapter to consider the drafting problems for pipes made of only the more common metals such as iron, steel, brass, copper, lead, and their alloys.

23.3 Pipe manufacture. Much of the pipe used in industry is cast iron. As the name implies, cast-iron pipe is cast in sand molds placed either horizontally or vertically, or centrifugally cast in metal molds lined with sand or some pulverized material.

The bulk of pipe other than cast iron is made of wrought metal such as steel, iron, brass, or copper. In principle the methods of manufacture of wrought-metal pipe differ widely from those of making cast-iron pipe. In one common method, pipe-length strips of metal are rolled into cylindrical shapes and the edges are welded together. The electric-weld method is used quite extensively. Another common method is to bring a cylindrically shaped piece of metal to a high forging temperature, force a hole through the center of the cylinder and then roll it down to the desired wall thickness. In general, copper tubing is made by the cold-drawn process.

23.4 Pipe sizes and specifications. Inside diameter depends mainly upon the volume of flow desired. Wall thickness depends upon a number of variables such as internal and external pressure, shock, vacuum, and thermal expansion.

Careful consideration must be given to the meaning of pipe sizes, which are usually indicated simply as ½ inch, 1 inch, 2 inch, etc. When such reference is made to the size of steel or wrought-iron pipe up to 12 inch, the specified size refers to the nominal inside diameter because this is close to, but not, the exact inside diameter. For example, the inside diameter of a nominal 1-inch "standard weight" steel pipe is 1.049 inches, "extra-strong" is .957 inch, and "double-strong" is .599 inch, yet the outside diameter in each case is

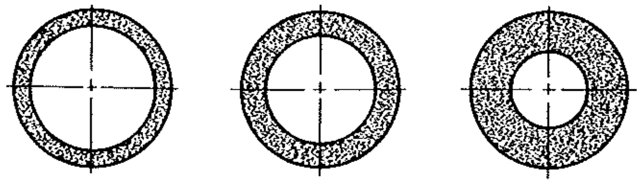


Fig. 23.1. Sections of 1-inch steel pipe.

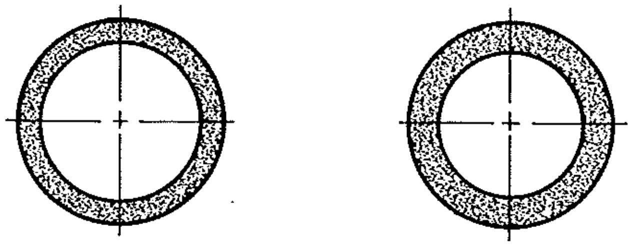


Fig. 23.2. Sections of 1-inch brass pipe.

1.315 inches. The great advantage in keeping the outside diameter the same for each nominal diameter, regardless of wall thickness, is the adaptability of standard valves and fixtures to pipes, regardless of the thickness of walls. Figure 23.1 shows the outside diameter, inside diameter, and wall thickness of typical 1-inch steel pipe. See Table 35 in the Appendix for dimensions of wrought-steel pipe.

When reference is made to standard steel or wrought-iron pipe sizes larger than 12 inches, such as 14-inch, 16-inch, etc., the specified size now refers to the outside diameter. Such large pipe is often called O.D. pipe. When outside diameter is used to designate the pipe size, thickness of walls must also be stated so that inside diameter can be determined.

Cast-iron pipe is available in a wide variety of standard sizes and weights with the bell-and-spigot joint. It is also available in sizes 1¼ inches to 12 inches with threaded ends. Nominal size of cast-iron pipe always indicates inside diameter regardless of size. Terms such as "strong" and "extra-strong" are not commonly used in connection with cast-iron pipe; consequently wall thickness or outside diameter or both should be indicated in connection with nominal size. See Table 36 of Appendix for common characteristics of bell-and-spigot-end cast-iron pipe.

Brass and copper pipes are available in sizes from ⅛ inch to 12 inches and in two weights called "regular" and "extra-strong." They are very similar in wall thickness and inside diameter to steel pipe classified as "standard" and "extra-strong." Outside diameters are exactly the same as outside diameters of corresponding nominal sizes of steel pipe. Figure 23.2 shows outside diameter, inside diameter, and wall thickness of 1-inch "regular" and "extra-strong" brass pipe. See Table 37 of the Appendix for dimensions of brass and copper pipe.

Copper water tubing is available in sizes from ⅛ inch to 12 inches. Its wall thickness is considerably less than that of most other piping material. Nominal size indicates neither outside diameter nor inside diameter. Actual outside diameter is consistently .125 inch greater than nominal size. Consequently in specifying size of tubing, outside diameter and wall thickness must be given. Three wall thicknesses are available. Figure 23.3 shows outside diameter, inside diameter, and wall thickness of 1-inch Type K, Type L, and Type M copper water tubing. See Table 38 of Appendix for sizes of copper water tubing.

Specifications and recommendations for manufacture, composition, strength, use, size, etc., of pipe and pipe products have been developed by such organizations as the American Water Works Association, American Gas Association, American Petroleum Institute, American Society for Testing Materials, American Standards Association, and others. The American Standards Association is working toward a unification of all pipe specifications in an attempt to eliminate odd sizes and varieties and to develop some coordination applicable to all common types and sizes. Printed copies of complete standards for pipes and pipe products may be obtained from the American Standards Association.

Pipe standards, piping handbooks, manufacturers' manuals, and catalogues are available to supplement the limited amount of data in tables in the Appendix.

23.5 Pipe joints. In order to properly join pipe lengths, fittings, and valves, suitable connections must be provided. These connections must withstand pressures, shock, and stresses to which the pipes, fittings, and valves are subjected.

One of the most common methods of connecting cast-iron pipe is by means of the conventional bell-and-spigot joint. This joint is suitable where there is relatively low pressure and little vibration such as in underground installations. Lead, cement, sulphur compounds, oakum, and jute are the usual packing materials.

Other joints used on cast-iron pipe may be classed as mechanical joints because of the manner in which the jointing material is forced into place. In this type

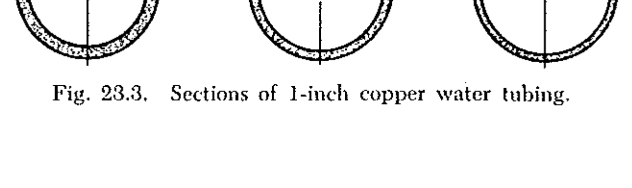


Fig. 23.3. Sections of 1-inch copper water tubing.

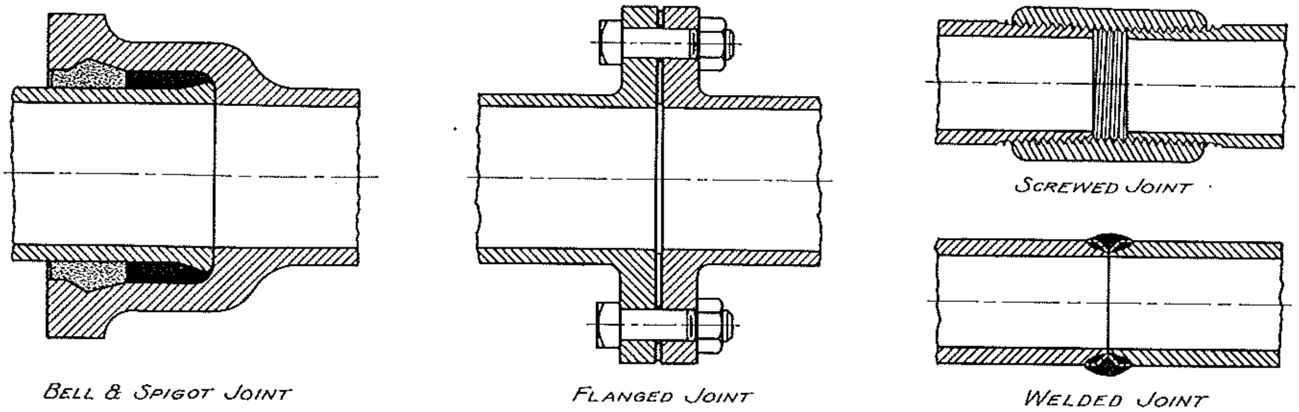


Fig. 23.4. Pipe joints.

of joint, the jointing material is rolled or pushed along the outside of the inserted spigot end of one pipe into the bell end of the other, either by bolt action or screw action. This type of joint usually requires some modifications of the conventional bell-shaped end of the pipe. This joint will withstand greater pressure and vibration, and allows for greater lateral deflection and thermal expansion than the conventional bell-and-spigot joint. Additional packing materials especially adaptable to mechanical joints, are rubber, composition materials, and bituminous compounds. Frequently these materials are pre-formed before use.

Still other methods of connecting cast-iron pipe include the use of mechanical joints such as the gland type, ball-and-socket and universal joints, sleeve couplings, and welding. Screwed couplings and fittings similar to those used for steel pipe are not uncommon where small size cast-iron pipe is used. The conventional bell-and-spigot joint is illustrated in Fig. 23.4.

Standard steel and wrought-iron pipes are usually connected by flanges, threaded couplings, or welds.

The flange joint can be quite readily disassembled and may be designed to withstand high pressures. Flanges are attached to the pipe ends either by being screwed on, welded, or lapped. To complete the joint the flange faces are drawn tightly together with bolts.

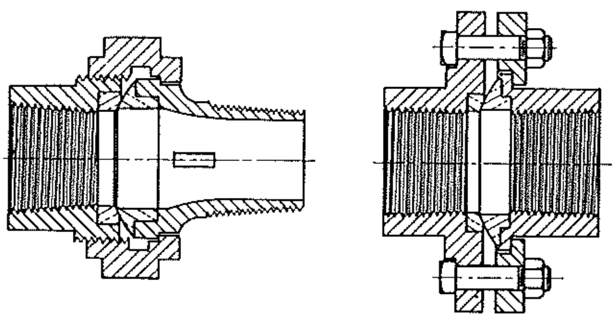


Fig. 23.5. Screwed and flanged unions.

Flange design, face type and finish, gasket design and composition, and bolt load are all important factors in this type of joint. One of the more simple flange joints is illustrated in Fig. 23.4.

Welded joints and connections are not uncommon in high-pressure pipe assemblies. They are becoming more common in low-pressure assemblies as less expensive low-pressure valves and fixtures are being developed. Butt welds with conventional modifications are most frequently used. See Fig. 23.4.

Threaded couplings are simply short cylinders, threaded on the inside at each end to form pressure-tight joints for end-threaded pipe. This type of joint is illustrated in Fig. 23.4. These joints are not so readily disassembled as flange joints. They may be designed to withstand relatively high pressures. The thread design of the coupling must conform to the thread design of the pipes to be connected. For pipe sizes over 2 inches the threads are tapered 1 inch in 16 or .75 inch per foot measured on the diameter and along the axis. See Fig. 10.34. For pipe sizes of 2 inches and under, straight threads are frequently used on both ends of the coupling. Straight threads on one end and tapered threads on the other, or left-hand threads on one end and right-hand threads on the other are not unusual. To expedite disassembly in a threaded pipe system, couplings called pipe unions are used. See Fig. 23.5 for conventional screwed and flanged unions.

Soldered joints are frequently used on copper and brass tubing, but pressure and temperature restrict the extensive use of solder as a jointing material.

23.6 Pipe fittings. In order to control and change direction of flow in a piping system of any extent, a number of pipe fittings are necessary. Elbows, tees, crosses, laterals, return bends, and reducers are some of many in use. They are made of cast iron, steel, malleable iron, brass, and sometimes of special materials. They are not necessarily made of the same

material as the pipe to which they are attached. Connections of these fittings to pipes and valves are made by flanges, screw fittings, welding, soldering, or jointing materials. A number of screw fittings are shown in Fig. 23.6.

Most pipe fittings are specified by material, name, and nominal pipe size. Some fittings such as tees, laterals, and crosses are sometimes used to connect pipes of different sizes. When this occurs, the fitting is called a reducing fitting and sizes of openings must be properly indicated. In the case of the reducing tee, lateral, and cross, the size of the largest opening is given first and then the size of the opening at the opposite end. When the fitting is a tee or a lateral, the third dimension is that of the outlet. When the fitting is a cross, the third dimension is the largest outlet opening and the fourth is the opposite opening. Figure 23.7 indicates the method of specifying sizes of reducing fittings.

23.7 Valves. Volume of flow in pipes is controlled primarily by valves. The more common types are the gate valve, globe valve, and check valve. Many other types such as the angle valve, relief valve, needle valve, pressure-reducing valve, butterfly valve, and plug valve are not uncommon.

Most valve bodies in the smaller sizes are made of

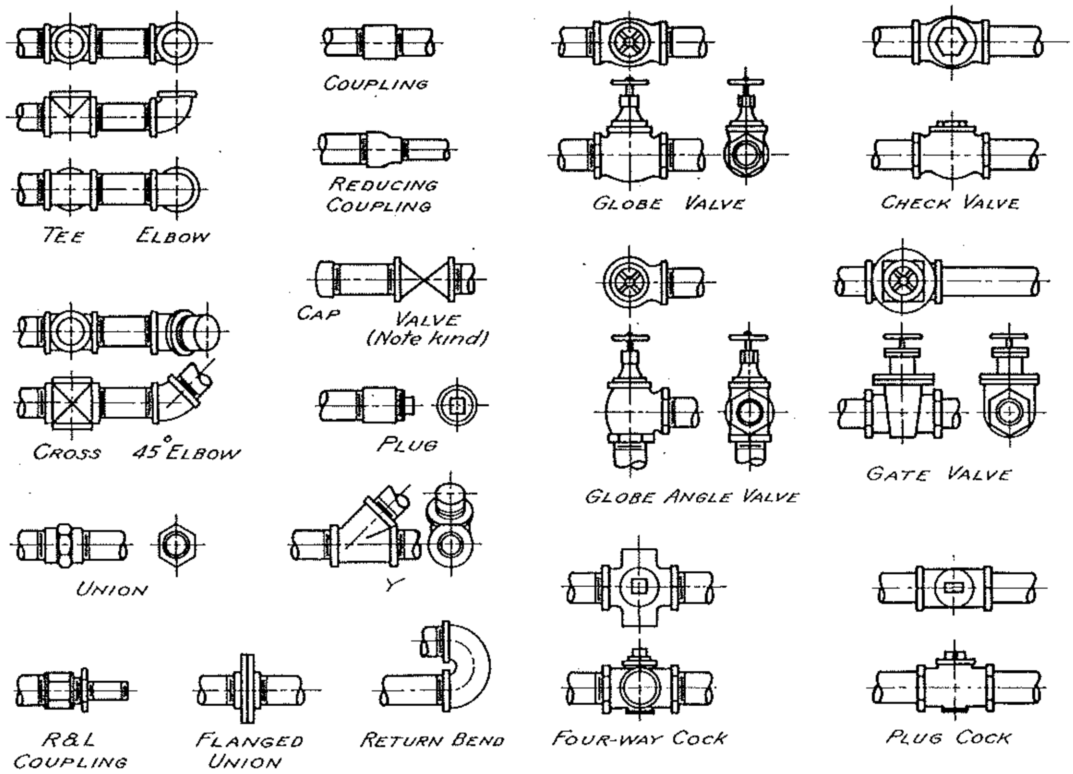


Fig. 23.6. Double-line pipe and valve symbols for screw fittings.

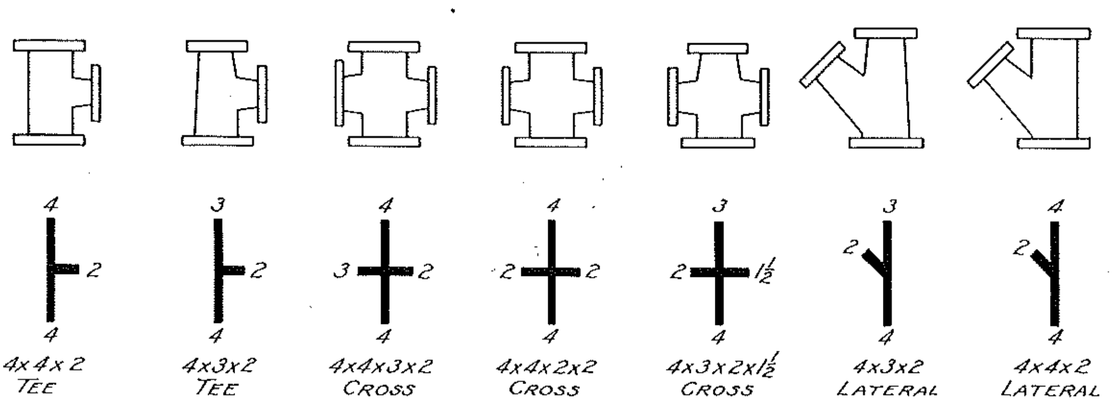


Fig. 23.7. Method of designating sizes of reducing fittings.

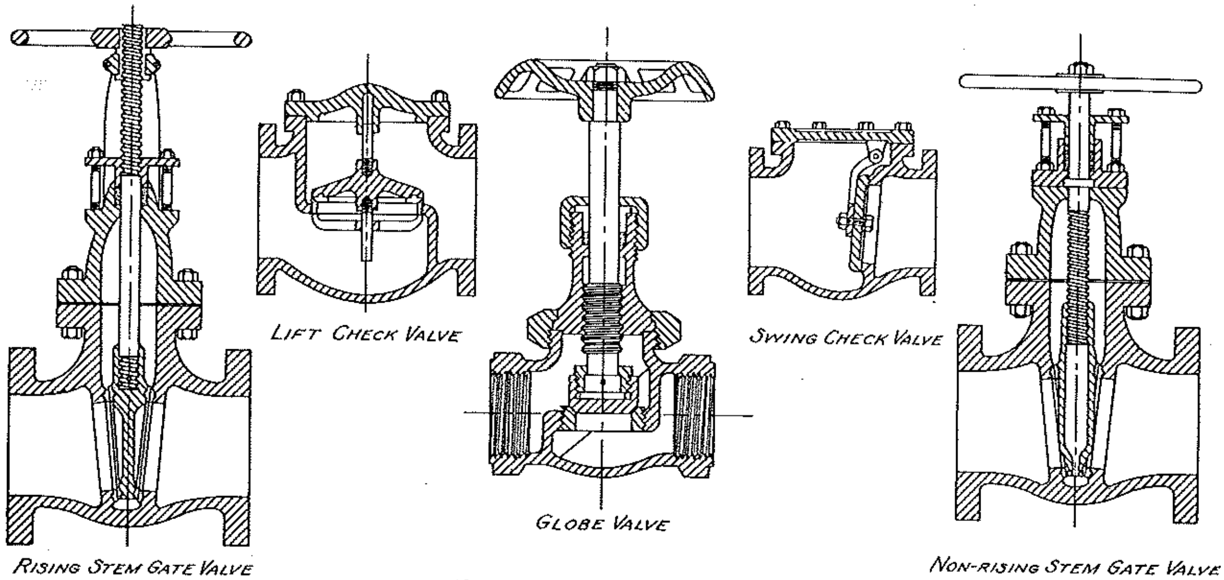


Fig. 23.8. Sections of valves.

brass or bronze. Those in the larger sizes are usually made of cast iron for intermediate pressures, and cast steel or cast alloy for high pressures. They are not necessarily made of the same material as the pipes to which they are attached. Connections to pipes and fittings are usually made by flanges, screw fittings, or welding.

The gate valve is used more frequently than any other valve. When open it offers little restriction to straight-line flow. It is used on lines conveying water and other liquids.

If the design is such that the gate moves out of the body of the valve with the stem, it is called a rising-stem valve. If the gate moves out of the body of the valve along the stem, it is called a non-rising-stem valve. Consideration of the mechanics of these two styles of gate valves is important. The rising-stem type requires more space for stem clearance than does the non-rising-stem type, but an open or closed position of the gate is clearly indicated by the position of the stem.

The globe valve is less expensive than the gate valve. It is used extensively for throttling on steam lines and where close regulation of volume of flow of liquids is necessary. In general, the design requires two changes of direction of flow which causes some loss of pressure in the system. All globe valves are of the rising-stem type. Ample space must be provided for operation to open completely.

The check valve is used to prevent reversal of the direction of flow. The design is usually quite simple, and in most cases gravity plays a part in its operation. The swing check and lift check, with variations, are the two principal types of check valves in common use.

Conventional gate, globe, and check valves are shown in Fig. 23.8.

23.8 Pipe bends. Where conventional long-turn elbows are not suitable for high velocity flow, fabricated pipe bends are frequently used. Lineal expansion and space limitations may also require their use. They may be obtained in almost any size and shape but requirements must be described to the manufacturer in the form of complete drawings and specifications.

Some conventional pipe bends are shown in Fig. 23.9.

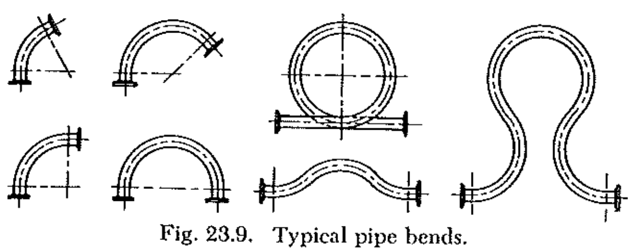


Fig. 23.9. Typical pipe bends.

23.9 Pipe supports and accessories. Pipe lines of any considerable extent require hangers and supports to provide for dead weight and stresses due to thermal expansion and vibration. Provision must also be made for adequate drainage of the line. Location, type, and spacing of supports are all important factors which must be given careful consideration. For horizontal runs, rods or straps are usually adequate where the pipes are relatively small. They are usually attached to joists or steel work in the ceiling. For

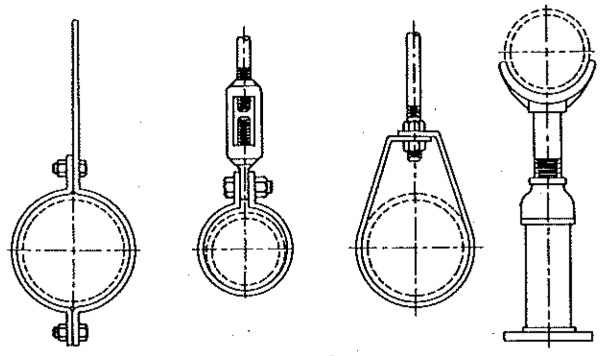


Fig. 23.10. Typical pipe supports.

long vertical runs of considerable weight, bottom supports set on the floor are frequently used. Many types of supports with recommendations for spacing and slope are available from pipe manufacturers. Their recommendations should be carefully considered. A few types of pipe hangers are shown in Fig. 23.10.

In steam lines, special provision must be made for drainage of condensation. The slope of piping in these lines should be in the direction of steam flow. Drip pockets, steam separators, and steam traps are some of the devices used in this connection. A few of the more common accessories on steam and cold water lines are shown in Fig. 23.11. Many other accessories to pipe lines are illustrated in manufacturers' catalogues.

23.10 Pipe symbols. Pipes, fittings, valves, fixtures, and accessories common to piping systems are most frequently represented on drawings by accepted standard symbols. The standard single-line symbols used on small-scale drawings are shown in Fig. 23.12. Shown in the Appendix are standard symbols for plant equipment and plumbing fixtures. These standard symbols are from the American Standards Association. Complete copies of graphical symbols may be purchased from the American Standards Association.

23.11 Pipe drawings and diagrams. The purpose of pipe drawings is to show the location and size of pipes and the location and identification of valve fixtures and apparatus which go to make up all or parts of piping systems large or small. In general they are much like other engineering drawings. Orthographic, oblique, and axonometric are the types of projection most commonly used in pipe drawing. The use of either double-line or single-line representation of pipes, valves, and pipe fixtures is approved.

Orthographic one-, two-, or three-view projections are used in drawings of many installations. Double-line representation is ordinarily used where the system is made up principally of large pipe and where the drawings may be used a number of times as reference on similar projects. Such a drawing is shown in Fig. 23.13. Single-line representation of small pipe is permissible on double-line pipe drawings. Where the number of pipe lines in a system is large it is good practice to make up several sheets for the same plant layout. One or more sheets might properly show the main lines only, others return lines, and still others laterals, etc. Such drawings should be made upon tracing paper or cloth so they can be checked one over the other to see that no conflicts in the system exist.

For systems in which relatively small pipe is used it is good practice to represent all the pipes and pipe fixtures by single-line representation. This scheme saves much time in drafting and proves very satisfactory in drawings of small units or parts of systems. Figure 23.14 shows such a single-line piping diagram in one-view projection. A modification of the con-

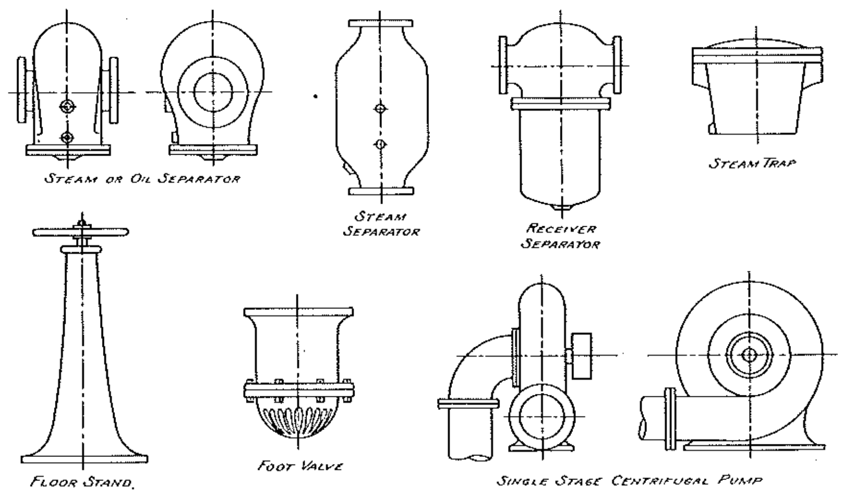


Fig. 23.11. Devices used in pipe lines.

ventional two-view orthographic drawing of a small section of a piping system, sometimes called a developed view, is shown in Fig. 23.15. In this scheme the pipes are imagined to be revolved into a single plane, either the horizontal or the vertical. This results in a one-view drawing and proves very effective on small-job studies and estimates.

For preliminary layouts and for reference in connection with complete drawings of piping systems, conventional pictorial drawings such as axonometric and oblique are very useful. Rules of projection governing proper pictorial representation of machine parts must be followed in the pictorial representation of piping. An isometric of a small section of piping both single-line and double-line is shown in Fig. 23.16. Single-line isometric is more frequently used than double-line since it serves the purpose equally well in most cases and is much more easily done.

Single-line oblique drawings may be used for the same purpose as isometrics and have advantages in

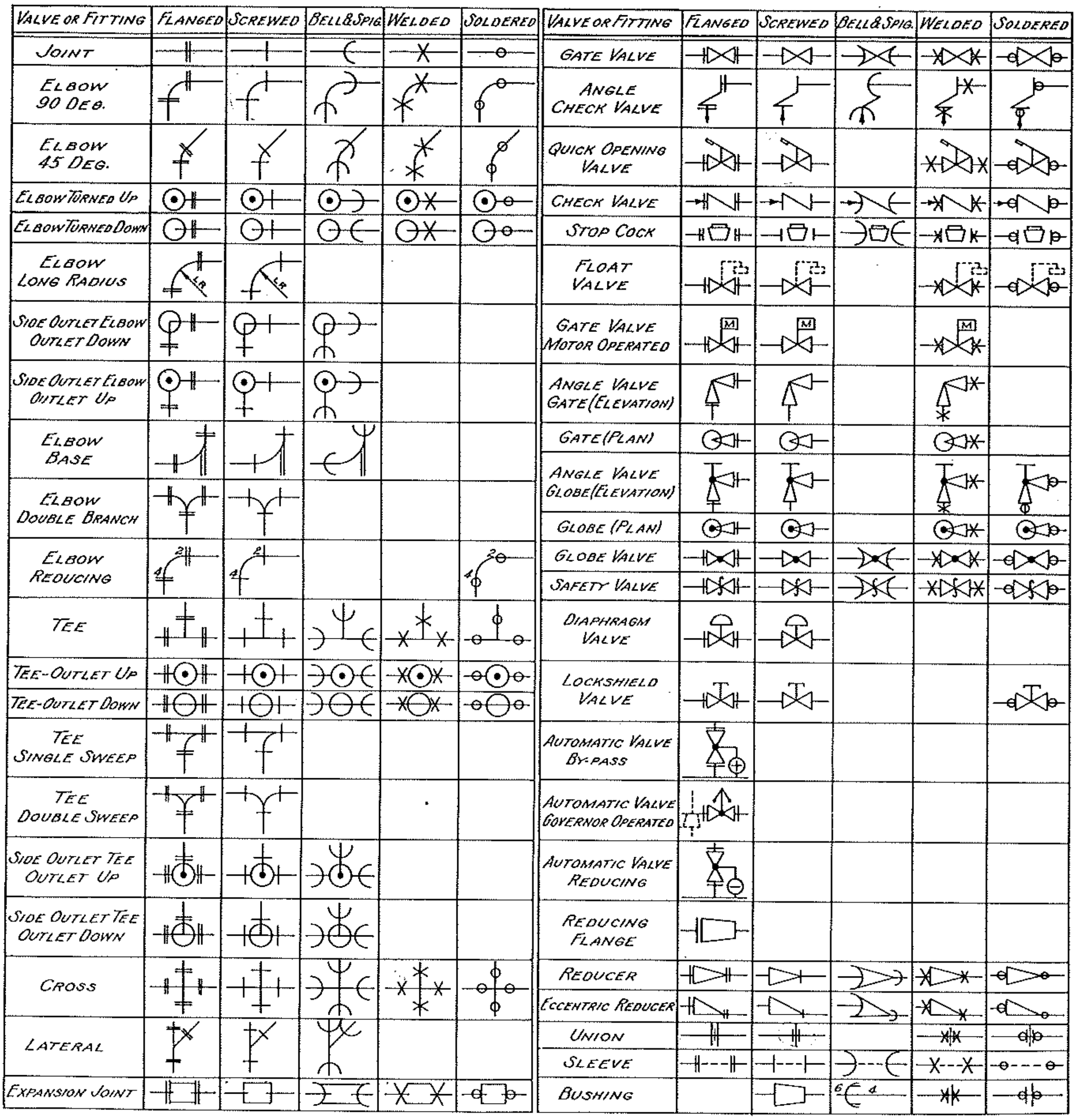


Fig. 23.12. American Standard single-line pipe and valve symbols.

allowable modifications that isometrics do not have. An oblique of a small heat distribution system is shown in Fig. 23.17. It should be noted that the usual method of oblique projection has been modified to allow a clear interpretation of the location of risers and returns in this layout. Such modifications of oblique are used only when necesasry to add clearness to the drawing. On almost all pictorial drawings and diagrams of pipe layouts the single-line representation of pipes and pipe fixtures is used regardless of changes of pipe sizes in the system. In single-line pipe drawings, for heating systems, the weight of the line representing supply is usually heavier than that representing return. See Fig. 23.17.

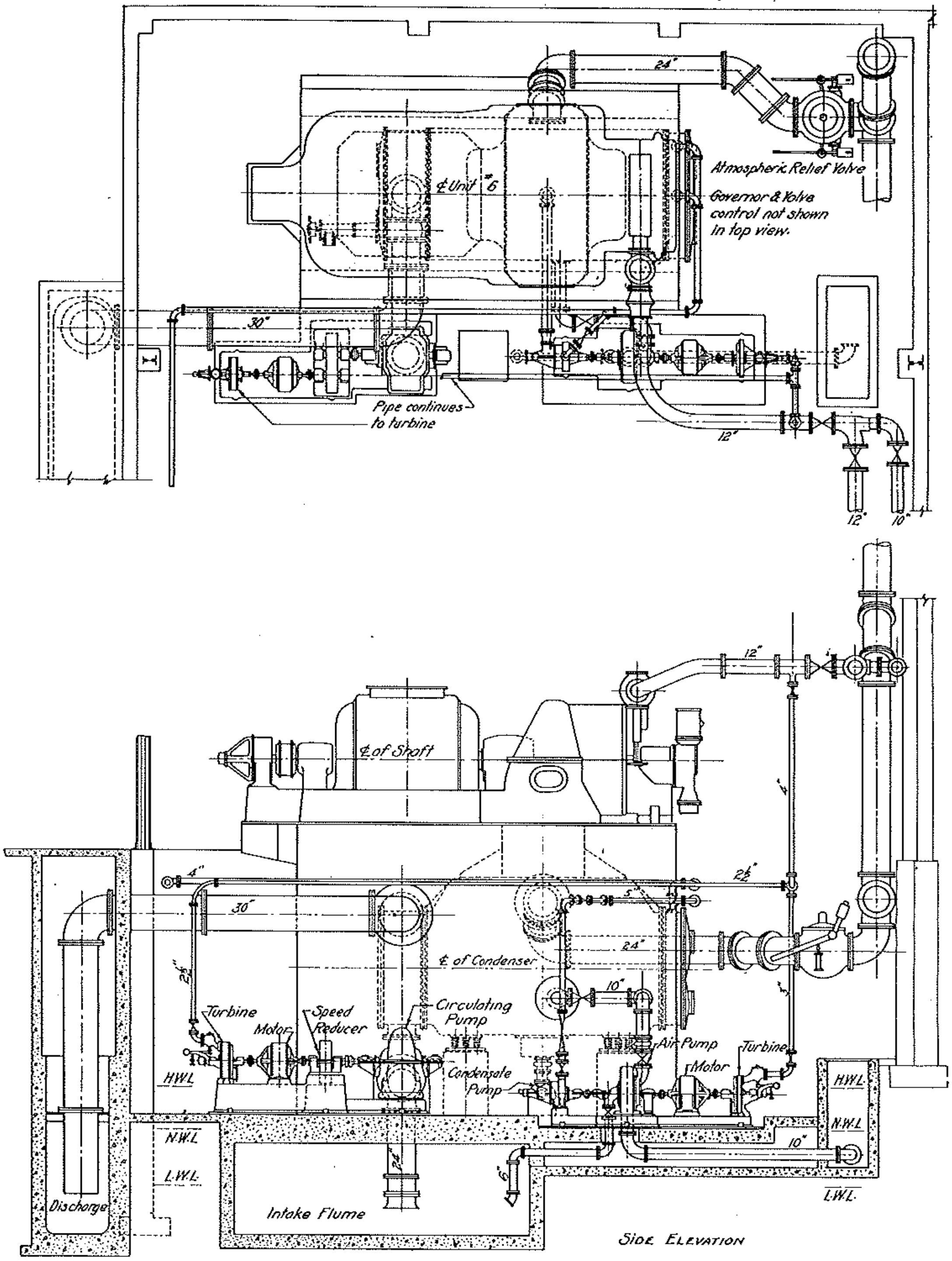


Fig. 23.13. Orthographic layout of a power plant unit.

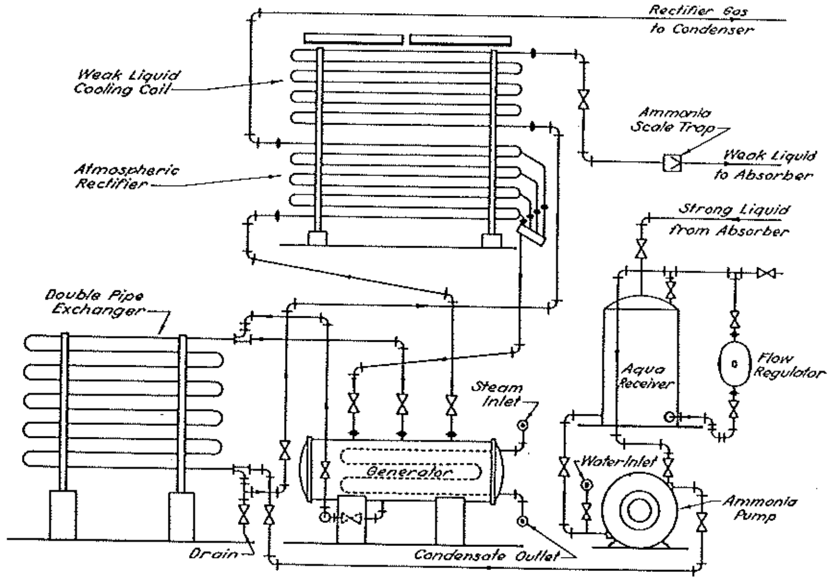


Fig. 23.14. A diagrammatic layout of an absorption unit.

23.12 Dimensions on pipe drawings. The general rules for dimensioning orthographic, axonometric, and oblique apply to pipe drawings. All lengths of straight runs of pipe must be dimensioned. The pipe sizes are indicated by writing the nominal pipe diameter near the side of the pipe, using leaders when necessary. Practically all other dimensions are location dimensions; consequently center lines of pipes, fixtures, and apparatus must be used freely. Overall dimensions of valves and fixtures are seldom shown since their sizes are standard. Valves and apparatus are frequently identified by name or manufacturer's number on the drawing. The material of which the pipes, pipe fixtures, and valves are made is usually indicated in general specifications. Sizes of flanges, length of threads, and similar details are indicated on the drawing by conventional representation. On most pipe drawings, the dimensions are written on the dimension line rather than in a break in the line.

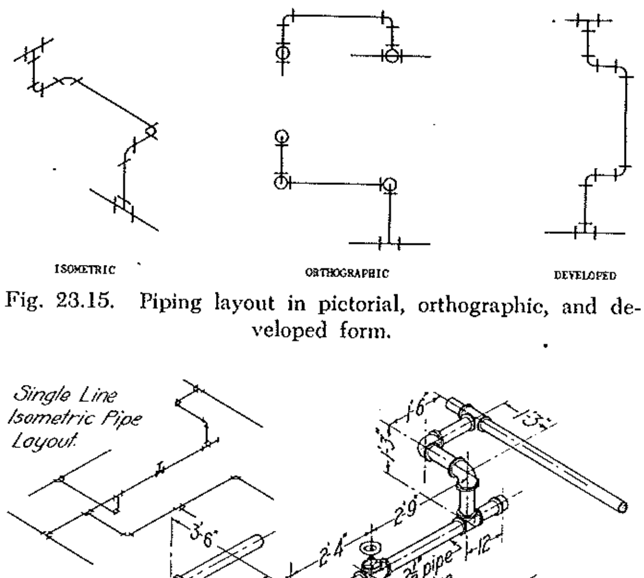


Fig. 23.15. Piping layout in pictorial, orthographic, and developed form.

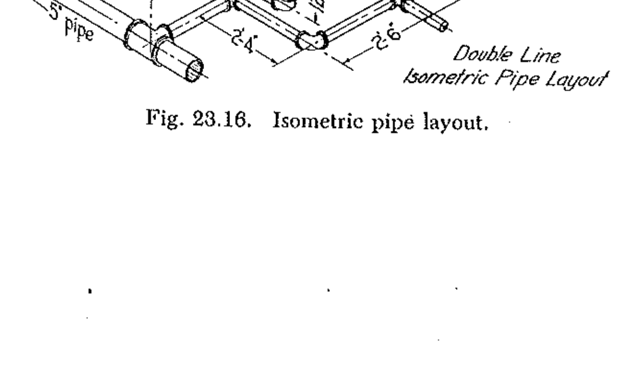


Fig. 23.16. Isometric pipe layout.

Problems

The following problems are typical of many that can be assigned. Excellent sources of material and references are actual building plans, water treatment systems, valve catalogues, and trade journals.

Sheet sizes, scales, paper, etc., should be chosen to meet the requirements of the problems. In general, $8\frac{1}{2}'' \times 11''$ or $11'' \times 17''$ should be a suitable sheet size.

1. Make a one-view freehand sketch of a gate valve, globe valve, or check valve for either flange or threaded connections as assigned.

2. Make an orthographic two-view double-line piping drawing of a section of a piping system to include 5 elbows, 3 valves (cross, check, and angle), 2 couplings (R. and L. and union), 1 cross, 1 reducer, 1 plug, and connecting pipe runs. Use either flanged or threaded connections as assigned.

3. Make a single-line isometric layout of the section of piping described in Problem 2.

4. In Fig. 23.18 is shown an isometric single-line piping diagram for a small pump house. In Fig. 23.19 is shown a partial double-line layout for the same system. Standard wrought-iron pipe is to be used in the interior. Standard cast-iron pipe is to be used underground. Five-inch pipe is

to be used from supply to pump. All other pipe is to be 4 inch. Standard cast-iron valves and fittings are to be used throughout. Flange fittings are to be used from pump to supply and pump to storage tank. Threaded fittings are to be used from the main line to the compound chamber and return. Complete the double-line pipe drawing of the system. Show pipe sizes and all necessary location dimensions and elevations necessary for construction and operation of the system.

5. Make a list of the pipe and fittings to be ordered for the system in Problem 4. Arrange the list in tabular form under headings of size, pipe lengths, valves (number and kind), fittings (number and kind), material, remarks.

6. Following are some typical piping layouts. Make an isometric single-line layout of all, or assigned, portions from any of the given layouts in Figs. 23.20 to 23.22.

7. Make a two-view orthographic drawing of portions assigned in Problem 6. Show pipe sizes and all necessary location dimensions.

8. Make a pipe and fittings list for portions assigned in Problem 6. Arrange as suggested in Problem 5.

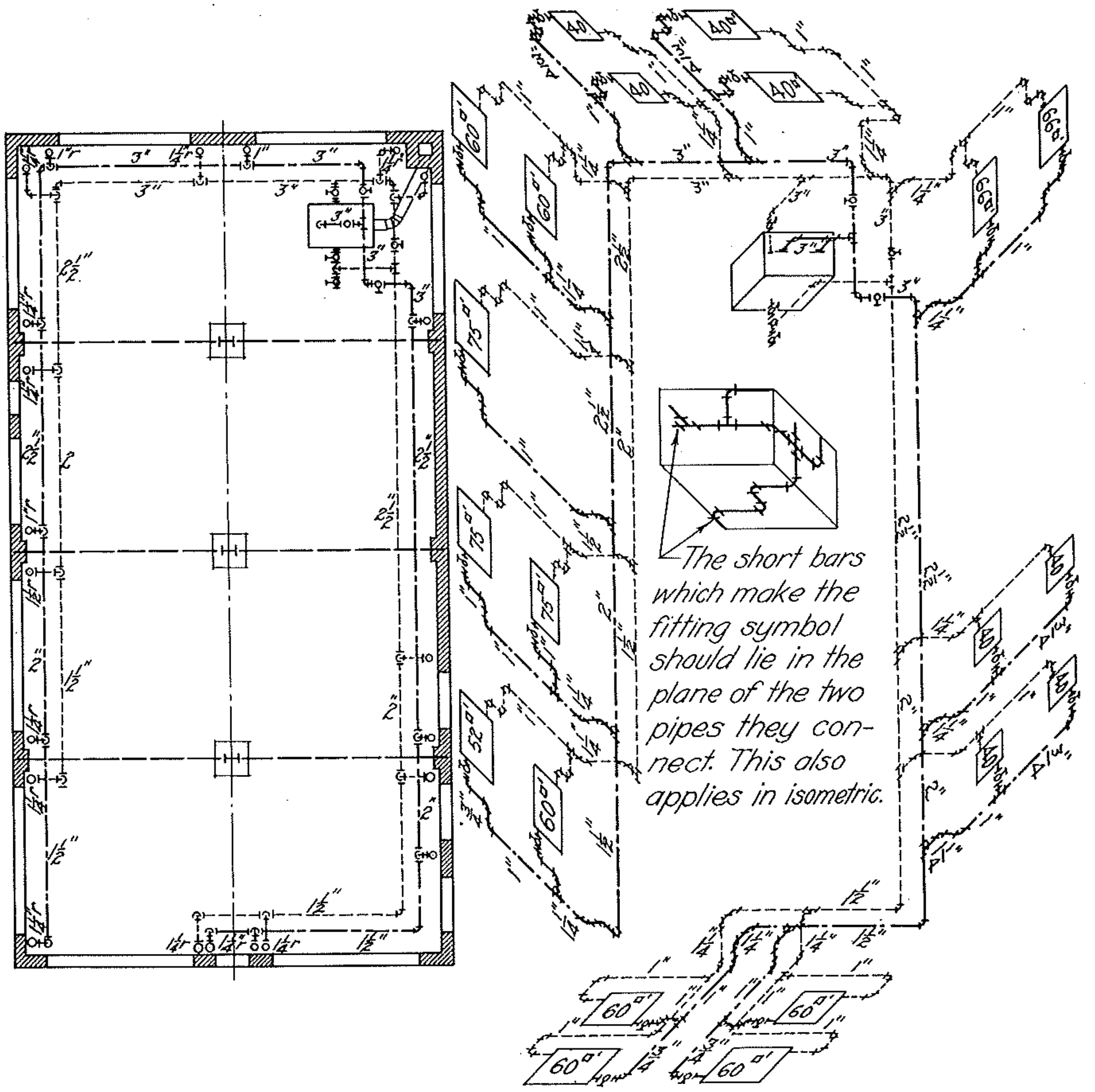


Fig. 23.17. Oblique pipe layout of a heating plant.

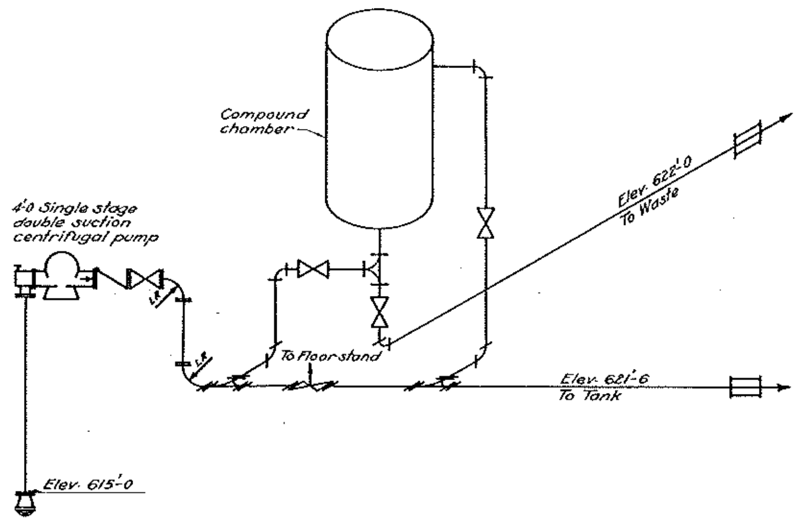


Fig. 23.18. Single-line piping diagram for a small pump house.

