ENGINEERING DRAWING

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PREFACE TO THIRD EDITION

The third edition contains many important improvements over the two previous editions. The chief considerations that have dictated changes in the plan of organization and expansion in the materials presented are: (1) the necessity of bringing before students and other users of the graphical languages the recently approved American Standards in Drawing after more than five years of review and study of present practices; (2) the desirability of including more of the basic principles of descriptive geometry in teaching the student how to read and construct the projections of objects with which he has to deal; (3) the need for additional and a better grouping of related materials than existed heretofore; and (4) the demand that the problem and tabular sections be expanded and brought forward from the back part of the text to the individual chapters to which they relate.

In more detail, the revisions include: the addition of two new chapters, XXII and XXIV, "Pipe Drawing" and "Gears and Cams," respectively; the division and expansion of two chapters into four, thus adding the chapter titles, "Intersections and Developments" and "Section Planes and Views"; the expansion of the problem sections by the addition of a large number of new figures, bringing the problem number up to seven hundred; and the redrawing or enlargement of many old figures throughout the text in the interest of clarity.

These and other changes, such as the complete rewriting of the chapter on fasteners, the inclusion of new illustrative and text materials in the chapter on charts and diagrams and in those on map, architectural, and structural drawing, bring the text into accord with the best drawing practice of the day. The recently approved American Standards Association's drawing standards have been adhered to closely in the fields covered thus far. Generally adopted standards in the profession have been used where "American" standards are not available.

Nothing has been done to disturb the proved features of the text, that the subject-matter of drawing shall develop in the student's mind in a logical manner through small chapter groupings, or learning units, which pass from theory to practice and from the basic and general to the specialized. The segregation of all advanced drawing material into Part II of the text carries out the sound principle of previous editions that two basic courses in drawing — elementary and advanced — must be offered in institutions where students come with widely varying degrees of training from preparatory schools. Those wishing to offer combined courses in drawing and descriptive geometry will find the new arrangement and material very well suited to that purpose. The book is to be considered a reference work as well as a classroom text for college students.

The authors have profited greatly from the suggestions offered by users of the book, particularly from those tendered by their colleagues, A. Jorgensen and S. G. Hall, and by others in the Department of General Engineering Drawing at the University of Illinois. To all these they express their sincere appreciation. Also appreciation is expressed to the following authors and publishers for permission to use cuts from their published works: H. J. Macintire, T. C. Shedd, F. D. Furman, W. H. Motz; Nickerson & Collins Company.

URBANA, ILLINOIS,
March, 1935.

PREFACE TO SECOND EDITION

No change from the first edition in the plan of organization of materials has been made in the second edition. Changes in the method of presenting certain topics and in content have been made as follows.

Chapter V has been entirely rewritten with the purpose of simplifying the presentation of the fundamental theory of orthographic projection. The figures are all new in this chapter and are done in pictorial drawing to a large extent. Chapter VI has also been revised on the same basis as Chapter V and expanded to include the second auxiliary plane of projection. Several working drawings have been added to Chapter VIII. The chapters on Lettering, Use of Instruments, and Chart and Diagram Drawing have been expanded considerably. Several new pages of tables and symbols on pipe layout work have been added to the appendix. In all, forty-two new figures have been added and sixty-one redrawn. All errors detected in the first edition have been eliminated.

The authors gratefully acknowledge the constructive criticisms offered by the users of the text.

URBANA, ILLINOIS,
May, 1928.

PREFACE TO FIRST EDITION

An author's justification for offering to the public a new text book on any subject must find its root in one or both of two purposes — either to present the discovery of new facts and the development of new theories, or to reclassify and revitalize already known facts and theories in a manner better calculated to meet the changing needs of the times in which he lives.

The authors of this text on Engineering Drawing present it to the Engineering profession and others desirous of perfecting themselves in the technics of the graphical language, with no claim, thereby, to having added to the common stock of the world's knowledge. Rather, it is with the hope and aspiration of putting many closely related, though sometimes isolated, bits of knowledge into a more complete and harmonious whole than has hitherto been done, that the work has been undertaken and accomplished. The success of their labors must depend largely upon how well they have wrought in this respect.

It has been well said that Drawing is simply the expression of the geometrical concepts of man in a graphical language. To the understanding of its fundamental grammar and composition, therefore, must be added the manual skill necessary to its successful execution. The authors have been keenly mindful of these premises and, although subordinating perfect execution to thorough understanding in emphasizing fundamental phases of the various topics, they have attempted to treat the subject-matter from the point of view of users and teachers of a universal language.

Five kinds of materials have been recognized as proper to be included in this book: (1) elementary fundamental theories and concepts underlying all forms of Drawing; (2) illustrations explaining the theory and demonstrating proper modes of execution; (3) complex but related principles; (4) encyclopedic or handbook materials — sometimes called commercial practices; and (5) problems.

Materials in the first and second divisions have been developed in a consistent and orderly manner through chapter arrangement. These are in themselves complete units or entities. Those using the text will find them not too long, but self-contained and comprehensive. Those materials falling in the third division have been segregated into subsections in the chapters in which they naturally belong and are thus kept from obscuring and confusing the objective things on which a student's attention must be focused in the main section of the chapter. Materials falling into the fourth group have been collected into the Appendix and indexed; or, in some cases, they have been put into the subsection of a related chapter. Problems have been omitted altogether, on the ground that they destroy the local color and initiative of the department of Drawing using them, and soon become a stereotyped list of exercises planned by a person or persons in whom the student has no interest, and which have been solved and put on file by scores of his fellow students before him. It is intended that a book of such exercises for instructor's use and guidance shall be prepared later, as the demands may become great enough to warrant such compilation.

Part I deals with the four fundamental kinds of projections and their applications in mechanical and freehand drawing. Chapters on Shop Terms and Processes, Sketching, and Reproduction of Drawings are included at the proper coördinating places. This part of the text should be considered the minimum content of any thorough course on Drawing.

Part II treats of the applications of the principles laid down in Part I to the various fields of Drafting, such as Architectural, Structural, Map, Patent Office, etc. A comprehensive chapter embodying the fundamental and underlying principles of Graphic Methods, hitherto omitted from Drawing texts, is considered opportune and in its proper setting.

The Appendix contains symbols and conventions in various fields of Drawing, geometrical constructions, and tables of data generally needed by students in the drawing room or office.

Grateful acknowledgment is made to those members of the Department of General Engineering Drawing at the University of Illinois who have made helpful suggestions during the preparation of the manuscript, and especially to Professor J. K. McNeely who has so effectively read the text material and offered helpful criticism.

The authors also express sincere appreciation and acknowledgment to the Department of Architecture at the University and to several individuals and commercial companies, for permission to use drawings and cuts and in some cases text material, which have added greatly to the value of the work. Reference is made to this assistance at the proper places in the body of the text material.

Urbana, Illinois,
May, 1923.

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ENGINEERING DRAWING

PART I

CHAPTER I

INTRODUCTORY

1. In designing machines, factories, dams, railroads, and other structures for man's use, the engineer must first form a clear mental picture of the thing to be built, before any work can be done on its actual construction. He must then convey his picture to the constructor, furnishing him data which will give the exact sizes of all parts, the kind of materials of which they are to be made, the positions they are to occupy with respect to each other in the completed machine or structure, the finish and exactness required in their construction, and many other bits of information which are of importance to the builder in his work.

Only two agencies exist by which the ideas of the designer may be transmitted to the constructor without the use of models — the first and older being that of written or oral language, the second, that of drawings or pictures. A little reflection serves to convince one that it would be an impossible task to describe in oral or written language such a simple machine as a gas engine, for instance, with dimensions and data sufficient to allow of its construction in pattern, foundry, and machine shop. Many printed pages would be consumed in the effort, and few workmen would be able to form from such data any conception of the machine desired to be built.

It is on account of this inability of the written and oral language to convey the designs of the engineer to his fellowmen that he has devised for his use another language called the *Graphical Language*, or *Drawing*. This graphical language, although quite unlike our everyday language in some respects, has, however, many points of similarity with it; and these likenesses should always be kept in mind when learning this newer medium for conveying ideas. Before studying these points of resemblance in detail, the beginner should learn thoroughly a few definitions of terms generally used among draftsmen and engineers in describing and classifying various kinds of drawings.

2. Two main divisions of engineering drawing are usually recognized, namely, *Mechanical Drawing* and *Freehand Drawing*. Much the same differences exist between them as between the typewritten sheet and one done in longhand. Under the title of mechanical drawing are included all drawings made with the use of instruments of precision, commonly called the *Draftsman's Kit*. In making such drawings, not only does the draftsman have to master the principles of the language itself, but he must also become wholly proficient in the use of the tools with which he writes the language. When the graphical language is written without the aid of instruments of precision and with only pencils or pens for tools, the drawings are called *Freehand Drawings*, or *Sketches*.

The use of mechanical drawing as defined above is limited almost exclusively to engineers and architects, whereas freehand drawing is used by the artist as well as by the engineer. The artist, however, endeavors to show only the form, proportions, texture of materials, and the effect of light upon an object by means of shades and shadows. The engineer must not only show form, proportions, and the nature of the materials, but he must also give the exact sizes of the parts, their finish, and the clearances to be maintained. Ordinarily, he has nothing to do with shades and shadows.

We are chiefly concerned in this text with mechanical drawing, and freehand drawing as used by the engineer.

Each of the two kinds of drawing described above may be subdivided into *Orthographic*, *Isometric*, *Oblique*, and *Perspective Drawing*, according to the method of projection used, in much the same way as the written language is divided into four major forms of composition, namely, description, narration, exposition, and argumentation. Each of these main divisions may then be further subdivided into various fields of drawing, each of which has its own idiomatic forms of expression, such as *Machine*, *Structural*, *Topographical*, etc. As in the various forms of written composition, so is it true in the different kinds of drawing, that the fundamental principles of the language are the same in all cases. We are interested here more with the **fundamentals**, or **grammar**, of the language itself than with the **styles** it may assume in the hands of individual users.

The importance of the **engineer's** learning how to read and write this most useful and forceful language can hardly be overemphasized. Our object in this text is to study this graphical language in order that we may use it in engineering practice in the same way as an author uses the written language in the practice of his profession. In the words of one writer on drawing,[1] " We must know the alphabet, the grammar and the rhetoric, and be familiar with the idioms, the accepted conventions, and the abbrevi-

[1] "Engineering Drawing" by Professor Thomas E. French.

ations." It should be noted in passing that this graphical language is the only language in existence which is understood and written readily in all countries where scientific knowledge is applied at all to the purposes of man.

3. Always it must be understood that our study of this most important tool of all those in the engineer's possession is not in itself the end or goal to be reached, but is rather to be considered as a means to an end; that end is the ability to do engineering work and converse in the engineer's language. Few men attain distinction as **draftsmen,** just as few men become authors or poets, but every engineering student should strive to master the techniques of graphical expression, not with the hope of becoming a draftsman, but rather with the determination of becoming an engineer. It can hardly be said that there is a *profession of drafting,* since most draftsmen are engineers in the true sense of the word, and they apply their knowledge of drawing in the same way and for the same purposes as they do their knowledge of mathematics.

In studying the text, a student should read a paragraph or a group of related paragraphs and then see if he can restate the main points correctly in his own terms without reference to the text. If he cannot, he should reread the material and underscore lightly those phrases and sentences that give the gist of the matter and then again attempt to state the facts. Repeat, if necessary. When an entire chapter or assignment has been covered in this way, a comprehensive outline of the principal points should be written without reference to the text. The outline need not be filled in with much detail but enough should be jotted down to permit a careful check against the book. Omitted portions should be added and the whole reviewed to get the proper relations of the parts.

PROBLEM LAYOUT

4. The problems at the end of each chapter in this text have been designed to fit one or another of the sheet sizes shown in Figs. 1 to 4. For the convenience of both student and instructor, the scale and sheet size to be used with any problem figure have been lettered directly upon the figure itself, rather than given in the verbal statement of the problem. Thus, Scale A: $1'' = 1''$ means that the problem may be drawn to this scale upon sheet A; Scale B: $\frac{1}{2}'' = 1''$ means that the problem may be drawn to this scale upon sheets B, C, or D, since these three sheets are so nearly the same size that the given scale will be suitable for all three. In some problems, only one scale and sheet specification is given. This indicates the *minimum* size of sheet which may be used. In others, however, both scales are designated. With the size of the drawing paper specified, the student can then select the proper scale.

Title and signature forms are also suggested for convenience. See Figs. 5 and 6. These forms have been found satisfactory in many schools. Other forms can, of course, be substituted if desired.

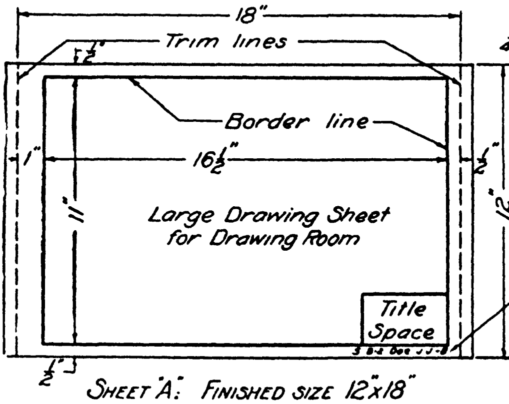

FIG. 1. Layout of drawing sheet.

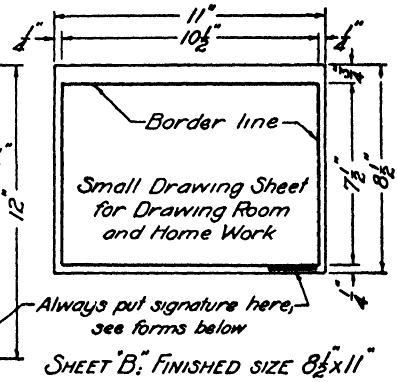

FIG. 2. Small sheet layout.

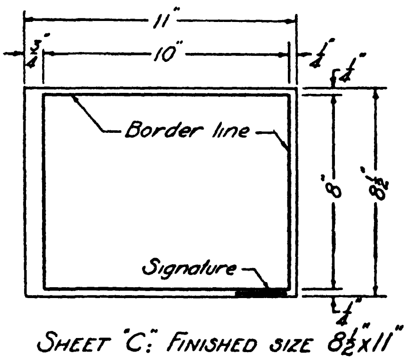

FIG. 3. Small sheet layout.

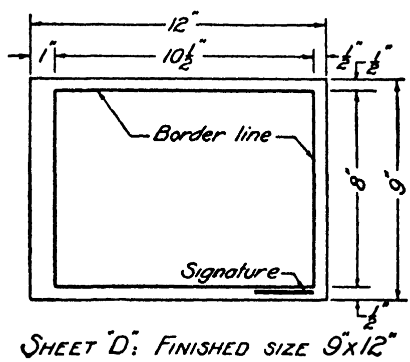

FIG. 4. Small sheet layout.

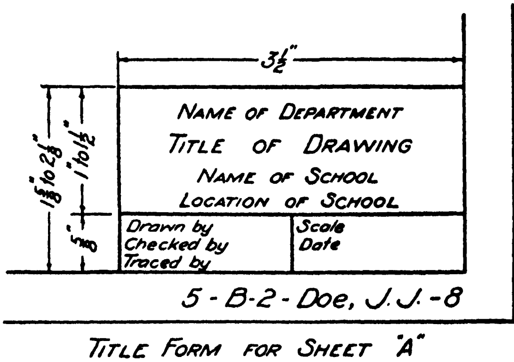

FIG. 5. Title layout.

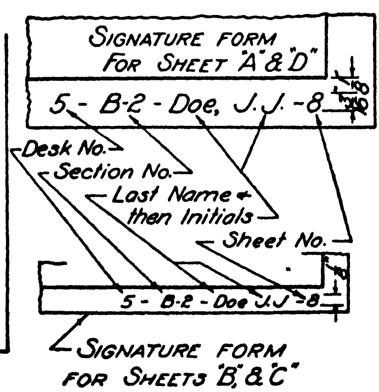

FIG. 6. Title layout.

CHAPTER II

LETTERING

SECTION 1

5. The first essential prerequisite to the successful use of the graphical language is a complete mastery of the art of lettering. Every drawing must have dimensions, a title, and notes placed upon it before it becomes workable — has life, as it were. Besides making it workable, the lettering put upon a drawing will either embellish it or ruin it, depending upon the skill of the draftsman in making the simple style of letter and figure which the engineering profession has approved.

Nearly all engineers, except the architectural engineer, use a style of letter called the Reinhardt vertical or slant letter. Mr. Reinhardt was for many years engineering draftsman and illustrator for the *Engineering News*, and he evolved from his experience a very simple kind of lettering which, in honor of his genius, has been called the *Reinhardt style* by common consent of the engineering profession. Any student can learn to do this kind of lettering well, with a little careful study of its component parts and diligent practice in its proper execution.

6. **Style in Lettering.** — In referring to any piece of lettering as having a certain *style*, we mean to convey three principal ideas either by direct statement or by implication. The first is that of the *original or basic form and character* of the type of letter used; the second is that of the *modification or change* from the original form; and the third is that of the *direction of stroke or slope* used in making the individual letters. In the example shown in Fig. 1, the word "Gothic" indicates the basic form of the alphabet; the words "single stroke" give the information that the width of the components of the letters is to equal the width of a single stroke of the pen; and the word "vertical" tells us that the *stem* strokes are to be straight up and down the sheet in such letters as *H*, *I*, *M*, *N*, *L*, etc. These three factors must always be taken into account when designating the style of any alphabet or job of lettering. Each is discussed briefly in the following paragraphs.

EHTAWXN
BCDOPSU

Fig. 1. Single stroke vertical Gothic letters.

7. Original Alphabets. — The oldest type of letter bearing close resemblance to the kind now used by engineers is the Roman. It was derived from the Greek, which in turn was adapted from the Phoenician. It is well to remember that the Roman alphabet, in almost the same form as we now have it, came into existence twenty-five hundred years ago, and it undoubtedly will continue to be the most generally used alphabet in the world. The original form of this alphabet is referred to as the Old Roman. A complete alphabet of Old Roman is shown in Section 2, Chapter II. This alphabet is still used by architects, although many modifications have been devised.

8. Modified Alphabets. — It is only natural that the original alphabets should have undergone considerable modification in the interest of simplicity of design or to suit the fancy of some ingenious printer. Thus we find that considerable change in the first Roman alphabet has been made by those who have been users of it during the last twenty centuries, until a very definite and beautiful style, called the Modern Roman, has been evolved. In Section 2, Chapter II, the Modern Roman alphabet is shown in contrast with the Original Roman. The former is still much used in engineering work, particularly where an excellent and striking appearance is desired, for instance, in a title or inscription. Its more standardized and simplified appearance, as well as its inherent beauty and stateliness, should be studied carefully.

Another one of the older modified forms which is much simpler in its construction, although not so beautiful as the Roman, is called the Gothic. This style is plain and severe, being stripped of all serifs, that is, of all fine lines of ornamentation, especially the cross lines at the top and bottom of letters, as shown in Figs. 1 to 5, inclusive, of Section 2, Chapter II. All the components of the letters are of the same weight, and hence are more easily made. It may be built up to any width and height, or the outlines of the letters may be stroked in and the open spaces filled with brush or pen.

It was this very fact of modification and simplification which caused the Reinhardt style to be so instantly accepted for engineering use. This modification of the Gothic — originally derived from the Roman — lends itself readily to rapid construction and is very easy to read. It is made with a single stroke of the pen for each component part and is therefore called the *Single-Stroke Gothic.* See Fig. 1.

9. Slope. — To indicate the style of a letter completely, we must mention the direction of stroke, whether it be vertical or slanting. Vertical lettering is spoken of by some as "upright" lettering; as its name suggests, the strokes are perpendicular to the axis of the line of lettering. In slant lettering, many angles of slope are used, and although good appearance may be obtained at any angle between 65 and 75 degrees, consideration of best effect dictates adherence to a fairly well-determined standard of 67½ degrees from the horizontal.

Bearing the above observations in mind, we shall direct our attention to the study of those types of lettering known as the *Reinhardt slant and vertical styles.* Such modifications as are thought to improve upon the original forms will be suggested, and general rules for the execution of these styles will be given.

10. Upper- and Lower-Case Letters. — In any style of lettering, two kinds of letters are universally used. The one is known as the *Large Letters* or *Capitals,* the other is known as the *Small Letters.* On account of the custom of the early printers of keeping the capitals in the upper part of their case and the small letters in the lower part of the same case, they came to be known as the *Upper-* and *Lower-Case* letters, respectively. These dual names for each alphabet are still commonly used and must be understood by the engineer, who generally prefers, however, the names given first.

Whenever the capitals, or upper-case, letters, are used in the same words or sentences with the small, or lower-case, letters, a fixed ratio between their heights is always adhered to. The long strokes in the small letters are made equal to the height of the capitals, with the single exception of *t,* which is just a bit shorter than other strokes of its class. The bodies of the small letters, on the other hand, are two-thirds the height of the capitals. This ratio is always maintained by ruling guide lines, either with a scale and straight edge or with a lettering triangle. When tracing a drawing, the guide lines should be ruled again on the tracing cloth before attempting to trace the lettering. This practice should be followed strictly even in lettering a single word. The phrase " height of the letters " means the height of the capitals or long stems.

11. Elements. — The Reinhardt alphabet is composed of two simple elements, with slight variations in a few letters in the interest of better

A B C D E F G H I J K L M N O

P Q R S T U V W X Y Z &

abcdefghijklmnopqrstuvwxyyz

Fig. 2. Engineer's vertical single stroke alphabet.

appearance or on account of some peculiarity of an individual letter. The first of these elements is called the *Stem* of the letter and is made with a single downward stroke of the pen. The second element is called the *Oval* of the letter and is made with one or two strokes of the pen, depending upon the size being used. When one has mastered these two simple elements and has learned to combine them properly, he is able to produce satisfactorily the engineer's alphabets shown in Figs. 2 and 3.

12. Stems. — As indicated above, the stems of letters are those single straight-line strokes which form a part of more than four-fifths of all the letters in the alphabet. It is the direction of the stems of such letters as

ABCDEFGHIJKLMNOP
QRSTUVWXYZ&
abcdefghijklmnopqrstuvwxyyz

FIG. 3. Engineer's slant single stroke alphabet.

H, *M*, and *N* which determines the *slant* of the letters. In Fig. 2 the vertical alphabet is shown. In Fig. 3 a slope of $67\frac{1}{2}$ degrees, recognized as the American Standard for slant lettering, has been used.

It should be noted that all stems are of the same vertical height in the capitals, but in the small letters two heights are used. The shorter stems are two-thirds the height of the longer ones, which we remember is the exact ratio between the capitals and the small letters. It has always been customary to make the small *t* a little shorter than the long stems, thus automatically forcing the crossing bar to the level of the tops of the ovals and thereby making a better spacing appearance than would be the case if the stem were full length and the bar raised. Several straight-line strokes occur in some of the letters, such as the horizontals in *A*, *E*, *F*, and *H*, as well as the inclined strokes in *K* and *Y*, which are not classed as stems but which need no comment other than to direct attention to their off-center location — the bar in *A*, for instance, being below, and the bar in *H* being above, the center line. Further mention is made of these variations in a later paragraph.

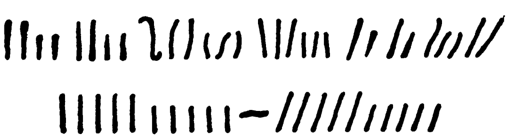

FIG. 4. Incorrect and correct stem strokes.

The only requisites of well-made stems are (1) uniform weight of strokes throughout their entire length, (2) perfect straightness of outline without curls either at the beginning or end of the stroke, and (3) uniformity of slant in all the letters. Much depends upon the ink and pen used in obtaining the proper weight of line, but straightness and uniformity of slant are mere matters of critical eye and hand practice. Good and poor results are shown in Fig. 4.

13. Ovals. — The second element in lettering is a perfect ellipse, with a fairly well-determined ratio between its major and minor axes. In Fig. 5, the horizontal width of the parallelogram enclosing the ellipse is made five-sixths its height. The ellipse touches the four sides of the parallelogram exactly at their midpoints. These proportions give what is termed the *normal* or *standard* vertical or slant oval, and when combined properly with the stem produces the normal or standard alphabet. It must not be understood that the five-sixths ratio is a hard and fast requirement, although it furnishes a good working basis. In any case, however, the horizontal width of the oval should be slightly less than the height, for normal letters.

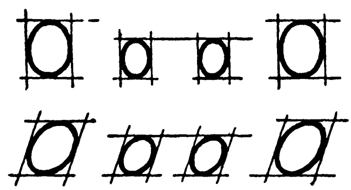

FIG. 5. Correct oval stroke.

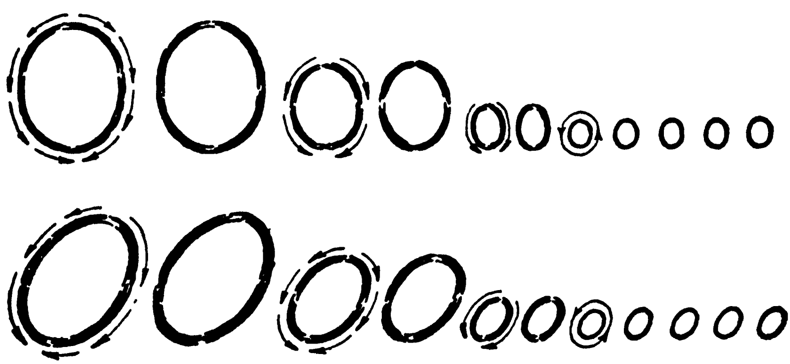

FIG. 6. Method of developing standard oval.

In executing the oval, it will be found helpful to begin with rather large sizes, say three-fourths of an inch high. The contour of the ellipse should be sketched in with full sweeping strokes, an attempt being made to secure the perfect shape so essential to a graceful style. As the smaller sizes are chosen, the sketch stroke should be abandoned and two smooth strokes used. Finally, with heights of one-eighth inch or less, a single stroke may be adopted. Figure 6 illustrates the procedure to be followed.

14. COMBINATION OF STEM AND OVAL. — When one has mastered the technique of the individual elements, it becomes a simple task to combine them in forming such letters as *b*, *d*, *p*, *n*, *r*, *u*, etc. The secret of success lies chiefly in remembering that the stem becomes one side of the parallelogram shown in Fig. 5, and that, in making the stem tangent to the oval, it will be found in practice that they must coincide with each other for some distance, as shown in Fig. 7. The oval should not be allowed, on this account, to degenerate into the form shown in Fig. 8, called the *pumpkin seed* letter, a form which is used by many engineers because of its easy construction, and in which the juncture of stem and oval is hardly more than a point. Another common inexcusable distortion of the oval in many of the small letters is shown in Fig. 9, where only a part of the oval is used, either alone or in combination with the stems. The corners indicated on the upper right segment of the oval rapidly become very sharp and detract materially from the beauty of the alphabet.

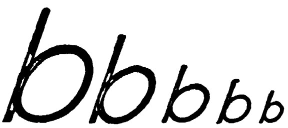

FIG. 7. Combined stem and oval.

FIG. 8. Incorrect ovals "Pumpkin seed."

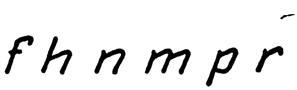

FIG. 9. Incorrect ovals, sharp corners.

A second element of success consists in making the stem and oval of the same weight, both when combined and when made separately. It should be observed in Fig. 7 that the weight of stroke varies directly with the size of letter, the larger letters having a width of stroke equal to about one-sixth the height, while the smaller letters are correspondingly decreased to the limit of the pen being used.

A third element entering into the successful construction of the alphabet, perhaps to a greater degree than either of the other two enumerated, is that of the width of each letter. Even a cursory examination of the alphabet is sufficient to impress upon the eye the necessity of varying the width of different letters to accommodate their shape to one another. In short, each letter must be proportioned upon some general principle or rule, often called the "rule of stability," which will take care of these differences due to shape and make proper allowance for balance in each letter.

15. Rule of Stability. — An examination of such capital letters as *A*, *F*, *J*, *K*, *P*, *T*, and *V* discloses at once the fact that, on account of their unsymmetrical form, some contraction should be made in the width of each to prevent them from appearing either top-heavy or bottom-heavy, as the case may be. Likewise, the mass form of *M* and *W* requires that they be made wider than the normal letter. Again, it is a well-known fact that a horizontal line drawn through the middle of an upright rectangle appears to be below the center of the rectangle, or, in other words, the top area appears greater than the bottom area. This optical illusion has an effect on such letters as *A*, *B*, *E*, *F*, *H*, *K*, *P*, *R*, *S*, and *X*.

The rule of stability takes all these factors into account by requiring that the irregular white surfaces enclosed by black lines appear to be balanced in each letter. The small tops of the letters *B* and *S* and the numerals *2*, *3*, and *8*; the high position of the bar in *H*, as well as the high crossing of the two strokes in *X*; the low position of the bar in *A*; and

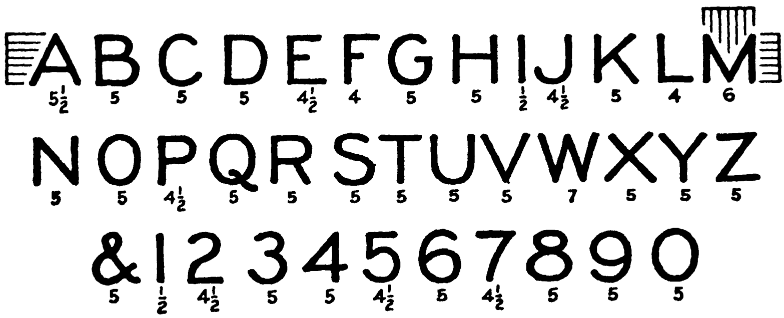

FIG. 10. Approximate widths of standard letters.

many other variations should be noted in this connection, as they result from a direct application of the rule of stability. Figure 10 shows the approximate relation which the widths of the various capital letters bear to one another, and the values may well be committed to memory. The numbers given are to be thought of in terms of the height of the letter, which is divided into six equal parts irrespective of the size of the letter. The small letters are more uniform in shape, and little can be done in the way of varying their width to improve their appearance.

16. SLOPE. — What has been said thus far applies equally well to slant or vertical letters, as indicated in Figs. 4 to 9, inclusive. As has been

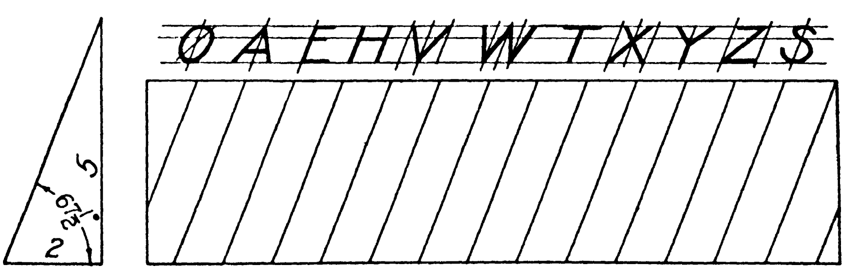

FIG. 11. Lettering slope guide.

stated in a previous paragraph, the standard slope of letters should be 67½ degrees. This slope may be obtained approximately by laying off a two-to-five triangle, as shown in Fig. 11. All stems, as well as the sides of the parallelogram enclosing the ovals, should be made parallel to the hypotenuse of the triangle. It will be noted that the major axis of the ellipse in slant lettering is nearly 45 degrees to the horizontal, and that the points of tangency occur at the midpoints of the parallelogram, as shown in Fig. 5. It should be further noted that the *median line* of the letters *A*, *V*, *X*, and *Y* is parallel to the standard slope.

A good practice for the beginner to follow is to lay off, on a stiff piece of paper, a slope guide similar to the one shown in Fig. 11, which can be placed just below the line on which the lettering is being done and thus aid the eye and hand in acquiring the proper slope.

17. Guide Lines. — In lettering on drawings or in compact composition, it is found impossible to maintain perfect alignment and correct height of letters without the use of mechanical aids called *Guide Lines.* These consist of three parallel, light pencil lines ruled with T-square or triangle on the space to be occupied by the lettering. The distance between the two outside lines is made equal to the chosen height of the letter. The third line is ruled above the bottom or base line a distance equal to two-thirds the height of the letter.

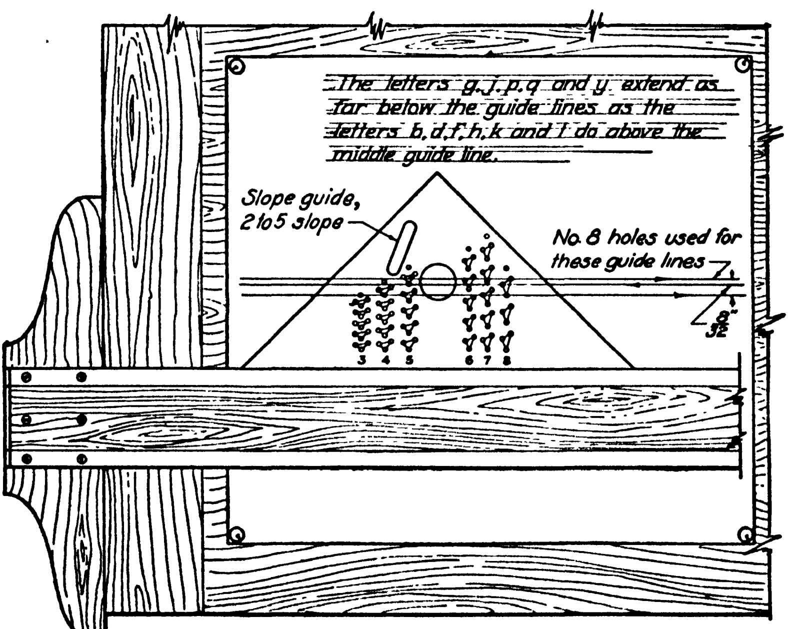

Fig. 12. Lettering triangle to rule guide lines.

For ordinary work, letters three-sixteenths or one-eighth inch in height are employed, the latter being the more generally used. Both these heights, as well as many others, may be obtained on the Braddock and other lettering triangles, and their use saves much valuable time. Figure 12 indicates the method of ruling guide lines with such triangles. Attention is called to the Arabic numbers printed at the bottom of each column of drilled holes in the triangle. They express, in thirty-seconds of an inch, the vertical distance between the lower and upper holes in a set of three. Thus, if one wishes to have the upper and lower guide lines five thirty-seconds of an inch apart, he should use the column marked with the numeral five. It is also important to know that each set of three holes in a column is so spaced, in reference to its neighbors in the column, that the proper distances between lines of words is assured if one rules in several guide lines at one setting of the T-square.

The triangle should be moved back and forth on the T-square edge, with the pencil point inserted in adjacent holes, as the ruling progresses down the page.

18. Position of Letters on Guide Lines. — All capitals and the stems of the small letters *b*, *d*, *f*, *h*, *k*, and *l* have their tops and bottoms resting on the two outer guide lines. The short stems and ovals in the small letters fall between the two lower guide lines. It will be found that the letters

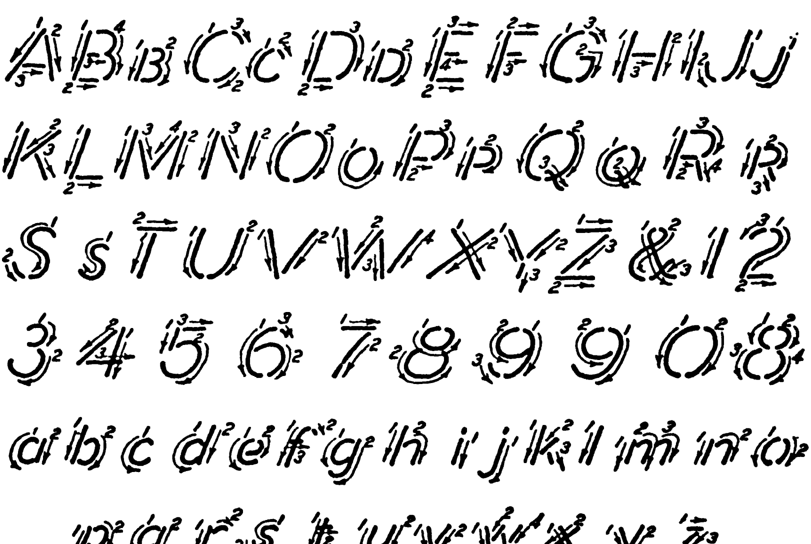

FIG. 13. Direction of pen strokes.

c, *e*, and *o*, on account of their shape, appear lower than other letters of their height; hence, when used adjacent to such letters in a word, these three ovals should be carried slightly above the second guide line.

In the letters *g*, *j*, *p*, *q*, and *y*, the bottom part of the stroke is carried below the lower guide line a distance equal to one-third the height of the letters, or, in other words, as far as the upper guide line is above the second. This is always done by eye and not with the aid of a fourth guide line.

The dots over the small *i* and *j* are placed midway between the second and third guide lines. The short cross lines on the letters *f* and *t* are sometimes raised slightly above the second guide line in lettering compact composition, but theoretically they should be put on the guide line.

19. Direction of Stroke. — In making the several letters of the alphabet, two general principles should be followed as regards direction of stroke, viz., all stroke motions should be from the top of the sheet towards the bottom and from left to right. Adherence to these principles will be sufficient guidance in making any letter, although some variations from them prove advantageous, especially in very small letters where a single stroke may be substituted for two required by rule. The direction of strokes for each letter in the alphabet is given in Fig. 13. Suggested variations, due to size of letter and other reasons, are shown. It must not be assumed that the pen is taken from the paper at the end of each stroke to begin the succeeding stroke; the arrows indicate the order and direction of strokes only. One's judgment is sufficient guide in determining when it is best to combine any two strokes.

20. Numerals. — Very great care is necessary, in preparing drawings and estimates, to see that no ambiguity arises, especially in regard to actual sizes of parts, amounts required, and cost of same. For this reason the engineer sticks closely to the use of numerals approved by his profession. Commercial styles should never be tolerated, and attempts to "individualize" the numerals on strictly engineering drawings should be condemned altogether. A close inspection of Fig. 14 reveals the fact that the numerals are in large part built up from the two elements used in forming the

Fig. 14. Engineer's vertical and slant numerals.

alphabet. The height of the numerals is the same as that of the capital letters with which they are used. Care should be taken to have the ovals open and full, as serious errors may otherwise occur, owing to the likeness between 3 and 5 and between 3 and 8, for instance. Note the reversibility of the 6 and 9; the small tops of the 2, 3, and 8; the closed-topped 4; and the alternative forms for 3 and 7. For the 3 and 7, it is recommended that the form printed first in the figure be used on all engineering drawings.

In fractions, the height of the numerals in numerator and denominator should be two-thirds the height of the integer, i.e., equal to the body of the small letters. A horizontal bar should separate the numerals, and a clear space should be left between it and each number. A single slope line should form the center line of the numerals of both the numerator and denominator, as shown in Fig. 14.

21. COMPOSITION. — The chief reason why so much poor lettering is turned out is that many draftsmen fail to acquire the knack of good composition. By good composition is meant that careful spacing of letters in words, and words in sentences, which compels the instant approval of the observer because of the ease with which it is read, the life and snap it possesses, and the pleasing effect it has upon the eye of the reader. These simple but desirable qualities cannot be secured with scale and dividers or by any " rule of thumb." One underlying principle, called the *Principle of Balance*, must be relied upon, since no table of spacing, however complete, could cover the multiple combinations of letters and words which may occur. Effect is given to this principle through the trained perception of the letterer alone; and no mechanical devices, however efficient and elaborate, will take the place of the critical and artistic demands of the human eye.

22. Principle of Balance. — Concisely stated, the principle of balance simply requires that the area of the white spaces between adjacent letters shall be approximately equal to one another and that the white areas between successive words shall appear the same. Further, in order to make the text matter readable with ease and rapidity, these areas between letters in words should be as small as practicable with a corresponding fullness in the letters themselves. The chief offense against good lettering committed by beginners is the universal tendency to separate the letters by excessively large spaces. Beauty in lettering is obtained more through compact and uniform composition than through excellence in fashioning the letters themselves.

In spacing words in a sentence, a good rule to follow is to make the distance between adjacent words equal to the height of the letters. Taste will dictate minor variations from the rule cited, but excellent results will follow from its general application.

Figure 15 illustrates the points just emphasized. A close inspection of the faults graphically portrayed will serve to prevent much loss of time and also aid in perfecting the student's own composition.

23. Refinements in Composition. — In order to secure perfect balance in composition, it has been found necessary to modify certain letters in the alphabet when followed by certain other letters. For instance, in

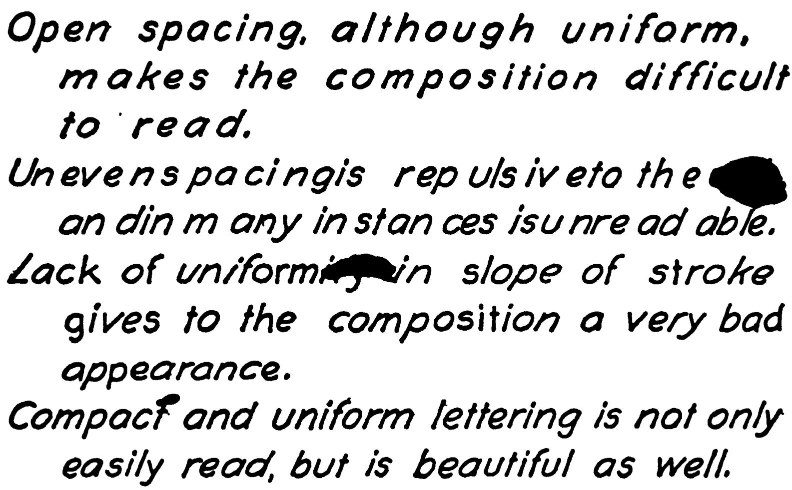

FIG. 15. Examples of good and bad composition.

Fig. 16 the word LATTICE has been materially improved by narrowing both *L* and *T*, thereby reducing the large amount of white space between them and the adjacent letters. The word WAVERLY has also been

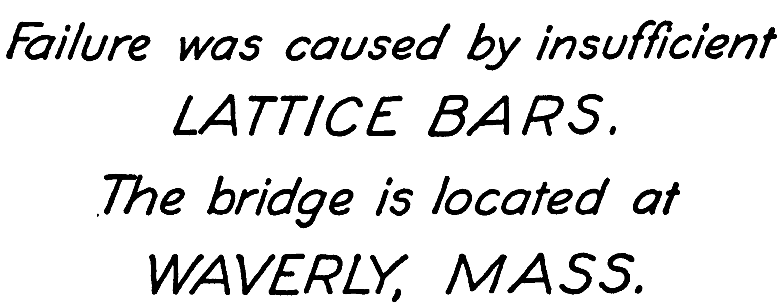

FIG. 16. Correct composition of difficult combinations.

improved by overlapping the letters *W*, *A*, and *V*, as well as *L* and *Y*. Similar improvements can be effected with the small letters. Thus, for instance, in combining the oval with the stems of such letters as *b*, *d*, and *p*, it will be found that a slightly less inclination of the axis of the oval to the horizontal than that used in the ovals *c*, *e*, and *o* when uncombined with stems, improves the composition appreciably. A somewhat similar improvement can be effected in *h*, *n*, and *m* by turning the hook more sharply than if the full oval were used. The student should study his composition carefully with the thought of improving it by the means described.

24. Compressed and Expanded Letters. — Very often the space available for a certain number of words is so small that the normal letters cannot be used, e.g., in a title or legend. To overcome this difficulty, each letter is made narrower than the normal width by compressing the

Fig. 17. Compressed and expanded alphabets.

ovals. This type of alphabet is known as the *Compressed Alphabet.* For diametrically opposite reasons, the letters may be widened, and the resultant alphabet is known as the *Expanded Alphabet.* Both alphabets are shown in Fig. 17.

Such distorted letters serve a very useful purpose in emphasizing material by making it contrast with other material of its kind. The compressed or expanded letters are made as readily as are the normal sizes, and the difficulties of composition are on the whole lessened; but the effect on the eye is not as pleasing, and the text is not as easily read.

25. Small Capitals. — In many drafting rooms it is the practice to use capital letters almost exclusively on the drawings turned out. In other places it is customary to use the capitals for legends, names of parts, or in the bill of materials. This practice has given rise to the use of a sub-capital letter called the *Small Capital.* The height of the small capitals is two-thirds the height of the larger ones being used with them, with a corresponding reduction in width.

26. Summary of Principles. — From the foregoing discussions is derived the principle that good lettering depends upon a certain uniformity of execution in five distinct ways, namely, uniformity of style, weight, slope, size, and spacing. These five items are easily kept in mind. They enable the student to concentrate his attention upon those points where trouble arises, and permit him to judge his own work accurately when it is finished.

Uniformity of style prevents the indiscriminate mixing of Gothic and Roman letters, and of upper- and lower-case letters, except for the legitimate purpose of capitalization.

Uniformity of weight is attained by careful attention to the filling of the pen, which should never be overfilled nor allowed to run dry. A steady, uniform, and light pressure should be maintained at all times. Certain special lettering pens are a great aid in attaining this objective.

Uniformity of slope is attained only through careful practice, but it may be more easily acquired through the use of slope guide lines.

Uniformity of size and spacing are again matters of patient practice. The former is secured by means of ruled guide lines. The latter is secured by applying the rule of balance which requires that the white areas between letters in words shall be equal, and that spaces between words shall be equal.

27. Drawing Pencils. — For ruling guide lines and layout work pencils as hard as 5H or 6H should be used. For actual lettering work, 2H and 3H pencils are best. Reference to pencils is made by giving the degree of hardness of the lead. This hardness is expressed in terms of the letters B, F, and H, the softer pencils being graded in varying degrees of B and F, while the engineer's pencils are graded in terms of the letter H, as follows: soft 2H and 3H, medium 4H and 5H, hard 6H and 7H. The *number* on certain pencils should not be confused with these degrees of hardness, as many companies do not indicate this quality of the lead in terms of the standard letters.

28. Lettering Pens. — In the preceding paragraphs on composition of stem and oval, and in the illustrations in Fig. 7, it has been shown that the width of the pen stroke should be proportional to the height of the letters. It is necessary, therefore, to provide one's self with several types of pens in order to allow latitude in the choice of sizes of lettering to be used.

For the ordinary height of lettering used in dimensioning drawings, a light ball-point pen is very successful. For larger work, either No. 510E.F. or 516E.F. ball-points, made by P. Leonardt and Company, England, are desirable. Gillott's Nos. 404 and 303 are well suited for finer work. The E. G. Henry Tank Pens are very satisfactory since they may be obtained with the straight or ball-points and are equipped with ink wells. See Fig. 19. For large letters, the Payzant pen will be found useful. Figure 18 shows some special lettering pens suited to special needs.

Pens should be " broken in " by preliminary use before being considered fit for work on valuable drawings. They generally come to the draftsman smooth and slippery on account of a thin coat of oil on the surface, which prevents the ink from clinging to them in an even coating. This may be overcome by dipping in alcohol or burning with a lighted match. The pen holder should be provided with a rubber grip of a size suited to the

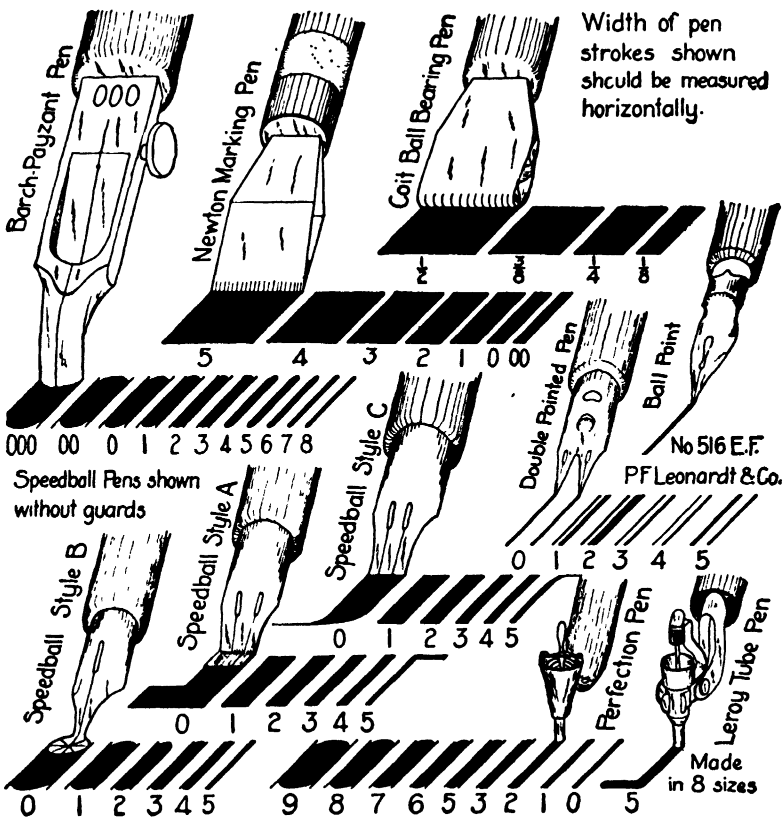

FIG. 18. Weight of lines with special pens.

hand of the letterer. Ink should not be allowed to dry hard on the pen, pains being taken to wipe the nibs dry and clean after each few minutes of use. The pen should be inked on the inside only, by means of the quill in the stopper of the ink bottle, instead of by dipping it in the bottle itself.

One of the chief difficulties encountered in lettering is that of keeping the weights of letters the same throughout the whole composition. Especially is this true between the last letters made when the pen is running dry and those made just after it has been inked. This trouble can be overcome to a large extent by improvising a simple guard for the pen point, which will serve to carry more ink at each filling and to distribute the flow more evenly over the entire period of use. A simple and effective device is that of bending a small piece of brass or steel into the shape shown in Fig. 19 and inserting it in the under side of the penholder grip in the manner shown in the figure. A leg of the well-known brass binding staple will

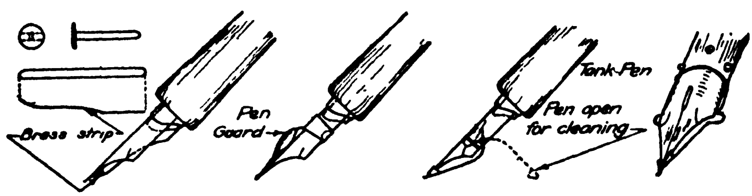

FIG. 19. Pen guards.

do for this purpose. Commercial guards may be purchased, or somewhat the same result may be attained by simply wrapping the pen point with a small rubber band. Several lines may be lettered without re-inking the pen, if these or similar devices are used. In every way the draftsman should treat his lettering pen as one of his most useful tools and care for it accordingly.

29. MECHANICAL LETTERS. — By mechanical letters is meant an alphabet *constructed with the aid of instruments*, in contradistinction to those *done freehand.* Although for ordinary use such letters are to be condemned completely, many instances arise where a mechanically constructed letter may be justified. For very large letters for inscriptions or panel work, it might be found advantageous to lay out the lines with the aid of T-square, triangle, and compass. In constructing a large title with the Roman alphabet, excellent results can often be obtained with mechanical aids, and their use is recommended. The engineer's scale proves of little help in this connection, since the units of measure to be used cannot be obtained from it directly. A new scale has to be devised for each size of letter, since the **unit** varies directly with the height of the letter.

30. Unit of Measure in Lettering. — The unit of measure to be used in the construction of mechanical letters is either one-sixth or one-seventh the height of the capital letter chosen for the particular piece of work at hand. The widths of letters, distances between letters, widths of stems and ovals, and the location of centers for serifs and ovals are then expressed in terms of this standard unit. Reference to Section 2 of Chapter II will make clear the method of constructing a mechanical alphabet. A study of the figure there shown will serve to fix in mind the proper ratio of the width of each letter to its height when freehand lettering is being done, since the values shown are approximately those to be used in freehand work.

31. Lettering Guides. — Where mechanical precision and strict uniformity are desired, as, for example, in titles of drawings or in other

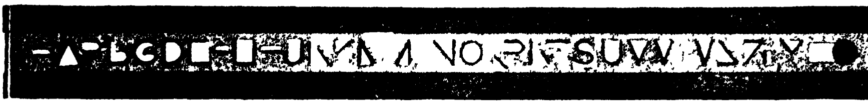

Fig. 20. Wrico lettering guide.

places where uniformity of appearance is of paramount importance, lettering guides made by the Wood-Regan Instrument Company, Inc., will be found very helpful.

The guides consist of strips of transparent pyralin, as shown in Fig. 20, with a series of openings so shaped that, when the point of a " Wrico " lettering pen, see Fig. 21, is moved in contact with the sides, the letters of the alphabet or numerals may be formed. Certain letters require only one opening; others require two complementary openings. Those requiring two openings are made as shown for the letter *B* in Fig. 22. After making the part of the letter shown in the second section of the figure, the shift button, see *B* in the right end of Fig. 20, is moved to the right end of the slot and pressed to the paper. The guide is then shifted to the right as far as the button will permit, which is the position shown in the third section of Fig. 22. The letter is then completed as shown in the fourth section of the figure.

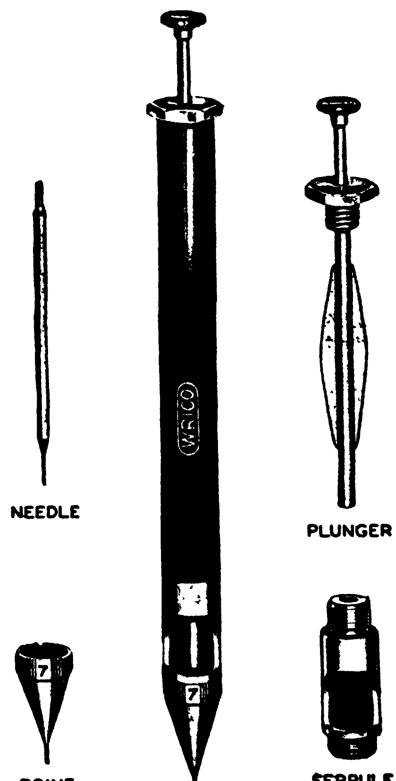

Fig. 21. Wrico lettering pen.

Figure 23 shows a Wrico guide in use. Note that it is operated against the T-square edge as any triangle might be.

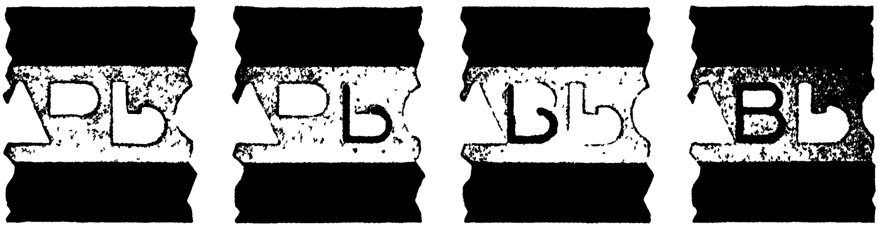

FIG. 22. Steps in forming a letter with Wrico guide.

Many users of the guides prefer to remove the button altogether and set the sliding guide by eye for each part of the letter. This obviates the danger that the button will be drawn across undried ink and cause a blot on the work.