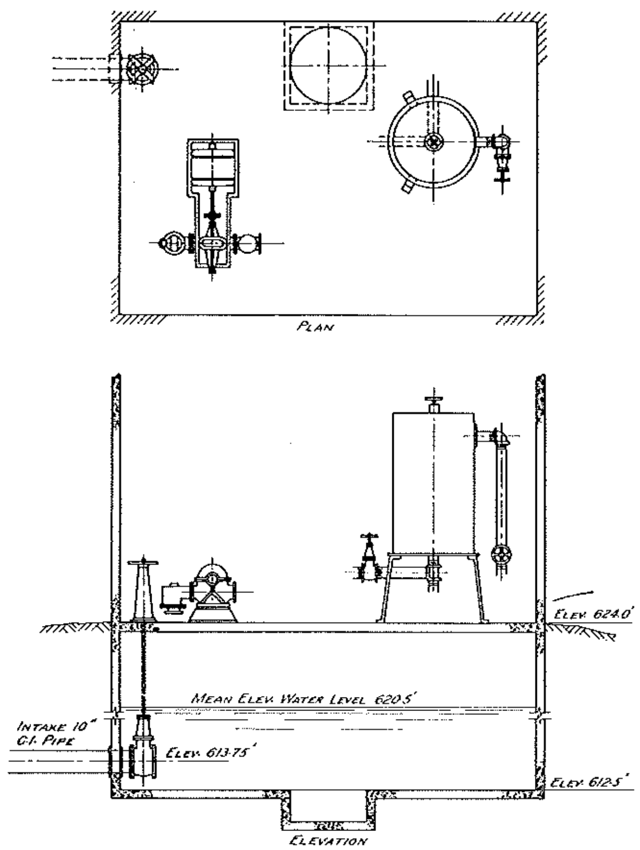


Fig. 23.19. Partial double-line piping layout for a small pump house.

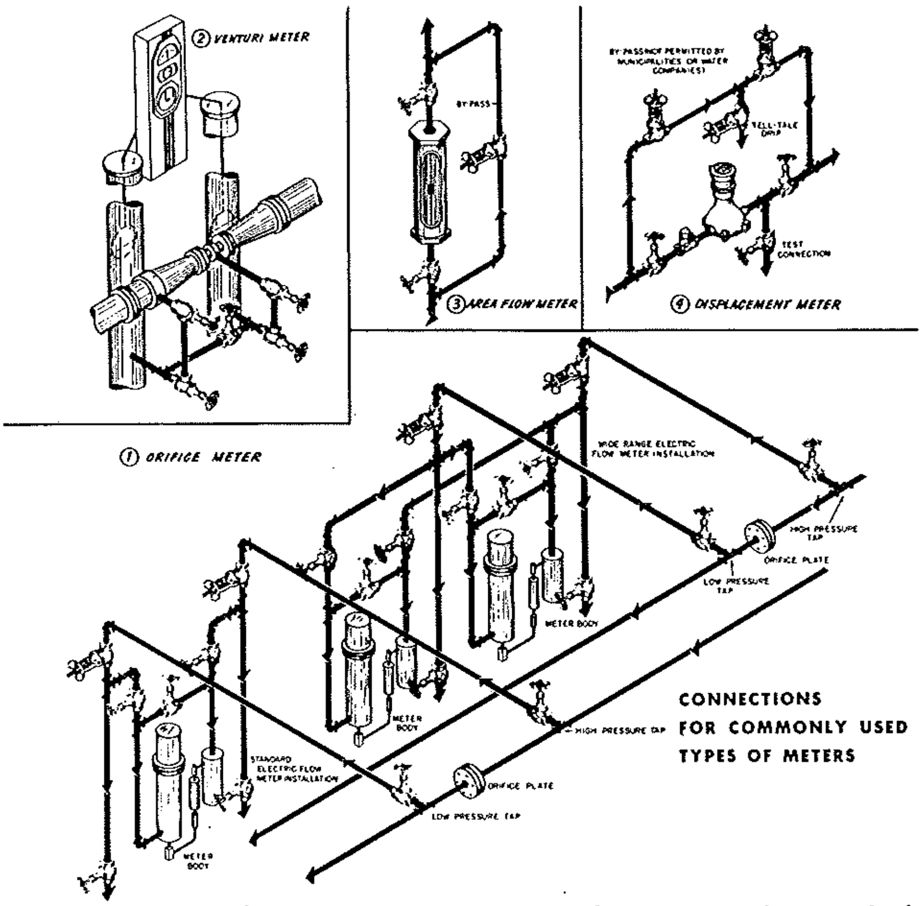
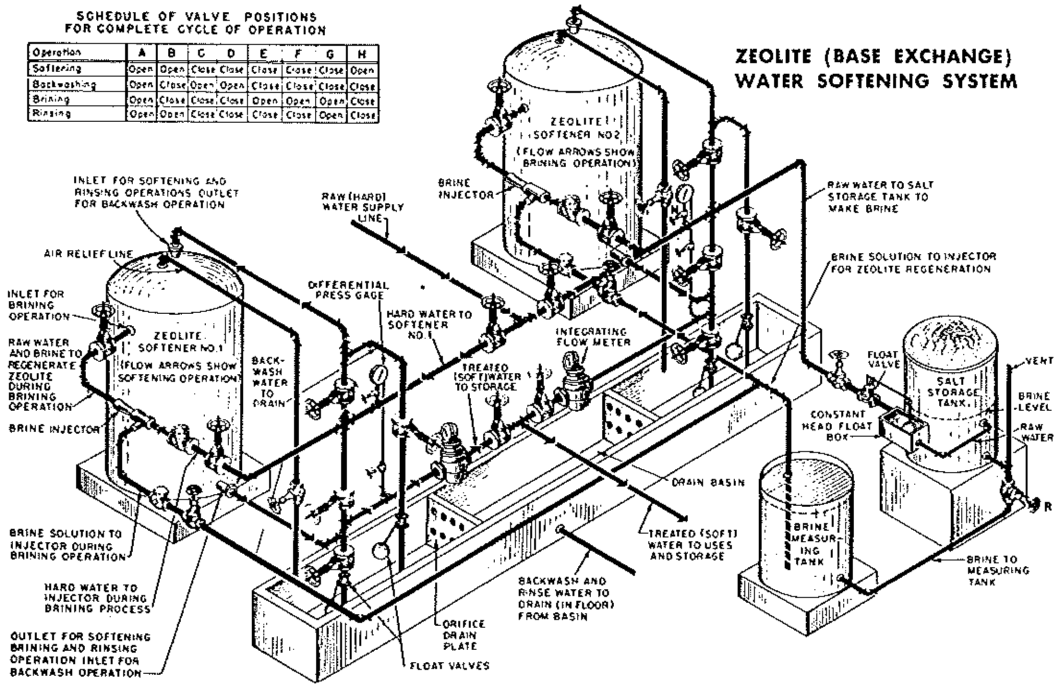


Fig. 23.20. Typical meter connections. Courtesy Jenkins Bros., manufacturers of valves.



SCHEDULE OF VALVE POSITIONS FOR COMPLETE CYCLE OF OPERATION

Operation	A	B	C	D	E	F	G	H
Softening	Open	Open	Close	Close	Close	Close	Close	Open
Backwashing	Open	Close	Open	Open	Close	Close	Close	Close
Brining	Open	Close	Close	Close	Open	Open	Open	Close
Rinsing	Open	Open	Close	Close	Close	Close	Open	Close

Fig. 23.21. Typical water-softening system layouts. Courtesy Jenkins Bros., manufacturers of valves.

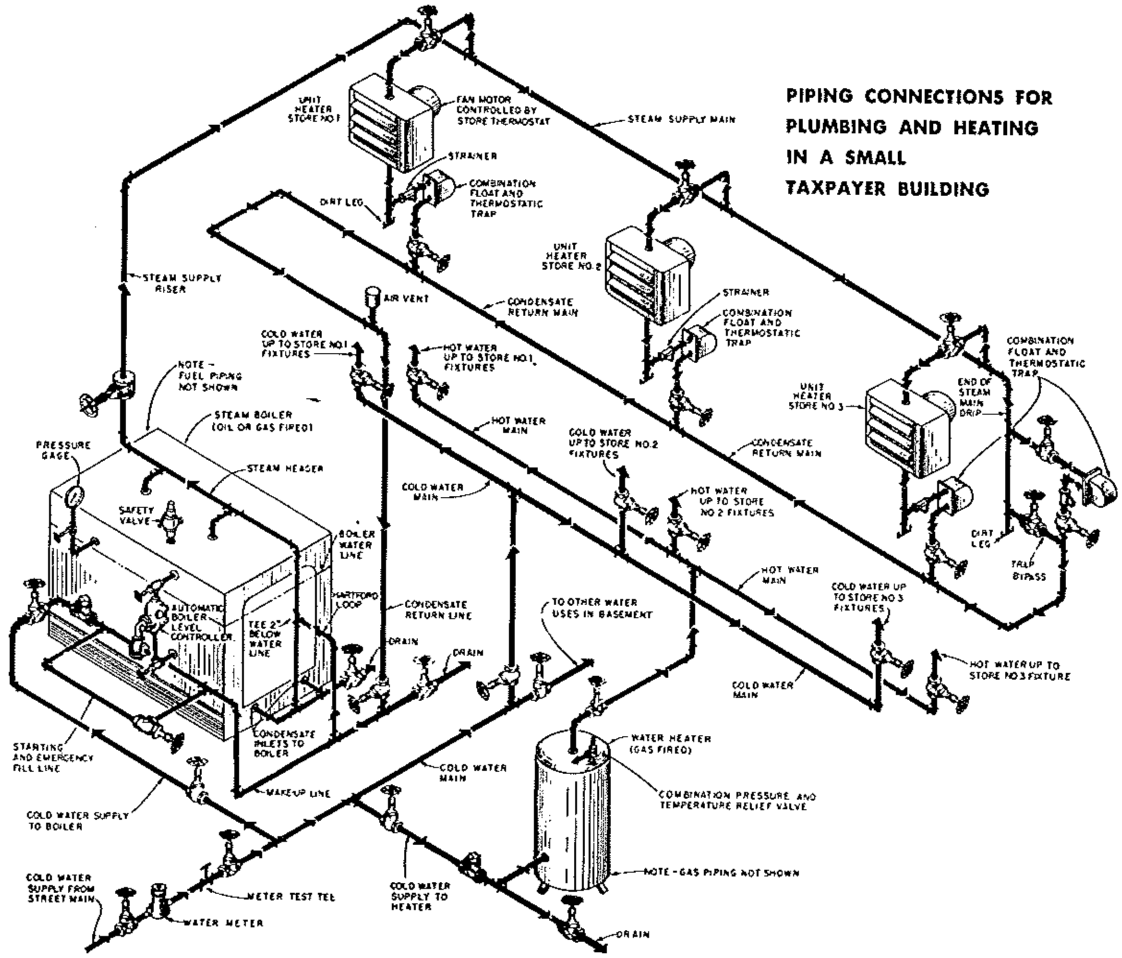


Fig. 23.22. Typical piping layout for plumbing and heating. Courtesy Jenkins Bros., manufacturers of valves.

Machine Drawing 24

24.1 In the design of any mechanism certain elements are always involved in the transmission of motion. Exclusive of linkages of various types these common elements are shafts, pulleys, gears, cams, bearings and seals for them, keys, splines, and the usual fasteners. To these must be added devices for the lubrication of moving parts.

Bolts, screws, keys, and keyways have been treated in Chapter 10. Tables of sizes of these elements are given in the Appendix.

24.2 Standard or stock sizes. All the items mentioned above and many others are carried in stock by companies who specialize in producing them. When production of an item is not to be in sufficient quantity to warrant manufacture of all parts, many can be purchased from suppliers, if this is kept in mind in the original design.

24.3 Shafts. Circular steel shafts for power transmission and machine parts may be obtained, finished to close tolerances. For machine parts, stock shafts vary in size, by $\frac{1}{16}$ inch, from $\frac{1}{2}$ inch to $2\frac{1}{2}$ inches in diameter. From $2\frac{1}{2}$ to 4 inches, they vary by $\frac{1}{8}$-inch intervals. Tolerances are always negative and vary from .002 for the smaller size to .004 on the larger ones.

24.4 Pulleys. Pulleys for flat belts offer no problem for the draftsman and can be made as desired. The shape of V-belts, however, has been standardized, and the grooves in the pulleys should conform to these standards as shown in Fig. 24.1 which is taken, by permission, from the SAE *Handbook*.

24.5 Gears. Gears are used to transmit motion and power from one part of a machine to another. The motion is usually uniform, but this does not imply that the two parts thus connected have the same rates of speed. The speed ratios depend upon the relative sizes of the gears. There are many types of gears, but we shall consider here only the spur gear, the bevel gear, and the worm gear and wheel, which constitute the basic types. All these are in the process of standardization, chiefly through the activities of the American Gear Manufacturers Association and the American Standards Association.

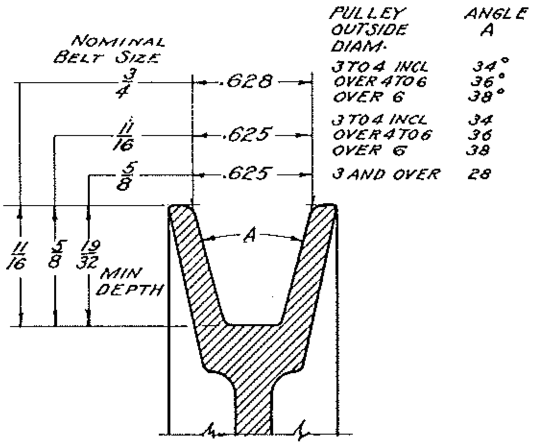


Fig. 24.1. Pulley for V-belt. Courtesy SAE.

A spur gear is simply a short hollow cylinder on which teeth have been cut, cast, or otherwise formed, with their elements (edge lines) all parallel to the axis of the cylinder. See Fig. 24.2. A bevel gear is a frustum of a hollow cone on which teeth have been cut, or cast, with their edge lines all meeting at the apex of the cone. See Figs. 24.6 and 24.7. In small gears the tooth cylinder or cone is joined to the hub by a web; on large gears by spokes or arms. A worm gear is a solid cylinder or shaft on which a continuous helical tooth has been cut to mesh with the teeth on a wheel, as shown in Fig. 24.9. The teeth on the wheel resemble those of the spur gear, but each is turned at a fixed angle relative to the plane of the axis of the wheel and the center of the tooth.

The smaller of two meshing spur or bevel gears is called a pinion. See Fig. 24.2. The minimum number of teeth on a pinion is limited by common practice to 12. When gear teeth are formed on a straight

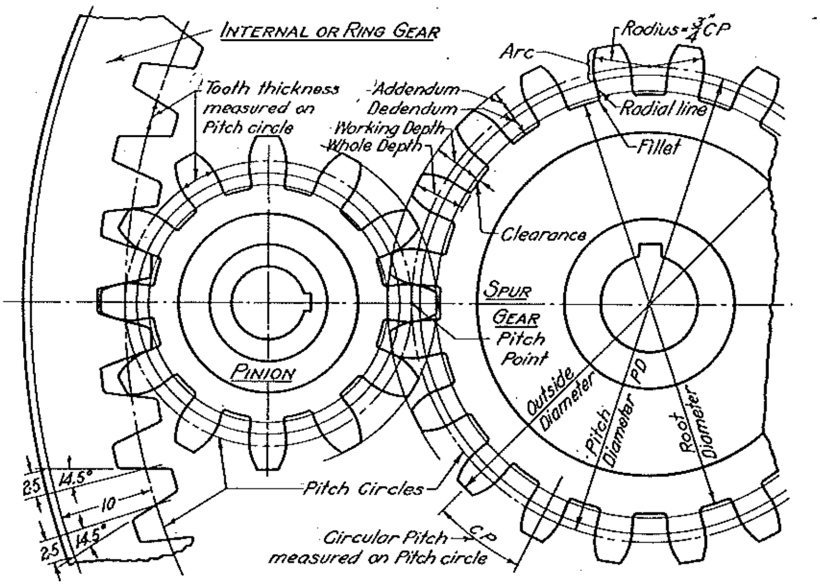


Fig. 24.2. Spur, pinion, and ring gear.

thick bar or plate, the product is called a rack. See Fig. 24.4. A rack is simply a gear of infinite radius. The shape of the tooth on a rack is not the same as on the gear, being absolutely straight in the involute system. Racks and gears having the same basic tooth form will mesh properly if the linear pitch of the one is equal to the circular pitch of the other.

A complete discussion of the design and manufacture of gears would constitute a treatise in itself. Limits of space in this book permit the presentation of only such elements of description and design as will enable the draftsman to represent properly the simpler gear types on shop drawings.

24.6 Spur gears—definition of terms and formulas. In order to make drawings of gears or to understand any discussion concerning them, the meaning of certain common terms must be understood. These are defined below and illustrated in Figs. 24.2 and 24.3. In the following formulas, N represents the number of teeth in a gear.

Pitch Circle. If two gears are in mesh, their pitch circles represent two cylinders in contact which would have the same motion as the gears, provided the cylinders do not slip.

Diametral Pitch. The number of teeth per inch of pitch diameter. $DP = N/PD$.

Pitch Diameter. The diameter of the pitch circle. $PD = N/DP$.

Circular Pitch. The distance between the centers of two consecutive teeth measured on the pitch circle. $CP = (PD \times 3.1416)/N$ or $3.1416/DP$.

Addendum. The radial distance from the pitch circle to the top of the tooth. $A = 1/DP$.

Dedendum. The radial distance from the pitch circle to the bottom of the tooth space. $D = 1.157/DP$.

Clearance. The distance between a tooth and the bottom of its engaging space. $C = .157/DP$.

Working Depth. The distance a tooth penetrates a space. It is equal to twice the addendum.

Whole Depth. The working depth plus the clearance. $WD = 2.157/DP$.

Tooth Thickness. The thickness of the tooth measured along the pitch circle. $TT = 1.57/DP$ or $CP/2$.

Chordal Thickness. The thickness of a tooth measured along a chord of the pitch circle. $CT = PD \sin (90°/N)$.

Distance between Gear Centers. $(N_1 + N_2)/2DP$.

Outside Diameter of Gears. $(N + 2)/DP$.

Base Circle. The circle from which the involute curve is formed.

Pressure Angle. The angle between the common perpendicular to two involute gear tooth profiles in contact and the normal to their center line.

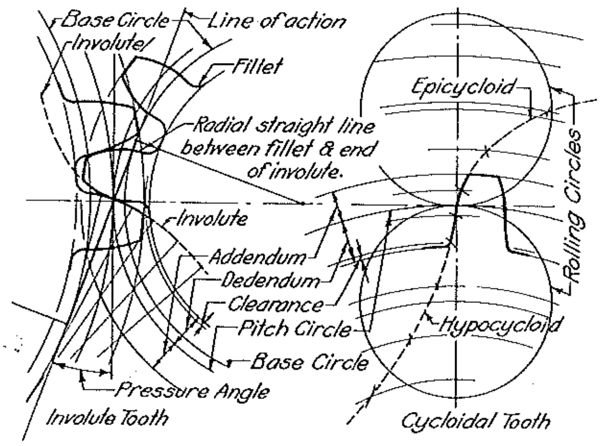


Fig. 24.3. Gear tooth curves or profiles.

To find the pitch diameters of two meshing gears when the distance between centers is known and the number of teeth is known:

$$(PD)_1 = [(2CD)/(N_1 + N_2)]N_1$$

$$(PD)_2 = [(2CD)/(N_1 + N_2)]N_2$$

24.7 Tooth forms in spur gearing and racks. Both the involute and cycloidal systems of tooth profiles are in use, but for many years the involute system has practically replaced the other. Both are illustrated in Fig. 24.3. The profiles shown are theoretically those obtained by the usual geometrical construction of the involute, the epicycloid, and the hypocycloid curves. Actually the profiles are close approximations to these curves, slight modifications being made in cutting the teeth to take care of interference and for consideration of strength. Circles are used on the drawings in place of curves.

Figure 24.4 illustrates two important departures from the older tooth forms, in the 14½° composite and 20° stub tooth systems which have become tentative American Standards. The latter of these systems is not widely used. Gears made with either one of these standards and having the same diametral pitch are interchangeable with each other but not as

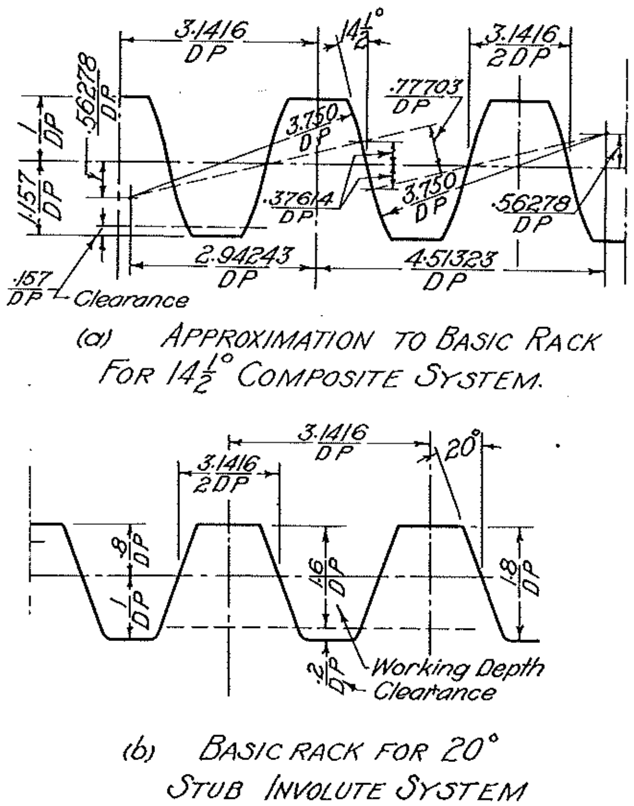


Fig. 24.4. Standard basic racks.

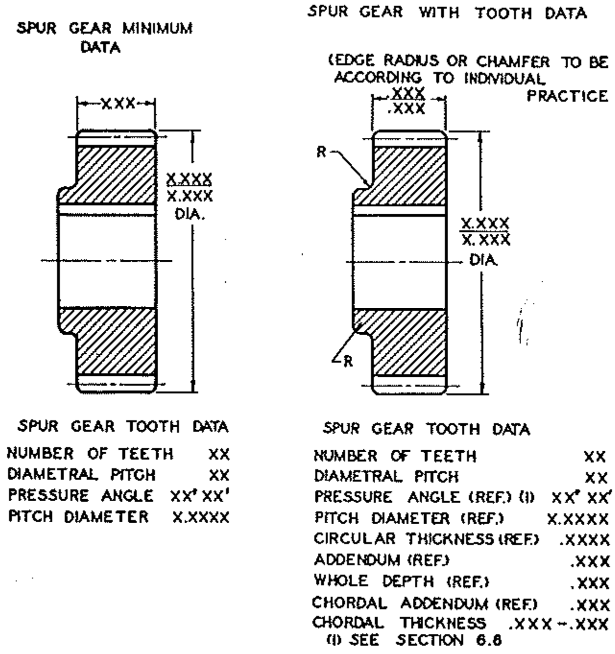


Fig. 24.5. Working drawing of spur gear.

between one standard and the other. Each has elements of simplicity both in drawing and cutting the teeth, since only the involute and cycloid are used in the composite tooth profiles and straight lines in the stub tooth profiles. Each is stronger than the older types. Close approximation to the actual tooth shape, for drawing purposes, is obtained, in the composite system, by using circles for the cycloids as shown in Fig. 24.4(*a*). When composite or stub teeth are cut on spur gears, the tooth proportions on page 24-04 are used.

24.8 Working drawings of spur gears. The working drawings of gears which are to be cut from blanks are very simple. The drawing itself and the dimensions upon it give information only about the gear blank. Information concerning the teeth is usually given in the form of notes, as illustrated in Fig. 24.5. If the gear is small and therefore has a solid web instead of arms, only the sectional view need be drawn. See drawing of pinion in Fig. 24.5. For the design of gear teeth it is recommended that the following American Standards be consulted: ASA–B6.1, ASA–B6, ASA–B6.7, and ASA–B6.8.

24.9 Assembly drawings of spur gears. In assembly drawings, especially those intended for display purposes, it is sometimes desirable to represent the gear-teeth profiles. A very simple approximate method which is suitable for all diametral pitches and pitch diameters is shown in Fig. 24.2. First draw the addendum, pitch, clearance, and dedendum circles.

TOOTH PROPORTIONS FOR SPUR GEARS

	Composite System		Stub System	
	In Terms of Diametral Pitch (Inches)	In Terms of Circular Pitch (Inches)	In Terms of Diametral Pitch (Inches)	In Terms of Circular Pitch (Inches)
1. Addendum	$\frac{1}{DP}$	$0.3183 \times CP$	$\frac{0.8}{DP}$	$0.2546 \times CP$
2. Minimum dedenum	$\frac{1.157}{DP}$	$0.3683 \times CP$	$\frac{1}{DP}$	$0.3183 \times CP$
3. Working depth	$\frac{2}{DP}$	$0.6366 \times CP$	$\frac{1.6}{DP}$	$0.5092 \times CP$
4. Minimum total depth	$\frac{2.157}{DP}$	$0.6866 \times CP$	$\frac{1.8}{DP}$	$0.5729 \times CP$
5. Pitch diameter	$\frac{N}{DP}$	$0.3183 \times N \times CP$	$\frac{N}{DP}$	$0.3183 \times N \times CP$
6. Outside diameter	$\frac{N+2}{DP}$	$0.3183 \times (N+2) \times CP$	$\frac{N+1.6}{DP}$	PD + (2 Addendum)
7. Basic tooth thickness on pitch line	$\frac{1.5708}{DP}$	$0.5 \times CP$		
8. Minimum clearance	$\frac{0.157}{DP}$	$0.5 \times CP$		

Then space off the teeth on the pitch circle in the usual manner, using one-fourth the circular pitch, or one-half the tooth thickness, in doing so. With a radius equal to three-fourths of the circular pitch and centers on the pitch circle, draw arcs from the addendum circle to a point below the pitch circle, where a radial line will be tangent to the arc. A circle can then be drawn lightly which will mark the lower limit of the tooth arcs. From this circle on into the clearance circle, draw radial lines, and then put in the fillet at the bottom of the tooth. It must be understood, of course, that this is only a convenient conventional scheme and does not represent the actual shape of the gear teeth. A note will indicate the type of teeth wanted.

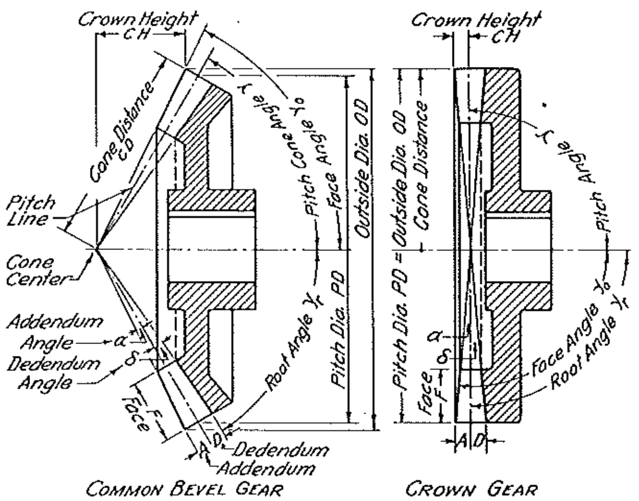


Fig. 24.6. Bevel gear types and terms.

The rack is usually represented in conventional form with the sides of the tooth straight, except for the fillet at the bottom, as shown in Fig. 24.4.

The 14½° and 20° angles for the composite and stub tooth can be readily laid off by using the tangents which are practically .25 and .36, respectively.

The teeth of internal gears are also represented with straight sides of the proper slope, as shown in Fig. 24.2. One type of internal gear tooth is actually made in this form.

24.10 Bevel gears. Bevel gears require the definition of a few new terms, the meanings of which are illustrated on the two common types of gears shown in Fig. 24.6. The equations for computing the value of these terms are given below. The terms and values are the same for all types of bevel gears.

Addendum (A) at large end is the same as spur gears having the same diametral pitch.

Dedendum (D) at large end is the same as for spur gears having the same diametral pitch.

Addendum angle (α), $\tan AA = A/PCR$.

Dedendum angle (δ), $\tan DA = D/PCR$.

Pitch cone radius or cone distance, $CD = PD/2 \sin \gamma$.

Cutting angle, $(\gamma_r) = \gamma - \delta$.

Face angle, $\gamma_0 = \gamma + \alpha$.

Outside diameter, $OD = PD + 2A \cos \gamma$.

Crown height, large end, $CH = OD/2 \tan FA$.

Face (F) must be less than ⅓ CD.

Number of teeth, from which to select cutter, $N' = N/\cos \gamma$.

Center angle (Σ) is the angle between the axes of the shafts of meshing gears.

The following values vary for different gears and for different center angles, as indicated in the table. The subscript (p) denotes pinion, and the subscript (g) the larger of two meshing gears.

	Acute Angle between Shaft Axes	Right Angle between Shaft Axes	Crown Gear	Obtuse Angle between Shaft Axes
Pitch cone angle (pinion)	$\tan \gamma_p = \dfrac{\sin \Sigma}{\dfrac{N_g}{N_p} + \cos \Sigma}$	$\tan \gamma_p = \dfrac{N_p}{N_g}$	$\sin \gamma = \dfrac{N_p}{N_g}$	$\tan \gamma_p = \dfrac{\sin (180° - \Sigma)}{\dfrac{N_g}{N_p} - \cos (180° - \Sigma)}$
Pitch cone angle (gear)	$\tan \gamma_g = \dfrac{\sin \alpha}{\dfrac{N_p}{N_g} + \cos \alpha}$	$\tan \gamma_g = \dfrac{N_g}{N_p}$	$\gamma_g = 90°$	$\tan \gamma_g = \dfrac{\sin (180° - \Sigma)}{\dfrac{N_p}{N_g} - \cos (180° - \Sigma)}$

24.11 Working drawings of bevel gears. Working drawings of bevel gears are usually made with only one view, unless the gear is of such size as to require a wheel with spokes, in which case two views with interpolated sections will be necessary. One view is always a full section, as illustrated in Fig. 24.7. As in spur gears, the dimensions on the drawing are for the gear blank, and the data for cutting the teeth are given in the form of notes. The actual dimensions and the cutting data given will depend upon the method of cutting the gears and will be determined by the shop in which the gears are made. Either front or rear face is used as the base for setting the gear blanks in the cutting machines, and hence the distance from the front or rear to the outside of the top of the tooth should always be specified in order that all gear blanks may be alike.

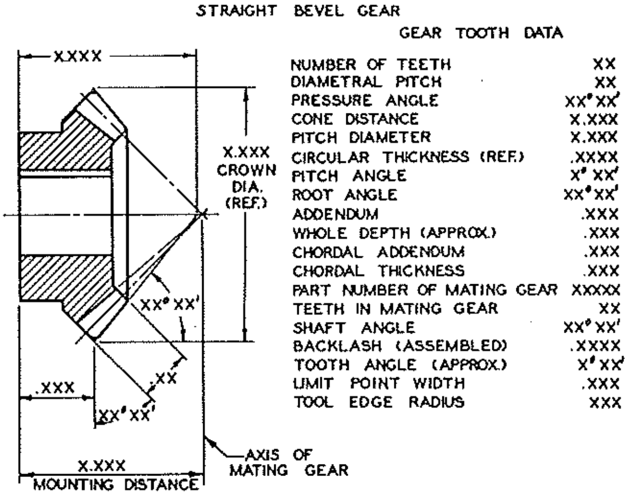


Fig. 24.7. Working drawing of bevel gear.

24.12 Assembly drawing of bevel gear teeth. In assembly drawings for display or advertising purposes, it is necessary to represent the actual gear teeth. The following conventional scheme is based upon Tredgold's approximation, which consists of drawing the gear teeth upon a development of the back cone, as illustrated in Fig. 24.8.

To make this construction, first draw the pitch cone axis and mark its intersection with the pitch diameter; draw the back cone axis at right angles to the pitch cone axis, and then locate the apex of both cones as shown in the figure. Locate addendum and dedendum points on the back cone axis, using the standard spur-gear formulas. With the back cone apex as a center, draw the developed arc of the addendum, pitch, and dedendum circles (A, PC, and D). On these arcs lay out a tooth profile by the conventional method for spur gears.

On the front view of the gear, draw the usual three layout circles for both the large and the small ends of the tooth. On the large end, lay out the dimensions of the tooth x and y, as indicated in Fig. 24.8.

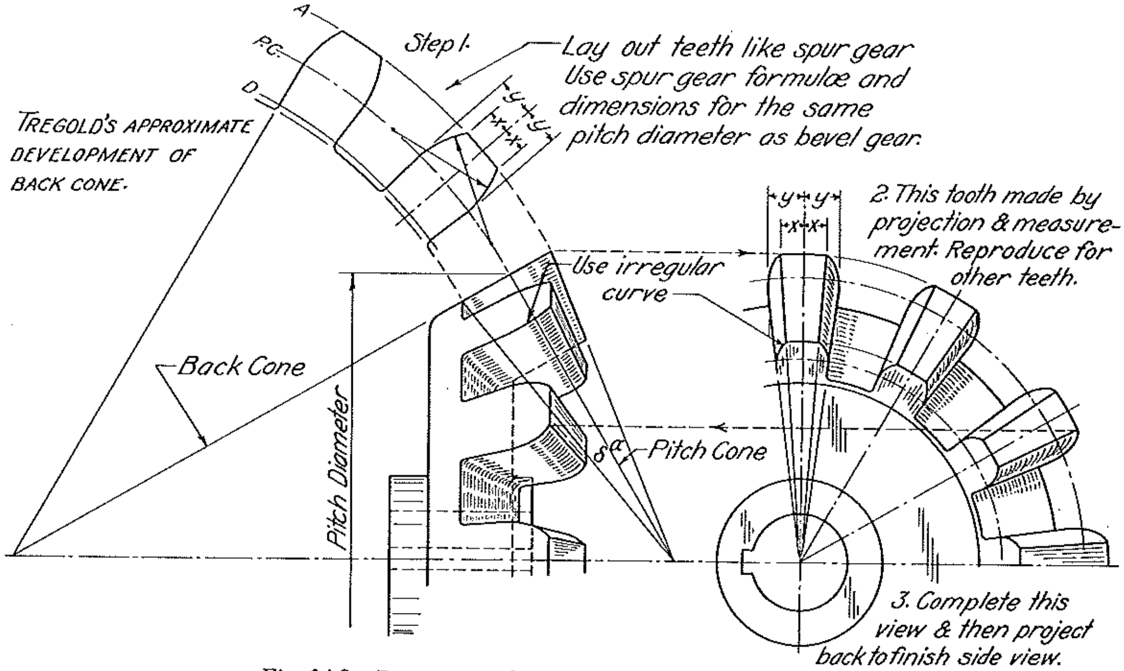


Fig. 24.8. Representing bevel gears in assembly drawings.

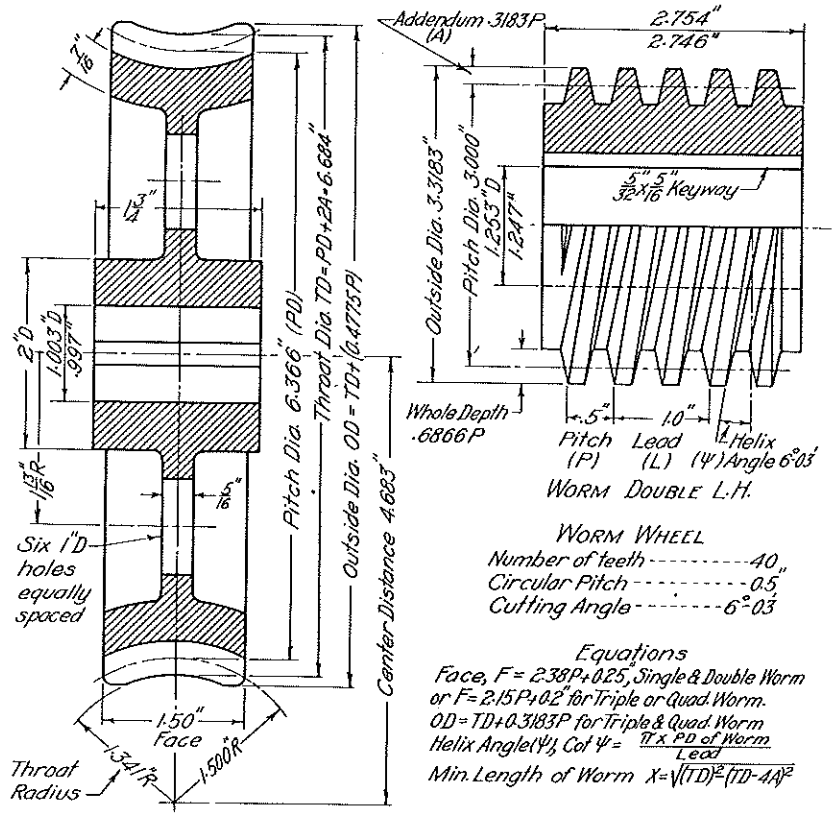


Fig. 24.9. Working drawing of worm gear and wheel.

Radial lines from these points will locate the corresponding points at the small end of the tooth. The curved outlines through the three points are best drawn in with an irregular curve. Lay out all teeth in the front view in the same way. The side view is then determined by projecting from the front view and locating the same three points as before to determine the tooth curve in each case. In the side view, each tooth curve is a little different from the others except for symmetrically placed teeth which, of course, are alike. In the front view, the draftsman must be careful to use the same part of the irregular curve for each tooth so that they will all look alike. This will be found much easier to do, however, than attempting to draw circular arcs with the compass.

24.13 Worm gear and wheel. The worm gear and wheel find wide application in the transmission of power when a large speed ratio is desired. The teeth on the worm are based on the standard involute rack which has straight sides with the 14½° slope. The meanings of new terms applying to these gears are illustrated in Fig. 24.9, and the equations for computation are also shown in this figure. Others may be determined from the figure by ordinary trigonometric formulas. In the worm gear the terms linear pitch and lead have the same meaning as they do for screw threads. The linear pitch of the worm is equal to the circular pitch of the wheel.

In practice it is desirable to have thirty or more teeth in the wheel in order to avoid interference. The efficiency varies with the thread angle, with a theoretical maximum of about 45° For thread or helix angles greater than about 15°, the dimensions of the thread must be based on a section at right angles to the helix. The pitch at right angles to the helix is called the normal pitch, and is equal to the pitch multiplied by the cosine of the helix angle. This value of the normal pitch should then be substituted in the equations for tooth dimensions.

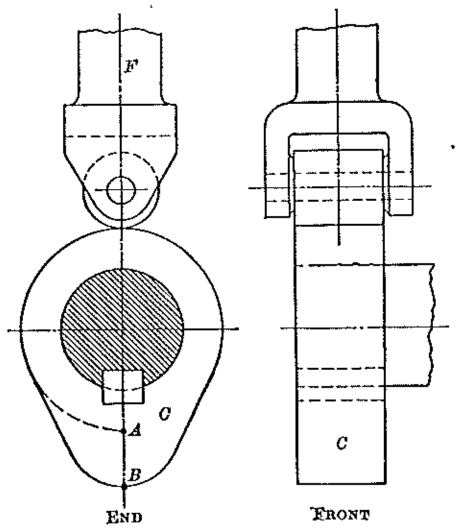


Fig. 24.10. Radial single-acting cam. (After Furman.)

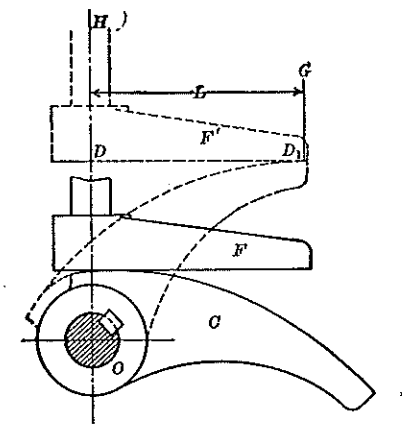


Fig. 24.11. Single-acting cam. (After Furman.)

24.14 Working drawings of worm gears and wheel. As with other gears, a one-view drawing will suffice for both the worm and the wheel unless the spokes of the wheel make two views essential. For the wheel, one view is a full section, whereas for the worm it may be either a half or full section. The dimensions on the drawings are for the gear blank; the cutting information is given in notes, as shown in Fig. 24.9.

24.15 Cams. A cam is a mechanism or device in a machine for transmitting a type of motion to another part of the machine that could not readily be transmitted by gears, linkages, and the like. The motion of the cam is usually rotational, being mounted on a shaft like a gear or pulley and turned by the same primary power source. See Figs. 24.10, 24.12, and 24.13. Some cams have an oscillating motion, as shown in Fig. 24.11. The cam has a specially cut periphery or track in its face surface with which a device called a follower is kept in contact. Roller contact between the follower and the cam is desirable on account of the reduction in friction between the two parts. The motion of the follower may be in a straight or curved line, depending upon the guides in which it slides or the rocker arms on which it is mounted. Also the motion of the follower may be continuous or intermittent as the needs of a particular case may require, and it may be uniform or variable in velocity in each separate phase of its action. In many cam designs, the follower remains at rest over a considerable part of the rotation of the cam. These various qualities and relationships of cams and followers are brought out more clearly in the several illustrations of typical cams of Figs. 24.10 to 24.13, inclusive.

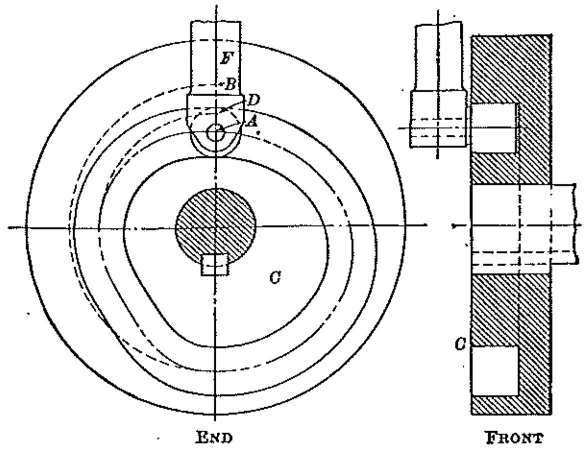


Fig. 24.12. Radial, double-acting, face or plate groove cam. (After Furman.)

The cam of Fig. 24.10 is called a radial cam because the follower edge or roller always moves in a radial direction with respect to the cam. The cam of Fig. 24.13 is called a side or cylindrical cam because the action of the follower roller is parallel to the axis of the cam. There are also conical, spherical, and other types of cams, not illustrated in the figures, which usually actuate roller followers mounted on swinging arms. The cam of Fig. 24.12 with the follower groove or track cut in the flat surface of the cam disk is called a face or plate groove cam. Similarly, if the follower track is cut into the surface of a cylinder, the cam is called a cylindrical groove cam.

The positive control of the movement of the follower by the cams of Figs. 24.10 and 24.11 is in one direction only, a spring or weight being relied upon to bring the follower back into starting position at the end of each revolution or stroke. This type of cam is called single acting. The cams of Figs. 24.12 and 24.13 are called double acting because they control the action of the follower throughout the entire rotation of the cam. If the rise of the follower is continuous from the beginning to the end of its stroke, it is said to be a one-step cam. If the rise is broken into two parts by a period of rest, it is said to be a two-step cam.

24.16 Empirical cam design. The technical design of cams involves not only the total range of motion imparted to the follower by the cam and the so-called pressure angle but also the elements of velocity and acceleration in the follower, elements which can be controlled in shaping the cam. Consideration of the last two factors is beyond the scope of this book. Empirical design, however, in which only range of motion and some phases of the pressure factor are considered, is not a difficult matter, and, with some degree of experience, satisfactory designs can be made on this basis.

24.17 Cam base curves. The first step in making a working drawing of a cam is to construct the so-called base curves. Their functions will be developed in the next article. Four common base curves used in cam design are shown in Fig. 24.14. The straight line gives a shock to the follower, and hence its beginning and end must have a transition curve which is given a radius equal to the rise, if the curve extends 360°. If the rise occupies less distance, the radius is shortened proportionally. See Fig. 24.15.

The crank curve gives simple harmonic motion with a uniformly changing velocity and acceleration. The parabolic curve gives a constant acceleration and deceleration and a uniformly increasing and decreasing velocity, increasing to the center of the curve and then decreasing. The elliptical curve gives variable velocities and acceleration, but it is slower in the starting and stopping portions and faster in the central portion than some of the other curves.

24.18 Drawing cams. The second step in making a working drawing of a cam is the construction of the cam chart. The third step is the construction of the cam working surface. These two steps are developed together below.

Let it be required to draw the cam curve according to the requirements given in the upper left-hand corner of Fig. 24.15. Draw first the cam chart, as in Fig. 24.15, using the different types of curves as specified in the problem for the rise and fall of the follower. The chart should be to scale vertically, but it may have

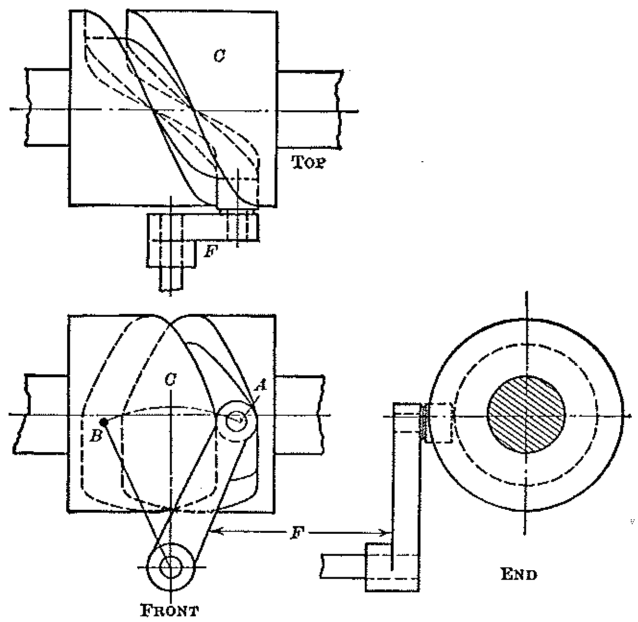


Fig. 24.13. Side or cylindrical, double-acting cam. (After Furman.)

any convenient length to represent 360°. The length is then subdivided according to problem requirements. The various curves are drawn as shown.

The drawing of the cam curve consists in obtaining the line on which the center of the follower roller will run as the cam turns, called the pitch surface, and, from this line, the working surface line, which determines the surface on which the follower roller, or edge line, runs. See Fig. 24.16. If no attention is given to the pressure angle, a radius OA may be arbitrarily chosen for the pitch circle and the pitch surface may then be constructed from it by dividing the circle into the same proportional parts as the cam chart, Fig. 24.16. If the pitch circle is made to the same scale as the rise, AG, of the cam chart in Fig. 24.15, then the ordinates to the base curve, measured up and down from the pitch line, may be laid off in a corresponding manner, out and in from the pitch circle, thus locating points on the pitch surface. A smooth curve is drawn through these points.

If a point follower is to be used, the pitch surface becomes the working surface and the design is complete. A working drawing showing the hub, bore, keyway, and cam curve may then be made in the usual way.

If a roller follower is to be used, the size of the roller may be arbitrarily selected so long as its radius is less than the least radius of curvature of the pitch surface. The working surface is then determined by drawing a series of arcs with centers on the pitch surface and a radius equal to the roller radius, as shown in the upper part of Fig. 24.16. The working surface curve is then drawn tangent to these circles. A working drawing may then be made as before.

If the limitation of a maximum pressure angle is to be observed, then the radius of the pitch circle must be computed by the equations shown at the top of Fig. 24.16. The terms d, a, and b are given in the problem data; the pressure angle factor p may be obtained from the chart in Fig. 24.17.

If a cam has but one step, the pitch circle is drawn with the radius computed and the rest of the construction then follows as described before.

If the cam has more than one step, a pitch circle radius can be computed for each step. The pitch line must then be adjusted so that the pitch circle radius is equal to the largest computed radius. The computations for the three steps of the cam of Fig. 24.16 are as follows:

Step one, 3 units.

$$R_1 = \frac{57.3 \times 3 \times 2.72}{60} = 7.77$$

Step two, 6 units.

$$R_2 = \frac{57.3 \times 6 \times 2.27}{90} = 8.66$$

Step three, 9 units.

$$R_3 = \frac{57.3 \times 9 \times 3.46}{90} = 19.8$$

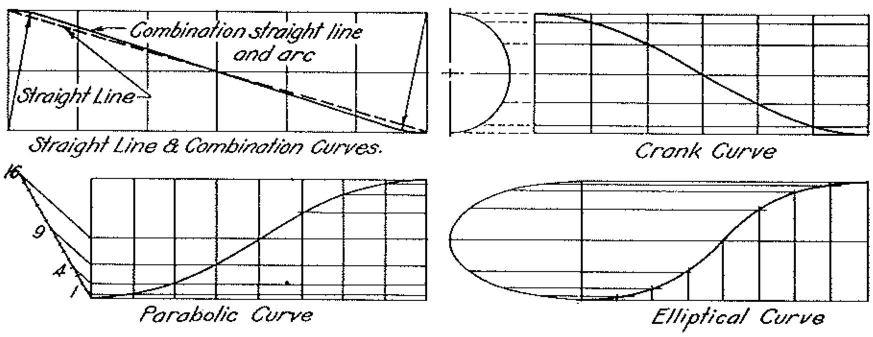


Fig. 24.14. Basic cam curves.

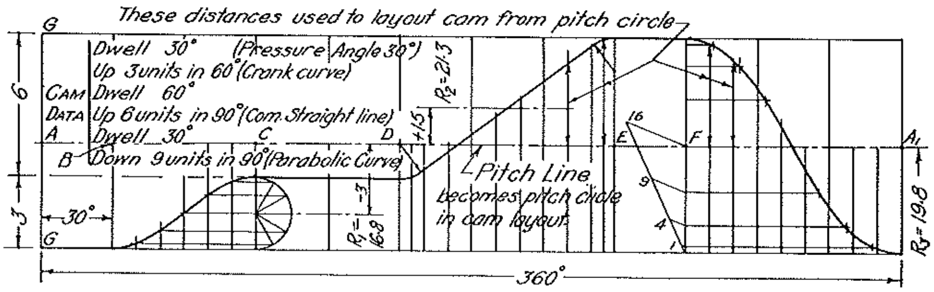


Fig. 24.15. Layout of a two-one step cam chart.

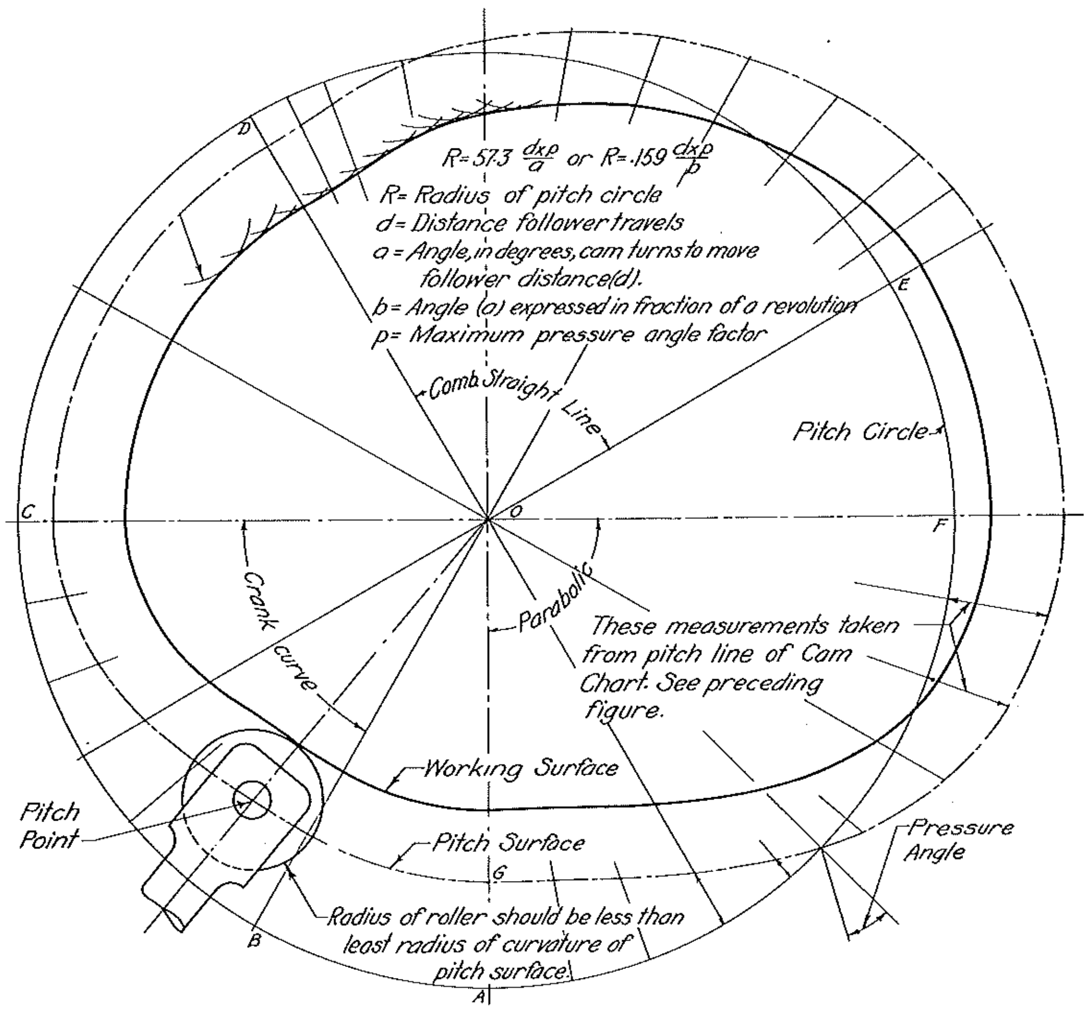


Fig. 24.16. Cam layout for base curve shown in Fig. 24.15.

If the largest radius for the parabolic section is used as a trial pitch circle, then it can be observed that this circle, being larger than that required by the other two equations, will be satisfactory since it keeps the pressure angle within the limits specified. The largest pitch radius, $R_3 = 19.8$, is therefore used, and the construction carried out as described before.

24.19 Bearings. All rotating parts of machinery are supported in bearings. There are many kinds, and all of them have elements of design beyond the scope of this book. The design of antifriction bearings is a field of specialization in itself. The material here presented consists of those matters which the young engineer should know in representing bearings on drawings.

24.20 Journal or sleeve bearings. Bearings in which the shaft is enclosed by a continuous metal surface in metal-to-metal contact except for clearance and oil films are called sleeve or journal bearings. The shaft is usually made of steel, and the bearing support is lined with Babbitt metal or bronze bushings. Such bearings are shown on drawings as illustrated in Fig. 24.18(a). On schematic layouts, any type of bearings may be shown as in Fig. 24.18(b).

Unless sleeve bearings are of the oil-impregnated type, they must be provided with oil grooves and

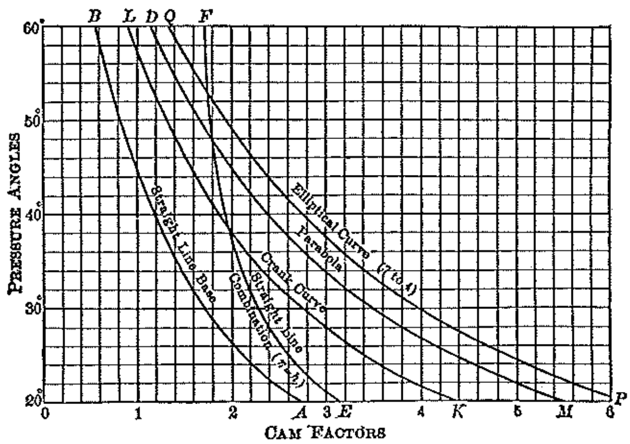


Fig. 24.17. Cam factors. (After Furman.)

some means of supplying oil. Under certain conditions they must be protected from dust and dirt by shields or seals. For various types of shields and seals the student is referred to manufacturers' catalogues. Bronze bushings are usually press fitted.

24.21 Antifriction bearings. Although all bearings have some frictional resistance, ball, roller, and needle bearings are commonly classified as antifriction bearings since the friction has been reduced to a minimum. The material presented here shows the method of representing bearings and a few illustrations of methods of holding them in place. Information concerning the dimensions of a very limited number of smaller-size bearings is given in the Appendix.

Ball bearings are made in a variety of styles and sizes for different purposes. A few of these are shown in Fig. 24.19. The medium, light, and extra light can

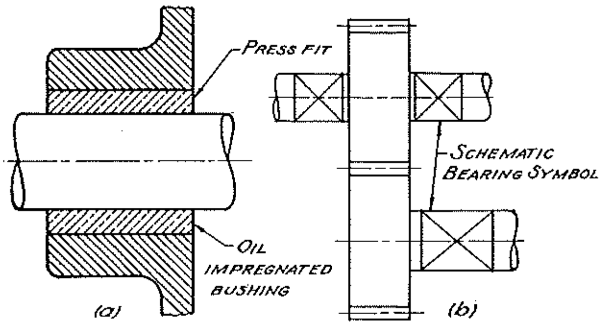


Fig. 24.18. Schematic bearing symbols.

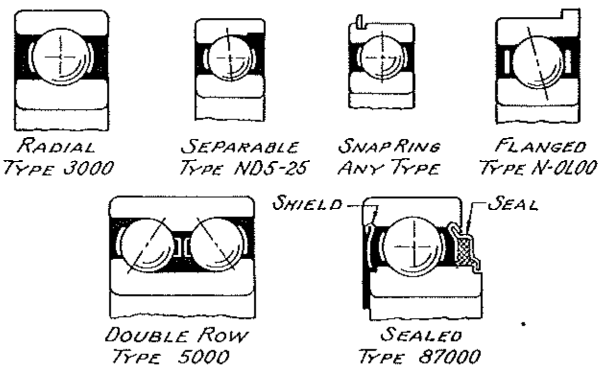


Fig. 24.19. Ball bearing symbols. Courtesy New Departure Division of General Motors.

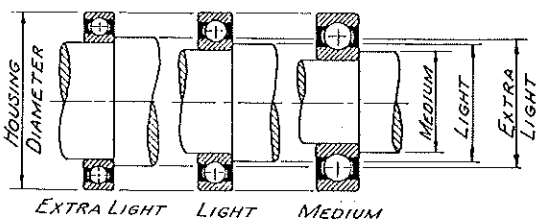


Fig. 24.20. Ball bearing housings. Courtesy New Departure Division of General Motors.

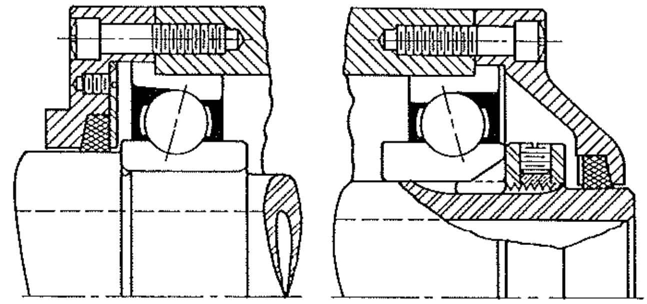


Fig. 24.21. Ball bearing mountings. Courtesy New Departure Division of General Motors.

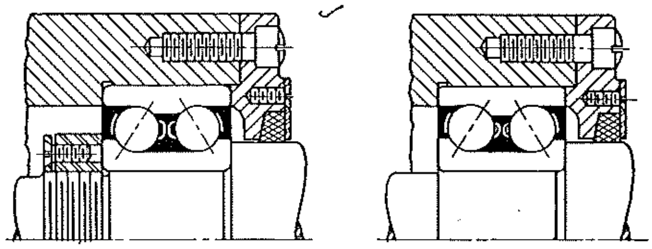


Fig. 24.22. Ball bearing mountings. Courtesy New Departure Division of General Motors.

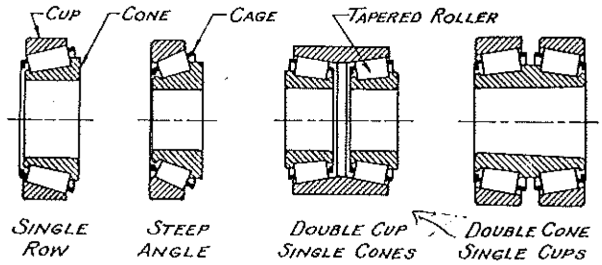


Fig. 24.23. Roller bearing mountings. Courtesy Timken Roller Bearing Co.

be used in different situations to accommodate larger shafts within limited housing dimensions, as shown in Fig. 24.20, when load conditions permit. A few methods of mounting these bearings are shown in Figs. 24.21 and 24.22. Many companies provide full-scale and half-scale sectional drawings of their bearings which can be removed from a loose-leaf catalogue and placed under a drawing on paper or cloth, and traced. This saves a great deal of time. When press fits are used on either shafts or housing, these must not be so tight as to affect the clearance provided in the bearing.

Roller bearings are of two kinds, namely, those having cylindrical rollers and those having tapered or conical rollers. The inner race of tapered bearings are parts of cones and are called cones. The outer race is called the cup and is also cone shaped. Several types of roller bearings taken from the *Timken Roller Bearing Handbook* are shown in Fig. 24.23.

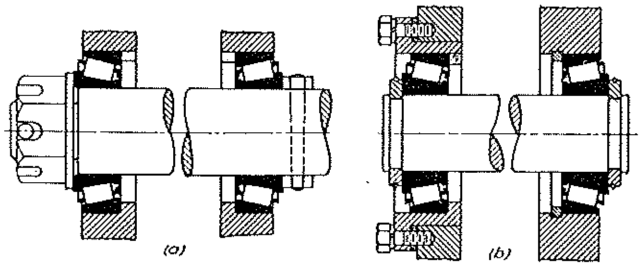


Fig. 24.24. Roller bearing mountings. Courtesy Timken Roller Bearing Co.

Several methods of mounting these bearings are shown in Fig. 24.24. In Fig. 24.24(a), the cone backing is obtained by a collar pinned to the shaft. The bearing adjustment is obtained by the castellated nut at the other end of the shaft. The cup is supported by a shoulder in the housing which is provided with knock-out grooves for removing the bearing as shown at the top of the figure.

In Fig. 24.24(b), one bearing is supported in a carrier with shoulders. An accurately ground spacer is used between the carrier and housing to obtain adjustment. Split rings with wire clamping rings to hold them in place support the cones at both ends of the bearing. At the right end, a snap ring supports the cup.

Problems

The following problems are intended only for students who are well grounded in the principles of drawing. Therefore, no directions are given as to scale, choice of views, or arrangement. In some problems, considerable latitude for the exercise of common sense and judgment has been allowed, and it is intended that the student get the exercise with as little help from the instructor as possible.

Tooth Profiles

1. Draw a 1 *DP* cycloidal gear tooth on a pitch circle of 5″ radius. Construct the tooth profile curves on one side and complete one tooth. The diameter of the rolling circle shall be one-half that of the pitch circle for a 12-tooth pinion. Mark all circles and curves having specific names.
2. Same as Problem 1. Use a 2 *DP* tooth.
3. Draw a 1 *DP* involute tooth on a pitch circle of 6″ radius and having a 20° pressure angle. Construct the tooth profile on one side, and complete one tooth. Mark all circles and curves having specific names.
4. Same as Problem 3. Use a 2 *DP* tooth.

Spur Gears

5. Make a working drawing of the gear shown in Fig. 24.25.
6. Same as Problem 5, Fig. 24.26.
7. Same as Problem 5, Fig. 24.27. (Note this is a special type of bevel gear.)
8. Same as Problem 5, Fig. 24.28.
9. Make a working drawing of a gear assigned from Fig. 24.29. The drive gear *A*, when meshed with the right part of double gear *C*, turns the lower shaft in one direction. When *A* is shifted to the left and meshed with *B*, since *B* is always meshed with the left part of *C*, *A* turns the lower shaft in the opposite direction.
10. Make a complete set of details for the speed-changing device shown in Fig. 24.29.
11. Make a copy of the assembly drawing shown in Fig. 24.30.

Bevel Gears

12. Make a working drawing of the large bevel gear assigned from Fig. 24.30. Gears *A* and *B*, with their respective clutch jaws, are free to revolve upon the drive shaft which is keyed to the central clutch jaw *C*. The clutch *C* may be shifted to engage either gear *A* or *B*, thus changing the direction of rotation of the gear *D* and its shaft. The handle for shifting the clutch should have some device for locking the clutch in any one of its three positions.
13. Same as Problem 12. Pinion gear, Fig. 24.30.
14. Make a complete set of details of the reversing mechanism shown in Fig. 24.30.
15. Make a copy of the assembly drawing shown in Fig. 24.30.

Worm Gear and Wheel

16. Make a working drawing of the worm gear and wheel shown in Fig. 24.31.
17. Same as Problem 16, Fig. 24.31. Change to double worm.
18. Make a complete set of details of the object shown in Fig. 24.31.

Cams

19. Draw the cam chart, and lay out the cam curve for a cam whose follower moves radially as follows: up 2″ on a crank curve base line in 90°; dwell 120°; down 2″ on a crank curve in 60°; dwell 90″. Use a pitch circle of 3½″ radius, select size of roller followers.
20. Same as Problem 19. Use a combination straight-line base curve.
21. Same as Problem 19. Use a parabolic base curve.
22. Same as Problem 19. Compute pitch circle radius for a 30° maximum pressure angle.
23. Draw the cam chart, and lay out the cam curve for a cam whose follower moves radially as follows: up 1″ in 45°; dwell 45°; up 1½″ in 90°; dwell 30°; down 1¼″ in 45°; dwell 30°; down 1¼″ in 45°; dwell 30°. Use a crank curve on first two steps and a parabolic curve on the last two. Pitch circle 4″ radius for second step, select size of roller follower.
24. Same as Problem 23. Use combination straight-line curve throughout.
25. Same as Problem 23. Compute pitch circle radius for 45° maximum pressure angle.
26. Draw a cam chart, and lay out the cam curve for a roller follower which moves as follows: up 1″ in 60°; dwell 30°; up 1¼″ in 75°; dwell 15°; down 2¼″ in 120°; dwell 60°. Pitch radius 4″ for last step. Select size of roller.
27. Same as Problem 26. Compute the pitch circle radius for a maximum pressure angle of 30°.
28. Same as Problem 26. Maximum pressure angle 45°.

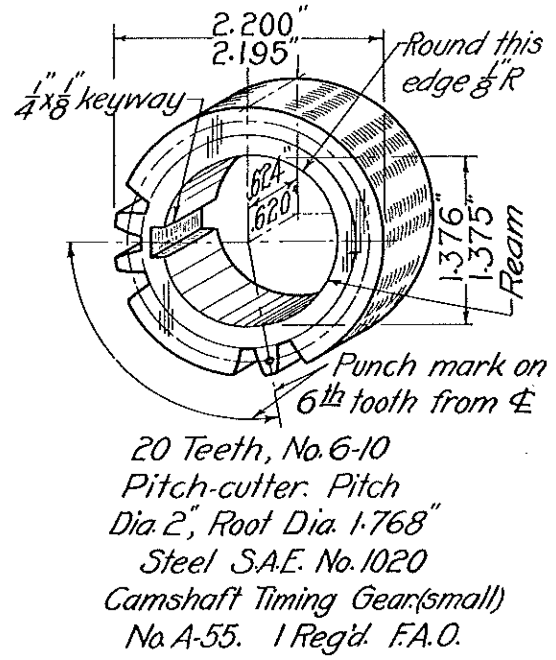


Fig. 24.25. Timing gear.

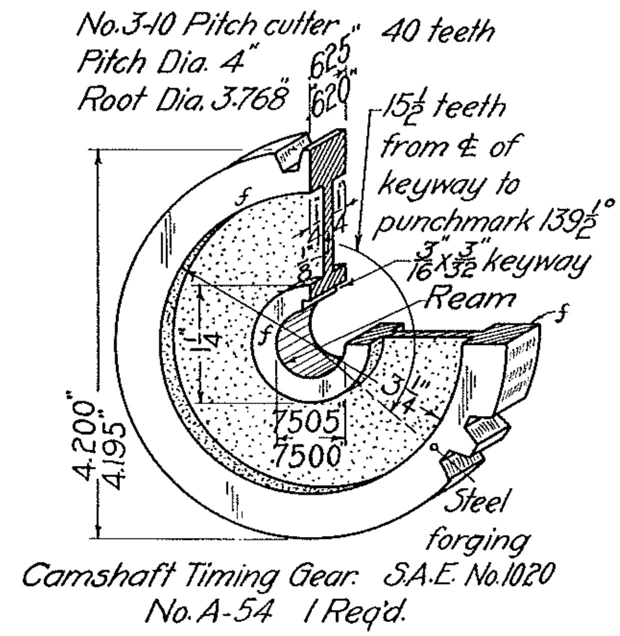


Fig. 24.26. Timing gear.

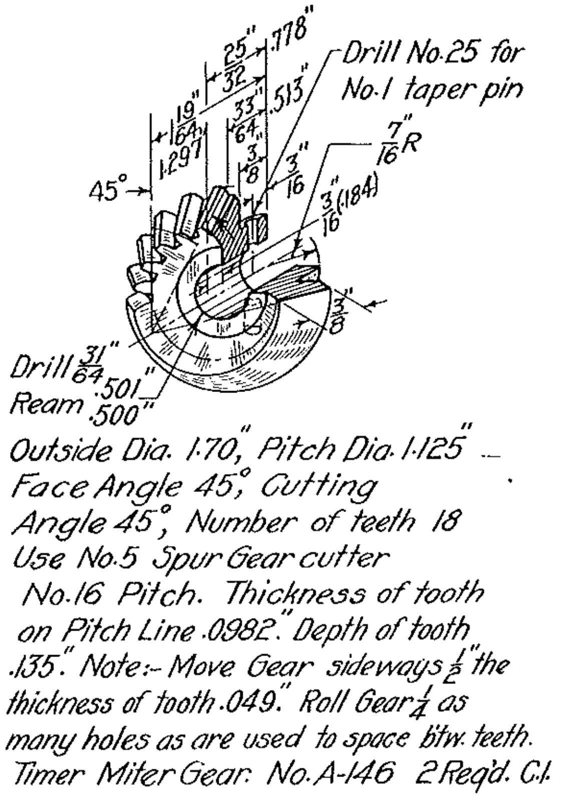


Fig. 24.27. Miter gear.

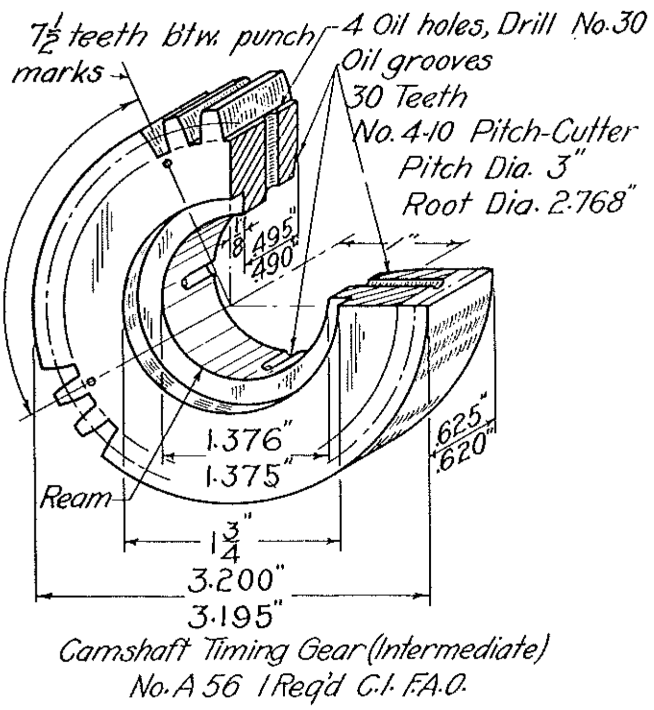


Fig. 24.28. Timing gear.

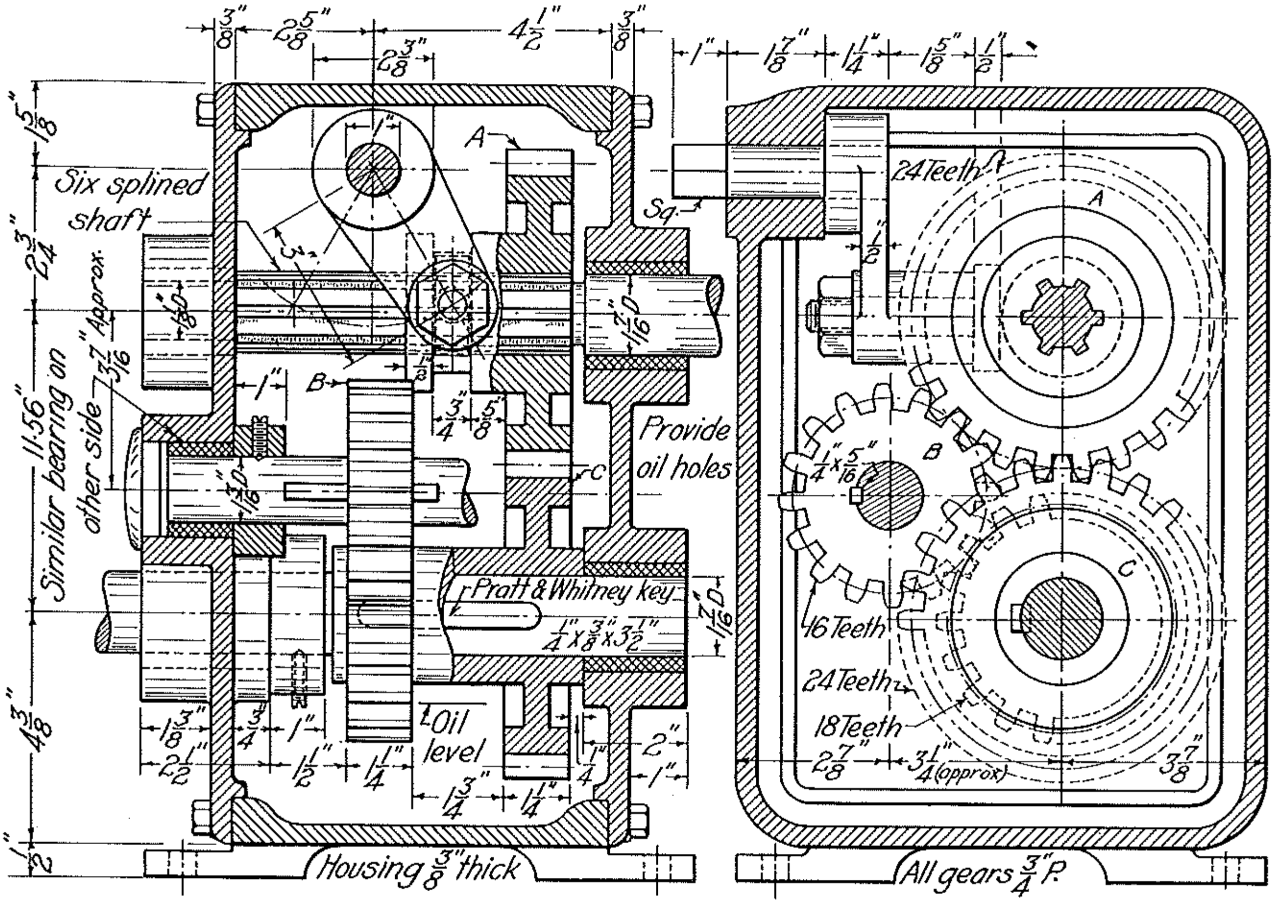


Fig. 24.29. Reversing mechanism.

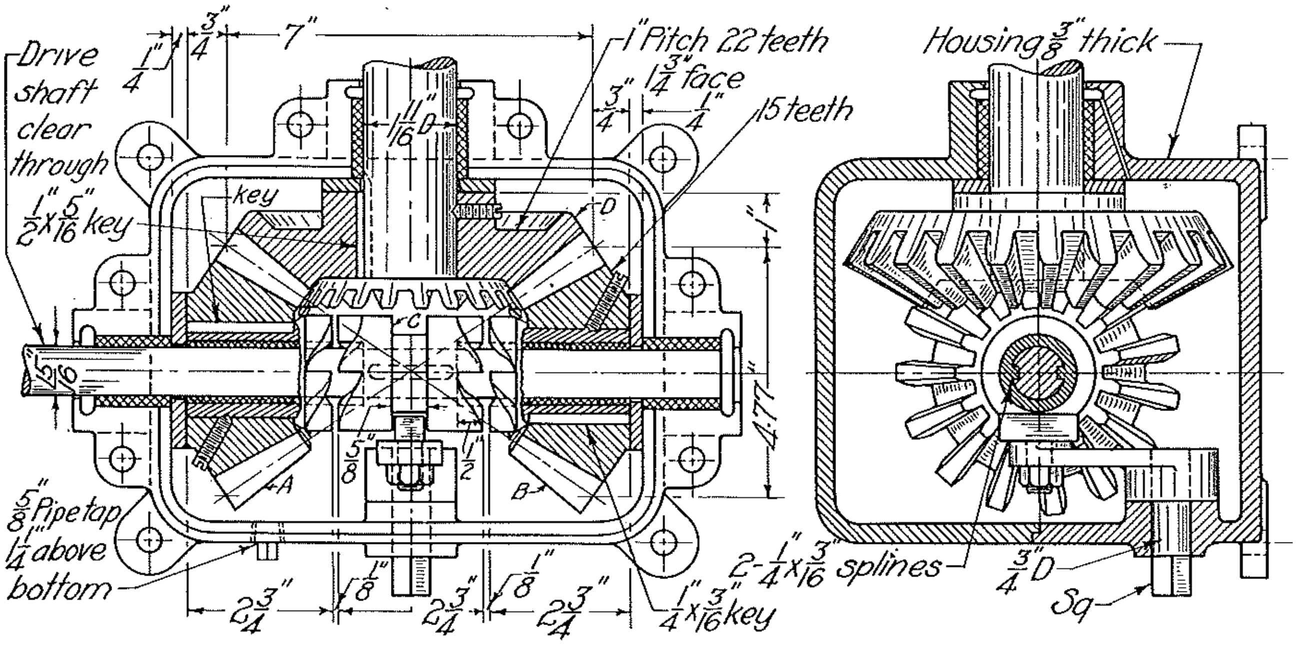


Fig. 24.30. Bevel gear reversing mechanism.

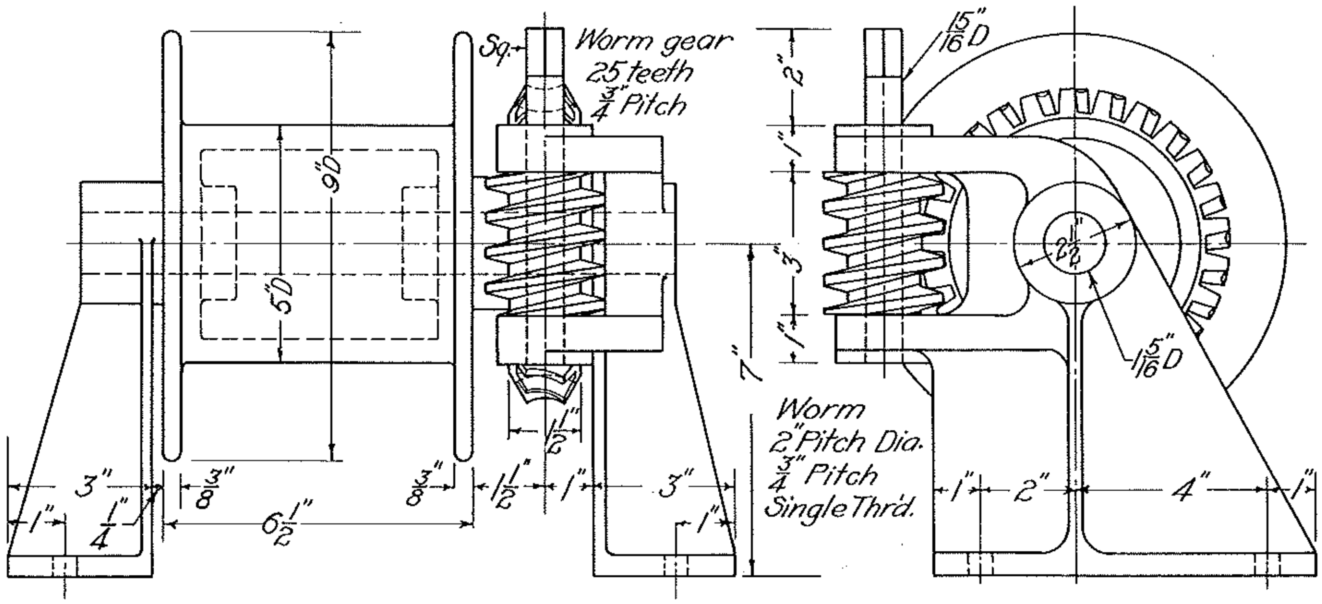


Fig. 24.31. Hand winch.

Tool Drawing* 25

25.1 The tool drawing room. The development of great industrial organizations today has resulted in the growth of large drafting rooms all over the country. Such organizations vary in specific detail but common working procedures place the design engineer in complete control of production results. It is his responsibility to provide needed information and instruction necessary for manufacturing. With the production engineering staff working cooperatively with the design staff, the idea for the part is developed. The product is then taken to the testing and experimental divisions for confirmation, changes, and improvement suggestions. Often this results in the development of a new product or the revision of one already in production. After the parts have been tested and approved by the proper departments, prints of the final detail and assembly and subassembly drawings are issued to the master mechanic's department.

Data sheets, sketches, freehand drawings, or actual parts developed by this time serve as a guide for the process engineer. The tool designer in turn furnishes the necessary design information and calculations for tooling required for a given workpiece (the part being placed in production).

Tool drawing requests may be assigned to several detail draftsmen working with a group leader who is the immediate supervisor of the project. He acts as a guide for the detailers, answering minor questions that are non-critical. He coordinates all drafting activity pertaining to the same set of component drawings.

25.2 Routing and work sheets. A tool routing sheet is prepared by the process engineer, and this with design sketches and machine and tool specifications with catalogue information pertaining to standard parts or tools completes the information from which a tool design assembly layout is made.

* This chapter was prepared by Earl D. Black, Section Head, Engineering Drawing and Kinematics, Product Engineering Department, General Motors Institute, Flint, Michigan.

The routing sheet lists the sequence of manufacturing steps and includes specific information about machines, tools, and inspection gages.

The work sheet is prepared by the process and/or tool engineer. It may give further detailed information regarding manufacturing processes. The main purpose of the work sheet, however, is to furnish the tool drafting department with necessary specifications and information as to the number of parts to be made; forces required for the various manufacturing operations; size, capacity, and number of machines to be used; size and specifications of special tools; clearance specifications between mating parts; and inspection instructions with names and makes of instruments where standard instruments will suffice. This information is given to the detail draftsman in order that his drawings may be made to agree with machine shop and production practices. (See Chapter 11, "Shop Terms and Processes.")

25.3 Standard tools. The tool draftsman is concerned with purchased standard tool details mainly in assembly drawings where they are shown being used with special tools or machines. However, there are also times when standard tools must be altered to do special machining operations and detail drawings may be required to show these necessary changes.

Standard tools and machines, such as the precision boring machine shown in Fig. 25.1, with which they are used must be thoroughly understood by the successful tool engineer and tool draftsman. Some of the precise work that can be done on the precision boring machine is shown in Figs. 25.2 and 25.3.

In general it is economical to use standard tools when they will perform satisfactorily. When they will not do the job required, special tools must be designed and made. Standard tools are made to specific limits by highly skilled machinists. Catalogue information usually gives the tolerance specifications to which they are made.

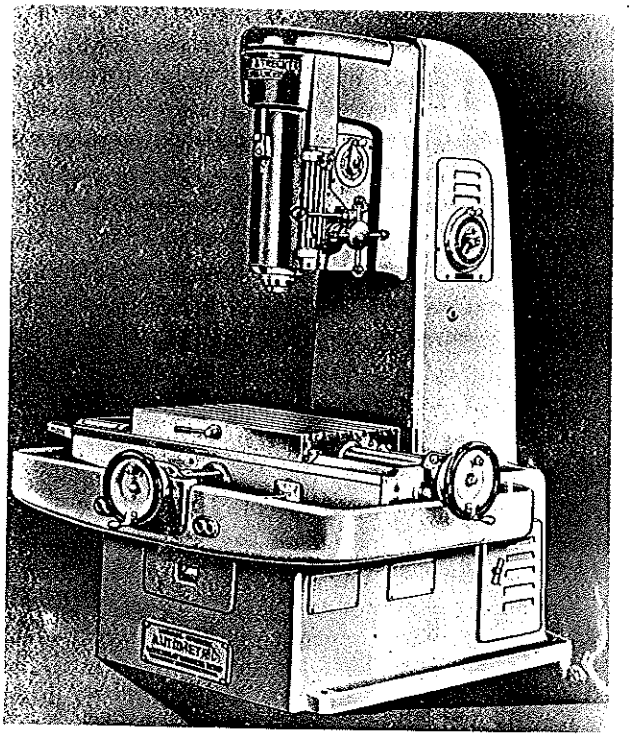


Fig. 25.1. Precision boring machine. Courtesy Kearney and Trecker.

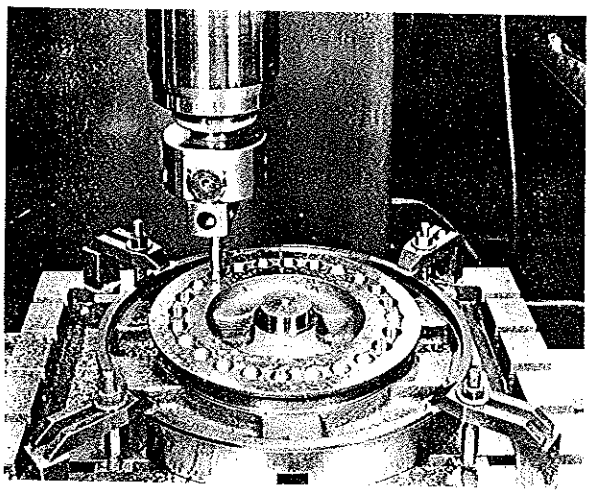


Fig. 25.2. Boring holes with tolerance of .0002. Courtesy Kearney and Trecker.

When selecting standard tools, the draftsman should thoroughly check catalogue specifications before such parts are incorporated in a tool drawing. Any chance for accumulation of tolerances or limits by variation in the machine with which tools are to be used must be thoroughly investigated and checked against the requirements of the part being machined. The combined limits on the tool and machine must give a satisfactory result in the workpiece with a minimum amount of scrap during production.

25.4 Jigs and fixtures. It is important that a draftsman working in jig and fixture design departments have a thorough understanding of standard components, machine shop processes, and methods if his drawings are to be satisfactory.

A jig is a special type of fixture. A jig locates and holds the workpiece and has provision for guiding the cutting tool while a specific machining operation is being performed, as does a drill jig. The jig is not a part of the machine. It may be clamped or bolted to the machine, however, or it may be moved about for variable requirements. Generally a fixture merely locates and holds the workpiece in relation to the cutting tool, as does a milling fixture. However, it may be a definite part of the machine and actually perform work as does a welding fixture where the machine is useless without the fixture. A fixture may also take the form of a device for checking the accuracy of a workpiece, as does a checking fixture.

Jigs and fixtures are used for quantity production where speed and accuracy are required. (See Chapter 12, "Drawing for Interchangeable Assembly.") The jig or fixture should reduce the cost of manufacturing by saving work time of both the machine and the operator. A jig or fixture must assure duplication of successive parts and give interchangeability to justify its use. The jig or fixture must also be easy and safe to operate.

25.5 Making design layouts for jigs and fixtures. Tool drawings for jigs and fixtures may be either freehand or mechanical drawings. Often the first drawings are freehand sketches used to record design thinking and standard parts information, but in more

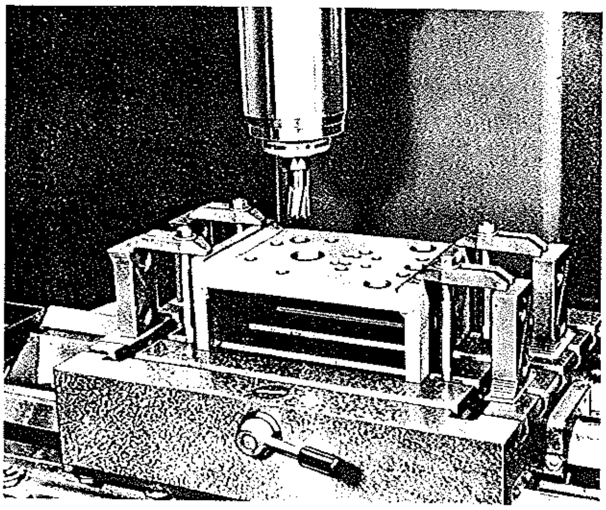


Fig. 25.3. Jig boring reamer. Courtesy Kearney and Trecker.

complicated and critical situations very accurate design layouts are required.

The tool draftsman plans the layout of the drawing so that ample space is provided between views for special notes and dimensions. The workpiece is traced on the drawing sheet in red phantom lines. In Fig. 25.4, the workpiece is outlined with phantom lines and the whole area shaded. In actual operation the outline would be in red with no shading. The detail drawing of the workpiece is then removed and used as a reference sheet for planning the design layout of the jig or fixture.

The drawing of the jig or fixture is made in black lines as if the red phantom lines of the workpiece did not exist. See Fig. 25.4. This method of working out the design is preferred over drawing the workpiece in solid and hidden lines, as the workpiece lines appear on the print and tend to confuse the machinist or toolmaker. Phantom lines therefore make the drawing much easier to read.

25.6 Locating details. The size and shape of the workpiece is always a factor in the design of the locating detail. Such details as pins are relatively easy to use, and they are inexpensive and accurate locators. Pins have been used as locators in Fig. 25.4. V-block locators may be used as clamping and locating combinations. Keyways and special features of the workpiece which are first machined may become possible surfaces of registry for later machining operations through the use of bushings, pins, keys, and special design attachments added to a standard jig body.

25.7 Clamping devices. Clamping must be done in accordance with surfaces and seats of registry. Clamping devices must be designed to avoid deflection of the workpiece during production. Deflection introduces inaccuracy when the workpiece is released from the clamping pressure. Clamping must also be applied at points on the workpiece that will withstand the pressure necessary to hold the workpiece firmly and accurately in place. The clamp must be durable but it must not mar the surface of the workpiece. It must be easy to operate for maximum production. The workpiece must go in the jig in its proper locating position easily and quickly. Likewise, the workpiece must be easily and quickly removable after the work operation has been performed.

25.8 Use of standard parts. Many standard parts may be used in designing a jig or fixture to handle a given workpiece. Standard parts catalogues list jig bushings, adjustable pins, V-blocks, bar clamps, slotted clamps, C-washers, pads, star knobs, set screws and studs, spiral-rise cam clamps, hooks, locks, and many new devices that should be carefully considered in preference to new designs. Any new design, to be economical, must outperform standard parts.