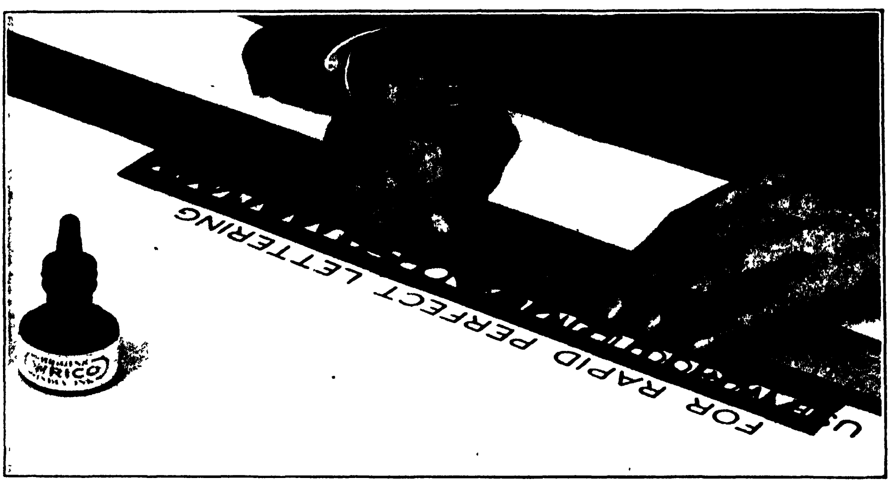

FIG. 23. Using Wrico lettering guide.

These Wrico guides may be obtained in both vertical and slant styles in a wide range of sizes. Outline letters and shadow letters are also available.

PROBLEMS

32. All lettering problems are to be done upon small-size standard sheets (see Art. 4, page 3) unless otherwise directed by the instructor.

Divide the space inside the border line of the selected sheet into four equal rectangles by means of horizontal and vertical center lines. Inside these spaces, rule guide lines as directed and then do the exercises assigned from the following problems. Allow a margin of $\frac{1}{2}$ inch at the top and on each side of the lettering space and a margin at the bottom as near $\frac{1}{2}$ inch as the guide line layout will permit. It is recommended that the Braddock lettering triangle or Ames lettering instrument be used for ruling guide lines that are within the limits of these instruments.

Where the term *guide lines* occurs in the following problems, it will mean a set of three lines (see Fig. 12) whose overall height is that specified in the problem. The space between sets of guide lines will be as produced by the lettering triangle, or two-thirds the overall height of the guide lines if a lettering instrument is not available.

1. Rule guide lines $\frac{3}{8}$" high and make an alternate series of smooth ovals and straight stems, as shown in Fig. 24. Make either slant or vertical style, as assigned.
2. Same as 1, using guide lines $\frac{1}{4}$" high.
3. Same as 1, using guide lines $\frac{3}{16}$" high.

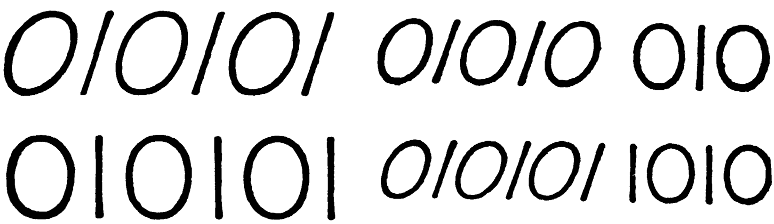

FIG. 24. Basic ovals and stems.

4. Rule guide lines $\frac{3}{16}$" high and then execute the group of lower-case letters or numerals assigned from Figs. 25 to 30 inclusive. Make approximately the same number of each letter to fill out the line, using the vertical or slant style, as assigned.
5. Same as 4, using guide lines $\frac{5}{32}$" high.

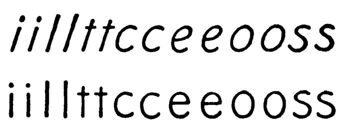

FIG. 25. Stem and oval letters.

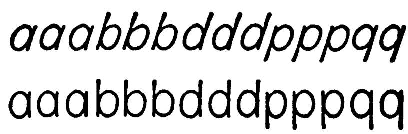

FIG. 26. Oval and stem combined.

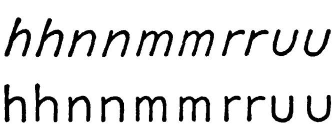

FIG. 27. Partial oval and stem.

FIG. 28. Partial oval and stem.

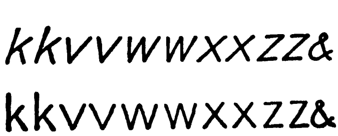

FIG. 29. Combined stems.

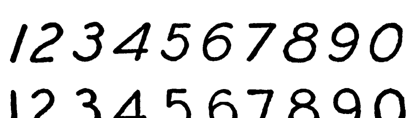

FIG. 30. Numerals.

6. Rule guide lines $\frac{3}{16}$" high and then execute the group of capital letters assigned from Figs. 31 to 35 inclusive. Make approximately the same number of each letter to fill out the line, using vertical or slant style, as assigned.

7. Same as 6, using guide lines $\frac{5}{32}$" high.

8. Rule guide lines $\frac{3}{16}$" high and then execute the letters of the alphabet in the order of their occurrence, as shown in Fig. 36. Fill out each line by repeating the alphabet as much as may be necessary.

FIG. 31. Stem capitals.

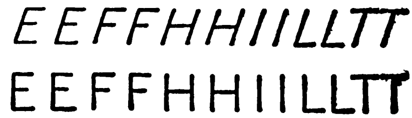

FIG. 32. Stem capitals.

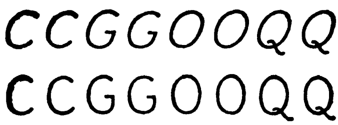

FIG. 33. Oval capitals.

FIG. 34. Stem capitals.

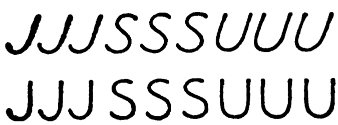

FIG. 35. Oval-stem capitals.

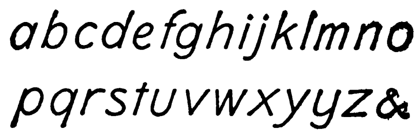

FIG. 36. Lower-case alphabet.

9. Rule guide lines $\frac{5}{32}$" high and then letter the material in one of the paragraphs assigned from the following group. The material is to be well balanced within the area reserved for it, whether done on regular lettering sheets or in connection with other drawing work.

a. In order that a piece of composition may look well, it must have uniformity in slope, weight, size and spacing of the letters and words.

b. Control of the hand in lettering is best accomplished through short daily drills of from ten to twenty minutes' duration. The work should be deliberately and critically done.

c. The pen should be suited to the size and character of the work being done. A ball-point pen can hardly be used for fine letters; a fine-point pen should not be used for heavy work.

d. Keep the points of the pen free from dried ink, and clean thoroughly at the end of each piece of work. Fill the pen by means of the quill in the stopper of the ink bottle instead of dipping it in the bottle itself.

e. Triangles and T-square should be kept clean and free from dust and soot to prevent the drawing paper and tracing cloth from becoming soiled and unfit to work upon. Perspiration from the hands soon injures the surface qualities of the tracing cloth.

f. Plan the location of all the views of a drawing before beginning any. Reserve space for the title the very first thing. Allow generous space for dimensions and notes. Place these, as far as possible, between views.

g. Omit no dimension that may be needed for clearness, but do not repeat unnecessarily. Always give the overall dimension, and place it outside the detail dimensions. Do not hesitate to give explanatory notes.

CHAPTER II

LETTERING

SECTION 2

33. The five following alphabets have already been alluded to in Section 1, Chapter II. They are included in this work both on account of their historical interest and their general utilitarian aspects.

Figure 1 is believed to be a faithful representation of the Old Roman alphabet as it was developed in the first and second centuries A.D. The root forms are taken from the inscription on the base of the Trajan column at Rome, which is said to have been cut in A.D. 114. The authors are indebted to Mr. Frederic Goudy's excellent work, "The Alphabet,"[1] for the reconstruction of the letters, the outlines of which they have carefully copied.

Figure 2 represents the first Roman type of distinction to be used in England. It is said to have been cut by the printer, Caslon, in 1724. This alphabet also has been faithfully copied from its reconstruction by Mr. Goudy.

Figure 3 is representative of the several modified forms of the Old English alphabet now in existence. It combines simplicity of design with a dignity of character sufficient to make it acceptable for most ornate work.

Figure 4 contains typical alphabets found on architectural plans and drawings. Although composed of simple characters which are easily mastered, they possess enough of the beautiful and distinctive qualities of more ornate forms to make them compatible with the character of the drawings upon which they are used.

Figure 5 shows the Modern Roman alphabet as it is used today on maps and inscriptions. Its stately beauty can hardly be denied. It is recommended that, when used in the larger sizes, the outlines of the letters be constructed mechanically, as suggested in the figure.

Figure 6 suggests what may be done, with speed and ease, when conditions demand large uniform titles, in the way of mechanically constructed alphabets. The severe Gothic alphabet there shown is typical of what may be done in other alphabets by proper adaptation.

[1] "The Alphabet," by Frederic W. Goudy, published by W. E. Rudge, New York, 1919.

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FIG. 1. Old Roman alphabet.

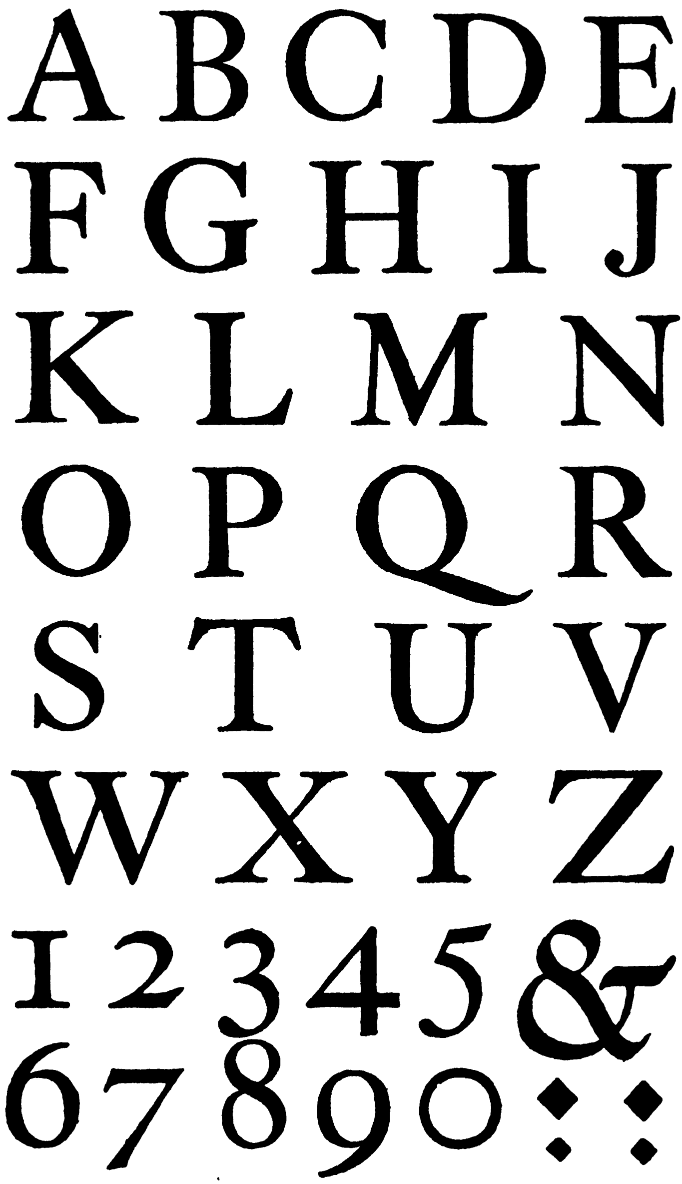


Fig. 2. Early Roman type.

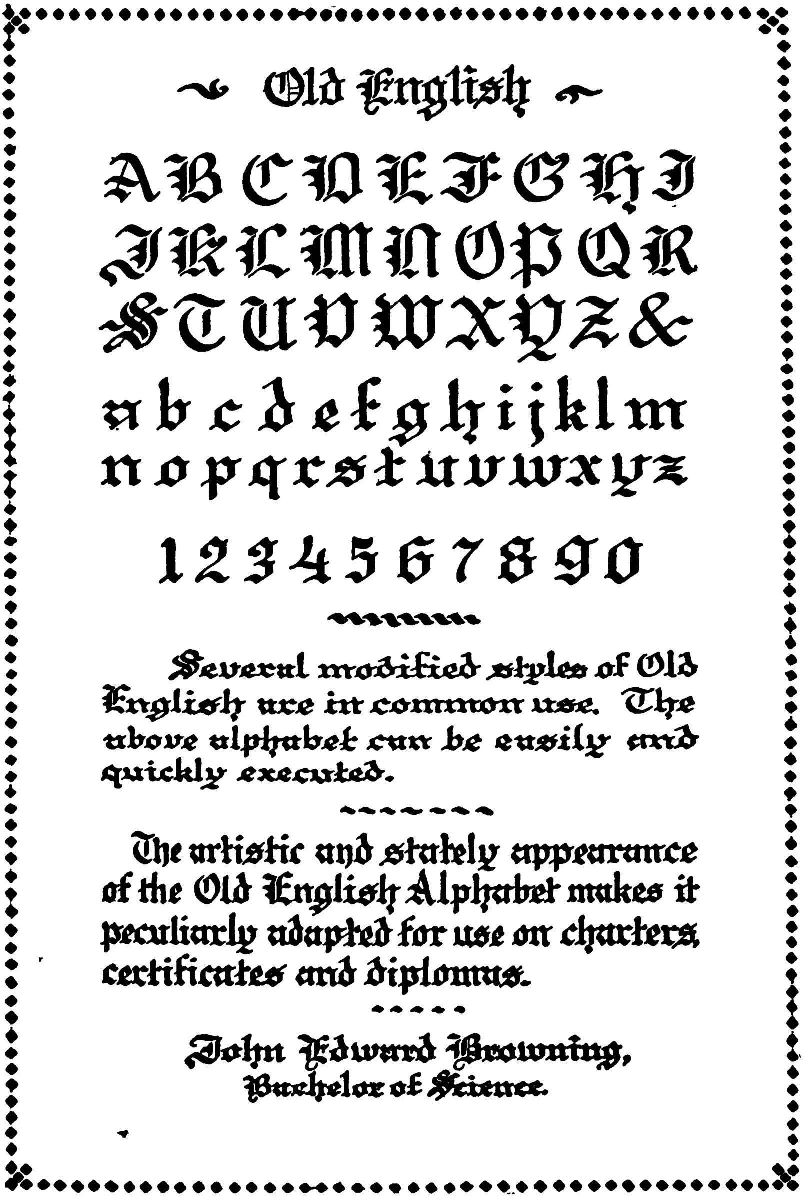


FIG. 3. Old English.

FIG. 4. Architectural alphabets.

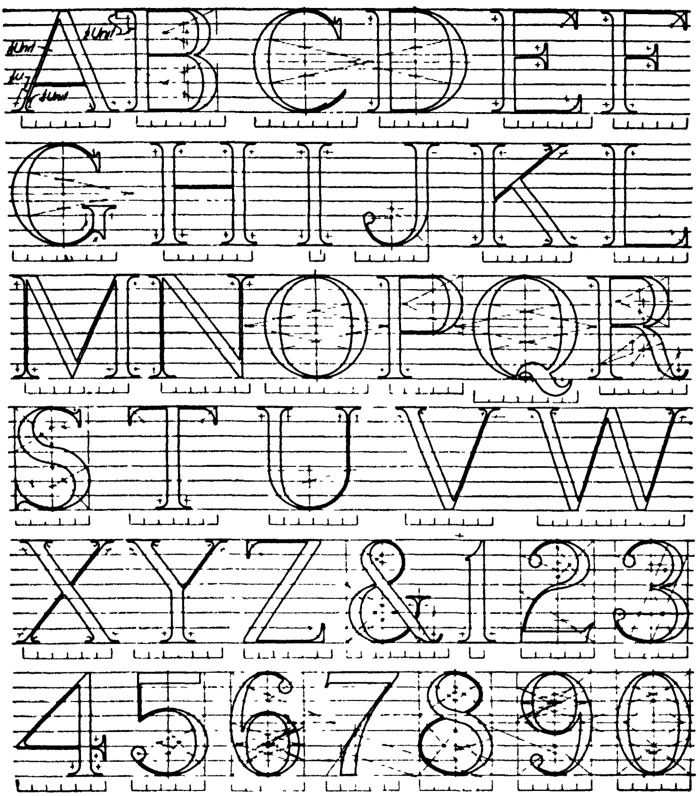


Fig. 5. Modern Roman alphabet.

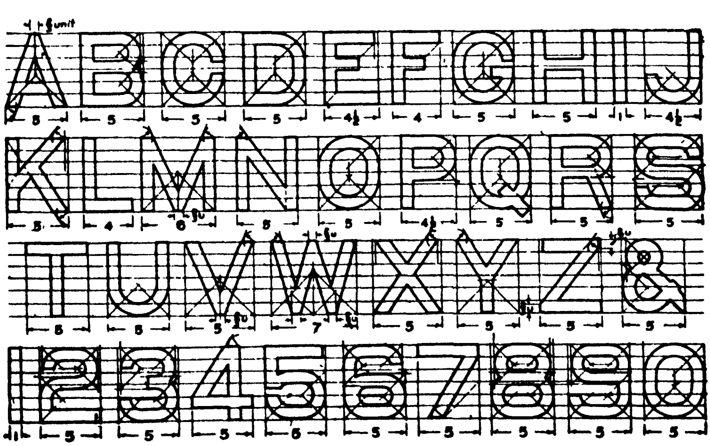


Fig. 6. Gothic alphabet.

CHAPTER III

TITLES

34. A drawing, like a piece of literature, must have a title. This title serves as a means of identification while the drawing is in use, and as a means of reference for correspondence, indexing, and filing. It may serve to convey certain specific information, such as the name of the draftsman, the scale and date of the drawing, or perhaps a statement of the purpose for which the drawing was made.

The importance of a proper title cannot be overestimated. A draftsman *may* be able to recognize his drawing and tell all about it six months or a year after he has made it, but the *probability* is that he will *not* be able to do so, and it is certain that another man would have considerable difficulty in identifying the drawing and making any use of it. For this reason, every drawing, even though it be only a rough preliminary pencil sketch, should have some title.

In order that a title may serve as a means of identification, it must tell briefly what the drawing is. Hence, the name of the object drawn should always appear, and sometimes a statement of the kind of drawing, as for example, Detail of Crankshaft, Gas Engine " E," or Assembly of Turret Lathe No. 3074. The words Detail and Assembly specify the kind of drawing; the other words name the object. Where the object shown on the drawing is not stock work, the title should also give the name and location of the person for whom it is to be made. This is essential, as it serves to identify two pieces which may be quite similar but which are to be made for two different persons and must be shipped to different points.

The title should also contain the name and location of the manufacturer when he makes both the drawings and the machine or structure; otherwise it should contain the name of the architect or engineer who designed the machine or structure. The scale of the drawing is also essential, and the date is always of sufficient importance to be included. An index or filing number must also be provided for. If the sheet is one of a large number which belong to the same project, it must be given a sheet number.

An examination of drawing titles will show that the foregoing items are included in almost every one. See Fig. 1. Practice varies somewhat in regard to making the draftsman's name a part of the title. In many titles a place is provided for the initials of the draftsman, tracer, and checker, The title must be neat and business-like and not time-consuming in its construction. Hence the usual practice today is to make machine drawing titles in vertical or slant Gothic. As a rule, the most prominent parts of the title are lettered entirely in capitals. Since the Gothic can be made quite rapidly with single strokes, this type is to be preferred for shop drawings. See Fig. 2. For drawings requiring a little higher finish, the heavy or bold-face Gothic is quite appropriate, see Fig. 3; the Roman, which requires the most time and skill to execute well, is generally reserved for drawings of a highly finished character, such as display drawings, gov-

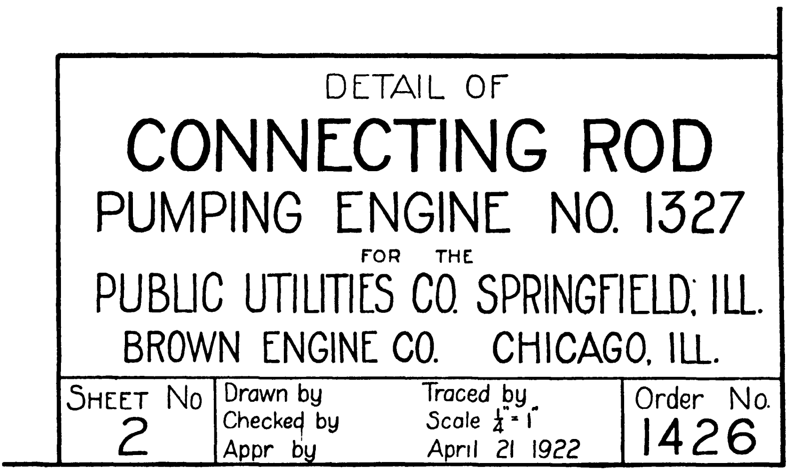


FIG. 3. Heavy face Gothic title.

ernment maps, etc. The size of title space and style of letters may be chosen without special reference to the actual wording of the title.

The style of lettering is usually fixed in a commercial drafting room to give uniformity to all the work turned out, so that the draftsman's first task is to arrange his title matter into lines and to space and group these lines so as to secure the best effect in the chosen title area. In doing this the draftsman must consider several things at the same time, such as the prominence to be given certain words, the contour of the title as a whole, and the balance, or symmetry, of the title when finished. As a preliminary step it is best to write out the title in longhand, arranging the lines with a view to obtaining a pleasing appearance and giving proper weight or prominence to important parts.

39. Prominence of Parts of Title. — The principle upon which the order of prominence is based is simply to make most emphatic the item which best describes the drawing for identification purposes. Other items then follow in the order of their importance. Obviously, the name of the object drawn is of primary importance, and the name of the party for whom it is to be made stands a very close second. The manufacturer's name should have about third rank, but as a matter of advertising it is usually made most prominent. One would not care for the scale, date, or draftsman's name unless he were making a careful examination of the drawing; hence these items are of minor importance, although absolutely necessary. On ordinary titles such as those shown in this chapter, there may be four or five degrees of prominence, with a commensurate number where the matter to be included covers a wider range.

Prominence may be secured in several ways, for example, by increasing the height or width of letters, by changing the slope, or by making any other noticeable alteration in the style or shape of the letters. See Fig. 2. A line may also be made to stand out by extending it in each direction some distance beyond other lines.

40. Contour of Titles. — By this term we mean the outline shape of the title itself or, better still, the shape of the figure enclosed by drawing lines tangent to the ends of the consecutive lines of the title. See Fig. 2. The contour should enclose a regular symmetrical figure, the simpler forms being the more desirable.

41. Balancing Titles. — By the term *balance* we mean the symmetrical distribution of the lines around a vertical center line and the equal or uniform arrangement of black and white spaces. In other words, the margin at the left of the title should be equal to that on the right; likewise the spaces at the top and bottom should be very nearly equal. In order to balance black and white spaces, the most important lines should not be at the very top, but rather as near the center as conditions will permit. One or two comparatively heavy lines above the most prominent line will, of course, balance a greater number of lighter ones below it. A title can be balanced in other ways than the one indicated, but this is the customary drafting-room scheme.

It is possible, of course, to balance a title by a cut-and-try process, first lettering lightly in pencil the outlines of the letters and then erasing and relettering where the first trial was unsatisfactory. For small titles of few words this scheme is sufficiently rapid and accurate, since with a little practice one soon learns to estimate the proper amount of space to allow for various words and phrases. With large titles, however, such as title sheets for sets of drawings, it will save time to adopt the scratch-paper scheme suggested below.

Assuming that the size of the letters for each line has already been determined on the basis of the prominence desired, guide lines for each line in the title are ruled on separate strips of paper a little wider than the height of letters. A length is marked on the scratch-paper strip approximately equal to the length which it is desired the line shall occupy, and the words are then put in with single-stroke Gothic letters.

After each line of the title has been made on a strip of paper, all the strips may be assembled in the title space at once, and shifted around until a satisfactory balance is obtained. Then both the guide lines and location of letters may be readily transferred to the drawing paper and the work completed.

42. Finish of Title. — The term "finish," as applied to a title, has much the same meaning that it has when applied to machine parts. Machine parts may be finished to a hundredth of an inch or to one ten-thousandth of an inch, depending upon their use. In much the same way, the use of the drawing upon which the title is placed determines the degree of finish it is justifiable to impart to the title. For working drawings to be used only in the shop, the single-stroke or bold-faced Gothic is sufficient. For display drawings the modern or old Roman is more appropriate and may be done freehand or with instruments, depending upon the size of the letters and the skill of the draftsman. Greater care must be exercised in the construction of such titles, and the same finish should be given to all parts. Titles on drawings intended for photographic reproduction should be carefully finished off, as defects are not eliminated by reduction.

43. Embellishments. — Occasionally, in order to balance a title or to break up large white areas, embellishments in the form of little scrolls or geometric figures are added. If properly executed and used sparingly, these add considerably to the appearance of an open title.

44. Subtitles. — It frequently happens that a drawing sheet will contain several details. It is then necessary to distinguish each part by a subtitle of some kind. Ordinarily this consists simply of the name of the piece, but sometimes other words of explanation are needed. Such titles on machine drawings should be made in small, single-stroke Gothic letters. If possible, the center of the line should come under the center of the detail to which it belongs.

45. Modern Title-Making Methods. — In a complete set of drawings, it is desirable that all of the lettering, and particularly the titles, have the same characteristics. This may be accomplished by having one man do all the lettering in ink, but this plan cannot always be followed. Moreover, title making at best is a slow process, whether one man or several do it. Therefore, to speed up the work and at the same time to provide greater uniformity, several labor-saving methods have been worked out. One of these is to have the border line and title printed on standard size sheets. Such parts of the title as the company's name and location, the words Drawn by ...., Checked by........, Scale, File No., etc., are printed. The other words, of course, must be lettered in. One difficulty is that the portion put in freehand and that put in on the printing press always differ in appearance. To overcome this defect, a rubber stamp may be used to do the printed part and then the draftsman can go over it with ink. Or a copy may be made and slipped under the tracing cloth, as a guide to aid in securing speed and uniformity in size and style.

PROBLEMS

46. All title problems are to be done upon the small-size standard sheet, B (see Art. 4, page 3), unless otherwise directed by the instructor.

Divide the space inside the border line into four equal rectangles by means of horizontal and vertical center lines. Within these areas make the titles, subtitles, or legends assigned from the following group of problems. Where the title is to be enclosed, draw the enclosing rectangle in a well-balanced position within the area and with respect to the outlines of the title. For titles not requiring an enclosing " box," balance them with respect to the whole area. In all cases, titles should be balanced about their own center lines. The last item is the most important feature of the problems.

1. Design a title to be placed on drawings made in an engineer's office on 18″ × 24″ drawing sheets. The building shown on the drawing will be a foundry for the Perfect Caster Company, located at Chicago, Illinois. Include a fictitious name of the engineering firm, its address, and such items as drawn by, checked by, traced by, scale, date, etc., with allowance of space for the signatures to follow such items. Use either slant Gothic or Roman, as assigned by the instructor, for the more important items of the title. Select the proper size of letters to use in each part of the title yourself.

2. Design a standard title for use on the large drawing sheets in your drawing course. The title should include the name of the object drawn, the name of the school and its location, the name of the department, if any, and the other standard items which are included in all well-designed titles. Use the style of lettering assigned by your instructor. Select the size of letters yourself.

3. Design a map title suitable for an 18″ × 24″ drawing sheet which shall be a property map of the Taylor Lumbering Company at Duluth, Minnesota. In addition to the draftsman's name, the surveyor's name and the date of the survey should appear in the title. Such items as space for the checker, tracer, etc., may be omitted, but both a graphical and verbal scale should be given preferably at the bottom of the title. The title should not be enclosed but should be perfectly balanced about its center line. Use vertical or slant Roman letters for the more important lines of the title and single-stroke Gothic for the remainder.

4. Balance within the area allowed and about its own center line one or more of the following subtitles, as assigned. Choose your own size and style of lettering.

a. West Side Elevation. Scale $\frac{1}{4}'' = 1' - 0''$.
b. First Floor Plan. Scale $\frac{1}{8}'' = 1' - 0''$.
c. Equalizer Fulcrum, cast iron, 20 Required.
d. Spring Hangers, mild steel, 14 Required.
e. Column Detail, South Row, Main Street Subway.
f. Spandrel Detail, Girder E, 5th to 20th Floors.

CHAPTER IV

USE AND CARE OF INSTRUMENTS

47. The purpose of a drawing course is twofold: it aims first to give the student an understanding of the principles upon which drawing is based, and second, to give him instruction and practice in the use of his instruments, so that he may acquire a workmanlike facility in their manipulation. The instruments may be used in a variety of ways — good, bad, and indifferent — and results of a corresponding kind produced. The engineer's object is not to produce something that will just "get by," but rather to secure the best results, from the standpoint of appearance and accuracy, in the least possible time.

Speed, accuracy, and neatness are largely matters of proper habit. Correct habits may be just as easily acquired as slovenly habits, by learning the proper form at the beginning. As the athlete who runs or jumps "in poor form" has very little chance of winning because he must put forth a much greater effort than the man who works "in form," just so the draftsman who violates the rules of proper form, simple and almost trivial though they seem, can achieve success in the use of his instruments only by a much greater expenditure of time and energy than would otherwise be necessary. By the word *instruments* we mean all the equipment in the draftsman's kit, including pencils, erasers, scales, etc.

To learn the correct *form* of handling instruments, one should study the proper *use* of the instruments in order that awkward and useless movements may be eliminated and inaccurate methods avoided.

48. PENCILS. — Drawing pencils may be obtained in seventeen degrees of hardness, varying from 6B, the softest and blackest, to 9H, the hardest. The proper grade to be used depends upon the kind of work to be done and the quality of paper employed. For all-round usefulness the 4H pencil is perhaps the best, although for very accurate work, the harder grades should be used, and for sketching and lettering the softer grades are desirable. For general mechanical drawing, the 5H pencil is recommended for laying out the work on Normal or other good detail paper. A 3H pencil may be used for finishing the drawing and for the lettering.

More important, however, than the quality of the pencil is the condition in which it is kept. The proper shape for a pencil point is shown in Fig. 1. The tapered wood portion should be about seven-eighths of an inch long, and three-eighths of an inch of lead should be exposed. The lead should be brought to a point by means of a file or sandpaper. For a conical point, as in *A*, Fig. 1, the pencil should be rotated slowly while it is rubbed back and forth. The pencil should be kept inclined to the direction of motion,

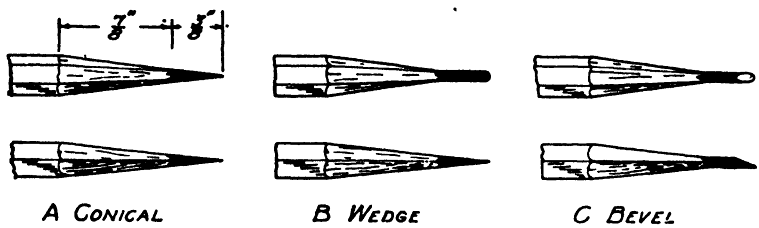


FIG. 1. Correct shapes of pencil points.

not at right angles to it. To produce the wedge point, as in *B*, Fig. 1, the opposite sides of the lead must be rubbed down. The bevel point, *C*, is made by rubbing entirely on one side.

The wedge point is used for drawing long straight lines, since it does not wear down so rapidly; its use, however, is limited to straight lines. The conical point may be used for all general drafting purposes and should always be used for lettering, for which it is particularly adapted. The bevel point is recommended for use in the compass, as it has the same advantages there as the wedge point has for straight lines. When the point is inserted in the compass, the beveled face should be turned directly away from the needle point. Since the ordinary drawing pencil wears away rapidly, the sandpaper or file should always be kept handy to resharpen the lead.

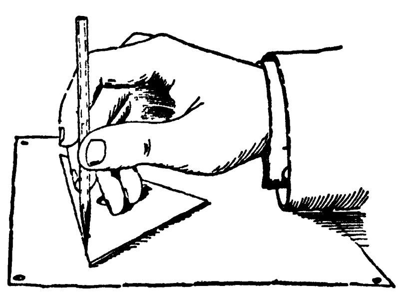


FIG. 2. Correct method of holding pencil against T-square or triangle edges.

In drawing a straight line, the pencil should be held in a plane perpendicular to the paper along the edge of the T-square or triangle, and should be slightly inclined in the direction of motion. See Fig. 2. Note that the pencil is held in a little different manner from that used in writing or lettering. The pencil should not be allowed to rock back and forth transversely to the direction of motion. Just enough pressure should be applied to the pencil to make a firm, light line that can be readily seen, but not enough pressure to make a groove in the paper, as a groove cannot be erased and spoils the appearance of a drawing. The importance of clean-cut pencil work cannot be overemphasized; it tends toward both speed and accuracy in tracing. A careless pencil job is difficult to improve either in inking or tracing.

49. Eraser. — Only a pencil eraser and art gum are necessary in mechanical drawing. Their purpose is, of course, to remove lines drawn in error, and hence the less the eraser has to be used the better. On tracings, the pencil eraser should be used to remove ink lines. A little more rubbing is required than with erasers containing grit, but the tracing is left in good condition for inking over the erased spot. An ink eraser or knife should not be used. The erasing shield is quite convenient in protecting lines which are not to be removed, and it should be used where occasion demands. The art gum is used to clean the sheet, but it is much better policy to keep the drawing as clean as possible and not depend on art gum to remove the dirt, since it also removes the luster of the ink lines.

50. Lettering Pens. — See Chapter II.

51. Drawing Board. — The drawing board should be made of soft white pine or basswood, with properly cleated ends. It should be perfectly flat, free from cracks, and have one end edge straight. The true edge should be determined with some reliable straight edge, marked when found, and thereafter always used as the left-hand edge. The top and bottom edges of the board need not be at right angles to the edge selected, and as a matter of fact they seldom are; nor is the right edge often exactly parallel to the left. The board should not be used for cutting purposes as this practice destroys the drawing surface in a short time. When it is possible to do so, the board should be so placed that the light comes from the left and front. This obviates annoying shadows.

52. T-Square. — The common T-square consists of two parts, the blade and the head, which should be rigidly fastened together. A variety of kinds and sizes may be obtained from the trade, a few of which are shown in Fig. 3. Different lengths may be obtained, ranging from 18″ to 72″. The upper edge of the blade and the inner edge of the head should be perfectly straight. Both parts should be made of hard wood, but a celluloid edge on the blade is desirable for the sake of transparency. The accuracy of the T-square blade may be tested by drawing a straight

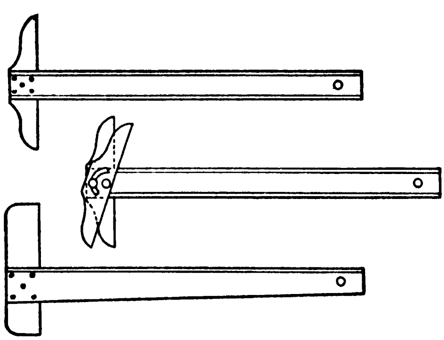


Fig. 3. T-squares.

line between two points and then turning the blade over and drawing the same line again, using the same edge as before, as shown in Fig. 4. If the two lines coincide the blade is true. To keep the T-square in good condition, careful handling is required. It should not be used as a hammer nor allowed to drop on the floor. The upper, or drawing, edge should not be used as a guide for the knife in cutting paper.

The purposes of the T-square are, first, to draw horizontal lines, and second, to serve as a support for the triangles when vertical and diagonal

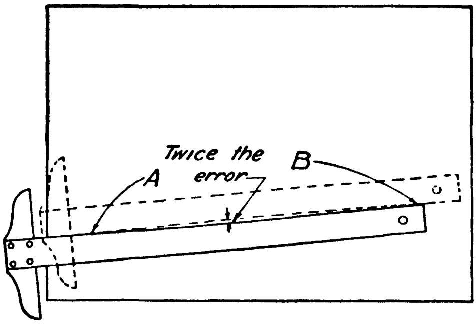


Fig. 4. Testing T-square edge.

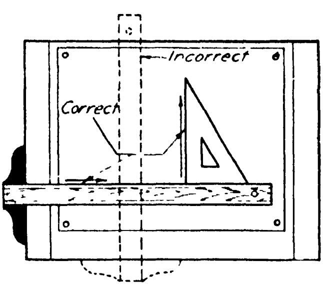


Fig. 5. Ruling horizontal and vertical lines.

lines are being drawn. The head of the T-square should be held to the board with the left hand and the line drawn with the right. Horizontal lines should always be drawn from left to right. One should not stroke back over an ink line, for the result is usually a line of varying width and in any event represents a waste of time. Only the upper edge of the blade should be used for drawing, because the lower edge is not necessarily parallel to the upper edge; hence, inaccuracy may result if it is used. The T-square should not be used to draw vertical lines, as shown in Fig. 5, because the two edges of the board may not be at right angles to each other. To draw any line longer than the triangles will accommodate, whether vertical or otherwise, locate the line by two points and then turn the T-square over and draw the line. When drawing vertical lines, which should be drawn from the bottom toward the top, the triangle should be turned with the vertical edge to the left and held against the T-square, as shown in Fig. 5.

53. Triangles. — The 30- 60-degree triangle and the 45-degree triangle are used not only to draw vertical lines but also lines making angles of 30, 60, 45, 15, and 75 degrees with the horizontal or vertical. The proper combinations for drawing the last two angles are shown in Fig. 6. It is frequently necessary to draw a line parallel to another line which does not make any of the above angles with the horizontal. The proper method for drawing such a line is shown in Fig. 7. Two lines may be drawn perpendicular to each other by means of two triangles, or a T-square and a triangle, as shown in Fig. 8. In drawing any line, the direction of motion

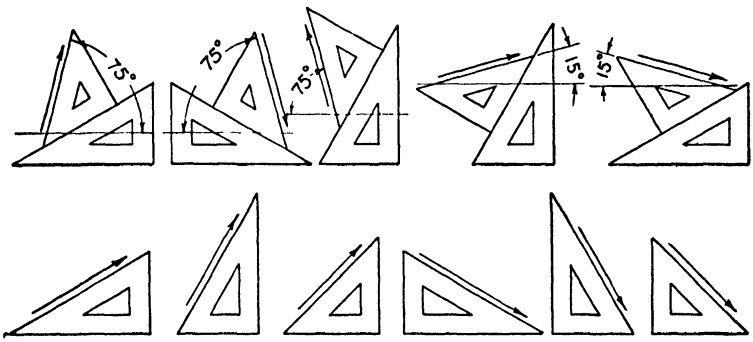


FIG. 6. Direction of motion in ruling sloping lines.

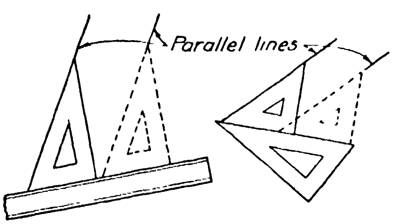


FIG. 7. Drawing parallel lines.

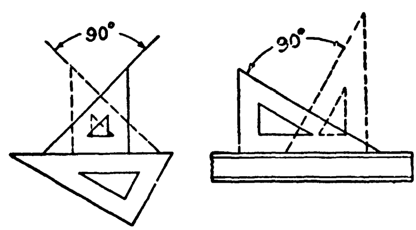


FIG. 8. Drawing perpendicular lines.

should, in general, be away from the body and not toward it. The accuracy of the 90-degree angle of any triangle may be tested as shown in Fig. 9.

54. PAPER. — Commercial practice varies considerably in the use of drawing paper. Some shops use standard sheets which are obtained already cut to size; others use paper from the roll, the draftsman cutting off what he needs each time. The same practice holds for tracing cloth. The sheets may be obtained not only cut to size but also having the border line and a standard title form printed on them. The common standard sizes for paper and cloth are 9 × 12, 12 × 18, 18 × 24, 24 × 36, and 36 × 42. The sizes for hot- and cold-pressed, hand-made papers vary from those given above, but

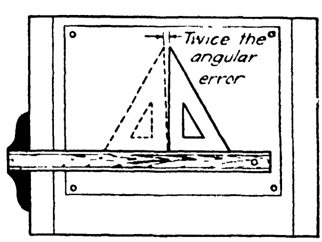


FIG. 9. Testing the triangle.

they are seldom used by engineers except in architectural work. The name of each size is given below.

Cap	13 × 17	Imperial	22 × 30
Demy	15 × 20	Double Royal	24 × 36
Medium	17 × 22	Double Elephant	27 × 40
Royal	19 × 24	Antiquarian	31 × 53
Super Royal	19 × 27		

Because of the widely extended use of photography, particularly as applied in the photostat process, in reducing all kinds of drawings to letter and other filing equipment sizes, there has developed the need of a basic standard of proportion of width to length for all sizes of drawing papers. This need is fully met in the ratio $1 : \sqrt{2}$. Drawings of various sizes can be reduced to one standard size by photographic means providing the sheets of paper on which they are made are cut in this ratio. If a single sheet is folded, or cut, on its short axis, the new sheets will have the same ratio of width to length. The advantages of these possibilities are obvious. This standard has long been in use in Germany and is being recommended to the American Standards Association for adoption in this country in a slightly modified form. The basic manufacturing size will be 17″ × 22″. Other standard sizes will develop from this base size, as industrial and engineering needs may dictate, in the following proportions:

$8\frac{1}{2}$″ × 11″ (base size); 11″ × 17″; 17″ × 22″; 22″ × 34″; 34″ × 44″.

It is recommended that drawings made with the metric scale for use in foreign correspondence and business be made on one or another of the following standard metric sheet sizes, which are also based on the proportion of 1 to $\sqrt{2}$.

105 mm × 148 mm; 148 mm × 210 mm; 210 mm × 297 mm; 297 mm × 420 mm; 420 mm × 594 mm; 594 mm × 841 mm; 841 mm × 1189 mm.

Hot-pressed paper, designated simply H. P., has a smooth surface and is used mostly for ink work, such as fine mechanical drawings. Cold-pressed paper, C. P., is fine-grained and is used chiefly for general pencil drawing and water-color painting. The quality of paper designated " rough " or " egg-shell " has, as its name signifies, a rough surface and is used principally for bold pencil drawings, charcoal work, and water-color sketches.

Where standard size sheets are used, the space to be included inside the border line is known to begin with. Hence, to lay out the border lines, place the sheet at a convenient position on the drawing board and put a thumb tack through the upper left-hand corner. Then rotate the sheet until its upper or lower edge is in contact with the upper edge of the T-square. When it is in this position, put a thumb tack through the upper right-hand corner, and then tack the remaining corners down, taking care to have the sheet stretched out smoothly. The border lines may then be laid out by measurement from the edges of the sheet, or from its horizontal and vertical center lines if the edges are not at right angles to each other or are cut unevenly. The thumb tacks should be pushed down as far as they will go so that the T-square and triangles may slide over them readily. Figure 10 shows a standard sheet layout with trim lines and border lines indicated. When the paper is trimmed, the thumb-tack holes are, of course, removed.

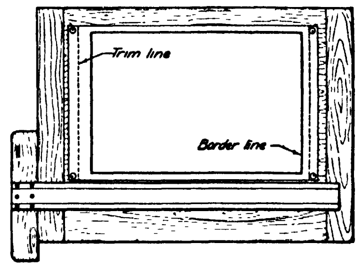


FIG. 10. Layout of sheet.

When standard size sheets are not used, the drawing is usually made first and the border line placed around it afterward.

55. THUMB TACKS. — Thumb tacks may be obtained from the trade in many styles and sizes. Cheap ones may be obtained in boxes of one hundred, for less than the price of a dozen good ones. The types shown in Fig. 11, *C* and *D*, will be found to give the greatest satisfaction, since they can be pushed down tight against the paper and then offer little obstacle to the movement of the T-square and triangles. They are worth several times their extra cost in the annoyance they prevent.

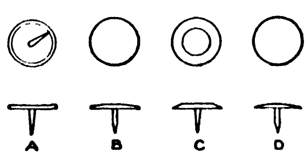


FIG. 11. Types of thumb tacks.

56. SPECIAL PAPER FASTENERS. — The drawing paper may also be held on the board by means of fine wire staples. The staples are driven through the paper into the board by a machine similar to that used in fastening papers together. The staples are quite fine and do not damage the drawing board and also offer no obstruction at all to the T-square and triangles.

Scotch drawing tape may be used in fastening paper to the board. This is a pliable adhesive tape and may be used several times. Short pieces are usually fastened across the corners of the paper.

57. SCALES. — The size of the drawing papers upon which an engineer must work is quite limited, but the size of the object or project he may be required to draw may vary from a fraction of an inch to hundreds or thousands of feet in extent. As long as the object is considerably smaller than the convenient sizes of drafting paper, it may be drawn in its natural size. The drawing is then spoken of as a *full-size drawing*. If the object is larger it may be drawn one-half size, that is, 6 inches on the drawing will represent 1 foot on the object. Likewise, it may be drawn one-quarter size, which means that 3 inches on the drawing represents 1 foot on the object. In this way the size of the drawing may be greatly reduced. For one-half size drawings, the necessary reductions may be made mentally and laid off on the paper with a regular scale having $\frac{1}{16}$-inch divisions. For the smaller sizes, however, time and effort can be saved by having scales made to represent the reduced dimensions. Three kinds of scales are in common use in this country, namely, the architect's, civil engineer's (or simply engineer's), and mechanical engineer's. They are made in both triangular and flat shapes, shown in Fig. 12, and contain the following divisions:

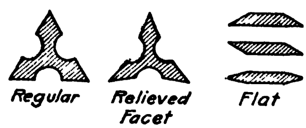


FIG. 12. Sections of standard scales.

Architect's Scales	Civil Engineer's Scales	Mechanical Engineer's Scales
1 " equals 0'-1"	1" equals 10'-0"	24" = 1'-0" or 2 " = 1"
3 " " 1'-0"	1" " 20'-0"	18" = 1'-0" or 1½" = 1"
1½" " 1'-0"	1" " 30'-0"	12" = 1'-0" or 1" = 1"
1 " " 1'-0"	1" " 40'-0"	9" = 1'-0" or ¾" = 1"
¾" " 1'-0"	1" " 50'-0"	6" = 1'-0" or ½" = 1"
½" " 1'-0"	1" " 60'-0"	3" = 1'-0" or ¼" = 1"
⅜" " 1'-0"	1" " 80'-0"	1½" = 1'-0" or ⅛" = 1"
¼" " 1'-0"	1" " 100'-0"	
$\frac{3}{16}$" " 1'-0"		
⅛" " 1'-0"		
$\frac{3}{32}$" " 1'-0"		

On the architect's scale, the main divisions represent 1 foot, and hence the basic scaling divisions at each end of the rule are subdivided into 12 parts and fractions thereof, as in Fig. 13. The civil engineer's scale has the inch space subdivided into some multiple of 10; hence the main divisions represent 10 feet, 20 feet, etc., or 100 feet, and 200 feet, as conditions may require. On the mechanical engineer's scale the main divisions represent 1 inch, and the basic scaling divisions are then subdivided into halves, quarters, eighths, sixteenths, etc.

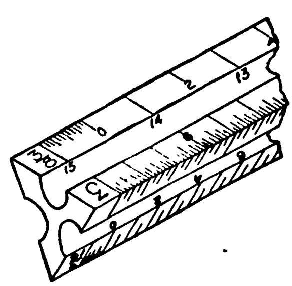


FIG. 13. Architect's scale.

When it is necessary to lay off a large number of equal spaces which must total a certain specified amount, the scale should be used, and not the dividers. The end of the scale should be made to coincide with the first mark on the paper, and then all the spaces should be laid off, if possible, without moving the scale. In this way, small discrepancies may occur in any one unit, but there will not be a cumulative error in the whole. When

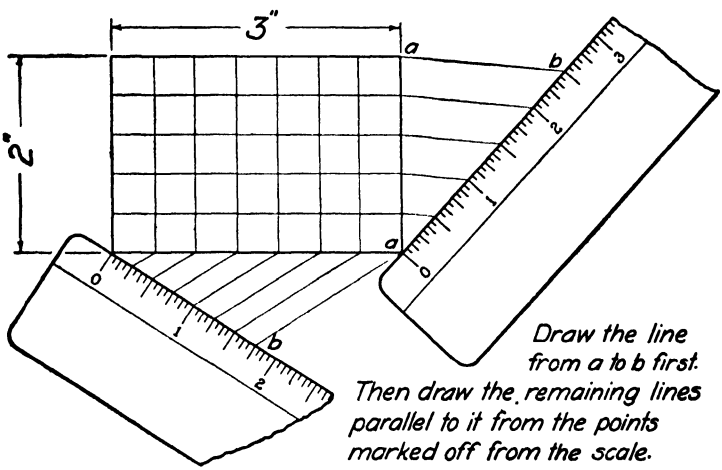


FIG. 14. Use of scale to divide a space into equal parts.

it is desired to divide a given space into an odd number of equal parts, as, for example, 2 inches into 5 parts, this should be done with the scale, as shown in Fig. 14.

To employ the scale properly, one should place the working edge farthest from him against the paper and then, looking down over it, mark off the required dimensions with a conical-pointed pencil.

58. SET OF INSTRUMENTS. — A complete drafting equipment includes all of the foregoing items, and in addition a small box or case of drawing tools, usually referred to as a "set of instruments." A set of instruments should include the following pieces:

1 — 6" compass with interchangeable pencil, pen, and needle points
1 — 6" hair spring divider
1 — Bow pen
1 — Bow pencil
1 — Bow divider
1 — 6" Detail pen
1 — 4" Ruling pen
1 — Key or screw driver to adjust instruments
1 — Box of leads
1 — Lengthening bar for compass

This is the minimum acceptable as a complete set of instruments, but it includes everything a draftsman needs for ordinary work. Where special work requires other instruments, they are usually supplied by the concern for whom the draftsman works. Some of the more common special instruments are the drop pen, the contour pen, the parallel straight edge, the beam compass, the ellipsograph, the pantograph, the section liner, and the railroad curves or ship curves.

In selecting instruments, the chief point of consideration should be quality. An expert may produce satisfactory drawings with inferior instruments, but the beginner will find his task sufficiently difficult without the handicap of poor equipment. Unfortunately, to all outward appearances, good instruments and poor instruments may look quite alike, so that it is best to secure the advice of an experienced man before making a purchase. For the student who expects to follow the engineering profession, it is good economy to spend a few extra dollars for a high-grade set which will last a lifetime, rather than save the money and endure the annoyance of loose joints, broken parts, and rusted or stripped threads, which so frequently are encountered with cheap instruments. In any event, the draftsman should not purchase materials which do not have the manufacturer's or dealer's name or trade mark stamped on each piece.

The following paragraphs make clear the proper methods for handling the various pieces of a set of instruments. The use to which they are subjected and the care they receive when not in use determine to a large extent how long they will last.

59. Dividers. — The dividers are used chiefly for transferring measurements and for dividing spaces into equal parts. To set the divider, it should be held as shown in Fig. 15. If the distance to be set permits, the second and third fingers are placed inside to help control the movement of the points. If the space to be set is small, the divider must first be opened wider than the space and then closed down to the proper measurement by pressure from the thumb and fingers. The divider may be set directly from the scale, by setting one point very lightly at the top of one of the division marks and then bringing the other point to the proper place without sticking it into the wood. This practice, of course, destroys the marks on the scale; but with ordinary care it will be worn out from other causes long before the prick marks from the dividers have materially affected it.

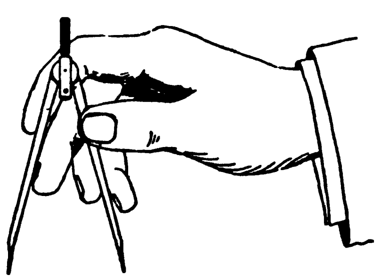


FIG. 15. Correct holding of dividers.

To step off distances, grasp the knurled top of the divider between the thumb and first finger, and rotate first in one direction and then in the other. This avoids taking a new hold on the instrument which would be necessary if it were always turned in the same direction. The points of the instrument should not be pushed through the paper, but instead only small dents need be made. These may be identified by making small rings around them freehand, after which they can always be found. The divider points should be kept sharp and of the same length; they should not be stuck in the drawing board when not in use.

60. Ruling Pen. — The ruling pen should be held in the same manner as the drawing pencil, that is, slightly inclined in the direction of motion in a plane perpendicular to the paper through the line being drawn. Great care must be exercised to get and keep the correct position of the pen, since only a slight deviation is necessary to bring disastrous results. Figure 16 shows the right and wrong relation between the ruling pen and the triangle or T-square. The two ruling parts of the pen are called *nibs*, and from the figure it is clear that both nibs must touch the paper. The bevel of the nibs keeps the point away from the triangle when properly held. If the pen is held as in *B*, Fig. 16, a ragged line results; if held as in *C*, Fig. 16, the ink will run under the triangle.

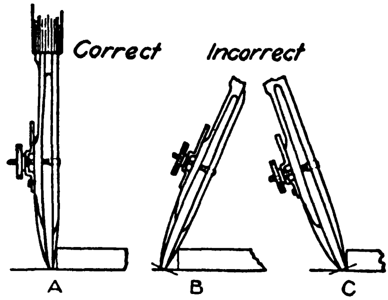


FIG. 16. Common positions of ruling pen.

The small bottles of ink are supplied with a quill which is fastened in the cork. The ruling pen should be filled by placing the quill between the nibs and allowing the ink to run into the pen. The ink should not stand higher than one-fourth of an inch in the pen, as the weight of a higher column will frequently cause it to run out and make a blot the moment the pen is touched to the paper.

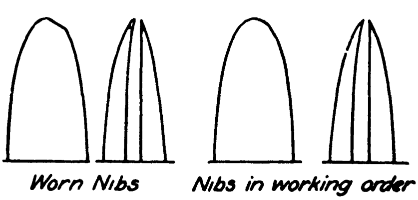


FIG. 17. Nibs of ruling pen.

In the better sets of instruments, the pens are ground and polished ready for use. Sometimes, however, the nibs are not properly pointed, and, of course, well-pointed nibs will in time wear down, so every draftsman should know how to sharpen his pen. Figure 17 shows how the nibs usually wear and how they should appear when in proper condition.

The first operation in preparing the nibs for use consists of grinding them to an even length and then rounding them off so that the end has the shape of a parabola, as shown in the figure. This can be done by closing the pen and then rubbing the nibs over an oilstone, keeping the pen in a plane perpendicular to the surface of the stone and rocking it back and forth in the direction of motion as the grinding proceeds. The next operation is that of sharpening the nibs. This must be done by grinding entirely from the outside, until the edges of the nibs do not show any flat shiny spots when viewed edgewise. Care should be exercised in this operation to see that the nibs are not again made unequal in length, and also to avoid making them so sharp that they will cut the paper.

Faulty lines always reflect upon the draftsman, for either he does not know how to keep his pen in order or else he does not know how to use it when it is in order. Long lines should always be drawn with an arm movement, coming almost to rest near the end and finishing with a finger movement. Short lines, of course, are always drawn with finger movement. The pressure upon the paper should be but little more than the natural weight of the pen. Additional pressure serves only to tire the arm and fingers and groove the paper, with no corresponding improvement in the flow of ink. Likewise, the side pressure upon the T-square or triangle should be just enough to ensure a firm and continuous contact.

In inking straight lines and curves that join each other, the curve should be inked first and great care taken to stop the arc exactly at the tangent point as shown in Fig. 18. The ruling pen should then be lined up with

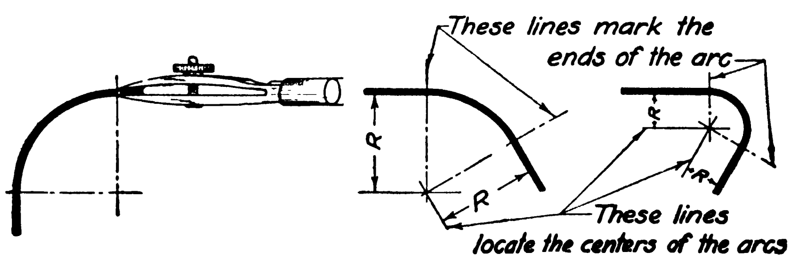


FIG. 18. Joining arcs and straight lines.

the end of the arc, as shown in the figure, before actually touching it to the paper.