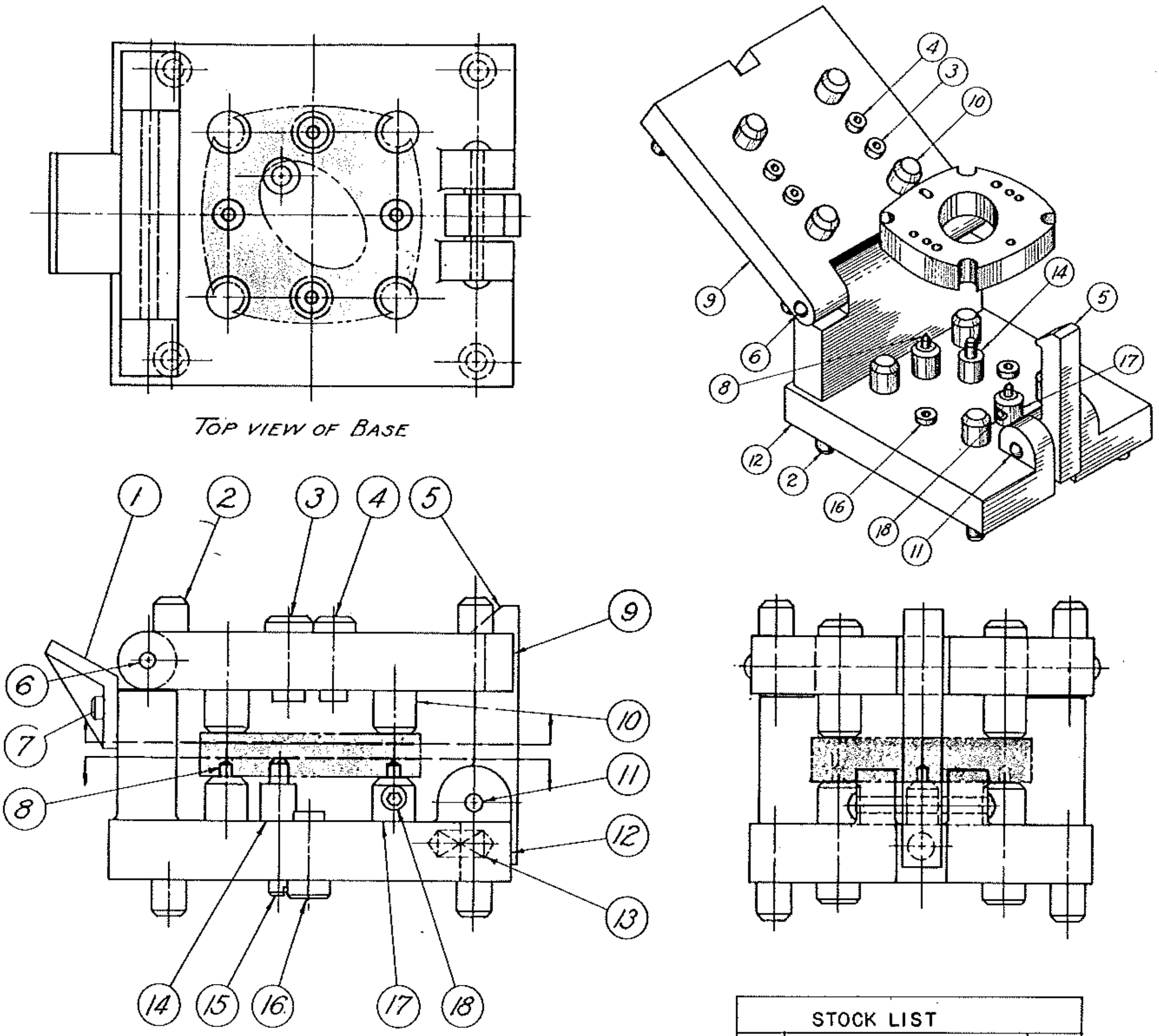
Jig bodies for small machined parts may be obtained in several standard arrangements. The type to use is determined by the mass and shape of the workpiece and the method and process of the machining to be done. The completed jig should be easy to handle, it must be rigid, and it must provide necessary accuracy. All exposed corners should be rounded off, and sharp edges and burrs should be removed. Light-weight jigs may be equipped with handles for easy moving, but heavy jigs may require such details as crane hooks.

The jig body that is to be moved about on a table surface should be provided with four feet as opposed to three feet as any unevenness in setting, as by rocking, may attract the attention of the operator at once. The surface of the feet that rest upon the machine table or frame are finished in a plane parallel to the locating surface in the base of the jig.

Jig bodies should be chosen that give ample clearance for machining tools, chips, and chip removal. Points of location and tool approach in the jig should be visible to the operator. The jig body should be sturdy and durable.

25.9 Assembly layouts. The tool designer or draftsman follows the same basic principles of engineering drawing for the layout of fixtures as he does for jigs. See Fig. 25.4. The drawing usually consists of four principal views augmented by any necessary explanatory section or detail views. The layout drawing shows the front elevation as an edge view. The top view is a layout of the lower member of the body and the parts attached to it. The bottom view is a layout of the top member of the body and the parts attached to it. The parts that are attached to the top member are ignored in the plan view of the bottom member and likewise parts attached to the lower member of the body are ignored in the plan view of the upper member. The side elevation is in line horizontally with the front elevation and shows both members and their parts attached. Any detail not clearly shown in these four views must be included in special explanatory section or detail views. These special views are located conveniently and correctly projected on the drawing sheet. Any irregularity in arrangement of views should include proper titles for these views as an aid in reading them.

The assembly layout should have all parts properly numbered with part numbers being placed on the drawing in vertical or horizontal alignment. These numbers are also included in a stock list which identifies each part. Both standard and special parts are listed giving the material from which each part is made. The number of each part required for one



STOCK LIST

NO.	NAME	NO. REQ.
1	JIG LEAF STOP	
2	REST BUTTON (PAD)	
3	DRILL JIG BUSHING (A)	
4	DRILL JIG BUSHING (B)	
5	LATCH	
6	HINGE PIN	
7	HEX-SOCKET H'D CAP SCREW	
8	LOCATING PIN	
9	JIG LEAF	
10	REST BUTTON	
11	LATCH HINGE PIN	
12	JIG BASE	
13	SPRING	
14	LOCATING PIN HOLDER	
15	SLOTTED FILL. H'D SCREW	
16	DRILL JIG BUSHING (C)	
17	LOCATING PIN HOLDER	
18	HEX-SOCKET SET SCREW	

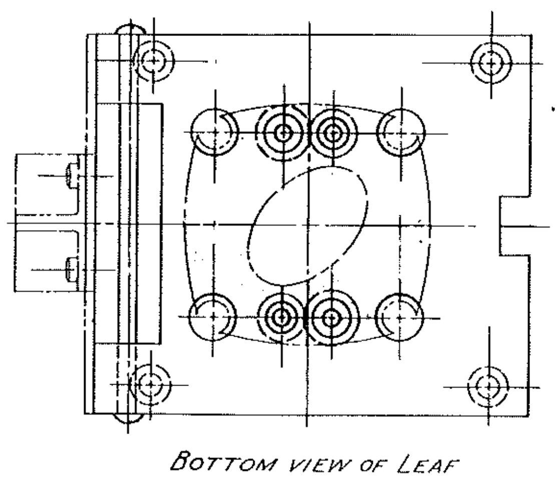


Fig. 25.4. Drill jig.

assembly is also given in the stock-list information. See Fig. 25.7.

The tool drawing title block requires additional space for identification and special information not required on product drawings. Space is usually provided for recording the tool number, machine number, department number, and drawing sheets record numbers. See Fig. 25.5. Often space for recording the model number and operation number is also included.

25.10 Detail drawings. When the design assembly layout has been completed, all special parts and altered standard parts are detailed on detail sheets. Unlike product drawings, which have only one detail drawing on a sheet, tool drawing detail sheets are the same size as those used for the assembly layout, and as many detail drawings are placed on each sheet as will give desirable spacing. Each detail drawing has the same part number as is assigned to it on the assembly layout and parts list. This number, the part name, the material from which the part is made, and the number required for one assembly are placed preferably under the detail drawing of the part or close by. The name or title of the detail sheets should be the same as that given to the assembly layout drawing except that the word "details" is substituted for the word "assembly."

25.11 Dimensioning by transfer. Special practices in dimensioning mating parts are used on tool detail drawings. The first detail drawing made of mating parts shows complete locating dimensions. Later detail drawings made for mating parts have locating dimensions for non-mating details only and omit those locating dimensions that may be found on the first detail drawing. Where locating dimensions are omitted, the part number of the first detail is added to the notes describing the features which must be mated to them. Such notes should be as simple and specific as possible for clarity.

Example:

$.500 {+.002 \atop -.000}$ Dia. 4 Holes Locate by Transfer with Part No. XX

or:

$.500 {+.002 \atop -.000}$ Dia. 4 Holes Locate with Part No. XX

This note means that the machinist will locate these holes on one part only and mating parts will be made from it, using the first as a guide for mating accuracy. This is called "dimensioning by transfer."

25.12 Die drawings. The die designer must approach his problem from the needs of the workpiece in its final shape. The die designer must carefully consider all successive steps in securing this result.

The standard die set comes with a lower shoe, upper shoe, guide posts, and guide-post bushings.

TOOL AND DIE DRAWINGS	
DRAWN BY:	DATE:
SCALE:	DEPARTMENT:
REFERENCE DRAWINGS:	
CHECKED BY:	DATE:
APPROVED BY:	DATE:
PART NAME:	PART NO.
MACHINE NAME:	MACHINE NO.
TOOL NAME:	TOOL NO.
ASSOCIATED DWGS.	DRAWING NO.

Fig. 25.5. Tool drawing title block.

Guide-post lengths and shank sizes must be specified. Die shanks are optional with the die set.

Die drawing follows the same general procedure and techniques used on jig and fixture drawings with some modification. See Figs. 25.4 and 25.5. The plan view of the lower die shoe with die parts attached to it is placed directly and vertically in line with the front elevation of the die set. To conserve drawing space, the plan view of the upper die shoe with punch parts attached to it is often placed horizontally in line with the plan of the lower die shoe as if the upper shoe were lifted from its position above the lower shoe and inverted from left to right. See Fig. 25.6. A side elevation is placed horizontally in line with the front elevation, showing parts attached to both die shoes. The views are clearly identified by titles to further simplify the reading of the drawing. All parts may not be shown in any one view. Parts attached to the lower die shoe will not appear in the plan view of the upper die shoe. Likewise, parts attached to the upper die shoe are not shown in the plan view of the lower die shoe. Hidden lines that would confuse the interpretation of a layout should be omitted in the assembly layout drawing. The use of sectional, auxiliary, and other explanatory detail views may be used to give complete information to the die maker.

Standard die parts are more economical where they will perform satisfactorily and are therefore used in preference to parts that are specially made.

The title block and stock list on the assembly lay-

out of dies are similar to those used on jig and fixture drawings. All parts, both standard and special, are included in the parts list. See Fig. 25.7.

All non-standard or standard parts that are altered are detailed on detail sheets. These detail sheets are numbered Sheet 2, Sheet 3, etc., and the total number of sheets is recorded in the record space as indicated in the title block. The size of detail drawing sheets for dies is usually the same as that used for the assembly layout.

25.13 Conclusion. Industrial manufacturing today is preceded by the making of product engineering drawings. Prints of these drawings with orders and specifications for tooling are then issued to the master mechanics department, including the process, tool design, and drafting sections. When the tool designer receives the assignment, it will be his responsibility to furnish design sketches or design layouts to the tool drafting section for tools, dies, jigs, fixtures, and checking devices that will control interchangeability and guarantee the functional requirements of the assembly.

After tool drawings are completed and checked for design and drafting accuracy, they are sent to the printing department for duplication. These prints are used by engineers and designers to express and record the ideas and information necessary for the building of machines and tools. Tool drawings assist in coordinating all departments and individuals in the actual designing, testing, production, inspecting, and servicing of parts made by high-production processes.

Problems

The basis for performing the following problems is found in the chapter on "Tool Drawings." In each case the student is expected to make the correct and complete shop drawings. He should first make an assembly layout from which he makes detail drawings of non-standard parts that cannot be purchased. He also furnishes detailed information for changes in standard parts. Such alterations require a detail drawing of these changes.

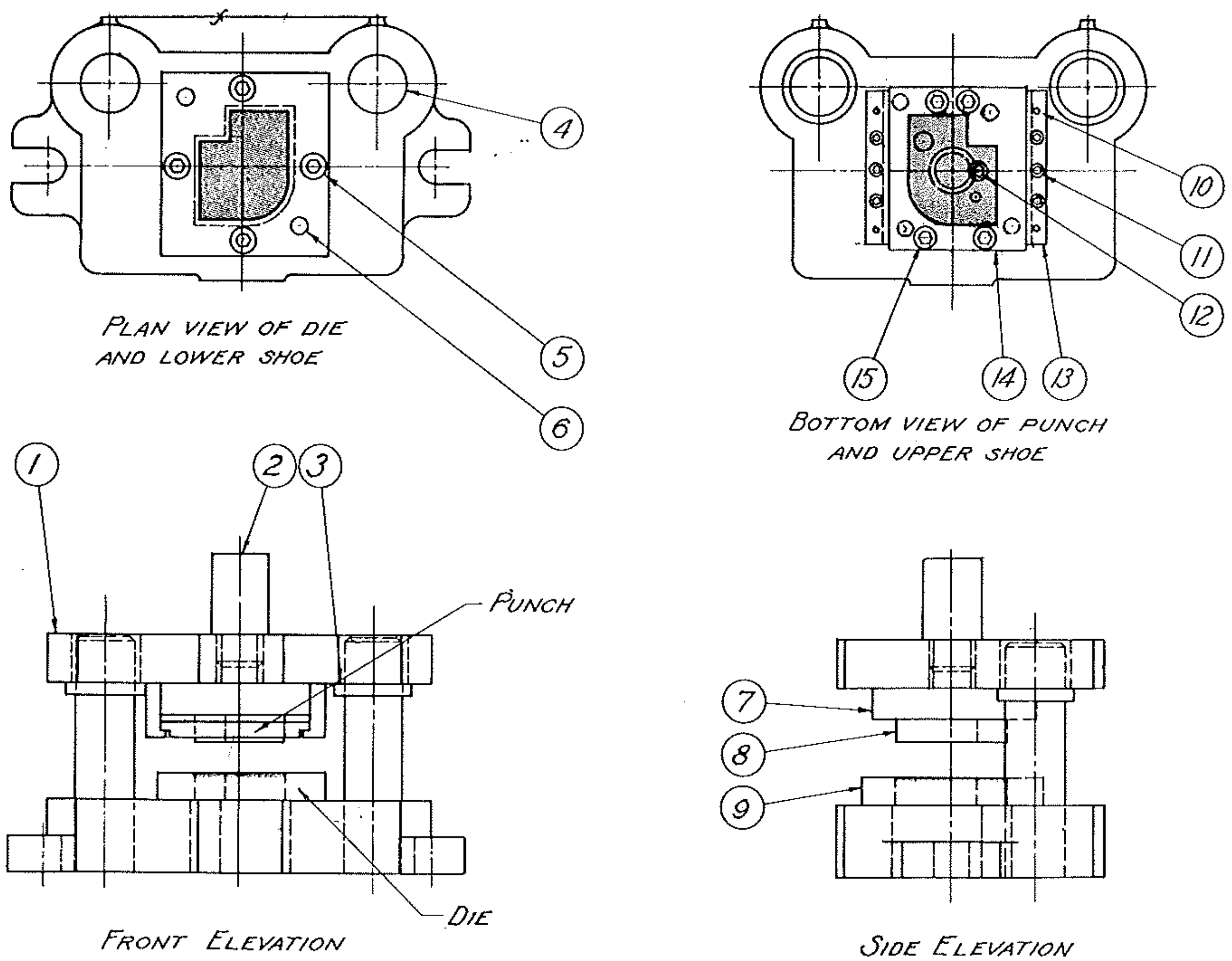


Fig. 25.6. Die drawing.

The student should first make sketches of his proposed jig, fixture, die, or tool as a means of progressive planning of the final assembly layout. His sketches should be accompanied by catalogue information necessary to the final assembly layout and detail drawings.

Engineering changes may be included at the end of the assignment along with corrections and alterations necessary to bring each detail drawing into compatibility with component parts of the assembly.

All drawing sheets should be of the same size. The size of the drawing sheet chosen for the assembly layout should also be used for detailing. The detail sheets should not be crowded.

The balloon and part number, the part name, the material from which the part is made, and the number required for one assembly should be lettered carefully under each detail drawing. This information should be recorded in the stock list on the assembly layout.

1. Make an assembly layout and detail drawings of a fixture to mill or grind the end surfaces of the ½"-diameter bosses on the counterbalance, Fig. 12.48. Include complete stock list for the fixture on the assembly layout.

2. Make an assembly layout and detail drawings of a drill jig to drill the ½"-diameter hole in the counterbalance, Fig. 12.46. Include a complete stock list on the assembly layout for the jig.

3. Make an assembly layout and detail drawings of a drill jig to drill the four ¼" cap screw holes in the cover, Fig. 11.52, Chapter 11. Locate the workpiece from the outside surface of the flange. Locate workpiece in jig by use of three contact points. Standard parts are not detailed. Include stock list on the assembly layout.

4. Make an assembly layout and detail drawings of a jig to drill and ream the $\frac{15}{16}$"-dia. center hole in the Governor support bracket, Fig. 12.50. The two holes, ⅜"-dia. ream, located 2¾" apart, are to be used for locating the workpiece in the jig. Include a complete stock list on the assembly layout.

5. Make a subassembly drawing of the reservoir baffle plate, Fig. 25.8 and the reservoir cover, Fig. 25.9. Use this subassembly drawing as a workpiece, and make an assembly layout and detail drawings of a welding fixture to weld these two parts together. Include a complete stock list on the assembly layout.

6. Make an assembly layout and detail drawings for a fixture to mill the half-inch slot in the pump plunger, Fig. 12.60. Include a complete stock list on the assembly layout.

7. Make an assembly layout and detail drawings of a jig to tap the center hole in the reservoir plate, Fig. 25.10. Include complete stock list on the assembly layout.

8. Make an assembly layout and detail drawings of a die to blank and pierce the .406-dia. hole of the reservoir baffle plate, Fig. 25.8. Include a complete stock list on the assembly layout.

9. Make an assembly layout and detail drawings of a die to pierce four .126"-dia. holes, and emboss four welding projections on the reservoir baffle plate, Fig. 25.8. Include a complete stock list on the assembly layout.

10. Make an assembly layout and detail drawings of a die to punch two holes, .276"/.286" dia., in the reservoir plate, Fig. 25.10. Include a complete stock list on the assembly layout.

11. Make an assembly layout and detail drawings of a die to blank and pierce the two rectangular holes and the two ⅛" holes adjacent thereto in the ski binding bracket, Fig. 25.11. Include a complete stock list on the assembly layout.

15	4	DIE SPRING #936611	STD	HT	1
14	1	STRIPPER PLATE	SAE 1020	HR	4
13	2	KEEPER	SAE 1020	HR	4
12	1	HEX SOCKET SET		–	1
		SCREW #222527			
11	6	HEX CAP SCR #782700	STD	–	1
10	4	DOWEL PIN #764179	STD	–	1
9	1	DIE	GM A-2	CM AH	3
8	1	PUNCH	GM A-2	CM AH	3
7	1	PUNCH RETAINER	GM W-10	CWH	3
6	2	DOWEL PIN #784160	STD	–	1
5	4	HEX CAP SCR #138293	STD	–	1
4	2	DIE SET POST #783326	STD	–	1
3	2	GUIDE POST	STD	–	1
2	1	SHANK #783494	STD	–	1
1	1	DIE SET #936101	STD	–	2
DETAIL NO.	NO. REQ.		MAT.	HT. TR.	SH. NO.
STOCK LIST					

Fig. 25.7. Stock list.

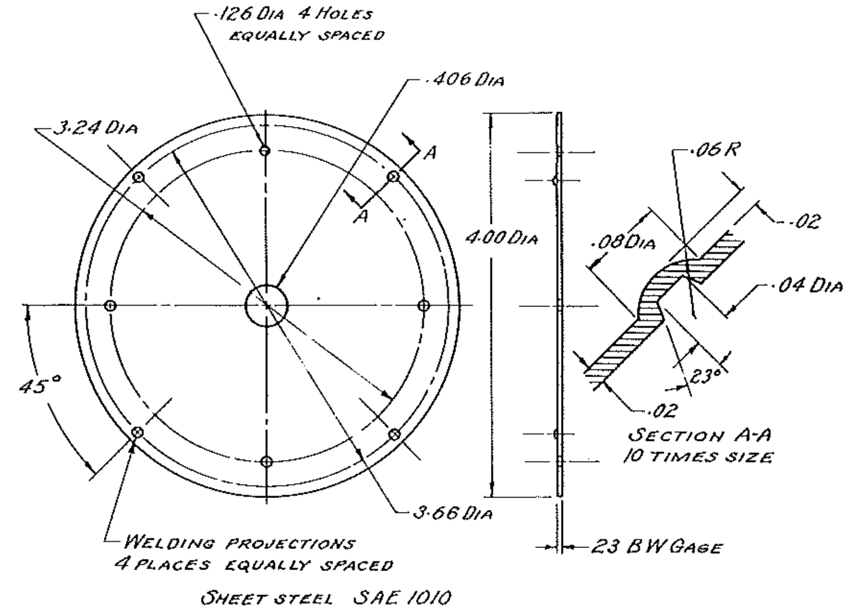


Fig. 25.8. Reservoir baffle plate.

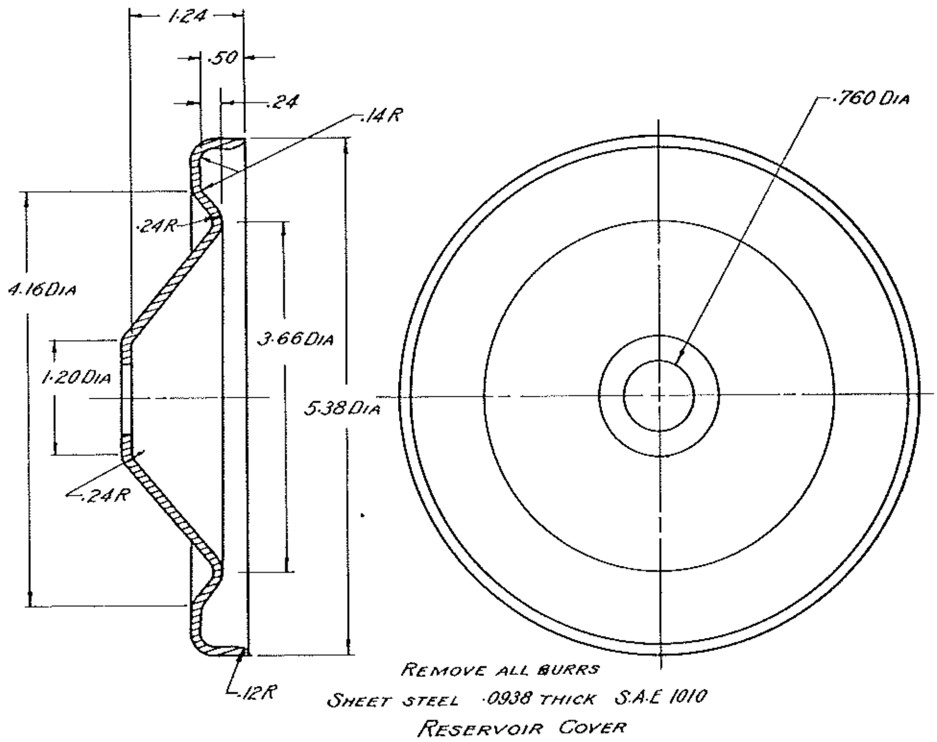


Fig. 25.9. Reservoir cover.

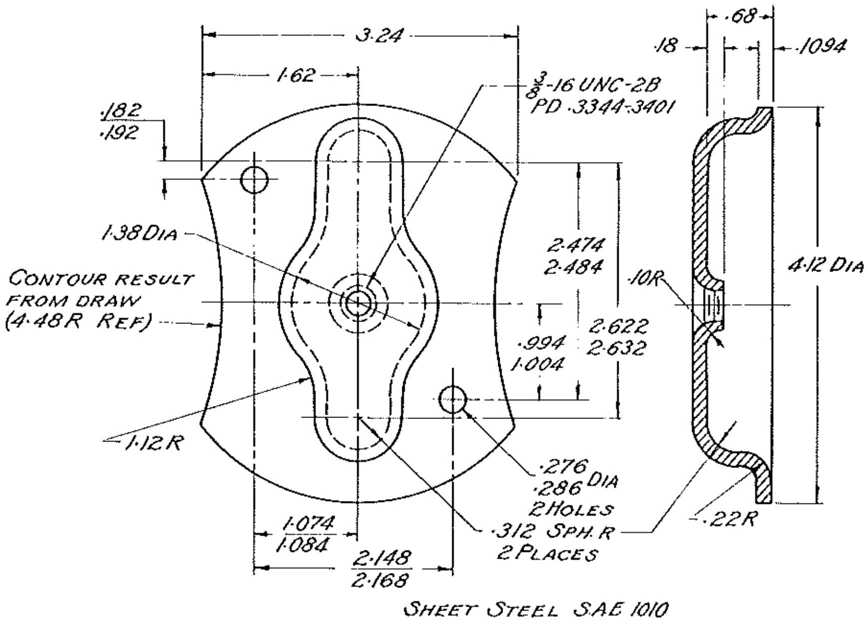


Fig. 25.10. Reservoir plate.

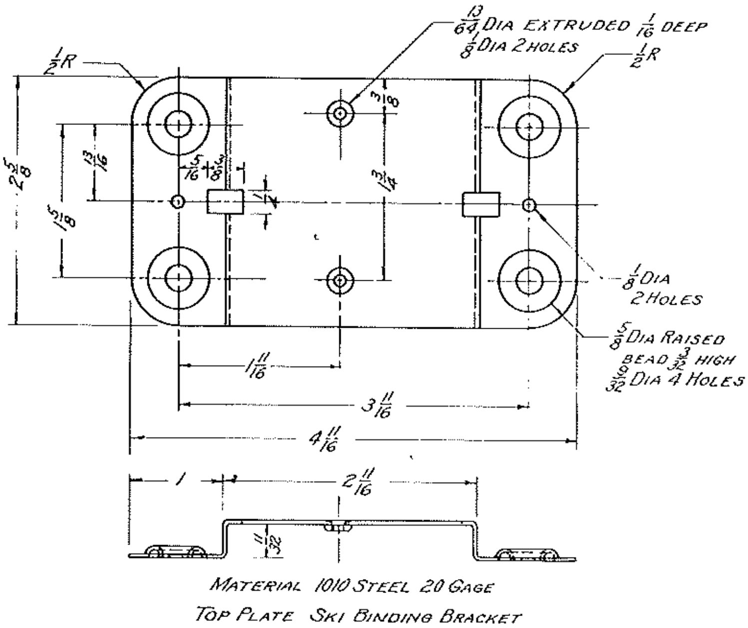


Fig. 25.11. Ski binding bracket.

Welding Drawing 26

26.1 Introduction. For permanent fastening of parts of a structure, welding is a very important method. Many machine parts are now being constructed by welding various units together, thus making a built-up structure to replace a complicated casting or riveted part.

The earliest form of welding consisted of heating the parts and pounding them together on an anvil until they were joined together. From this stage the process of welding has been developed to its present state of perfection where almost any kind of metal may be satisfactorily welded. The two principal kinds of welding now generally used are fusion welding and forge welding.

a. Fusion welding is the term applied to the method of joining two pieces of metal by melting metal into a joint that has been raised to the melting temperature. Thus a fusion weld is actually a process whereby two parts are joined by bringing the metal of each part to a liquid state and adding extra molten metal which forms the joint when cooled.

b. Forge welding is the term applied to the method of joining two pieces of metal by heating them to the plastic state and then forcing the parts together either by pressure or by a blow of a hammer. In modern welding various kinds of machines are used to apply the pressure or the hammer blow.

26.2 Methods of welding. Welding may also be classified according to the method of applying the heat. Under this group there are four main divisions, gas welding, arc welding, resistance welding, and Thermit welding.

26.2.1 GAS WELDING is that type in which the heat is supplied by burning acetylene or hydrogen gas. The gas under pressure is mixed with oxygen and ignited. This creates a very hot flame which can be regulated to give various characteristics by adjusting the flow of the gas or the oxygen. Temperatures as

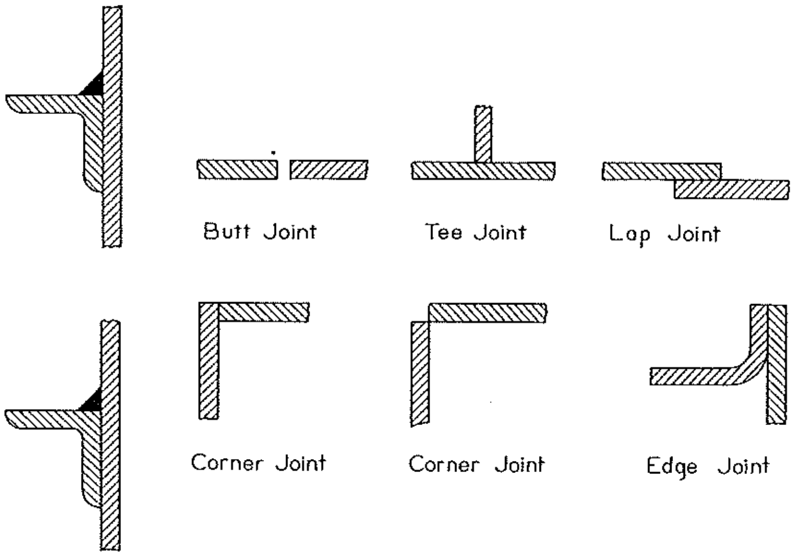


Fig. 26.1. Types of joints.

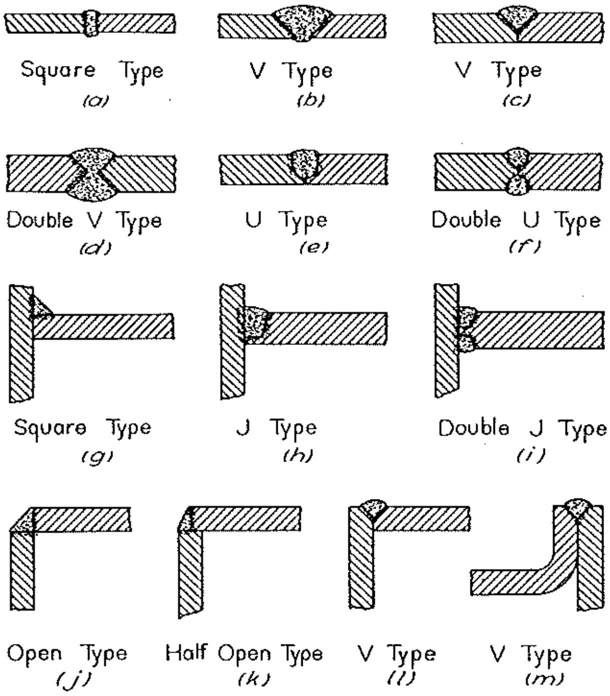


Fig. 26.2. Types of welds.

high as 6000° F may be obtained with the oxyacetylene torch.

26.2.2 ARC WELDING is that type in which the heat is applied by means of an electric arc. Usually the parts to be welded are wired as one pole of the arc with the electrode held by the operator forming the other pole. Sometimes this is a carbon electrode, in which case the extra metal for the weld is supplied by a welding rod held in the arc in a manner similar to gas welding. More frequently the welding rod is used as the electrode so that the electrode itself gradually melts away, thus supplying the extra metal for the weld. Sometimes the arc is formed between two tungsten points, neither of which touches the metal being welded, in which case extra metal must be supplied by a filler rod. This latter method is used in atomic-hydrogen arc welding. The temperature of the arc is about 6000° F.

26.2.3 RESISTANCE WELDING. Electric current is also used as a source of heat in a type of welding known as resistance welding. This is usually considered the easiest and cheapest method of fastening the pieces of metal together permanently. It is based on the fact that electric current flowing through metal will heat the metal when the resistance increases. Therefore, since current flowing from one plate to another will encounter the greatest resistance at the joint, whether it be a lap joint or a butt joint, the tendency is to heat the metal at the joint. The temperature at the joint may be regulated by the amount of the current. When the proper temperature is attained, pressure applied by some kind of machine will create a forge weld, thus fastening the two pieces together. This may be done over the entire joint, forming a butt or seam weld, or at particular points forming a spot weld. The term flash weld is sometimes used when the ends of two parts are joined by resistance welding.

26.2.4 THERMIT WELDING is a method based on the strong affinity of aluminum for oxygen. A mixture of finely divided aluminum and iron oxide may be ignited at one spot, and it will then burn rapidly at a very high temperature, leaving a quantity of molten metal and aluminum oxide slag in the container. The temperature resulting from this reaction is about 4500° F. The reaction must be started by lighting a small quantity of special ignition powder.

For the fusion method of Thermit welding, it is first necessary to build a wax mold around the break or joint. A refractory sand mold is then constructed around the wax, which is dried out and preheated by some method such as blowing vaporized kerosene and air into the mold. During this preheating process the wax is burned out, leaving a space into which the metal melted by the Thermit reaction may be poured. This molten metal fuses with the parts to be joined together and upon cooling leaves a welded joint.

In some cases, such as the Thermit pipe weld, only the heat of the Thermit metal and slag is used to make a forge weld. With the ends of the pipe faced and butted together, the slag and the Thermit metal are poured around the joint. The heat of the metal raises the temperature of the pipe to a point where the forge weld can be made by pressing the two pieces together. After cooling the Thermit metal can be broken off because the slag forms a coating on the pipe which prevents the Thermit metal from sticking to the pipe.

26.3 Types of joints. One very valuable feature of welding is that the parts may be fastened together in almost any relative position. However, there are certain standard joints that are most frequently encountered in welding operations. Figure 26.1 shows the joints most commonly found in practice.

26.3.1 CROSS SECTION OF JOINT. The thickness of the parts to be joined will have a large bearing on the cross section of the joint. If the plates are thin the plain butt joint may be used as shown in Fig. 26.2(*a*). Plates with a little greater thickness might be prepared with a single V butt joint as in Fig. 26.2(*b*) or a Y type butt joint as in Fig. 26.2(*c*). Still greater thickness might require a double V butt joint with the welding being done from both sides. See Fig. 26.2(*d*).

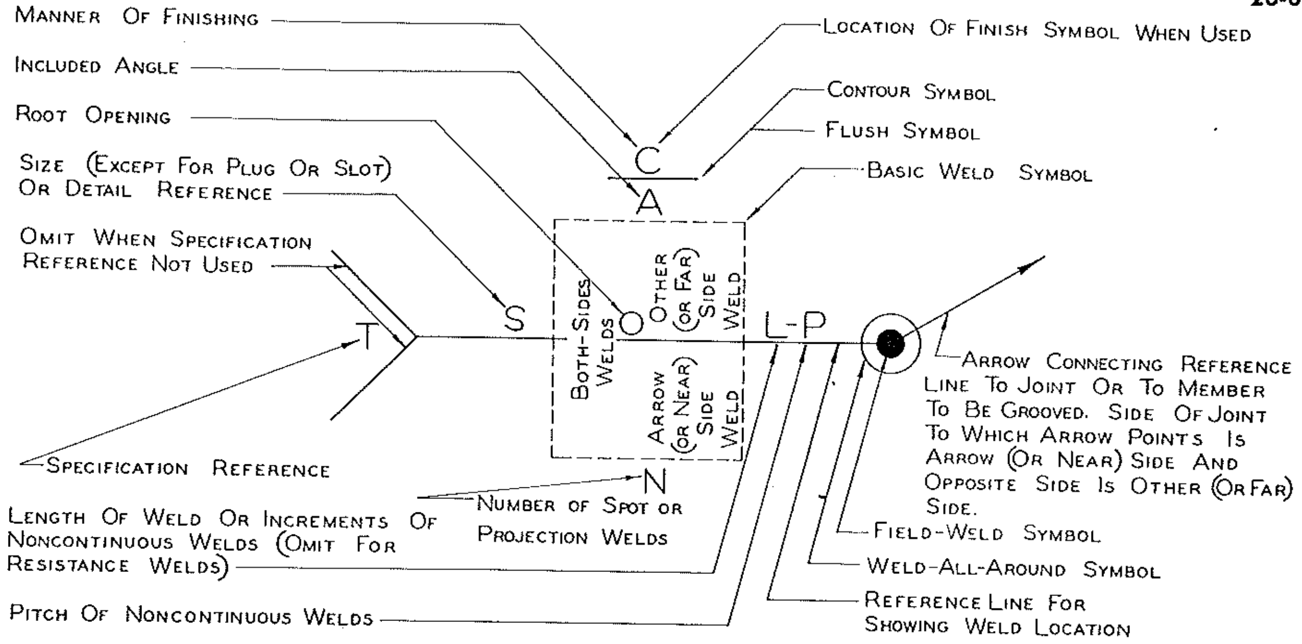


Fig. 26.3. Welding symbol.

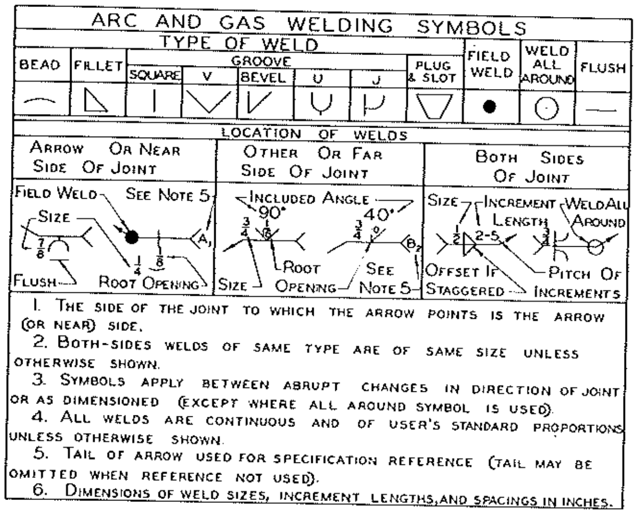


Fig. 26.4. Arc and gas welding symbols.

Other methods of preparing the parts for welding are shown in Figs. 26.2(e) to (m).

26.4 Welding symbols for fusion welding. There are so many different conditions under which welding is done and so much information to be conveyed from the office to the welding operator that the American Welding Society has devised a composite symbol by means of which all this information may be transmitted. This symbol is in the general form of an arrow on which other symbols, letters, and marks may be placed to give complete instructions for fusion welding. The form of this arrow as well as the kind and position of other symbols is given in Fig. 26.3.

26.5 Welding legend for fusion welding. When fusion welding is specified on a drawing by means of the welding symbols, a legend should be placed on the drawing to aid in interpreting the symbols. This legend is shown in Fig. 26.4. To further aid in clarifying the use of the welding symbol, many of the figures shown in Fig. 26.2 are repeated in Fig. 26.5 together with the proper welding symbols.

These symbols may be made either mechanically or freehand.

Fillet, bevel and groove weld symbols should always be shown with the perpendicular leg to the left.

The size dimension should be to the left of the symbol with length and spacing of increments to the right.

The finish of a weld may be indicated as shown in Fig. 26.5(k). The letters C, G, and M are used to indicate chip, grind, or machine. The standard finish mark f may also be used.

When only one member is to be grooved, it is important that the arrow point specifically to that member as in Fig. 26.5(h) or (i).

For complete instructions for making these symbols, see the booklet entitled "Welding Symbols" by the American Welding Society, 33 West 39th Street, New York City.

26.6 Welding legend for resistance welding. When resistance welding is specified there must be some difference in the symbols because there is no significance to the terms "arrow" side or "other" side, since the weld always occurs between the two parts.

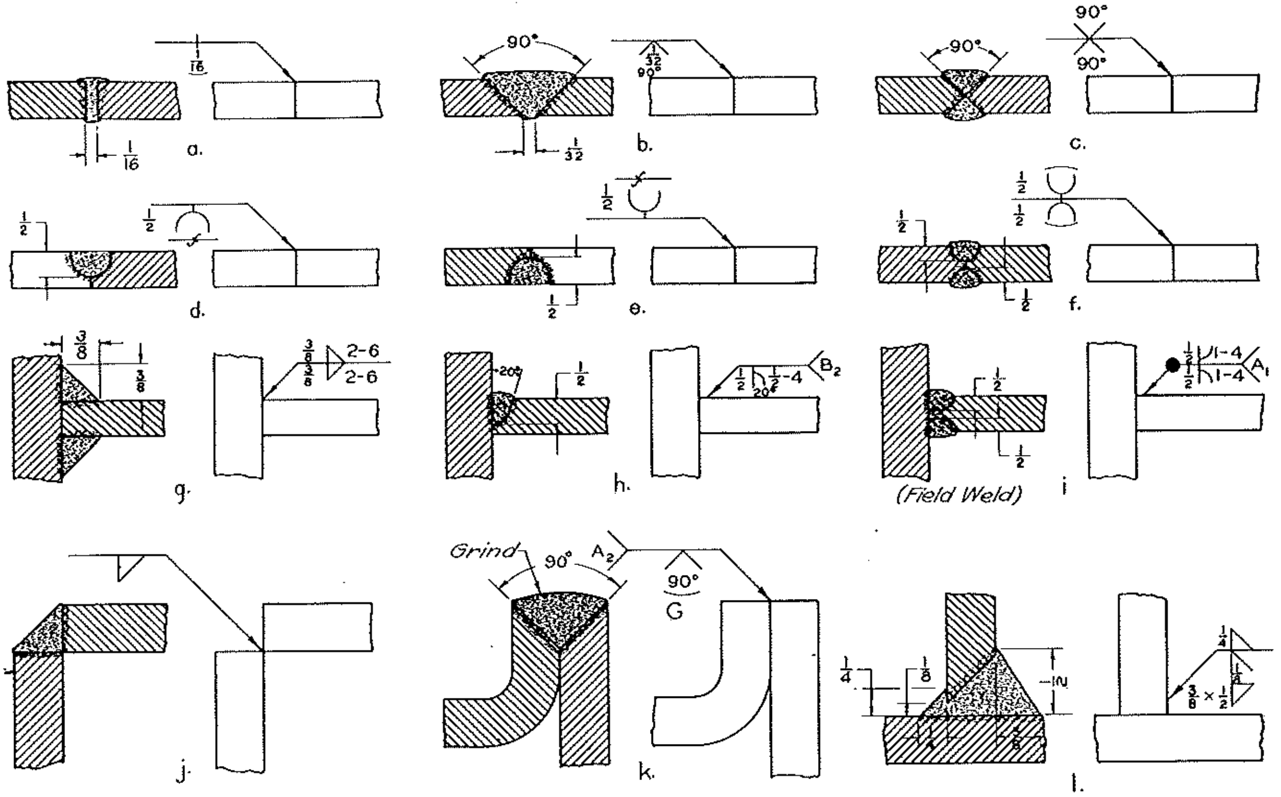


Fig. 26.5. Application of welding symbol.

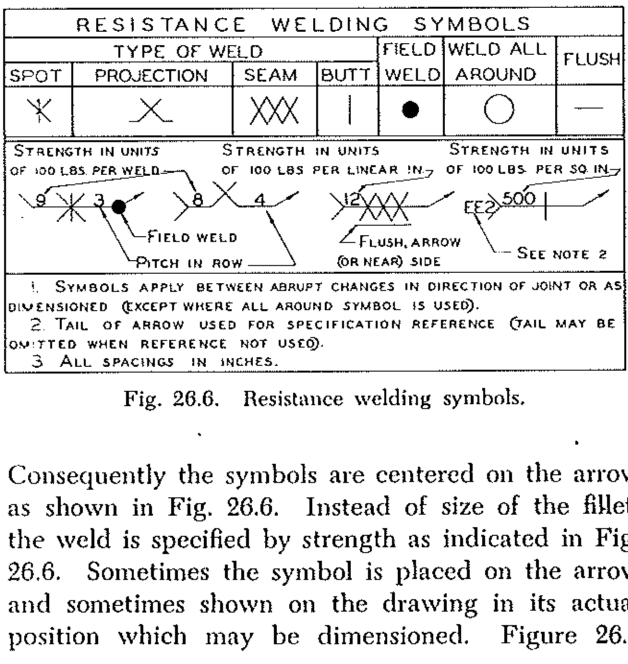


Fig. 26.6. Resistance welding symbols.

Consequently the symbols are centered on the arrow as shown in Fig. 26.6. Instead of size of the fillet, the weld is specified by strength as indicated in Fig. 26.6. Sometimes the symbol is placed on the arrow and sometimes shown on the drawing in its actual position which may be dimensioned. Figure 26.6 shows the legend to be placed on the drawing when resistance welds are to be specified.

The use of resistance weld symbols is shown in Fig. 26.7. Note that when the welding symbol is placed on the drawing, only the strength specification is placed on the arrow.

26.7 Other methods of specifying welds. Although the symbols of the American Welding Society are being used in many industries, welds are still being specified by other means. Probably the most common is to show cross hatching on the drawing at the place where the weld is to be placed. In that case notes and dimensions on the drawing give the required information about the weld. This method is illustrated in Fig. 26.8.

26.8 Welding symbols on working drawings. An application of fusion welding symbols to a working drawing of a machine part is shown in Fig. 26.9. A second application to a structural joint of a truss is shown in Fig. 26.10.

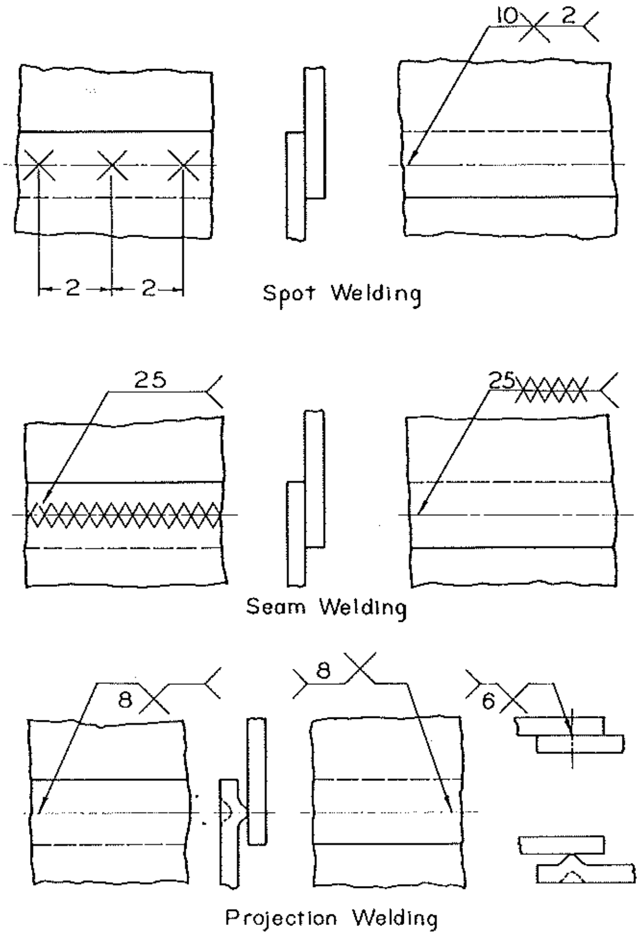


Fig. 26.7. Application of resistance welding symbol.

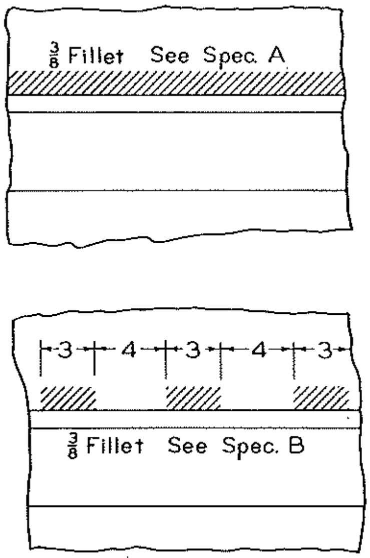


Fig. 26.8. Alternate method of showing welds.