One of the common faults of beginners is that of running the lines beyond their proper stopping points. It should be remembered that the ink flows just a little ahead of the pen; therefore, when the line being drawn is to end upon another line, the pen must be stopped at the near side of the line. A little practice on scratch paper will enable the draftsman to determine just when to stop his pen to avoid over-running. Drawing ink dries quite rapidly and forms little cakes on the inside of the nibs; therefore, the pen must be frequently cleaned while in use, and it should always be cleaned before it is put away. A clogged pen is one of the most common causes of poor lines. Another cause of poor lines is the presence of lint, dust, and dirt on the paper. The ruling pen will pick these up and cause a sudden widening of the line.

If a pen is in proper working order and is properly held, it is almost certain to produce a good line, except on tracing cloth, where a slightly oily surface may give trouble. This may be overcome by rubbing the surface with magnesium carbonate and then wiping it clean with a cloth. Avoid touching the tracing cloth with the hands any more than is necessary, for the hands may leave traces of oil on its surface.

In order to make a drawing give the feeling of "life and vigor," there must be a variation in the weight of the different lines employed. The outline of an object should stand out sharply, with the hidden lines somewhat less prominent. Dimension lines, auxiliary lines, and center lines should be still lighter. Figure 19 shows the proper weight for the various kinds of lines. These weights of lines should be learned through diligent practice.

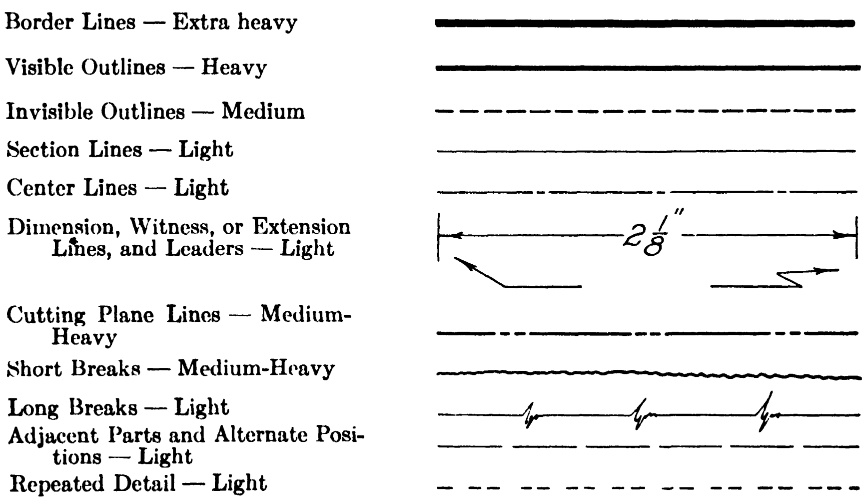


FIG. 19. Proper weight of ink lines.

61. Compass. — The compass should be adjusted before it is used for the first time, and then maintained in this condition One leg is arranged to hold either a lead or a pen. The pen is put into the compass, and then the needle point is adjusted so that it is about one thirty-second of an inch longer than the pen. Thus, when the point sinks into the paper the pen will be perpendicular to the paper and just touch it, when the compass is held in a vertical position. The needle point, once adjusted, should not be changed again for the lead points; instead, the lead points should be made to suit the needle point. In this way the compass can be quickly changed from pencil to ink work. The lead for the compass should be as hard as the drawing pencil and should be sharpened to a wedge or bevel point, and kept sharp just as is the drawing pencil. For small circles, the legs of the compass may be kept straight; but for the larger ones both legs should be bent as in Fig. 20, in order that the pen may be perpendicular to and have both its nibs touching the paper. The center is also perpendicular to the paper; and in this position it will not wear a large unsightly hole, as it otherwise would if several concentric circles were to be drawn. It is best in drawing circles to move the pen clockwise and to go around the circle only once. The line should not be gone over a second time in either direction.

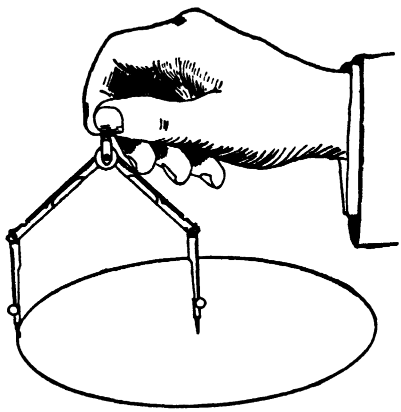


FIG. 20. Correct position of compass legs.

62. Bow Instruments. — The bow instruments are used for making small circles and arcs. The general directions given above for the large compass apply equally to the bow instruments. In addition to following the previous instructions, it is well, in setting the bow instruments to any given dimension, to relieve the pressure of the spring by pinching the points together in order to reduce the wear on the thread. This applies to side adjustment instruments only.

63. IRREGULAR CURVE. — This instrument, which is sometimes called a French curve, is one of the most difficult to use skilfully, especially when doing ink work. The skill required lies chiefly in the handling of the pen, but also to a considerable extent in the placing of the curve. If the curve is to be drawn through a series of points, as is usually the case, the irregular curve should be made to fit as many of the points as possible at one time. This fitting of the curve to the points must be accomplished by trial. In no case should a line be drawn when the curve does not fit at least three points and have the proper curvature toward the next points on both sides. Figure 21 shows how the curve may be set several times to complete one curved line.

64. TECHNIQUES OF PENCIL DRAWING. — To make a good pencil drawing on paper, tracing cloth, and tracing paper, requires the same general technique in each case. The original layout of the problem must be made with a 4H pencil or one of harder grade. When the drawing is thus completed, all construction lines, over running corners, etc., should be carefully erased. The drawing is then made a second time with a soft pencil, (H, B or 2B) in the same fashion as one would ink a drawing. The soft pencil must be very frequently resharpened so that the same weight

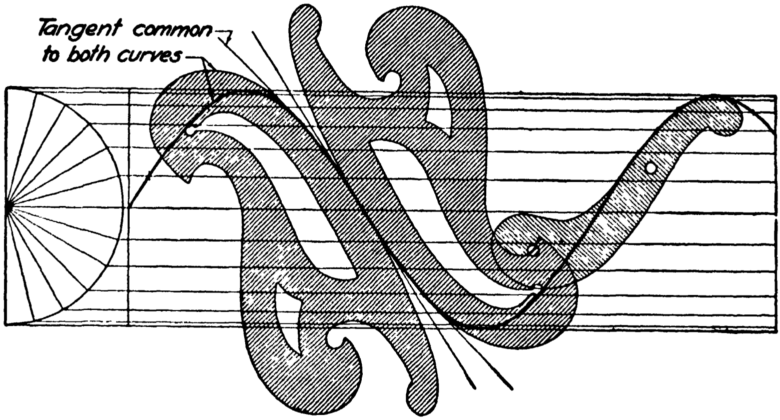


FIG. 21. Proper use of irregular curve.

of line is maintained throughout the drawing. The T-square and triangles should not be permitted to slide over the soft black lines since they will smudge the lines and ruin the drawing almost as badly as rubbing them across a wet ink line would do.

Contrast between visible outlines, hidden lines, and dimension lines should be maintained. This may be done by using somewhat harder pencils, by keeping the points much sharper, and by using a little less pressure on the pencil.

PROBLEMS

65. Arrange the problems assigned from the following group to make a well-balanced sheet. The scale in all cases is to be full size unless otherwise specified by the instructor. In Figs. 22 to 26, draw the heavy straight lines or circles first and then locate the center of the tangent arc and draw it. Show clearly the construction in all problems. Ink problems unless otherwise directed.

Accuracy of construction is the primary aim. All problems should, therefore, be constructed with a hard pencil sharpened to produce a hair line. In all tangency problems, exact tangency is to be secured even though this requires a slight shifting of the center of a circle from its geometrical location. Leave all construction lines in pencil when inking the problems. All geometrical constructions may be found in the Appendix of this text. See pages 499 to 507.

1. Draw a circle of given radius tangent to two straight lines at right angles to each other. Fig. 22.
2. Draw a circle of given radius tangent to two straight lines making an acute angle with each other. Fig. 23.
3. Draw a circle of given radius tangent to two straight lines making an obtuse angle with each other. Fig. 24.

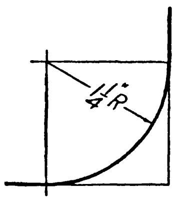


Fig. 22.

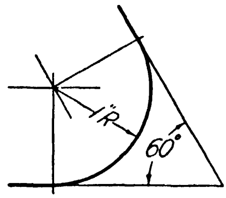


Fig. 23.

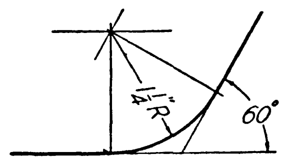


Fig. 24.

4. Draw a circle of given radius tangent to a given straight line and circle. Fig. 25.
5. Draw a circle of given radius tangent to two given circles. Fig. 26.
6. Reproduce the two circles of Fig. 26 and then draw a circle of 2″ radius tangent internally to the smaller circle and externally to the larger.
7. Reproduce the two circles of Fig. 26 and then draw a circle of 3″ radius tangent internally to both circles.

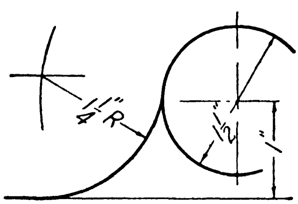


Fig. 25.

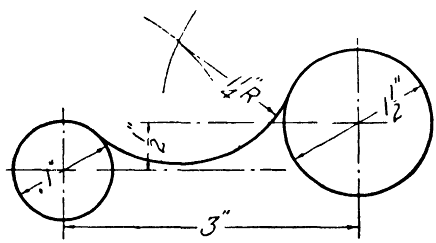


Fig. 26.

8. Draw an ellipse of given major and minor axes by the exact method. Fig. 27.
9. Draw an ellipse of given major and minor axes by the four-center method. Fig. 28.

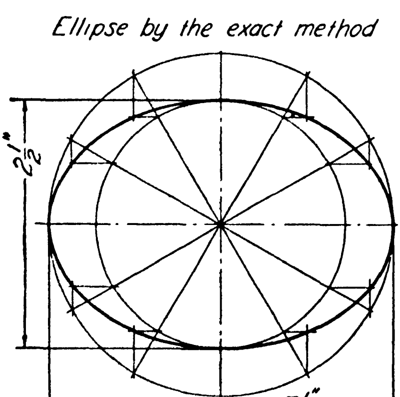


Fig. 27. Construction of ellipse.

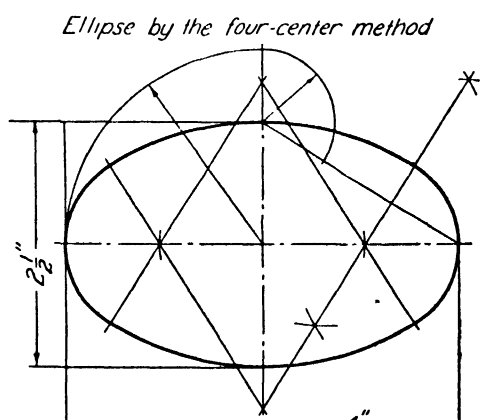
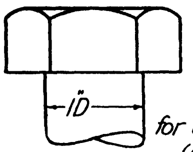
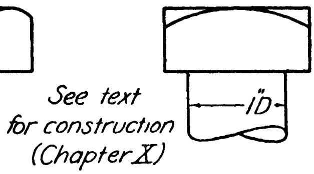


Fig. 28. Construction of ellipse.

10. Draw the hexagonal bolt head of Fig. 29.
11. Draw the square bolt head of Fig. 30.
12. Draw the round-head machine screw of Fig. 31.





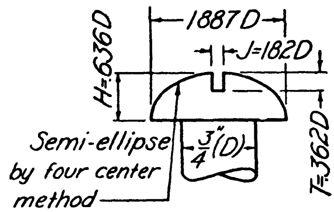


FIG. 29. Hex. bolt head. FIG. 30. Square bold head. FIG. 31. Round head (screw).

13. Construct a parabola tangent to two straight lines intersecting at and symmetrical about a center line bisecting their angle. Fig. 32.

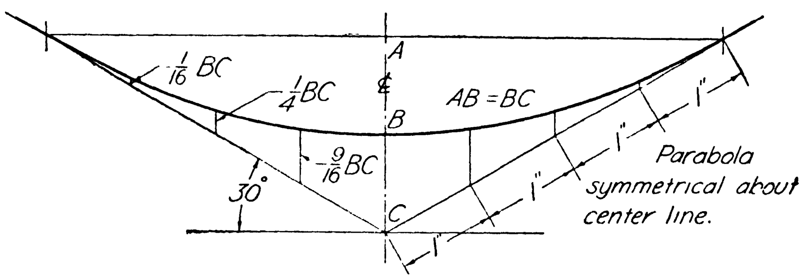


FIG. 32. Construction of parabola.

14. Construct an helix of given lineal pitch and pitch diameter. Fig. 33.

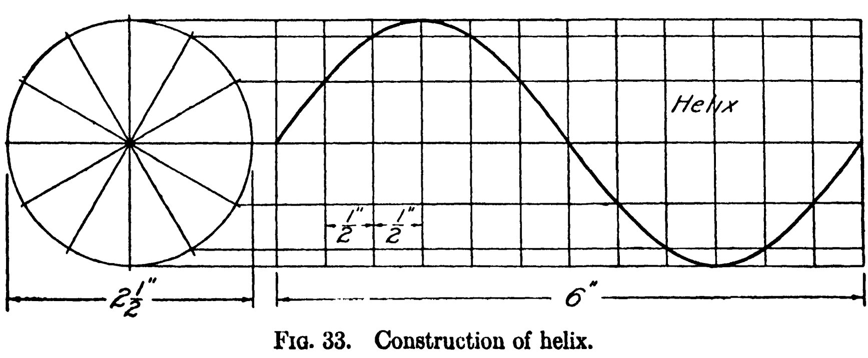


FIG. 33. Construction of helix.

15. Construct a cycloid with a given diameter of rolling circle. Fig. 34.

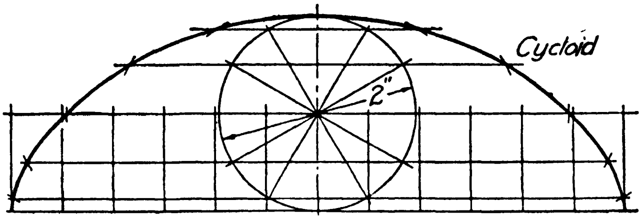


FIG. 34. Construction of cycloid.

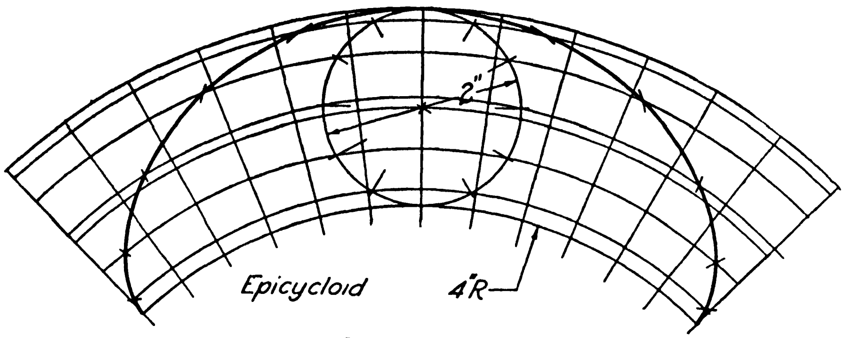


FIG. 35. Construction of epicycloid.

16. Construct an epicycloid with given diameters of the rolling and fixed circles. Fig. 35.

CHAPTER V

ORTHOGRAPHIC PROJECTION

66. Elements of Projection. — There are three major kinds of projection, namely, *Orthographic, Oblique,* and *Perspective.* In discussing any one of them, *four distinct elements* must be considered. These elements are the projecting lines, the point of sight, the surface upon which the projection or drawing is made, and finally, the object itself. No real understanding of the theory of projection can be had without considering the fullest relationships of these four factors. They are so closely interrelated that a discussion of one of them must necessarily involve the others;

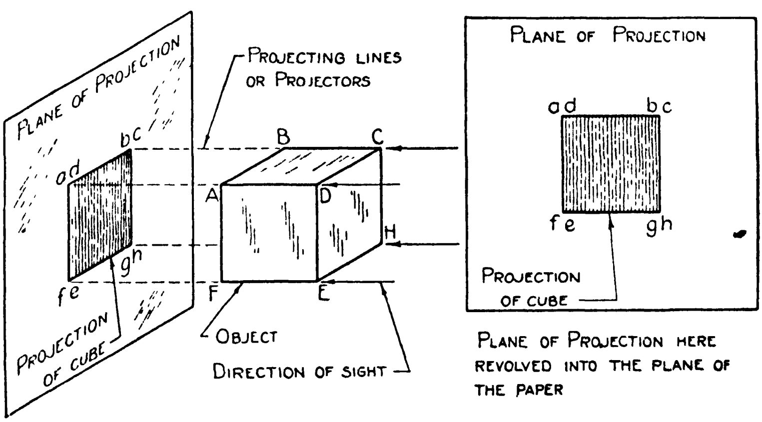


Fig. 1. One plane of orthographic projection.

hence, any treatment of a single item should not be considered as complete until all four have been finished in turn. A study of Fig. 1 will give a general idea of the meaning of these four elements, which may be briefly defined as follows:

Projecting Lines are the imaginary lines along which points are projected from the object of which they are a part, to the surface on which the drawing is made.

The *Point of Sight* is the real or imaginary position of the observer from which the projection or view is obtained.

The *Plane of Projection* is the plane surface upon which the object is projected or drawn.

The *Object* may be anything real or imaginary which it is desired to represent.

67. Theory of Projection. — The projection of any point of an object on a plane of projection is the point (projection) in the plane of projection where the projecting line through the given point pierces the plane. Thus, in the first drawing of Fig. 1, the projection or corner *A* of the cube is at *a* in the plane of projection. Similarly, the projection of the edge *AB* of the cube is the line *ab* in the plane of projection. The projection of the face *ABCD* is the line *ab* or *dc*. The projection of the face *ADEF* is the line *af* or *de*. The projections of all six faces and twelve edge lines of the whole cube are simply the four sides of the shaded square. Hence, the projection of any object may be obtained by getting the projections of all of its outstanding or bounding points and lines, or faces. The projection of any point or line within the cube would, of course, fall within the boundaries of the square.

The appearance of the projection of an object will depend upon the relation to each other of the four items mentioned above, most important of which is the relation of the projecting lines to the plane of projection.

68. Projecting Lines. — Three possible situations may arise in the relation of projecting lines to the plane of projection as illustrated in Fig. 2. In the first drawing of Fig. 2, the projectors are *parallel to each other and*

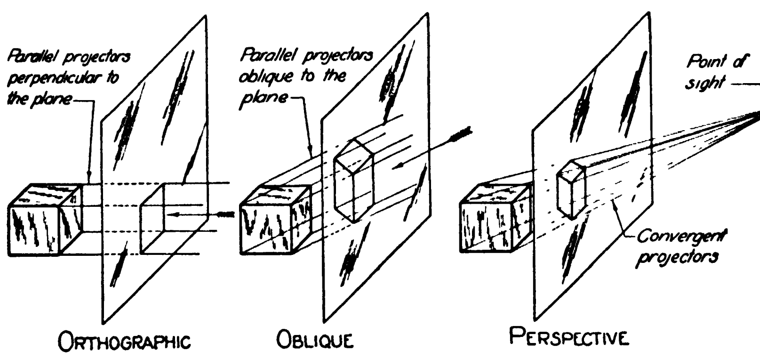


Fig. 2. Projectors or lines of sight.

perpendicular to the plane of projection. Projections made upon this basis are called *Orthographic Projections.* Orthographic projection may be defined, therefore, as *any projection made upon the theory that the projecting lines are perpendicular to the plane of projection.* This is the kind of projection with which this chapter is concerned. An important division of orthographic projection, called *Isometric Projection,* is treated in considerable detail in Chapter XIII.

The second illustration of Fig. 2 shows parallel projecting lines which are oblique to the plane of projection. Projections made upon this basis are called *Oblique Projections.* The last drawing of the figure shows convergent projecting lines which necessarily make different angles with the plane of projection, unless there are one or more planes of symmetry in the whole projective system. This type of projection is called *Scenographic Projection* or *Perspective.*

69. POINT OF SIGHT. — Although it may be possible to think of projections as being made by mechanical projecting lines which fulfill certain geometrical conditions, useful drawings cannot be made without a definite conception of a point of sight and of its location. The relation of the projecting lines to one another may be said to depend upon the location of the point of sight, which may be assumed in either of two general positions. It may be at an *infinite* distance from the object or at a *finite* distance from it. If the point of sight is at infinity, the projecting lines must, as a result, be parallel to each other, as in the first and second drawings of Fig. 2; whereas, if the point of sight has a finite location, the projecting lines converge to this point as in the third drawing of Fig. 2.

It is this fact of a chosen point of sight from which the object is assumed to be seen, or viewed, and through which all projectors must pass, that gives rise to the general practice of calling a projection of an object *a view.* Hence there are *top views, front views, side views,* and the like.

Considering only orthographic projection, with which this chapter deals, it is obvious that there must be a point of sight for each view or projection of the object represented. Hence there is not just one point of sight but as many as there are views to be made of the object. To get a top view, the point of sight must be above the object. For a front view, the point of sight must be in front of the object; for a right side view, it must be to the right of the object; and for a left side view, it must be to the left of the object. In each case, of course, it is said to be at infinity.

70. PLANES OF PROJECTION. — Drawings may be made upon any kind of surface, as, for example, the paintings upon the curved walls and domes of cathedrals and other public buildings. The engineer's drawings, however, are always conceived as projected upon a plane surface. Such a plane is called a plane of projection. See Fig. 1. In the imagination, the plane is conceived to be transparent, although, as a matter of fact, it is represented by the sheet of paper, or tracing cloth, upon which the drawing is made.

For use in actual construction, a projection upon a single plane (isometric and oblique drawing excepted in simple cases) is found to be inadequate. Referring again to Fig. 1, it will be noted that the length of AD, the dimension of the cube which is perpendicular to the plane of projection, is not shown by the projection of AD at all. If one did not know the object to be a cube, either from a note on the drawing or from previous knowledge, no idea of the length of the object would be conveyed by the drawing.

Since in construction work previous knowledge certainly cannot be assumed, and since notes on a drawing may be overlooked and would in themselves be inadequate for most objects, two planes of projection at right angles to each other form the minimum basis for all engineering drawings of this type. Figure 3 represents two such planes of projection

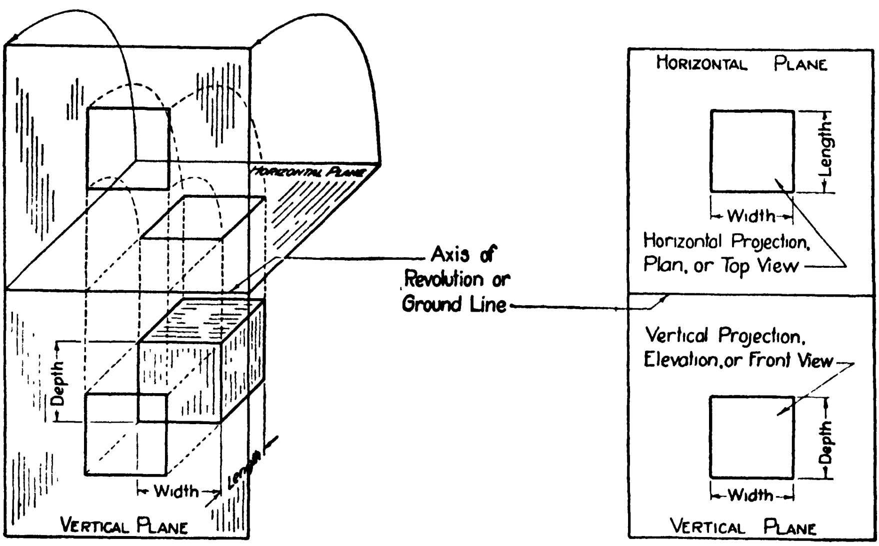


FIG. 3. Two planes of orthographic projection.

at right angles to each other. One of the planes is always assumed to be horizontal and the other vertical. They are designated by these names as shown in the figure.

The three dimensions of the cube in Fig. 3 have been designated as the length, width, and depth. It will be noted that the projection on the vertical plane, called the elevation or front view, shows the width and depth of the object, while the horizontal projection, called the plan or top view, shows the width and length. These two views thus give all necessary dimensions of this simple object.

While two projections like those of Fig. 3 suffice to give the shape and size of most three-dimensional objects, it frequently happens that even they fall short of giving complete information. A careful examination of the pictorial sketch and the corresponding orthographic projections of Fig. 4 will show that three views are necessary to describe the shape of this object completely. In order to obtain three views, a third plane, called a profile plane, is set up perpendicular to the other two.

The three planes of projection which we have just shown to be necessary are often called the *Coördinate* or the *Principal Planes of Projection.* For brevity in discussion and illustration, these planes are designated by the initial letter of the word which describes them. Thus, the vertical plane

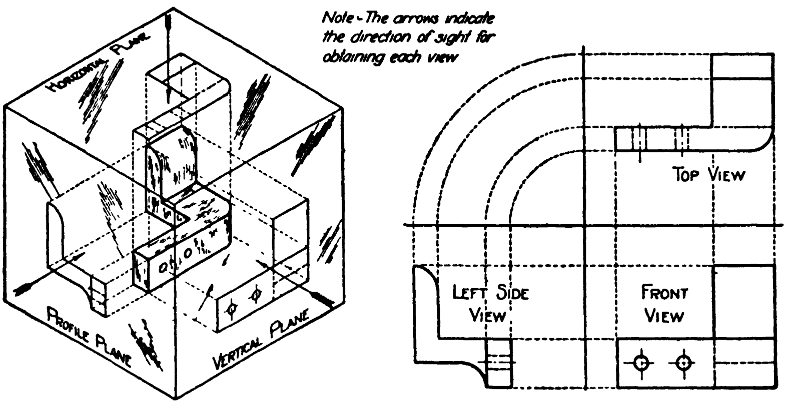


FIG. 4. Three planes of orthographic projection.

is called the V-plane, the horizontal plane is called the H-plane, and the profile plane is called the P-plane, or simply V, H, and P.

71. ROTATION OF THE COÖRDINATE PLANES. — Drawings, whether composed of one, two, three, or more views, are always shown on a single plane surface, namely, the sheet of drawing paper. The transformation from three planes at right angles to each other, illustrated in Figs. 3 and 4, to a single plane may be readily accomplished by imagining the vertical plane to remain fixed while the others are revolved into coincidence with it. Each plane is revolved away from the object about its line of intersection with the V-plane as an axis, as shown in Fig. 5. From this figure it can be seen that where more than two views are required, the bottom part of a drawing sheet will be somewhat crowded, particularly if several objects are drawn on the same sheet. This condition is accentuated by the fact that the title is almost invariably placed in the lower right-hand corner of the sheet.

To overcome this situation an alternate method of rotating the planes may be adopted. Thus, in Fig. 6, the profile plane or planes are first rotated about their line of intersection with the H-plane into coincidence with it, after which the H-plane is rotated in the usual way. This arrangement transfers the crowding from the bottom to the top of the sheet but lessens it to a considerable degree. By a proper combination of the two methods, a drawing sheet may be nicely balanced. If there is no specific reason for doing otherwise, the first method of revolution, illustrated in Fig. 5, is to be preferred.

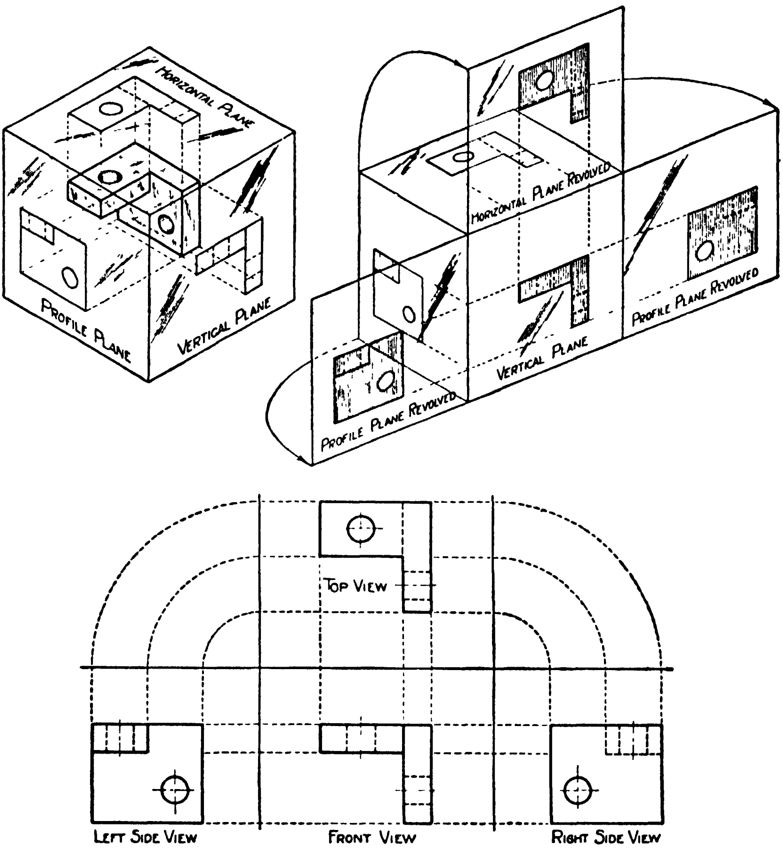


Fig. 5. Revolution of coördinate planes (standard method).

It should be carefully observed that the process of revolution of the coördinate planes brings the various views of an object into a very definite relationship to one another. The views are said to be " in projection " with each other. The position of the views depends upon the method of rotation; but, since the horizontal plane is always turned the same way, the top and front views are always in alignment vertically. When the imaginary rotation is performed, as in Fig. 5, the profile and front views will come into horizontal alignment; whereas, when the rotation is performed as in Fig. 6, the top and profile views come into horizontal alignment. No departure from the arrangement of views shown in these two figures can be tolerated, for otherwise the drawing becomes unintelligible to everyone save the draftsman who made it.

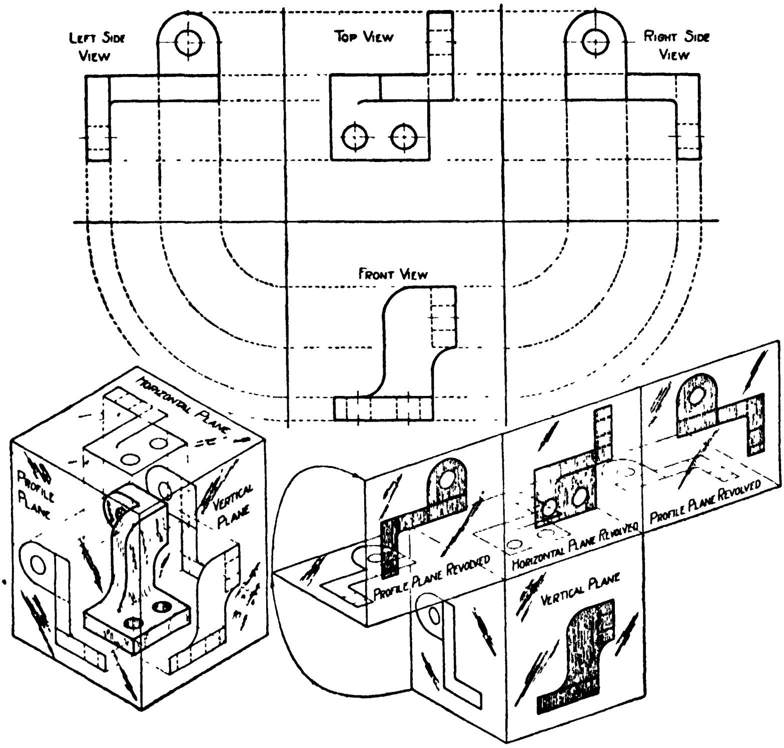


Fig. 6. Revolution of coordinate planes (alternate method).

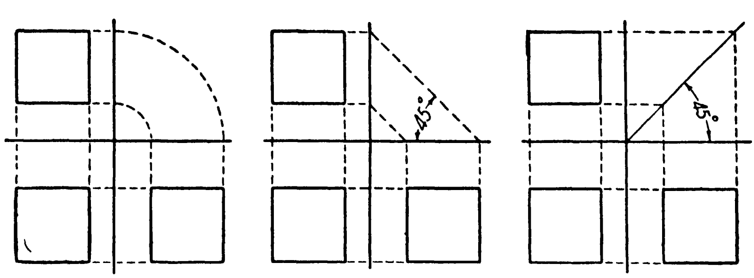


Fig. 7. Mechanical methods of transferring distances.

Three mechanical schemes for constructing the third view from the other two are shown in Fig. 7. On working drawings, the lines which represent the axes about which the planes have been revolved, usually called ground lines, are erased when the views have been completed; or the views themselves are constructed without the aid of ground lines by projecting from one view to another and transferring the measurements with the scale or dividers. Thus, the right side view in Fig. 8 has been constructed by projecting horizontally from the front view and transferring the dimensions *a*, *b*, and *c* from the top view as indicated. It should be noted that every point, line, or plane on an object is represented in every view that is made of it. The draftsman must be able to identify these representations in all the views. Note points *X* and *Y* in the figure.

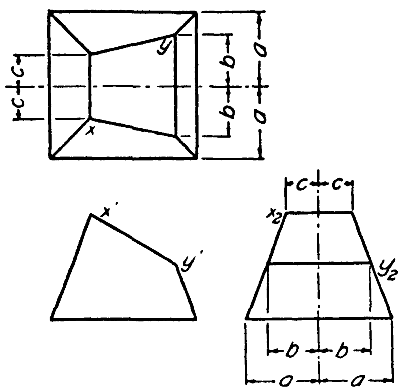


FIG. 8. Scale method of transferring distances.

72. DIHEDRAL ANGLES OR QUADRANTS. — The illustrations of this chapter have for convenience and of necessity shown the planes of projection as limited in extent, but they are really infinite or unlimited in extent. A plane is not limited by its intersection with other planes but may extend on through them as shown in Fig. 9. The horizontal and vertical planes divide all space into four equal parts called dihedral angles or quadrants. In referring to these angles, it is understood that the observer's point of sight is always *in front of the vertical plane and above the horizontal plane.* That portion of space in front of the vertical plane and above the horizontal plane is called the first angle or quadrant; that portion of space behind the vertical plane and above the horizontal is called the second angle or quadrant; that portion behind the vertical and below the horizontal, the third angle or quadrant; and that in front of the vertical and below the horizontal, the fourth angle or quadrant. See Fig. 9. Setting up the third coör-

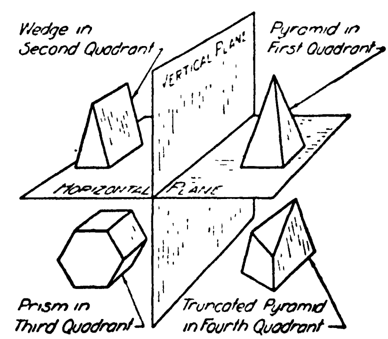


FIG. 9. Dihedral angles or quadrants.

dinate or profile plane does not in any way change the quadrants or limit their extent.

73. Choice of Quadrants. — From Fig. 9 it may be seen that an object can be placed in any one of the four quadrants and then projected upon the three coördinate planes. For certain reasons, the portion of the horizontal plane in front of the vertical is always turned down and the portion in back of the vertical must, consequently, be turned up as has been indicated in Figs. 3, 5, and 6. With this direction of rotation of the H-plane definitely fixed, the second and fourth quadrants are immediately eliminated from consideration, since the horizontal and vertical projections would overlap each other and be useless.

If the first quadrant is used and the planes are rotated according to the rules already established, then the arrangement of views shown in Fig. 10 must result. The point of sight for the profile view is taken to the left of

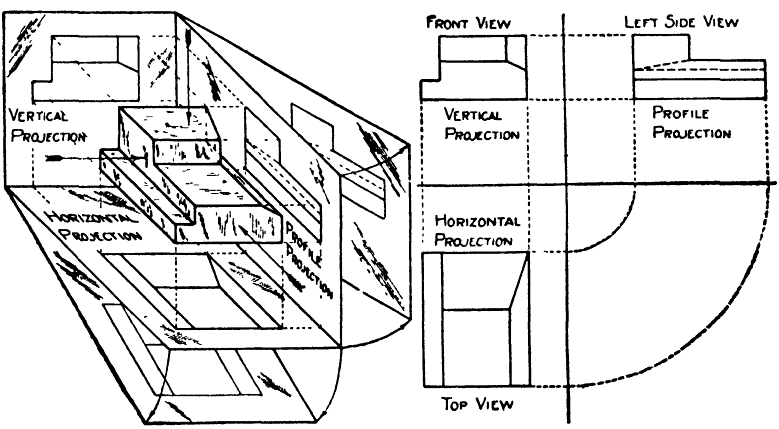


Fig. 10. First angle projection.

the object, in this case, on the basis that *the object is always between the point of sight and the plane of projection in the first quadrant.* Had the profile plane been placed on the left side of the object, the point of sight would have been taken to the right of the object.

The objection to the result obtained from first quadrant projection is the unnatural arrangement of views. In looking at most objects which the draftsman must represent, the eye is usually above the object so that the top is seen above the front, which is just the opposite of the arrangement given by a first quadrant projection. The *left* side view appears on the *right* of the front view, because the object must be kept between the observer and the plane of projection in this quadrant. This unnatural arrangement of views is the only objection to the first quadrant, but it is sufficient to have eliminated its use entirely in the United States, except for a few special kinds of drawing.

If an object is placed in the third quadrant and the rules for rotating planes are observed, a natural and pleasing arrangement of views follows, as may be seen from Figs. 4, 5, and 6. In this quadrant the top view of an object appears above the front as it should, and the right side view appears at the right as it should, without doing violence to the logical arrangement of object, point of sight, and plane of projection. It will be noted that *in the third quadrant the plane of projection is always between the point of sight and the object.*

74. Position of the Object. — It will be noted, from the preceding discussion, that the theory of projection developed is entirely independent of the shape of the object and its location in space. This is true so long as theoretical projections are the chief concern; but if useful drawings are to be made, the position of the object relative to the plane of projection is of great importance. A comparison of Fig. 11 with Fig. 1 serves to show that the position of the object makes a difference, not only in the appearance but also in the usefulness of the views. The projection of Fig. 1 shows the true size and shape of the cube whereas that of Fig. 11 shows only

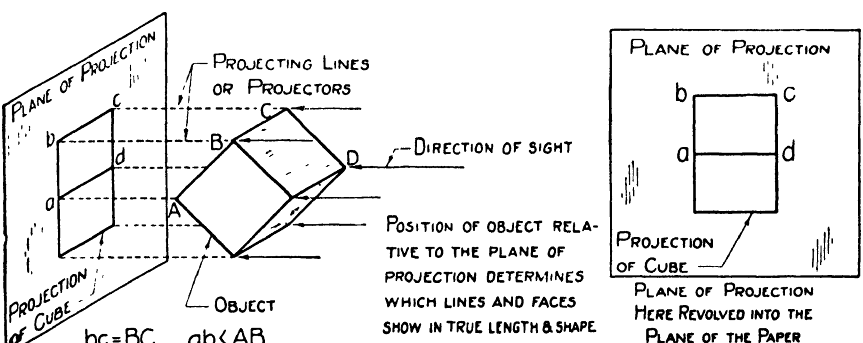


Fig. 11. Effect of position of object on projection.

the true width of the cube. From observation and from geometry it is known that *the true value of the angles between lines, or the true length of lines, shows in projection when the lines themselves are parallel to the plane of projection.* It may be stated, therefore, as a definite rule that, for engineering working drawings, the principal faces of the object should be placed parallel to the planes of projection. All figures of this chapter except Fig. 11 comply with this rule.

In the shop or factory or in nature, we are accustomed to see objects in certain definite positions, and when we see them upside down, inside out, or in other unusual positions, they are quite unfamiliar. What is true of the objects themselves is equally true of the drawings of the objects; hence, it may be stated, as a second definite rule, that objects should be placed and drawn in their normal or natural position or as near thereto as possible. Figure 12 represents a bearing cap which may be seen either on

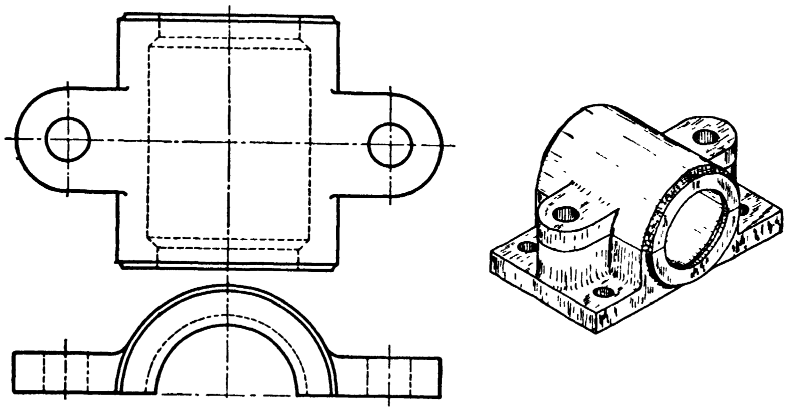


FIG. 12. Object drawn in natural position.

the top, side, or bottom of a bearing, depending upon the position of the bearing as a whole, but, in any event, it is normally viewed from the outside and should be drawn as shown in the figure.

75. INVISIBLE LINES. — Regardless of how the object is placed or where the point of sight is selected, there will always remain, on even comparatively simple objects, certain lines which cannot be seen except by imagination. Although they are not visible to the observer, such lines must be shown in a drawing in order to portray accurately the shape of the object. Moreover, they must be distinguished from the visible outlines in some way. This is accomplished by using a different type of line to represent the hidden edges. A dash line is universally used for this purpose. Examples of its use may be found in many of the figures of this chapter. The length and weight of the hidden lines to be used on a drawing are shown in Fig. 19 of Chapter IV.

When the number of invisible or hidden lines on a drawing becomes too great, they are difficult to interpret. It is, therefore, highly desirable that the projections be selected with a view to reducing the number of hidden lines to a minimum without, of course, turning the object out of its natural position. For example, in the object shown in Fig. 5, only three of the four views are actually required. Either the left or right side view can be chosen with the top and front view. In this case, the left side view is better since it has the fewer number of invisible lines and in all other respects is as good as the right side view. The same is true of Fig. 6.

Whether or not a line on an object is visible in any particular view depends entirely upon the position of the point of sight. In making the top view, the point of sight must be above the object. This is true regardless of the quadrant in which the object is placed. The front of the object can be seen only if the point of sight is in front; therefore, the point of sight is always in front of the object for this view. Likewise, the right side is viewed from the right, and the left side from the left. It is emphasized again that in none of these cases does the placing of the object in various quadrants have any effect upon the location of the point of sight. Only the *arrangement* of views is affected by the quadrant chosen.

76. READING DRAWINGS. — The practicing engineer is always concerned with drawings, and he must be able to read them even if he does not have the opportunity to make them. In any case, he must be able to determine from a drawing at least five things, as follows:

a. The position of one point on an object relative to another point, that is, the direction and distance of one point from another.

b. The position of a line on an object relative to the horizontal, vertical, and profile planes, that is, the angles of inclination of the line with the various planes.

c. The position of lines on an object relative to each other, that is to say, whether lines are parallel, perpendicular, or inclined to each other.

d. The position of plane faces of an object relative to the horizontal, vertical, and profile planes.

e. The position of plane faces of an object relative to each other.

In Fig. 13, a block with certain portions removed is shown pictorially in the upper right corner and by three views in the remainder of the drawing. The corners have been marked and the figure dimensioned for convenient reference. The problem is to read and correctly interpret the three-view drawing. The pictorial view has been added merely as an aid in reading. It may be referred to for that purpose but will not be mentioned in the discussion which follows.

77. Location of Points. — Let it be required to locate the point K with reference to the point F in Fig. 13. From the top view it can be seen that K is $1\frac{1}{8}$ inches to the right and $1\frac{1}{8}$ inches in front of F. No further information can be obtained from the top view. The front view, however, shows that K is $\frac{5}{8}$ inch below F. This definitely locates the point. The profile view, added because it is necessary to provide certain facts about some of the plane faces of the object, repeats a part of the information given in the top and front views, namely, that the point K is $\frac{5}{8}$ inch below and $1\frac{1}{8}$ inches in front of F.

As a second example, let it be required to locate the point E with reference to the point P in Fig. 13. Proceeding as before, the top view shows

E to be $\frac{7}{8}$ inch to the right and $1\frac{1}{2}$ inches behind P, while the front view shows E to be $1\frac{1}{2}$ inches above P. The student should study the relationships of other points on the object in a similar manner and always to the extent of three directions.

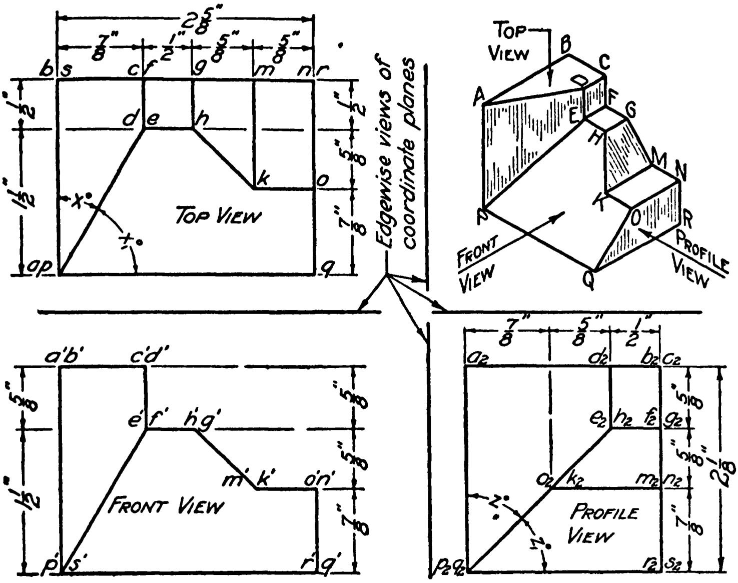


FIG. 13. Lettered views for "reading" lines.

78. Position of Lines. — Lines on an object may have three distinctive positions with reference to the principal planes of projection: they may be (1) parallel to one of the three planes and inclined to the other two; or (2) perpendicular to one of the planes and parallel to the other two; or (3) inclined to all three planes. The plane faces of the object parallel to the principal planes may be substituted for the latter in discussing these relations, but they are not preferred since in many objects the side faces are inclined rather than being parallel to the principal planes of projection. In Fig. 13, lines GM, AD, and QO are parallel to the V-, H-, and P-planes, respectively. They are inclined to two planes in each case. Lines ON, NR, and MN are perpendicular to the V-, H-, and P-planes, respectively. Each is also parallel to two of the planes. Lines PE and HK are inclined to all three coördinate planes.

The fact that a line is parallel to V, H, P, or any other plane, for that matter, is always indicated in the view that shows the plane edgewise, by projecting in that view as a point or as a line parallel to the line that represents the edgewise view of the plane. In the lines BC, CF, FG, GM, MN, and NR in Fig. 13, for instance, the horizontal ground line represents the

V-plane edgewise in the top view, and the H-projections of the six lines mentioned show the lines to be parallel to the V-plane for the reasons given. The lower vertical ground line shows the V-plane edgewise as a profile view, and, therefore, the profile projections also show the six lines to be parallel to the V-plane by the same principle.

In a similar way, if we wish to note which lines are parallel to the H-plane, we must obtain a view which shows that plane edgewise. This situation occurs in both the front and profile views. In each, the projections of the lines *AD*, *DC*, and *FG*, for example, clearly show them to be parallel to the H-plane, since they project as a point or as a line parallel to the horizontal ground line in both views. Lines which are parallel to the profile plane may be identified in the same manner. The profile plane appears edgewise in the front and top views, and in either of these the lines *QO*, *ON*, and *NR*, for example, are seen to be parallel to the P-plane.

A line which is parallel to one of the principal planes shows on that plane the true angles which it makes with the other two planes by the angles its projection makes with the corresponding edgewise views of the two planes. Thus, from the top view, it can be seen that *AD* which is parallel to H makes an angle of X degrees with the P-plane and X_1 degrees with the V-plane. Likewise, the angles which *QO* makes with V and H are shown in the profile view as Z degrees and Z_1 degrees, respectively. The true lengths of these lines also show on the planes to which the lines are parallel.

If a line is perpendicular to a plane, its projection on that plane will be a point. Conversely, if the projection of any line on a plane is a point, that line is perpendicular to the plane. With this in mind, an examination of the top view in Fig. 13 will show that lines *AP*, *BS*, *DE*, *CF*, and *NR* are perpendicular to the H-plane. The front view in Fig. 13 shows lines *AB*, *CD*, *EF*, *HG*, and several others to be perpendicular to V. The profile view shows lines *PQ*, *EH*, *FG*, *KO*, and others to be perpendicular to the profile plane. As previously stated, if a line is perpendicular to one of the principal coördinate planes, it is parallel to the other two, a fact that can be checked in the above instances by the tests for parallelism detailed in the preceding paragraphs.

Again using the fact that an edgewise view of a plane (ground line in the case of a coördinate plane) and the projections of lines on the same plane on which the edgewise view is seen show the general relationships of the lines to that plane, it is observed from the top view in Fig. 13 that lines *PE* and *HK* are inclined to both V and P. The front view, in which the horizontal ground line becomes the edgewise view of the H-plane, shows that these lines are inclined to H also. Therefore, the lines are inclined to all three planes. The profile view confirms this conclusion as to the H- and V-planes. The exact angles which these lines make with the planes do not show in any of the three views. Likewise, the true lengths of the lines do not appear in any of the three views since the lines are not parallel to any one of the three principal planes. A method for finding the true lengths of lines of this kind will be given in the next chapter.

79. Position of Planes. — The plane faces of an object may have any one of three distinctive positions relative to the principal planes: they may be (1) parallel to any one of the three planes and perpendicular to the other two; or (2) perpendicular to any one of the planes and inclined to the other two; or (3) inclined to all three planes.

In Fig. 14, the top and bottom faces of the object are parallel to the H-plane. This fact can be determined from any view in which the H-plane shows edgewise and the face projects as a straight line parallel to the edgewise view. This occurs in the front and profile views where the projections $a'b'c'd'e'$ and $a_2b_2c_2d_2e_2$ represent edgewise views of the top of

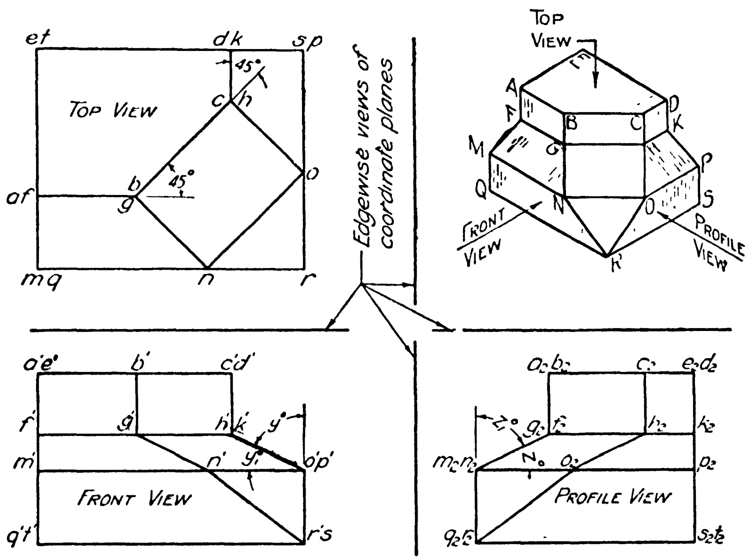


FIG. 14. Lettered views for "reading" planes.

the object showing it to be parallel to the H-plane, which in both cases appears edgewise in a horizontal ground line. The plane faces *MNRQ*, *ABGF*, and *EDKPST* are seen to be parallel to the V-plane from the top and profile views, their projections being parallel to the corresponding edgewise views (ground lines) of that plane. Likewise, the planes *EAFMQT*, *CDKH*, and *OPSR* are seen to be parallel to the profile plane which appears edgewise in the top and front views as vertical ground lines. All the faces enumerated are perpendicular to two coördinate planes as specified in type (1) above.

The plane face *BCHG* in Fig. 14 is perpendicular to the H-plane since it appears as a straight line (edgewise) in the top view. The angles which it makes with the vertical and profile planes are shown in their true size as 45 degrees since these planes also appear edgewise in this same view. The plane face *KPOH* is perpendicular to the V-plane since it appears edgewise in the front view as the line $k'p'o'h'$. It makes an angle of y degrees with the P-plane and y_1 degrees with the H-plane as shown in this same view. The plane face *FGNM* is perpendicular to the profile plane because it appears edgewise in the profile view as the line $f_2g_2n_2m_2$. The angles which this face makes with the H- and V-planes show in the profile view in true size as Z degrees and Z_1 degrees, respectively, since these planes also appear edgewise as ground lines. All three faces enumerated in this paragraph fall under type (2) above.

The relationships between the plane faces of an object which may be obtained from their edgewise views should be thoroughly studied. It is the fact of perpendicularity to the same coördinate plane that, more than anything else, gives the various views of an object the meaning of depth and solidity. Every view must be thought of not as a flat plane figure but rather as the particular aspect of a solid body of three dimensions, two of which are usually parallel to the plane of the view and the third perpendicular to it.

Two of the plane faces of the object in Fig. 14 are neither parallel nor perpendicular to any one of the three principal planes. These are the faces *GHON* and *NOR*. They do not appear as a single straight line in any view. Since they are not parallel to any plane of projection, they do not show in true shape in any of the views; and since they do not appear edgewise in any of the views, the true values of the angles which they make with H, V, and P, or with the other plane faces, are likewise unknown. Methods for finding the true shape of a plane face which is inclined to the principal planes and the true value of the angle between plane faces will be explained in the next chapter under the heading of Auxiliary Projections.

80. Geometrical Principles in Drawing. — From an examination of any of the orthographic views in this text it may be observed that, if two lines are parallel in space, their projections on any plane are parallel. This may also be stated as purely a proposition in geometry which can be proved. It will be accepted here simply as a fact to be used in drawing. Hence, if one line is to be made parallel to another, this can be accomplished by simply making each projection of the second line parallel to the corresponding projection of the first. It may likewise be observed and proved that, if two parallel planes intersect a third plane, their intersections are parallel.

The two geometrical principles just stated may be used to great advantage in drawing. For example, let it be required to draw the front, top, and right side views of a square hole through a rectangular block from which the upper right front corner has been cut off by a plane as shown in Fig. 15. The front view of the hole will, of course, appear as the square $a'b'c'd'$, the size of the hole, and located by scale. The top face of the hole is in a plane parallel to the plane of the top of the cube. Both of these

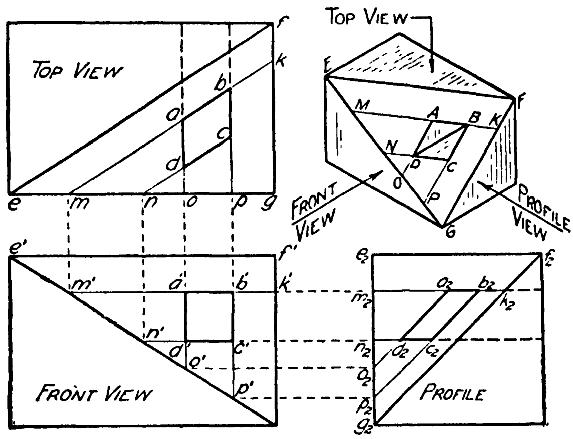


FIG. 15. Projections of parallel lines.

planes are intersected by the sloping plane face in parallel lines; hence, the projection of the upper front edge-line, AB, of the hole will be parallel in each view to that of the diagonal intersection line, EF, in the top face. The plan view of this edge-line may be located by extending $a'b'$ until it intersects $g'e'$ at m' which projects to the corresponding position at m on eg in the top view, drawing mk parallel to ef, and then establishing ab, the view sought, by projectors from a' and b', respectively. A similar construction locates the plan view, dc, of the bottom line of the hole. The construction is also worked out for the profile views a_2d_2 and c_2b_2, of the same two faces.

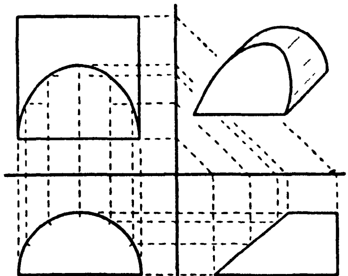


FIG. 16. Projections of curved lines.

81. PROJECTION OF CURVED LINES. — Thus far we have dealt only with straight-line projections which are always determined in one of two ways, either by means of two points or by one point and a specified direction. Curved lines, however, cannot be so projected. A sufficient number of points must be located in each view of the curve to enable the draftsman to draw a smooth curve through them. The points must be sufficiently close together to determine the direction of the curved projection at any place. This requires that points be closer together where the curvature is changing rapidly in the projection, while they may be farther apart in so-called flat curves. Figure 16 illustrates the method of representing a curved line where the top view has been worked out from known front and profile views. The proper method of using the irregular curve in such problems is shown on page 53.

82. PROJECTION OF CURVED SURFACES. — Many objects are bounded by curved surfaces. These consist for the most part of portions of cones, cylinders, and spheres, which occur in various combinations with one another and with plane surfaces. A curved surface is represented by the

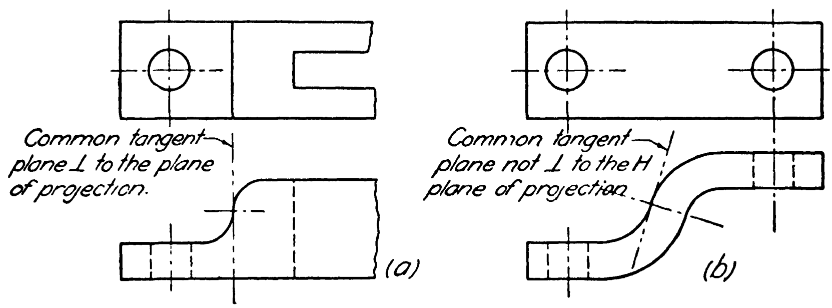


FIG. 17. Projections of intersection of curved surfaces.

projection of its enveloping or contour element in any view, that is, by the projection of the line in the surface to which the so-called lines of sight are tangent. For example, on a sphere the great circle which is parallel to the V-plane forms the enveloping or contour element in the front view.

When combinations of curved surfaces or curved and plane surfaces occur, difficulty is sometimes experienced in determining whether or not to represent their line of intersection in a particular view. In general it may be said that when two parts of a continuous surface are tangent to each other (intersect) in a common tangent plane which is perpendicular to the plane of projection on which the view is to be made, the projection of the line of intersection should be drawn, as shown in Fig. 17*a*. When the tangent plane is at an angle to the plane of projection, no line is to be shown, as illustrated in Fig. 17*b*. The method of obtaining and representing curved lines of intersection of various kinds is treated in Section 2 of Chapter IX. Two other applications of the principles involved are shown in the following paragraphs dealing with fillets and rounded corners.

83. PROJECTION OF FILLETS AND ROUNDED CORNERS. — Figure 18 shows the sectional elevation of a tapering pulley hub with corners rounded or filleted. In drawing the end view, the question arises whether any circles, representing these parts of the hub, may properly be shown.

The rule should be followed in such cases that as long as the surfaces are at right angles to each other, or approximately so, and the corners are rounded simply to add finish, or the standard fillet is used to give added strength, then a circle should be included in the end view representing the circle of intersection before the corner was rounded or the fillet added.

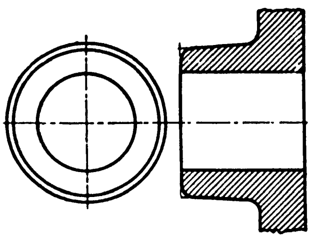


FIG. 18. Projection of small round corners.

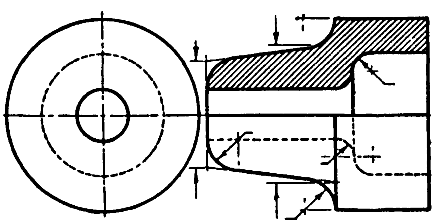


FIG. 19. Projection of large round corners.

The dimension given should be that of the circle of intersection before rounding. The extended lines in Fig. 18 indicate the correct procedure to be followed.

If, however, the rounding of the corner is of large radius and meets the other surfaces in tangential lines, and is done for the purpose of giving stream-line effects to the design rather than simple shop corner finish, then the intersecting circles, if indeed there can be said to be any, should not be shown in the end view. Figure 19 furnishes an example of this kind.

PROBLEMS

84. Among the following fifty or more drawings, there is a series of figures on which significant points have been lettered — *A, B, C, D,* etc., on pictorial drawings, and corresponding small letters where orthographic views are shown. In solving Problems 1 to 16, inclusive, first draw the object in the manner specified and then letter neatly the answer to a sub-requirement assigned from the group below. Arrange the lettering so that the finished drawing sheet is well balanced.

For meaning of sheet size and scale specifications, see Art. 4, page 3.

SUB-REQUIREMENTS FOR PROBLEMS 1 TO 16 INCLUSIVE

a. Describe the positions of the points *C, D, F, H, J,* and *L* relative to point *A*. That is, give the distance each point is above or below, in front or in back of, and to the right or left of point *A*.

b. Describe the position of all lettered lines relative to the H, V, and P coördinate planes, stating the position in terms of parallelism, perpendicularity, or inclination to the planes.

c. Describe the position of the lettered plane faces of the object relative to the H, V, and P coördinate planes, in specific terms such as parallel, perpendicular, or inclined to the planes.

d. List all lettered lines which are perpendicular to H, V, or P, respectively, in groups.

e. List all lettered lines which are parallel to each other, in groups.

f. List all intersecting lines which are perpendicular to each other, in pairs.

g. List all lines which are parallel to H, V, or P, in groups.

NOTE: In all problems above, list the points, lines, and planes in alphabetical order, so far as possible, unless otherwise specified.

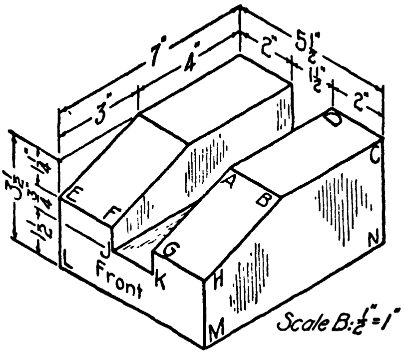


FIG. 20. Cut block.

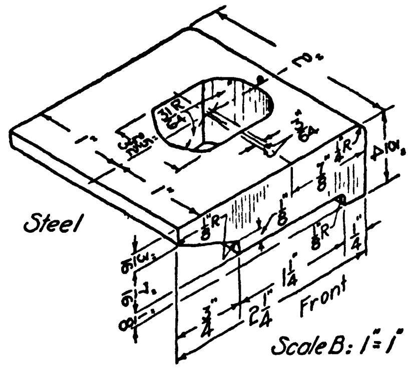


FIG. 21. Rail clip.

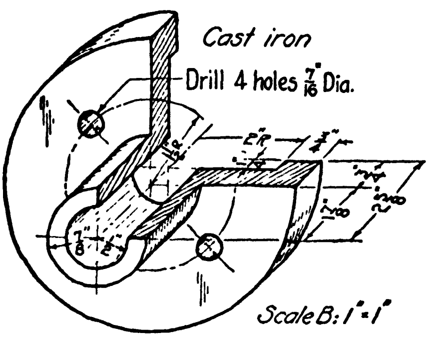


FIG. 22. Cylinder end.

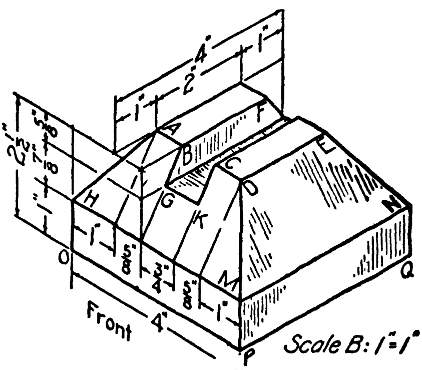


FIG. 23. Cut block.

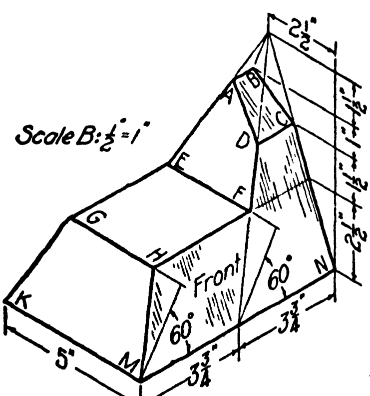


FIG. 24. Cut block.

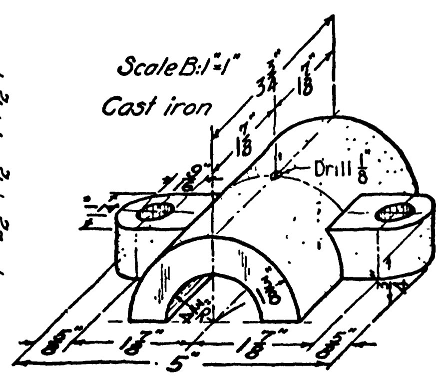


FIG. 25. Bearing cap.

1. Make a two-view lettered undimensioned orthographic drawing of the object in Fig. 20. Do sub-requirement *a*, *b*, *c*, . . . *g*, as assigned.

2. Same as Prob. 1, Fig. 23.

3. Same as Prob. 1, Fig. 24.

4. Make an undimensioned front and top view of the object represented in Fig. 21.

5. Same as Prob. 4, Fig. 22.

6. Same as Prob. 4, Fig. 23.

7. Same as Prob. 4, Fig. 24.

8. Same as Prob. 5, Fig. 25.

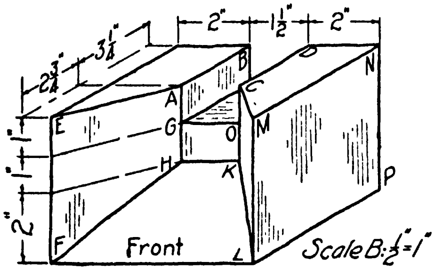


FIG. 26. Cut block.

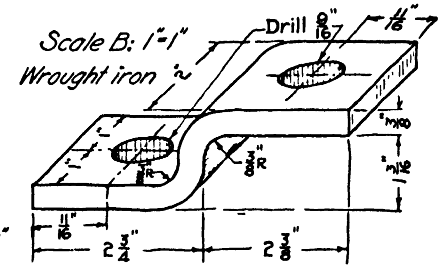


FIG. 27. Offset strap.

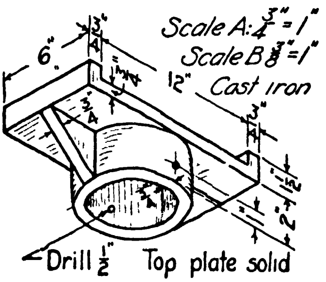


FIG. 28. Post cap.

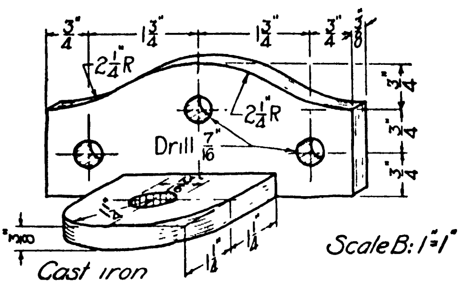


FIG. 29. Bracket.

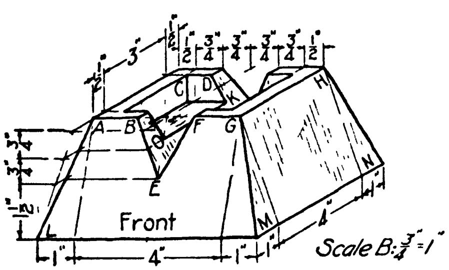


FIG. 30. Cut block.

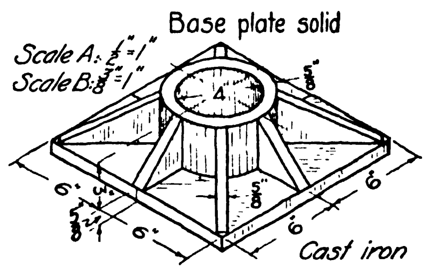


FIG. 31. Column base.

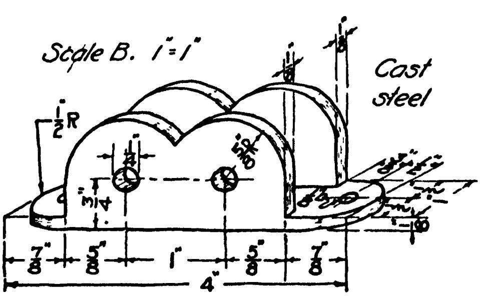


FIG. 32. Sharpener frame.

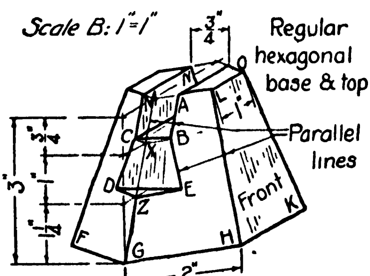


FIG. 33. Cut block.

9. Make an undimensioned front and top view of the object represented in Fig. 26.
10. Same as Prob. 9, Fig. 27.
11. Same as Prob. 9, Fig. 28.
12. Same as Prob. 9, Fig. 29.
13. Same as Prob. 9, Fig. 30.
14. Same as Prob. 9, Fig. 31.
15. Same as Prob. 9, Fig. 32.
16. Same as Prob. 9, Fig. 33.

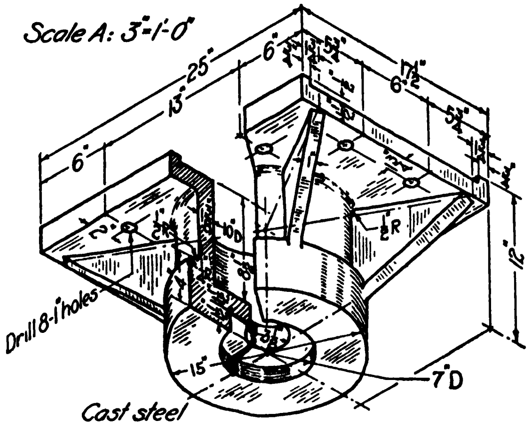


FIG. 34. Truck center bearing.

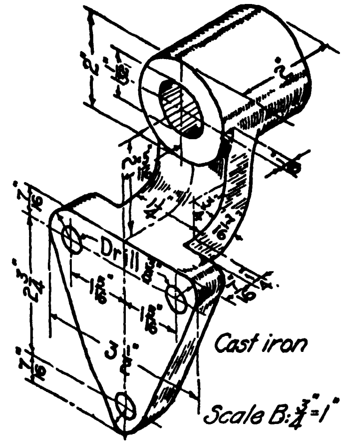


FIG. 35. Offset bearing.

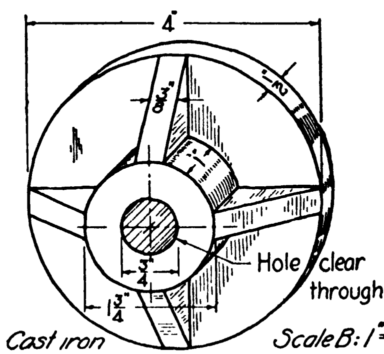


FIG. 36. Washer.

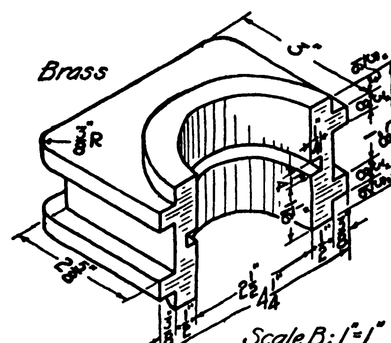


FIG. 37. Bearing brass.

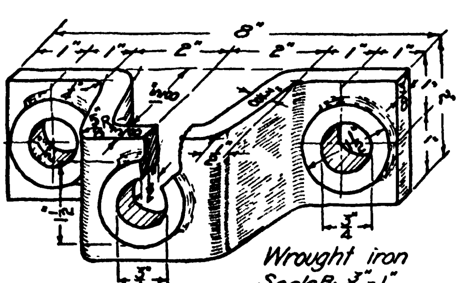


FIG. 38. Rocker arm bracket.

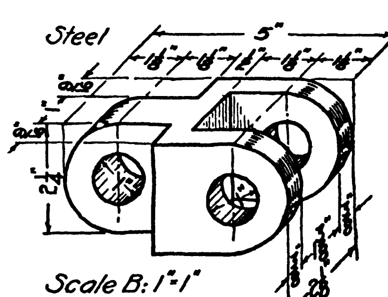


FIG. 39. Link.

17. Make a front and top view of the object shown in Fig. 34.
18. Same as Prob. 17, Fig. 37.
19. Same as Prob. 17, Fig. 38.
20. Same as Prob. 17, Fig. 39.
21. Make a front and side view of the object shown in Fig. 35.
22. Same as Prob. 21, Fig. 36.

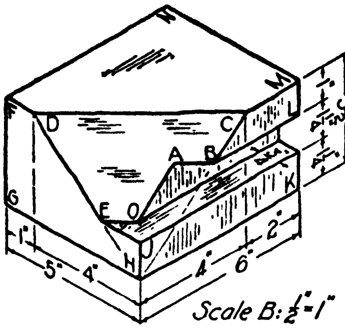


FIG. 40. Cut block.

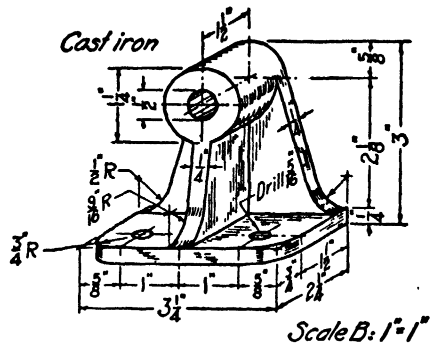


FIG. 41. Bearing bracket.

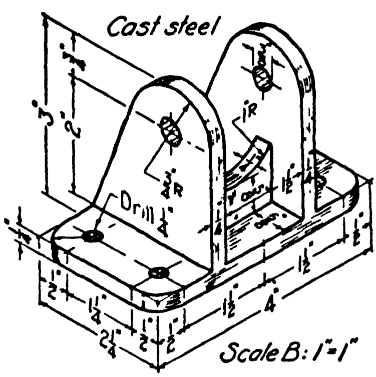


FIG. 42. Eccentric bracket.

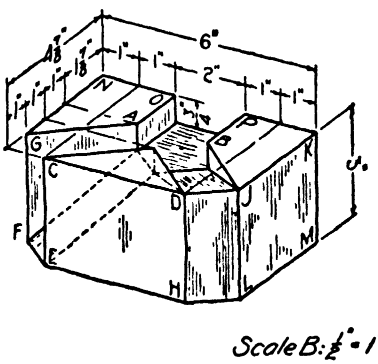


FIG. 43. Cut block.

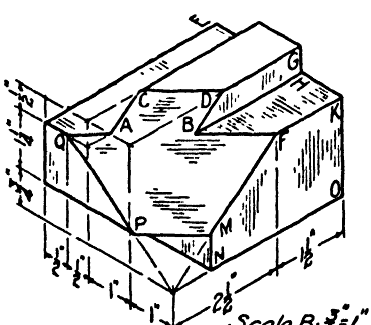


FIG. 44. Cut block.

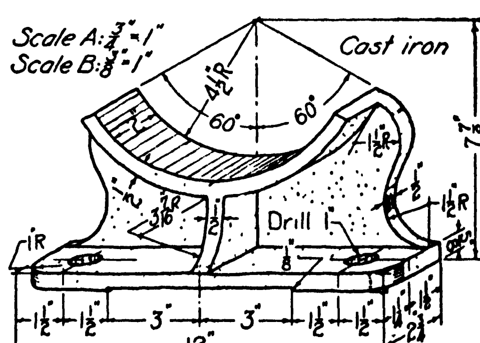


FIG. 45. Conveyor saddle.

23. Make a three-view lettered undimensioned orthographic drawing of the object in Fig. 40. Do sub-requirement *a*, *b*, *c*, . . . *g*, as assigned.

24. Same as Prob. 23, Fig. 43. **25.** Same as Prob. 23, Fig. 44.

26. Make a three-view drawing of the object shown in Fig. 41.

27. Same as Prob. 26, Fig. 42. **28.** Same as Prob. 26, Fig. 45.

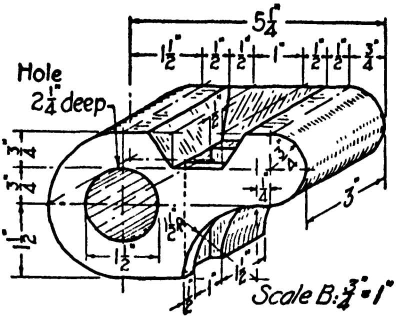


Fig. 46. Cut block.

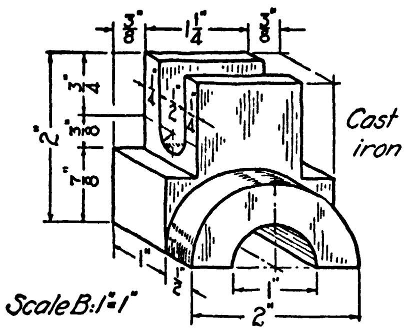


Fig. 47. Carrier bearing cap.

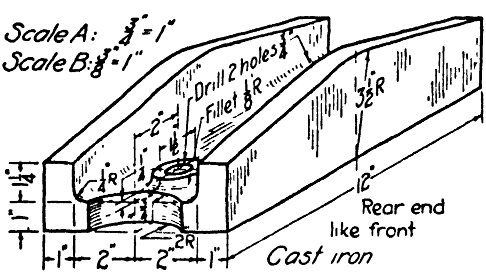


Fig. 48. Crusher bearing end stay.

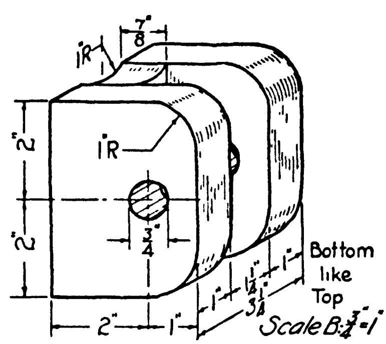


Fig. 49. Cut block.

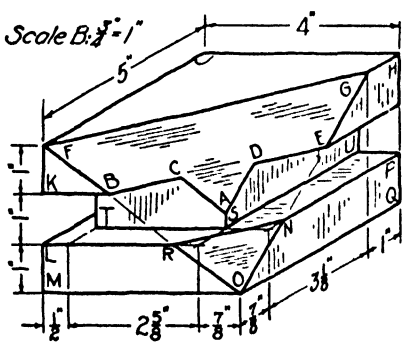


Fig. 50. Cut block.

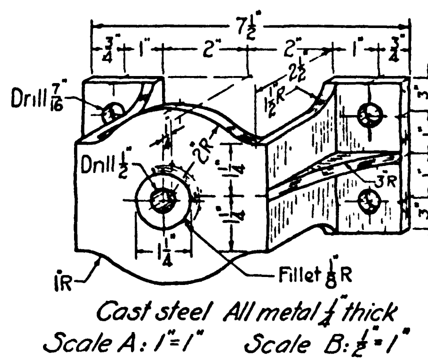


Fig. 51. Swivel bracket.

29. Make a three-view drawing of the object shown in Fig. 46.

30. Same as Prob. 29, Fig. 47.

31. Same as Prob. 29, Fig. 48.

32. Same as Prob. 29, Fig. 49.

33. Same as Prob. 29, Fig. 51.

34. Make a three-view lettered undimensioned orthographic drawing of the object in Fig. 50. Do sub-requirement *a*, *b*, *c*, . . . *g*, as assigned.

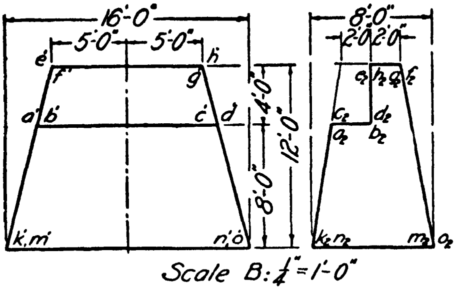


Fig. 52. Bridge abutment.

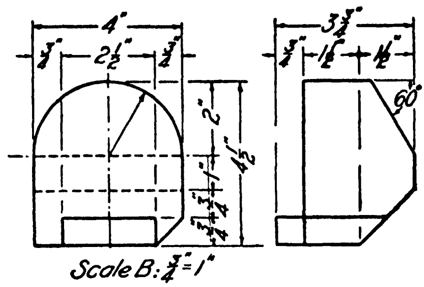


Fig. 53. Cut block.

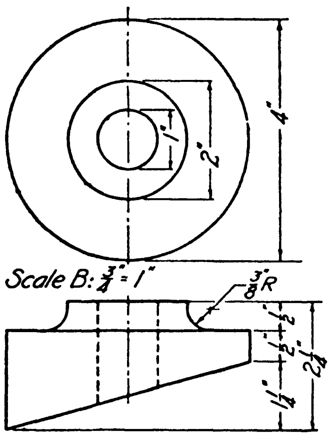


Fig. 54. Bevel washer.

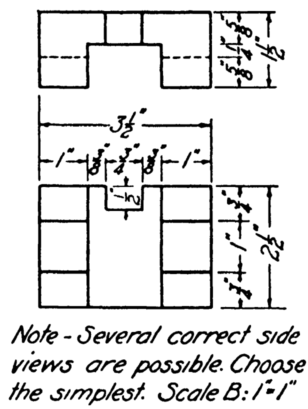


Fig. 55. Cut block.

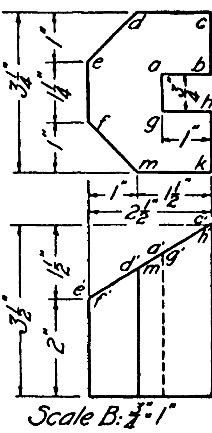


Fig. 56. Cut block.

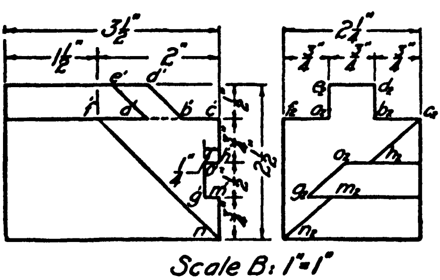


Fig. 57. Cut block.

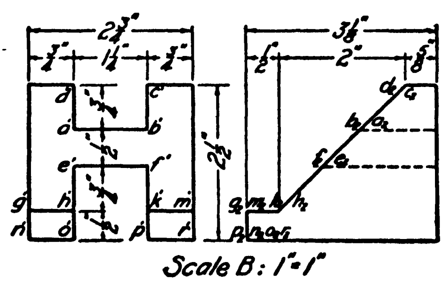


Fig. 58. Cut block.

35. Reproduce the two orthographic views of Fig. 52, lettered but undimensioned, draw a lettered third view, and then do sub-requirement *a*, *b*, *c*, . . . *g*, as assigned.

36. Same as Prob. 35, Fig. 56.

37. Same as Prob. 35, Fig. 57.

38. Same as Prob. 35, Fig. 58.

39. Reproduce the two views of the object shown in Fig. 53 and then make a third view.

40. Same as Prob. 39, Fig. 54.

41. Same as Prob. 39, Fig. 55.

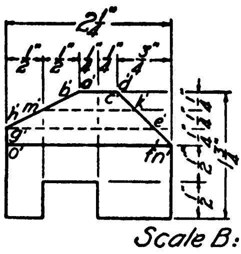


FIG. 59. Cut block.

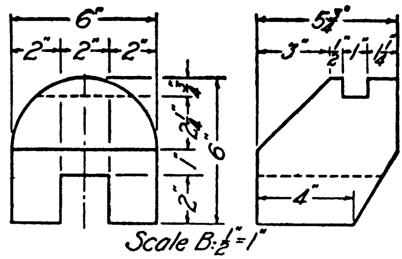


FIG. 60. Cut block.

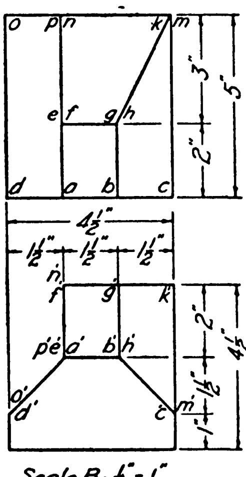


FIG. 61. Cut block.

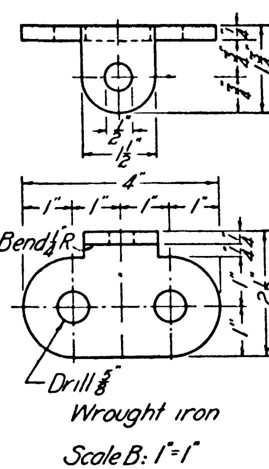


FIG. 62. Chain link attachment.

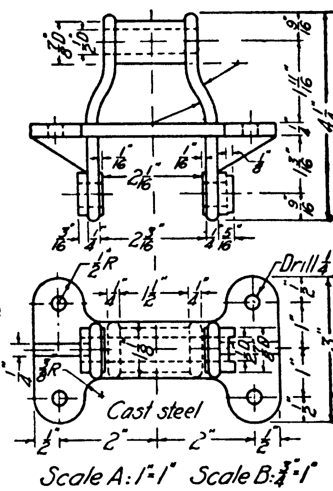


FIG. 63. Chain link flight attachment.

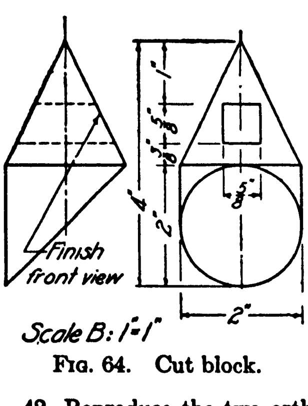


FIG. 64. Cut block.

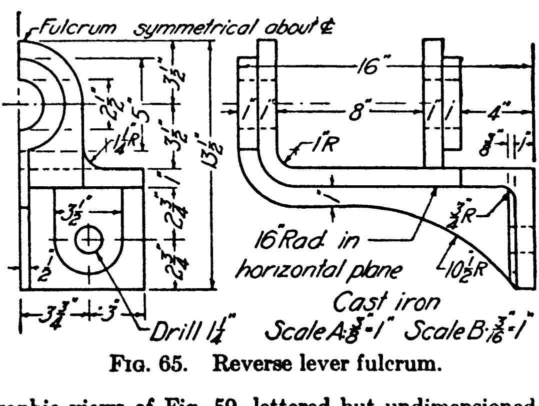


FIG. 65. Reverse lever fulcrum.

42. Reproduce the two orthographic views of Fig. 59, lettered but undimensioned, draw a lettered third view, and then do sub-requirement $a, b, c, \ldots g$, as assigned.

43. Same as Prob. 42, Fig. 61.

44. Reproduce the two views of the object shown in Fig. 60 and then make a third view.

45. Same as Prob. 44, Fig. 62.

46. Same as Prob. 44, Fig. 63.

47. Same as Prob. 44, Fig. 64.

48. Same as Prob. 44, Fig. 65.

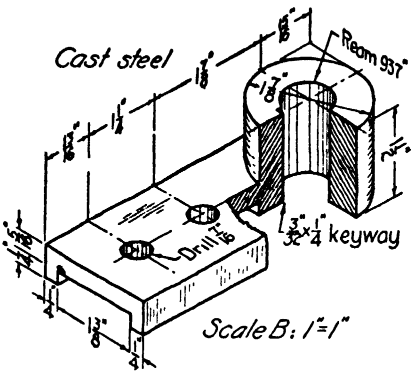


FIG. 66. Connecting rod end.

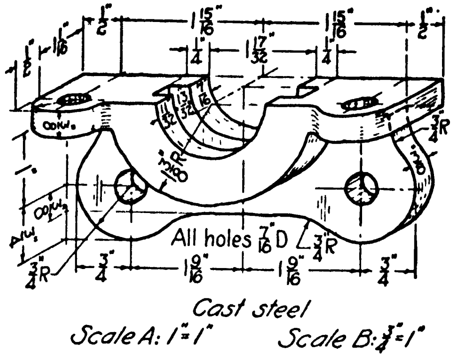


FIG. 67. Swivel sheave base.

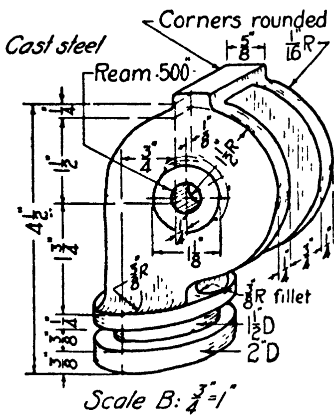


FIG. 68. Sheave holder.

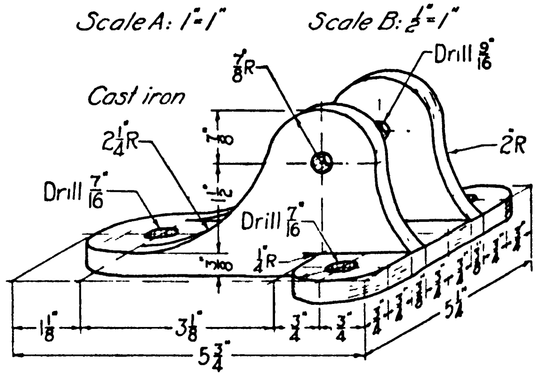


FIG. 69. Bracket.

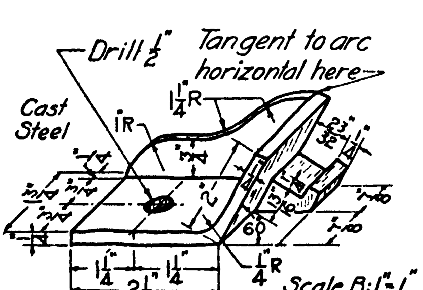


FIG. 70. Swinging draw stop.

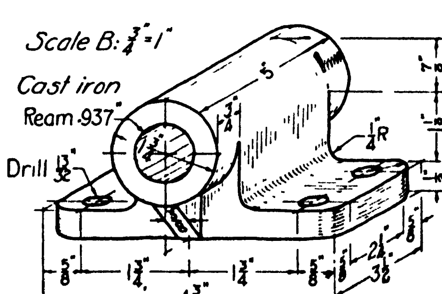


FIG. 71. Pillow block.

49. Make a three-view drawing of the object shown in Fig. 66.
50. Same as Prob. 49, Fig. 67.
51. Same as Prob. 49, Fig. 68.
52. Same as Prob. 49, Fig. 69.
53. Same as Prob. 49, Fig. 70.
54. Same as Prob. 49, Fig. 71.

CHAPTER VI

AUXILIARY PROJECTIONS

85. In the preceding chapter it was observed that one of the types of lines discussed, namely, the inclined line, did not appear in its true length on any of the three principal planes of projection. It was also observed that the true shape of several plane faces of irregular objects was not shown, and that the angles between certain planes and between certain lines were nowhere revealed in their true size on any coördinate plane. All these geometrical factors, namely, the true length of lines, the true shape of plane faces, the angle between plane faces, and the angle between lines, are essential in the actual construction of the objects on which they occur. It is necessary, therefore, to have views on other planes besides the three principal planes. These additional planes of projection are called *Auxiliary Planes.*

86. First Auxiliary Plane. — As a means of simplifying the discussion, the numbering of planes and projections, as given in the preceding chapter, will be extended to the auxiliary planes. Since the H-, V-, and P-planes are marked *0*, *1*, and *2*, respectively, the first auxiliary plane will be numbered *3*. When this plane is set perpendicular to the H-plane, the intersection of these two planes, or ground line as it is called, will be marked with the numbers of the two planes, *0* and *3*, as shown in Fig. 1. If the auxiliary plane were set perpendicular to the V-plane, the ground line would be marked with the numbers *1* and *3*.

The lettered projections of points are marked with a subscript according to the number of the plane on which they lie — *0* or no subscript for H, *1* or a prime marking for V, *2* for P, and *3* for the first auxiliary, as illustrated in Fig. 1.

87. Position of Auxiliary Plane. — In order that the construction of projections upon these first auxiliary planes be simply and rapidly done, they are always set *perpendicular to one of the principal planes of projection.* This arrangement makes it possible to follow all the rules of projection which apply to the principal planes. In order to make the auxiliary projections useful, the planes must also have definite positions relative to some line or face of the object. These positions relative to the object will be discussed in turn in connection with the following stated problems.

88. True Length of a Line. — When a line is parallel to one of the principal coördinate planes, its projection on that plane represents the true length of the line. When a line is inclined to all three planes, its true length does not show on any of the planes. Obviously, then, if a line is not parallel to one of the principal planes, and its true length is required, this may be obtained by setting an auxiliary plane *parallel to the line* and projecting the line upon the plane. In Fig. 1, for example, the true length of the sloping line AB can be found by setting the plane 3 parallel to AB.

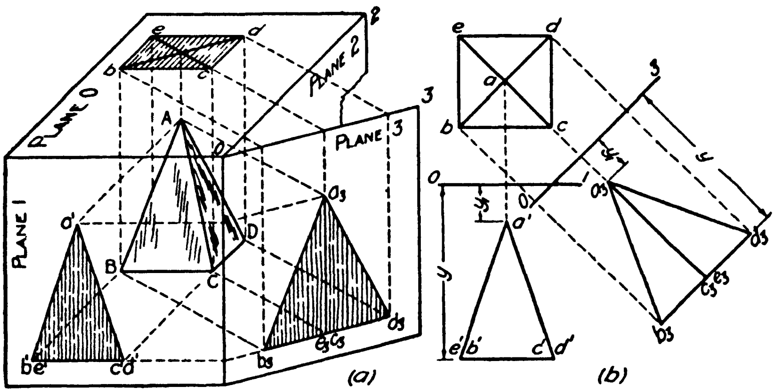


FIG. 1. True length of a line (auxiliary plane method).

This is accomplished by making *0–3* parallel to ab. It will be noticed that since the 3-plane is perpendicular to H, just as is the V-plane, the projections of all points of the line on plane 3 will be just as far from H as the projections of the same points on plane V are from H. Hence, in constructing the auxiliary view of the line, it is only necessary to erect perpendiculars to the *0–3* ground line from a and b and measure off on them from *0–3* the respective distances of a' and b' from the *0–1* ground line. These two distances, y and y_1, represent the same things in both views, namely, the distances of the points A and B below the H-plane, respectively. The projection a_3b_3 is the true length of line AB. If the true length of AB only were needed, it would not have been necessary to draw the plane 3 view of the remainder of the pyramid. It should be observed that a_3d_3 shows the length of AD in this view, since plane 3 is also parallel to AD. The true length of AB could also have been found by setting the auxiliary plane 3 perpendicular to V. In this case the ground line would have been drawn parallel to $a'b'$ and numbered *1–3*.

The true length of AB can be found by another method which is sometimes more convenient than the auxiliary projection scheme. Instead of setting a plane parallel to AB, as in Fig. 1, the line AB may be revolved until it is parallel to a coördinate plane, for example, the V-plane (H projection parallel to the horizontal ground line) as shown in Fig. 2, in which position it will project on V in its true length. The axis of rotation is always a projecting line, or projector, of one end of the line. In Fig. 2 the axis of rotation is the projector of the end *A* that is perpendicular to the H-plane. When the line is revolved about this vertical axis, the point *B* simply moves in a circle in a horizontal plane. The desired position of *AB* is attained when *B* is at its extreme right or left movement as indicated by the revolved horizontal projection. The projection $a'b'_r$ is the true length of the line.

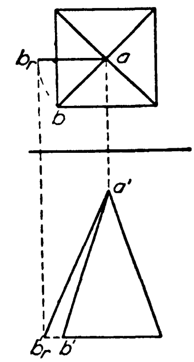


FIG. 2. True length of a line (rotational method).

89. True Shape of a Plane Face. — None of the faces of the pyramid in Fig. 1 except the base is shown in its true shape since none is parallel to any of the principal planes of projection. The faces *ABE* and *ACD*, however, appear edgewise in the front view; hence it will be possible to set an auxiliary plane 3 *parallel to each of them in turn*, project the faces upon the planes, and thus get their true shape. For example, the auxiliary plane parallel to the face *ACD* will be perpendicular to the V-plane; hence the ground line will be drawn parallel to $a'c'd'$ and marked *1–3*, as shown in Fig. 3.

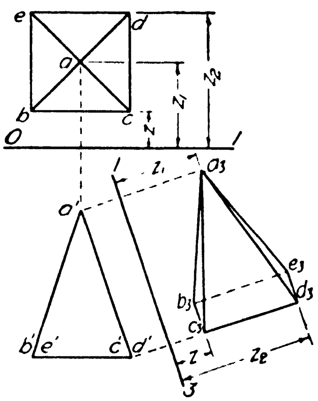


FIG. 3. Shape of a plane face.

The construction then is as follows: Erect perpendiculars from a', c', and d' to the ground line *1–3*. On these perpendiculars measure off from *1–3* distances z, z_1, and z_2 equal to the respective distances of a, c, and d from *0–1*. Connect the points a_3, c_3, and d_3 thus found. The resulting triangle is the true shape of the face *ACD*.

It should be emphasized that an auxiliary plane cannot be set parallel to a face of an object unless that face shows edgewise in one of the principal views. Thus, in Fig. 3, an auxiliary plane cannot be set parallel to faces *ABC* or *AED* without first getting another view of the object which will show these faces edgewise. The profile view would answer the purpose in this case. An edgewise view of a face, however, is not always obtained even with the profile projection shown. A method of obtaining such a view which can be used in any case depends upon the fact that an auxiliary plane 3 may be set up perpendicular to a line and hence perpendicular to any plane containing the line, providing the line is parallel to one of the three principal planes of projection.

90. Auxiliary Plane Perpendicular to a Line. — In Fig. 4 the front view shows the line AB to be parallel to the H-plane. Plane 3 has been set up perpendicular to the line (*0–3* is perpendicular to ab) and at the same time perpendicular to the H-plane, and hence it satisfies the requirement of an auxiliary plane of projection. The projection of the line upon this plane is the point a_3b_3. The construction is obvious from the figure.

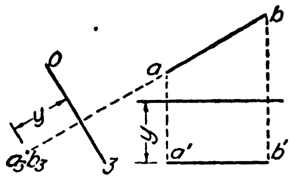


FIG. 4. Auxiliary plane perpendicular to a line.

91. Auxiliary Plane Perpendicular to a Plane Face. — None of the plane faces of the pyramid in Fig. 5, except the base, presents an edgewise view in either the H or V projections. An edgewise view of any face may be readily obtained, however, by drawing a line parallel to the H- or V-plane in the face whose edgewise view is desired, as, for example, line NC in face ACD. Auxiliary plane 3 has been set perpendicular to the line NC, see Fig. 4, and the auxiliary projection, $a_3c_3d_3$, represents an edgewise view of the face because, by plane geometry, we know that if a plane is perpendicular to a line, it is perpendicular to any plane containing the line. The method of construction is obvious.

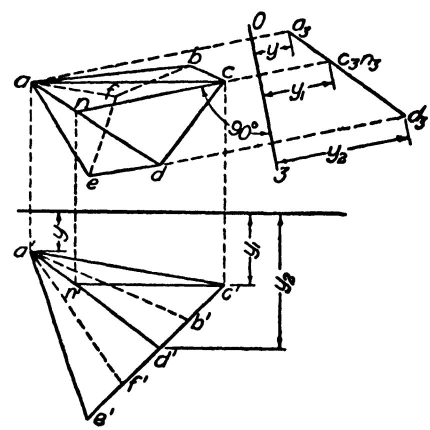


FIG. 5. Auxiliary plane perpendicular to a plane face.

92. SECOND AUXILIARY PLANE. — Having obtained a method of getting an edgewise view of any plane face of an object in any position, see Fig. 5, it now becomes possible to get the true shape of the face by setting up a second auxiliary plane (number 4) parallel to the face and perpendicular to the plane 3 on which the edgewise view appears. The true shape of the face ABF of the object in Fig. 6 is found by this method. The construction is made as follows: Draw a line parallel to the H-plane in the face ABF from the point B terminating it at N on the edge AF of the face ABF. This is done by drawing a horizontal line from b' to n', projecting from n' to af, thus locating n, and drawing nb. Set *0–3* perpendicular to nb at any convenient place. Obtain the auxiliary projection $a_3b_3f_3$ in the usual way. This is the edgewise view of ABF which appears, of course, as a straight line. Set the auxiliary plane 4 parallel to the face ABF by drawing its ground line, *3–4*, parallel to $a_3b_3f_3$ at a convenient place. Erect perpendiculars from a_3, b_3, and f_3 to the *3–4* ground line and measure off distances equal respectively to the distances of *a*, *b*, and *f* from *0–3*. The reason for this equality of distances from the two ground lines lies in the fact that plane 3 is perpendicular to both the H-plane and plane 4, and hence the distances represent the same thing, namely, the distances the actual points *A*, *B*, and *F* are from plane 3. The view thus obtained gives the true shape of the face *ABF*.

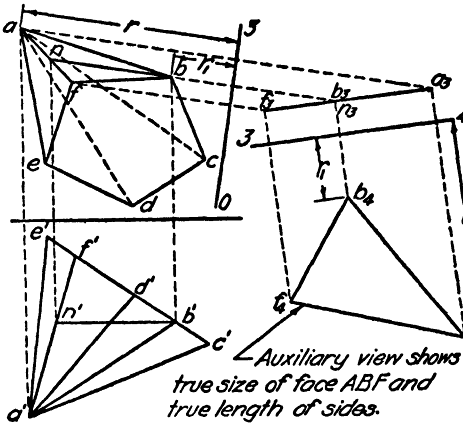


FIG. 6. Second auxiliary plane view.

It should be emphasized that second auxiliary planes, or planes numbered 4, are always set up perpendicular to auxiliary planes numbered 3 and not to the principal planes.

93. TRUE SIZE OF ANGLE BETWEEN PLANES. — To find the angle between two planes, such as *AEB* and *AED* in Fig. 7, it is only necessary to get an endwise view of the line of intersection *AE* of the two planes, because this view will also show both planes edgewise and hence the true value of the angle between them. To obtain an endwise view of a line requires simply that the line be projected upon a plane perpendicular to it. In order to set an auxiliary plane perpendicular to a line, the line must first be parallel to a plane of projection. Since the line *AE* is not parallel to H, V, or P, it will be necessary first to set an auxiliary plane parallel to the line (*0–3* parallel to *ae*) and get the auxiliary view. Now, since the line is parallel to the plane 3, the second auxiliary plane may be placed perpendicular to the line and to the plane 3 at the same time, as is shown by *3–4* being

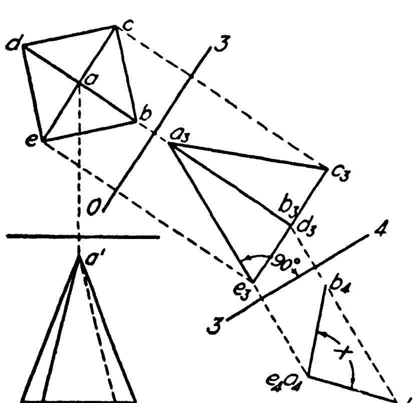


FIG. 7. Angle between planes.

perpendicular to a_3e_3 in the figure. The plane 4 auxiliary views are made in the manner described in the preceding article and show the angle X between the two planes in question.

94. Construction of Principle Views By Means of Auxiliary Projections. — Let it be required to find the top and front views of a right pentagonal pyramid whose axis is the line AB in Fig. 8. The point A is the apex and B is the center of the base. The point C is one of the corners of the base. The projections ab, $a'b'$, c, and c' are given.

Since the pyramid is a right pyramid the plane of the base is perpendicular to the line AB, and, therefore, an auxiliary view on a plane perpendicu-

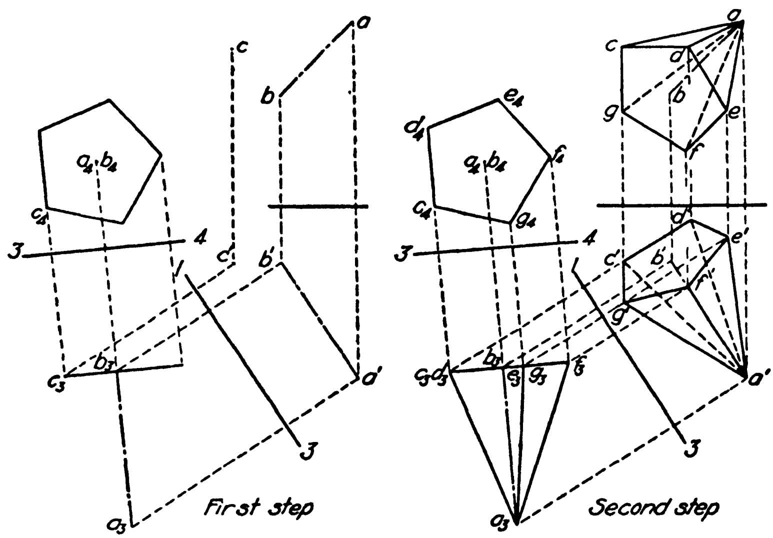


Fig. 8. Construction of principal views from auxiliary views.

lar to the line AB will show the true shape of the base. The first step, then, will be to get an endwise view of the line AB by means of two auxiliary planes, the first of which is set parallel to AB as shown by the ground line *1–3* with the resulting projections a_3, b_3, and c_3. The second auxiliary plane is set up perpendicular to AB as shown by the ground line *3–4*. The projections of the axis AB and the point C on this plane appear as a_4b_4 and c_4. With b_4 as a center, a circle may be drawn passing through c_4 and the plane 4 projection of the pentagon constructed. The pentagon will then be projected back to plane 3 where it shows edgewise as one straight line. From this view the points can be projected back to the front view and then to the top view by simply reversing the order of projection and measurement used in finding a_4, b_4, and c_4. For the sake of clarity, these constructions are shown in the portion of the figure marked

"Second Step." These latter projections joined to the corresponding projections of the apex give the two principal views desired.

95. Eliminating the Ground Lines. — In all the foregoing discussion, the planes of projection have been used as reference planes from

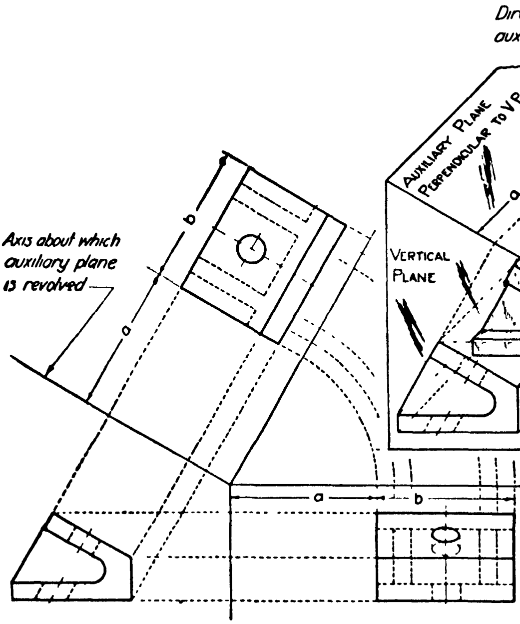


Fig. 9. Projection on one auxiliary plane.

which measurements were made in constructing the various views. This, of course, requires the use of ground lines which frequently cause the views to be placed unnecessarily far apart. In order to avoid this difficulty, *planes of symmetry in the object or plane faces of the object* may be used as planes of reference. The only condition to be met is that these planes shall be parallel to the auxiliary planes which would have been used had ground lines been drawn. Their representations on the drawing are, of course, straight lines parallel to the ground lines of the

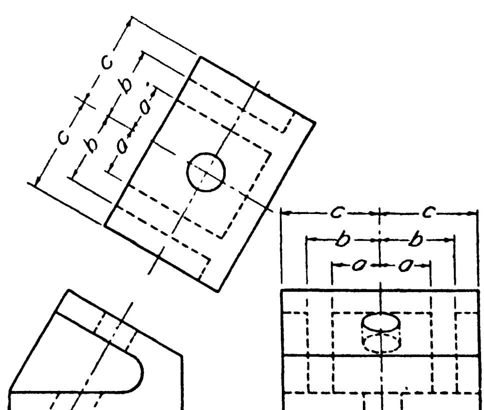


Fig. 10. Views by transfer of measurements.

omitted planes of projection. Figure 9 shows a bevel truss block in pictorial form and in orthographic projection with the customary ground lines. This object has a plane of symmetry which is parallel to the V-plane. In the profile and auxiliary views, this plane is represented by the center lines of the projections. Figure 10 shows a more compact arrangement of the views based upon the use of the plane of symmetry as a plane of reference. The measurements may be transferred by scale or dividers from the profile to the auxiliary view, and vice versa, as indicated in the figure. This form of construction should be carefully studied since it is the way in which the views are usually prepared in making working drawings.