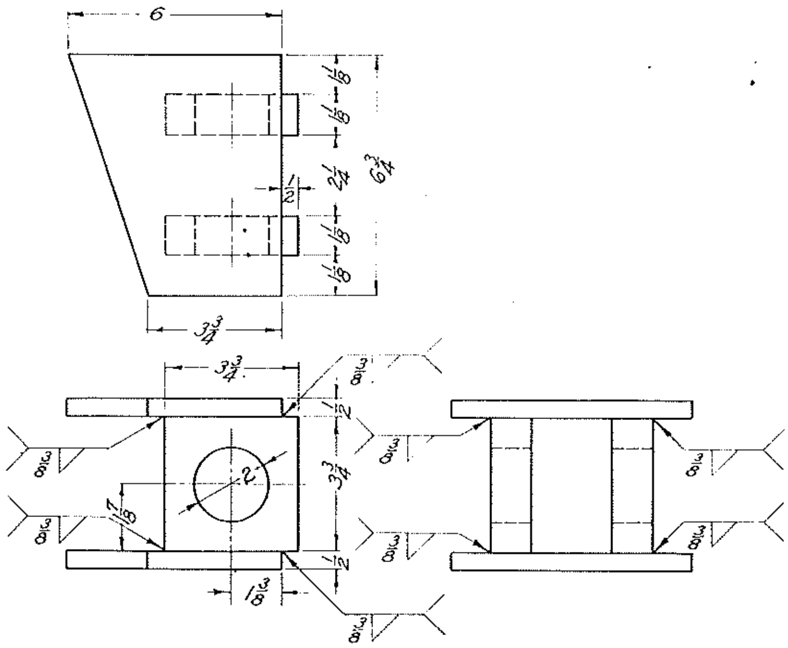


Fig. 26.9. Application of welding symbol to a machine part.

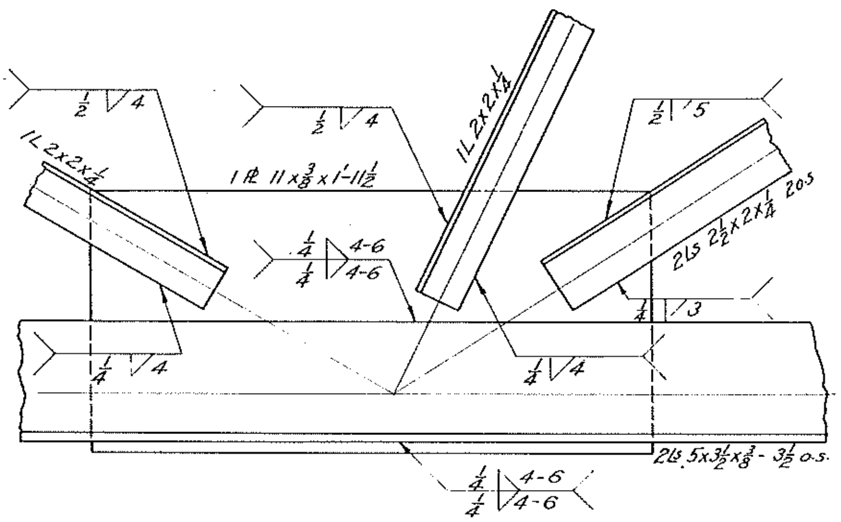


Fig. 26.10. Application of welding symbol to a structural connection.

Reproduction of Drawings* 27

27.1 Introduction. During the early years of the past century, drawings were made directly on drawing paper and used for production purposes. As our methods of production advanced, the need for more than one copy of each drawing developed. This need brought about the discovery by Sir John Hershel of the Cyanotype Process in 1842. It was not until 1876 that this process was introduced in the United States. This process is the basis for the present day blueprint and other methods of reproduction that will be explained in the following paragraphs.

27.2 Blueprint. Blueprinting is the oldest form of reproduction process still in use to any great extent in the United States. The paper used in blueprinting is a good grade of white paper free of wood pulp and sulphite, coated with a solution of ammonium citrate of iron and potassium ferricyanide. When exposed to light, the ferric salt is reduced to a ferrous state, and when the print is washed in water a blue precipitate called Prussian blue is formed on parts of the paper that have been exposed to the light. On the portion of the paper not exposed to the light, the chemicals wash away, leaving the color of the original paper.

Originally, the tracing to be reproduced and the blueprint paper were placed in a printing frame and exposed to the rays of the sun. Since the intensity of the sun's rays vary from one exposure to another, this was a very uncertain method of exposure. This uncertainty and the need for greater speed in production brought about the development of the blueprinting machine.

The first type of machine was the vertical blueprint machine, which consisted of a large cylindrical glass plate set in a vertical position, with a canvas covering that could be rolled to one side, allowing tracing and blueprint paper to be inserted against the glass and then covered with the canvas. An arc light traveling in a vertical direction furnished the light for printing. The time of exposure was regulated by the traveling speed of the arc light. After exposure, the print was placed first in a wash—usually clear water; second, in a solution of potassium bichromate and water; and finally washed thoroughly in clear water. The print was then allowed to dry naturally, or by the use of a gas or electric dryer.

As our methods of mass production developed, this method of reproducing drawings proved slow and cumbersome, and brought about the development of a more elaborate blueprinting machine, a combination printer, washer, and dryer, as shown in Fig. 27.1.

27.3 Brown print. A paper, coated with a solution having a high concentration of silver nitrate, when exposed in a manner similar to that used for blueprint paper, produces a negative transparency print with brown background and white lines. The print, after being washed, is placed in a fixing solution of hyposulphite of soda, making the print permanent. This brown negative may be used with ordinary blueprint paper to produce a blue-line print with white background. These negatives are transparentized with a light oil before printing with them.

This brown print also may be used when changes are desired on the original without the expense of making a new tracing. The changes are blocked out before printing, leaving a white spot on the finished brown print on which corrections or changes may be made, and a final print is made from the changed brown print.

27.4 White print. Although blueprints are still most predominantly used in industrial practice, other reproduction processes are used and are being developed. One of these is the BW or Bruning "Copyflex" Process—a type of the Diazo Process patented about 1890. This process is described by a scientist very closely related to its development as "an aniline de-

* This chapter was prepared by Prof. C. I. Carlson of the Chicago Undergraduate Division of the University of Illinois.

rivative that has been diazotized, forming a diazo compound of two nitrogen atoms fixed to each other and fixed to a basic molecule." (Not all diazo compounds are sensitive to light.) Special classes of diazo compounds are yellow, and therefore have a very nice absorption for the near ultraviolet rays ranging from 3500 to 4000 angstrom units. The action of this particular light causes a decomposition of the diazo compound into nitrogen molecules and another product which is no more light sensitive. On the other hand, this kind of diazo compound, like all other diazo compounds, can form, under certain circumstances, with a phenol, a so-called azo dye. Phenol has a great affinity to diazo compounds.

BW paper is made in five colors, including white, with four colors of lines, making possible 20 combinations of color in background and print.

A recent development by the Chas. Bruning Company, makes it possible to produce a positive print direct from an opaque original without the usual intermediate steps. This is known as the BW Screen Reflex Film Process. The film used in this process is made by superimposing a screen on the sensitized surface of the film. The screen is exceedingly fine, about three times as fine as those used in high-quality publication printing.

To make a print, BW Reflex Film is placed screen side up on top of the opaque copy. See Fig. 27.2. Exposure is made by subjecting the film to intense light, which passes between the dots (*A*) of the screen and through the film. The microscopic square dots (*A*) which compose the screen, intercept some of the light. They protect the sensitized surface immediately below them. The portion of light which passes between the dots decomposes the emulsion at these spots and continues on its way until it strikes the surface of the material being copied.

Where the surface is light in color on the master (*B*), the light is reflected back at a controlled maximum angle. This reflected light exposes part of the sensitized surface of the film under the dots.

Where the light which passes through the film strikes a dark area (*C*) on the master, such as printing ink, pencil lines, and drawing ink, it is absorbed.

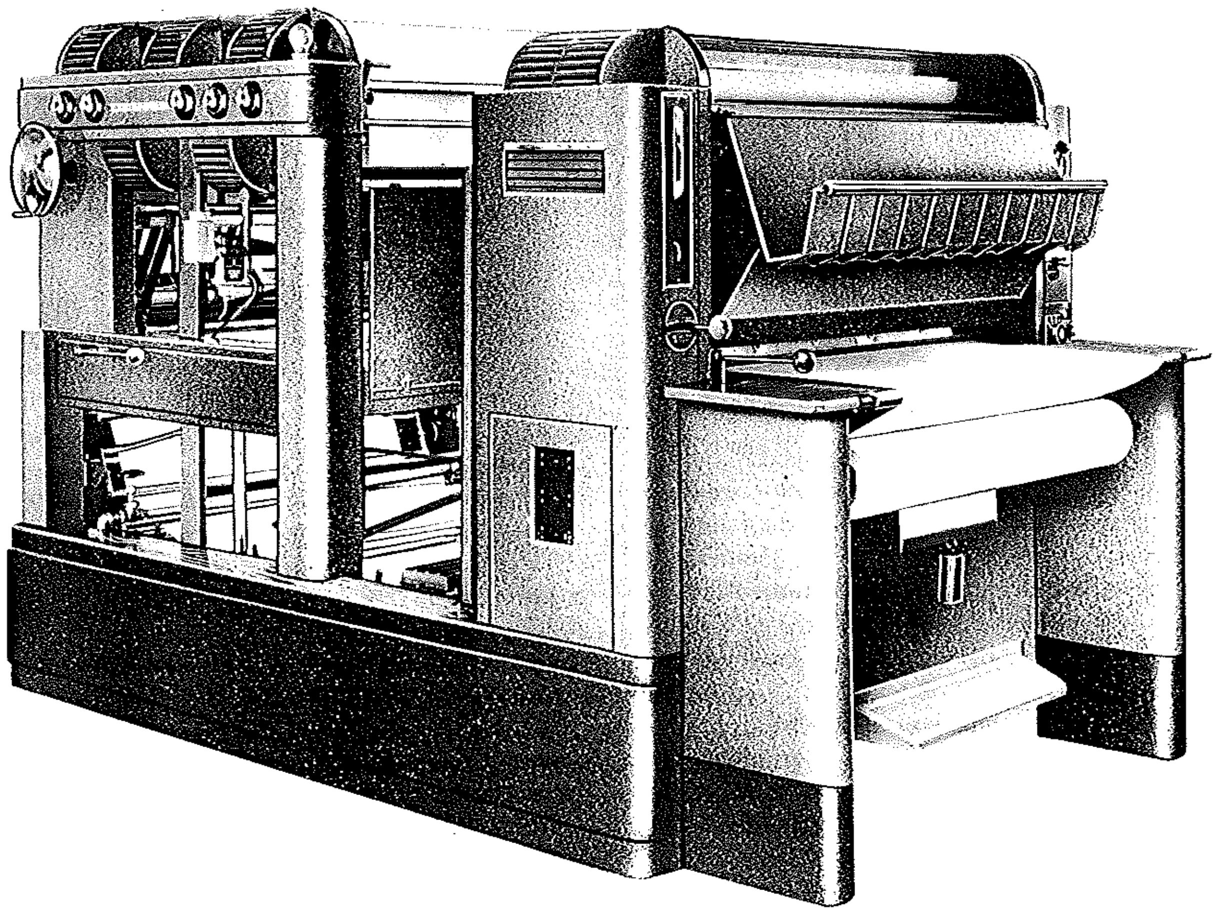


Fig. 27.1. Blueprinting machine. Courtesy C. F. Pease Co.

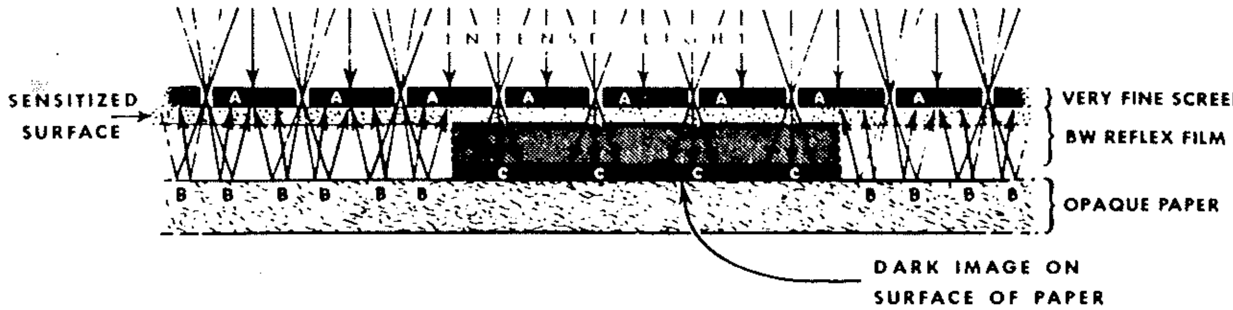


Fig. 27.2. Principle of reflex printing. Courtesy Charles Bruning Co.

Because there is no reflected light from these areas, the sensitized surface under the screen at this point remains unexposed.

After the film has been exposed, the screen is removed with a screen stripper and the film is developed. The result is a clear film positive from which prints may be made.

27.5 Ozalid. Another diazo-type method of reproduction is known as the Ozalid Process. In the Ozalid Process, the sensitized paper, as in the BW Process, is sensitive to actinic light, but instead of using a solution for a developing agent, ammonia fumes are used. The paper and tracing are first passed over the light source, and then the paper is passed over the section of the machine containing the ammonia fumes. The Ozalid Process has the advantage of being a dry process, but it has the disadvantage of requiring proper venting of the machine to carry off the excess ammonia fumes. As in the BW Process, it is possible to obtain the various color combinations.

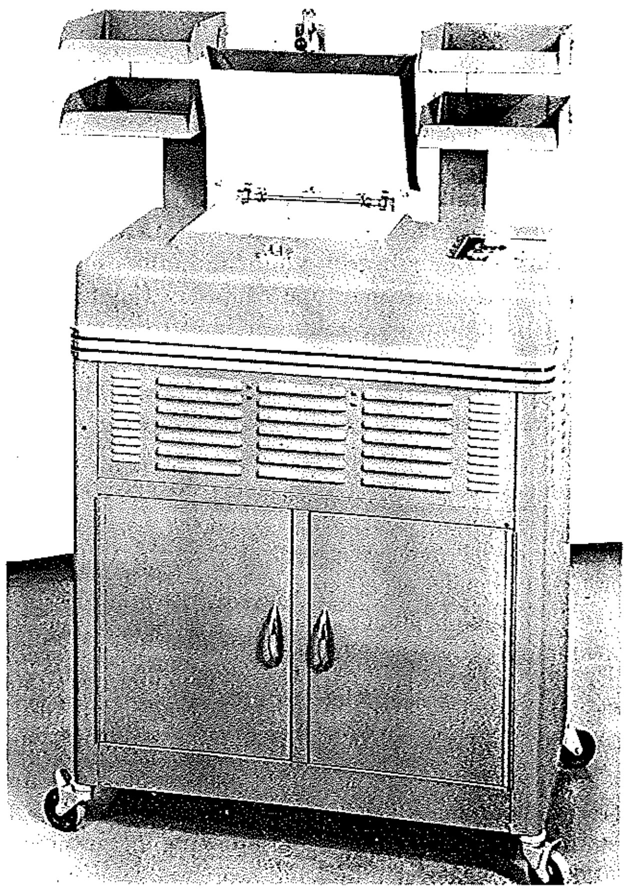


Fig. 27.3. Thermo-Fax printer. Courtesy Minnesota Mining and Mfg. Co.

27.6 Photact prints. To reproduce prints from opaque originals or poor tracings that were beyond their useful stage, the contact or vacuum printer was developed. With this printer, composed of a vacuum print frame with counterbalanced hinged cover and vacuum pump and a light source for both direct and reflex printing, it is possible to reproduce either by direct method (tracing), or reflex method (opaque original), a tracing on paper, cloth, or foil. It is possible to copy a tracing that cannot be used for reproduction purposes to obtain one that is usable.

27.7 Thermo-Fax. One of the newer processes that have been developed for reproduction purposes is the Thermo-Fax Process, developed by the Minnesota Mining and Manufacturing Company. The principle involved in this process is based on the use of a sheet which is heat sensitive, that is, it changes from a light color to a dark color by being heated to a temperature of 65° C or higher. This sheet is also transparent to the near infrared region of the spectrum. To reproduce a copy by this process, the sheet is placed in close contact with the original to be copied, and the intense light from the tungsten filament lamp passes through it, falling upon the original. The printed characters on the original, being black, absorb the light, become hot, and make their impressions in the heat-sensitive sheet directly in contact with it.

The machine used in this process, Fig. 27.3, consists of a horizontal plate glass to which is attached a sheet of silk screen cloth. The sheet of Thermo-Fax is laid with the white side down on the silk screen. The original copy is then laid face down on the dark side

of the Thermo-Fax sheet. A cover, when closed, causes an air bladder to press the two sheets against the silk screen and glass plate. Below the glass plate, within the body of the machine, is a track which traverses along its length. On this track a carriage, consisting of a linear reflector of elliptical cross section, moves. The linear axis is at right angles to the track, and the line joining the two foci of the ellipse is vertical. The reflector is cut off so that the upper focus of the ellipse lies just in the plane of the silk screen. Since the reflector is a linear reflector of the elliptical cross section, each focus forms a line in the horizontal plane and at right angles to the track. On the lower focal line, deep within the reflector, lies the filament of a 2500W tungsten lamp. The filament is a straight-line filament 12″ long, and the reflector is also 12″ long. Radiation from the filament lying on the lower focal line is reflected to a focus on the upper line in the plane of the silk screen. When the lamp is on, this line appears to be ¼″ wide and has such a brilliance that, if it were held stationary for any length of time, it might cause combustion. Whenever the lamp is lit, the carriage moves on the track, and thus the ¼″ line, traversing the width of the silk screen, moves in a path at right angles to itself, thereby sweeping out the complete area of the glass plate. As the focal line passes over the various characters on the original, infrared energy passes through the heat-sensitive sheet, heats the black characters, and causes them to make their impression on the heat-sensitive paper. This is almost instantaneous, as the focal line dwells on any one point in the original for less than 1/10 second.

The machine is entirely automatic, and the light moves from one end to the other. Upon reaching completion of its movement, the carriage stops and the light goes out. The Thermo-Fax sheet is not sensitive to light as such, but is only sensitive to the heat generated by the light when it is absorbed by the black images on the original. It will not be affected by temperatures lower than 65° C, and therefore may be shipped under most climatic conditions, as the temperature of 65° C corresponds to 150° F, a temperature that is very seldom exceeded in the hottest of areas.

At present it is not possible to print satisfactorily copies of colored images, which include fountain pen ink and any other organic inks. Ordinary typing copies, carbon copies, pencil or India ink copy very well. The main advantage of this process, as claimed by the company, is the simplicity and speed with which copies may be made.

27.8 Xerography. Another development in reproduction processes is Xerography (Zee-rog-ra-fee), a dry, electrical, direct positive process, which means that no negative is required. Powders are used instead of chemicals and water. No film or specially treated paper is necessary for this process. The mechanical unit, Fig. 27.4, is made up of three parts, reading from right to left: 1. XeroX camera; 2. XeroX copier; 3. XeroX fuser.

The general method involved in this process is as follows:

First, the surface of a specially coated plate is electrically charged with positive ions. The original copy is projected through the lens of the camera on the coated plate. The positive charges in the portion affected by the light disappear. A negatively charged powder is spread over the charged plate and adheres to the positive charges. After the powder treatment, a sheet of paper is placed over the plate and receives a positive charge attracting the powder from the plate, forming a direct positive image on the paper. The print is then heated in the fuser for a few seconds to fuse powder and to form a permanent print.

27.9 Photographic reproduction. When a copy of a drawing is desired for record only, a reproduction may be made by a photographic process, which will make direct copies of any drawing or printed matter whether in single sheets or in book form, without the use of negative plates, films, or a dark room. Several such machines are on the market, in which the lens focuses the images directly upon a sensitized paper, which is then developed and fixed within the machine itself by turning various cranks and levers. One of these machines is shown in Fig. 27.5. Drawings may be enlarged or reduced within the limits of the machine. This particular type of photographic reproduction is known as photostatic, and the machine is called a photostat.

27.10 Kodograph autopositive prints. The Eastman Kodak Company has developed a process whereby positive prints may be made from tracings or from drawings on opaque paper, using ordinary blueprinting equipment. A dark room is not necessary. These prints may be made on cloth or paper. A waterproof cloth has been developed so that the lines may be removed and changes made without spoiling the tracing.

27.11 Micro-film. Because of the enormous quantity of drawings made by some companies and the large amount of storage space required to file them, some companies are copying their drawings on 35 mm or 70 mm film. These films may then be used to reproduce the drawing by simple photographic enlargement. After filming, the original drawings may be destroyed or shipped away from the plant for permanent storage where space is cheap.

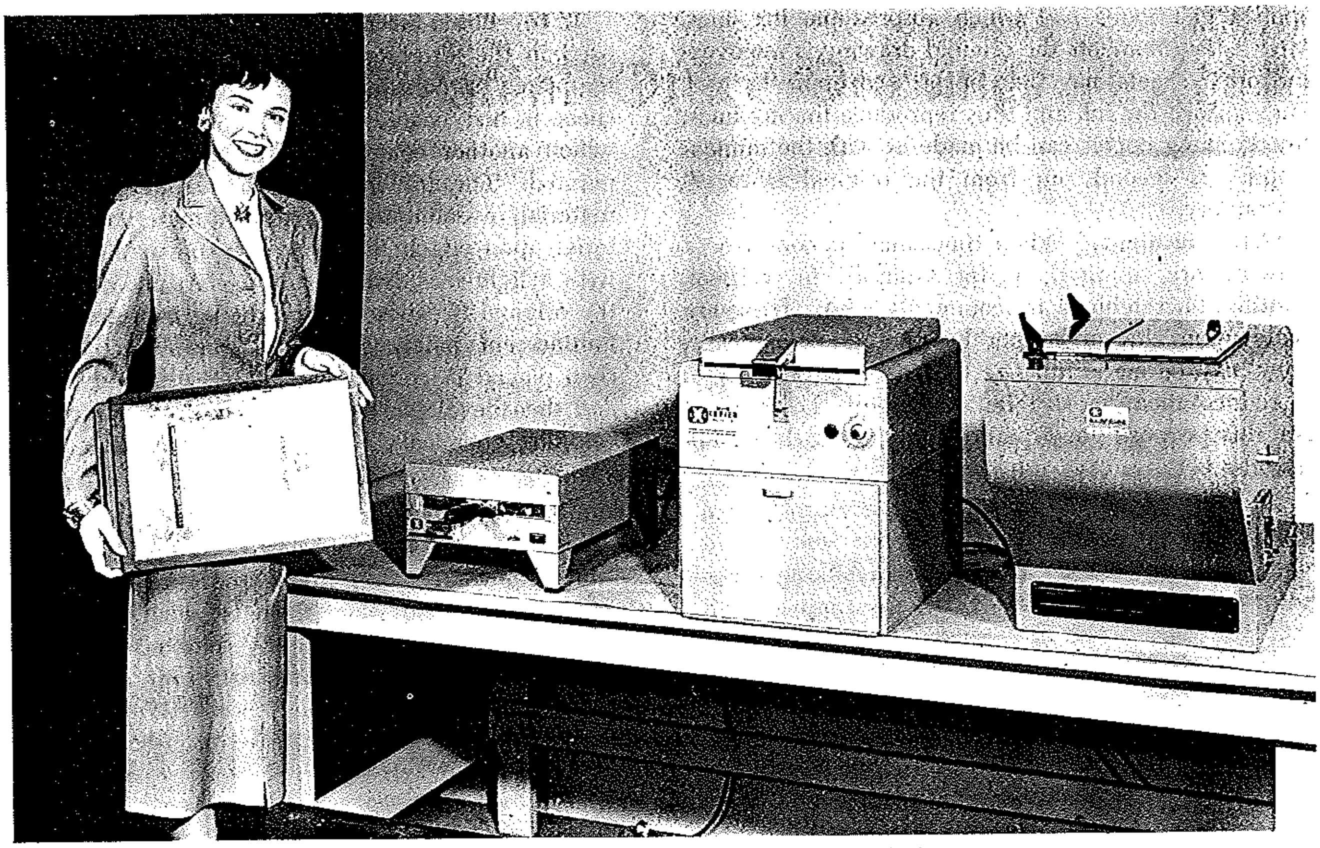


Fig. 27.4. Xerography equipment. Courtesy the Haloid Co.

27.12 Lithography. The lithographic process is rarely used in reproducing engineering drawings except maps. The drawing is reproduced on a lithographic stone either by photography or by transfer through a rubbing process. Prints are then made from the stone or indirectly by an offset method.

Another method of photolitho-printing sometimes called planographing involves the use of polished aluminum sheets. The drawings are reproduced upon the metal surface by photographic methods and printed by the offset process.

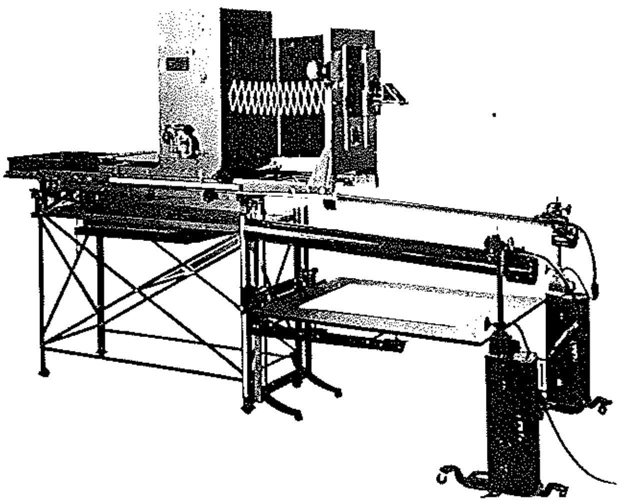


Fig. 27.5. Photostat. Courtesy Photostat Corporation.

This method is being introduced in some of the larger industries where hundreds of prints of the same drawing are required. These are usually reduced to half-size of the original drawing. The only change required in the original drawing is that the lettering must be made larger so that it will be clearly legible when reduced.

27.13 Mimeograph. The mimeograph, a common office machine, can be used to reproduce drawings in quantities. The quality of the drawing depends upon the skill of the draftsman in drawing with a stylus upon the mimeograph stencil. At best the drawings cannot have the sharpness and contrast obtained by other methods. The mimeograph stencil cannot be preserved indefinitely and hence it is usually used where it is known in advance that only one run of copies will be required.

27.14 Hectograph. The hectograph appears in offices under a number of trade names. Drawings are made with special hectograph ink or through carbon paper. The drawing is then placed face down

upon a gelatinous pad which absorbs the ink lines. After a few moments the original drawing is removed, and other sheets may then be pressed upon the pad. They absorb the ink and thus reproduce the ink lines. Not as many copies can be made as with the mimeograph. A second run from the original is rarely satisfactory.

27.15 Etchings. When thousands of copies of a drawing are required, as for example, in textbook printing, line etchings are commonly used. These are made upon zinc or copper by photographic means. They may be made full size but the usual practice is to reduce them in size below that of the original. For this purpose good-quality drawings in black ink give the best results.

27.16 Photo-mechanical process. This process is used in the aircraft industry to reproduce full-scale templates or part layouts from drawings. A metal sheet is first coated with a luminescent paint over which another coat of opaque masking material is painted. The drawing is scribed through the opaque material, revealing the luminescent material. The material upon which the copy is to be made is coated with a light-sensitive substance. To make the copy, the original is exposed to bright light to activate the luminescent paint. The second sensitized sheet is then placed in contact with it for the required time and then developed with the usual photographic developing chemicals. The original may be activated any number of times.

Patent Office Drawings 28

28.1 Meaning of patents.* The patent, as a physical entity (more properly "Letters Patent"), is a document stating the "grant" and including a "specification" describing the invention concerned and ending with one or more claims defining specifically the novel features of the invention. There must also be a drawing, if the invention permits of illustration, which drawing is fully described in the specification.

The Statute limits the field of patentable inventions (other than growing plants and designs) to processes, machines, manufactures, and compositions of matter. It also requires that the invention be "new and useful." It does not define the term "invention" other than to state that it means "invention or discovery." Many courts have tried to pass upon the degree of "genius" that must be displayed in the thing patented in order to amount to "invention." Some have said there must be a sudden inspiration, or a "flash of genius." In most cases, however, it has been regarded as sufficient if there is shown a degree of ingenuity beyond that to be expected of an average worker "skilled in the art."

The new Code tries to elucidate the matter by stating, Section 103, that a patent may not be granted "if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time when the invention was made to a person having ordinary skill in the art to which said subject matter pertains."

Let us assume that an inventor has perceived a need or a possible use for something new falling within the statutory classes noted above. By careful study or by a "happy thought," he arrives at a way in which the desired object or result may be obtained or a mechanism may be constructed by which an improvement may be effected. So far, this may have been only a mental process and, if so, no matter how definite his idea or how certain he may be that he has a solution to the problem in hand, he has not "made an invention" in the legal sense. He has only a "conception" and no means of proving even that.

If he then makes some sketches of the device or writes a description or both and signs and dates them, he now has available something in the nature of proof of the conception, but still no "invention." Furthermore, these documents need one or more witnesses who can testify that they saw the documents at a certain time. Accordingly, the cautious inventor will take the matter up with someone able to understand the device, explain it to him, and have the papers dated and signed. Now we have "corroboration," a highly important element in establishing an inventor's dates. These steps should be taken at the earliest possible time.

After "conception" the next step is to reduce the invention to practice. Without this the invention is not regarded as "completed." "Reduction to practice" may be accomplished in one of two ways, either by "actual" reduction, i.e., by making and operating the structure and actual carrying out of a process, or by filing an application for patent thereon in the Patent Office. Such filing is regarded, by a sort of legal fiction, as fully equivalent to actual reduction and is termed "constructive" reduction to practice.

"Actual" reduction to practice requires successful use under substantially the same conditions as those for which the device is designed. As an example, a man had devised a stoplight for automobiles but his only test had been by mounting the mechanism on a bench and operating it by a lever. He was held not to have "reduced to practice" since the device was not used on an automobile. This may be an extreme case but it illustrates the principle.

In order to prove actual reduction to practice one

* This article was abstracted by permission from a paper by George A. Lovett, Patent Attorney (retired), General Motors Corporation.

should have witnesses and records similar to those required in proof of conception. The device used in demonstrating successful use should be preserved if possible.

28.2 Application for patents. Applications for patents must be made to the Commissioner of Patents. A complete application comprises: (*a*) a petition or request for a patent; (*b*) a specification, including a claim or claims; (*c*) an oath; (*d*) drawings, when necessary; (*e*) the prescribed filing fee.

28.3 Specifications. The specifications accompanying a patent petition should be arranged in the following order:

a. Title of the invention; or a preamble stating the name, citizenship, and residence of the applicant and the title of the invention may be used.

b. Brief summary of the invention.

c. Brief description of the several views of the drawing, if there are drawings.

d. Detailed description.

e. Claim or claims.

f. Signature.

28.4 The drawings required by the Patent Office differ somewhat from those used in engineering practice. Before beginning the drawings the inventor should secure a copy of "Rules of Practice of the United States Patent Office" from the Supt. of Documents, Washington 25, D. C. The cost is $.40. Stamps are not acceptable in payment. The drawings used for patents are made according to the usual rules of orthographic projection, but it is not necessary that they appear in projection with each other nor on one sheet. The following rules quoted verbatim from "Rules of Practice of the United States Patent Office" must be followed exactly. They are illustrated in Fig. 28.1.

Drawings required. The applicant for patent is required by statute to furnish a drawing of his invention whenever the nature of the case admits of it; this drawing must be filed with the application. Illustrations facilitating an understanding of the invention (for example, flow sheets in cases of processes, and diagrammatic views) may also be furnished in the same manner as drawings, and may be required by the Office when considered necessary or desirable.

Signature to drawing. The drawing must either be signed by the applicant in person or have the name of the applicant placed thereon followed by the signature of the attorney or agent as such.

Content of drawing. The drawing must show every feature of the invention specified in the claims. When the invention consists of an improvement on an old machine the drawing must when possible exhibit, in one or more views, the improved portion itself, disconnected from the old structure, and also in another view, so much only of the old structure as will suffice to show the connection of the invention therewith.

Standards for drawings. The complete drawing is printed and published when the patent issues, and a copy is attached to the patent. This work is done by the photolithographic process, the sheets of drawings being reduced about one-third in size. In addition, a reduction of a selected portion of the drawing of each application is published in the *Official Gazette*. It is therefore necessary for these and other reasons that the character of each drawing be brought as nearly as possible to a uniform standard of execution and excellence, suited to the requirements of the reproduction process and of the use of the drawings, to give the best results in the interest of inventors, of the Office, and of the public. The following regulations with respect to drawings are accordingly prescribed:

(*a*) *Paper and ink.* Drawings must be made upon pure white paper of a thickness corresponding to two-ply or three-ply Bristol board. The surface of the paper must be calendered and smooth and of a quality which will permit erasure and correction. India ink alone must be used for pen drawings to secure perfectly black solid lines. The use of white pigment to cover lines is not acceptable.

(*b*) *Size of sheet and margins.* The size of a sheet on which a drawing is made must be exactly 10 by 15 inches. One inch from its edges a single marginal line is to be drawn, leaving the "sight" precisely 8 by 13 inches. Within this margin all work and signatures must be included. One of the shorter sides of the sheet is regarded as its top, and, measuring down from the marginal line, a space of not less than 1¼ inches is to be left blank for the heading of title, name, number, and date, which will be applied subsequently by the Office in a uniform style.

(*c*) *Character of lines.* All drawings must be made with drafting instruments or by photolithographic process which will give them satisfactory reproduction characteristics. Every line and letter (signatures included) must be absolutely black. This direction applies to all lines however fine, to shading, and to lines representing cut surfaces in sectional views. All lines must be clean, sharp, and solid, and fine or crowded lines should be avoided. Solid black should not be used for sectional or surface shading. Free-hand work should be avoided wherever it is possible to do so.

(*d*) *Hatching and shading.* Hatching should be made by oblique parallel lines, which may be not less than about one-twentieth inch apart.

Heavy lines on the shaded side of the object should be used except where they tend to thicken the work and obscure reference characters. The light should come from the upper left-hand corner at an angle of 45°. Surface delineations should be shown by proper shading, which should be open.

(*e*) *Scale.* The scale to which a drawing is made ought to be large enough to show the mechanism without crowding when the drawing is reduced in reproduction, and views of portions of the mechanism on a larger scale should be used when necessary to show details clearly; two or more sheets should be used if one does not give sufficient room to accomplish this end, but the number of sheets should not be more than is necessary.

(*f*) *Reference characters.* The different views should be consecutively numbered figures. Reference numerals (and letters, but numerals are preferred) must be plain, legible and carefully formed, and not be encircled. They should, if possible, measure at least one-eighth of an inch in height so that they may bear reduction to one twenty-fourth of an inch; and they may be slightly larger when there is sufficient room. They must not be so placed in the close and complex parts of the drawing as to interfere with a thorough comprehension of the same, and therefore should rarely cross or mingle with the lines. When necessarily grouped around a certain part, they

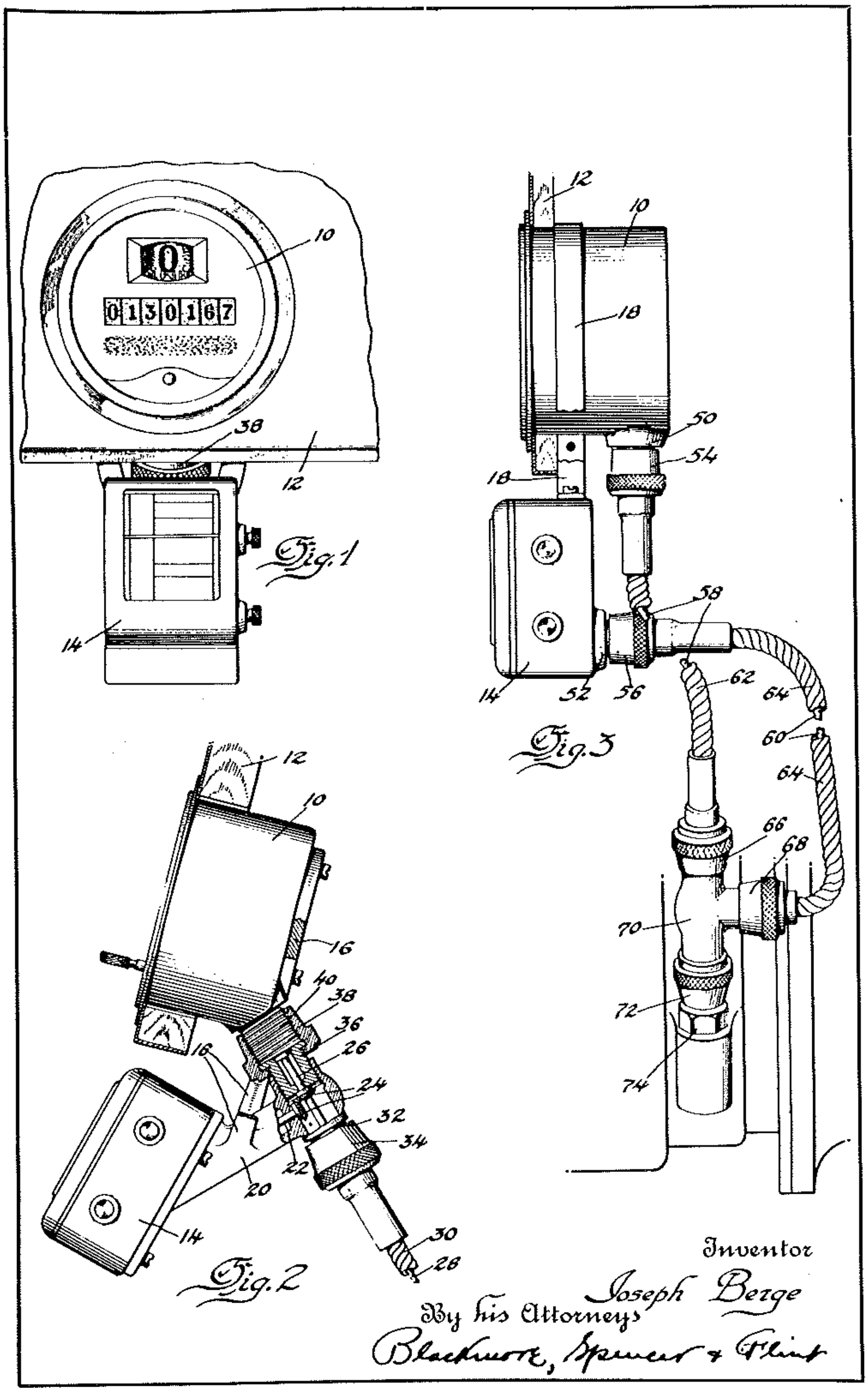


Fig. 28.1. Patent Office drawing.

should be placed at a little distance, at the closest point where there is available space, and connected by lines with the parts to which they refer. They should not be placed upon hatched or shaded surfaces but when necessary, a blank space may be left in the hatching or shading where the character occurs so that it shall appear perfectly distinct and separate from the work. The same part of an invention appearing in more than one view of the drawing must always be designated by the same character, and the same character must never be used to designate different parts.

(*g*) *Symbols, legends.* Graphical drawing symbols for conventional elements may be used when appropriate, subject to approval by the Office. The elements for which such symbols are used must be adequately identified in the specification. While descriptive matter on drawings is not permitted, suitable legends may be used, or may be required in proper cases, as in diagrammatic views and flow sheets. The lettering should be as large as, or larger than, the reference characters.

(*h*) *Location of signature and names.* The signature of the applicant, or the name of the applicant and signature of the attorney or agent, should be placed in the lower right-hand corner of each sheet within the marginal line. Signatures of witnesses are not required. The title of the invention must not be placed on the drawing but may be written in pencil below the lower marginal line.

(*i*) *Views.* The drawing must contain as many figures as may be necessary to show the invention; the figures should be consecutively numbered if possible, in the order in which they appear. The figures may be plan, elevation, section, or perspective views, and detail views of portions or elements, on a larger scale if necessary may also be used. Exploded views, with the separated parts of the same figure embraced by a bracket to show the relationship or order of assembly of various parts, are permissible. When necessary a view of a large machine or device in its entirety may be broken and extended over several sheets if there is no loss in facility of understanding the view (the different parts should be identified by the same figure number but followed by the letters, *a*, *b*, *c*, etc., for each part). The plane upon which a sectional view is taken should be indicated on the general view by a broken line, the ends of which should be designated by numerals corresponding to the figure number of the sectional view and have arrows applied to indicate the direction in which the view is taken. A moved position may be shown by a broken line superimposed upon a suitable figure if this can be done without crowding, otherwise a separate figure must be used for this purpose. Modified forms of construction can only be shown in separate figures. Views should not be connected by projection lines nor should center lines be used.

(*j*) *Arrangement of views.* All views on the same sheet must stand in the same direction and should, if possible, stand so that they can be read with the sheet held in an upright position. If views longer than the width of the sheet are necessary for the clearest illustration of the invention, the sheet may be turned on its side. The space for a heading must then be reserved at the right and the signatures placed at the left, occupying the same space and position on the sheet as in the upright views and being horizontal when the sheet is held in an upright position. One figure must not be placed upon another or within the outline of another.

(*k*) *Figure for Official Gazette.* The drawing should, as far as possible, be so planned that one of the views will be suitable for publication in the *Official Gazette* as the illustration of the invention.

(*l*) *Extraneous matter.* An agent's or attorney's stamp, or address, or other extraneous matter, will not be permitted upon the face of a drawing, within or without the marginal line, except that the title of the invention in pencil and identifying indicia, to distinguish from other drawings filed at the same time, may be placed below the lower margin.

(*m*) *Transmission of drawings.* Drawings transmitted to the Office should be sent flat, protected by a sheet of heavy binder's board, or may be rolled for transmission in a suitable mailing tube; but must never be folded. If received creased or mutilated, new drawings will be required.

See rule 152 for design drawings, 165 for plant drawings, and 174 for reissue drawings.

Informal drawings. The requirements of rule 84 relating to drawings will be strictly enforced. A drawing not executed in conformity thereto may be admitted for purpose of examination, but in such case the drawing must be corrected or a new one furnished, as required. The necessary corrections will be made by the Office upon applicant's request and at his expense. (See rule 21.)

Draftsman to make drawings. Applicants are advised to employ competent draftsmen to make their drawings.

The Office may furnish the drawings at the applicant's expense as promptly as its draftsmen can make them, for applicants who can not otherwise conveniently procure them. (See rule 21.)

Return of drawings. The drawings of an accepted application will not be returned to the applicant except for signature.

A photographic print is made of the drawing of an accepted application.

Use of old drawings. If the drawings of a new application are to be identical with the drawings of a previous application of the applicant on file in the Office, or with part of such drawings, the old drawings or any sheets thereof may be used if the prior application is, or is about to be, abandoned, or if the sheets to be used are cancelled in the prior application. The new application must be accompanied by a letter requesting the transfer of the drawings, which should be completely identified.

28.5 Symbols. The symbols to be used on patent drawings may be found in the "Rules of Practice" quoted above. Other symbols may be used if their meaning is clear and unequivocal.

Appendix 29

TABLE OF CONTENTS

In Numerical Order

In Alphabetical Order

TABLE OF CONTENTS (*Continued*)

IN NUMERICAL ORDER

IN ALPHABETICAL ORDER

TABLE 1. STANDARD DRILL SIZES

Fractional Letter Number	Decimal	Tolerance
80	0.0135	
1/64	.0156	Plus 0.0000
75	.021	
70	.028	
1/32	.0312	Minus 0.0006
65	.035	
60	.040	
3/64	.0469	
55	.052	
1/16	.0625	Plus 0.0000
50	.070	
5/64	.0781	
45	.082	Minus 0.0008
3/32	.0938	
40	.098	
7/64	.1094	
35	.110	
1/8	.125	
30	.1285	
9/64	.1406	
25	.1495	
5/32	.1562	
20	.161	Plus 0.0000
11/64	.1719	
15	.180	
3/16	.1875	Minus 0.0010
10	.1935	
13/64	.2031	
5	.2055	
7/32	.2188	
A	.234	
15/64	.2344	
1/4-E	.250	
F	.257	

Fractional Letter Number	Decimal	Tolerance
17/64	0.2656	
I	0.272	
9/32	0.2812	
M	0.295	
19/64	0.2969	
5/16	0.3125	
21/64	0.3281	Plus 0.0000
Q	0.332	
11/32	0.3438	
23/64	0.3594	
U	0.368	Minus 0.0015
3/8	0.375	
W	0.386	
25/64	0.3906	Plus 0.0000
Y	0.404	
13/32	0.4062	Minus 0.0015
Z	0.413	
27/64	0.4219	
to		
3/4 by 1/64 intervals	0.750	
3/4 to 1 1/2 by 1/64 intervals	1.500	Plus 0.0000 Minus 0.0020
1 1/2 to 1 3/4 by 1/64 intervals	1.750	Plus 0.0000
1 3/4 to 2 1/4 by 1/32 intervals	2.250	Minus 0.0025
2 1/4 to 3 1/2 by 1/16 intervals	3.500	

There is a drill size for every number from 80 to 1 and for every letter from A to Z.