The scheme just explained may be carried out when a second auxiliary plane is required, as illustrated in Figs. 11 and 12. Figure 12 is a redrawing

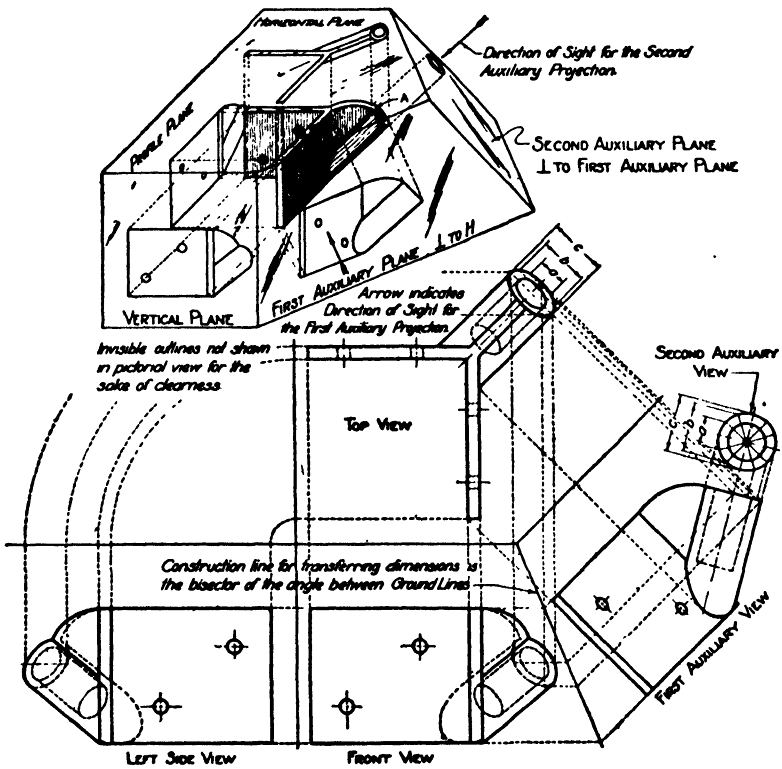


FIG. 11. Projection on two auxiliary planes.

of the orthographic views of Fig. 11 in the way they would be done using center lines to represent planes of reference instead of ground lines. The distances a, b, and c are transferred from the second auxiliary view to the top view by scale or dividers, the central plane of symmetry of the cylindrical portion serving as the plane of reference. This central plane is

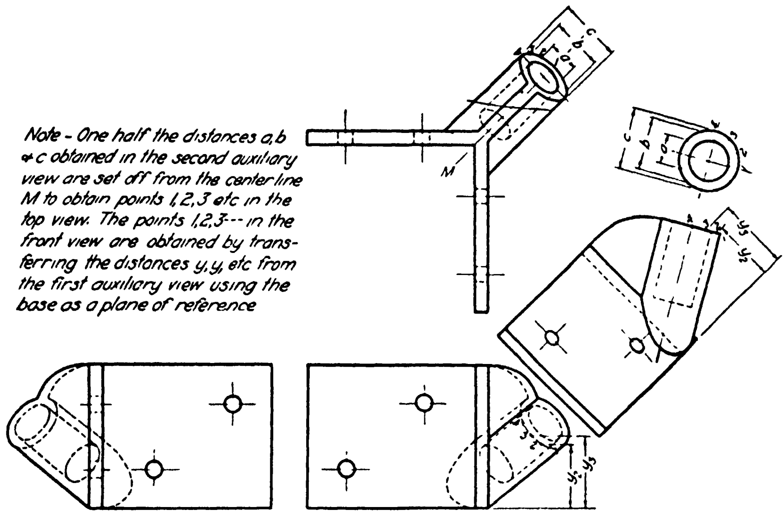


FIG. 12. Compact arrangement of views of Fig. 11.

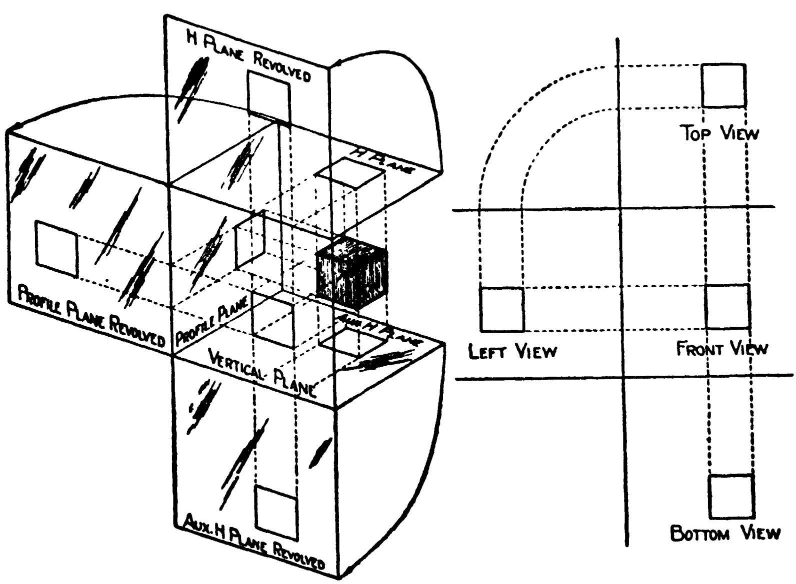


FIG. 13. Bottom view an auxiliary projection.

parallel to the first auxiliary plane 3. Distances are transferred from the first auxiliary view to the front view by scale or dividers instead of by a construction scheme as in Fig. 11 — for example, the heights y_2 and y_3 of points *2* and *3* on the face of the staff holder. In this case the bottom plane of the object, which is parallel to H, serves as the reference plane. Some of the projecting lines are left in the figure as an aid in following out the construction of the views. Such lines are always erased in the finished drawings.

Although the above scheme allows greater freedom in the arrangement of views as regards their distances apart, it must be clearly understood that views on perpendicular planes whose intersection is used as an axis of rotation must still be in projection with each other in exactly the same manner as if ground lines were used. This principle cannot be violated in any way.

It occasionally happens that it is necessary to make a bottom view of an object. This situation may be handled with an auxiliary H-plane by placing it below the object and following the usual rules for projection and rotation. See Fig. 13.

An auxiliary V-plane of projection is likewise employed in making a rear view of an object. The same rules for projection and rotation hold

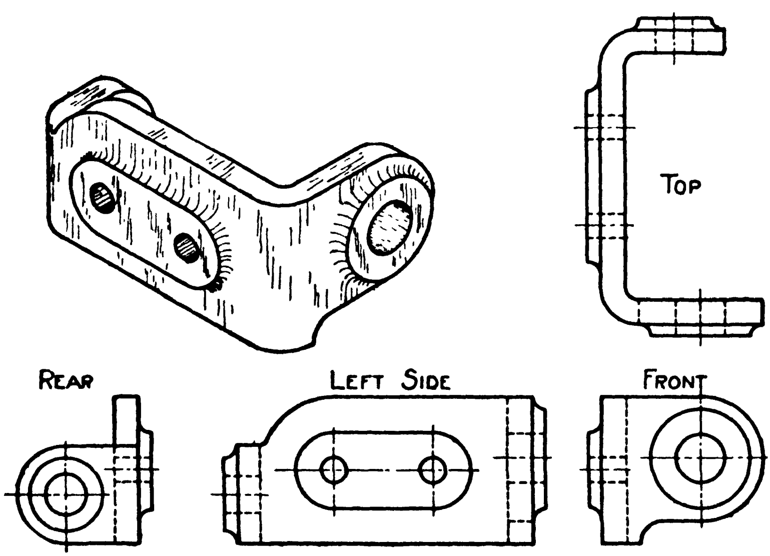


Fig. 14. Correct position of rear view.

as before. A standard arrangement of views is shown in Fig. 14. When space on the drawing paper does not permit the standard arrangement to be followed, or if for other reasons it seems advisable, the planes may be rotated so as to place the rear view above the top view.

PROBLEMS

96. In solving the following problems, it should be remembered that the second auxiliary plane should not be used if the result can be obtained by the use of one plane. Omit dimensions in all cases. For meaning of sheet sizes and scale specifications, see Art. 4, page 3.

1. Reproduce the views of the object represented in Fig. 15 and then find the true shape of the face *ABC* by means of auxiliary projection.
2. Same as Prob. 1, Fig. 16.
3. Same as Prob. 1, Fig. 17.
4. Same as Prob. 1, Fig. 18.
5. Same as Prob. 1, Fig. 19.
6. Same as Prob. 1, Fig. 20.
7. Same as Prob. 1, Fig. 22.
8. Same as Prob. 1, Fig. 23.

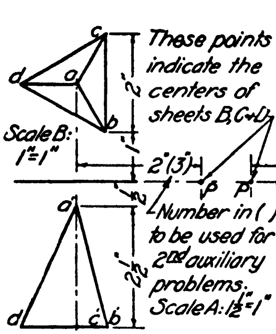


FIG. 15. Tetrahedron.

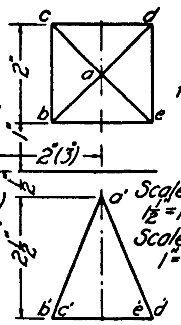


FIG. 16. Pyramid.

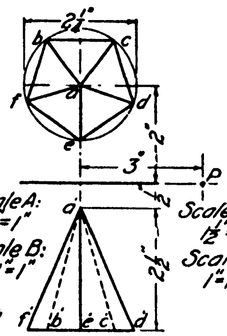


FIG. 17. Pyramid.

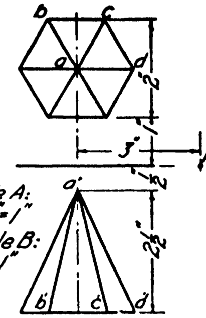


FIG. 18. Pyramid.

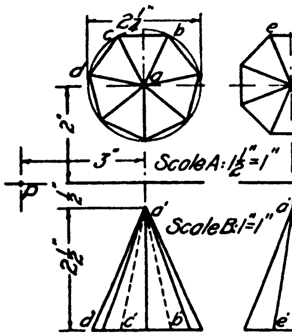


FIG. 19. Pyramid.

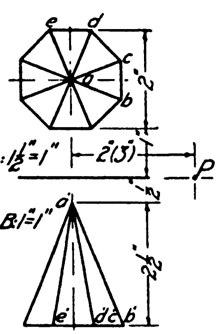


FIG. 20. Pyramid.

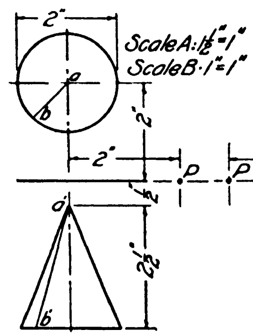


FIG. 21. Cone.

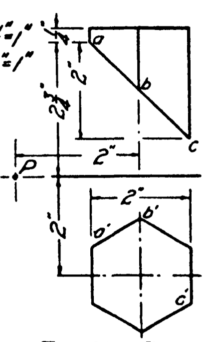


FIG. 22. Prism.

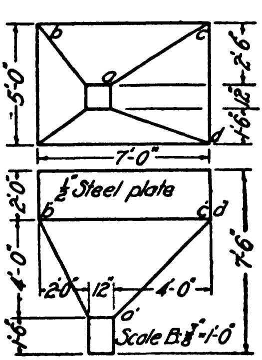


FIG. 23. Steel bin.

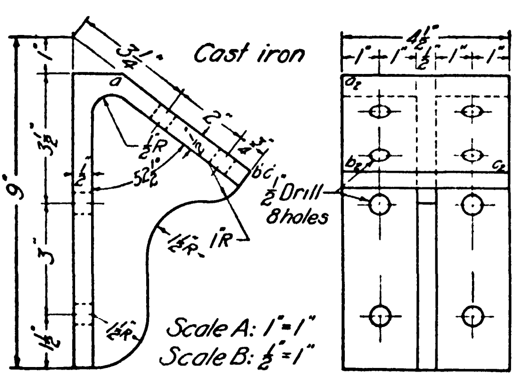


FIG. 24. Angle bracket.

9. Reproduce the views of the object represented in Fig. 15 and then find the true value of the angle between faces *ABC* and *ACD* by means of auxiliary projection.

10. Same as Prob. 9, Fig. 16.

11. Same as Prob. 9, Fig. 17.

12. Same as Prob. 9, Fig. 18.

13. Same as Prob. 9, Fig. 19.

14. Same as Prob. 9, Fig. 20.

15. Reproduce the two views of Fig. 24 and make an auxiliary view showing the true shape of the sloping face.

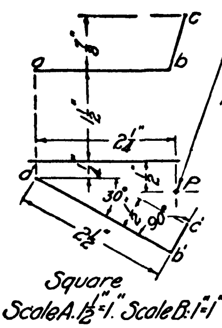


FIG. 25.

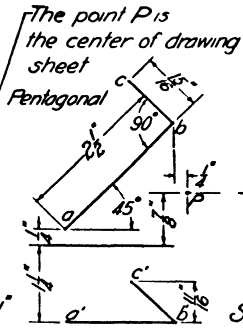


FIG. 26.

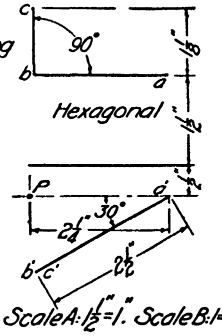


FIG. 27.

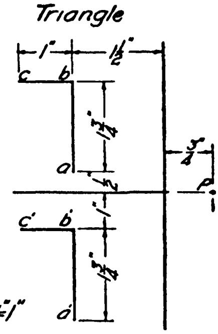


FIG. 28.

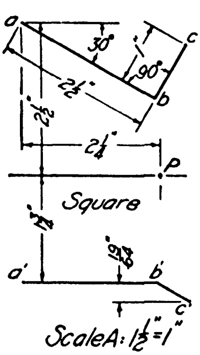


FIG. 29.

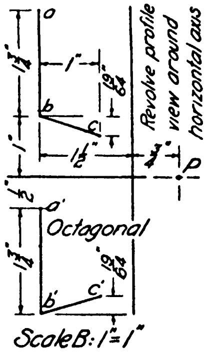


FIG. 30.

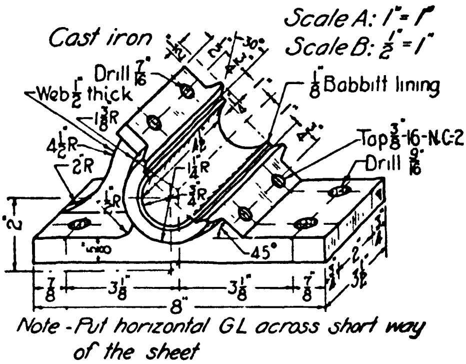


FIG. 31. Angle bearing.

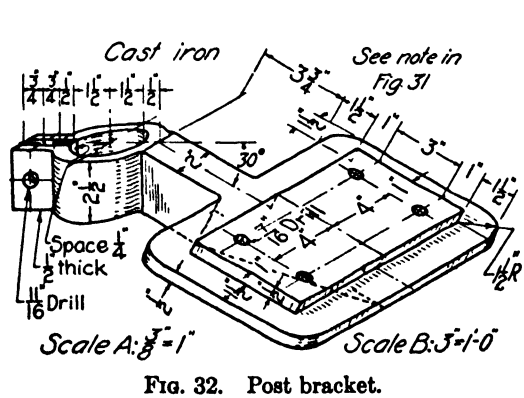


FIG. 32. Post bracket.

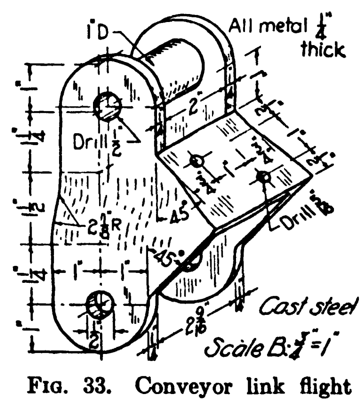


FIG. 33. Conveyor link flight attachment.

16. Construct the pyramid specified on the drawing in Fig. 25. The line AB is the axis of the pyramid and the point C is one corner of the base. Lay out the given lines as shown and then begin the construction in the auxiliary view.

17. Same as Prob. 16, Fig. 26.
18. Same as Prob. 16, Fig. 27.
19. Same as Prob. 16, Fig. 28.
20. Same as Prob. 16, Fig. 29.
21. Same as Prob. 16, Fig. 30.
22. Same as Prob. 16, Fig. 31.
23. Make three views (including auxiliary view) of the object represented in Fig. 31.
24. Same as Prob. 23, Fig. 32.
25. Same as Prob. 23, Fig. 33.

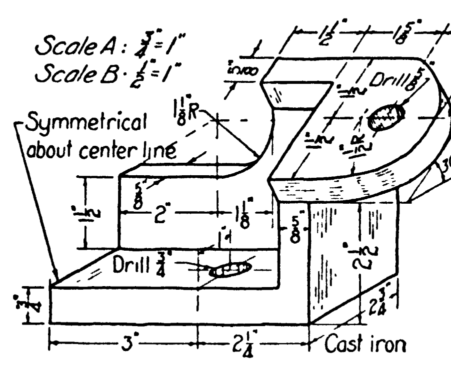


FIG. 34. Sand box step base.

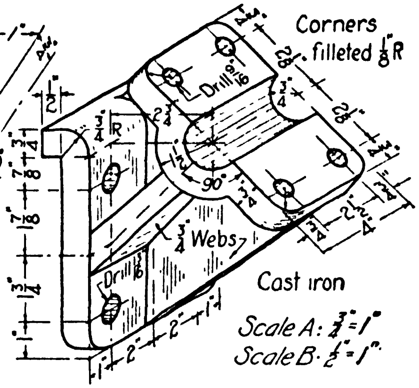


FIG. 35. Angle bearing block.

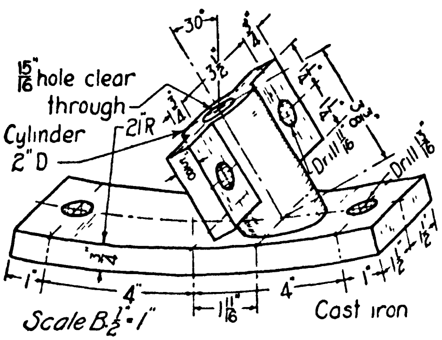


FIG. 36. Damper shaft bearing.

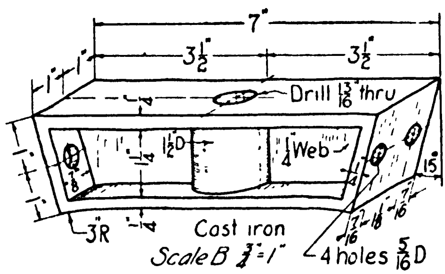


FIG. 37. Conveyor bearing support.

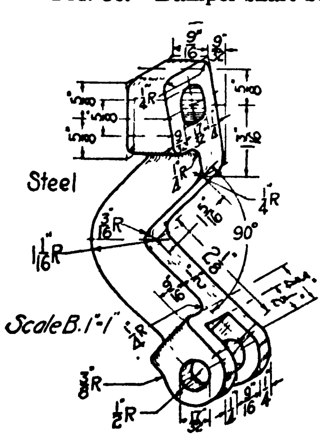


FIG. 38. Valve stem clamp.

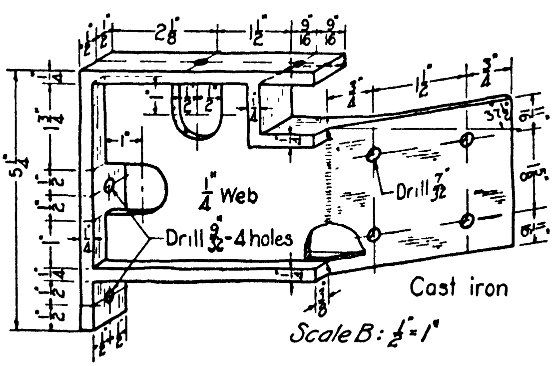


FIG. 39. Door stop bracket.

26. Make the necessary views to completely describe the object represented in Fig. 34.
27. Same as Prob. 26, Fig. 35.
28. Same as Prob. 26, Fig. 36.
29. Same as Prob. 26, Fig. 37.
30. Same as Prob. 26, Fig. 38.
31. Same as Prob. 26, Fig. 39.

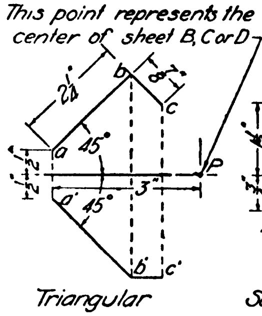


FIG. 40.

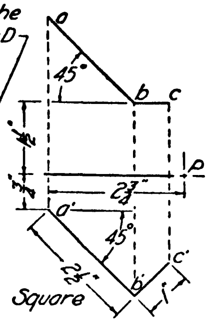


FIG. 41.

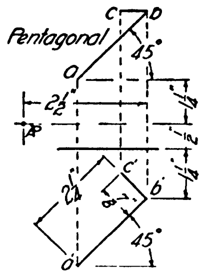


FIG. 42.

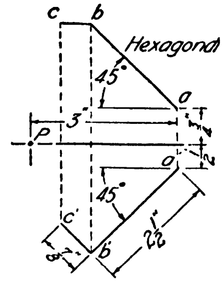


FIG. 43.

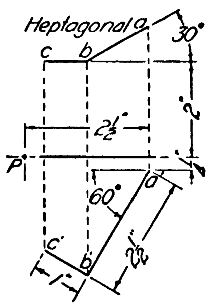


FIG. 44.

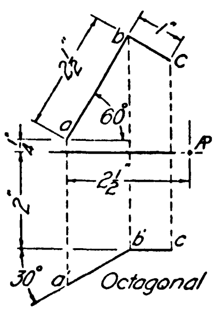


FIG. 45.

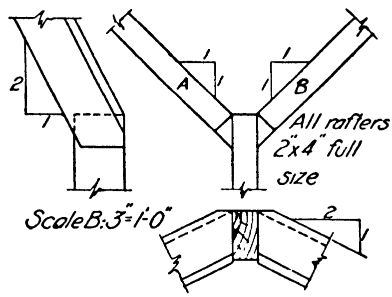


FIG. 46. Ridge and hip rafters.

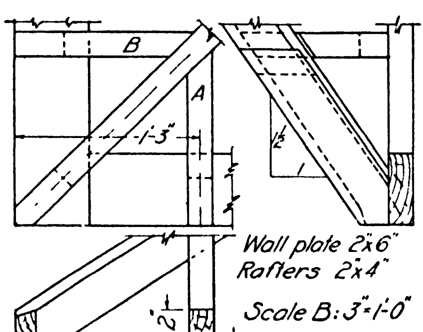


FIG. 47. Hip and jack rafters.

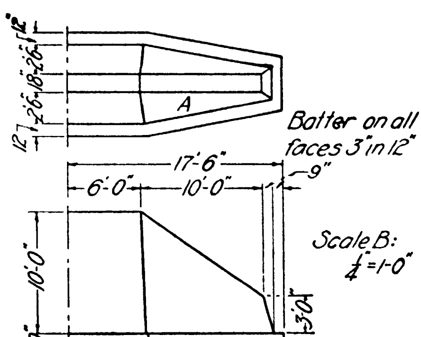


FIG. 48. Abutment and wing wall.

32. Construct the front and top views of the regular pyramid specified on the drawing in Fig. 40. The line AB is the axis of the pyramid, and the point C is one corner of the base. Reproduce the given lines as shown and then begin construction in the second auxiliary view.

33. Same as Prob. 32, Fig. 41.

34. Same as Prob. 32, Fig. 42.

35. Same as Prob. 32, Fig. 43.

36. Same as Prob. 32, Fig. 44.

37. Same as Prob. 32, Fig. 45.

38. Make a layout of the saw cut (direction of line of cutting in each face) in rafter A or B of Fig. 46.

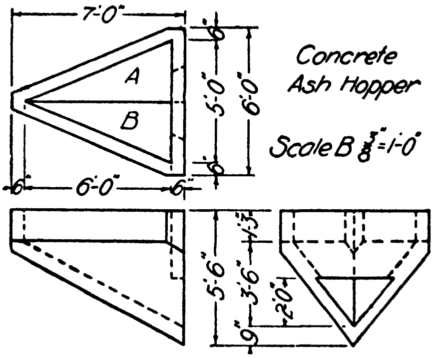


FIG. 49. Ash bin.

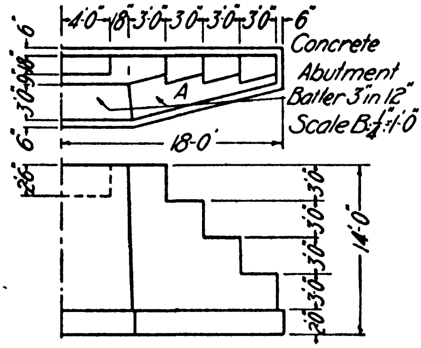


FIG. 50. Abutment and wing wall.

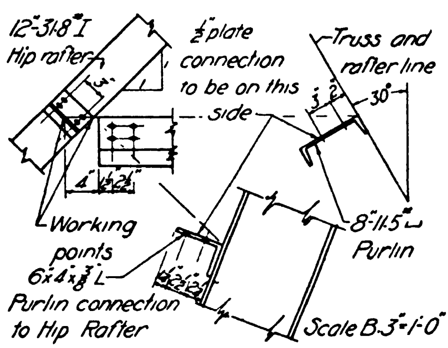


FIG. 51. Roof purlin connection.

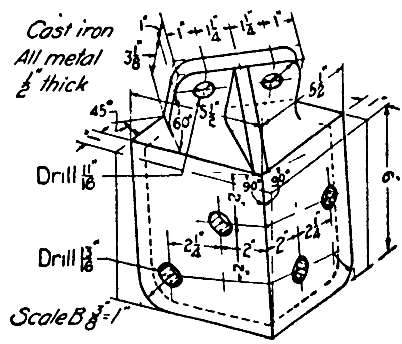


FIG. 52. Corner anchor.

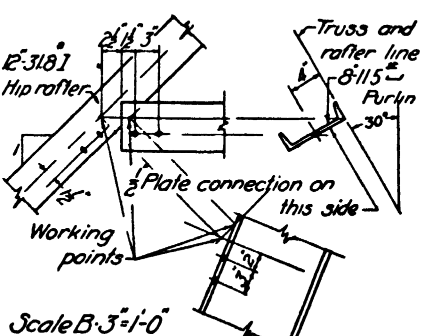


FIG. 53. Roof purlin connection.

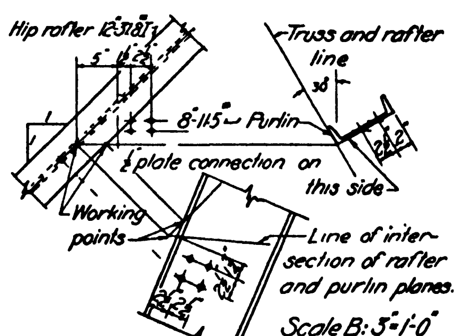


FIG. 54. Roof purlin connection.

39. Make a layout of the saw cut (direction of line of cutting in each face) in rafter *A* or *B* of Fig. 47.

40. Find the true shape of the face *A* of the concrete abutment in Fig. 48.

41. Find the true shape of the face *A* of the object represented in Fig. 49.

42. Find the true shape of the face *A* of the object represented in Fig. 50.

43. Make the necessary drawings to describe the shape of the connecting plate required to connect the purlin and hip rafter of Fig. 51.

44. Same as Prob. 43, Fig. 53.

45. Same as Prob. 43, Fig. 54.

46. Make the necessary orthographic views to describe the object of Fig. 52.

CHAPTER VII

SECTION PLANES AND VIEWS

97. If no further principles of drawing were available, it would often happen that the views obtained upon the planes of projection thus far discussed would be obscure and almost impossible of interpretation because of the excessive number of dash lines on the drawings, resulting from invisible outlines which delineate interior construction. Furthermore, two- and three-view drawings sometimes fail to show the real shape of an object because of the absence of sharp contours on the object itself and a consequent lack of definitive lines in the drawing. This condition generally obtains on castings of beds of machinery, hoods and casings for revolving parts, and other body structure where the stream-line effect is sought in design.

98. Passing Section Planes. — One method of obviating this difficulty is to pass a section plane or set of section planes, in such a way as to cut from the object certain portions which obstruct the view of the interior. One main cutting plane is always passed parallel to a principal plane, and the others, if there be any, are passed either parallel or perpendicular to the first cutting plane. The part of the object included in the angle of these cutting planes is considered as being taken away bodily, although, of course, the whole process is one of the imagination only. The object is then projected in the usual way upon the principal plane to which the one main cutting plane is parallel, with the obstructing part removed. It must be clearly understood that this cutting away of certain parts of an object does not affect the drawing of any other view than the one on the principal plane to which the main cutting plane is parallel. These other views are drawn just as if no section were being cut away at all. Figure 1 illustrates the general plan of passing a set of section planes and of representing the result in one of the main views.

99. Half and Full Sections. — It is the general practice to remove only one-quarter of an object by means of section planes, but often one-half is cut away. These practices have given rise to the terms " quarter section " and " half section " to describe the two procedures, respectively. Much confusion has come about in drafting rooms and textbooks through the use of the words " half section " and " full section " to describe identically the same things as are described by the terms " quarter section " and "half section," respectively. This ambiguity arises from the fact that, in the one instance when the words "quarter" and "half" sections are used, the method of cutting the object is being described, whereas in the other the result or appearance of the drawings is being referred to.

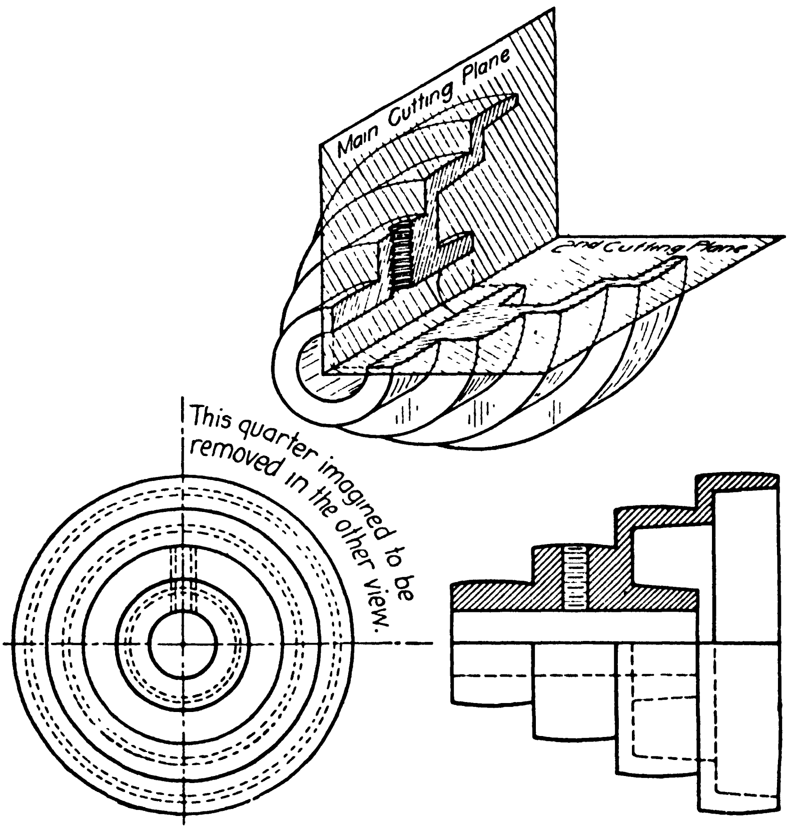


FIG. 1. Method of passing section planes — half section.

The better practice is to use the phrases "half section" and "full section" exclusively, and no departure from this rule occurs in this text. Thus, we should speak of the front view in Fig. 1 as a half section, and the corresponding view in Fig. 4 would be called a full section.

Some draftsmen indicate the position of the cutting plane, or planes, by drawing heavy dash-two-dot lines on an unsectioned view, for both half and full section drawings, just as is done for the "offset" sections of Fig. 5. This practice seems unnecessary, unless the sectioned view is shown out of projection with other views, and is not adhered to in this text, even in the case of rotated sections, as shown in Figs. 14 and 15.

Wherever doubt might arise as to the exact location of the cutting plane, then, of course, the break line should be used.

100. Section Lining. — In order that those parts of an object which have been cut by the main section plane may stand out on the drawing, a conventional scheme called cross-hatching, or section lining, is employed. This consists simply in drawing light, inclined lines on those parts of the view of the object which indicate where the cutting plane actually comes in contact with the material out of which the object is made. The section lines may be drawn at any angle to the horizontal, but 45-degree lines are

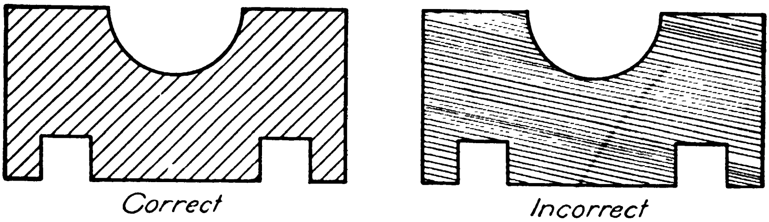


Fig. 2. Examples of good and poor section line spacing.

usually employed. They should be spaced uniformly and slightly less than one-sixteenth inch apart. In weight they should approximate a dimension line, and they should always be drawn completely up to the outlines of the object. Figure 2 shows examples of good and faulty section lining.

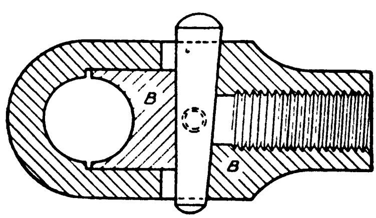


Fig. 3. Correct sectioning.

Where several adjacent parts of a machine are of the same material and are cut by a section plane, each part should be distinguished from its neighbor by a change in slope of the section lining. The more nearly the cross-section lines approximate 90 degrees to each other the better the effect will be. See Fig. 3. If the section plane cuts the same part at different places in the object, the section lining should, of course, be given the same slope in the two corresponding places on the drawing, as shown in Fig. 3.

Often adjacent parts of a machine are made of different materials, such as cast iron for frames with brass linings for bearings and seats. Here, not only should the section lining be changed in slope, but one of two methods should be employed to represent the kind of materials used. If the details of construction are complicated and contrasts on the drawing are desirable, symbolic section lines should be used for each kind of material. A chart of approved section lines for various metals is given in the Appendix. It will be noted that full lines are used for white metals, such as cast iron and steel, and a combination of full and dash lines is used for the yellow metals, such as copper and brass. The name of the metal to be used should always be given, either in the form of an abbreviation printed in an open space left in the section lining for the purpose, or in the form of a note or legend placed outside the views.

A second method, applicable to simple details of construction and drawing, is to use the full-line symbolic sectioning for cast iron, with the abbreviation of the name of the metal inserted in the sectioning, or the name printed outside the views as before.

The authors recommend the use of the second method wherever possible. Figure 4 illustrates both methods. Attention is again called to the requirement that the same slope must be used for section lines on the different parts of the drawing which represent the same piece in a sectioned view. Note the application of this rule in Fig. 4.

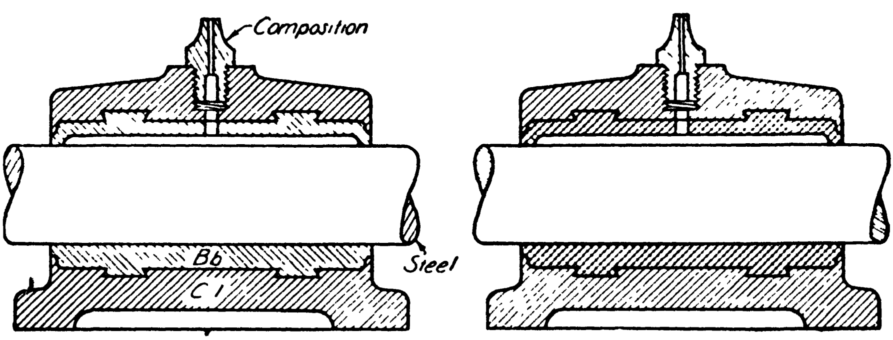


FIG. 4. Two types of section representation.

For wood, stone, and other non-metallic materials used in construction, proper conventions and imitations should be used. A chart of these well-nigh standard forms will be found in the chapter on Architectural Drawing, Part II.

101. HIDDEN LINES IN SECTIONED VIEWS. — It is standard practice not to show broken lines, representing invisible backgrounds of a section, across the section lines themselves. This rule may be violated in extreme cases where the drawing would otherwise be impossible of interpretation, but usually it would be better to draw another view or section.

102. OFFSET SECTIONS. — The cutting planes are almost always passed through axes of symmetry of the object. It may occur that there are several such axes of symmetry not coinciding with a single center axis of the object, in which case the cutting plane is offset, as in Fig. 5, to include both axes and thus serve a double purpose. No particular difficulty is experienced in reading the drawing when this is done; yet it is always best to show the location of the cutting planes by a characteristic line and the direction in which the view is taken by arrows, as is done in Fig. 5.

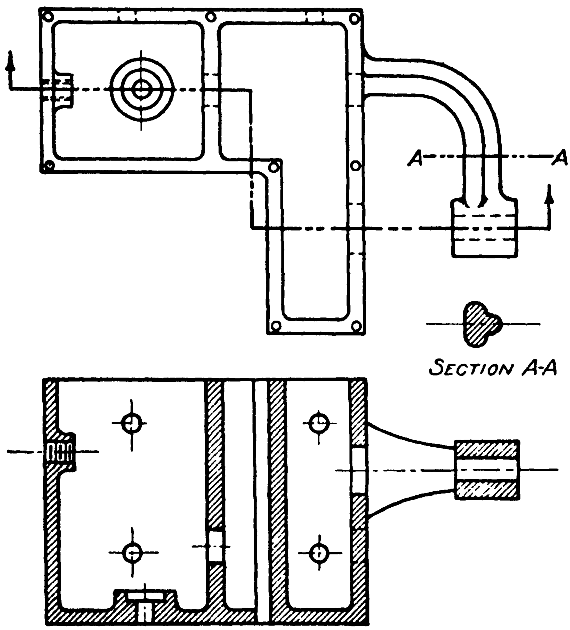


FIG. 5. Offset section planes.

103. REVOLVED, TURNED, OR INTERPOLATED SECTIONS. — In many instances the cross-section of some parts of a machine or structure may best be shown, without the trouble of drawing extra views, by passing a cutting plane perpendicular to one of the planes of projection and revolving the cross-section of the part concerned about an axis of symmetry within the cross-section itself until it is parallel to the principal plane. The revolved section is then projected upon the principal plane, to which it is parallel in the same way as is any other outline in the object.

Figure 6 illustrates the method as applied to cylinders, standard structural shapes, and hollow tubes. Figure 7 illustrates the same scheme applied to spokes of wheels, arms, and braces, in machines and other ribbed members. These revolved views are drawn with the same kind of section lines as are used on regular cross-sections explained above.

The advantages of these kinds of cross-sections are very great, inasmuch as they convey to the mind instantly the shapes of pieces used in the design of any structure, simply from an examination of one view of the object, without the necessity of a study of a second or third projection. Dimensions are frequently placed on such sections, thereby adding to their effectiveness. A slight variation in the method of placing the revolved

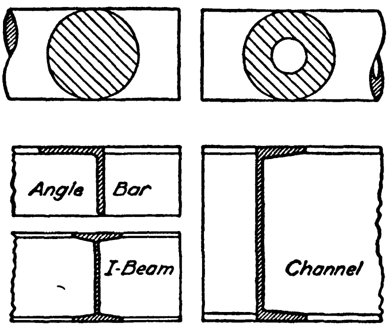


Fig. 6. Revolved sections.

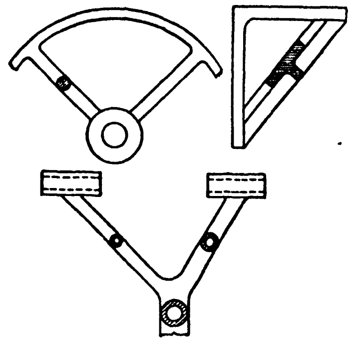


Fig. 7. Revolved sections.

section on the drawing is used by many draftsmen, namely, that of breaking out a portion of the piece being drawn at the point where the section is

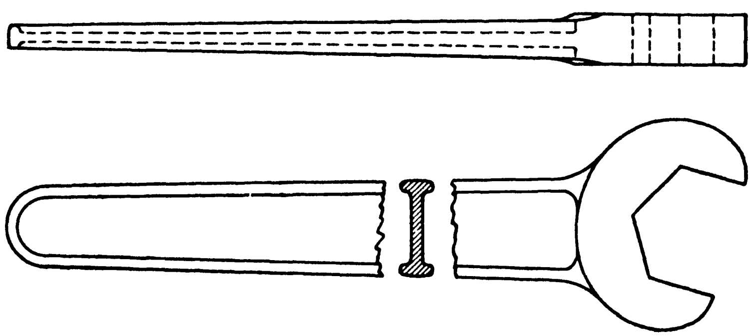


Fig. 8. Revolved section — broken view.

to be taken, and placing the revolved section in this break. Some advantages are obtained in certain instances through the employment of this scheme. Figure 8 shows the arrangement of such views in a drawing.

104. Removed Sectional Views. — In complicated machines and structures, it often occurs that neither of the methods of showing sectional views previously explained is suitable or sufficient, because of the absolute necessity of showing the outside contours of the object with many full lines which must not be complicated by superimposed section lines. The method of overcoming this difficulty is simply to indicate on the principal views, by means of lines and arrows, where section planes have been passed, and then to remove the resulting cross-sectional views to some clear place on the drawing sheet. Figure 9 shows two such views taken at different places on the hook. Each section is " tied up " to the main views by means of such phrases as " Section AA " and " Section BB," etc. Proper notation to correspond to these sections is, of course, placed on the main views as indicated in the figure. Only the outlines actually formed from the parts cut by the plane are shown, except in a few instances where it may be proper to show some of the outlines behind the section taken.

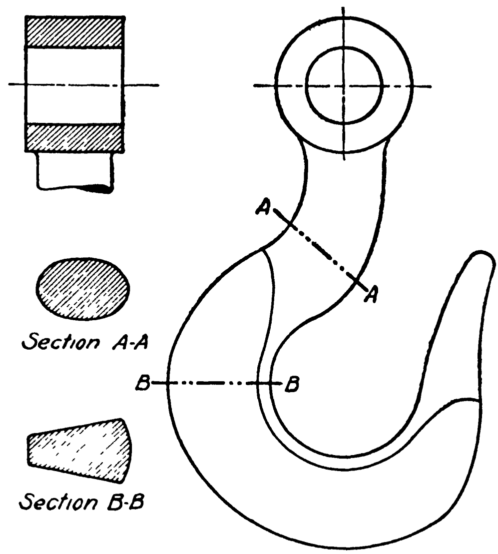


FIG. 9. Removed sectional views.

One of the chief advantages of the above scheme of sectioning lies in the fact that the sectional views may be drawn to a much larger scale than the main views, thus showing the detail more clearly. A second advantage is that the main views showing the general outlines of the object are not confused by a large number of broken lines or cross-section lines. A third advantage may be found in the better balanced drawing sheets, since the cross-sectional views may be moved to any open space on the sheet.

105. BROKEN SECTIONS. — In some instances it will be found that a single interior detail needs to be made clearer than any of the principal views are able to make it, and yet the trouble of using any of the schemes of sectioning thus far described is too great to justify its use in the particular case involved. Resort may be had to still another method of sectioning illustrated in Fig. 10, and called a "broken section." The procedure is clearly presented by the figure.

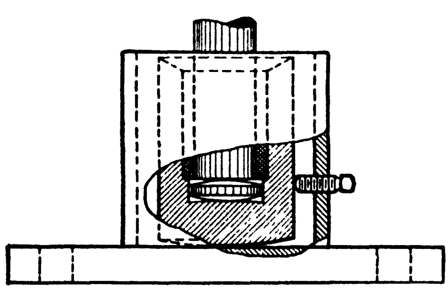


FIG. 10. Broken section.

106. VARIATIONS IN SECTIONING IN COMMERCIAL PRACTICE. — In order to save time in the drafting room and to make the meaning of a

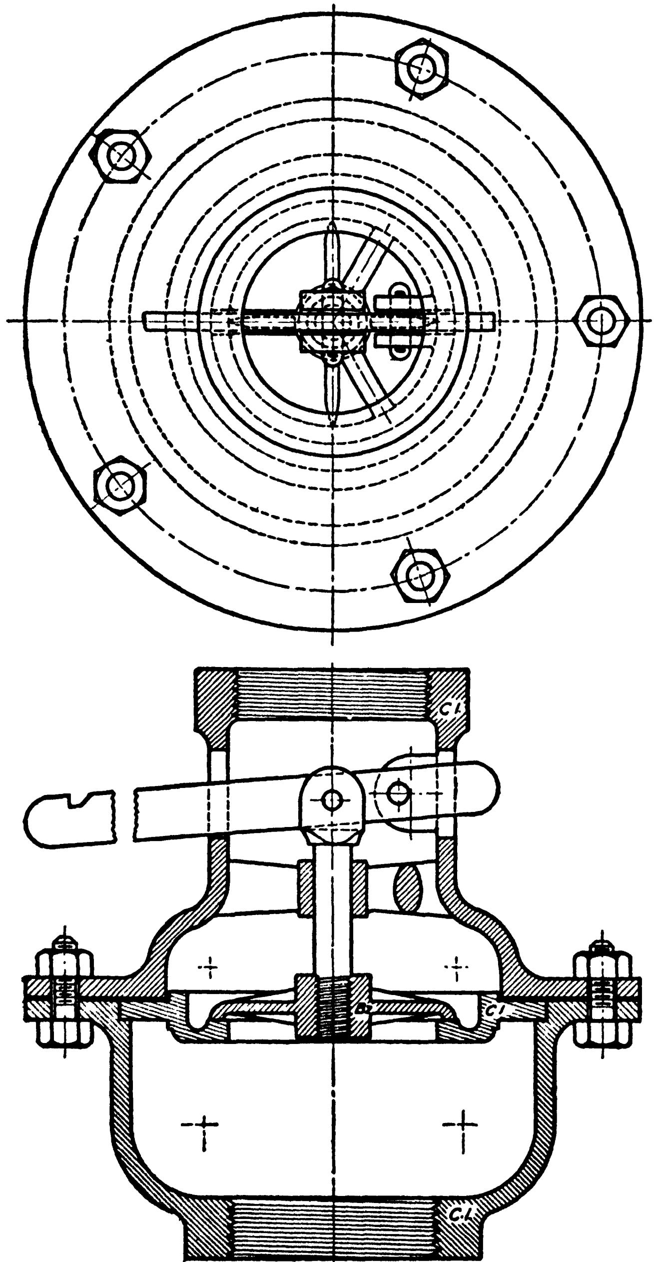


Fig. 11. Conventional variations in sectioning.

drawing more definite, certain variations from the strict theory of projection have become so widely adopted that they are now standard practice. These variations are purely conventional in character and are indicated in the following paragraphs.

107. Solid Shafts and Bars, Bolts, Pins, and Screws. — When the cutting planes pass through the longitudinal axes of solid cylinders such as shafts, bolts, and screws, it is the custom to consider that these parts are not cut by the section plane, because nothing is gained by showing the solid interior of such parts, and a great deal of time is saved by eliminating a large amount of cross-hatching. Figure 11 illustrates a safety valve, the stem, weight bar, bearing arms, and two bolts of which come under this rule.

108. Spokes of Wheels and Thin Webs. — Spokes of wheels are not sectioned even though the cutting plane passes through them. This not only saves time but also gives a method of distinguishing, in the sectioned

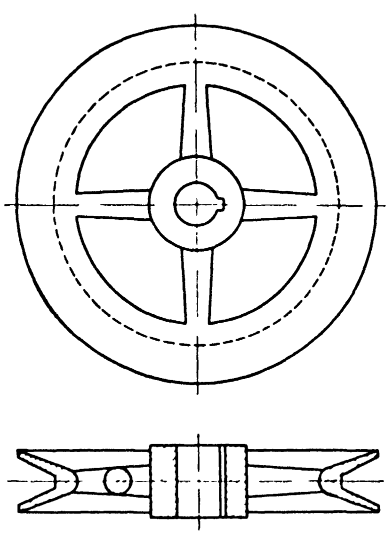


FIG. 12. Section through spokes of wheel.

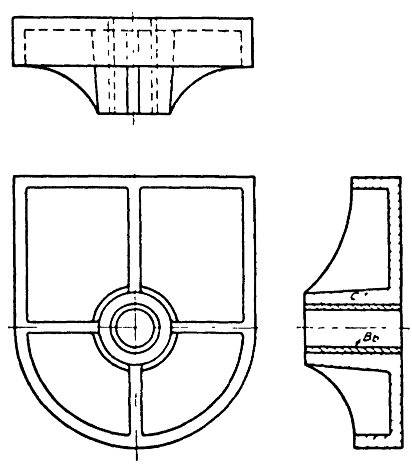


FIG. 13. Section through thin webs.

view, between a wheel with spokes and a wheel with a solid web. Figure 12 illustrates the general practice in the arms of the sheave.

Similar reasoning applies to a thin web when cut by a section plane parallel to the principal face. No section lines are shown. Figure 13 illustrates the accepted practice in the webs of the box end bearing.

109. ROTATION OF PARTS IN SECTIONING. — In passing a section plane through such objects as pulleys with three, five, or some other odd number of spokes, or through webs of couplings with an odd number of drilled holes, and similar objects, only one of the spokes or holes will fall in the plane. A second one will fall immediately behind the plane. It is customary in representing this second one to consider it rotated into the

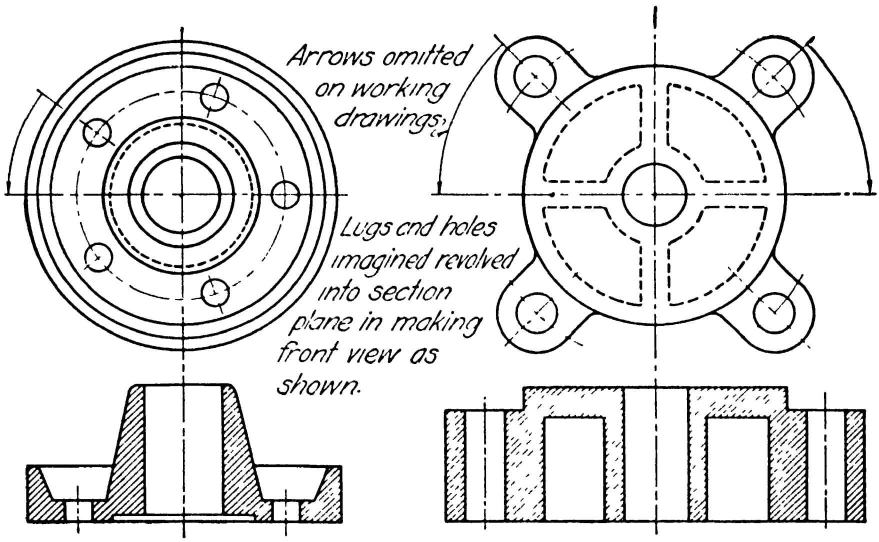


FIG. 14. Rotation in sectioning.

FIG. 15. Rotation in sectioning.

section plane instead of showing it as it actually appears in true projection. See Figs. 11 and 14.

In Fig. 15, the object has four planes of symmetry, but either the lugs or spokes will occur behind the section plane if the section plane is chosen

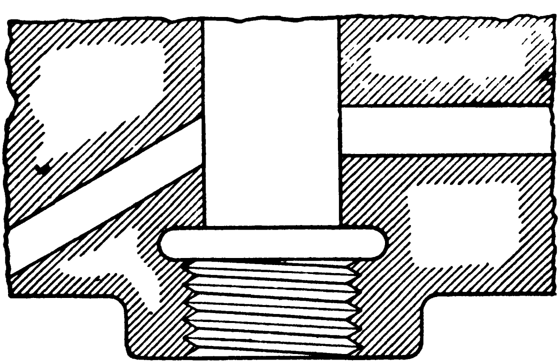


FIG. 16. Partial section lining.

on any plane of symmetry. In the case illustrated, it is preferable to choose the section plane passing through the spokes of the bearing. The lugs are considered to be rotated in the manner shown when the sectioned view is drawn.

Care must be taken not to extend this perversion of the principle of strict orthographic projection, that is, the rotation of parts either in a sectioned or unsectioned drawing, to objects which do not fall into the class of cylindrical shapes. And further, it is not proper to rotate parts of all cylindrical shapes in the manner described above, because the drawing can be readily understood without doing so in many instances.

110. Partial Section Lining. — In many instances, the appearance of large areas which have to be cross-hatched can be improved by simply drawing the lines only a short distance out from the edges of the surface and leaving the central portions blank, as shown in Fig. 16. Not only is time saved by this practice, but also the otherwise objectionable black-ink areas are done away with. The blueprints of tracings made in this way are even more improved in their appearance.

PROBLEMS

111. In solving the following problems, care should be taken to select the right view in which to show the section, as well as to choose the kind of section and its location in the object.

For meaning of sheet sizes and scale specifications, see Art. 4, page 3.

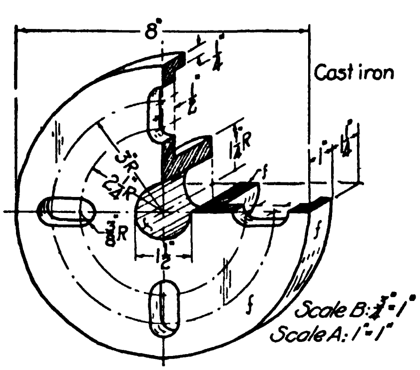


FIG. 17. Face plate blank.

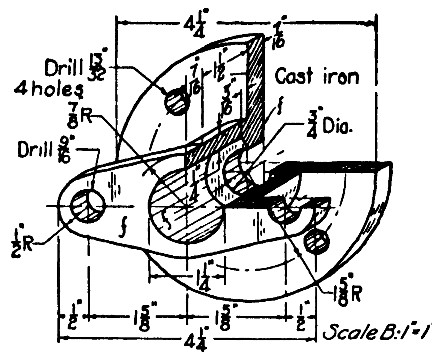


FIG. 18. Stuffing box body.

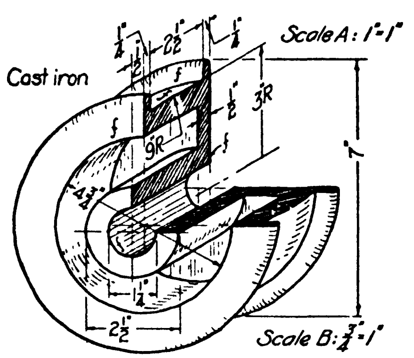


FIG. 19. Pulley.

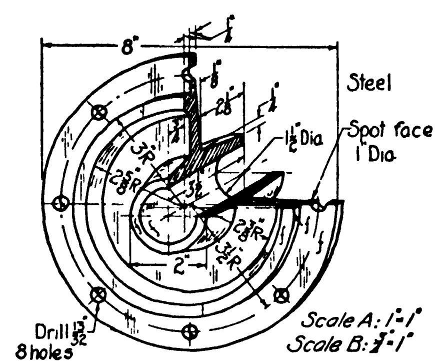


FIG. 20. Motor end bearing.

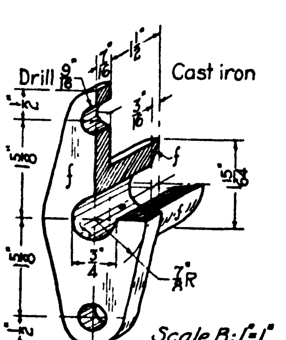


FIG. 21. Packing gland.

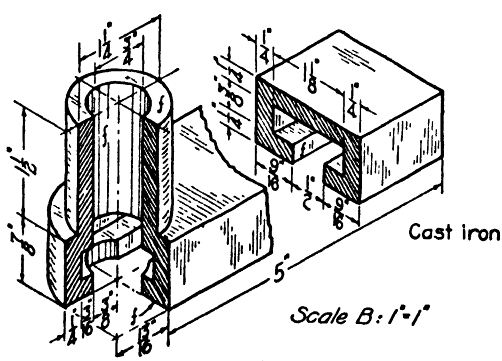


FIG. 22. Tool rest holder.

1. Make a two- or three-view drawing, as needed, to describe the object of Fig. 17, and show a full or half section in one view to bring out the shape of the object to the best advantage.

2. Same as Prob. 1, Fig. 18.
3. Same as Prob. 1, Fig. 19.
4. Same as Prob. 1, Fig. 20.
5. Same as Prob. 1, Fig. 21.
6. Same as Prob. 1, Fig. 22.

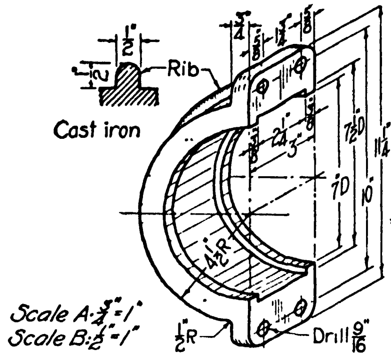


FIG. 23. Eccentric cap.