TABLE 2. UNIFIED AND AMERICAN THREADS

Coarse-Thread Series—UNC and NC

(Basic Dimensions)

Sizes	Basic Major Diameter, D	Thds. per Inch, n	Basic Pitch Diameter,* E	Minor Diameter Ext. Thds. K_s	Minor Diameter Int. Thds. K_n	Lead Angle at Basic Pitch Diameter, λ		Section at Minor Diameter at $D - 2h_b$	Stress Area †	Tap Drill Number or Size
	Inches		Inches	Inches	Inches	Deg.	Min.	Sq In.	Sq In.	
1(.073)	0.0730	64	0.0629	0.0538	0.0561	4	31	0.0022	0.0026	53
2(.086)	0.0860	56	0.0744	0.0641	0.0667	4	22	0.0031	0.0036	50
3(.099)	0.0990	48	0.0855	0.0734	0.0764	4	26	0.0041	0.0048	47
4(.112)	0.1120	40	0.0958	0.0813	0.0849	4	45	0.0050	0.0060	43
5(.125)	0.1250	40	0.1088	0.0943	0.0979	4	11	0.0067	0.0079	38
6(.138)	0.1380	32	0.1177	0.0997	0.1042	4	50	0.0075	0.0090	36
8(.164)	0.1640	32	0.1437	0.1257	0.1302	3	58	0.0120	0.0139	29
10(.190)	0.1900	24	0.1629	0.1389	0.1449	4	39	0.0145	0.0174	26
12(.216)	0.2160	24	0.1889	0.1649	0.1709	4	1	0.0206	0.0240	16
1/4	**0.2500**	**20**	**0.2175**	**0.1887**	**0.1959**	**4**	**11**	**0.0269**	**0.0317**	**7**
5/16	**0.3125**	**18**	**0.2764**	**0.2443**	**0.2524**	**3**	**40**	**0.0454**	**0.0522**	**F**
3/8	**0.3750**	**16**	**0.3344**	**0.2983**	**0.3073**	**3**	**24**	**0.0678**	**0.0773**	**5/16**
7/16	**0.4375**	**14**	**0.3911**	**0.3499**	**0.3602**	**3**	**20**	**0.0933**	**0.1060**	**U**
1/2	0.5000	13	0.4500	0.4056	0.4167	3	7	0.1257	0.1416	27/64
1/2	**0.5000**	**12**	**0.4459**	**0.3978**	**0.4098**	**3**	**24**	**0.1205**	**0.1374**	**27/64**
9/16	**0.5625**	**12**	**0.5084**	**0.4603**	**0.4723**	**2**	**59**	**0.1620**	**0.1816**	**31/64**
5/8	**0.6250**	**11**	**0.5660**	**0.5135**	**0.5266**	**2**	**56**	**0.2018**	**0.2256**	**17/32**
3/4	**0.7500**	**10**	**0.6850**	**0.6273**	**0.6417**	**2**	**40**	**0.3020**	**0.3340**	**21/32**
7/8	**0.8750**	**9**	**0.8028**	**0.7387**	**0.7547**	**2**	**31**	**0.4193**	**0.4612**	**49/64**
1	**1.0000**	**8**	**0.9188**	**0.8466**	**0.8647**	**2**	**29**	**0.5510**	**0.6051**	**7/8**
1 1/8	**1.1250**	**7**	**1.0322**	**0.9497**	**0.9704**	**2**	**31**	**0.6931**	**0.7627**	**63/64**
1 1/4	**1.2500**	**7**	**1.1572**	**1.0747**	**1.0954**	**2**	**15**	**0.8898**	**0.9684**	**1 7/64**
1 3/8	**1.3750**	**6**	**1.2667**	**1.1705**	**1.1946**	**2**	**24**	**1.0541**	**1.1538**	**1 13/64**
1 1/2	**1.5000**	**6**	**1.3917**	**1.2955**	**1.3196**	**2**	**11**	**1.2938**	**1.4041**	**1 11/32**
1 3/4	**1.7500**	**5**	**1.6201**	**1.5046**	**1.5335**	**2**	**15**	**1.7441**	**1.8983**	**1 9/16**
2	**2.0000**	**4 1/2**	**1.8557**	**1.7274**	**1.7594**	**2**	**11**	**2.3001**	**2.4971**	**1 25/32**
2 1/4	**2.2500**	**4 1/2**	**2.1057**	**1.9774**	**2.0094**	**1**	**55**	**3.0212**	**3.2464**	**2 1/32**
2 1/2	**2.5000**	**4**	**2.3376**	**2.1933**	**2.2294**	**1**	**57**	**3.7161**	**3.9976**	**2 1/4**
2 3/4	**2.7500**	**4**	**2.5876**	**2.4433**	**2.4794**	**1**	**46**	**4.6194**	**4.9326**	**2 1/2**

* British: Effective Diameter.

† The stress area is the assumed area of an externally threaded part which is used for the purpose of computing the tensile strength.

Bold type indicates unified threads.

Courtesy ASA.

TABLE 3. Unified and American Threads
Fine-Thread Series—UNF and NF
(Basic Dimensions)

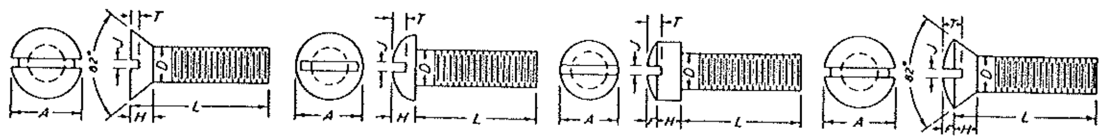
Sizes	Basic Major Diameter, D	Thds. per Inch, n	Basic Pitch Diameter,* E	Minor Diameter Ext. Thds. K_s	Minor Diameter Int. Thds. K_n	Lead Angle at Basic Pitch Diameter, λ		Section at Minor Diameter at $D - 2h_b$	Stress Area †	Tap Drill Number or Size
	Inches		Inches	Inches	Inches	Deg.	Min.	Sq In.	Sq In.	
0(.060)	0.0600	80	0.0519	0.0447	0.0465	4	23	0.0015	0.0018	3/64
1(.073)	0.0730	72	0.0640	0.0560	0.0580	3	57	0.0024	0.0027	53
2(.086)	0.0860	64	0.0759	0.0668	0.0691	3	45	0.0034	0.0039	50
3(.099)	0.0990	56	0.0874	0.0771	0.0797	3	43	0.0045	0.0052	45
4(.112)	0.1120	48	0.0985	0.0864	0.0894	3	51	0.0057	0.0065	42
5(.125)	0.1250	44	0.1102	0.0971	0.1004	3	45	0.0072	0.0082	37
6(.138)	0.1380	40	0.1218	0.1073	0.1109	3	44	0.0087	0.0101	33
8(.164)	0.1640	36	0.1460	0.1299	0.1339	3	28	0.0128	0.0146	29
10(.190)	0.1900	32	0.1697	0.1517	0.1562	3	21	0.0175	0.0199	22
12(.216)	0.2160	28	0.1928	0.1722	0.1773	3	22	0.0226	0.0257	14
1/4	0.2500	28	0.2268	0.2062	0.2113	2	52	0.0326	0.0362	3
5/16	0.3125	24	0.2854	0.2614	0.2674	2	40	0.0524	0.0579	I
3/8	0.3750	24	0.3479	0.3239	0.3299	2	11	0.0809	0.0876	Q
7/16	0.4375	20	0.4050	0.3762	0.3834	2	15	0.1090	0.1185	25/64
1/2	0.5000	20	0.4675	0.4387	0.4459	1	57	0.1486	0.1597	29/64
9/16	0.5625	18	0.5264	0.4943	0.5024	1	55	0.1888	0.2026	33/64
5/8	0.6250	18	0.5889	0.5568	0.5649	1	43	0.2400	0.2555	37/64
3/4	0.7500	16	0.7094	0.6733	0.6823	1	36	0.3513	0.3724	11/16
7/8	0.8750	14	0.8286	0.7874	0.7977	1	34	0.4805	0.5088	13/16
1	1.0000	12	0.9459	0.8978	0.9098	1	36	0.6245	0.6624	59/64
1 1/8	1.1250	12	1.0709	1.0228	1.0348	1	25	0.8118	0.8549	1 3/64
1 1/4	1.2500	12	1.1959	1.1478	1.1598	1	16	1.0237	1.0721	1 11/64
1 3/8	1.3750	12	1.3209	1.2728	1.2848	1	9	1.2602	1.3137	1 19/64
1 1/2	1.5000	12	1.4459	1.3978	1.4098	1	3	1.5212	1.5799	1 27/64

* British: Effective Diameter.
† The stress area is the assumed area of an externally threaded part which is used for the purpose of computing the tensile strength.
Bold type indicates unified threads.

Courtesy ASA.

TABLE 4. Slotted Head Machine Screws (American Standard)

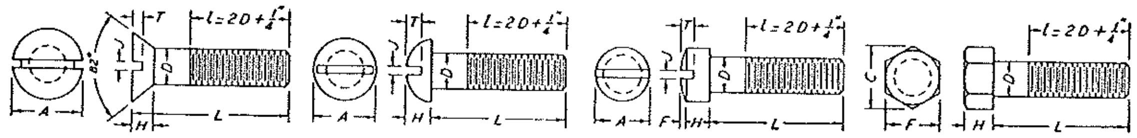
Flat Head — Round Head — Fillister Head — Oval Head



Nominal Size	Maximum Diameter	Threads per Inch (Coarse Series)	Maximum Diameter of Head: Flat and Oval	Maximum Diameter of Head: Round	Maximum Diameter of Head: Fillister	Maximum Height of Head: Flat and Oval	Maximum Height of Head: Round	Maximum Height of Head: Fillister	Maximum Width of Slot	Maximum Depth of Slot: Flat	Maximum Depth of Slot: Round	Maximum Depth of Slot: Fillister	Maximum Depth of Slot: Oval	Maximum Height of the Head: Oval	Maximum Height of the Head: Fillister
	(D)		(A)	(A)	(A)	(H)	(H)	(H)	(J)	(T)	(T)	(T)	(T)	(F)	(F)
2	0.086	56	0.172	0.162	0.140	0.051	0.070	0.055	0.036	0.023	0.048	0.037	0.045	0.036	0.028
3	.099	48	.199	.187	.161	.059	.078	.063	.038	.027	.053	.043	.052	.038	.032
4	.112	40	.225	.211	.183	.067	.086	.072	.040	.030	.058	.048	.059	.040	.035
5	.125	40	.252	.236	.205	.075	.095	.081	.043	.034	.062	.054	.067	.043	.039
6	.138	32	.279	.260	.226	.083	.103	.089	.045	.038	.067	.060	.074	.045	.043
8	.164	32	.352	.309	.270	.100	.119	.106	.050	.045	.076	.071	.088	.050	.050
10	.190	24	.385	.359	.313	.116	.136	.123	.055	.053	.086	.083	.103	.055	.057
12	.216	24	.438	.408	.357	.132	.152	.141	.059	.060	.095	.094	.117	.059	.064
¼	.250	20	.507	.472	.414	.153	.174	.163	.066	.070	.108	.109	.136	.066	.074
5/16	.3125	18	.636	.591	.519	.192	.214	.205	.077	.088	.130	.137	.171	.077	.092
⅜	.375	16	.762	.708	.622	.230	.254	.246	.088	.106	.153	.164	.206	.088	.109

TABLE 5. Slotted and Hexagonal-Head Cap Screws (American Standard)

Flat Head — Button Head — Fillister Head — Hexagonal Head



Nominal Size	Maximum Diameter	Threads per Inch	Maximum Diameter of Head: Flat	Maximum Diameter of Head: Button	Maximum Diameter of Head: Fillister	Maximum Height of Head: Flat (Nominal)	Maximum Height of Head: Button	Maximum Height of Head: Fillister	Maximum Width of Slot	Maximum Depth of Slot: Flat	Maximum Depth of Slot: Button	Maximum Depth of Slot: Fillister	Maximum Height of Fillister Head Oval	Finished Hexagonal-Head Cap Screw: Maximum Width Across Flats	Finished Hexagonal-Head Cap Screw: Minimum Width Across Corners	Finished Hexagonal-Head Cap Screw: Maximum Height
	(D)		(A)	(A)	(A)	(H)	(H)	(H)	(J)	(T)	(T)	(T)	(F)	(F)	(C)	(H)
¼	0.2500	20	½	7/16	⅜	0.146	0.191	11/64	0.070	0.073	0.117	0.097	0.044	0.4375	0.488	0.194
5/16	0.3125	18	⅝	9/16	7/16	.183	.246	13/64	.079	.091	.151	.115	.050	0.5000	0.577	.242
⅜	0.3750	16	¾	⅝	9/16	.220	.273	¼	.088	.110	.167	.142	.061	0.5625	0.628	.289
7/16	0.4375	14	13/16	¾	⅝	.220	.328	19/64	.098	.110	.202	.168	.071	0.6250	0.698	.337
½	0.5000	13	⅞	13/16	¾	.220	.355	21/64	.110	.110	.219	.188	.084	0.7500	0.840	.385
9/16	0.5625	12	1		13/16	.256	.410	⅜	.123	.128	.253	.214	.091	0.8125	0.910	.433
⅝	0.6250	11	1⅛		⅞	.293	.438	27/64	.138	.146	.270	.240	.099	0.8750	0.980	.481
¾	0.7500	10	1⅜		1	.366	.547	½	.154	.183	.337	.283	.112	1.0000	1.121	.576
⅞	0.8750	9			1⅛			19/32	.173			.334	.126	1.1250	1.261	.672
1	1.0000	8			1 5/16			21/32	.194			.372	.146	1.3125	1.473	.768
1⅛	1.1250	7												1.5000	1.684	.863
1¼	1.2500	7												1.6875	1.896	.959

TABLE 6. Regular Bolt Heads

Nominal Size or Basic Major Diameter of Thread		Width across Flats: Unfinished and Semifinished		Width across Corners: Square Unfinished	Width across Corners: Hexagonal Unfinished and Semi-finished	Height of Head: Unfinished Nom.	Height of Head: Unfinished Max.	Height of Head: Semifinished Nom.	Height of Head: Semifinished Max.
1/4	0.2500	3/8	0.3750	0.498	0.413	11/64	0.188	5/32	0.172
5/16	0.3125	1/2	0.5000	0.665	0.552	13/64	0.220	3/16	0.205
3/8	0.3750	9/16	0.5625	0.747	0.620	1/4	0.268	15/64	0.252
7/16	0.4375	5/8	0.6250	0.828	0.687	19/64	0.316	9/32	0.300
1/2	0.5000	3/4	0.7500	0.995	0.826	21/64	0.348	19/64	0.317
9/16	0.5625	7/8	0.8750	1.163	0.966	3/8	0.396	11/32	0.365
5/8	0.6250	15/16	0.9375	1.244	1.033	27/64	0.444	25/64	0.413
3/4	0.7500	1 1/8	1.1250	1.494	1.240	1/2	0.524	15/32	0.493
7/8	0.8750	1 5/16	1.3125	1.742	1.447	19/32	0.620	9/16	0.589
1	1.0000	1 1/2	1.5000	1.991	1.653	21/32	0.684	19/32	0.622
1 1/8	1.1250	1 11/16	1.6875	2.239	1.859	3/4	0.780	11/16	0.718
1 1/4	1.2500	1 7/8	1.8750	2.489	2.066	27/32	0.876	25/32	0.813
1 3/8	1.3750	2 1/16	2.0625	2.738	2.273	29/32	0.940	27/32	0.878
1 1/2	1.5000	2 1/4	2.2500	2.986	2.480	1	1.036	15/16	0.974
1 5/8	1.6250	2 7/16	2.4375	3.235	2.686	1 3/32	1.132	1 1/32	1.069
1 3/4	1.7500	2 5/8	2.6250	3.485	2.893	1 5/32	1.196	1 3/32	1.134
1 7/8	1.8750	2 13/16	2.8125	3.733	3.100	1 1/4	1.292	1 3/16	1.230
2	2.0000	3	3.0000	3.982	3.306	1 11/32	1.388	1 7/32	1.263

Thickness of washer face on semifinished heads shall be approximately 1/64 inch, included in the head height. Diameter of washer shall be the same as the width across flats.

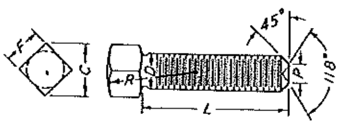
Courtesy ASA.

TABLE 7. REGULAR NUTS

Nominal Size or Basic Major Diameter of Thread		Width across Flats		Width across Corners		Thickness of Regular Nuts				Thickness of Regular Jam Nuts			
		Unfinished and Semifinished		Square Unfinished	Hexagonal Unfinished and Semifinished	Unfinished		Semifinished		Unfinished		Semifinished	
						Nom.	Max.	Nom.	Max.	Nom.	Max.	Nom.	Max.
1/4	0.2500	7/16	0.4375	0.584	0.484	7/32	0.235	13/64	0.219	5/32	0.172	9/64	0.157
5/16	0.3125	9/16	0.5625	0.751	0.624	17/64	0.283	1/4	0.267	3/16	0.204	11/64	0.189
3/8	0.3750	5/8	0.6250	0.832	0.691	21/64	0.346	5/16	0.330	7/32	0.237	13/64	0.221
7/16	0.4375	3/4	0.7500	1.000	0.830	3/8	0.394	23/64	0.378	1/4	0.269	15/64	0.253
1/2	0.5000	13/16	0.8125	1.082	0.898	7/16	0.458	27/64	0.442	5/16	0.332	19/64	0.317
9/16	0.5625	7/8	0.8750	1.163	0.966	1/2	0.521	31/64	0.505	11/32	0.365	21/64	0.349
5/8	0.6250	1	1.0000	1.330	1.104	35/64	0.569	17/32	0.553	3/8	0.397	23/64	0.381
3/4	0.7500	1 1/8	1.1250	1.494	1.240	21/32	0.680	41/64	0.665	7/16	0.462	27/64	0.446
7/8	0.8750	1 5/16	1.3125	1.742	1.447	49/64	0.792	3/4	0.776	1/2	0.526	31/64	0.510
1	1.0000	1 1/2	1.5000	1.991	1.653	7/8	0.903	55/64	0.887	9/16	0.590	35/64	0.575
1 1/8	1.1250	1 11/16	1.6875	2.239	1.859	1	1.030	31/32	0.999	5/8	0.655	39/64	0.639
1 1/4	1.2500	1 7/8	1.8750	2.489	2.066	1 3/32	1.126	1 1/16	1.094	3/4	0.782	23/32	0.751
1 3/8	1.3750	2 1/16	2.0625	2.738	2.273	1 13/64	1.237	1 11/64	1.206	13/16	0.846	25/32	0.815
1 1/2	1.5000	2 1/4	2.2500	2.986	2.480	1 5/16	1.348	1 9/32	1.317	7/8	0.911	27/32	0.880
1 5/8	1.6250	2 7/16	2.4375	3.235	2.686	1 27/64	1.460	1 25/64	1.429	15/16	0.976	29/32	0.944
1 3/4	1.7500	2 5/8	2.6250	3.485	2.893	1 17/32	1.571	1 1/2	1.540	1	1.040	31/32	1.009
1 7/8	1.8750	2 13/16	2.8125	3.733	3.100	1 41/64	1.683	1 39/64	1.651	1 1/16	1.104	1 1/32	1.073
2	2.0000	3	3.0000	3.982	3.306	1 3/4	1.794	1 23/32	1.763	1 1/8	1.169	1 3/32	1.138

Courtesy ASA.

TABLE 8. American Standard Set Screw (Cup Point)



Nominal Diameter	Threads per Inch	Maximum Width across Flats	Minimum Width across Corners	Nominal Height of Head	Radius of Crown	Nominal Diameter of Cup Point
(*D*)		(*F*)	(*C*)	(*H*)	(*R*)	(*P*)
1/4	20	1/4	0.331	3/16	5/8	0.125
5/16	18	5/16	0.415	15/64	25/32	0.164
3/8	16	3/8	0.497	9/32	15/16	0.203
7/16	14	7/16	0.581	21/64	13/32	0.242
1/2	13	1/2	0.665	3/8	1 1/4	0.281
9/16	12	9/16	0.748	27/64	1 13/32	0.321
5/8	11	5/8	0.833	15/32	1 9/16	0.359
3/4	10	3/4	1.001	9/16	1 7/8	0.438
7/8	9	7/8	1.170	21/32	2 3/16	0.516
1	8	1	1.337	3/4	2 1/2	0.594
1 1/8	7	1 1/8	1.506	27/32	2 13/16	0.672
1 1/4	7	1 1/4	1.674	15/16	3 1/8	0.750
1 3/8	6	1 3/8	1.843	1 1/32	3 7/16	0.828
1 1/2	6	1 1/2	2.010	1 1/8	3 3/4	0.906

Sizes larger than 5/16 are necked to a width twice the pitch and to a diameter equal to the minor diameter of the threads.

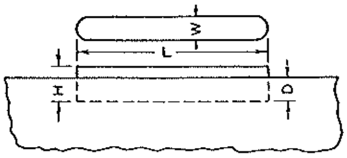
TABLE 9. American National Pipe Thread Tap Drill Sizes

Sizes of Pipe, Inches	Number of Threads per Inch	Root Diameter Small End of Pipe and Gage, Inches	Tap Drill	
			Size	Decimal Equivalent
1/8	27	0.3339	R	0.339
1/4	18	0.4329	7/16	0.437
3/8	18	0.5676	37/64	0.578
1/2	14	0.7013	23/32	0.719
3/4	14	0.9105	59/64	0.921
1	11 1/2	1.1441	1 5/32	1.156
1 1/4	11 1/2	1.4876	1 1/2	1.500
1 1/2	11 1/2	1.7265	1 47/64	1.734
2	11 1/2	2.1995	2 7/32	2.218
2 1/2	8	2.6195	2 5/8	2.625
3	8	3.2406	3 1/4	3.250
3 1/2	8	3.7375	3 3/4	3.750
4	8	4.2344	4 1/4	4.250

Courtesy Brown & Sharpe Mfg. Co.

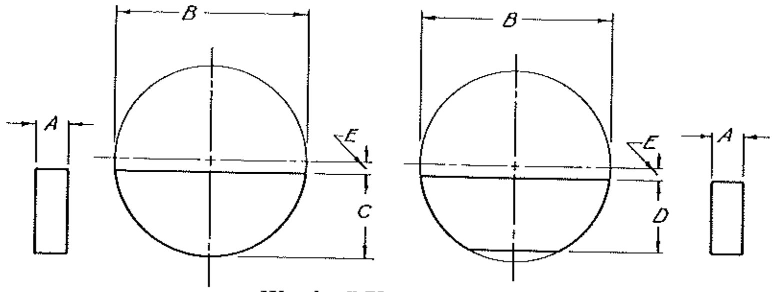
TABLE 10. PROPORTIONS OF KEYS IN THE PRATT AND WHITNEY SYSTEM

(Numbers same as in the Woodruff system.)



No. of Key	L	W	H	D	No. of Key	L	W	H	D
1	1/2	1/16	3/32	1/16	22	1 3/8	1/4	3/8	1/4
2	1/2	3/32	9/64	3/32	23	1 3/8	5/16	15/32	5/16
3	1/2	1/8	3/16	1/8	F	1 3/8	3/8	9/16	3/8
4	5/8	3/32	9/64	3/32	24	1 1/2	1/4	3/8	1/4
5	5/8	1/8	3/16	1/8	25	1 1/2	5/16	15/32	5/16
6	5/8	5/32	15/64	5/32	G	1 1/2	3/8	9/16	3/8
7	3/4	1/8	3/16	1/8	51	1 3/4	1/4	3/8	1/4
8	3/4	5/32	15/64	5/32	52	1 3/4	5/16	15/32	5/16
9	3/4	3/16	9/32	3/16	53	1 3/4	3/8	9/16	3/8
10	7/8	5/32	15/64	5/32	26	2	3/16	9/32	3/16
11	7/8	3/16	9/32	3/16	27	2	1/4	3/8	1/4
12	7/8	7/32	21/64	7/32	28	2	5/16	15/32	5/16
A	7/8	1/4	3/8	1/4	29	2	3/8	9/16	3/8
13	1	3/16	9/32	3/16	54	2 1/4	1/4	3/8	1/4
14	1	7/32	21/64	7/32	55	2 1/4	5/16	15/32	5/16
15	1	1/4	3/8	1/4	56	2 1/4	3/8	9/16	3/8
B	1	5/16	15/32	5/16	57	2 1/4	7/16	21/32	7/16
16	1 1/8	3/16	9/32	3/16	58	2 1/2	5/16	15/32	5/16
17	1 1/8	7/32	21/64	7/32	59	2 1/2	3/8	9/16	3/8
18	1 1/8	1/4	3/8	1/4	60	2 1/2	7/16	21/32	7/16
C	1 1/8	5/16	15/32	5/16	61	2 1/2	1/2	3/4	1/2
19	1 1/4	3/16	9/32	3/16	30	3	3/8	9/16	3/8
20	1 1/4	7/32	21/64	7/32	31	3	7/16	21/32	7/16
21	1 1/4	1/4	3/8	1/4	32	3	1/2	3/4	1/2
D	1 1/4	5/16	15/32	5/16	33	3	9/16	27/32	9/16
E	1 1/4	3/8	9/16	3/8	34	3	5/8	15/16	5/8

TABLE 11. Woodruff Keys



Woodruff Key Dimensions

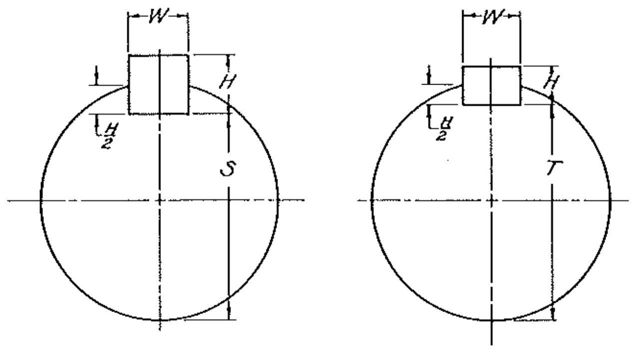
Key * Number	Nominal Key Size $A \times B$	Width of Key A Max.	Width of Key A Min.	Diam. of Key B Max.	Diam. of Key B Min.	Height of Key C Max.	Height of Key C Min.	Height of Key D Max.	Height of Key D Min.	Distance Below Center E
204	$\frac{1}{16} \times \frac{1}{2}$	0.0635	0.0625	0.500	0.490	0.203	0.198	0.194	0.188	$\frac{3}{64}$
304	$\frac{3}{32} \times \frac{1}{2}$	.0948	.0938	0.500	0.490	.203	.198	.194	.188	$\frac{3}{64}$
305	$\frac{3}{32} \times \frac{5}{8}$	.0948	.0938	0.625	0.615	.250	.245	.240	.234	$\frac{1}{16}$
404	$\frac{1}{8} \times \frac{1}{2}$	.1260	.1250	0.500	0.490	.203	.198	.194	.188	$\frac{3}{64}$
405	$\frac{1}{8} \times \frac{5}{8}$	.1260	.1250	0.625	0.615	.250	.245	.240	.234	$\frac{1}{16}$
406	$\frac{1}{8} \times \frac{3}{4}$	.1260	.1250	0.750	0.740	.313	.308	.303	.297	$\frac{1}{16}$
505	$\frac{5}{32} \times \frac{5}{8}$	.1573	.1563	0.625	0.615	.250	.245	.240	.234	$\frac{1}{16}$
506	$\frac{5}{32} \times \frac{3}{4}$	.1573	.1563	0.750	0.740	.313	.308	.303	.297	$\frac{1}{16}$
507	$\frac{5}{32} \times \frac{7}{8}$	.1573	.1563	0.875	0.865	.375	.370	.365	.359	$\frac{1}{16}$
606	$\frac{3}{16} \times \frac{3}{4}$	.1885	.1875	0.750	0.740	.313	.308	.303	.297	$\frac{1}{16}$
607	$\frac{3}{16} \times \frac{7}{8}$	.1885	.1875	0.875	0.865	.375	.370	.365	.359	$\frac{1}{16}$
608	$\frac{3}{16} \times 1$	.1885	.1875	1.000	0.990	.438	.433	.428	.422	$\frac{1}{16}$
609	$\frac{3}{16} \times 1\frac{1}{8}$	.1885	.1875	1.125	1.115	.484	.479	.475	.469	$\frac{5}{64}$
807	$\frac{1}{4} \times \frac{7}{8}$	.2510	.2500	0.875	0.865	.375	.370	.365	.359	$\frac{1}{16}$
808	$\frac{1}{4} \times 1$	.2510	.2500	1.000	0.990	.438	.433	.428	.422	$\frac{1}{16}$
809	$\frac{1}{4} \times 1\frac{1}{8}$	.2510	.2500	1.125	1.115	.484	.479	.475	.469	$\frac{5}{64}$
810	$\frac{1}{4} \times 1\frac{1}{4}$	.2510	.2500	1.250	1.240	.547	.542	.537	.531	$\frac{5}{64}$
811	$\frac{1}{4} \times 1\frac{3}{8}$	.2510	.2500	1.375	1.365	.594	.589	.584	.578	$\frac{3}{32}$
812	$\frac{1}{4} \times 1\frac{1}{2}$	.2510	.2500	1.500	1.490	.641	.636	.631	.625	$\frac{7}{64}$

All dimensions given in inches.

* Note: Key numbers indicate the nominal key dimensions. The last two digits give the nominal diameter (B) in eighths of an inch and the digits preceding the last two give the nominal width (A) in thirty-seconds of an inch. Thus, 204 indicates a key $\frac{2}{32} \times \frac{4}{8}$ or $\frac{1}{16} \times \frac{1}{2}$ inches; 1210 indicates a key $\frac{12}{32} \times \frac{10}{8}$ or $\frac{3}{8} \times 1\frac{1}{4}$ inches.

Courtesy ASA.

TABLE 12. Plain Parallel Stock Keys

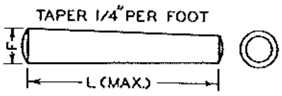


Dimensions of Square and Flat Plain Parallel Stock Keys

Shaft Diameter	Square Key *W* × *H*	Flat Key *W* × *H*	Tolerance on *W* and *H* (−)	Bottom of Keyseat to Opposite Side of Shaft	
				Square Key *S*	Flat Key *T*
1/2	1/8 × 1/8	1/8 × 3/32	0.0020	0.430	0.445
9/16	1/8 × 1/8	1/8 × 3/32	.0020	0.493	0.509
5/8	3/16 × 3/16	3/16 × 1/8	.0020	0.517	0.548
11/16	3/16 × 3/16	3/16 × 1/8	.0020	0.581	0.612
3/4	3/16 × 3/16	3/16 × 1/8	.0020	0.644	0.676
13/16	3/16 × 3/16	3/16 × 1/8	.0020	0.708	0.739
7/8	3/16 × 3/16	3/16 × 1/8	.0020	0.771	0.802
15/16	1/4 × 1/4	1/4 × 3/16	.0020	0.796	0.827
1	1/4 × 1/4	1/4 × 3/16	.0020	0.859	0.890
1 1/16	1/4 × 1/4	1/4 × 3/16	.0020	0.923	0.954
1 1/8	1/4 × 1/4	1/4 × 3/16	.0020	0.986	1.017
1 3/16	1/4 × 1/4	1/4 × 3/16	.0020	1.049	1.081
1 1/4	1/4 × 1/4	1/4 × 3/16	.0020	1.112	1.144
1 5/16	5/16 × 5/16	5/16 × 1/4	.0020	1.137	1.169
1 3/8	5/16 × 5/16	5/16 × 1/4	.0020	1.201	1.232
1 7/16	3/8 × 3/8	3/8 × 1/4	.0020	1.225	1.288
1 1/2	3/8 × 3/8	3/8 × 1/4	.0020	1.289	1.351
1 9/16	3/8 × 3/8	3/8 × 1/4	.0020	1.352	1.415
1 5/8	3/8 × 3/8	3/8 × 1/4	.0020	1.416	1.478
1 11/16	3/8 × 3/8	3/8 × 1/4	.0020	1.479	1.542
1 3/4	3/8 × 3/8	3/8 × 1/4	.0020	1.542	1.605

Courtesy ASA.

TABLE 13. Standard Taper Pins



No. of Pin	Diameter of Pin at Large End		Maximum Length	No. of Pin	Diameter of Pin at Large End		Maximum Length
	Decimal	Fractional			Decimal	Fractional	
	(*F*)	(*F*)	(*L*)		(*F*)	(*F*)	(*L*)
00000	0.094	3/32	3/4	5	0.289	19/64	2 1/4
0000	0.109	7/64	7/8	6	0.341	11/32	3
000	0.125	1/8	1	7	0.409	13/32	3 3/4
00	0.141	9/64	1 1/8	8	0.492	1/2	4 1/2
0	0.156	5/32	1 1/4	9	0.591	19/32	5 1/4
1	0.172	11/64	1 1/4	10	0.706	23/32	6
2	0.193	3/16	1 1/2	11	0.860	55/64	7 1/4
3	0.219	7/32	1 3/4	12	1.032	1 1/32	9
4	0.250	1/4	2	13	1.241	1 15/64	11
				14	1.523	1 33/64	13

TABLE 14. LOOSE FIT (CLASS 1)—LARGE ALLOWANCE, INTERCHANGEABLE

This fit provides for considerable freedom and embraces certain fits where accuracy is not essential.

Size			Limits				Tightest Fit	Loosest Fit
From	Up to and Incl.	Mean	Hole or External Number		Shaft or Internal Member		Allowance	Allowance + Tolerances
			+		−	−	+	+
0	3/16	1/8	0.001	0.000	0.001	0.002	0.001	0.003
3/16	5/16	1/4	.002	.000	.001	.003	.001	.005
5/16	7/16	3/8	.002	.000	.001	.003	.001	.005
7/16	9/16	1/2	.002	.000	.002	.004	.002	.006
9/16	11/16	5/8	.002	.000	.002	.004	.002	.006
11/16	13/16	3/4	.002	.000	.002	.004	.002	.006
13/16	15/16	7/8	.002	.000	.002	.004	.002	.006
15/16	1 1/16	1	.003	.000	.003	.006	.003	.009
1 1/16	1 3/16	1 1/8	.003	.000	.003	.006	.003	.009
1 3/16	1 3/8	1 1/4	.003	.000	.003	.006	.003	.009
1 3/8	1 5/8	1 1/2	.003	.000	.003	.006	.003	.009
1 5/8	1 7/8	1 3/4	.003	.000	.004	.007	.004	.010
1 7/8	2 1/8	2	.003	.000	.004	.007	.004	.010
2 1/8	2 3/8	2 1/4	.003	.000	.004	.007	.004	.010
2 3/8	2 3/4	2 1/2	.003	.000	.005	.008	.005	.011
2 3/4	3 1/4	3	.004	.000	.005	.009	.005	.013
3 1/4	3 3/4	3 1/2	.004	.000	.006	.010	.006	.014
3 3/4	4 1/4	4	.004	.000	.006	.010	.006	.014

Courtesy ASA.

TABLE 15. FREE FIT (CLASS 2)—LIBERAL ALLOWANCE, INTERCHANGEABLE

For running fits with speeds of 600 rpm or over, and journal pressures of 600 lb per sq in. or over.

Size			Limits				Tightest Fit	Loosest Fit
From	Up to and Incl.	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances
			+		−	−	+	+
0	3/16	1/8	0.0007	0.0000	0.0004	0.0011	0.0004	0.0018
3/16	5/16	1/4	.0008	.0000	.0006	.0014	.0006	.0022
5/16	7/16	3/8	.0009	.0000	.0007	.0016	.0007	.0025
7/16	9/16	1/2	.0010	.0000	.0009	.0019	.0009	.0029
9/16	11/16	5/8	.0011	.0000	.0010	.0021	.0010	.0032
11/16	13/16	3/4	.0012	.0000	.0012	.0024	.0012	.0036
13/16	15/16	7/8	.0012	.0000	.0013	.0025	.0013	.0037
15/16	1 1/16	1	.0013	.0000	.0014	.0027	.0014	.0040
1 1/16	1 3/16	1 1/8	.0014	.0000	.0015	.0029	.0015	.0043
1 3/16	1 3/8	1 1/4	.0014	.0000	.0016	.0030	.0016	.0044
1 3/8	1 5/8	1 1/2	.0015	.0000	.0018	.0033	.0018	.0048
1 5/8	1 7/8	1 3/4	.0016	.0000	.0020	.0036	.0020	.0052
1 7/8	2 1/8	2	.0016	.0000	.0022	.0038	.0022	.0054
2 1/8	2 3/8	2 1/4	.0017	.0000	.0024	.0041	.0024	.0058
2 3/8	2 3/4	2 1/2	.0018	.0000	.0026	.0044	.0026	.0062
2 3/4	3 1/4	3	.0019	.0000	.0029	.0048	.0029	.0067
3 1/4	3 3/4	3 1/2	.0020	.0000	.0032	.0052	.0032	.0072
3 3/4	4 1/4	4	.0021	.0000	.0035	.0056	.0035	.0077

Courtesy ASA.

TABLE 16. MEDIUM FIT (CLASS 3)—MEDIUM ALLOWANCE, INTERCHANGEABLE

For running fits under 600 rpm and with journal pressures less than 600 lb per sq in.; also for sliding fits, and the more accurate machine-tool and automotive parts.

Size			Limits				Tightest Fit	Loosest Fit
From	Up to and Incl.	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances
			+		−	−	+	+
0	3/16	1/8	0.0004	0.0000	0.0002	0.0006	0.0002	0.0010
3/16	5/16	1/4	.0005	.0000	.0004	.0009	.0004	.0014
5/16	7/16	3/8	.0006	.0000	.0005	.0011	.0005	.0017
7/16	9/16	1/2	.0006	.0000	.0006	.0012	.0006	.0018
9/16	11/16	5/8	.0007	.0000	.0007	.0014	.0007	.0021
11/16	13/16	3/4	.0007	.0000	.0007	.0014	.0007	.0021
13/16	15/16	7/8	.0008	.0000	.0008	.0016	.0008	.0024
15/16	1 1/16	1	.0008	.0000	.0009	.0017	.0009	.0025
1 1/16	1 3/16	1 1/8	.0008	.0000	.0010	.0018	.0010	.0026
1 3/16	1 3/8	1 1/4	.0009	.0000	.0010	.0019	.0010	.0028
1 3/8	1 5/8	1 1/2	.0009	.0000	.0012	.0021	.0012	.0030
1 5/8	1 7/8	1 3/4	.0010	.0000	.0013	.0023	.0013	.0033
1 7/8	2 1/8	2	.0010	.0000	.0014	.0024	.0014	.0034
2 1/8	2 3/8	2 1/4	.0010	.0000	.0015	.0025	.0015	.0035
2 3/8	2 3/4	2 1/2	.0011	.0000	.0017	.0028	.0017	.0039
2 3/4	3 1/4	3	.0012	.0000	.0019	.0031	.0019	.0043
3 1/4	3 3/4	3 1/2	.0012	.0000	.0021	.0033	.0021	.0045
3 3/4	4 1/4	4	.0013	.0000	.0023	.0036	.0023	.0049

Courtesy ASA.

TABLE 17. Snug Fit (Class 4)—Zero Allowance, Interchangeable

This is the closest fit which can be assembled by hand and necessitates work of considerable precision. It should be used where no perceptible shake is permissible and where moving parts are not intended to move freely under load.

Size			Limits				Tightest Fit	Loosest Fit
From	Up to and Incl.	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances
			+			−		+
0	3/16	1/8	0.0003	0.0000	0.0000	0.0002	0.0000	0.0005
3/16	5/16	1/4	.0004	.0000	.0000	.0003	.0000	.0007
5/16	7/16	3/8	.0004	.0000	.0000	.0003	.0000	.0007
7/16	9/16	1/2	.0005	.0000	.0000	.0003	.0000	.0008
9/16	11/16	5/8	.0005	.0000	.0000	.0003	.0000	.0008
11/16	13/16	3/4	.0005	.0000	.0000	.0004	.0000	.0009
13/16	15/16	7/8	.0006	.0000	.0000	.0004	.0000	.0010
15/16	1 1/16	1	.0006	.0000	.0000	.0004	.0000	.0010
1 1/16	1 3/16	1 1/8	.0006	.0000	.0000	.0004	.0000	.0010
1 3/16	1 3/8	1 1/4	.0006	.0000	.0000	.0004	.0000	.0010
1 3/8	1 5/8	1 1/2	.0007	.0000	.0000	.0005	.0000	.0012
1 5/8	1 7/8	1 3/4	.0007	.0000	.0000	.0005	.0000	.0012
1 7/8	2 1/8	2	.0008	.0000	.0000	.0005	.0000	.0013
2 1/8	2 3/8	2 1/4	.0008	.0000	.0000	.0005	.0000	.0013
2 3/8	2 3/4	2 1/2	.0008	.0000	.0000	.0005	.0000	.0013
2 3/4	3 1/4	3	.0009	.0000	.0000	.0006	.0000	.0015
3 1/4	3 3/4	3 1/2	.0009	.0000	.0000	.0006	.0000	.0015
3 3/4	4 1/4	4	.0010	.0000	.0000	.0006	.0000	.0016

Courtesy ASA.

TABLE 18. WRINGING FIT (CLASS 5)—ZERO TO NEGATIVE ALLOWANCE, SELECTIVE ASSEMBLY

This is also known as a "tunking fit" and it is practically metal-to-metal. Assembly is usually selective and not interchangeable.

Size			Limits				Tightest Fit	Loosest Fit	Selected Fit
From	Up to and Incl.	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances	Average Interference of Metal
			+		+		−	+	
0	3/16	1/8	0.0003	0.0000	0.0002	0.0000	0.0002	0.0003	0.0000
3/16	5/16	1/4	.0004	.0000	.0003	.0000	.0003	.0004	.0000
5/16	7/16	3/8	.0004	.0000	.0003	.0000	.0003	.0004	.0000
7/16	9/16	1/2	.0005	.0000	.0003	.0000	.0003	.0005	.0000
9/16	11/16	5/8	.0005	.0000	.0003	.0000	.0003	.0005	.0000
11/16	13/16	3/4	.0005	.0000	.0004	.0000	.0004	.0005	.0000
13/16	15/16	7/8	.0006	.0000	.0004	.0000	.0004	.0006	.0000
15/16	1 1/16	1	.0006	.0000	.0004	.0000	.0004	.0006	.0000
1 1/16	1 3/16	1 1/8	.0006	.0000	.0004	.0000	.0004	.0006	.0000
1 3/16	1 3/8	1 1/4	.0006	.0000	.0004	.0000	.0004	.0006	.0000
1 3/8	1 5/8	1 1/2	.0007	.0000	.0005	.0000	.0005	.0007	.0000
1 5/8	1 7/8	1 3/4	.0007	.0000	.0005	.0000	.0005	.0007	.0000
1 7/8	2 1/8	2	.0008	.0000	.0005	.0000	.0005	.0008	.0000
2 1/8	2 3/8	2 1/4	.0008	.0000	.0005	.0000	.0005	.0008	.0000
2 3/8	2 3/4	2 1/2	.0008	.0000	.0005	.0000	.0005	.0008	.0000
2 3/4	3 1/4	3	.0009	.0000	.0006	.0000	.0006	.0009	.0000
3 1/4	3 3/4	3 1/2	.0009	.0000	.0006	.0000	.0006	.0009	.0000
3 3/4	4 1/4	4	.0010	.0000	.0006	.0000	.0006	.0010	.0000

Courtesy ASA.

TABLE 19. TIGHT FIT (CLASS 6)—SLIGHT NEGATIVE ALLOWANCE, SELECTIVE ASSEMBLY

Light pressure is required to assemble these fits, and the parts are more or less permanently assembled, such as the fixed ends of studs for gears, pulleys, and rocker arms. These fits are used for drive fits in thin sections or extremely long fits in other sections, and also for shrink fits on very light sections. Used in automotive, ordnance, and general machine manufacturing.

Size			Limits				Tightest Fit	Loosest Fit	Selected Fit
From	Up to and Incl.	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances	Average Interference of Metal
			+		+	+	−		−
0	3/16	1/8	0.0003	0.0000	0.0003	0.0000	0.0003	+0.0003	0.0000
3/16	5/16	1/4	.0004	.0000	.0005	.0001	.0005	+ .0003	.0001
5/16	7/16	3/8	.0004	.0000	.0005	.0001	.0005	+ .0003	.0001
7/16	9/16	1/2	.0005	.0000	.0006	.0001	.0006	+ .0004	.0001
9/16	11/16	5/8	.0005	.0000	.0007	.0002	.0007	+ .0003	.0002
11/16	13/16	3/4	.0005	.0000	.0007	.0002	.0007	+ .0003	.0002
13/16	15/16	7/8	.0006	.0000	.0008	.0002	.0008	+ .0004	.0002
15/16	1 1/16	1	.0006	.0000	.0009	.0003	.0009	+ .0003	.0003
1 1/16	1 3/16	1 1/8	.0006	.0000	.0009	.0003	.0009	+ .0003	.0003
1 3/16	1 3/8	1 1/4	.0006	.0000	.0009	.0003	.0009	+ .0003	.0003
1 3/8	1 5/8	1 1/2	.0007	.0000	.0011	.0004	.0011	+ .0003	.0004
1 5/8	1 7/8	1 3/4	.0007	.0000	.0011	.0004	.0011	+ .0003	.0004
1 7/8	2 1/8	2	.0008	.0000	.0013	.0005	.0013	+ .0003	.0005
2 1/8	2 3/8	2 1/4	.0008	.0000	.0014	.0006	.0014	+ .0002	.0006
2 3/8	2 3/4	2 1/2	.0008	.0000	.0014	.0006	.0014	+ .0002	.0006
2 3/4	3 1/4	3	.0009	.0000	.0017	.0008	.0017	+ .0001	.0008

Courtesy ASA.

TABLE 20. MEDIUM FORCE FIT (CLASS 7)—NEGATIVE ALLOWANCE, SELECTIVE ASSEMBLY

Considerable pressure is required to assemble these fits, and the parts are considered permanently assembled. These fits are used in fastening locomotive wheels, car wheels, armatures of dynamos and motors, and crank disks to their axles or shafts. They are also used for shrink fits on medium sections or long fits. These fits are the tightest which are recommended for cast-iron holes or external members as they stress cast iron to its elastic limit.

Size			Limits				Tightest Fit	Loosest Fit	Selected Fit
From	Up to and Incl.	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances	Average Interference of Metal
			+		+	+	−		−
0	3/16	1/8	0.0003	0.0000	0.0004	0.0001	0.0004	+0.0002	0.0001
3/16	5/16	1/4	.0004	.0000	.0005	.0001	.0005	+ .0003	.0001
5/16	7/16	3/8	.0004	.0000	.0006	.0002	.0006	+ .0002	.0002
7/16	9/16	1/2	.0005	.0000	.0008	.0003	.0008	+ .0002	.0003
9/16	11/16	5/8	.0005	.0000	.0008	.0003	.0008	+ .0002	.0003
11/16	13/16	3/4	.0005	.0000	.0009	.0004	.0009	+ .0001	.0004
13/16	15/16	7/8	.0006	.0000	.0010	.0004	.0010	+ .0002	.0004
15/16	1 1/16	1	.0006	.0000	.0011	.0005	.0011	+ .0001	.0005
1 1/16	1 3/16	1 1/8	.0006	.0000	.0012	.0006	.0012	.0000	.0006
1 3/16	1 3/8	1 1/4	.0006	.0000	.0012	.0006	.0012	.0000	.0006
1 3/8	1 5/8	1 1/2	.0007	.0000	.0015	.0008	.0015	− .0001	.0008
1 5/8	1 7/8	1 3/4	.0007	.0000	.0016	.0009	.0016	− .0002	.0009
1 7/8	2 1/8	2	.0008	.0000	.0018	.0010	.0018	− .0002	.0010
2 1/8	2 3/8	2 1/4	.0008	.0000	.0019	.0011	.0019	− .0003	.0011
2 3/8	2 3/4	2 1/2	.0008	.0000	.0021	.0013	.0021	− .0005	.0013
2 3/4	3 1/4	3	.0009	.0000	.0024	.0015	.0024	− .0006	.0015
3 1/4	3 3/4	3 1/2	.0009	.0000	.0027	.0018	.0027	− .0009	.0018
3 3/4	4 1/4	4	.0010	.0000	.0030	.0020	.0030	− .0010	.0020

Courtesy ASA.

TABLE 21. Heavy Force and Shrink Fit (Class 8)—Considerable Negative Allowance, Selective Assembly

These fits are used for steel holes where the metal can be stressed to its elastic limit. These fits cause excessive stress for cast-iron holes. Shrink fits are used where heavy force fits are impractical, as on locomotive wheel tires, heavy crank disks of large engines, etc.

Size			Limits				Tightest Fit	Loosest Fit	Selected Fit
From	Up to and Incl.	Mean	Hole or External Member		Shaft or Internal Member		Allowance	Allowance + Tolerances	Average Interference of Metal
			+		+	+	−		−
0	3/16	1/8	0.0003	0.0000	0.0004	0.0001	0.0004	+0.0002	0.0001
3/16	5/16	1/4	.0004	.0000	.0007	.0003	.0007	+ .0001	.0003
5/16	7/16	3/8	.0004	.0000	.0008	.0004	.0008	.0000	.0004
7/16	9/16	1/2	.0005	.0000	.0010	.0005	.0010	.0000	.0005
9/16	11/16	5/8	.0005	.0000	.0011	.0006	.0011	− .0001	.0006
11/16	13/16	3/4	.0005	.0000	.0013	.0008	.0013	− .0003	.0008
13/16	15/16	7/8	.0006	.0000	.0015	.0009	.0015	− .0003	.0009
15/16	1 1/16	1	.0006	.0000	.0016	.0010	.0016	− .0004	.0010
1 1/16	1 3/16	1 1/8	.0006	.0000	.0017	.0011	.0017	− .0005	.0011
1 3/16	1 3/8	1 1/4	.0006	.0000	.0019	.0013	.0019	− .0007	.0013
1 3/8	1 5/8	1 1/2	.0007	.0000	.0022	.0015	.0022	− .0008	.0015
1 5/8	1 7/8	1 3/4	.0007	.0000	.0025	.0018	.0025	− .0011	.0018
1 7/8	2 1/8	2	.0008	.0000	.0028	.0020	.0028	− .0012	.0020
2 1/8	2 3/8	2 1/4	.0008	.0000	.0031	.0023	.0031	− .0015	.0023
2 3/8	2 3/4	2 1/2	.0008	.0000	.0033	.0025	.0033	− .0017	.0025
2 3/4	3 1/4	3	.0009	.0000	.0039	.0030	.0039	− .0021	.0030
3 1/4	3 3/4	3 1/2	.0009	.0000	.0044	.0035	.0044	− .0026	.0035
3 3/4	4 1/4	4	.0010	.0000	.0050	.0040	.0050	− .0030	.0040

Courtesy ASA.

TABLE 22. DIMENSIONS OF PLAIN WASHERS

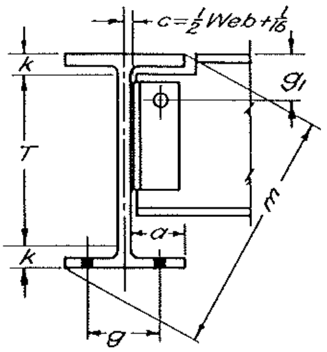
Inside Diameter,* In.	Outside Diameter,† In.	Thickness ‡ Max.	Thickness ‡ Min.	Inside Diameter,* In.	Outside Diameter,† In.	Thickness ‡ Max.	Thickness ‡ Min.
5/64	3/16	0.025	0.016	13/32	13/16	0.080	0.051
3/32	7/32	.025	.016	7/16	7/8	.104	.064
3/32	1/4	.025	.016	7/16	1	.104	.064
1/8	1/4	.028	.017	7/16	1 3/8	.104	.064
1/8	5/16	.040	.025	15/32	59/64	.080	.051
5/32	5/16	.048	.027	1/2	1 1/8	.104	.064
5/32	3/8	.065	.036	1/2	1 1/4	.104	.064
11/64	13/32	.065	.036	1/2	1 5/8	.104	.064
3/16	3/8	.065	.036	17/32	1 1/16	.121	.074
3/16	7/16	.065	.036	9/16	1 1/4	.132	.086
13/64	15/32	.065	.036	9/16	1 3/8	.132	.086
7/32	7/16	.065	.036	9/16	1 7/8	.132	.086
7/32	1/2	.065	.036	19/32	1 3/16	.121	.074
15/64	17/32	.065	.036	5/8	1 3/8	.132	.086
1/4	1/2	.065	.036	5/8	1 1/2	.132	.086
1/4	9/16	.065	.036	5/8	2 1/8	.160	.108
1/4	9/16	.080	.051	21/32	1 5/16	.121	.074
17/64	5/8	.065	.036	11/16	1 1/2	.160	.108
9/32	5/8	.080	.051	11/16	1 3/4	.160	.108
5/16	3/4	.080	.051	11/16	2 3/8	.192	.136
5/16	7/8	.080	.051	13/16	1 1/2	.160	.108
11/32	11/16	.080	.051	13/16	1 3/4	.177	.122
3/8	3/4	.080	.051	13/16	2	.177	.122
3/8	7/8	.104	.064	13/16	2 7/8	.192	.136
3/8	1 1/8	.080	.051	15/16	1 3/4	.160	.108

* Tolerance is +0.005 on inside diameter to and including 7/32 inside diameter, and ±0.010 on inside diameter greater than 7/32.
† Tolerance is ±0.010 on outside diameter for all sizes.
‡ Thickness of washers are Birmingham gage. The limits given are a tolerance of plus or minus one gage, or the spread from the minimum of one gage minus to the maximum of one gage plus.

Courtesy *SAE Handbook 1952.*

TABLE 23. WF Shapes

Dimensions for Detailing

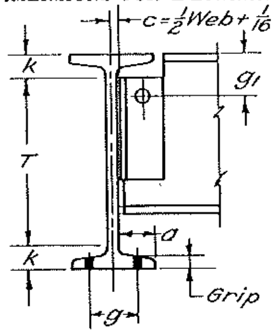


Nominal Size	Weight per Foot	Depth	Flange		Web		Distance						Usual Gage g
			Width	Thickness	Thickness	Half Thickness	a	T	k	m	g_1	c	
In.	Lb	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
36 × 16½	230	35⅞	16½	1¼	¾	⅜	7⅞	31⅛	2⅜	39½	3½	7/16	5½
36 × 12	150	35⅞	12	15/16	⅝	5/16	5⅝	32¼	1 13/16	37⅞	3	⅜	5½
33 × 15¾	200	33	15¾	1⅛	¾	⅜	7½	28⅝	2 3/16	36⅝	3½	7/16	5½
33 × 11½	130	33⅛	11½	⅞	9/16	5/16	5½	29¾	1 11/16	35⅛	3	⅜	5½
30 × 15	172	29⅞	15	1 1/16	11/16	5/16	7⅛	25¾	2 1/16	33½	3¼	⅜	5½
30 × 10½	108	29⅞	10½	¾	9/16	5/16	5	26⅞	1½	31⅝	2¾	⅜	5½
24 × 14	130	24¼	14	⅞	9/16	5/16	6¾	20¾	1¾	28	3	⅜	5½
24 × 12	100	24	12	¾	½	¼	5¾	20⅞	1 9/16	26⅞	2¾	5/16	5½
24 × 9	76	23⅞	9	11/16	7/16	¼	4¼	21⅜	1¼	25⅝	2½	5/16	5½
21 × 13	112	21	13	⅞	9/16	¼	6¼	17¾	1⅝	24¾	3	5/16	5½
21 × 9	82	20⅞	9	13/16	½	¼	4¼	18	1 7/16	22¾	2¾	5/16	5½
21 × 8¼	62	21	8¼	⅝	⅜	3/16	4	18⅝	1 3/16	22⅝	2½	¼	5½
18 × 11¾	96	18⅛	11¾	13/16	½	¼	5⅝	15⅛	1½	21¾	2¾	5/16	5½
18 × 8¾	64	17⅞	8¾	11/16	7/16	3/16	4⅛	15⅜	1¼	20	2½	¼	5½
18 × 7½	50	18	7½	9/16	⅜	3/16	3⅝	15⅞	1 1/16	19½	2¼	¼	3½
16 × 11½	88	16⅛	11½	13/16	½	¼	5½	13⅛	1½	19⅞	2¾	5/16	5½
16 × 8½	58	15⅞	8½	⅝	7/16	¼	4	13⅜	1¼	18	2½	5/16	5½
16 × 7	36	15⅞	7	7/16	5/16	3/16	3⅜	14	15/16	17⅜	2¼	¼	3½
14 × 12	78	14	12	11/16	7/16	¼	5¾	11⅜	1 5/16	18½	2½	5/16	5½
14 × 10	61	13⅞	10	⅝	⅜	3/16	4¾	11⅜	1¼	17⅛	2½	¼	5½
14 × 8	43	13⅝	8	½	5/16	3/16	3⅞	11⅜	1⅛	15⅞	2½	¼	5½
12 × 10	53	12	10	9/16	⅜	3/16	4⅞	9¾	1 3/16	15⅝	2½	¼	5½
12 × 8	40	12	8	½	5/16	3/16	3⅞	9¾	1⅛	14⅜	2½	¼	5½
12 × 6½	27	12	6½	⅜	¼	⅛	3⅛	10⅜	13/16	13⅝	2¼	3/16	3½
10 × 8	33	9¾	8	7/16	5/16	3/16	3⅞	7⅞	15/16	12⅝	2¼	¼	5½
10 × 5¾	21	9⅞	5¾	5/16	¼	⅛	2¾	8½	11/16	11½	2	3/16	2¾
8 × 6½	24	7⅞	6½	⅜	¼	⅛	3⅛	6⅜	¾	10¼	2¼	3/16	3½
8 × 5¼	17	8	5¼	5/16	¼	⅛	2½	6¾	⅝	9⅝	2¼	3/16	2¾

Courtesy *AISC Manual.*

TABLE 24. AMERICAN STANDARD I BEAMS

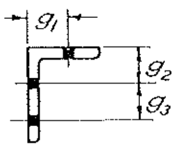
DIMENSIONS FOR DETAILING



Depth of Section	Weight per Foot	Flange Width	Flange Mean Thickness	Web Thickness	Web Half Thickness	Distance a	Distance T	Distance k	Distance g_1	Distance c	Grip	Max. Flange Rivet	Usual Gage g
In.	Lb	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
24	79.9	7	7/8	1/2	1/4	3 1/4	20 3/4	1 5/8	3	5/16	7/8	1	4
20	65.4	6 1/4	13/16	1/2	1/4	2 7/8	16 7/8	1 9/16	3	5/16	3/4	7/8	3 1/2
18	54.7	6	11/16	1/2	1/4	2 3/4	15 1/4	1 3/8	2 3/4	5/16	11/16	7/8	3 1/2
15	42.9	5 1/2	5/8	7/16	1/4	2 1/2	12 1/2	1 1/4	2 3/4	5/16	9/16	3/4	3 1/2
12	31.8	5	9/16	3/8	3/16	2 3/8	9 3/4	1 1/8	2 1/2	1/4	1/2	3/4	3
10	25.4	4 5/8	1/2	5/16	3/16	2 1/8	8	1	2 1/2	1/4	1/2	3/4	2 3/4
8	18.4	4	7/16	5/16	1/8	1 7/8	6 1/4	7/8	2 1/4	3/16	7/16	3/4	2 1/4
7	15.3	3 5/8	3/8	1/4	1/8	1 3/4	5 3/8	13/16	2	3/16	3/8	5/8	2 1/4
6	12.5	3 3/8	3/8	1/4	1/8	1 1/2	4 1/2	3/4	2	3/16	5/16		
5	10.0	3	5/16	1/4	1/8	1 3/8	3 5/8	11/16	2	3/16	5/16	1/2	1 3/4
4	7.7	2 5/8	5/16	3/16	1/8	1 1/4	2 3/4	5/8	2	3/16	5/16		
3	5.7	2 3/8	1/4	3/16	1/8	1 1/8	1 7/8	9/16		3/16	1/4	3/8	1 1/2

Courtesy *AISC Manual.*

TABLE 25. STANDARD GAGES FOR ANGLES, INCHES

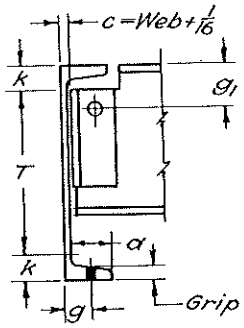


Leg	8	7	6	5	4	3 1/2	3	2 1/2	2	1 3/4	1 1/2	1 3/8	1 1/4	1	3/4
g_1	4 1/2	4	3 1/2	3	2 1/2	2	1 3/4	1 3/8	1 1/8	1	7/8	7/8	3/4	5/8	1/2
g_2	3	2 1/2	2 1/4	2											
g_3	3	3	2 1/2	1 3/4											
Max. Rivet	1 1/8	1	7/8	7/8	7/8	7/8	7/8	3/4	5/8	1/2	3/8	3/8	3/8	1/4	1/4

Courtesy *AISC Manual.*

TABLE 26. American Standard Channels

Dimensions for Detailing



Depth of Section	Weight per Foot	Flange		Web		Distance					Grip	Max. Flange Rivet	Usual Gage g
		Width	Mean Thickness	Thickness	Half Thickness	a	T	k	g_1	c			
In.	Lb	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
15	33.9	3⅜	⅝	7/16	3/16	3	12⅜	1 5/16	2¾	½	⅝	1	2
12	20.7	3	½	5/16	⅛	2⅝	9⅞	1 1/16	2½	⅜	½	⅞	1¾
10	15.3	2⅝	7/16	¼	⅛	2⅜	8⅛	15/16	2½	5/16	7/16	¾	1½
9	13.4	2⅜	7/16	¼	⅛	2¼	7¼	⅞	2½	5/16	⅜	¾	1⅜
8	11.5	2¼	⅜	¼	⅛	2	6⅜	13/16	2¼	5/16	⅜	¾	1⅜
7	9.8	2⅛	⅜	¼	⅛	1⅞	5⅜	13/16	2	5/16	⅜	⅝	1¼
6	8.2	1⅞	⅜	3/16	⅛	1¾	4½	¾	2	¼	5/16	⅝	1⅛
5	6.7	1¾	5/16	3/16	⅛	1½	3⅝	11/16	2	¼	5/16	½	1⅛
4	5.4	1⅝	5/16	3/16	⅛	1⅜	2¾	⅝	2	¼	¼	½	1
3	4.1	1⅜	¼	3/16	⅛	1¼	1¾	⅝		¼	¼		

Courtesy *AISC Manual.*

TABLE 27. Rivet Spacing

(*Cambria Handbook*)

(All dimensions in inches.)

Size of Rivet	Minimum Pitch		Maximum Pitch at Ends of Compression Members	Minimum Distance from Edge of Piece to Center of Rivet Hole		Maximum Pitch in Line of Stress for Plate and Shape Members
	Allowable	Preferable		Sheared Edge	Rolled Edge	
¼	¾	. . .	. . .	. . .	. . .	. . .
⅜	1⅛	. . .	. . .	. . .	. . .	. . .
½	1½	1¾	. . .	1	⅞	4
⅝	1⅞	2	2½	1⅛	1	4½
¾	2¼	2½	3	1¼	1⅛	6
⅞	2⅝	3	3½	1½	1¼	6
1	3	. . .	4	. . .	. . .	. . .
1⅛	3⅜	. . .	4½	. . .	. . .	. . .

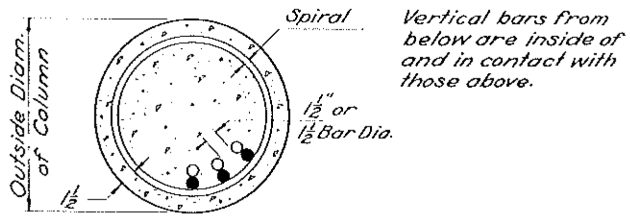
TABLE 30. Maximum Spacing of Column Ties

Vertical Bar Size	Size and Spacing of Ties, In. Maximum spacing not to exceed least column dimension.		
	#2	#3	#4
#5	10	10	10
#6	12	12	12
#7	12	14	14
#8	12 *	16	16
#9	12 *	18	18
#10	12 *	18	20
#11	12 *	18	22

* #2 ties are not recommended for #8 or larger verticals.

Courtesy ACI.

TABLE 31. Maximum Number of Column Bars for Round Columns



Diameter of Column	Spiral Size	Bar Size						
		#5	#6	#7	#8	#9	#10	#11
14	3/8	12	11	10	9	7	6	
15	3/8	13	12	11	10	8	7	6
16	3/8	15	13	12	11	9	8	6
17	3/8	16	15	14	12	11	9	7
18	3/8	18	16	15	14	12	10	8
19	3/8	19	18	16	15	13	11	9
20	3/8	21	19	18	16	14	12	10
21	1/2	22	20	19	17	15	13	11
22	1/2	23	22	20	18	16	14	11
23	1/2	25	23	21	20	17	15	12
24	1/2	26	24	22	21	18	16	13

Courtesy ACI.

TABLE 32. Lapping of Bars

Inches of lap corresponding to number of bar diameters.

(Figure to next largest whole inch.)

Number of Diameters	Size of Bar									
	#2 *	#3	#4	#5	#6	#7	#8	#9	#10	#11
16	4	6	8	10	12	14	16	18	21	23
17	5	7	9	11	13	15	17	20	22	24
18	5	7	9	12	14	16	18	21	23	26
19	5	8	10	12	15	17	19	22	25	27
20	5	8	10	13	15	18	20	23	26	29
21	6	8	11	14	16	19	21	24	27	30
22	6	9	11	14	17	20	22	25	28	31
23	6	9	12	15	18	21	23	26	30	33
24	6	9	12	15	18	21	24	28	31	34
25	7	10	13	16	19	22	25	29	32	36
27	7	11	14	17	21	24	27	31	35	39
30	8	12	15	19	23	27	30	34	39	43
32	8	12	16	20	24	28	32	36	41	45
34	9	13	17	22	26	30	34	39	44	48
36	9	14	18	23	27	32	36	41	46	51
38	10	15	19	24	29	34	38	43	49	54
40	10	15	20	25	30	35	40	46	51	57

* #2 bars are generally furnished in plain rounds only.

Courtesy ACI.

TABLE 33. Minimum Beam Widths—ACI Code

Size of Bars	Number of Bars in Single Layer of Reinforcing							Add for Each Added Bar
	2	3	4	5	6	7	8	
#4	5¾	7¼	8¾	10¼	11¾	13¼	14¾	1½
#5	6	7¾	9¼	11	12½	14¼	15¾	1⅝
#6	6¼	8	9¾	11½	13¼	15	16¾	1¾
#7	6½	8½	10¼	12¼	14	16	17¾	1⅞
#8	6¾	8¾	10¾	12¾	14¾	16¾	18¾	2
#9	7¼	9½	11¾	14	16¼	18½	20¾	2¼
#10	7¾	10¼	12¾	15¼	17¾	20¼	23	2⅝
#11	8	11	13¾	16½	19½	22¼	25	2⅞

Courtesy ACI.

TABLE 34. Electrical Symbols

ASA Z32.9-1943

GENERAL OUTLETS

Ceiling	Wall	
○	○	Outlet.
Ⓑ	Ⓑ	Blanked Outlet.
Ⓓ		Drop Cord.
Ⓔ	Ⓔ	Electrical Outlet; for use only when circle used alone might be confused with columns, plumbing symbols, etc.
Ⓕ	Ⓕ	Fan Outlet.
Ⓙ	Ⓙ	Junction Box.
Ⓛ	Ⓛ	Lamp Holder.
$Ⓛ_{PS}$	$Ⓛ_{PS}$	Lamp Holder with Full Switch.
Ⓢ	Ⓢ	Pull Switch.
Ⓥ	Ⓥ	Outlet for Vapor Discharge Lamp.
ⓧ	ⓧ	Exit Light Outlet.
Ⓒ	Ⓒ	Clock Outlet. (Specify Voltage)

CONVENIENCE OUTLETS

=⊖	Duplex Convenience Outlet.
$=⊖_{1,3}$	Convenience Outlet other than Duplex. 1 = Single, 3 = Triplex, etc.
$=⊖_{WP}$	Weatherproof Convenience Outlet.
$≡⊖_{R}$	Range Outlet.
$=⊖_{S}$	Switch and Convenience Outlet.
=⊖[R]	Radio and Convenience Outlet.
▲ (in circle)	Special Purpose Outlet. (Des. in Spec.)
⊙	Floor Outlet.

SWITCH OUTLETS

S	Single Pole Switch.
S_2	Double Pole Switch.
S_3	Three Way Switch.
S_4	Four Way Switch.
S_D	Automatic Door Switch.
S_E	Electrolier Switch.
S_K	Key Operated Switch.
S_P	Switch and Pilot Lamp.
S_{CB}	Circuit Breaker.
S_{WCB}	Weatherproof Circuit Breaker.
S_{MC}	Momentary Contact Switch.
S_{RC}	Remote Control Switch.
S_{WP}	Weatherproof Switch.
S_F	Fused Switch
S_{WF}	Weatherproof Fused Switch.

SPECIAL OUTLETS

○a,b,c, etc. =⊖a,b,c, etc. S a,b,c, etc.	Any Standard Symbol as given above with the addition of a lower case subscript letter may be used to designate some special variation of Standard Equipment of particular interest in a specific set of Architectural Plans. When used they must be listed in the Key of Symbols on each drawing and if necessary further described in the specifications.

PANELS, CIRCUITS, AND MISCELLANEOUS

▬ (solid)	Lighting Panel.
▨ (hatched)	Power Panel.
——	Branch Circuit; Concealed in Ceiling or Wall.
— —	Branch Circuit; concealed in Floor.
- - - -	Branch Circuit; Exposed.
—→→	Home Run to Panel Board. Indicate number of Circuits by number of arrows. Note: Any circuit without further designation indicates a two-wire circuit. For a greater number of wires indicate as follows: —///— (3 wires) —////— (4 wires), etc.
▬ (heavy)	Feeders. Note: Use heavy lines and designate by number corresponding to listing in Feeder Schedule.
≡□≡	Underfloor Duct and Junction Box. Triple System. Note: For double or single systems eliminate one or two lines. This symbol is equally adaptable to auxiliary system layouts.
Ⓖ	Generator.
Ⓜ	Motor.
Ⓘ	Instrument.
Ⓣ	Power Transformer. (Or draw to scale.)
⊠	Controller.
□	Isolating Switch.

AUXILIARY SYSTEMS

⊡	Push Button.
□	Buzzer.
□D	Bell.
-◇	Annunciator.
◀ (solid)	Outside Telephone.
◁	Interconnecting Telephone.
|◁	Telephone Switchboard.
Ⓣ	Bell Ringing Transformer.
[D]	Electric Door Opener.
[F]	Fire Alarm Bell.
[F]	Fire Alarm Station.
⊠	City Fire Alarm Station.
[FA]	Fire Alarm Central Station.
[FS]	Automatic Fire Alarm Device.
[W]	Watchman's Station.
[[W]]	Watchman's Central Station.
[H]	Horn.
[N]	Nurse's Signal Plug.
[M]	Maid's Signal Plug.
[R]	Radio Outlet.
[[SC]]	Signal Central Station.
□	Interconnection Box.
ǀǀǀǀǀ	Battery.
—·—·—	Auxiliary System Circuits. Note: Any line without further designation indicates a 2-Wire System. For a greater number of wires designate with numerals in manner similar to --. --12-No. 18W-3/4"C., or designate by number corresponding to listing in Schedule.
□a,b,c	Special Auxiliary Outlets. Subscript letters refer to notes on plans or detailed description in specifications.

Courtesy ASA

TABLE 35. American Standard Steel Pipe Data
(All dimensions in inches. Weights in pounds.)

Nominal Size	Actual Outside Diameter	Standard Weight (40) *			Extra-Strong (80) †			Double-Extra Strong ‡		
		Inside Diameter	Wall Thick-ness	Weight per Foot §	Inside Diameter	Wall Thick-ness	Weight per Foot	Inside Diam-eter	Wall Thick-ness	Weight per Foot
⅛	0.405	0.269	0.068	0.244	0.215	0.095	0.314	.....	.....	.....
¼	0.540	0.364	.088	0.424	0.302	.119	0.535	.....	.....	.....
⅜	0.675	0.493	.091	0.567	0.423	.126	0.738	.....	.....	.....
½	0.840	0.622	.109	0.850	0.546	.147	1.087	0.252	0.294	1.714
¾	1.050	0.824	.113	1.130	0.742	.154	1.473	0.434	.308	2.440
1	1.315	1.049	.133	1.678	0.957	.179	2.171	0.599	.358	3.659
1¼	1.660	1.380	.140	2.272	1.278	.191	2.996	0.896	.382	5.214
1½	1.900	1.610	.145	2.717	1.500	.200	3.631	1.100	.400	6.408
2	2.375	2.067	.154	3.652	1.939	.218	5.022	1.503	.436	9.029
2½	2.875	2.469	.203	5.79	2.323	.276	7.66	1.771	.552	13.70
3	3.500	3.068	.216	7.58	2.900	.300	10.25	2.300	.600	18.58
3½	4.000	3.548	.226	9.11	3.364	.318	12.51	.....	.....	.....
4	4.500	4.026	.237	10.79	3.826	.337	14.98	3.152	.674	27.54
5	5.563	5.047	.258	14.62	4.813	.375	20.78	4.063	.750	38.55
6	6.625	6.065	.280	18.97	5.761	.432	28.57	4.897	.864	53.16
8	8.625	7.981	.322	28.55	7.625	.500	43.39	6.875	.875	72.42
10	10.750	10.020	.365	40.48	9.750	.500	54.74	.....	.....	.....
12	12.750	12.000	.375	49.56	11.750	.500	65.42	.....	.....	.....

* Same as ASA B36.10—"Schedule 40" except 12-inch diameter.
† Same as ASA B36.10—"Schedule 80" except 10- and 12-inch diameter.
‡ Not identified with ASA Schedule number, but available as indicated.
§ Plain ends.

TABLE 36. AGA Standard Cast-Iron Bell-and-Spigot Pipe Data
(All dimensions in inches. Approx. weights in pounds.)

Nominal Size Inside Diameter	Outside Diameter of Pipe	Pipe Wall Thickness	Inside Diameter of Socket	Depth of Socket	Thickness of joint	Weight per Foot, 12-Foot Lengths *
4	4.80	0.40	5.80	4.00	0.50	19.5
6	6.90	0.43	7.90	4.00	.50	30.58
8	9.05	0.45	10.05	4.00	.50	42.42
10	11.10	0.49	12.10	4.00	.50	55.91
12	13.20	0.54	14.20	4.50	.50	73.83
16	17.40	0.62	18.40	4.50	.50	112.58
20	21.60	0.68	22.85	4.50	.63	153.83
24	25.80	0.76	27.05	5.00	.63	206.41
30	31.74	0.85	32.99	5.00	.63	284.00
36	37.96	0.95	39.21	5.00	.63	379.25
42	44.20	1.07	45.45	5.00	.63	497.66
48	50.50	1.26	51.75	5.00	.63	663.50

* Including bell-and-spigot bead.

TABLE 37. ASTM STANDARD BRASS AND COPPER PIPE DATA

(All dimensions in inches. Weights in pounds.)

Nominal Size	Outside Diameter	Regular			Extra-Strong		
		Wall Thickness	Weight per Foot		Wall Thickness	Weight per Foot	
			Red Brass	Copper		Red Brass	Copper
1/8	0.405	0.062	0.253	0.259	0.100	0.363	0.371
1/4	0.540	0.082	0.447	0.457	0.123	0.611	0.625
3/8	0.675	0.090	0.627	0.641	0.127	0.829	0.847
1/2	0.840	0.107	0.934	0.955	0.149	1.23	1.25
3/4	1.050	0.114	1.27	1.30	0.157	1.67	1.71
1	1.315	0.126	1.78	1.82	0.182	2.46	2.51
1 1/4	1.660	0.146	2.63	2.69	0.194	3.39	3.46
1 1/2	1.900	0.150	3.13	3.20	0.203	4.10	4.19
2	2.375	0.156	4.12	4.22	0.221	5.67	5.80
2 1/2	2.875	0.187	5.99	6.12	0.280	8.66	8.85
3	3.500	0.219	8.56	8.75	0.304	11.6	11.8
3 1/2	4.000	0.250	11.2	11.4	0.321	14.1	14.4
4	4.500	0.250	12.7	12.9	0.341	16.9	17.3
5	5.562	0.250	15.8	16.2	0.375	23.2	23.7
6	6.625	0.250	19.0	19.4	0.437	32.2	32.9
8	8.625	0.312	30.9	31.6	0.500	48.4	49.5
10	10.750	9.365	45.2	46.2	0.500	61.1	62.4
12	12.750	0.375	55.3	56.5			

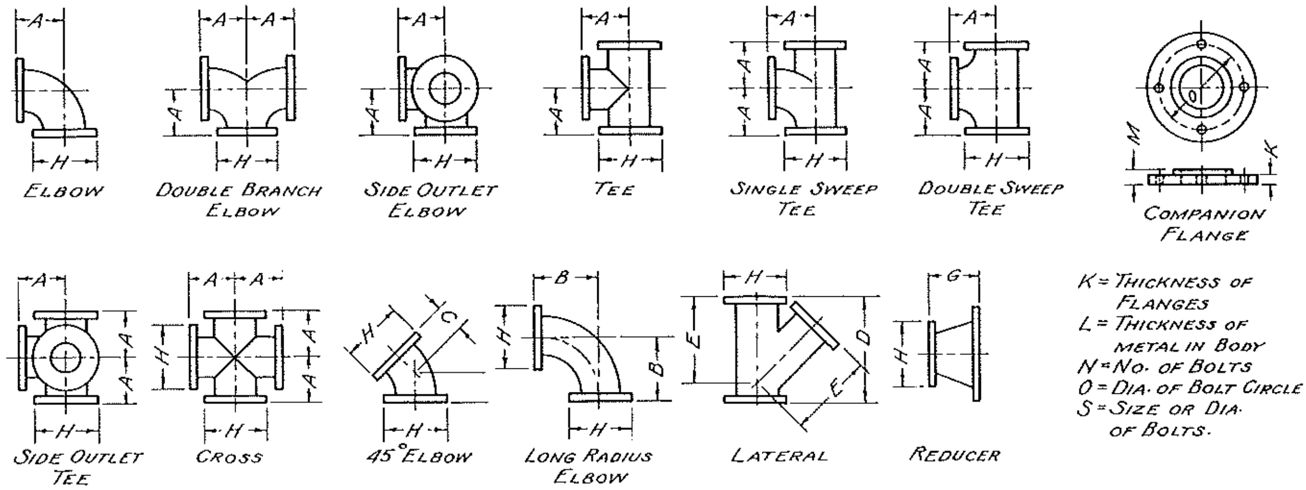
TABLE 38. ASTM STANDARD COPPER WATER TUBE DATA
(All dimensions in inches. Weights in pounds.)

Nominal Size	Outside Diameter	Type K Wall Thickness	Type K Weight per Foot	Type L Wall Thickness	Type L Weight per Foot	Type M Wall Thickness	Type M Weight per Foot
1/8	0.250	0.032	0.085	0.025	0.068	0.025	0.068
1/4	0.375	0.032	0.134	0.030	0.126	0.025	0.107
3/8	0.500	0.049	0.269	0.035	0.198	0.025	0.145
1/2	0.625	0.049	0.344	0.040	0.285	0.028	0.204
5/8	0.750	0.049	0.418	0.042	0.362	0.030	0.263
3/4	0.875	0.065	0.641	0.045	0.455	0.032	0.328
1	1.125	0.065	0.839	0.050	0.655	0.035	0.465
1 1/4	1.375	0.065	1.04	0.055	0.884	0.042	0.682
1 1/2	1.625	0.072	1.36	0.060	1.14	0.049	0.940
2	2.125	0.083	2.06	0.070	1.75	0.058	1.46
2 1/2	2.625	0.095	2.93	0.080	2.48	0.065	2.03
3	3.125	0.109	4.00	0.090	3.33	0.072	2.68
3 1/2	3.625	0.120	5.12	0.100	4.29	0.083	3.58
4	4.125	0.134	6.51	0.110	5.38	0.095	4.66
5	5.125	0.160	9.67	0.125	7.61	0.109	6.66
6	6.125	0.192	13.9	0.140	10.2	0.122	8.92
8	8.125	0.271	25.9	0.200	19.3	0.170	16.5
10	10.125	0.338	40.3	0.250	30.1	0.212	25.6
12	12.125	0.405	57.8	0.280	40.4	0.254	36.7

TABLE 39. AMERICAN STANDARD TAPER PIPE THREAD DATA
(All dimensions in inches. Weights in pounds.)

Nominal Size	Outside Diameter	Inside Diameter	Threads per Inch	Tap Drill	Weight per Foot Thds. and Couplings	Normal Engagement by Hand
1/8	0.405	0.269	27	11/32	0.245	0.180
1/4	0.540	0.364	18	7/16	0.425	0.200
3/8	0.675	0.493	18	37/64	0.568	0.240
1/2	0.840	0.622	14	23/32	0.852	0.320
3/4	1.050	0.824	14	59/64	1.134	0.339
1	1.315	1.049	11 1/2	1 5/32	1.684	0.400
1 1/4	1.660	1.380	11 1/2	1 1/2	2.281	0.420
1 1/2	1.900	1.610	11 1/2	1 47/64	2.731	0.420
2	2.375	2.067	11 1/2	2 7/32	3.678	0.436
2 1/2	2.875	2.469	8	2 5/8	5.82	0.682
3	3.500	3.068	8	3 1/4	7.62	0.766
3 1/2	4.000	3.548	8	3 3/4	9.20	0.821
4	4.500	4.026	8	4 1/4	10.89	0.844
5	5.563	5.047	8	5 5/16	14.81	0.937
6	6.625	6.065	8	6 5/16	19.18	0.958
8	8.625	7.981	8		29.35	1.063
10	10.750	10.020	8		41.85	1.210
12	12.750	12.000	8		51.15	1.360

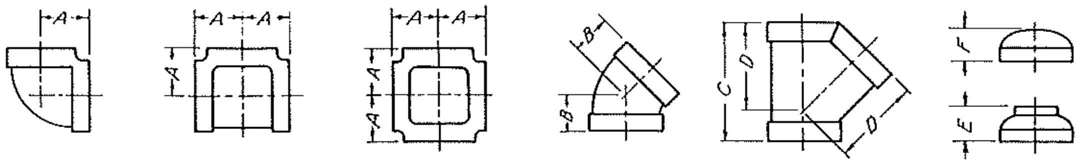
TABLE 40. STANDARD FLANGED FITTINGS
(125 lb per sq in. pressure.)



Size	*A*	*B*	*C*	*D*	*E*	*G*	*H*	*K*	*L*	*M*	*N*	*O*	*S*
1	3½	5	1¾	7½	5¾	....	4	7/16	7/16	11/16	4	3⅛	½
1¼	3¾	5½	2	8	6¼	....	4½	½	7/16	¾	4	3½	½
1½	4	6	2¼	9	7	....	5	9/16	7/16	⅞	4	3⅞	½
2	4½	6½	2½	10½	8	....	6	⅝	7/16	1	4	4¾	⅝
2½	5	7	3	12	9½	....	7	11/16	7/16	1 1/16	4	5½	⅝
3	5½	7¾	3	13	10	6	7½	¾	7/16	1⅛	4	6	⅝
3½	6	8½	3½	14½	11½	6½	8½	13/16	7/16	1 3/16	8	7	⅝
4	6½	9	4	15	12	7	9	15/16	½	1 3/16	8	7½	⅝
5	7½	10¼	4½	17	13½	8	10	15/16	½	1 5/16	8	8½	¾
6	8	11½	5	18	14½	9	11	1	9/16	1 7/16	8	9½	¾
8	9	14	5½	22	17½	11	13½	1⅛	⅝	1⅝	8	11¾	¾
10	11	16½	5½	25½	20½	12	16	1 3/16	¾	1⅞	12	14¼	⅞
12	12	19	7½	30	24½	14	19	1¼	13/16	2 1/16	12	17	⅞

TABLE 41. STANDARD CAST-IRON SCREW FITTINGS

(125 lb per sq in. pressure.)

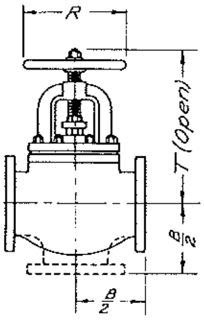


Size Inches	Dimensions in Inches					
	A	*B*	*C*	*D*	*E*	*F*
1/4	13/16	3/4				
3/8	15/16	13/16				
1/2	1 1/8	7/8	2 1/2	1 7/8		
3/4	1 5/16	1	3	2 1/4		
1	1 7/16	1 1/8	3 1/2	2 3/4		
1 1/4	1 3/4	1 5/16	4 1/4	3 1/4	2 1/8	
1 1/2	1 15/16	1 7/16	4 7/8	3 13/16	2 1/4	
2	2 1/4	1 11/16	5 3/4	4 1/4	2 7/16	
2 1/2	2 11/16	1 15/16	6 3/4	5 3/16	2 11/16	
3	3 1/8	2 3/16	7 7/8	6 1/8	2 15/16	
3 1/2	3 7/16	2 3/8	8 7/8	6 7/8	3 1/8	
4	3 3/4	2 5/8	9 3/4	7 5/8	3 3/8	2 1/16
5	7 7/16	3 1/16	11 5/8	9 1/4	3 7/8	2 3/8
6	5 1/8	3 7/16	13 7/16	10 3/4	4 3/8	2 5/8
8	6 1/2	4 1/4	16 15/16	13 5/8	5 1/4	3 1/8
10	8 1/16	5 3/16	20 11/16	16 3/4	6 3/16	3 5/8
12	9 1/2	6	24 1/8	19 5/8	7 1/8	4 1/4

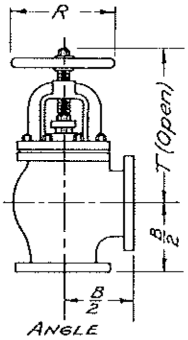
Fractional dimensions are nominal. See ASA Bulletin for decimal dimensions.

TABLE 42. DIMENSIONS OF STANDARD GLOBE, ANGLE, AND CROSS VALVES

(All dimensions in inches.)



GLOBE OR
CROSS VALVE



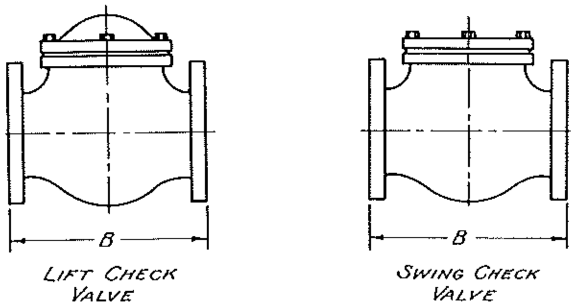
ANGLE
VALVE

Size	2	2 1/2	3	3 1/2	4	5	6	8	10	12
A	6 1/2	7	8	9	10	11 1/4	13	18 1/2		
B	8	8 1/2	9 1/2	10 1/2	11 1/2	13	14	19 1/2	24 1/2	27 1/2
T	11 1/8	11 1/2	13 1/8	13 3/8	15 1/2	17 3/8	19 1/2	24 3/4	30 1/4	33 1/2
R	8	8	9	9	10	10	12	16	18	20

Substitute *A* for *B* for screw fittings.

TABLE 43. DIMENSIONS OF STANDARD LIFT AND SWING VALVES

(All dimensions in inches.)

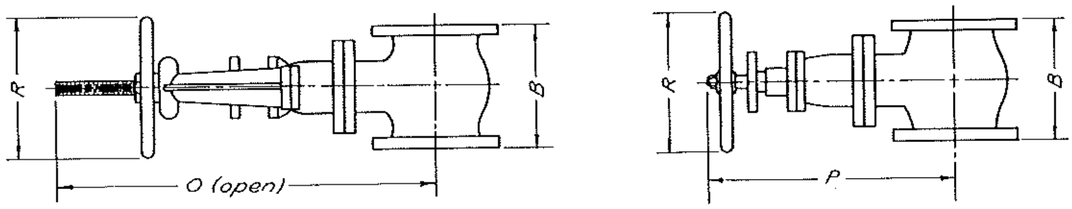


Size	2	2½	3	3½	4	5	6	8	10	12
A	6½	7	8	9	10	11¼	12½	18½		
B	8	8½	9½	10½	11½	13	14	19½	24½	27½

Substitute *A* for *B* for screw fittings.

TABLE 44. DIMENSIONS OF STANDARD GATE VALVES

(All dimensions in inches.)



Size	2	2½	3	3½	4	5	6	8	10	12
A	6⅛	6½	6¾	7⅜	7⅝	8½	8⅞	10¼		
B	7	7½	8	8½	9	10½	11	11½	13	14
O	14¾	17	19½	21¼	23¾	28¾	32⅝	41⅞	50¼	58
P	12¾	13⅝	15½	16½	18½	21¼	23⅜	27⅜	33	36¼
R	8	8	9	9	10	12	12	16	20	20

Substitute *A* for *B* for screw fittings.