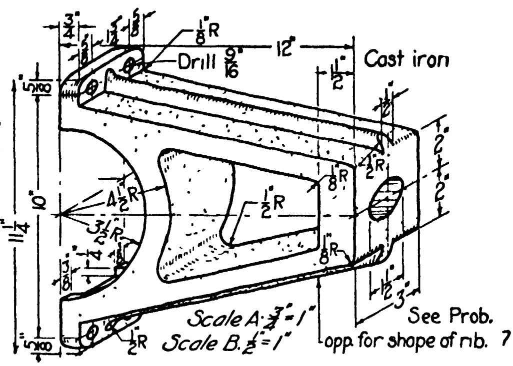


FIG. 24. Eccentric body.

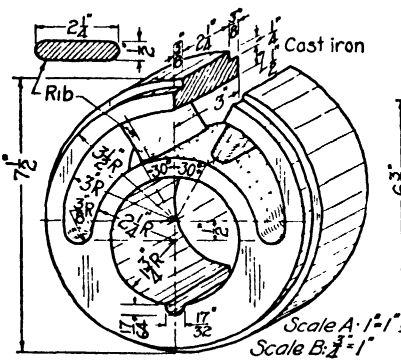


FIG. 25. Eccentric sheave.

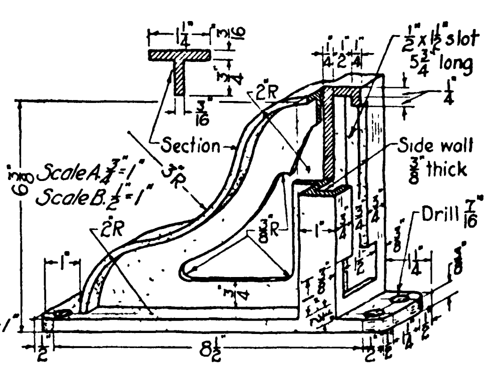


FIG. 26. Wall bracket.

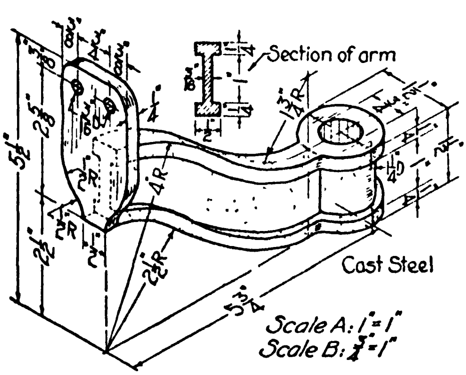


FIG. 27. Tool box holder.

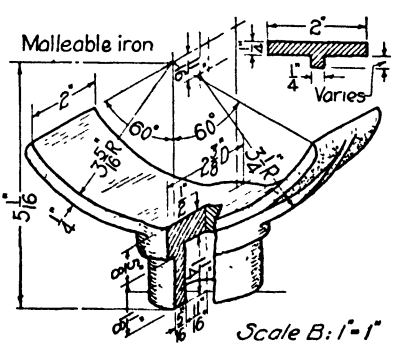


FIG. 28. Pipe support.

7. Make a two- or three-view drawing, as needed, to describe the object of Fig. 23, and include a revolved, or removed, section that will best meet the needs of a particular problem.
8. Same as Prob. 7, Fig. 24.
9. Same as Prob. 7, Fig. 25.
10. Same as Prob. 7, Fig. 26.
11. Same as Prob. 7, Fig. 27.
12. Same as Prob. 7, Fig. 28.

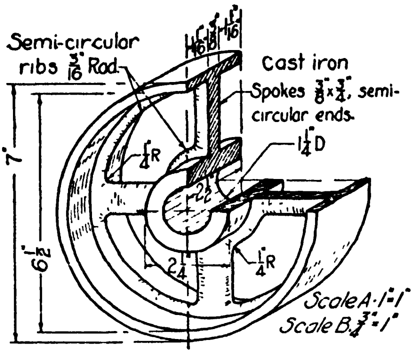


FIG. 29. Pulley.

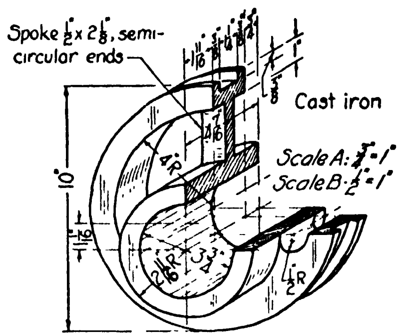


FIG. 30. Eccentric sheave.

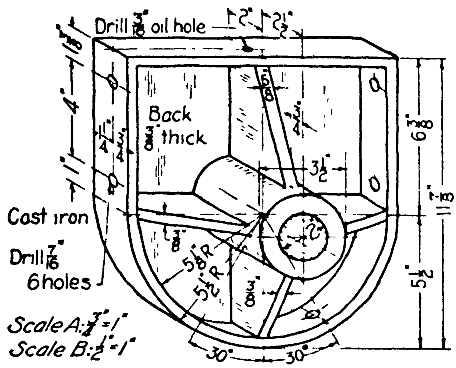


FIG. 31. Conveyor box end bearing.

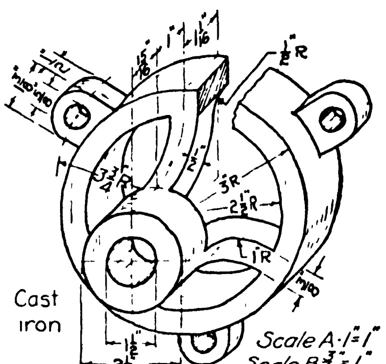


FIG. 32. Offset bearing.

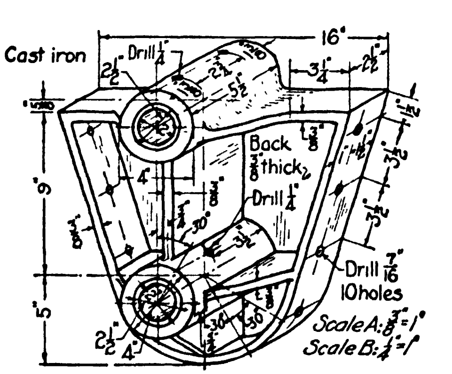


FIG. 33. Conveyor bearing.

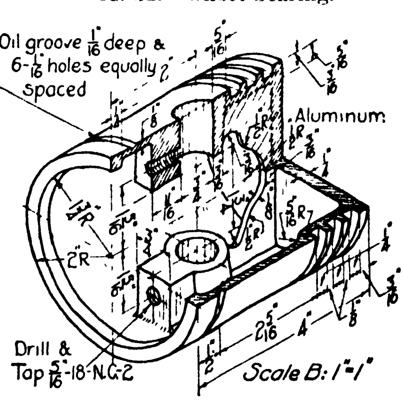


FIG. 34. Piston.

13. Make a two- or three-view drawing, as needed, to describe the object of Fig. 29. Follow the standard commercial practice in making the necessary sectional view, or views.

14. Same as Prob. 13, Fig. 30.
15. Same as Prob. 13, Fig. 31.
16. Same as Prob. 13, Fig. 32.
17. Same as Prob. 13, Fig. 33.
18. Same as Prob. 13, Fig. 34.

CHAPTER VIII

WORKING DRAWINGS

112. Using the principles of orthographic projection which have been presented thus far, it is possible to describe accurately the shape of any object. A knowledge of the shape, however, is not enough to enable a workman to construct the object. He must know, in addition, many other things, such as the size of the object, that is, the dimensions of all its details, the material of which it is to be made, how it is to be finished, and other items of importance which the orthographic views alone cannot show.

113. WORKING DRAWING. — In order, therefore, for a drawing to be useful in construction work the view or views which describe the shape must be fully dimensioned to indicate the size. Then notes must be added to give all the other information necessary for construction. Such a drawing is called a working drawing, or sometimes a shop, or construction, drawing. Briefly, then, *a working drawing may be defined as an adequate number of correctly made views which have been properly dimensioned and to which sufficient notes and explanatory statements have been added so that the workman can produce the object without further information.*

114. ASSEMBLY DRAWING. — Most of the machines and structures which the engineer is called upon to design and construct are composed of several parts. In machine drawing, it is the usual practice to draw each part by itself. Such drawings enable the workman to construct the various parts, but before a useful object is obtained it is necessary to put these pieces together in their correct position in the machine or structure. This requires, for complicated machines, another type of drawing called an assembly drawing which shows all the parts put together in their proper working order and containing an adequate number of views and dimensions for the purpose intended. The use to which the drawing is to be put will determine the number of views, the dimensions to be given, and other characteristics.

115. USES OF ASSEMBLY DRAWINGS. — There are numerous uses to which assembly drawings are put, but the following five are the most important. The drawings in the first three groups will usually be orthographic views, elaborately sectioned, with overall dimensions and dimensions giving the range of travel of moving parts.

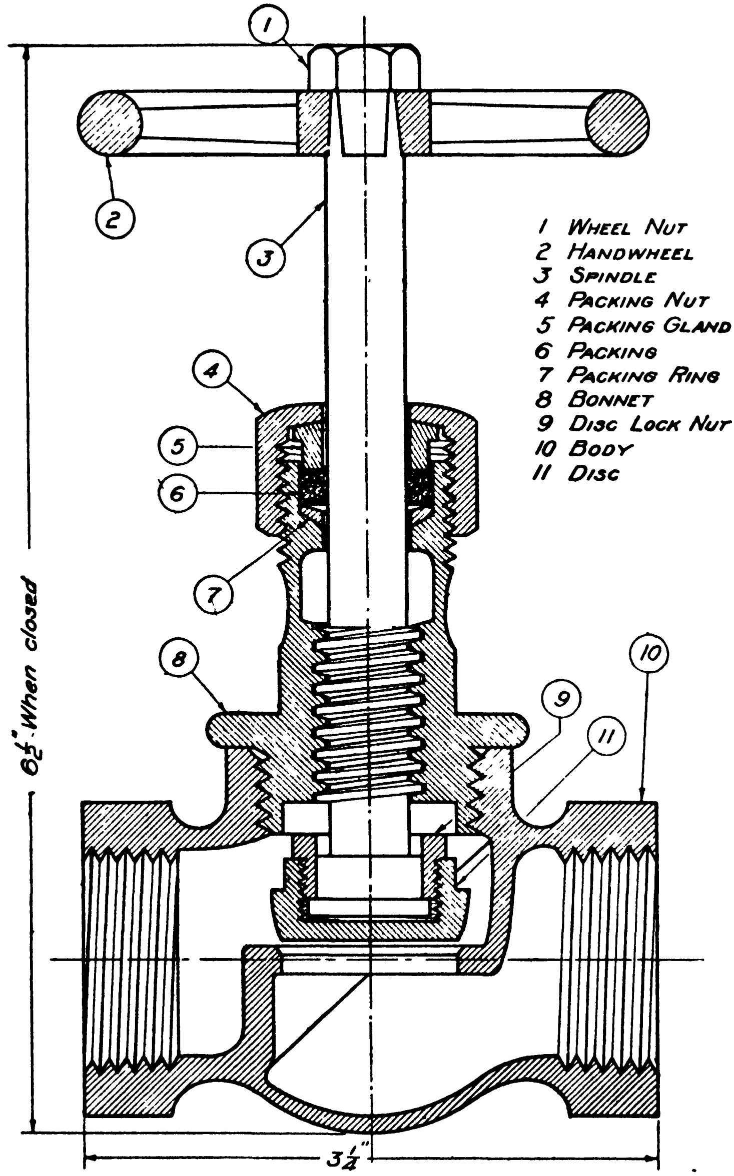


Fig. 1. Assembly drawing for checking design.

116. Original Designs. — In making designs of new machines, it is customary to begin with an assembly which shows the function and methods of operation of each part. From such an assembly, the draftsman works out the exact proportions of each piece so that it performs its function and has the necessary strength and wearing qualities.

117. Checking Completed Designs. — In order to secure adequate strength and proper performance, the parts of a machine may have to be changed considerably from the sizes shown in the original assembly. Such changes require a new assembly based upon the actual size of parts to see that they will function together and have the proper clearances. See Fig. 1.

118. Assembly in the Shop and Field. — The same type of drawing discussed in the preceding paragraph will also be used in the shop to assist the workman in putting the machine or structure together in proper working order, and in the field to aid in erection and operation as well as in ordering and replacing broken and worn-out parts.

119. Fitting in the Field. — Frequently buildings have to be constructed to receive certain machines which have been definitely designed to fit into them in advance. Foundations have to be built, anchor bolts placed, and clearances allowed for moving parts. Assembly drawings are prepared showing facts of this type prominently with all necessary dimensions and omitting many of the details which do not concern the building constructor. See Fig. 2 for an illustration of this kind of drawing.

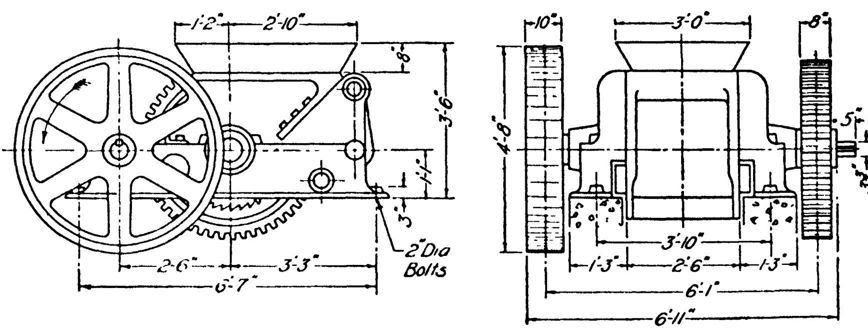
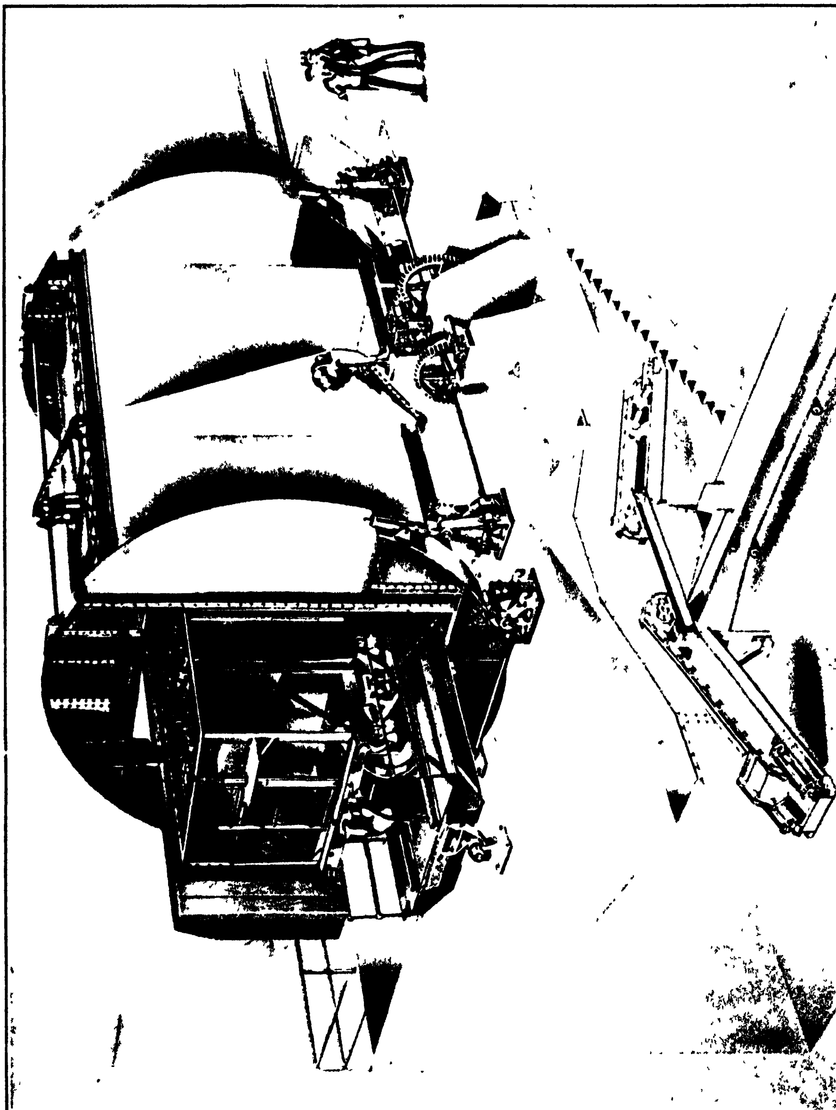


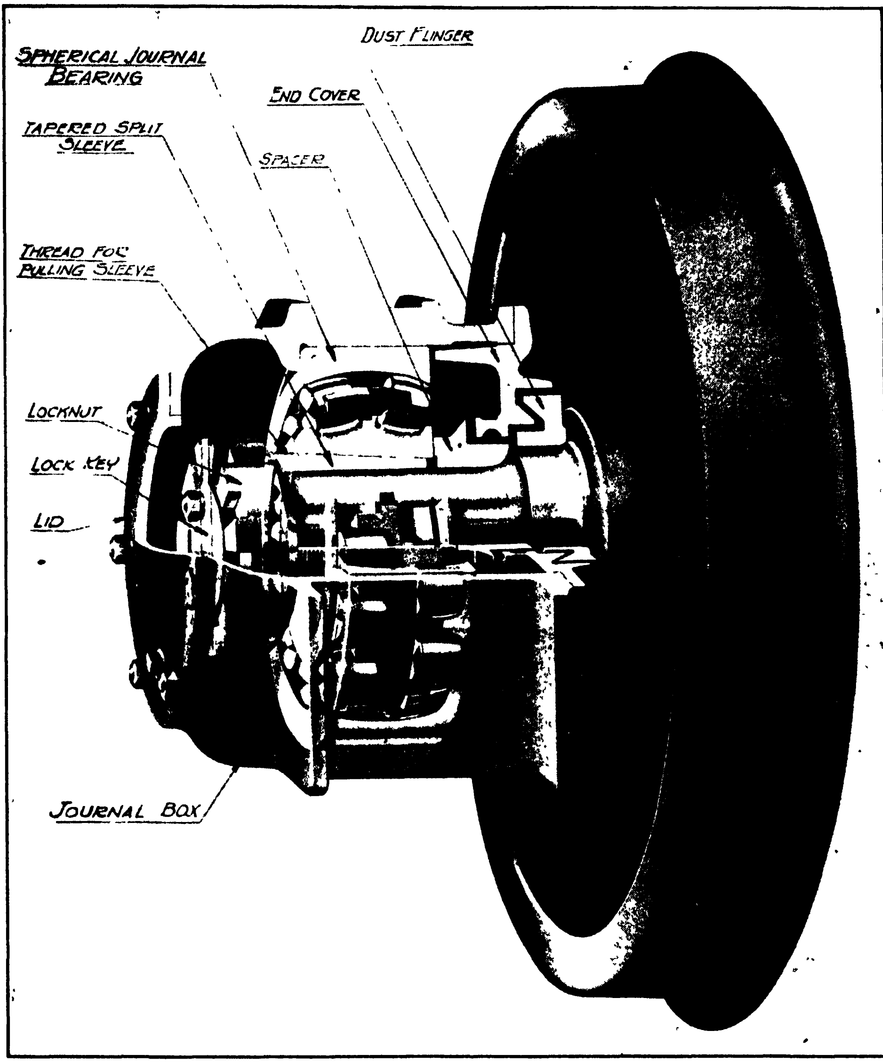
Fig. 2. Assembly for locating anchor bolts.

120. Sales and Advertising. — People who buy machines are interested in their construction and principles of operation. Frequently, a one-view assembly, elaborately sectioned, will enable the salesman to explain the principles of operation of the machine. On such drawings each piece is named and numbered so that the purchaser may order parts for replacement. For strictly advertising purposes phantom drawings in pictorial form are used as illustrated in Fig. 3. Figure 4 shows a variation in this



Courtesy of Link Belt Co.

Fig. 3. Phantom drawing.



Courtesy of Link Belt Co.

Fig. 4. Assembly drawing, with air brush and phantom features.

kind of drawing. It will be noted that the air brush has been used in both Fig. 3 and Fig. 4 to produce desired effects. It is also common to use the half-tone reproduction of a photograph for this purpose, instead of drawings. These forms of assembly drawings and cuts give general ideas of design, construction, and operation only, and are not dimensioned at all.

121. DETAIL DRAWINGS. — When a working drawing of a single part of a machine or structure is made, the drawing is called a *detail* drawing. For very simple machines and structures, which are not to be produced in quantity, all the parts may be put on a single sheet. Such a sheet is referred to as a *sheet of details.* If the machine is to be produced in large numbers, the drawing of each piece is put on a separate sheet. These sheets must be of a size to fit the requirements of the filing standards of the office in which they are made and at the same time permit the use of a scale large enough so that the drawings may be easily read by the workman. All the sheets comprising the drawings for a complete machine, assembled and bound together, are referred to as a *set of details.* The practice of making each part on a single sheet seems to be the more common method and will be discussed first.

122. MAKING A DETAIL DRAWING. — The steps which the draftsman must take in producing a finished detail drawing are listed below. They will be discussed in the order given.

1. Selecting the number and kind of views.
2. Selecting the scale and paper.
3. Drawing the views with proper use of conventional lines and symbols.
4. Dimensioning.
5. Lettering notes and legends, bill of materials, and title.
6. Inking and tracing.
7. Checking and correcting.
8. Reproducing for use in the shop.

123. SELECTION OF VIEWS. — The draftsman must first decide upon the number of views required to describe adequately the shape of the object he is to draw. Clearness of meaning is the chief objective in this decision, and though unnecessary views should not be made, it is false economy to leave any point in doubt which could be cleared up by an additional view.

The second consideration is that of sectional views versus unsectioned, or regular, views. The decision must not be based upon the bare possibility of interpreting a drawing with hidden lines but, as before, upon the principle of ease and accuracy of reading the drawing. The shopman's time costs money as does the draftsman's; hence, when a section is clearer than a drawing having a number of hidden lines, the general rule will be to make a section. Revolved or removed sections should be made where they add to the clearness of the drawing. With the number and kind of views determined, the next item in order is the selection of the scale and paper to be used.

124. SELECTION OF SCALE AND PAPER. — In selecting the correct scale for a proposed drawing, three chief factors must be considered, namely, the kind of drawing to be made, the purpose for which the drawing is to be used, and the size of paper available and approved for filing purposes.

125. Scale and Kind of Drawing. — By long experience, certain scales have been developed which are very convenient for different classes of work, and their use is now a well-established custom from which departure should not be made. For a detailed description of the more common scales see Chapter IV.

The civil engineer's scale is used for maps of all kinds except those of a geographic character, that is, maps showing large areas of the earth's surface with the principal civil and natural division lines placed thereon, for which much smaller scales are used such as 1″ = 62,500″. Scales of 1″ = 1 mile, 1″ = 4 miles, and on up to 1″ = hundreds of miles are also in common use on geographic maps. The civil engineer's scale is also used in making computation charts of various kinds where the decimal system is desirable.

The architect's scale is used on drawings of bridges and buildings of all kinds and on machine drawings of large parts. On these the dimensions are usually in feet and inches, hence the convenience of this scale.

The mechanical engineer's scale is used for small machine parts where inches and fractions of an inch are the common dimensions.

126. Scale and Purpose of a Drawing. — The purpose of the drawing will determine whether a large or small scale shall be used. For drawings conveying only general ideas of form, locations, routes, etc., such as architects' display drawings, real estate maps, and highway maps, very small scales may be used.

The most important drawings are those used for construction purposes, and, consequently, they require that larger scales be used. The general rule may be established that the scale should be large enough to serve the purpose of the drawing without the possibility of misinterpretation of any detail, however small it may be.

127. Scale and Size of Paper. — The choice of scale may be governed within certain limits by the sizes of paper available; but here, again, clearness of the drawing and not economy of paper must be the governing factor. There is no point in making a drawing unduly large, but miniature views and microscopic dimensions are useless in the shop. Ample room must be allowed for all dimensions, notes, legends, and title space without crowding the drawing. In many shops, drawing sheets are furnished in predetermined sizes with border lines and title spaces printed on them.

128. Drawing the Views. — Assuming that the draftsman is limited to certain standard size sheets without printed border lines or title spaces, from which he has made a selection and determined the scale he will use, his first step will be to draw the border lines and reserve a title space.

The second step will be to block out the views in their proper relationship to one another by means of rectangles which will just enclose the views. These rectangles can be quickly drawn and erased and should, therefore, be rearranged until a well-balanced sheet is secured.

If a sheet of details is to be made including all the parts of some simple machine, the views for each piece should be selected, and then the outline rectangles for the views should be drawn to scale, a proper space being left for dimensions and notes, and reasonable distances between views provided. In order to get a well-balanced sheet, it may occasionally be advisable to cut from scratch paper squares and rectangles, corresponding in size to the views to be drawn, which can then be moved around at will

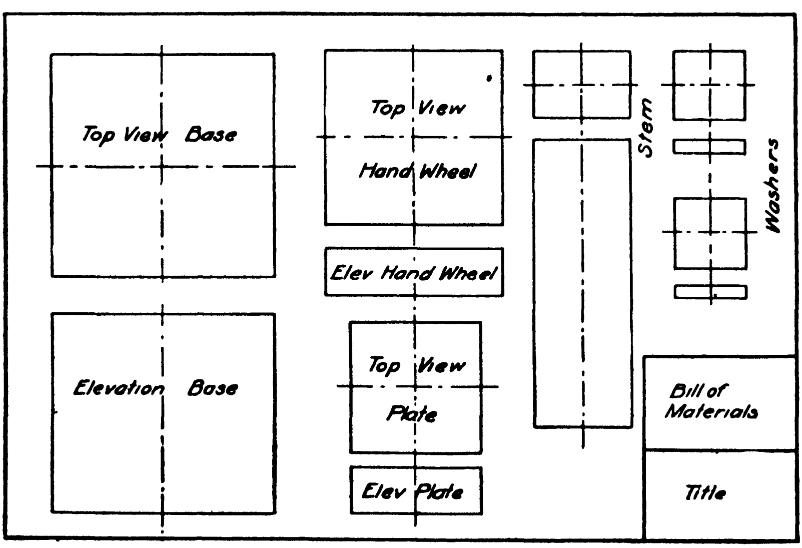


Fig. 5. Sheet layout for details of press.

on the drawing sheet until the best arrangement is found, as shown in Fig. 5. Each view on the drawing sheet should be marked, in order that no error may occur in connecting the several views of a piece with each other so that they will project properly. In deciding upon the arrange-

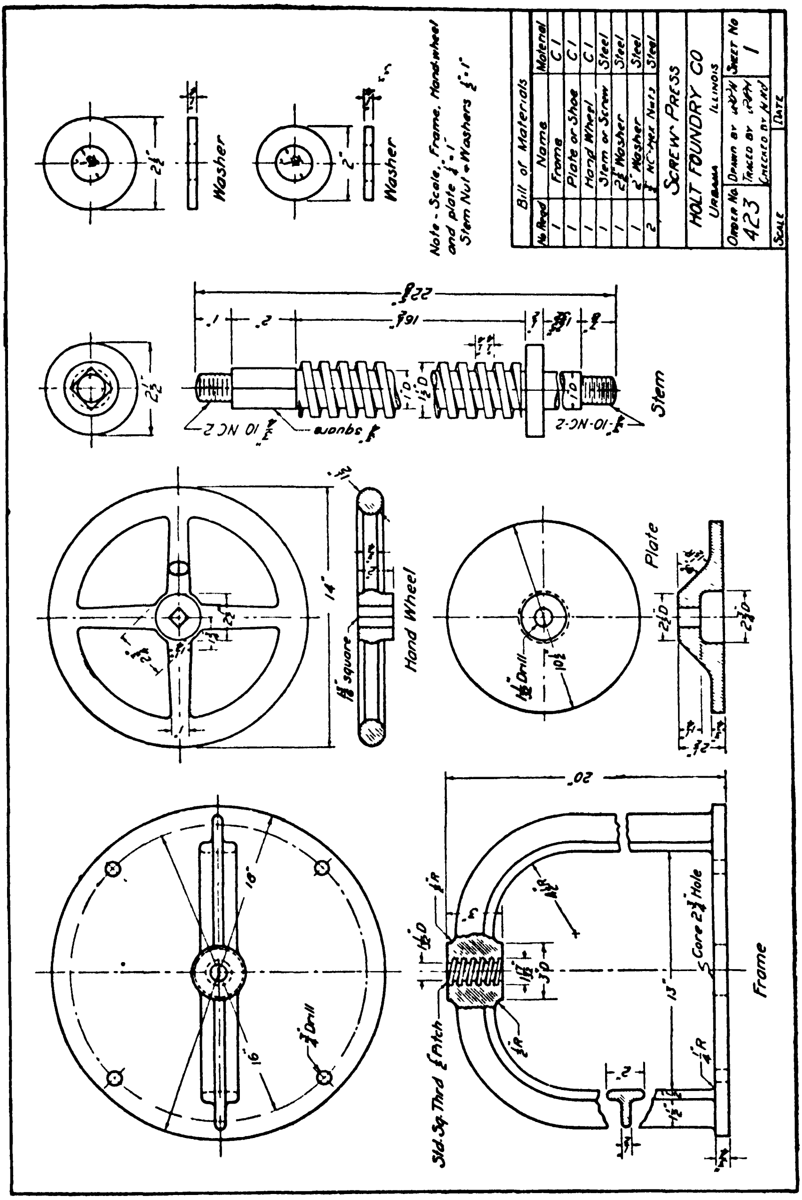


FIG. 6. Detail drawing of press.

ment of the different pieces or parts of an object on the drawing sheet, the draftsman should try to suggest the relation of each part to all the others, as it is when all are assembled. Under no circumstances should the views of one piece be placed between the views of any other part. Figure 6 illustrates a good arrangement of the parts of the press shown.

Having the rectangles located as in Fig. 5, the center lines may be drawn and the construction of views carried out by measurement and projection. Sectional views should be cross-hatched and all work completed in pencil exactly as the finished drawing is to appear. The standard conventional lines, represented here again in Fig. 7 for convenience, should be used, as well as the conventional symbols for such parts as screw threads, bolt heads, nuts, and scores of standard devices and features that are constantly recurring in design. Conventional symbols used in all kinds of drafting will be found in the various chapters and in the Appendix. With all views completely drawn, the next step will be to put in the dimensions.

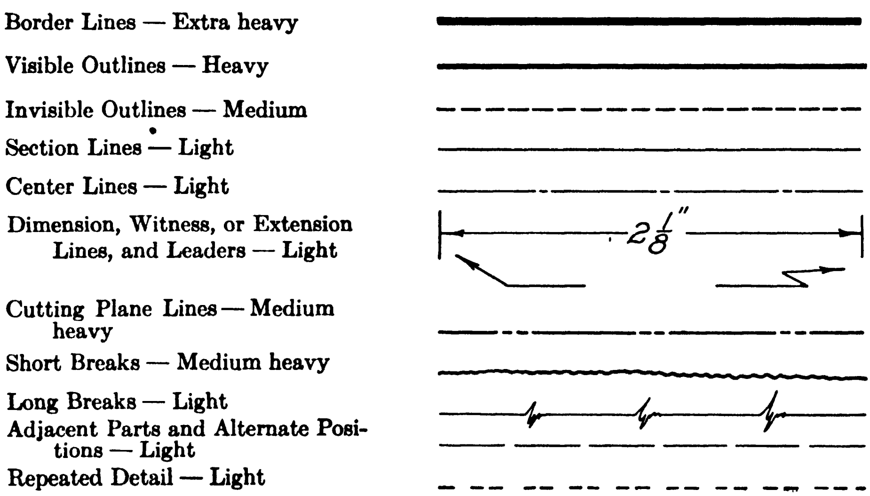


FIG. 7. Proper weight of ink lines.

129. DIMENSIONING — GENERAL CONSIDERATIONS. — The problem of dimensioning has two distinct phases. One deals with the *appearance* of the dimensions on paper from the standpoint of neatness, legibility, and unmistakable meaning; the other deals with the *usefulness* of the dimensions from the standpoint of actual construction. Both considerations are important because the workman must be able, first, to find the dimension he wants quickly and have its meaning perfectly clear, and second, of course, he must not be confused by dimensions on the drawing which he cannot use in constructing the object. For the first of these phases of dimensioning, a few simple rules obtained from experience can be given;

for the second, the draftsman must use his common sense, putting himself in the place of the workman who is to make the object and asking himself what dimensions will be needed. A knowledge of a few of the common shop and field operations will assist in this respect.

130. Mechanics of Dimensioning. — Under this heading are arranged two groups of simple rules which should be observed for the sake of neatness and clearness. These should be so thoroughly learned that they are followed as a matter of habit. The first group deals with the techniques or skills required, and the second with the placement of the dimensions in the proper spaces on the drawing.

131. Technique of Dimensioning. — 1. Dimension lines, witness, or auxiliary lines, and leaders should be light full lines. See Figs. 7, 8, and 9.

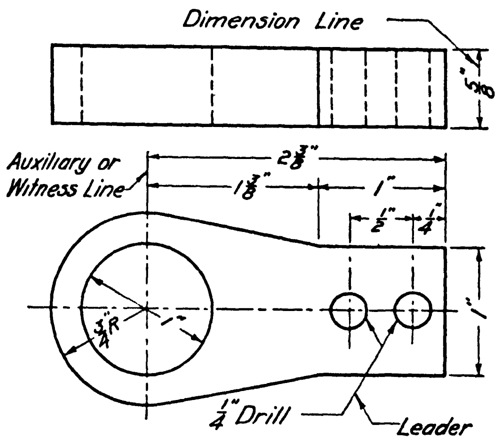


Fig. 8. Three elements of dimensioning.

2. Witness lines should not be brought fully up to the outlines of the views. See Fig. 9.

3. Open spaces should be left in dimension lines for the dimensions. See Fig. 9. In some shops the lines are made solid and figures are placed above the line. See figures in Chapter XXIII.

4. Arrow heads should be small, pointed, and fairly long. See Fig. 9. An enlarged view showing how the arrow is made is shown in Fig. 10.

5. In machine drawing, leaders should be made mechanically as shown in Fig. 11.

6. There should always be a horizontal line between the numerator and denominator of every fraction, and it should be in line with but not a part of the dimension line. See Fig. 9.

7. The symbol for feet is a single short accent above and to the right of the number; that for inches consists of two short accents in the same

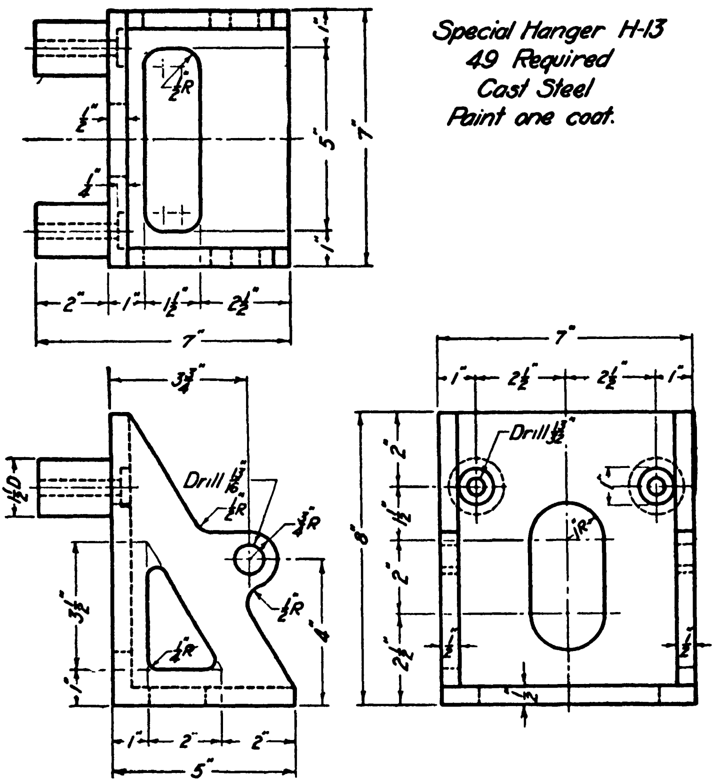


FIG. 9. Detail drawing of hanger.

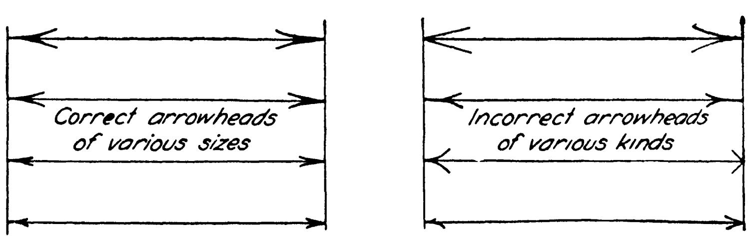


FIG. 10. Arrowheads.

position, as shown in dimensioned figures of this chapter or in figures of Chapter XXIII.

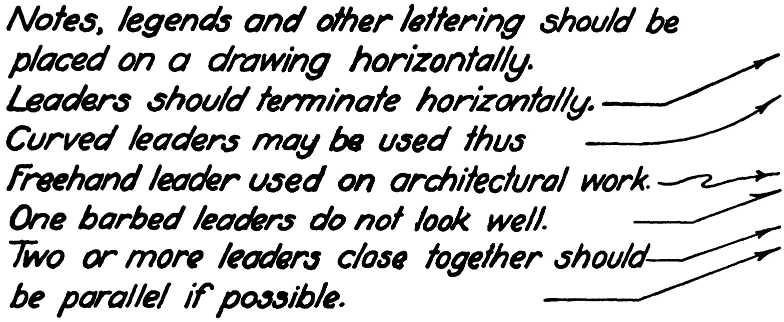


FIG. 11. Use of leaders.

132. Location of Dimensions on the Drawing. — Observance of the foregoing rules on *techniques* is very important in dimensioning a drawing, but strict adherence to the following group on *location* is of still greater importance.

1. Dimensions should read from left to right and from the bottom toward the top of the drawing sheet, diameters and radii excepted.

2. So far as possible and practicable, dimensions should be placed outside of the views themselves, preferably between views, diameters and radii excepted. The first line of dimensions should not be closer to the object than $\frac{3}{8}$ to $\frac{1}{2}$ inch.

3. Dimensions should never be put on or along center lines. See Fig. 12. Correct methods are shown in Fig. 12*a*.

4. A series of dimensions should be kept in the same straight line and not offset. An overall dimension should accompany each series but need not be repeated on the same view. See Figs. 9 and 13.

5. As far as possible, dimensions should not be put on hidden lines. Other views or sections should be used. See Figs. 8 and 13.

6. Unrelated dimensions should not be put in the same series. For example, in Fig. 8 the location of the centers of the two drill holes has nothing to do with the lengths of the outside surfaces; therefore, the two dimensions referring to these centers are put in a separate series.

7. Dimensioning from one face of an object as a reference plane is desirable in some classes of work, as shown in Fig. 12*a*.

8. The proper form for dimensioning very narrow spaces is shown in Fig. 14.

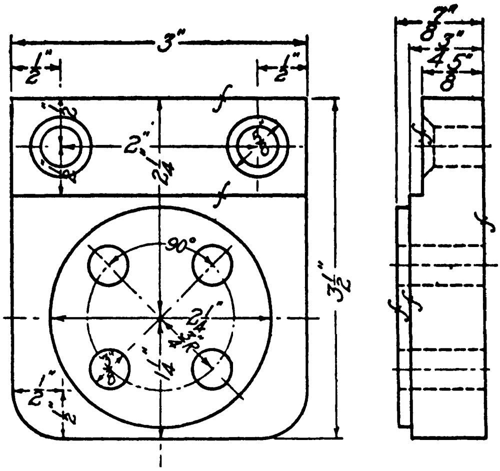


FIG. 12. Dimensions incorrectly placed.

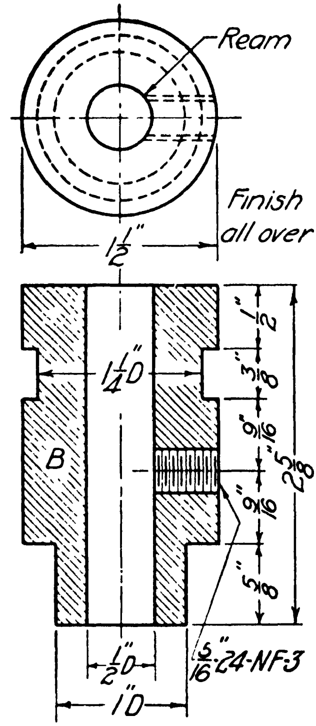


FIG. 13. Dimension notes.

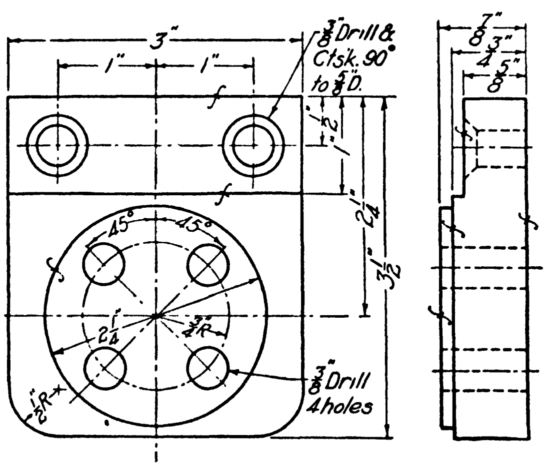


FIG. 12a. Dimensions correctly placed.

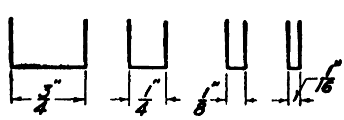


FIG. 14. Dimensioning narrow spaces.

133. Construction Dimensioning. — The constructor, in building a machine or structure, needs information on two points regarding dimensions, and these should always be kept in mind by the draftsman as a guide in choosing the dimensions to put on the drawing. They are, first, the size of the object and its several parts; and second, the location of the parts relative to the whole and to each other.

For example, in Fig. 9 the size of the two lugs on the back of the hanger must be known. These lugs will be turned separately on a lathe and then fastened on to the main part of the hanger, hence the essential dimensions are the length and diameter. The hole in the lug will be cored, hence its diameter should be given. In addition to these sizes the workman must know the location of the lugs. This is shown by dimensioning the centers of the holes in two directions in the body of the bracket in the end view at the right.

A second example of proper size and location dimensioning is that of the two holes in the sides of the hanger of Fig. 9. In the front view the diameter of the holes is given in the instructions to drill them $\frac{13}{16}$ inch in diameter. The size of the bosses is given by radii since these are the dimensions the workman would use rather than diameters. The centers of the holes and bosses are located by giving their dimensions from the faces of the object

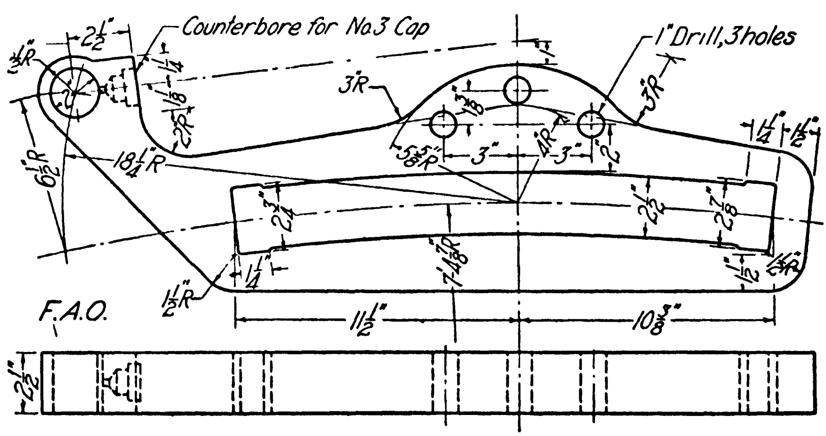


Fig. 15. Location dimension by arcs and radii.

in two directions at right angles to each other on the front view. The thickness of the bosses and their lateral positions on the bracket are shown in the view at the right.

Figure 15 shows another type of location dimensioning in which two intersecting arcs locate the center of the hole at the left end of the object. Figure 16 shows how an irregular curve may be dimensioned by reference to two plane faces of the object at right angles to each other. Figure 17 shows the use of the polar coördinate scheme, using an angle and a distance.

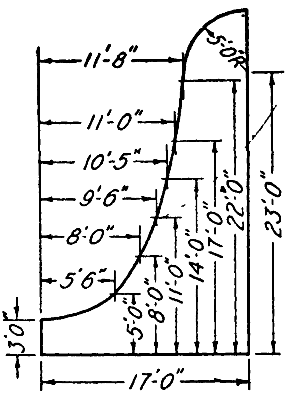


Fig. 16. Dimensioning an irregular curve.

The foregoing illustrations suffice to indicate that each object presents a problem in dimensioning in itself, to the solution of which the draftsman must bring his common sense and experience. However, a summary of the above with additional suggestions in the form of rules will be of assistance.

1. Circular holes should always be located by dimensions to their center lines, never to their edges. When holes are arranged in a circle, the center lines should be radial and circular as shown in Figs. 17 and 18.

2. Cylinders should always have diameters given rather than radii. See Figs. 9, 13, and 17.

3. Rounded corners, fillets, and larger arcs should be dimensioned by radii. The proper form for such dimensions is shown in Fig. 19.

4. The location of parts must be given in three directions, two of which may be by two lines at right angles to each other in one view as in Fig. 9,

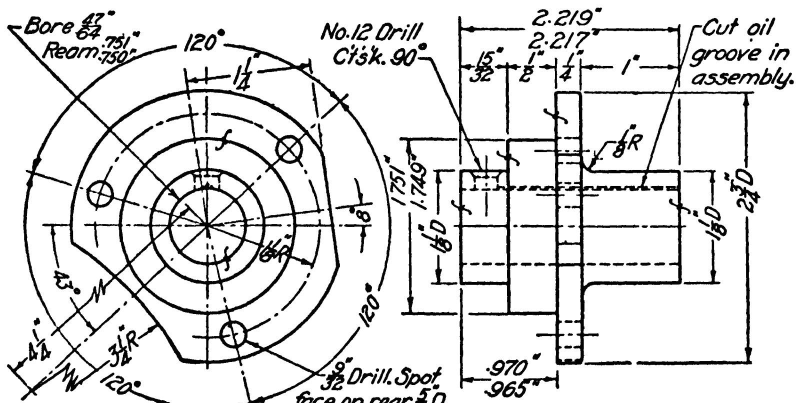


Fig. 17. Dimensioning by angle and distance.

by two intersecting arcs as in Fig. 15, or by an arc and a distance as shown in Fig. 17.

5. Finished surfaces should be indicated by the small letter *f* placed across the line representing the edgewise view of the surface to be finished as shown in Figs. 12, 17, and 18. If the object is to be finished all over,

the note " Finish all over " or the abbreviation F.A.O., is used, as in Fig. 15, and the letter *f* omitted.

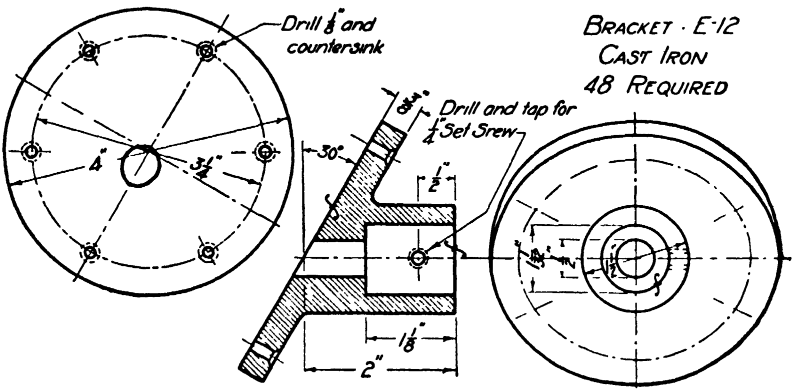


FIG. 18. Dimensioning holes centered on a circle.

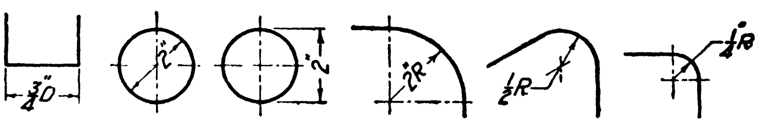


FIG. 19. Dimensioning arcs and circles.

Another system of showing on the drawing surfaces that are to be finished is being recommended to the American Standards Association for adoption. It consists of the symbol "V" placed so that its bottom touches the line that represents the surface to be finished. The angle of the "V" is 60 degrees. There is placed in the angle a mark to indicate the kind of finished desired, thus:

$\overset{R}{V}$ rough machine finish	$\overset{G}{V}$ grind
$\dot{V}$ smooth machine finish	$\overset{P}{V}$ polish
$\overset{RG}{V}$ rough grind	$\overset{F}{V}$ file

The system may be extended to include many types and grades of finish.

6. Holes to be cored, drilled, tapped, bored, reamed, countersunk, etc., should be so marked, as shown in Figs. 9, 13, 17, and 18.

134. PRODUCTION DIMENSIONING. — If an object represented in a working drawing is to be produced in quantity, it will be impossible to make every unit of exactly the same dimensions when measured, let us say, to thousandths of an inch, a degree of accuracy frequently specified. The greater the accuracy demanded, the higher the cost of production. It is desirable, therefore, to have some standards of deviation from specified dimensions which will allow the greatest freedom in production commensurate with the accuracy of the fit required. These deviations are called *production limits*, which include two main subdivisions, namely, tolerances and allowances.

The American Standards Association defines the term limits as " the extreme permissible dimensions of a part." In some cases, the limits are understood without specification as a matter of common practice; in others, they are included with the dimensions proper. The draftsman must be able to indicate the limits desired by his dimensioning in the ways explained below. The definitions and explanations here given conform in substance to those adopted by the American Standards Association and published in its bulletin B-4a-1925, to which reference should be made for more detailed information.

135. Tolerance. — Tolerance is defined as the amount of variation permitted in the size of a part in its manufacture or construction.

It is a common practice, when fractional dimensions only are given on the drawing for finished surfaces, to allow a variation of 0.01 inch either way from the dimensions given. If decimal dimensions are given without specifying limits, it is assumed that a variation of 0.005 inch either way may be allowed. When greater accuracy than this is required, the limits of variation which will be acceptable must be specified. The manner of doing this is clearly shown in Fig. 17.

136. Allowance. — Allowance is defined as an intentional difference in the dimensions of mating parts, or the minimum clearance space which is intended between mating parts. It represents the condition of the tightest permissible fit or the largest internal member mated with the smallest

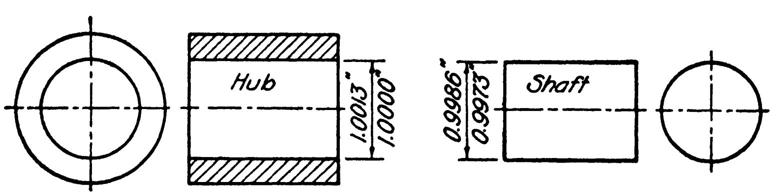


Fig. 20. Limit dimensioning.

external member. It is to provide for different classes of fit. An example of dimensioning that specifies a required allowance is shown in Fig. 20. Here an allowance of 0.0014 inch is required, and 0.0027 inch is specified as the allowance plus the tolerance permitted. This is a Class 2, or free fit, for the size of shaft given.

The classes of fits mentioned in the preceding paragraph have been standardized under the names indicated below, although many other names for these classes will be found in use. Those given, however, represent the standards adopted by engineers and manufacturers of the country through coöperation with the A.S.A. They are quoted from the bulletin mentioned above.

Loose Fit (Class 1) — **Large Allowance.** — This fit provides for considerable freedom and embraces certain fits where accuracy is not essential. Examples: machined fits of agricultural and mining machinery; controlling apparatus for marine work; textile, rubber, candy, and bread machinery; general machinery of a similar grade; and some ordnance material.

Free Fit (Class 2) — **Liberal Allowance.** — For running fits with speeds of 600 r.p.m. or above, and journal pressures of 600 lb. per sq. in. or above. Examples: dynamos, engines, many machine tool parts, and some automotive parts.

Medium Fit (Class 3) — **Medium Allowance.** — For running fits under 600 r.p.m. and with journal pressures less than 600 lb. per sq. in.; also for sliding fits; and the more accurate machine tool and automotive parts.

Snug Fit (Class 4) — **Zero Allowance.** — 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 a load.

Wringing Fit (Class 5) — **Zero to Negative Allowance.** — This is also known as a " tunking fit " and it is practically metal-to-metal. Assembly is usually selective and not interchangeable.

Tight Fit (Class 6) — **Slight Negative Allowance.** — 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, rocker arms, etc. 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.

Medium Force Fit (Class 7) — **Negative Allowance.** — 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 used also 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.

Heavy Force and Shrink Fit (Class 8) — **Considerable Negative Allowance.** — These fits are used for steel holes where metal can be highly stressed without exceeding its elastic limit. These fits cause excessive stress for cast-iron holes. Shrink fits are used where heavy force fits are impracticable, as on locomotive wheel tires, heavy crank disks of large engines, etc.

It is evident that, in manufacturing mating parts, tolerances and allowances must be considered together. The draftsman will be aided by the table of formulas of standard allowances and tolerances as given in the Appendix under the title of Recommended Formulas for these elements. Complete tables of allowances for a large range of sizes have been worked out and published in the A.S.A. bulletin referred to above.

137. Lettering Notes and Legends, Bill of Materials, and Title. — Information which cannot be shown by projection or dimensions such as kinds of material, finish, shop processes, painting, number of pieces wanted, etc., must be lettered on the drawing in the form of brief concise notes. When these notes become rather formal in tone and take on a standard or set phraseology, they are called *legends* or *subtitles*. Examples of common legends are: **Brass Bearing, 2 Wanted; Half Elevation, West End;** and **Section A-A.**

Sometimes on the sheet of details, but more often on separate sheets prepared for the purpose, appears a list of all the pieces and parts needed to build the machine or structure. This list or table will contain the names of the several pieces, the materials of which they are made, the sizes of each piece in so far as they can be given in such a list, and the sheet and erection numbers. This is called a *bill of materials*. If the bill of materials is placed on machine drawings, it should become a part of the title. For structural and architectural drawings, separate sheets $8\frac{1}{2}'' \times 11''$ should be used. Figures 6 and 21 illustrate the method of making the bill of material on a machine drawing a part of the title.

Complete information concerning the material to be put in the title, its location on the sheet, and details of its design will be found in Chapter III.

138. Inking and Tracing. — On some drawings, such as patent office, map, and display drawing, and the like, the inking is done directly on the penciled sheet. If it is known in advance that this is to be done, a paper that will take ink and that is suitable to the purpose in other respects, such as Bristol board or a hot-pressed paper, should be chosen. Before any ink is applied, the paper should be cleaned with art gum and then all dust, dirt, and lint should be carefully removed.

When tracings are to be made for reproduction purposes, the cloth should first have the selvage edge removed. It is then placed over the pencil drawing with the glossy side down, leaving the dull side up to receive the ink lines. The cloth should be held firmly in place by a suitable number of thumb tacks. If it is found that the ink does not spread evenly but tends to gather up in little globules, the surface of the cloth may be treated with powdered magnesium or other light prepared tracing powders or with chalk dust. The powder should be rubbed lightly over the surface to absorb any trace of oil and then thoroughly removed.

If tracing is to be continued for several days, it is best to confine each day's work to one portion of the sheet, if possible, in order that shrinkage or expansion of the cloth may not affect the scale of the views.

The cloth must be kept free of lint and dust, and under no circumstances should water be allowed to get on it at any time since this will dissolve the

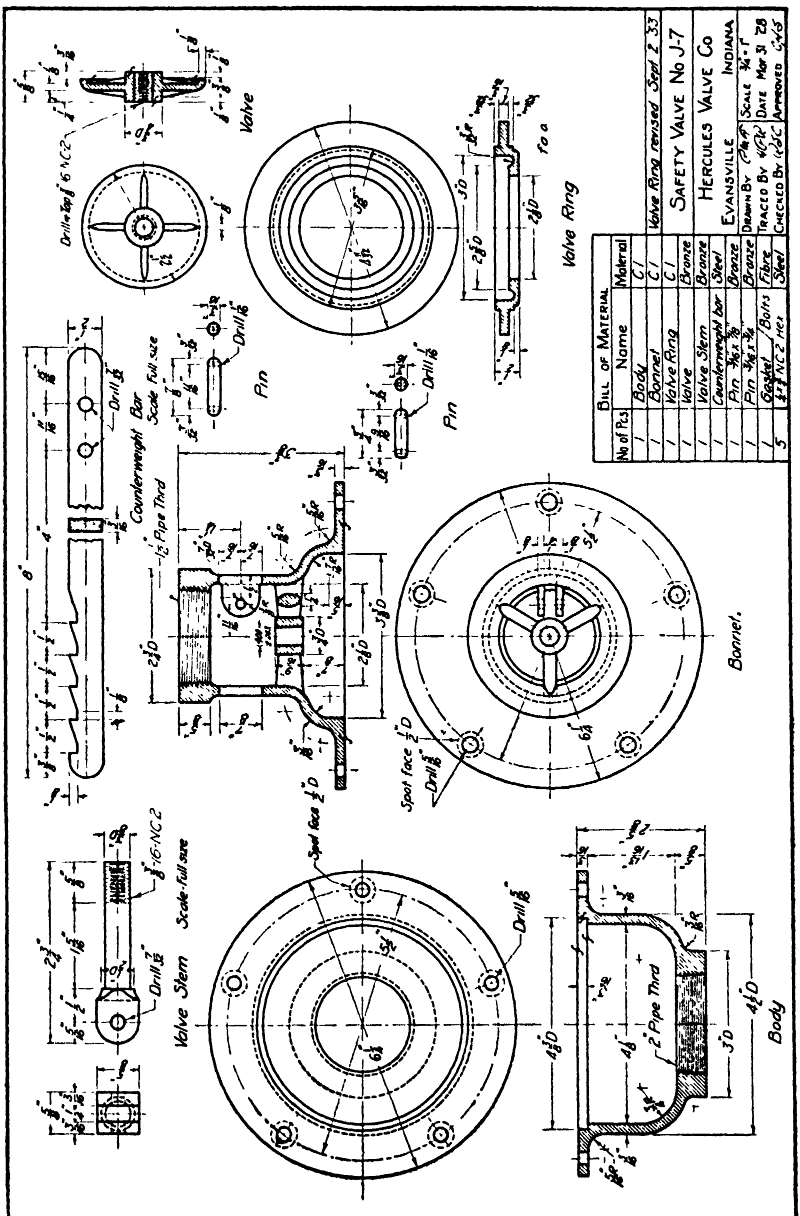


FIG. 21. Detail drawings of safety valve.

coating and ruin the cloth. Ink lines drawn in error may be removed with a pencil eraser. Never should a knife or grit eraser be used.

To speed up the work and improve the technique of the drawing, the following order of inking is recommended.

Order of Inking a Drawing or Tracing

1. Center lines.
2. Visible outlines, all of uniform weight, in the following order:
    a. Circles and arcs of circles and other curved outlines.
    b. Horizontal lines beginning at the top.
    c. Vertical lines beginning at the left.
    d. Inclined lines.
3. Invisible outlines in the same order as in (2) above.
4. Cross-hatching.
5. Dimension lines in the same order as in (2) above.
6. Dimensions, arrowheads, and other lettering.
7. Border lines and trim lines.

139. **Pencil Tracings.** — In many drafting rooms blueprints are made directly from pencil tracings which have been made directly on tracing paper or pencil tracing cloth. The latter is much whiter in color than the ordinary tracing cloth. For good results the drawing is made lightly with a hard pencil, and then the usual contrast between visible, invisible, and dimension lines is obtained by going over the drawing with a soft pencil to make the visible portions stand out in vivid contrast to the dimension lines. All lines, however, must be a dense black, regardless of their weight, in order to blueprint well.

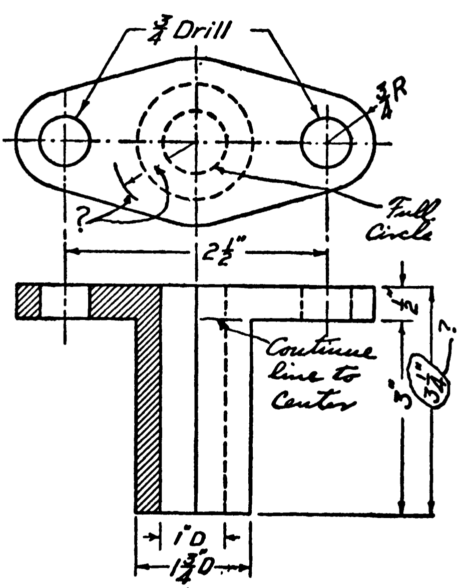


Fig. 22. Method of indicating revisions.

140. **Checking, Correcting, and Revising.** — All well-organized drafting offices have complete systems of checking a draftsman's work before it goes to the shop man. This is usually done, first, by the designing

engineer or chief draftsman to see if points in the design conform to standard practice, and secondly, by an assigned draftsman or checker to see if various details of dimensioning and projection are accurate and clear. Revisions and corrections are indicated and embodied in the drawings and tracings, and after final approval has been given by the engineer, they are turned over to the blueprinter for reproduction in quantity. Revisions should be indicated with a soft pencil, after some such method as is shown in Fig. 22. Each drafting office has its own standards for handling this part of its work, but the final results are the same. In checking a drawing, the following items should be given attention in the order named.

1. Check the drawings simply as orthographic projections, taking care that the shape of each part or piece is clear and fully projected in all views.
2. Scale enough of the projections to determine the accuracy of the work and at the same time secure base lengths sufficient to make eye comparisons.
3. Check all dimensions by addition or subtraction.
4. See if shop processes are correctly indicated by notes and symbols.
5. Check for clearances of moving parts.
6. Check for clearances to insert, drive, or tighten bolts, nuts, or rivets with standard equipment.
7. Check all notes and legends and add to them where doubt arises as to the exact meaning intended.
8. See that the bill of materials contains all parts needed and that piece marks agree with those on the drawing.
9. Examine title to see that complete information is given, including scale, date, and names of engineers and draftsmen.

141. Blueprints, Brownprints, and Other Prints. — It is evident, of course, that the purpose of the tracing is to furnish an intermediate means of transferring the drawings to more useful form for shop and field purposes. The tracing itself must be preserved with great care, as it will become valueless upon being crinkled, moistened, or stained. The blueprinting process, affording numerous reproductions of a tracing, allows us to utilize the tracing fully. So important is this phase of the draftsman's work that Chapter XVII, to which reference should be made, is devoted entirely to this subject. It is necessary to point out here that good blueprints can be obtained only from good tracings, and to this end all tracings should be made with firm lines and proper conventional contrasts.

PROBLEMS

142. A working drawing must be completely dimensioned and have notes specifying the materials, finish, number required, etc. The student should not place the dimensions as they are shown in the figure since the limitation of space on the pictorial drawings may have made it necessary to place dimensions in positions which would not be desirable in an orthographic drawing. Likewise, the notes on drawings which assist in describing the shape of the object, as, for example, the note " $\frac{1}{2}$" Drill through," should not be copied verbatim. The orthographic drawing will show the hole going through whereas the pictorial drawing may not. Finish marks, likewise, should be properly put on and not copied from the pictorial drawing.

Where invisible lines are not shown on a pictorial drawing, the hidden parts are assumed to be symmetrical with the visible portion or to follow the shape indicated by the visible part.

If dimensions of minor parts are found to be missing, common sense should be used in making an estimate of the probable size of the part. The scales for two different sizes of sheets are given on some figures (see Art. 4, page 3); choose the one that fits your paper. In a few figures no scale is indicated. The student should select one suited to the size of paper he is using and the dimensions of the object.

Some very simple pieces of the two-cylinder gas engine have been included for the purpose of making assembly drawings. They are not included in the working-drawing problems.

For additional suggestions concerning Problems 63 to 136 and 137 to 147, see Arts. 142*a* and 142*b*, respectively.

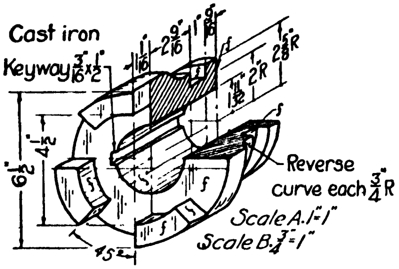


FIG. 23. Four jaw clutch.

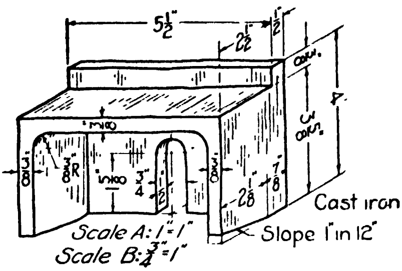


FIG. 24. Beam support.

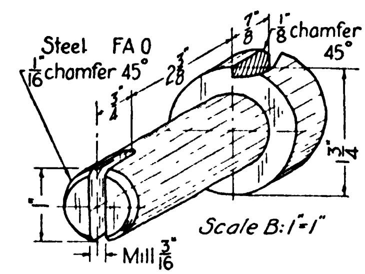


FIG. 25. Pin.

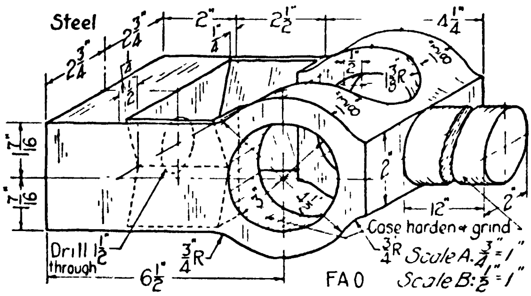


FIG. 26. Valve stem extension.

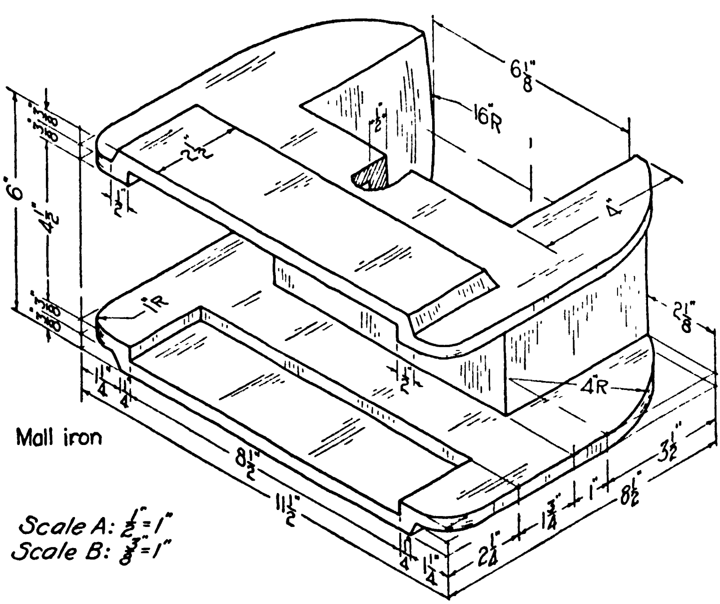


FIG. 27. Centering device.

1. Make a working drawing of the object shown in Fig. 23.
2. Same as Prob. 1, Fig. 24.
3. Same as Prob. 1, Fig. 25.
4. Same as Prob. 1, Fig. 26.
5. Same as Prob. 1, Fig. 27.

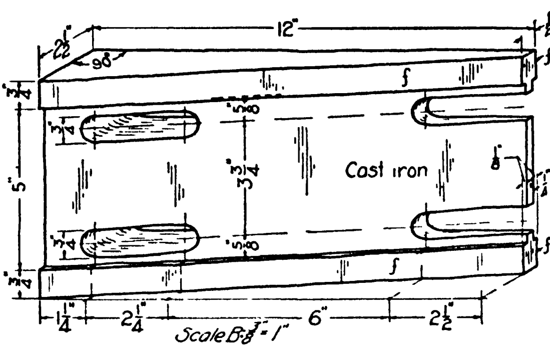


FIG. 28. Bearing wedge.

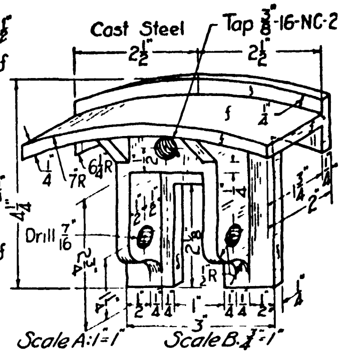


FIG. 29. Clutch — inside jaw.

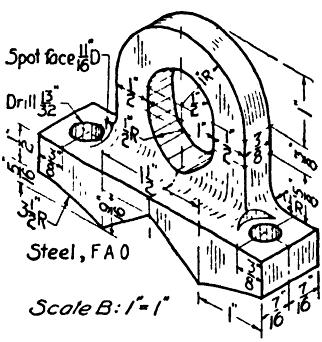


FIG. 30. Valve stem clamp. (Upper part)

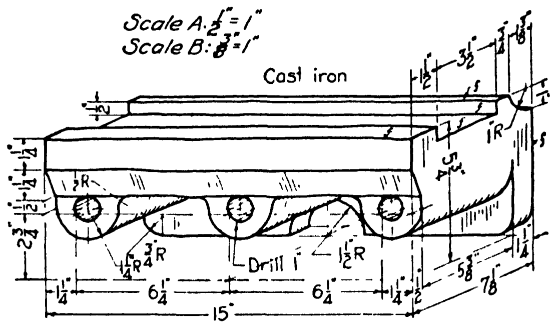


FIG. 31. Expansion pad.

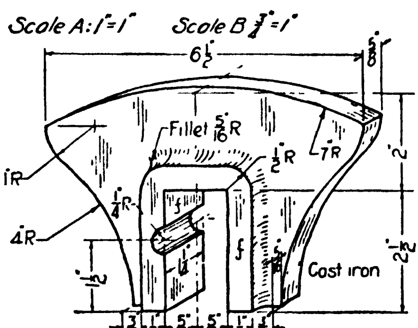


FIG. 32. Grate bar finger.

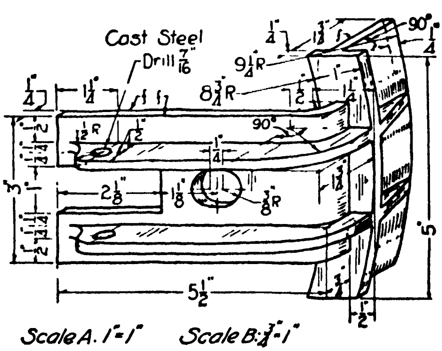


FIG. 33. Clutch — outside jaw.

6. Make a working drawing of the object shown in Fig. 28.
7. Same as Prob. 6, Fig. 29.
8. Same as Prob. 6, Fig. 30.
9. Same as Prob. 6, Fig. 31.
10. Same as Prob. 6, Fig. 32.
11. Same as Prob. 6, Fig. 33.

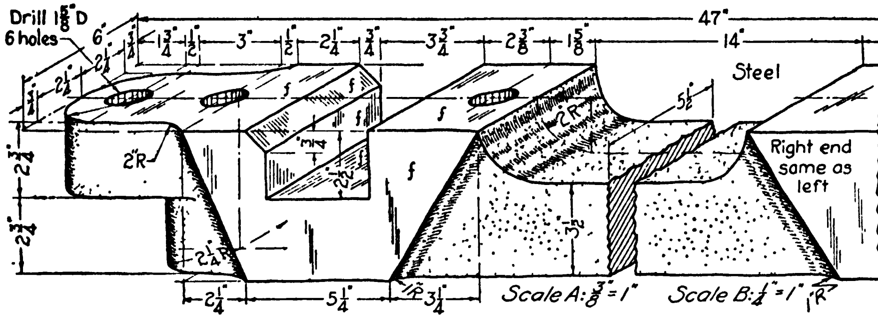


FIG. 34. Frame pedestal binders.

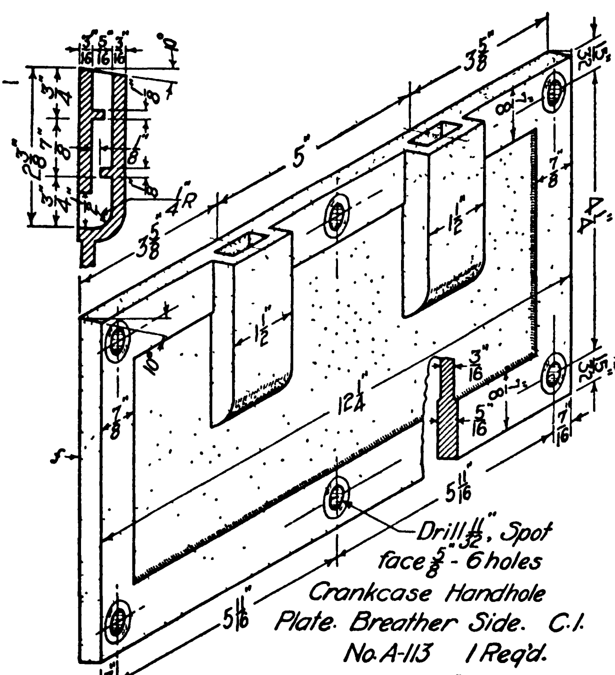
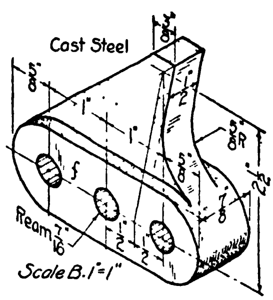


FIG. 35.



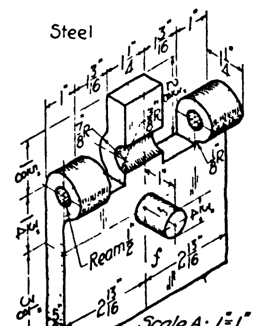
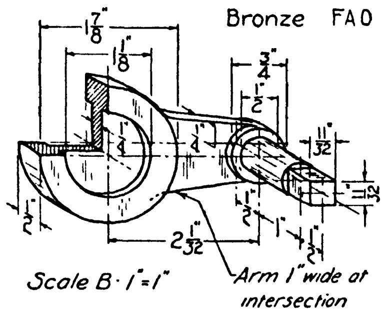
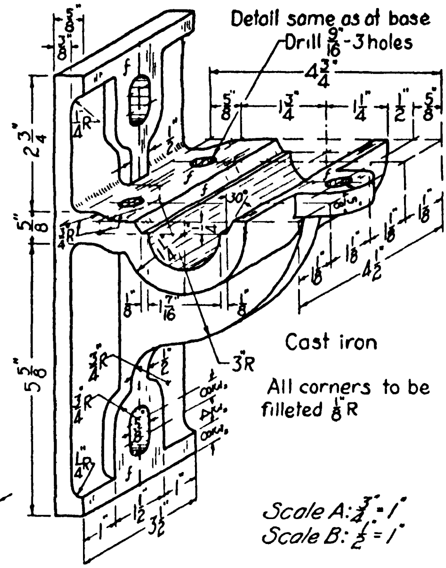
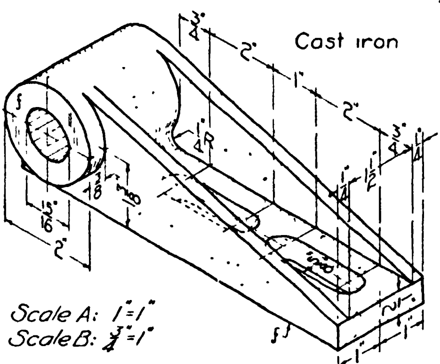


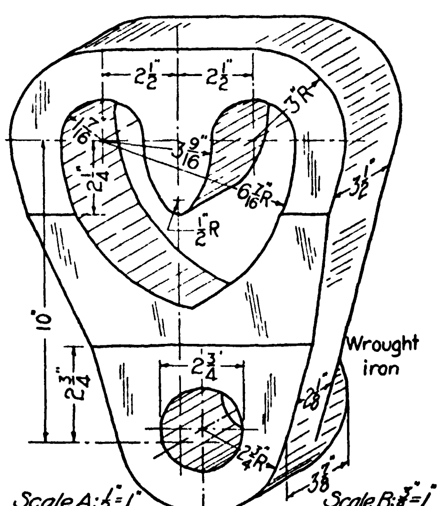
FIG. 36. Clutch fulcrum lever.
FIG. 37. Valve handle lock (base).

12. Make a working drawing of the object shown in Fig. 34.
13. Same as Prob. 12, Fig. 35.
14. Same as Prob. 12, Fig. 36.
15. Same as Prob. 12, Fig. 37.









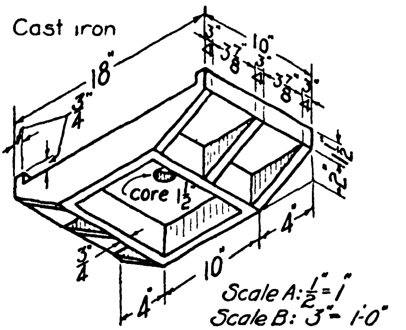
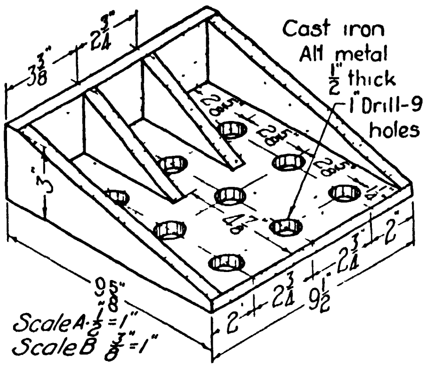


Fig. 38. Valve crank.
Fig. 39. Plain post box.
Fig. 40. Take-up bearing.
Fig. 41. Post cap.
Fig. 42. Truck hanger arm.

16. Make a working drawing of the object shown in Fig. 38.
17. Same as Prob. 16, Fig. 39.
18. Same as Prob. 16, Fig. 40.
19. Same as Prob. 16, Fig. 41.
20. Same as Prob. 16, Fig. 42.



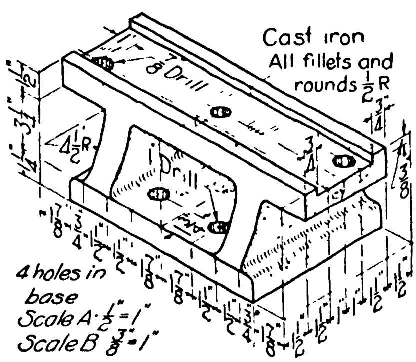


FIG. 43. Back draft stop.
FIG. 45. Truck side bearing.

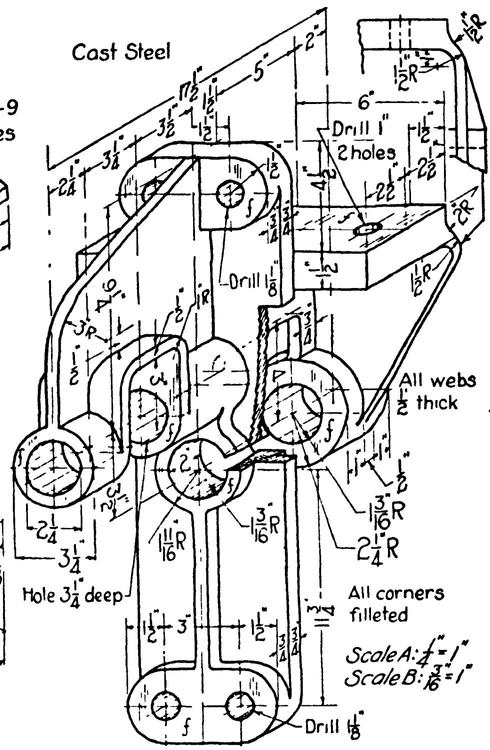


FIG. 44. Frame filling piece.

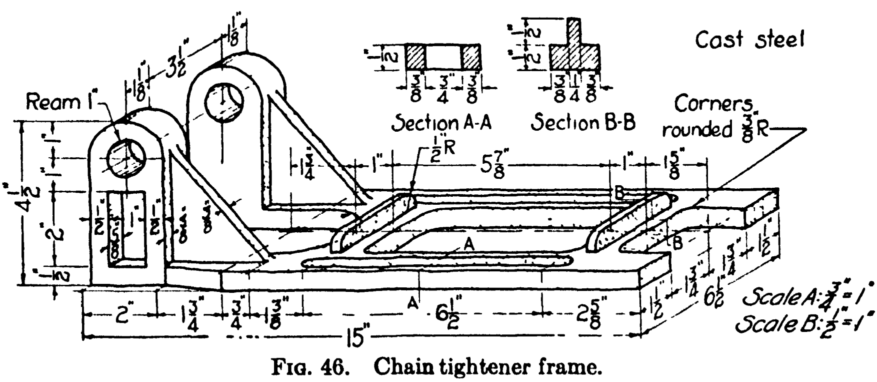


FIG. 46. Chain tightener frame.

21. Make a working drawing of the object shown in Fig. 43.
22. Same as Prob. 21, Fig. 44.
23. Same as Prob. 21, Fig. 45.
24. Same as Prob. 21, Fig. 46.

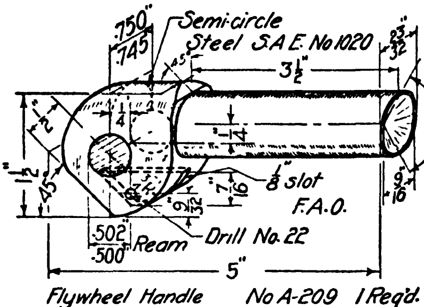


Fig. 47.

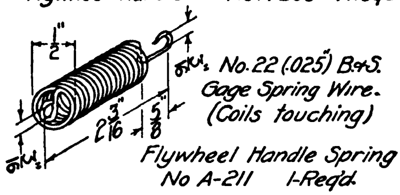


Fig. 49.

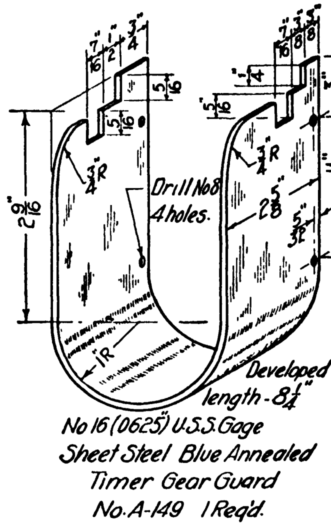


Fig. 48.

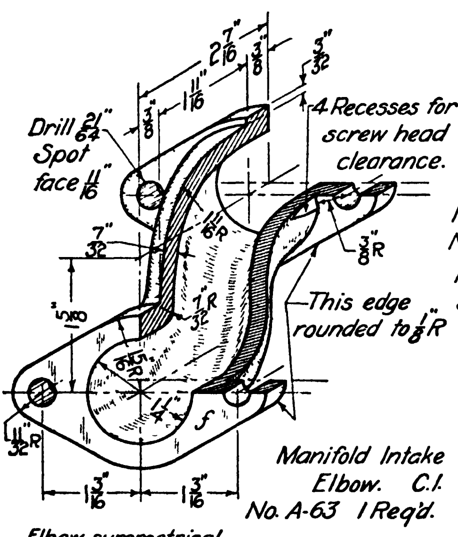


Fig. 50.

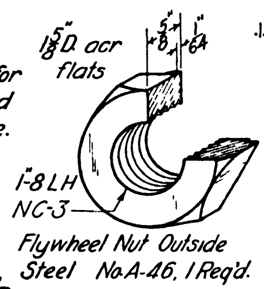


Fig. 51.

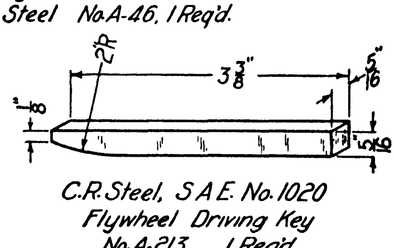


Fig. 52.

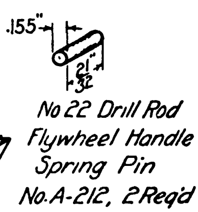
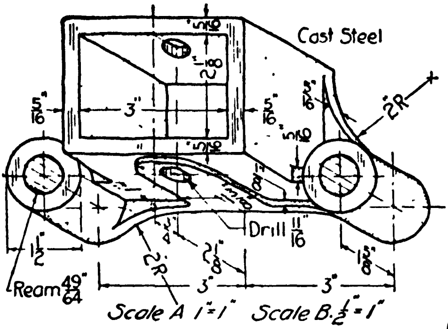
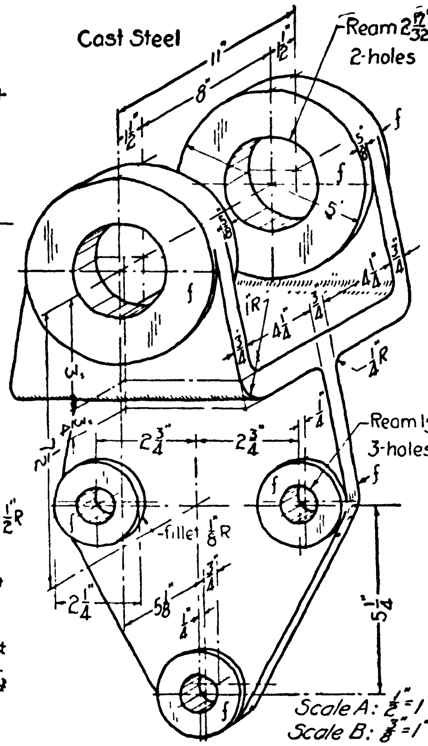


Fig. 53.

25. Make a working drawing of the object shown in Fig. 47.
26. Same as Prob. 25, Fig. 48.
27. Same as Prob. 25, Fig. 49.
28. Same as Prob. 25, Fig. 50.
29. Same as Prob. 25, Fig. 51.





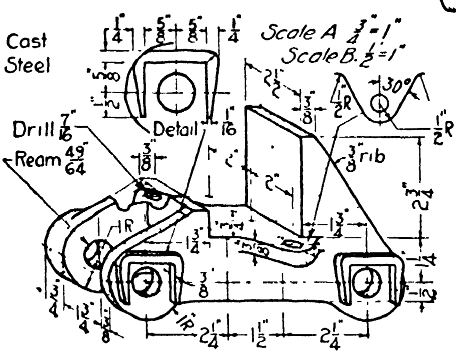


FIG. 54. Chain link attachment.
FIG. 55. Chain link attachment.

FIG. 56. Reverse lever fulcrum.

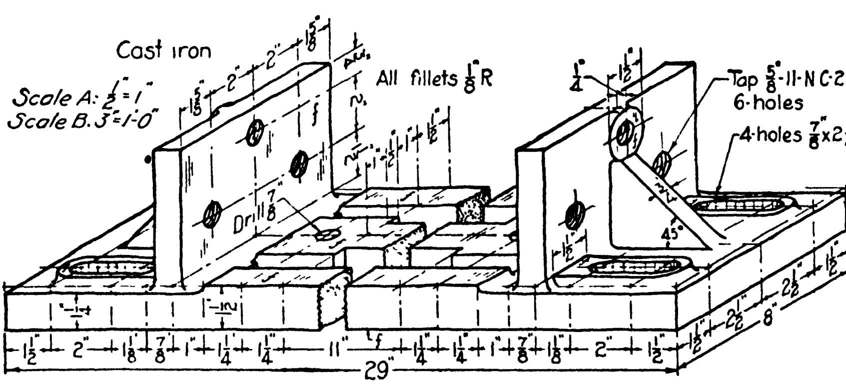


FIG. 57. Pillow block base.

30. Make a working drawing of the object shown in Fig. 54.
31. Same as Prob. 30, Fig. 55.
32. Same as Prob. 30, Fig. 56.
33. Same as Prob. 30, Fig. 57.

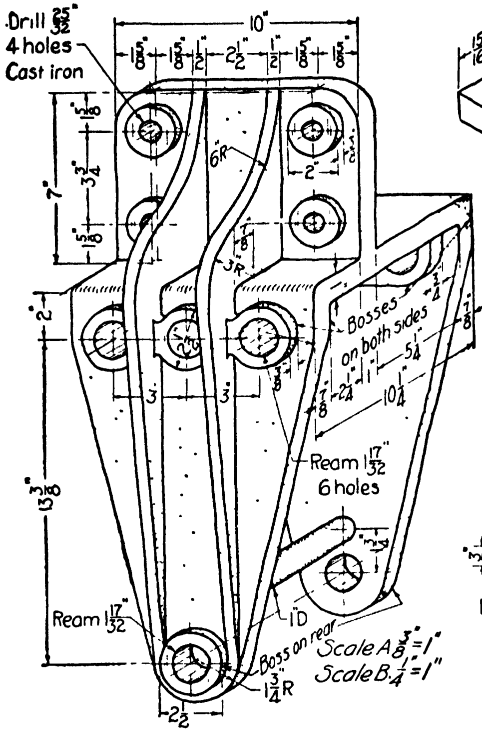
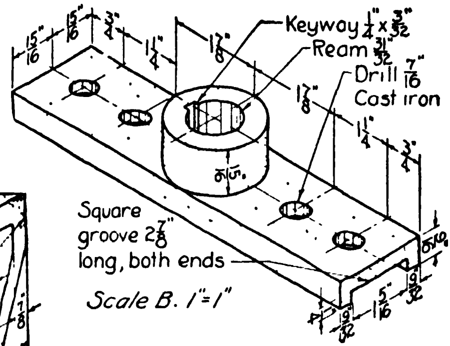


FIG. 58. Equalizer fulcrum.



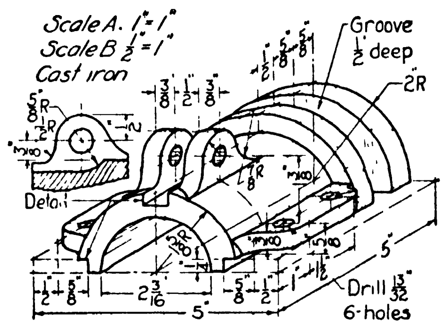


FIG. 59. Double lever end.
FIG. 60. Clutch cone.

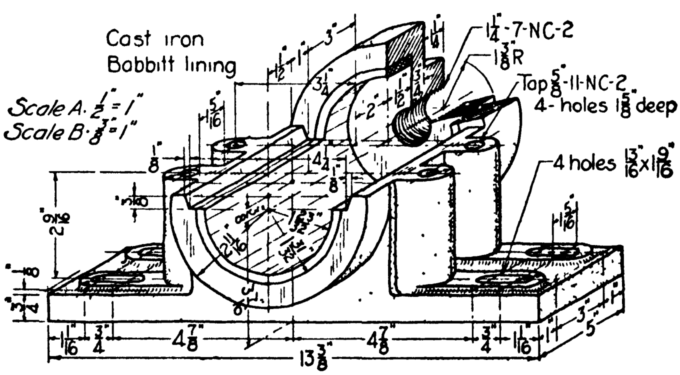


FIG. 61. End bearing.

34. Make a working drawing of the object shown in Fig. 58.
35. Same as Prob. 34, Fig. 59.
36. Same as Prob. 34, Fig. 60.
37. Same as Prob. 34, Fig. 61.

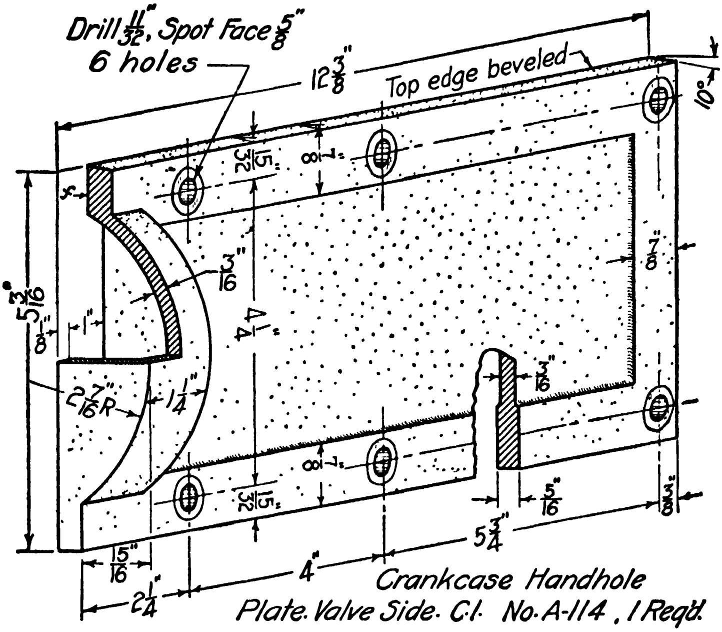


FIG. 62.

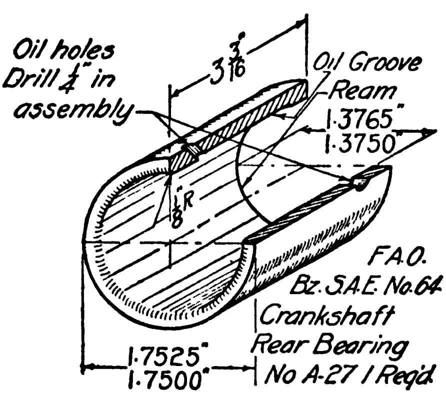


FIG. 63.

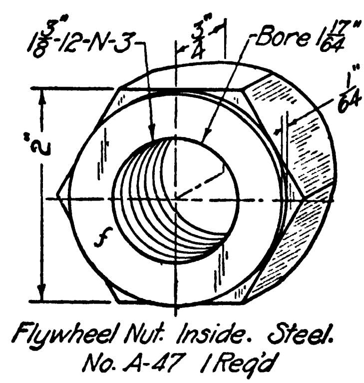


FIG. 64.

38. Make a working drawing of the object shown in Fig. 62.

39. Same as Prob. 38, Fig. 63.

40. Same as Prob. 38, Fig. 64.

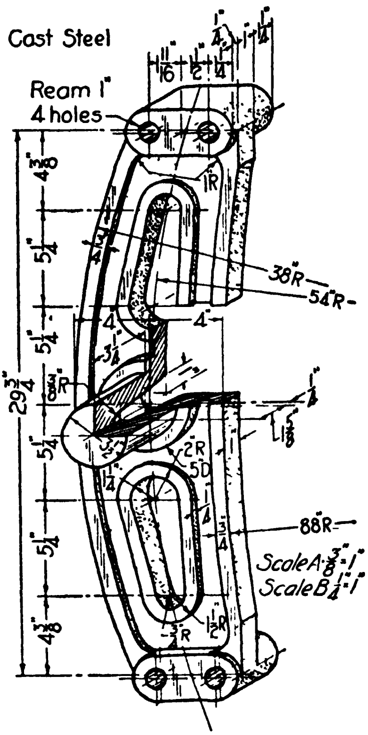


Fig. 65. Walscheart gear link.

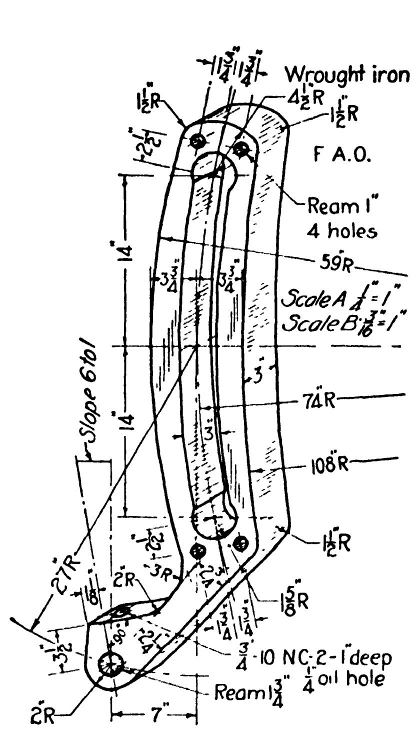


Fig. 66. Link.

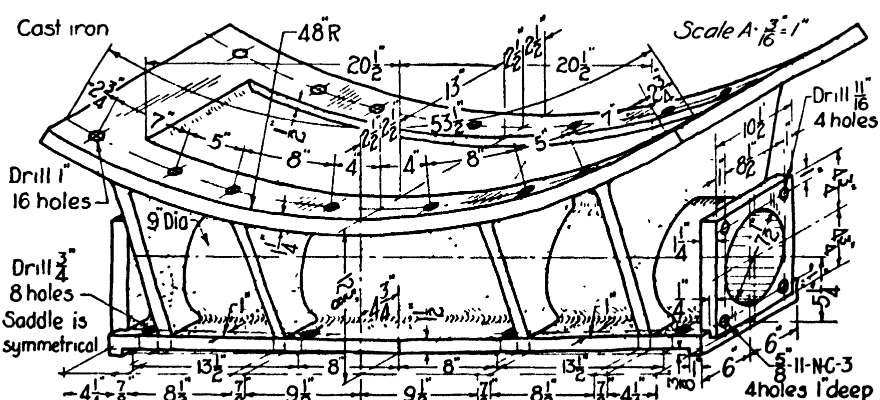


Fig. 67. Main boiler bearing saddle.

41. Make a working drawing of the object shown in Fig. 65.
42. Same as Prob. 41, Fig. 66.
43. Same as Prob. 41, Fig. 67.

(Beam compass required in Probs. 41 to 43.)

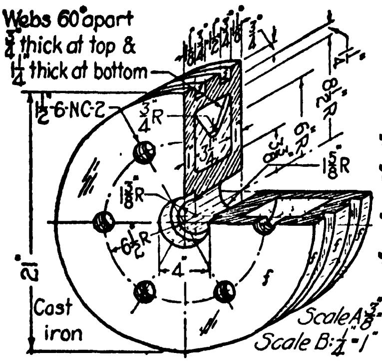


FIG. 68. Double plate piston.

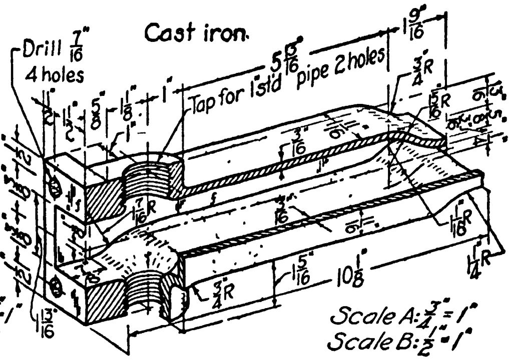


FIG. 69. Oil burner (outside).

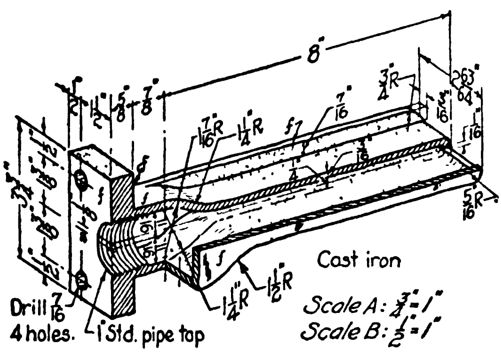


FIG. 70. Oil burner (inside).

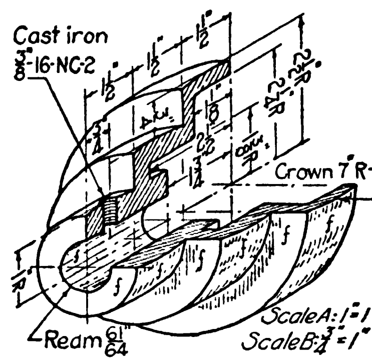


FIG. 71. Cone pulley.

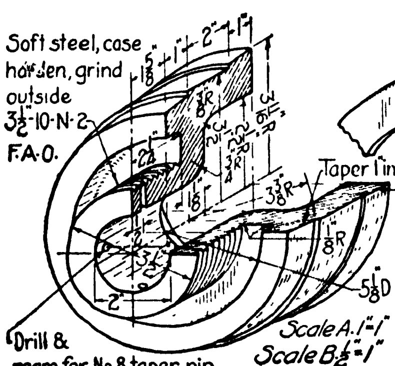


FIG. 72.

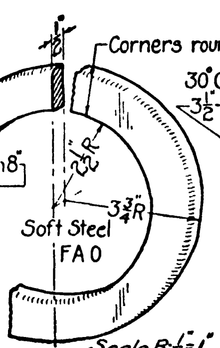


FIG. 73.

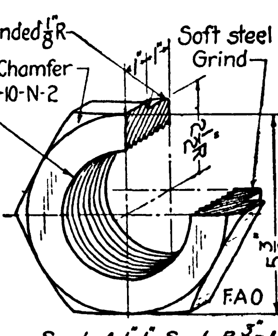


FIG. 74.

44. Make a working drawing of the object shown in Fig. 68.
45. Same as Prob. 44, Fig. 69.
46. Same as Prob. 44, Fig. 70.
47. Same as Prob. 44, Fig. 71.
48. Same as Prob. 44, Fig. 72.
49. Same as Prob. 44, Fig. 73.
50. Same as Prob. 44, Fig. 74.

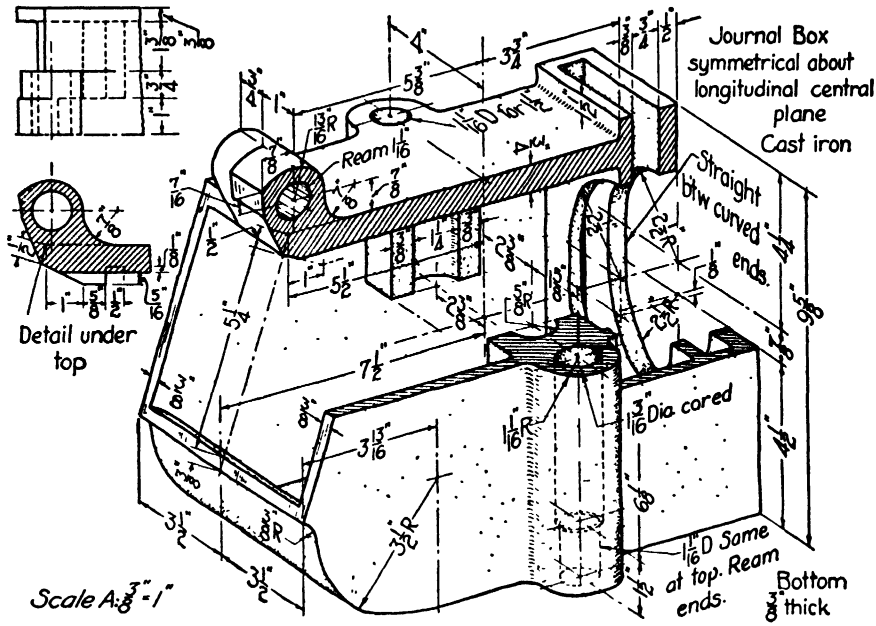


Fig. 75. Railway car journal box.

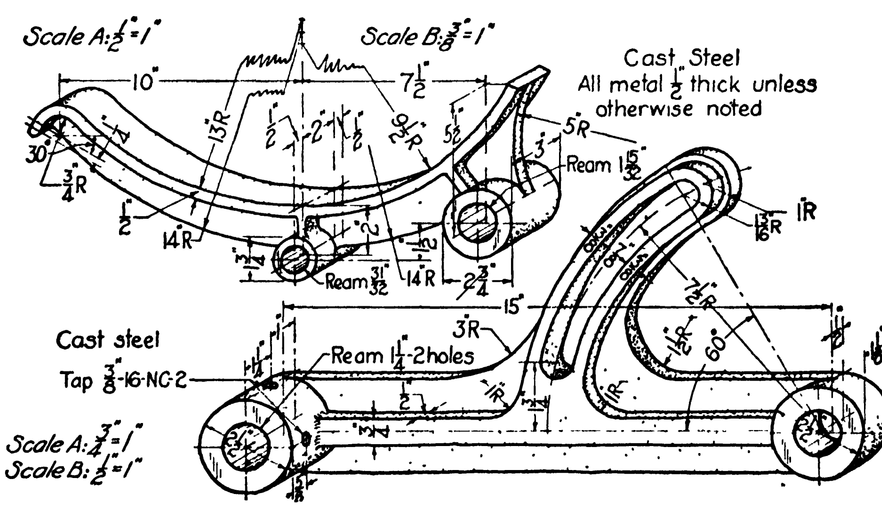


Fig. 76. Barrel carrier. Fig. 77. Belt tightener.

51. Make a working drawing of the object shown in Fig. 75.
52. Same as Prob. 51, Fig. 76. 53. Same as Prob. 51, Fig. 77.

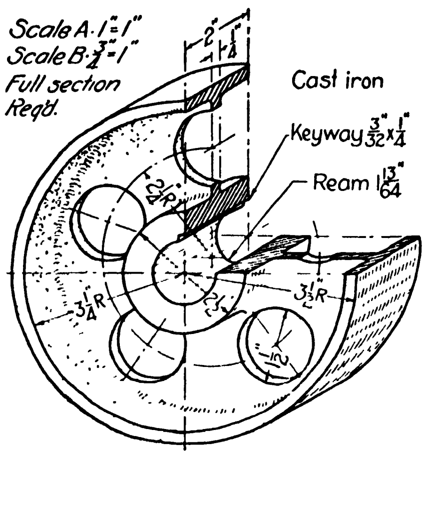


FIG. 78. Pulley.

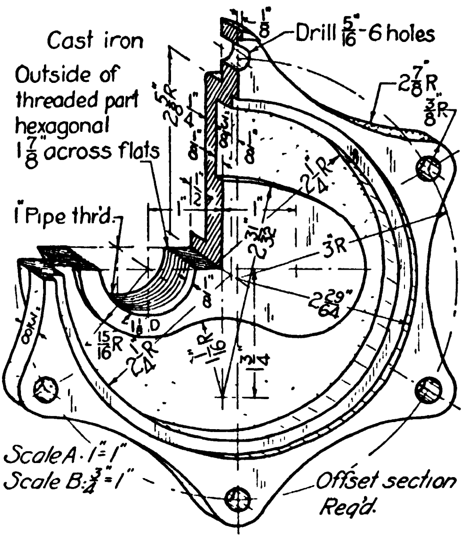


FIG. 79. Quick opening valve body (rear).

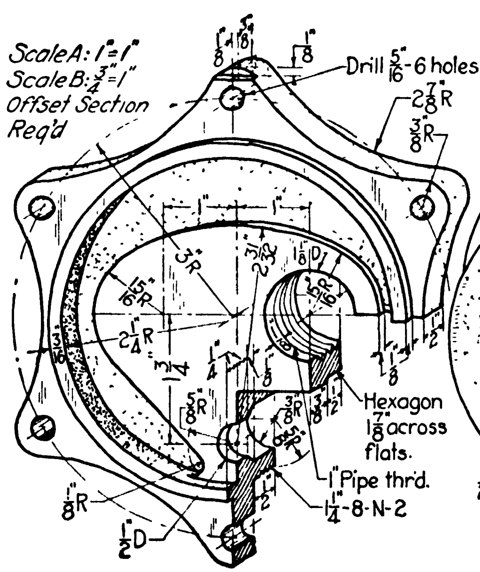


FIG. 80. Quick opening valve body (front).

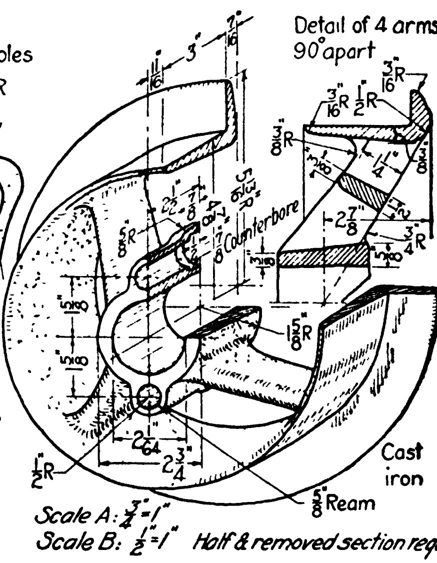


FIG. 81. Piston valve end.

54. Make a working drawing of the object shown in Fig. 78.
55. Same as Prob. 54, Fig. 79.
56. Same as Prob. 54, Fig. 80.
57. Same as Prob. 54, Fig. 81.

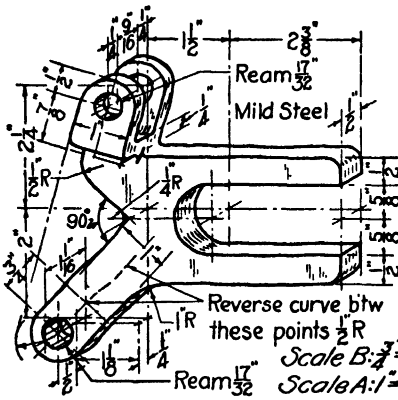


Fig. 82. Valve stem clamp.

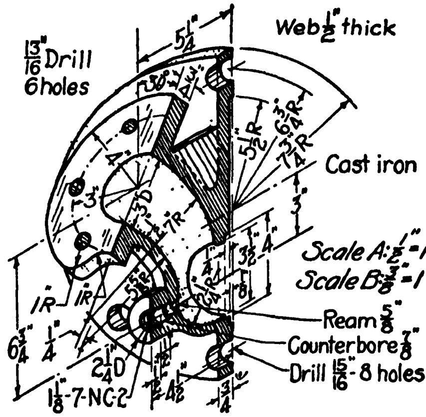


Fig. 83. Tank valve (body).

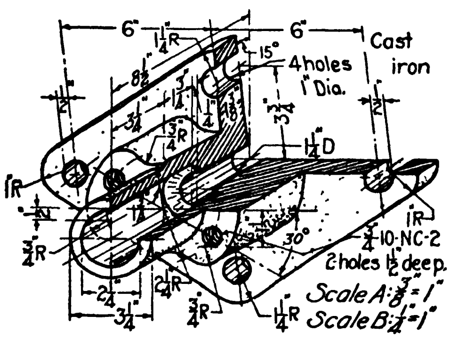


Fig. 84. Throttle valve stuffing box.

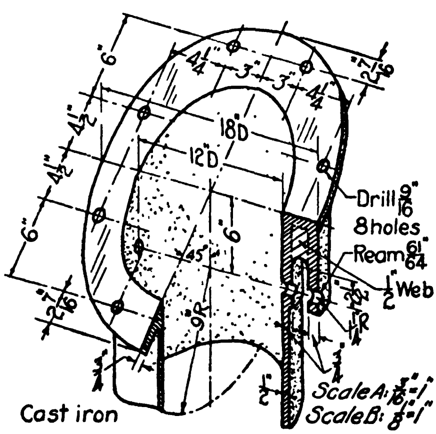


Fig. 85. Stoker gate.

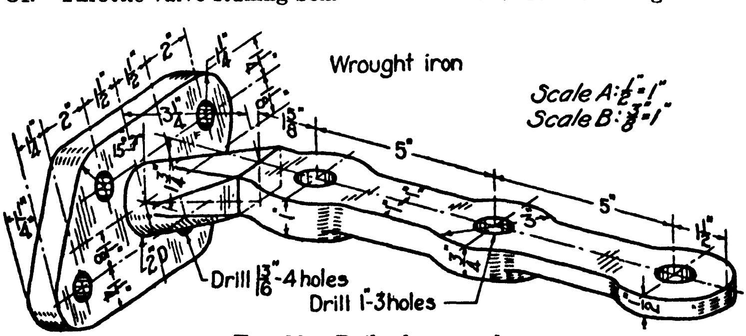


Fig. 86. Boiler brace end.

58. Make a working drawing of the object shown in Fig. 82.
59. Same as Prob. 58, Fig. 83.
60. Same as Prob. 58, Fig. 84.
61. Same as Prob. 58, Fig. 85.
62. Same as Prob. 58, Fig. 86.