TABLE 45. ASA Symbols for Heating, Ventilating, and Air Conditioning

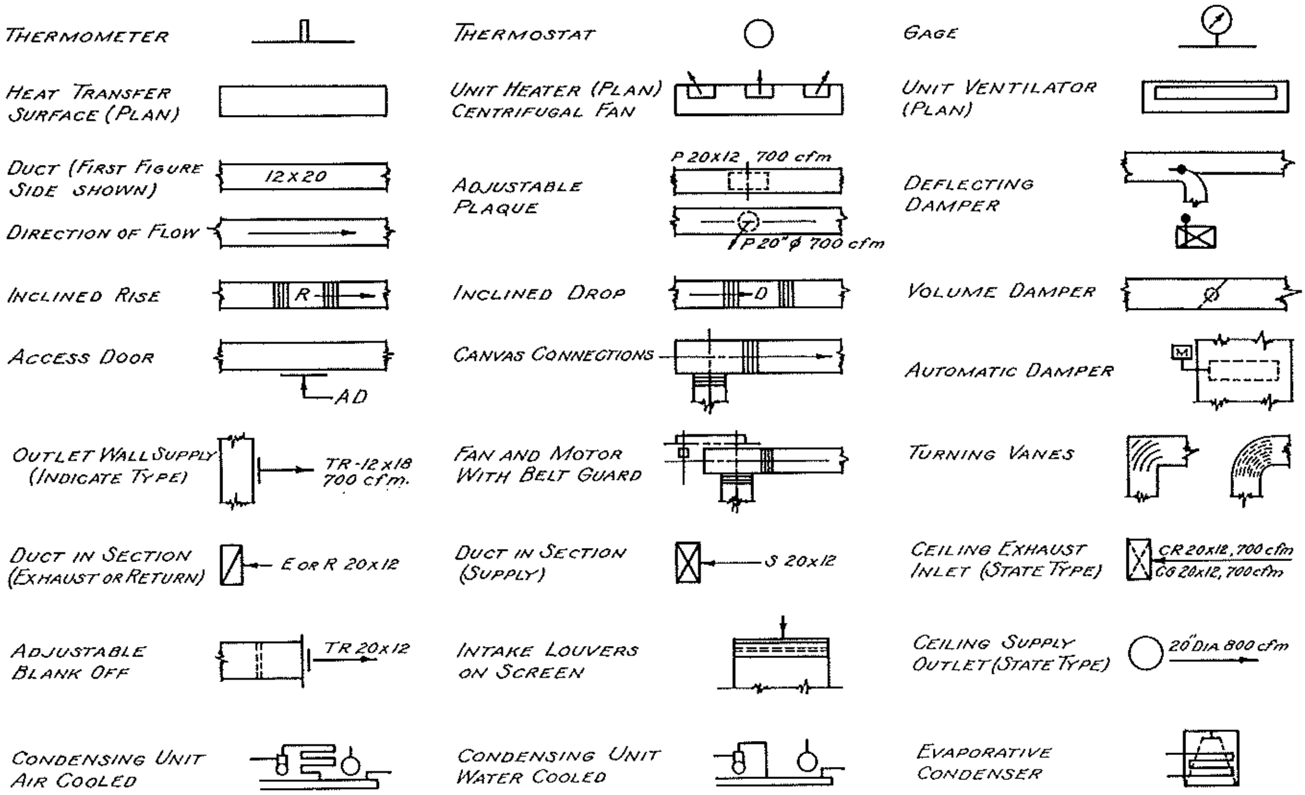
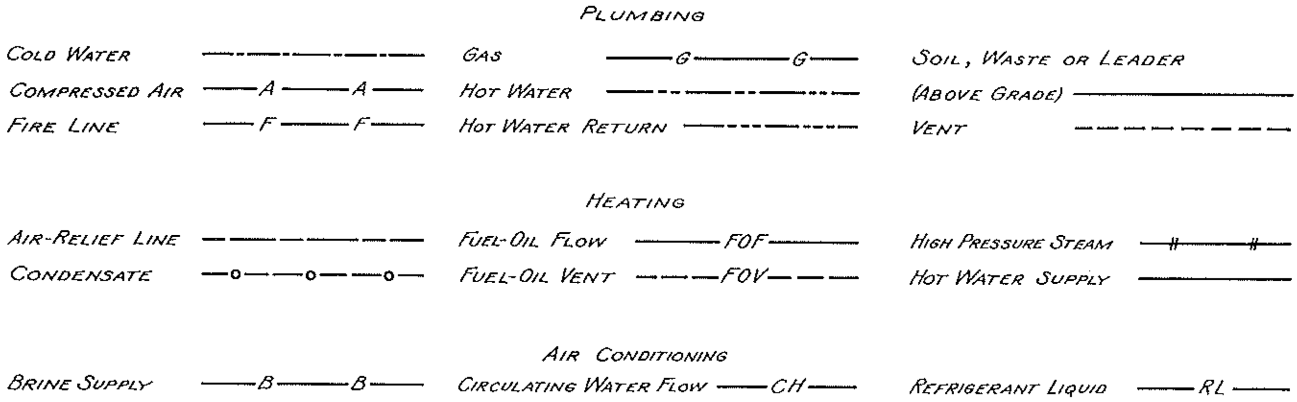


TABLE 46. ASA Graphic Symbols for Piping



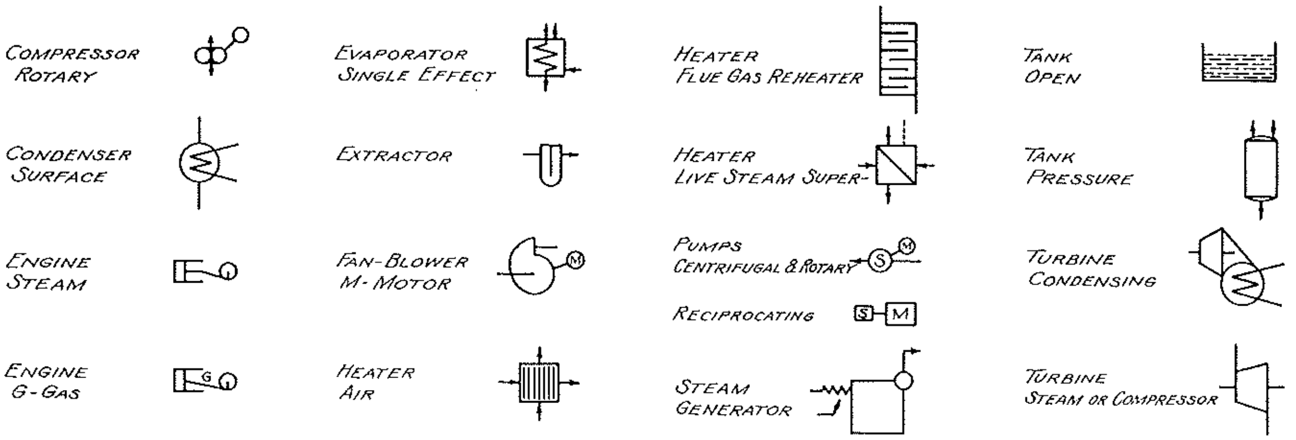


TABLE 47. ASA Plumbing Symbols

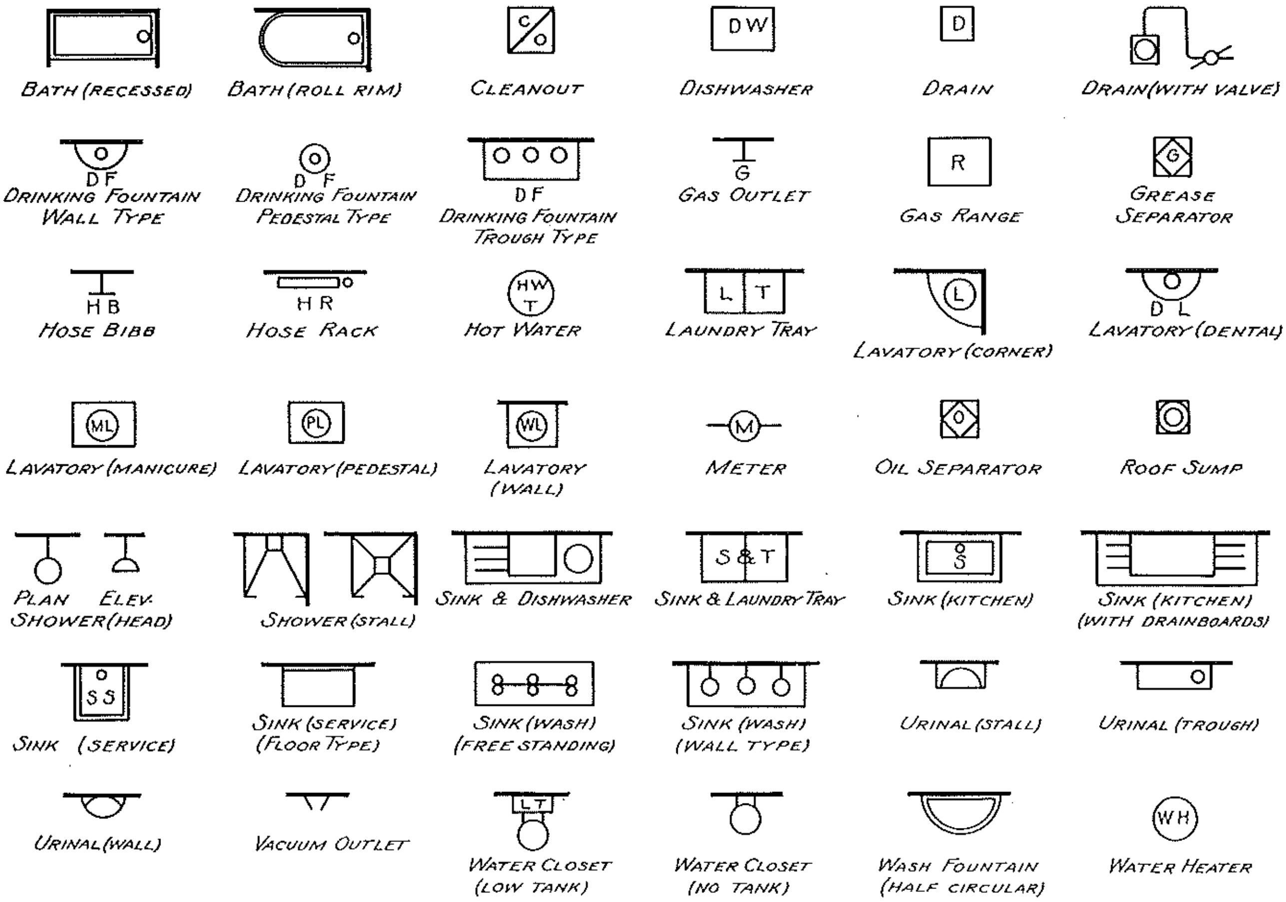
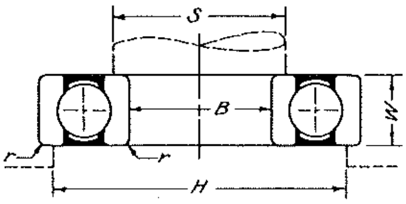


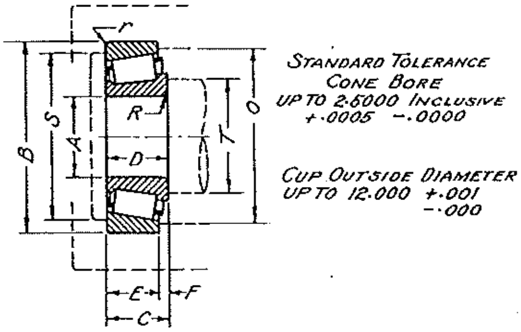
TABLE 48. BALL BEARING DATA



Brg. No.	Bore B	Dia. D	Width W	Balls		Rad. R	Shoulder Dia.		Radial Load at rpm		
				Dia.	No.		Shaft S	Housing H	500	1000	2000
34	0.1575	0.6299	0.1969	1/8	6	0.016	0.222	0.550	99	83	66
35	0.1969	0.7480	.2362	9/64	6	.016	0.261	0.668	119	100	80
36	0.2362	0.7480	.2362	9/64	6	.016	0.300	0.668	119	100	80
37	0.2756	0.8661	.2756	5/32	7	.016	0.341	0.786	160	133	106
38	0.3150	0.8661	.2756	5/32	7	.016	0.379	0.786	160	133	106
39	0.3543	1.0236	.3150	3/16	7	.025	0.454	0.899	230	195	155
3L00	0.3937	1.0236	.3150	3/16	7	.016	0.500	0.920	230	195	155
3L01	0.4724	1.1024	.3150	3/16	8	.016	0.570	1.000	255	215	170
3L02	0.5906	1.2598	.3543	3/16	9	.016	0.690	1.15	275	230	185
3L03	0.6693	1.3780	.3937	3/16	10	.016	0.780	1.27	295	245	195
3L04	0.7874	1.6535	.4724	1/4	9	.025	0.940	1.50	505	425	340
3L05	0.9843	1.8504	.4724	1/4	10	.025	1.14	1.69	545	455	360
3L06	1.1811	2.1654	.5118	9/32	11	.040	1.37	1.94	750	630	500
3L07	1.3780	2.4409	.5512	5/16	11	.040	1.58	2.21	935	785	625
3L08	1.5748	2.6772	.5906	5/16	12	.040	1.78	2.44	990	835	665

Courtesy New Departure Division, General Motors Corp.

TABLE 49. DIMENSIONS OF SINGLE ROW, STRAIGHT-BORE TYPE-S ROLLER BEARINGS



Bore *A*	Outside Dia. *B*	Width *C*	Rating at 500 rpm		Cone				Cup			
			Radial Lb	Thrust Lb	Radius *R*	Length *D*	Stand-out *F*	Shoulder Dia. *T*	Radius *R*	Length *E*	Shoulder Dia. *S*	Shoulder Dia. *O*
0.3750	1.2595	0.3940	255	205	3/64	0.4246	0.0815	1 1/16	3/64	0.3125	1	1 1/8
0.4720	1.2595	.3940	255	205	1/32	.4246	.0815	3/4	3/64	.3125	1	1 1/8
0.5000	1.3775	.4330	290	255	3/64	.4326	.0893	3/4	3/64	.3437	1 1/8	1 1/4
0.5900	1.3775	.4330	290	255	1/32	.4326	.0893	27/32	3/64	.3437	1 1/8	1 1/4
0.6250	1.5745	.4730	300	310	3/64	.4391	.0980	7/8	3/64	.3750	1 5/16	1 13/32
0.6690	1.5745	.4730	300	310	1/32	.4391	.0980	7/8	3/64	.3750	1 5/16	1 13/32
0.7500	1.5745	.4730	300	310	0.040	.4391	.0980	1	3/64	.3750	1 5/16	1 13/32
0.8125	1.9380	.7813	960	610	1/16	.7813	.1563	1 3/16	1/16	.6250	1 19/32	1 25/32
0.8750	1.9687	.5313	610	480	3/64	.5614	.1563	1 7/32	0.040	.3750	1 11/16	1 7/8
0.9375	2.2400	.7625	1010	610	1/32	.7810	.1375	1 1/4	3/64	.6250	1 15/16	1 31/32
1.000	2.2500	.6875	885	600	3/64	.6875	.1563	1 11/32	1/16	.5313	1 7/8	2 1/16
1.125	2.3750	.7813	1010	650	1/32	.7620	.1563	1 7/16	3/64	.6250	2	2 3/32
1.250	2.7500	.9375	1715	920	1/32	.9983	.1875	1 9/16	3/64	.7500	2 13/32	2 15/32

Courtesy Timken Roller Bearing Co.

TABLE 50. NATURAL TRIGONOMETRIC FUNCTIONS

Degrees	SINES							Cosines
	0′	10′	20′	30′	40′	50′	60′	
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01454	0.01745	89
1	.01745	.02036	.02327	.02618	.02908	.03199	.03490	88
2	.03490	.03781	.04071	.04362	.04653	.04943	.05234	87
3	.05234	.05524	.05814	.06105	.06395	.06685	.06976	86
4	.06976	.07266	.07556	.07846	.08136	.08426	.08716	85
5	.08716	.09005	.09295	.09585	.09874	.10164	.10453	84
6	.10453	.10742	.11031	.11320	.11609	.11898	.12187	83
7	.12187	.12476	.12764	.13053	.13341	.13629	.13917	82
8	.13917	.14205	.14493	.14781	.15069	.15356	.15643	81
9	.15643	.15931	.16218	.16505	.16792	.17078	.17365	80
10	.17365	.17651	.17937	.18224	.18509	.18795	.19081	79
11	.19081	.19366	.19652	.19937	.20222	.20507	.20791	78
12	.20791	.21076	.21360	.21644	.21928	.22212	.22495	77
13	.22495	.22778	.23062	.23345	.23627	.23910	.24192	76
14	.24192	.24474	.24756	.25038	.25320	.25601	.25882	75
15	.25882	.26163	.26443	.26724	.27004	.27284	.27564	74
16	.27564	.27843	.28123	.28402	.28680	.28959	.29237	73
17	.29237	.29515	.29793	.30071	.30348	.30625	.30902	72
18	.30902	.31178	.31454	.31730	.32006	.32282	.32557	71
19	.32557	.32832	.33106	.33381	.33655	.33929	.34202	70
20	.34202	.34475	.34748	.35021	.35293	.35565	.35837	69
21	.35837	.36108	.36379	.36650	.36921	.37191	.37461	68
22	.37461	.37730	.37999	.38268	.38537	.38805	.39073	67
23	.39073	.39341	.39608	.39875	.40142	.40408	.40674	66
24	.40674	.40939	.41204	.41469	.41734	.41998	.42262	65
25	.42262	.42525	.42788	.43051	.43313	.43575	.43837	64
26	.43837	.44098	.44359	.44620	.44880	.45140	.45399	63
27	.45399	.45658	.45917	.46175	.46433	.46690	.46947	62
28	.46947	.47204	.47460	.47716	.47971	.48226	.48481	61
29	.48481	.48735	.48989	.49242	.49495	.49748	.50000	60
30	.50000	.50252	.50503	.50754	.51004	.51254	.51504	59
31	.51504	.51753	.52002	.52250	.52498	.52745	.52992	58
32	.52992	.53238	.53484	.53730	.53975	.54220	.54464	57
33	.54464	.54708	.54951	.55194	.55436	.55678	.55919	56
34	.55919	.56160	.56401	.56641	.56880	.57119	.57358	55
35	.57358	.57596	.57833	.58070	.58307	.58543	.58779	54
36	.58779	.59014	.59248	.59482	.59716	.59949	.60182	53
37	.60183	.60414	.60645	.60876	.61107	.61337	.61566	52
38	.61566	.61795	.62024	.62251	.62479	.62706	.62932	51
39	.62932	.63158	.63383	.63608	.63832	.64056	.64279	50
40	.64279	.64501	.64723	.64945	.65166	.65386	.65606	49
41	.65606	.65825	.66044	.66262	.66480	.66697	.66913	48
42	.66913	.67129	.67344	.67559	.67773	.67987	.68200	47
43	.68200	.68412	.68624	.68835	.69046	.69256	.69466	46
44	.69466	.69675	.69883	.70091	.70298	.70505	.70711	45
	60′	50′	40′	30′	20′	10′	0′	
Sines	COSINES							Degrees

TABLE 50. Natural Trigonometric Functions (*Continued*)

Degrees	COSINES 0′	10′	20′	30′	40′	50′	60′	Sines
0	1.00000	1.00000	0.99998	0.99996	0.99993	0.99989	0.99985	89
1	0.99985	0.99979	.99973	.99966	.99958	.99949	.99939	88
2	0.99939	0.99929	.99917	.99905	.99892	.99878	.99863	87
3	0.99863	0.99847	.99831	.99813	.99795	.99776	.99756	86
4	0.99756	0.99736	.99714	.99692	.99668	.99644	.99619	85
5	0.99619	0.99594	.99567	.99540	.99511	.99482	.99452	84
6	0.99452	0.99421	.99390	.99357	.99324	.99290	.99255	83
7	0.99255	0.99219	.99182	.99144	.99106	.99067	.99027	82
8	0.99027	0.98986	.98944	.98902	.98858	.98814	.98769	81
9	0.98769	0.98723	.98676	.98629	.98580	.98531	.98481	80
10	0.98481	0.98430	.98378	.98325	.98272	.98218	.98163	79
11	0.98163	0.98107	.98050	.97992	.97934	.97875	.97815	78
12	0.97815	0.97754	.97692	.97630	.97566	.97502	.97437	77
13	0.97437	0.97371	.97304	.97237	.97169	.97100	.97030	76
14	0.97030	0.96959	.96887	.96815	.96742	.96667	.96593	75
15	0.96593	0.96517	.96440	.96363	.96285	.96206	.96126	74
16	0.96126	0.96046	.95964	.95882	.95799	.95715	.95630	73
17	0.95630	0.95545	.95459	.95372	.95284	.95195	.95106	72
18	0.95106	0.95015	.94924	.94832	.94740	.94646	.94552	71
19	0.94552	0.94457	.94361	.94264	.94167	.94068	.93969	70
20	0.93969	0.93869	.93769	.93667	.93565	.93462	.93358	69
21	0.93358	0.93253	.93148	.93042	.92935	.92827	.92718	68
22	0.92718	0.92609	.92499	.92388	.92276	.92164	.92050	67
23	0.92050	0.91936	.91822	.91706	.91590	.91472	.91355	66
24	0.91355	0.91236	.91116	.90996	.90875	.90753	.90631	65
25	0.90631	0.90507	.90383	.90259	.90133	.90007	.89879	64
26	0.89879	0.89752	.89623	.89493	.89363	.89232	.89101	63
27	0.89101	0.88968	.88835	.88701	.88566	.88431	.88295	62
28	0.88295	0.88158	.88020	.87882	.87743	.87603	.87462	61
29	0.87462	0.87321	.87178	.87036	.86892	.86748	.86603	60
30	0.86603	0.86457	.86310	.86163	.86015	.85866	.85717	59
31	0.85717	0.85567	.85416	.85264	.85112	.84959	.84805	58
32	0.84805	0.84650	.84495	.84339	.84182	.84025	.83867	57
33	0.83867	0.83708	.83549	.83389	.83228	.83066	.82904	56
34	0.82904	0.82741	.82577	.82413	.82248	.82082	.81915	55
35	0.81915	0.81748	.81580	.81412	.81242	.81072	.80902	54
36	0.80902	0.80730	.80558	.80386	.80212	.80038	.79864	53
37	0.79864	0.79688	.79512	.79335	.79158	.78980	.78801	52
38	0.78801	0.78622	.78442	.78261	.78079	.77897	.77715	51
39	0.77715	0.77531	.77347	.77162	.76977	.76791	.76604	50
40	0.76604	0.76417	.76229	.76041	.75851	.75661	.75471	49
41	0.75471	0.75280	.75088	.74896	.74703	.74509	.74314	48
42	0.74314	0.74120	.73924	.73728	.73531	.73333	.73135	47
43	0.73135	0.72937	.72737	.72537	.72337	.72136	.71934	46
44	0.71934	0.71732	.71529	.71325	.71121	.70916	.70711	45
Cosines	SINES 60′	50′	40′	30′	20′	10′	0′	Degrees

TABLE 51. NATURAL TRIGONOMETRIC FUNCTIONS

Degrees	TANGENTS 0′	10′	20′	30′	40′	50′	60′	Cotangents
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01455	0.01746	89
1	.01746	.02036	.02328	.02619	.02910	.03201	0.03492	88
2	.03492	.03783	.04075	.04366	.04658	.04949	0.05241	87
3	.05241	.05533	.05824	.06116	.06408	.06700	0.06993	86
4	.06993	.07285	.07578	.07870	.08163	.08456	0.08749	85
5	.08749	.09042	.09335	.09629	.09923	.10216	0.10510	84
6	.10510	.10805	.11099	.11394	.11688	.11983	0.12278	83
7	.12278	.12574	.12869	.13165	.13461	.13758	0.14054	82
8	.14054	.14351	.14648	.14945	.15243	.15540	0.15838	81
9	.15838	.16137	.16435	.16734	.17033	.17333	0.17633	80
10	.17633	.17933	.18233	.18534	.18835	.19136	0.19438	79
11	.19438	.19740	.20042	.20345	.20648	.20952	0.21256	78
12	.21256	.21560	.21864	.22169	.22475	.22781	0.23087	77
13	.23087	.23393	.23700	.24008	.24316	.24624	0.24933	76
14	.24933	.25242	.25552	.25862	.26172	.26483	0.26795	75
15	.26795	.27107	.27419	.27732	.28046	.28360	0.28675	74
16	.28675	.28990	.29305	.29621	.29938	.30255	0.30573	73
17	.30573	.30891	.31210	.31530	.31850	.32171	0.32492	72
18	.32492	.32814	.33136	.33460	.33783	.34108	0.34433	71
19	.34433	.34758	.35085	.35412	.35740	.36068	0.36397	70
20	.36397	.36727	.37057	.37388	.37720	.38053	0.38386	69
21.	.38386	.38721	.39055	.39391	.39727	.40065	0.40403	68
22	.40403	.40741	.41081	.41421	.41763	.42105	0.42447	67
23	.42447	.42791	.43136	.43481	.43828	.44175	0.44523	66
24	.44523	.44872	.45222	.45573	.45924	.46277	0.46631	65
25	.46631	.46985	.47341	.47698	.48055	.48414	0.48773	64
26	.48773	.49134	.49495	.49858	.50222	.50587	0.50953	63
27	.50953	.51320	.51688	.52057	.52427	.52798	0.53171	62
28	.53171	.53545	.53920	.54296	.54674	.55051	0.55431	61
29	.55431	.55812	.56194	.56577	.56962	.57348	0.57735	60
30	.57735	.58124	.58513	.58905	.59297	.59691	0.60086	59
31	.60086	.60483	.60881	.61280	.61681	.62083	0.62487	58
32	.62487	.62892	.63299	.63707	.64117	.64528	0.64941	57
33	.64941	.65355	.65771	.66189	.66608	.67028	0.67451	56
34	.67451	.67875	.68301	.68728	.69157	.69588	0.70021	55
35	.70021	.70455	.70891	.71329	.71769	.72211	0.72654	54
36	.72654	.73100	.73547	.73996	.74447	.74900	0.75355	53
37	.75355	.75812	.76272	.76733	.77196	.77661	0.78129	52
38	.78129	.78598	.79070	.79544	.80020	.80498	0.80978	51
39	.80978	.81461	.81946	.82434	.82923	.83415	0.83910	50
40	.83910	.84407	.84906	.85408	.85912	.86419	0.86929	49
41	.86929	.87441	.87955	.88473	.88992	.89515	0.90040	48
42	.90040	.90569	.91099	.91633	.92170	.92709	0.93252	47
43	.93252	.93797	.94345	.94896	.95451	.96008	0.96569	46
44	.96569	.97133	.97700	.98270	.98843	.99420	1.00000	45
Tangents	60′	50′	40′	30′	20′	10′	0′ COTANGENTS	Degrees

TABLE 51. Natural Trigonometric Functions (*Continued*)

Degrees	COTANGENTS							Tangents
	0′	10′	20′	30′	40′	50′	60′	
0	∞	343.77371	171.88540	114.58865	85.93979	68.75009	57.28996	89
1	57.28996	49.10388	42.96408	38.18846	34.36777	31.24158	28.63625	88
2	28.63625	26.43160	24.54176	22.90377	21.47040	20.20555	19.08114	87
3	19.08114	18.07498	17.16934	16.34986	15.60478	14.92442	14.30067	86
4	14.30067	13.72674	13.19688	12.70621	12.25051	11.82617	11.43005	85
5	11.43005	11.05943	10.71191	10.38540	10.07803	9.78817	9.51436	84
6	9.51436	9.25530	9.00983	8.77689	8.55555	8.34496	8.14435	83
7	8.14435	7.95302	7.77035	7.59575	7.42871	7.26873	7.11537	82
8	7.11537	6.96823	6.82694	6.69116	6.56055	6.43484	6.31375	81
9	6.31375	6.19703	6.08444	5.97576	5.87080	5.76937	5.67128	80
10	5.67128	5.57638	5.48451	5.39552	5.30928	5.22566	5.14455	79
11	5.14455	5.06584	4.98940	4.91516	4.84300	4.77286	4.70463	78
12	4.70463	4.63825	4.57363	4.51071	4.44942	4.38969	4.33148	77
13	4.33148	4.27471	4.21933	4.16530	4.11256	4.06107	4.01078	76
14	4.01078	3.96165	3.91364	3.86671	3.82083	3.77595	3.73205	75
15	3.73205	3.68909	3.64705	3.60588	3.56557	3.52609	3.48741	74
16	3.48741	3.44951	3.41236	3.37594	3.34023	3.30521	3.27085	73
17	3.27085	3.23714	3.20406	3.17159	3.13972	3.10842	3.07768	72
18	3.07768	3.04749	3.01783	2.98869	2.96004	2.93189	2.90421	71
19	2.90421	2.87700	2.85023	2.82391	2.79802	2.77254	2.74748	70
20	2.74748	2.72281	2.69853	2.67462	2.65109	2.62791	2.60509	69
21	2.60509	2.58261	2.56046	2.53865	2.51715	2.49597	2.47509	68
22	2.47509	2.45451	2.43422	2.41421	2.39449	2.37504	2.35585	67
23	2.35585	2.33693	2.31826	2.29984	2.28167	2.26374	2.24604	66
24	2.24604	2.22857	2.21132	2.19430	2.17749	2.16090	2.14451	65
25	2.14451	2.12832	2.11233	2.09654	2.08094	2.06553	2.05030	64
26	2.05030	2.03526	2.02039	2.00569	1.99116	1.97680	1.96261	63
27	1.96261	1.94858	1.93470	1.92098	1.90741	1.89400	1.88073	62
28	1.88073	1.86760	1.85462	1.84177	1.82907	1.81649	1.80405	61
29	1.80405	1.79174	1.77955	1.76749	1.75556	1.74375	1.73205	60
30	1.73205	1.72047	1.70901	1.69766	1.68643	1.67530	1.66428	59
31	1.66428	1.65337	1.64256	1.63185	1.62125	1.61074	1.60033	58
32	1.60033	1.59002	1.57981	1.56969	1.55966	1.54972	1.53987	57
33	1.53987	1.53010	1.52043	1.51084	1.50133	1.49190	1.48256	56
34	1.48256	1.47330	1.46411	1.45501	1.44598	1.43703	1.42815	55
35	1.42815	1.41934	1.41061	1.40195	1.39336	1.38484	1.37638	54
36	1.37638	1.36800	1.35968	1.35143	1.34323	1.33511	1.32704	53
37	1.32704	1.31904	1.31110	1.30323	1.29541	1.28764	1.27994	52
38	1.27994	1.27230	1.26471	1.25717	1.24969	1.24227	1.23490	51
39	1.23490	1.22758	1.22031	1.21310	1.20593	1.19882	1.19175	50
40	1.19175	1.18474	1.17777	1.17085	1.16398	1.15715	1.15037	49
41	1.15037	1.14363	1.13694	1.13029	1.12369	1.11713	1.11061	48
42	1.11061	1.10414	1.09770	1.09131	1.08496	1.07864	1.07237	47
43	1.07237	1.06613	1.05994	1.05378	1.04766	1.04158	1.03553	46
44	1.03553	1.02952	1.02355	1.01761	1.01170	1.00583	1.00000	45
Cotangents	60′	50′	40′	30′	20′	10′	0′	Degrees
	TANGENTS							

TABLE 52. RADII OF RAILROAD AND HIGHWAY CURVES

Degree of Curvature	Radius, Feet	Degree of Curvature	Radius, Feet	Degree of Curvature	Radius, Feet
0° 0′	∞	5° 0′	1146.28	10° 0′	573.69
10	34377.5	10	1109.33	10	564.31
20	17188.8	20	1074.68	20	555.23
30	11459.2	30	1042.14	30	546.44
40	8594.42	40	1011.51	40	537.92
50	6875.55	50	982.64	50	529.67
1° 0′	5729.65	6° 0′	955.37	11° 0′	521.67
10	4911.15	10	929.57	10	513.91
20	4297.28	20	905.13	20	506.38
30	3819.83	30	881.95	30	499.06
40	3437.87	40	859.92	40	491.96
50	3125.36	50	838.97	50	485.05
2° 0′	2864.93	7° 0′	819.02	12° 0′	478.34
10	2644.58	10	800.00	30	459.28
20	2455.70	20	781.84		
30	2292.01	30	764.49	13° 0′	441.68
40	2148.79	40	747.89	30	425.40
50	2022.41	50	732.01		
				14° 0′	410.28
3° 0′	1910.08	8° 0′	716.78	30	396.20
10	1809.57	10	702.18		
20	1719.12	20	688.16	15° 0′	383.06
30	1637.28	30	674.69	30	370.78
40	1562.88	40	661.74		
50	1494.95	50	649.27	16° 0′	359.26
				30	348.45
4° 0′	1432.69	9° 0′	637.27		
10	1375.40	10	625.71	17° 0′	338.27
20	1322.53	20	614.56	30	328.68
30	1273.57	30	603.80		
40	1228.11	40	593.42	18° 0′	319.62
50	1185.78	50	583.38	30	311.06

Note. The degree of curvature is the angle subtended at the center of the arc by a chord of 100 feet. The length of a curve is the length measured in 100-feet chords plus fractional 100-feet chords at the ends from P.C. to P.T.

TABLE 53. METRIC CONVERSION TABLES

Inches to centimeters—1 in. = 2.540005 cm

Units tens	0	1	2	3	4	5	6	7	8	9
0		2.540	5.080	7.620	10.160	12.700	15.240	17.780	20.320	22.860
1	25.400	27.940	30.480	33.020	35.560	38.100	40.640	43.180	45.720	48.260
2	50.800	53.340	55.880	58.420	60.960	63.500	66.040	68.580	71.120	73.660
3	76.200	78.740	81.280	83.820	86.360	88.900	91.440	93.980	96.520	99.060
4	101.600	104.140	106.680	109.220	111.760	114.300	116.840	119.380	121.920	124.460
5	127.000	129.540	132.080	134.620	137.160	139.700	142.240	144.780	147.320	149.860
6	152.400	154.940	157.480	160.020	162.560	165.100	167.640	170.180	172.720	175.260
7	177.800	180.340	182.880	185.420	187.960	190.500	193.040	195.580	198.120	200.660
8	203.200	205.740	208.280	210.820	213.360	215.900	218.440	220.980	223.520	226.060
9	228.600	231.140	233.680	236.220	238.760	241.300	243.840	246.380	248.920	251.460

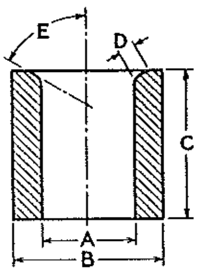
Centimeters to inches—1 cm = 0.3937 in.

Units tens	0	1	2	3	4	5	6	7	8	9
0		0.3937	0.7874	1.1811	1.5748	1.9685	2.3622	2.7559	3.1496	3.5433
1	3.9370	4.3307	4.7244	5.1181	5.5118	5.9055	6.2992	6.6929	7.0866	7.4803
2	7.8740	8.2677	8.6614	9.0551	9.4488	9.8425	10.2362	10.6299	11.0236	11.4173
3	11.8110	12.2047	12.5984	12.9921	13.3858	13.7795	14.1732	14.5669	14.9606	15.3543
4	15.7480	16.1417	16.5354	16.9291	17.3228	17.7165	18.1102	18.5039	18.8976	19.2913
5	19.6850	20.0787	20.4724	20.8661	21.2598	21.6535	22.0472	22.4409	22.8346	23.2283
6	23.6220	24.0157	24.4094	24.8031	25.1968	25.5905	25.9842	26.3779	26.7716	27.1653
7	27.5590	27.9527	28.3464	28.7401	29.1338	29.5275	29.9212	30.3149	30.7086	31.1023
8	31.4960	31.8897	32.2834	32.6671	33.0708	33.4645	33.8582	34.2519	34.6456	35.0393
9	35.4330	35.8267	36.2204	36.6141	37.0078	37.4015	37.7952	38.1889	38.5826	38.9763

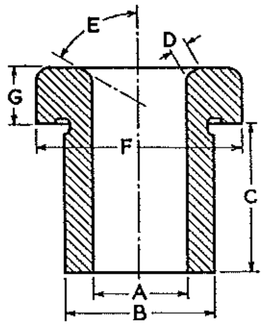
TABLE 56. AREAS AND VOLUMES

TRIANGLE: $Area = \frac{1}{2}bh = \frac{1}{2}ab \sin C$	REGULAR RIGHT PRISMS: $Surface\ Area = nah$; n = number of sides	REGULAR RIGHT PRISMS: $Volume = Bh$; B = area of base
RECTANGLE: $Area = bh$	REGULAR RIGHT PYRAMIDS: $Surface\ Area = \frac{1}{2}san$; n = number of sides; $s = h/\sin\alpha$	REGULAR RIGHT PYRAMID: $Volume = \frac{1}{3}Bh$
PARALLELOGRAM: $Area = bh = ab \sin C$	RIGHT CIRCULAR CYLINDER: $Surface\ Area = 2\pi rh$	RIGHT CIRCULAR CYLINDER: $Volume = \pi r^2 h$
TRAPEZOID: $Area = \frac{1}{2}(a+b)h$; $A = \frac{1}{2}d_1 d_2 \sin C$	SEGMENT OF CYLINDER: For Area of end segment see 1st Col.	$Volume = Bl$; B = area of segment see bottom of Col. 1.
ANY REGULAR POLYGON: $Area = \frac{1}{2}nbh$; n = number of sides; $h = (b/2)(\tan\alpha)$; $\alpha = ((n-2)/2n)180°$		HOLLOW CYLINDER: $Volume = \pi l(R^2 - r^2)$
CIRCLE: $Circum. = \pi d = 2\pi r$; $Area = \pi r^2 = \frac{\pi}{4}d^2$	RIGHT CIRCULAR CONE: $Surface\ Area = \pi rs$	RIGHT CIRCULAR CONE: $Volume = \frac{1}{3}\pi r^2 h$
ANNULUS: $Area = \pi(R^2 - r^2) = \frac{\pi}{4}(D^2 - d^2)$	FRUSTUM OF CONE: $Surface\ Area = \pi s(R+r)$	FRUSTUM OF CONE: $Volume = \frac{1}{3}\pi h(R^2 + Rr + r^2)$
SECTOR OF CIRCLE: $Area = \frac{1}{2}rs = \pi r^2(\alpha/360°)$; $s = 2\pi r(\alpha/360°)$	SPHERE: $Surface\ Area = 4\pi r^2$	SPHERE: $Volume = \frac{4}{3}\pi r^3$
SEGMENT OF CIRCLE: $Area = \frac{1}{2}[r(s-c) + ch]$; $c = 2r \sin\alpha$; $s = 4\pi r(\alpha/360°)$; $\cos\alpha = (r-h)/r$	SPHERICAL SEGMENT: $Surface\ Area = 2\pi rh$	SPHERICAL SEGMENT: $Volume = \frac{1}{6}\pi h(3a^2 + h^2)$; $a^2 = (h(2r-h))$

TABLE 57. Jig Bushings. Press Fit Wearing Bushings—Headless and Head Types



PRESS FIT, HEADLESS WEARING BUSHING



PRESS FIT, HEAD TYPE WEARING BUSHING

Range of Hole Size * † *A*		Body Diameter *B*					Body Length § *C*			Width of Chamfer ‖ *D*	Head Diameter ¶ *F* Max	Head Height *G* Max
		Unfinished ‡			Finished							
From	Up to and Including	Nominal	Max	Min	Max	Min	Short	Medium	Long			
0.0156	0.0625	5/32	0.166	0.161	0.1578	0.1575	5/16	...	1/2	1/32	1/4	3/32
0.0630	0.0995	13/64	0.213	0.208	0.2046	0.2043	5/16	...	1/2	1/32	5/16	3/32
0.1024	0.1378	1/4	0.260	0.255	0.2516	0.2513	5/16	...	1/2	1/32	3/8	3/32
0.1406	0.1875	5/16	0.327	0.322	0.3141	0.3138	5/16	1/2	3/4	1/32	7/16	1/8
0.1910	0.2500	13/32	0.421	0.416	0.4078	0.4075	5/16	1/2	3/4	1/16	17/32	5/32
0.2520	0.3125	1/2	0.520	0.515	0.5017	0.5014	5/16	1/2	3/4	5/64	5/8	7/32
0.3160	0.4219	5/8	0.645	0.640	0.6267	0.6264	1/2	3/4	1	3/32	13/16	7/32
0.4375	0.5000	3/4	0.770	0.765	0.7518	0.7515	1/2	3/4	1	7/64	15/16	7/32
0.5156	0.6250	7/8	0.895	0.890	0.8768	0.8765	3/4	1	1 3/8	7/64	1 1/8	1/4
0.6406	0.7500	1	1.020	1.015	1.0018	1.0015	3/4	1	1 3/8	7/64	1 1/4	5/16
0.7656	1.0000	1 3/8	1.395	1.390	1.3772	1.3768	3/4	1	1 3/8	9/64	1 5/8	3/8
1.0156	1.3750	1 3/4	1.770	1.765	1.7523	1.7519	1	1 3/8	1 3/4	9/64	2	3/8
1.3906	1.7500	2 1/4	2.270	2.265	2.2525	2.2521	1	1 3/8	1 3/4	7/32	2 1/2	3/8

All dimensions given in inches.
Tolerance on fractional dimensions where not otherwise specified shall be ±0.010 inch.
* Hole sizes are in accordance with the American Standard for Twist Drill Sizes (ASA B5.12—1940).
† The maximum and minimum values of the hole size, *A*, shall be as follows:

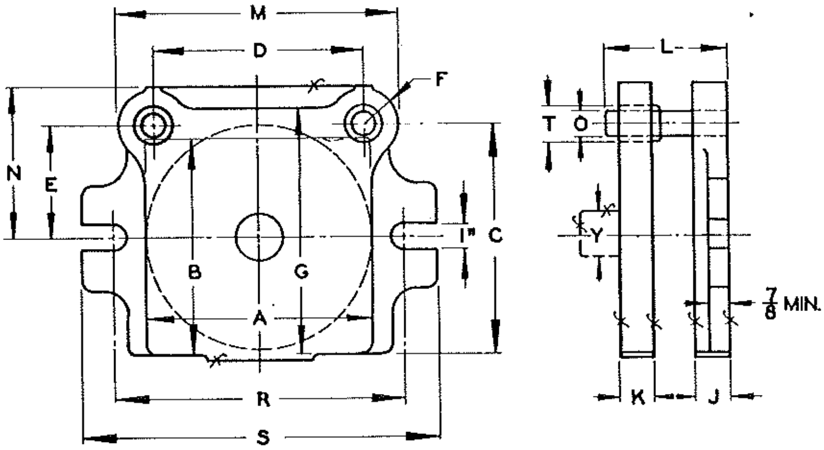
Nominal Size of Hole	Maximum	Minimum
Above 0.0000 to 1/4 in. incl.	Nominal +0.0004 in.	Nominal +0.0001 in.
Above 1/4 to 3/4 in. incl.	Nominal +0.0005 in.	Nominal +0.0001 in.
Above 3/4 to 1 1/2 in. incl.	Nominal +0.0006 in.	Nominal +0.0002 in.
Above 1 1/2	Nominal +0.0007 in.	Nominal +0.0003 in.

‡ The body diameter, *B*, for unfinished bushings is larger than the nominal diameter in order to provide grinding stock for fitting to jig plate holes. The grinding allowance is 0.005 to 0.010 in. for sizes 5/32, 13/64, and 1/4 in.,
0.010 to 0.015 in. for sizes 5/16 and 13/32 in., and
0.015 to 0.020 in. for sizes 1/2 in. and up.

§ The length, *C*, is the overall length for the headless type and the length underhead for the head type.
‖ The angle of chamfer, *E*, shall be 59 deg ± 1 deg, and a slight radius shall be provided at the intersection of this chamfer with the hole, *A*.
¶ The head design shall be in accordance with the manufacturer's practice.

TABLE 58. Heavy-Duty Die Sets

Commercial series, regular type.



Flanged Punch Holder and Die Holder
Heavy Guide Posts

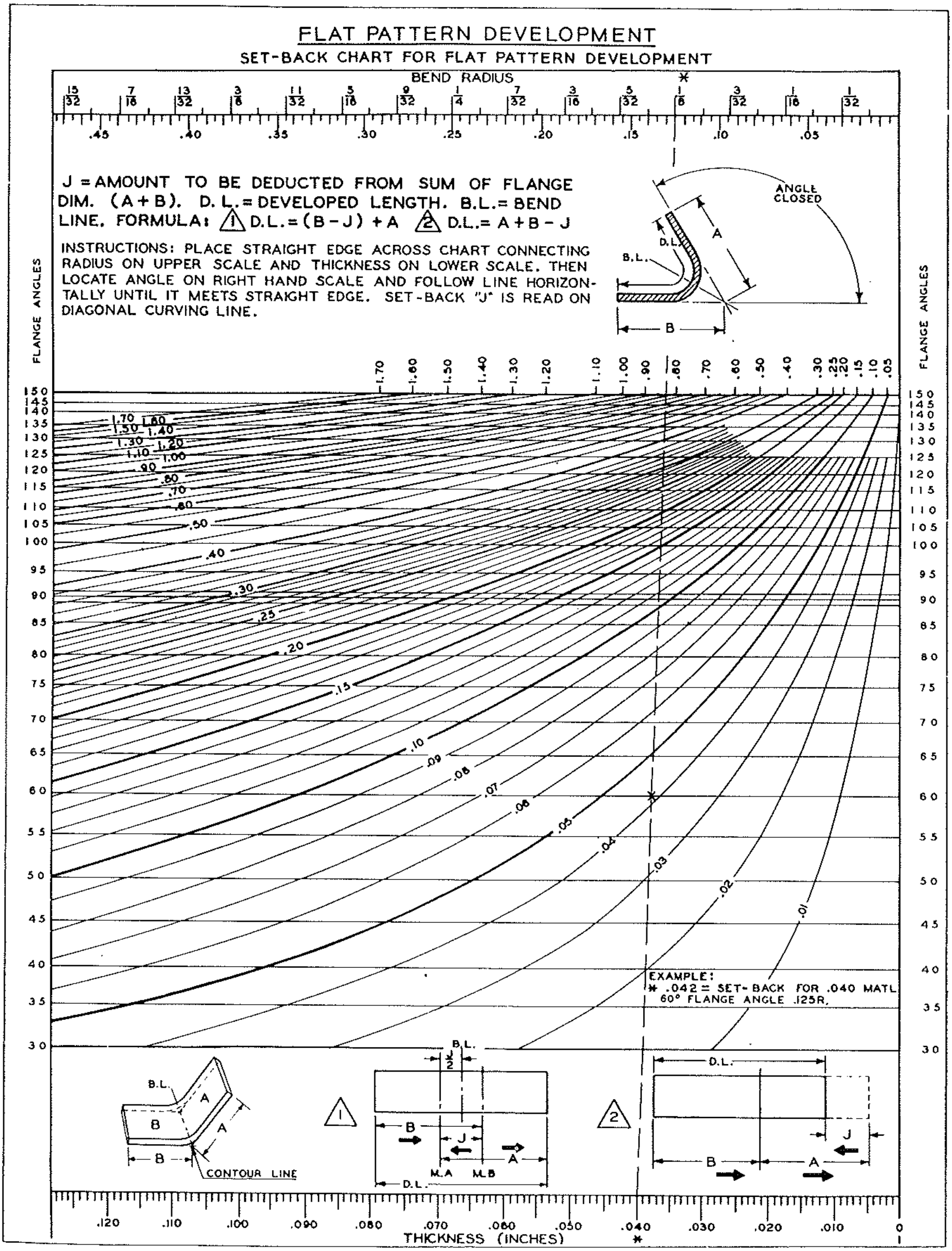
Die Area		Thickness		Steel Die Holder Steel Punch Holder	General Dimensions										
A	*B*	Die Holder *J*	Punch Holder *K*		*C*	*D*	*E*	*F*	*G*	*M*	*N*	*O*	*R*	*S*	*T*
6	4	1½ 2	1¼ 1¾	939116 939117	4¾	7½	2¾	1⅝	5¼	10¾	4½	1½	8¼	10¾	2
8	6	1½ 2	1¼ 1¾	939118 939119	6¾	9½	3¾	1⅝	7¼	12¾	5½	1½	10¼	12¾	2
10	8	1¾ 2¾	1½ 2	939120 939121	8⅞	11¾	4⅞	2	9⅜	15¾	7	1¾	12¼	14¾	2¼
12	10	2 3	1¾ 2½	939122 939123	10⅞	13¾	5⅞	2	11⅜	17¾	8	1¾	14¼	16¾	2¼
14	12	2¼ 3¼	2 2¾	939124 939125	13	16	7	2½	14	21	9⅝	2	16¼	18¾	2½
16	14	2¼ 3½	2 2¾	939126 939127	15	18	8	2½	16	23	10⅝	2	18¼	20¾	2½

Courtesy General Motors Corp.

TABLE 59. Standard Bend Radii

Material Thickness	Aluminum Alloy							Magnesium Alloy		Steel			
											Stainless		
	2SO 3SO 52SO 53SO	2S½H 3S¼H 4SO 52S¼H 53S¼H	2S¾H 3S½H 4S¼H 52S½H 53S½H	3S¾H 4S½H 17SO 24SO 52S¾H 53S¾H 61SO	4S¾H 17ST 24ST 53ST 53SW 61ST 61SW	75SO	27ST 75ST	Cold Formed	Hot Formed	Low Carbon X4130 Annealed	Annealed	¼ Hard	½ Hard
0 through 0.013	0.031	0.031	0.031	0.031	0.062	0.031	0.062	0.062	0.031	0.031	0.031	0.062	0.062
0.014 through .017	.031	.031	.031	.031	.062	.031	0.062	0.062	.031	.031	.031	.062	.062
.018 through .022	.031	.031	.031	.031	.062	.062	0.094	0.094	.031	.031	.031	.062	.062
.023 through .027	.031	.031	.031	.062	.094	.062	0.125	0.125	.062	.031	.031	.062	.062
.028 through .035	.062	.062	.062	.062	.125	.062	0.156	0.156	.062	.031	.031	.062	.094
.036 through .044	.062	.062	.062	.062	.125	.094	0.219	0.219	.094	.062	.062	.094	.125
.045 through .054	.062	.062	.094	.094	.156	.125	0.250	0.250	.125	.062	.062	.094	.125
.055 through .068	.062	.094	.094	.125	.219	.125	0.312	0.312	.156	.062	.062	.125	.188
.069 through .075	.094	.094	.125	.125	.250	.156	0.375	0.375	.188	.062	.062	.125	.188
.076 through .084	.094	.094	.156	.125	.281	.188	0.406	0.406	.219	.094	.094	.156	.219
.085 through .097	.094	.094	.188	.125	.312	.188	0.469	0.469	.250	.094	.094	.188	.250
.098 through .113	.125	.125	.188	.156	.375	.219	0.531	0.625	.250	.125	.125	.219	.312
.114 through .139	.125	.156	.219	.188	.438	.281	0.688	0.750	.312	.125	.188		
.140 through .172	.156	.188	.250	.250	.562	.375	0.875	1.000	.375	.156	.188		
.173 through .219	.188	.250	.375	.312	.750	.438	1.062	1.250	.500	.188	.188		
.220 through .262	.250	.312	.500	.469	.938	.531	1.250	1.500	.625	.250	.250		

TABLE 60



Courtesy McDonnell Aircraft Co.

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