142a. Production Dimensioning. — The following problems include all the parts of a two-cylinder marine engine except a few gaskets and the timer. The function of each piece can be identified in the assembly drawing in Fig. 141. Rule guide lines for the dimensions expressing limits and for the others if necessary. Use a 4 or 5 thirty-seconds guide line. The specification of parts required on the figures is for one motor. Where no specification is given, only one part is required.

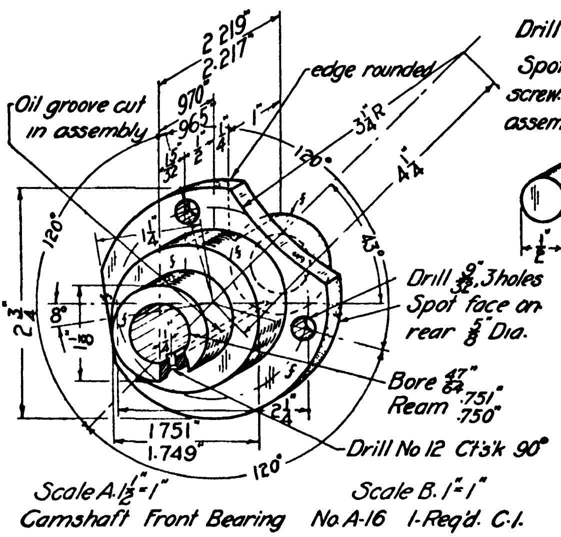


FIG. 87.

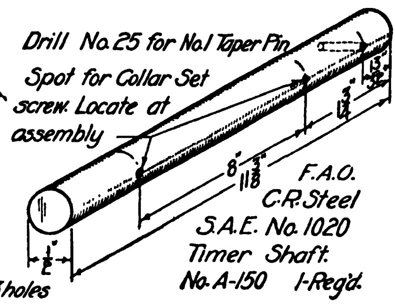


FIG. 88.

63. Make a working drawing of the object shown in Fig. 87.
64. Same as Prob. 63, Fig. 88.

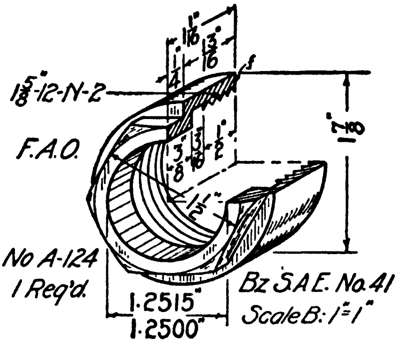


Fig. 89. Pump packing gland.

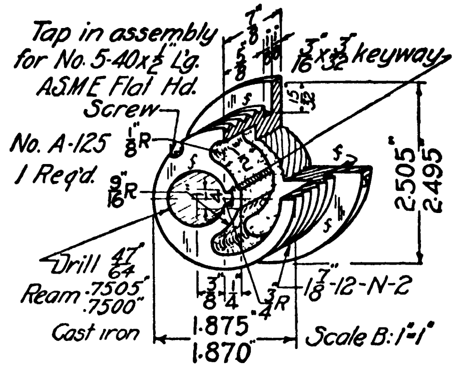


Fig. 90. Pump eccentric (inside).

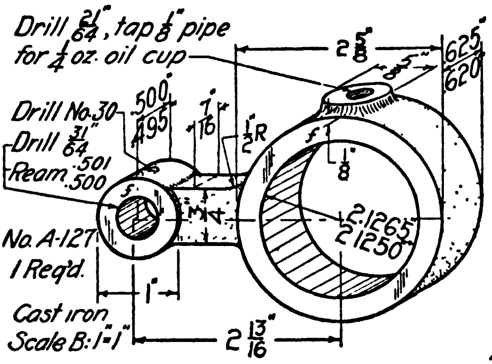


Fig. 91. Pump eccentric strap.

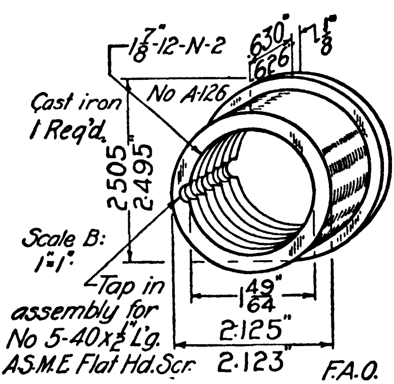


Fig. 92. Pump eccentric (outside).

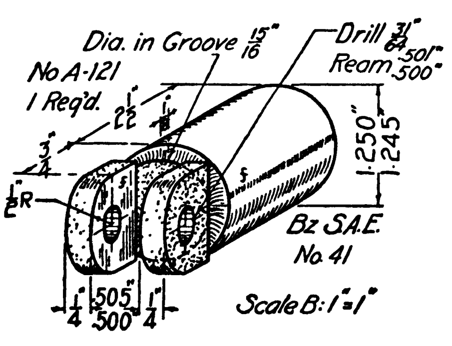


Fig. 93. Pump plunger.

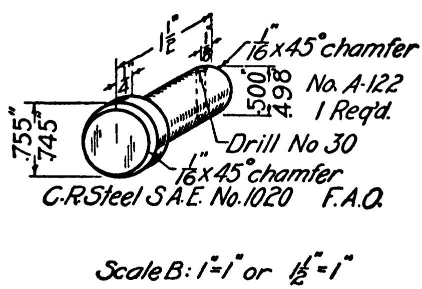


Fig. 94. Pump plunger bolt.

65. Make a working drawing of the object shown in Fig. 89.
66. Same as Prob. 65, Fig. 90.
67. Same as Prob. 65, Fig. 91.
68. Same as Prob. 65, Fig. 92.
69. Same as Prob. 65, Fig. 93.
70. Same as Prob. 65, Fig. 94.

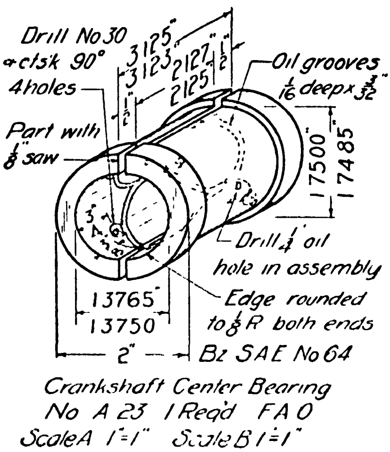


FIG. 95.

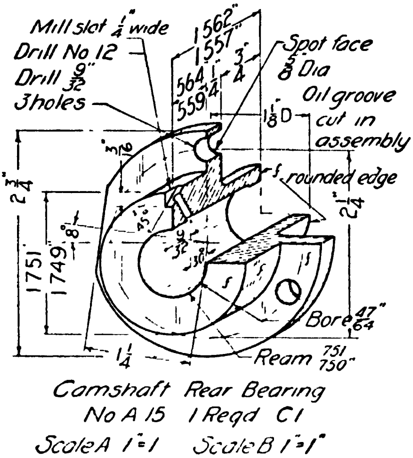


FIG. 96.

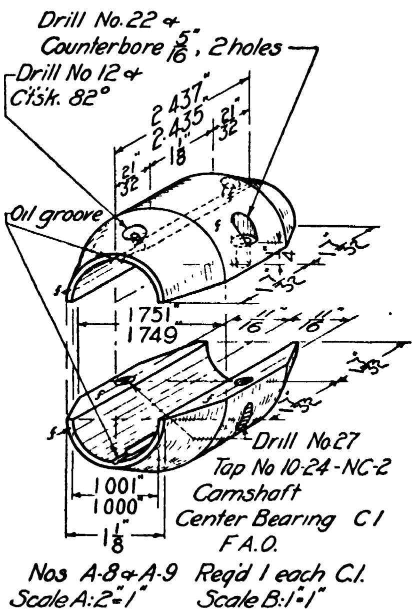


FIG. 97.

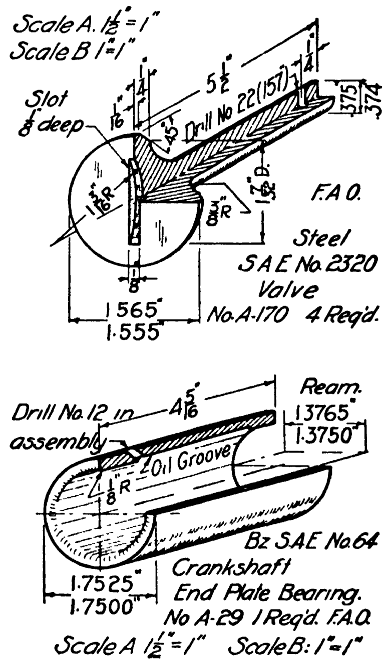


FIG. 98.
FIG. 99.

71. Make a working drawing of the object shown in Fig. 95.
72. Same as Prob. 71, Fig. 96.
73. Same as Prob. 71, Fig. 97.
74. Same as Prob. 71, Fig. 98.
75. Same as Prob. 71, Fig. 99.

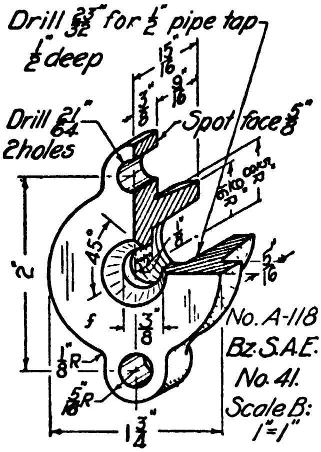


FIG. 100. Pump intake flange.

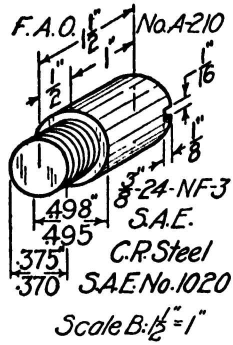


FIG. 101. Flywheel handle hinge pin.

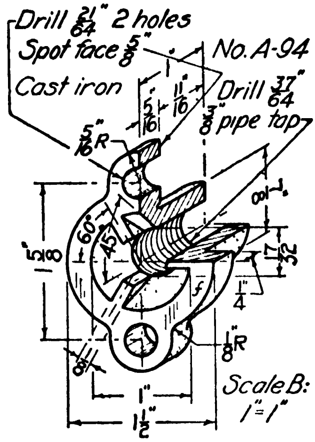


FIG. 102. Pump outlet flange.

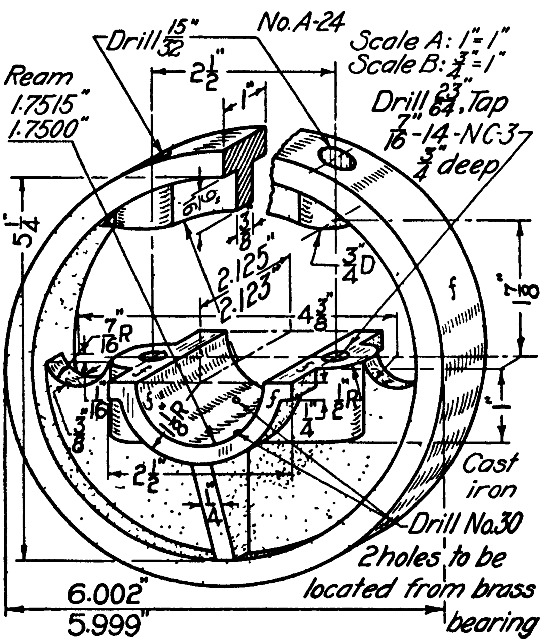


FIG. 103. Crankshaft center bearing support.

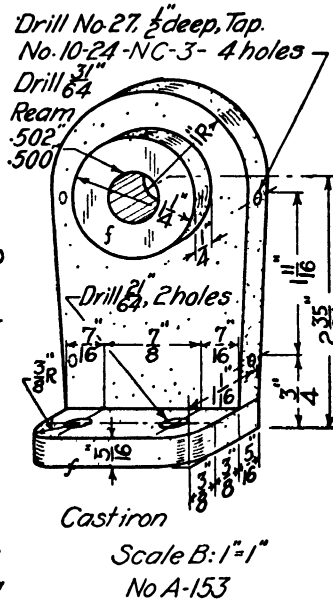


FIG. 104. Timer shaft bracket (lower).

76. Make a working drawing of the object shown in Fig. 100.
77. Same as Prob. 76, Fig. 101.
78. Same as Prob. 76, Fig. 102.
79. Same as Prob. 76, Fig. 103.
80. Same as Prob. 76, Fig. 104.

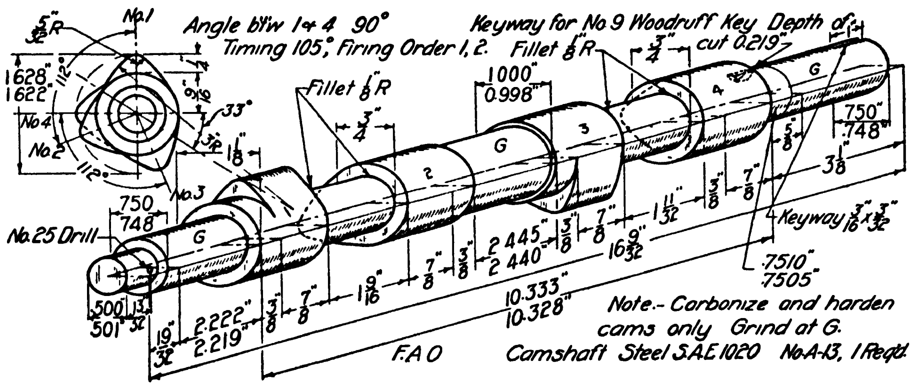


Fig. 105.

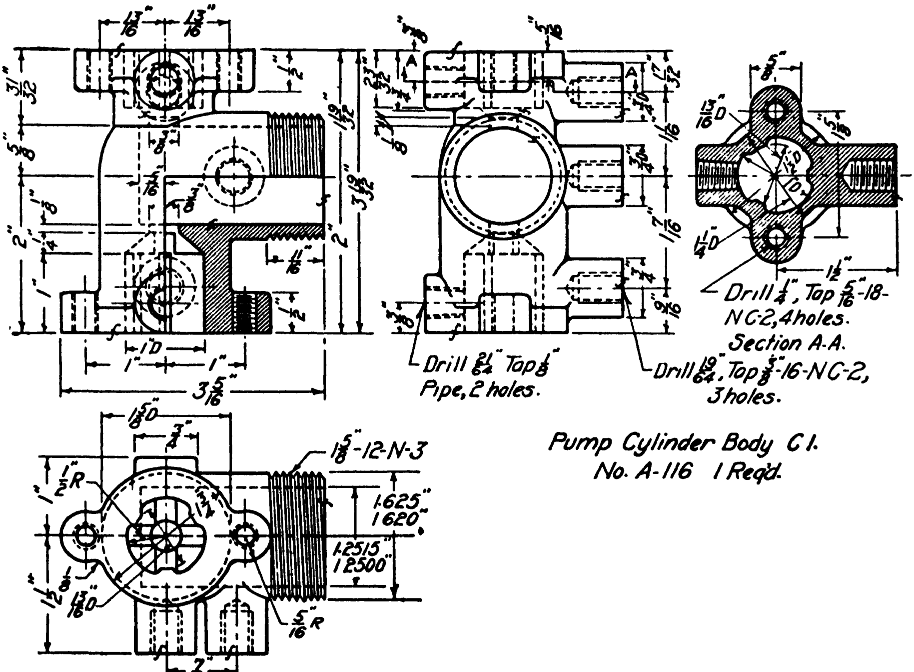


Fig. 106.

81. Make a working drawing of the camshaft shown in Fig. 105.
82. Make a working drawing of the pump cylinder body shown in Fig. 106.

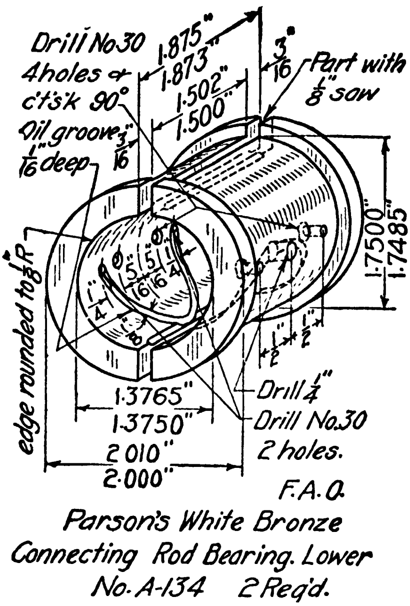


Fig. 107. Connecting rod bearing (lower).

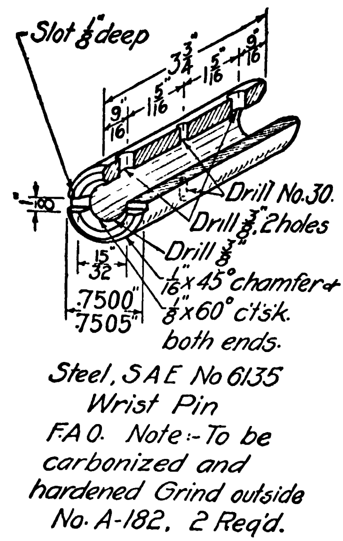


Fig. 108. Wrist pin.

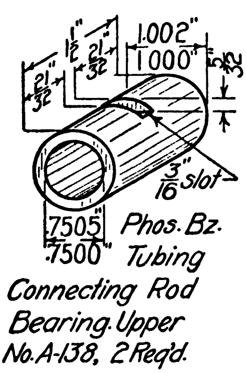


Fig. 109. Connecting rod bearing (upper).

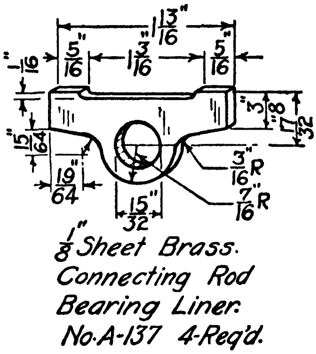


Fig. 110. Connecting rod bearing liner.

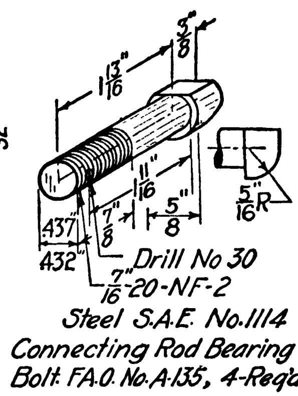


Fig. 111. Connecting rod bearing bolt.

83. Make a working drawing of the object shown in Fig. 107.
84. Same as Prob. 83, Fig. 108.
85. Same as Prob. 83, Fig. 109.
86. Same as Prob. 83, Fig. 110.
87. Same as Prob. 83, Fig. 111.

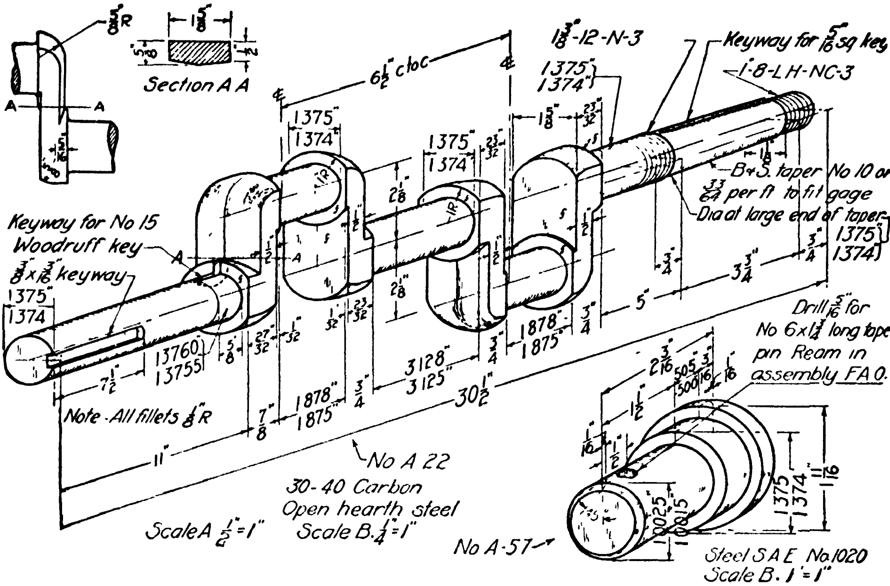


Fig. 112. Crankshaft.

Fig. 113. Camshaft intermediate gear stud.

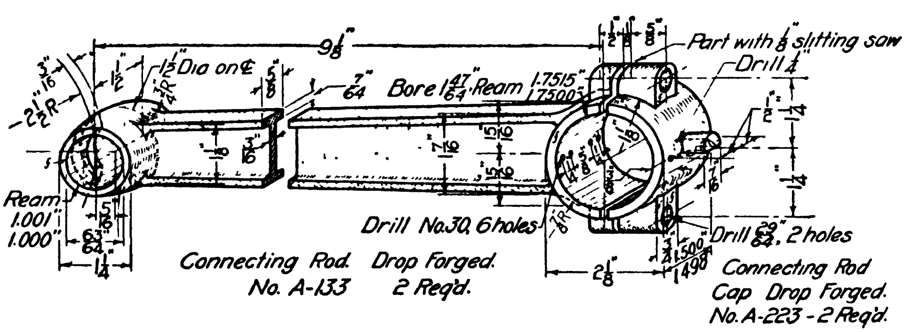


Fig. 114.

88. Make a working drawing of the object shown in Fig. 112.
89. Same as Prob. 88, Fig. 113. 90. Same as Prob. 88, Fig. 114.

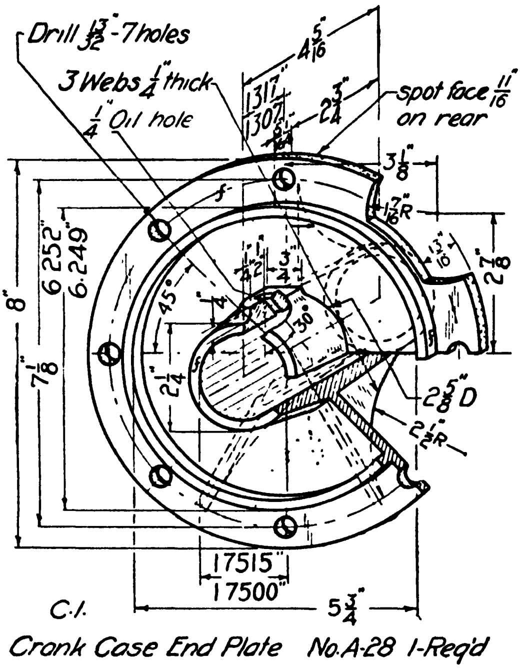


Fig. 115.

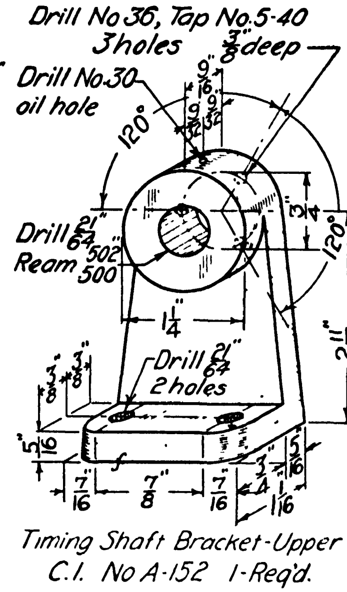


Fig. 116.

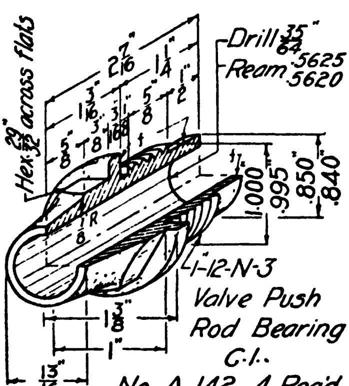


Fig. 117.

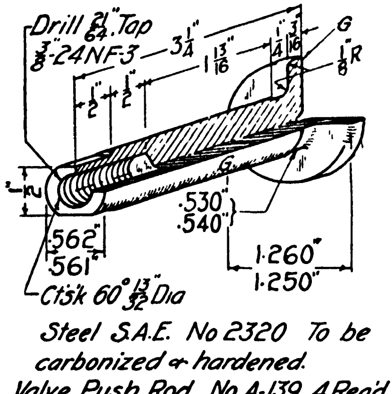


Fig. 118.

91. Make a working drawing of the object shown in Fig. 115.
92. Same as Prob. 91, Fig. 116.
93. Same as Prob. 91, Fig. 117.
94. Same as Prob. 91, Fig. 118.

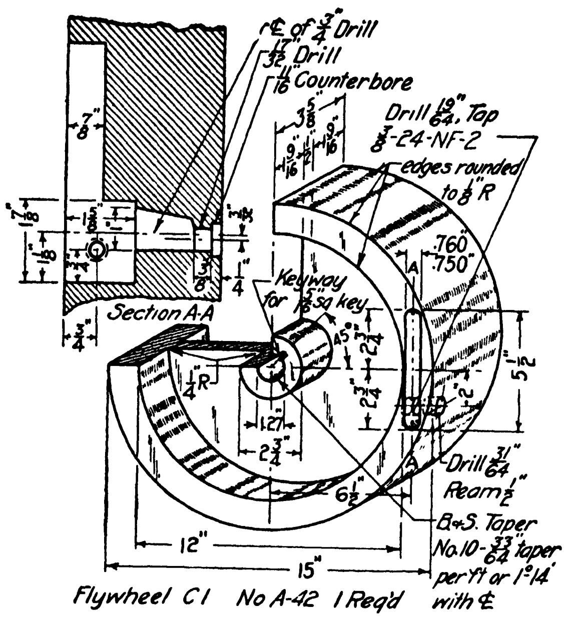
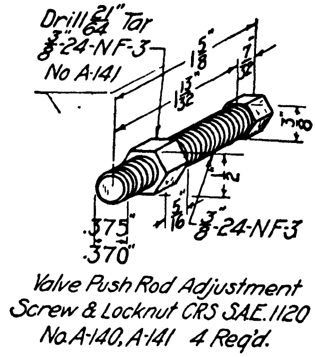


FIG. 119.



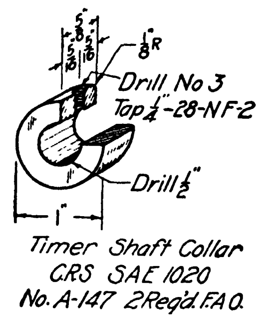


FIG. 120.
FIG. 121.

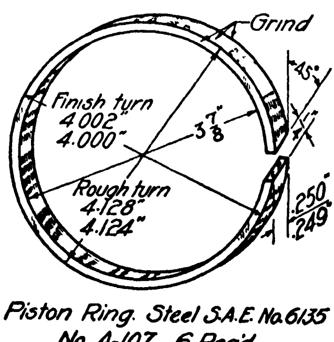


FIG. 122.

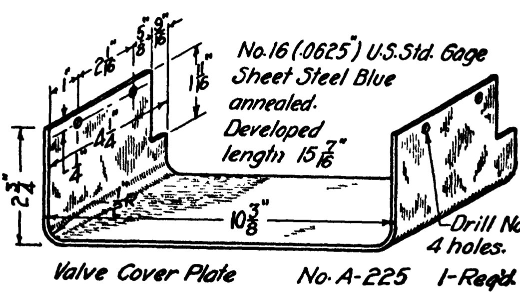


FIG. 123.

95. Make a working drawing of the object shown in Fig. 119.
96. Same as Prob. 95, Fig. 120.
97. Same as Prob. 95, Fig. 121.
98. Same as Prob. 95, Fig. 122.
99. Same as Prob. 95, Fig. 123.

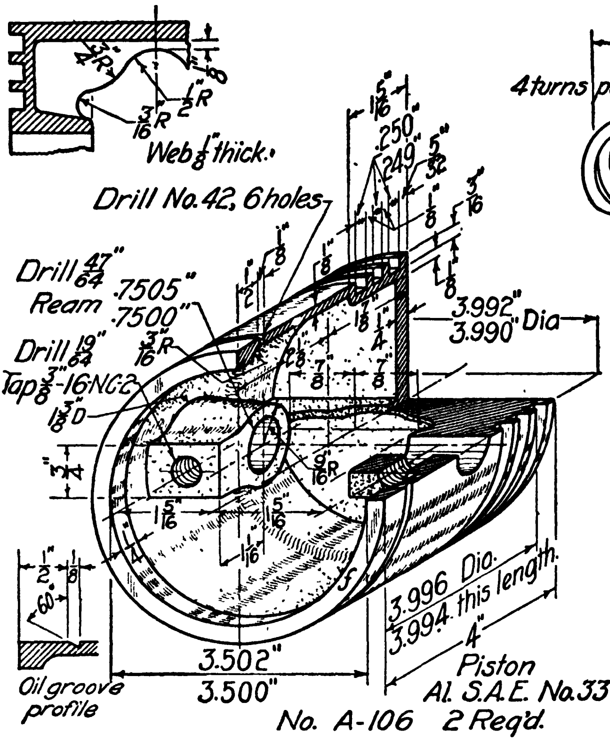
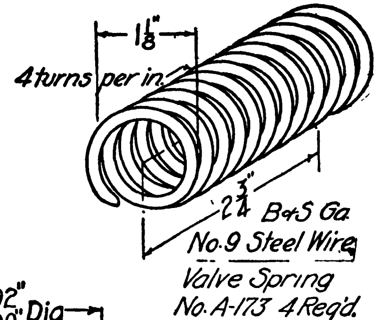


FIG. 124.



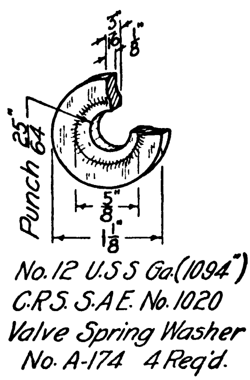


FIG. 125.
FIG. 126.

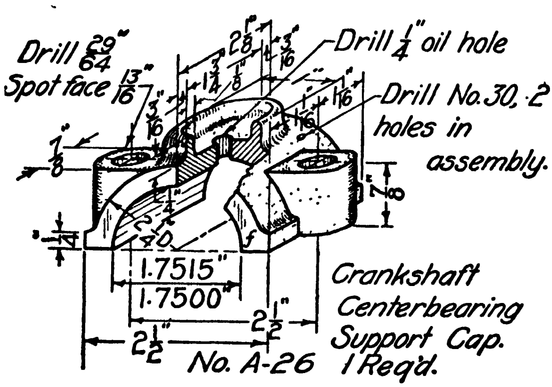
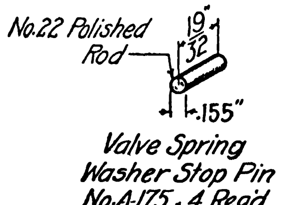


FIG. 127.



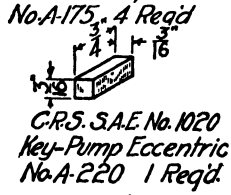


FIG. 128.
FIG. 129.

100. Make a working drawing of the object shown in Fig. 124.
101. Same as Prob. 100, Fig. 125. **102.** Same as Prob. 100, Fig. 127.

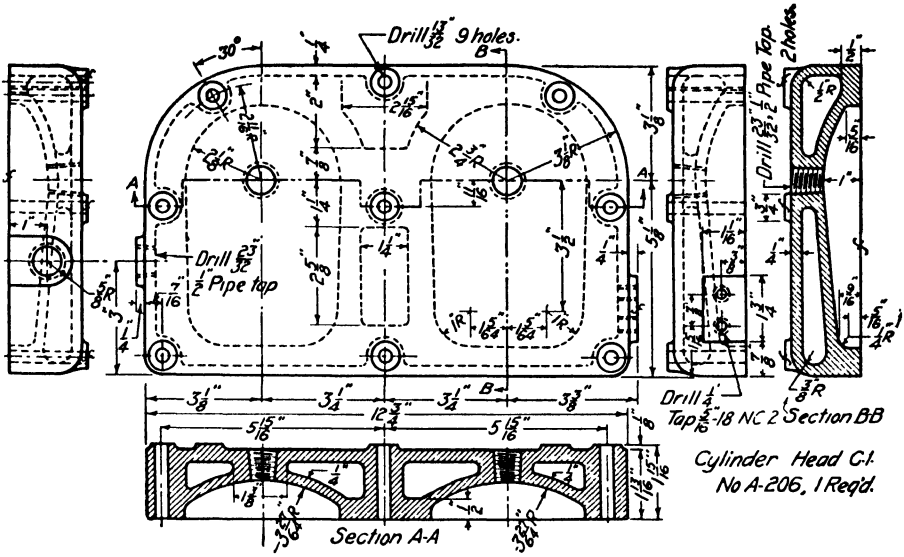


FIG. 130.

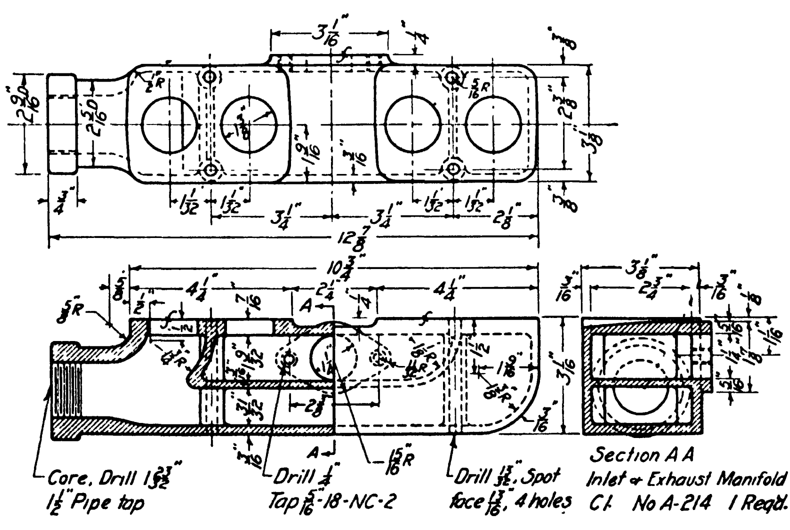


FIG. 131.

103. Make a working drawing of the cylinder head shown in Fig. 130.
104. Make a working drawing of the manifold shown in Fig. 131.

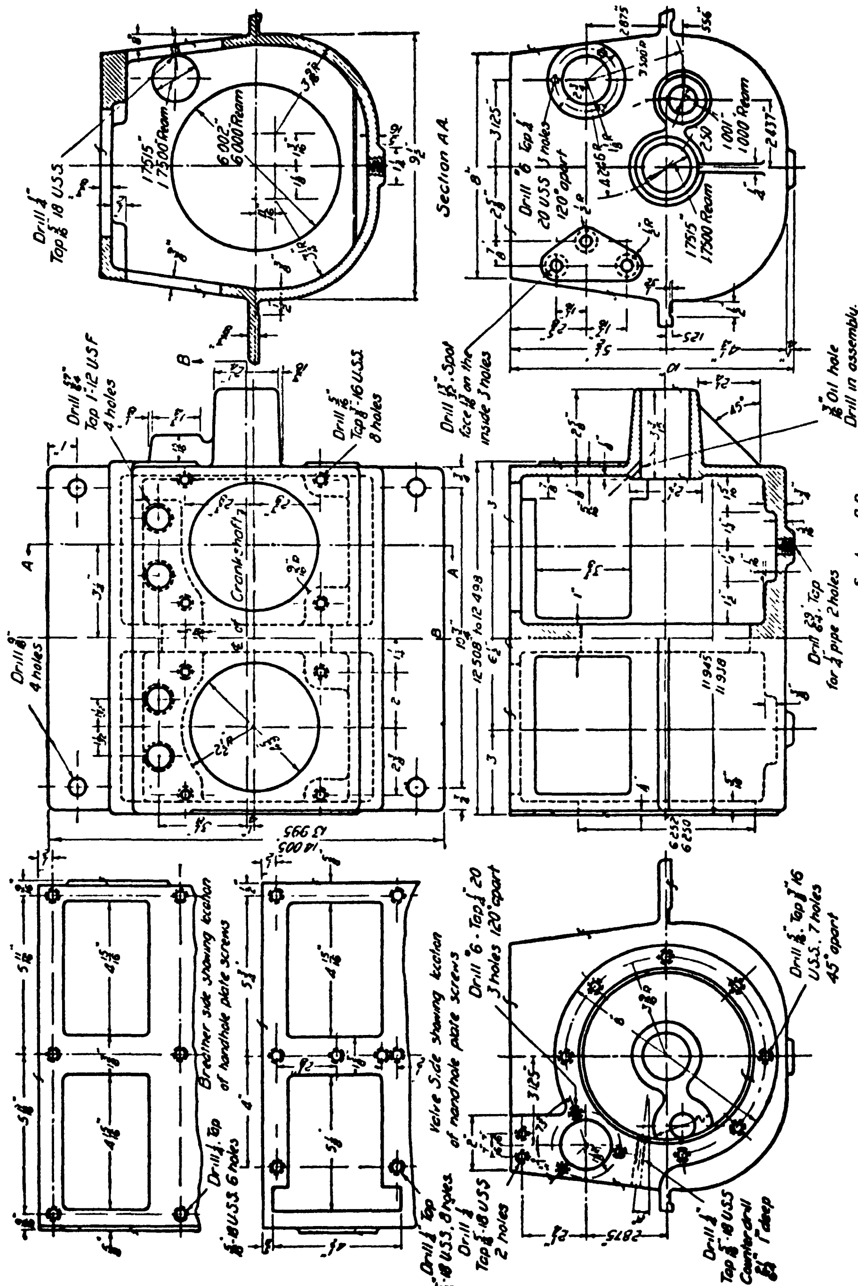


FIG. 132.

105. Make a working drawing of the crankcase shown in Fig. 132.

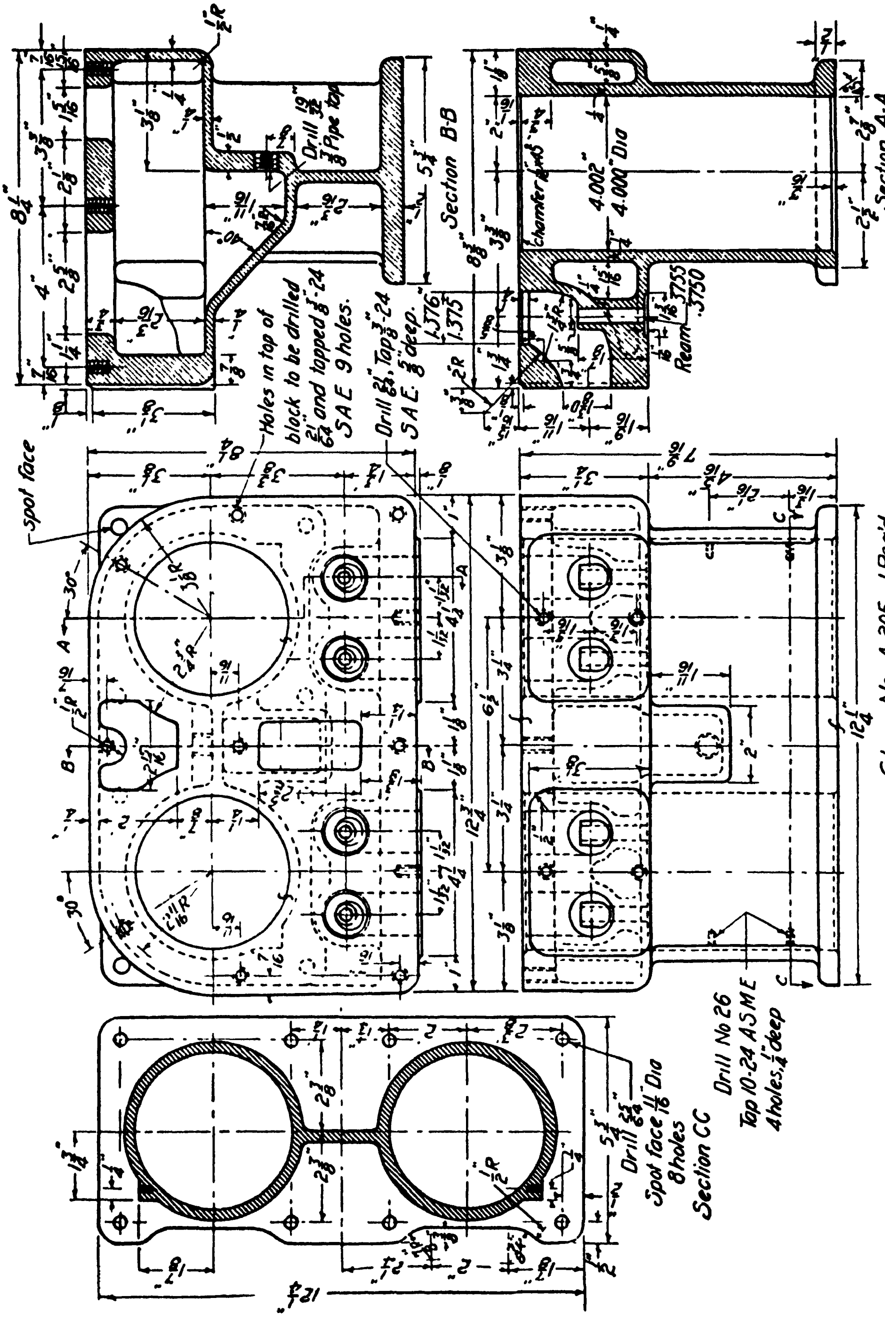


FIG. 133. Cylinder block.

106. Make a working drawing of the cylinder block shown in Fig. 133.

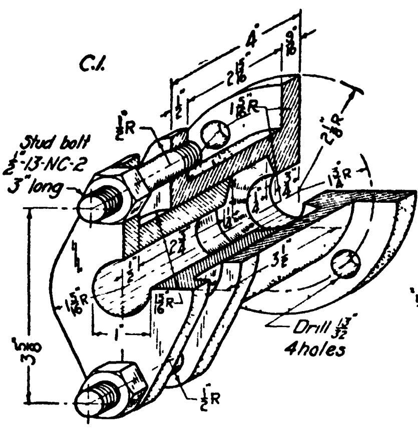


FIG. 134. Stuffing box.

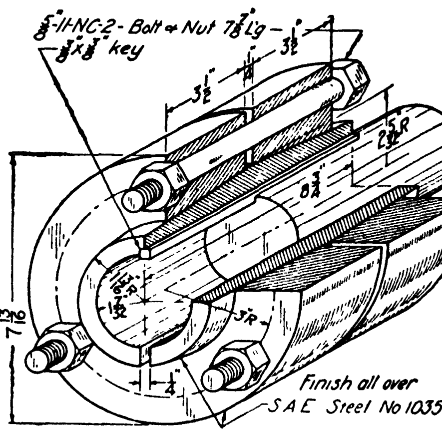


FIG. 135. Double cone coupler.

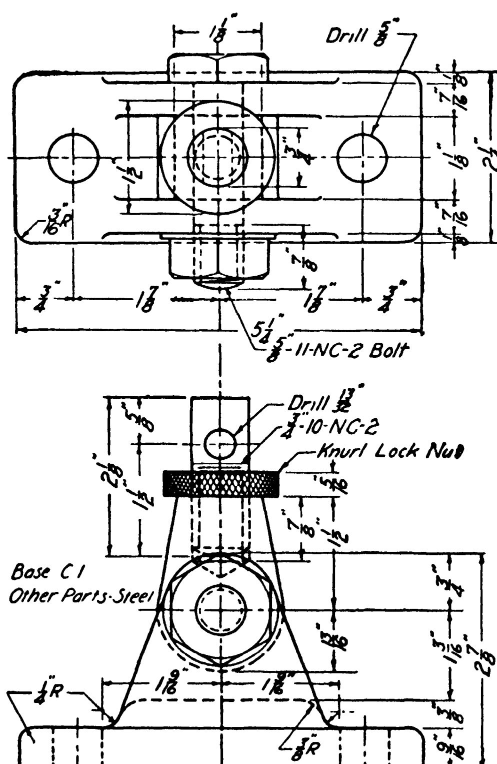


FIG. 136. Planer jack.

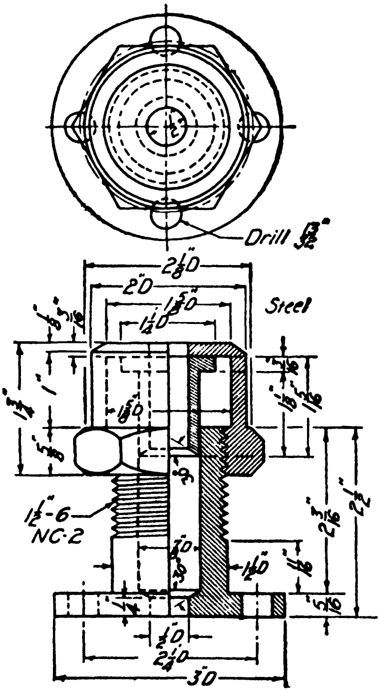


FIG. 137. Stuffing box.

107. Make a complete set of details of the object shown in Fig. 134.
108. Same as Prob. 107, Fig. 135.
109. Same as Prob. 107, Fig. 136.
110. Same as Prob. 107, Fig. 137.

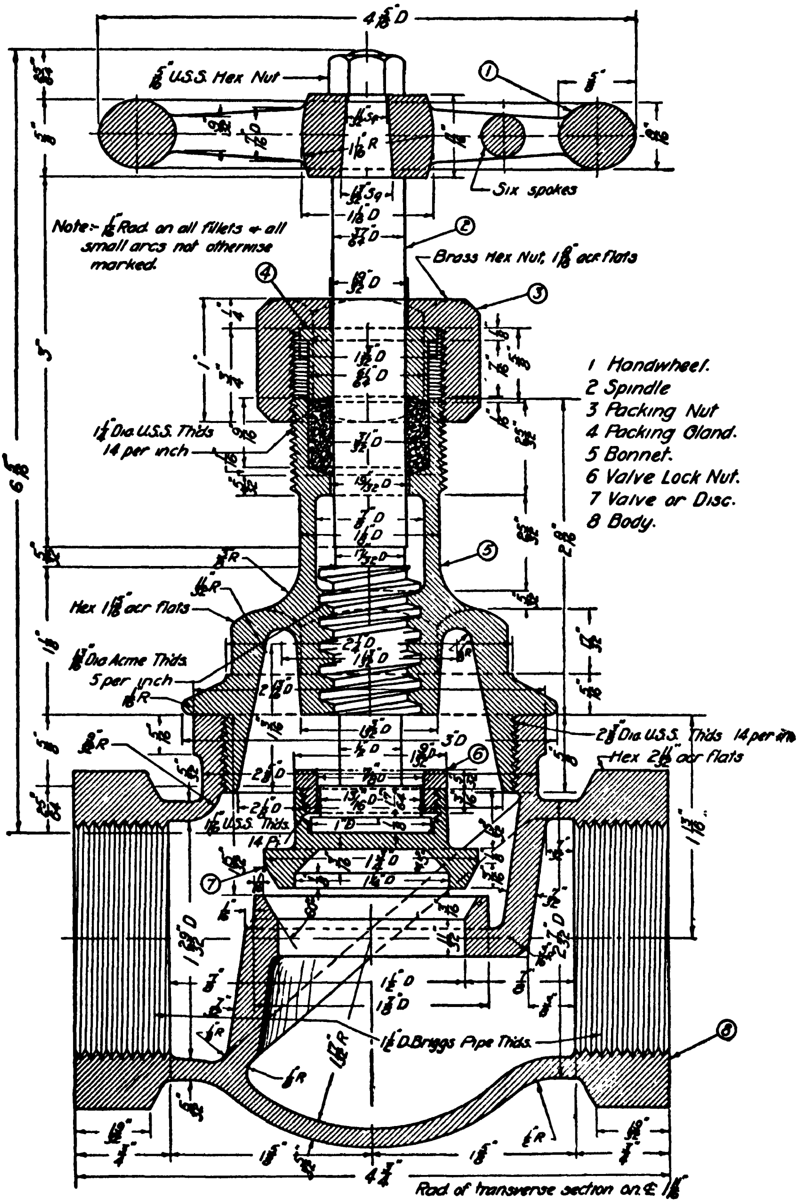


FIG. 138. Globe valve.

111. Make a complete set of details of the valve shown in Fig. 138.
112. Make a working drawing of Part No. 1, Fig. 138.
113. Same as Prob. 112, Part No. 2.
114. Same as Prob. 112, Part No. 3.
115. Same as Prob. 112, Part No. 4.
116. Same as Prob. 112, Part No. 5.
117. Same as Prob. 112, Part No. 6.
118. Same as Prob. 112, Part No. 7.
119. Same as Prob. 112, Part No. 8.

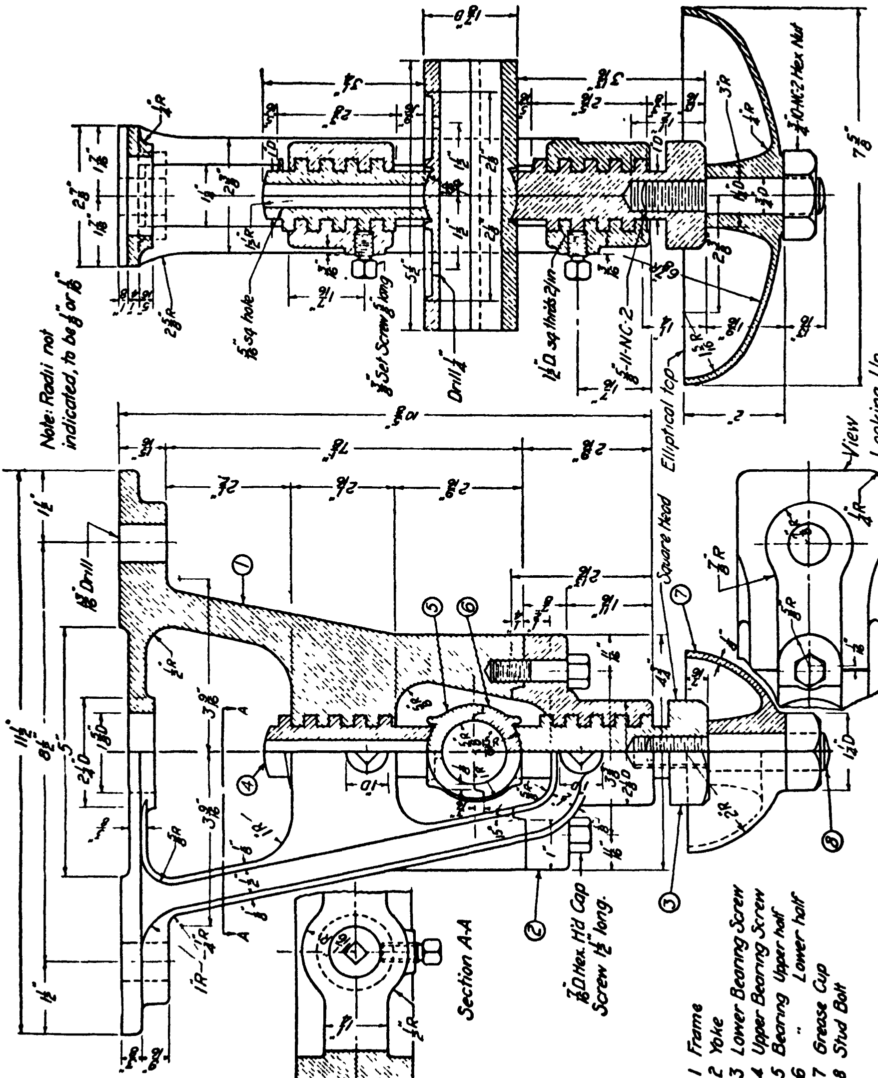


FIG. 139. Shaft hanger.

120. Make a complete set of details of the hanger shown in Fig. 139.
121. Make a working drawing of Part No. 1, Fig. 139.
122. Same as Prob. 121, Part No. 2.
123. Same as Prob. 121, Part No. 3.
124. Same as Prob. 121, Part No. 4.
125. Same as Prob. 121, Part No. 5.
126. Same as Prob. 121, Part No. 6.
127. Same as Prob. 121, Part No. 7.
128. Same as Prob. 121, Part No. 8.

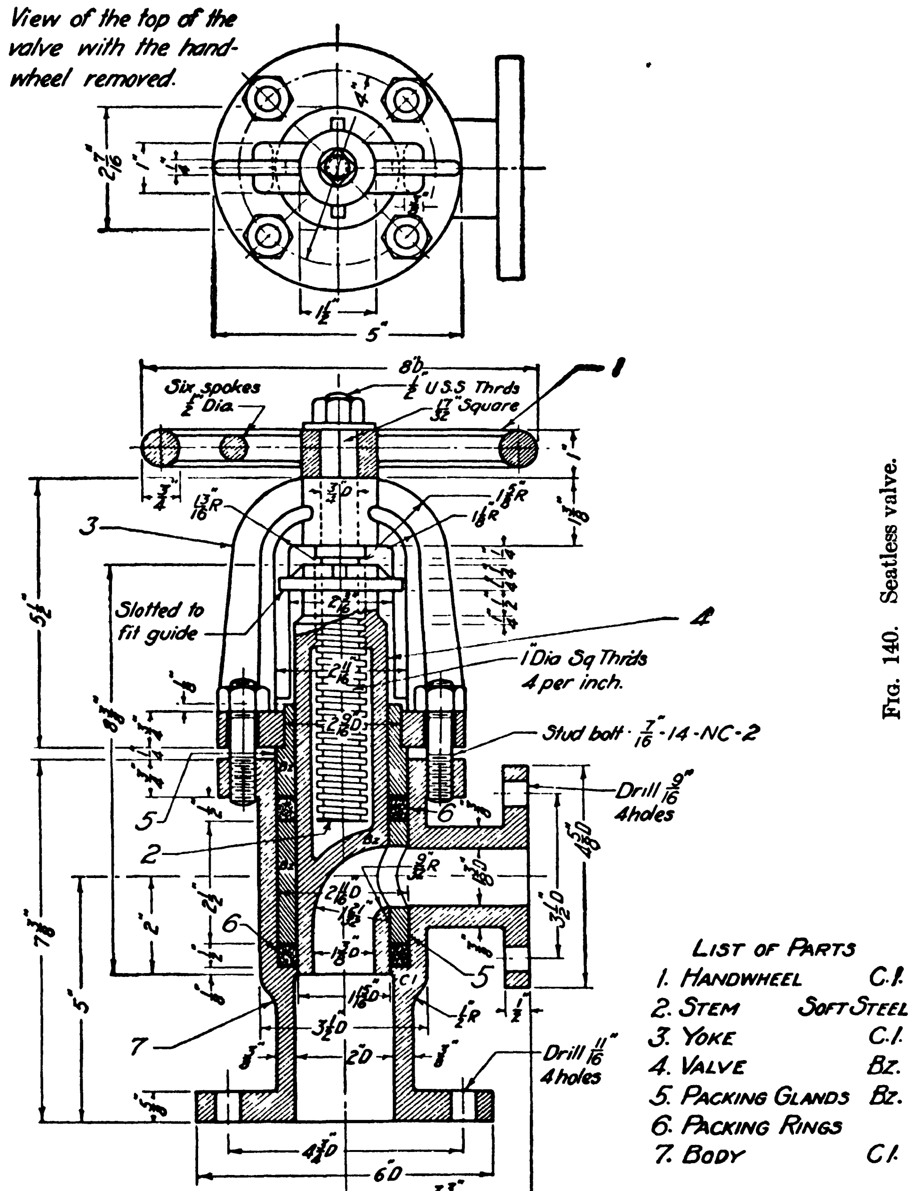


Fig. 140. Seatless valve.

129. Make a complete set of details of the valve shown in Fig. 140.
130. Make a working drawing of Part No. 1, Fig. 140.
131. Same as Prob. 130, Part No. 2.
132. Same as Prob. 130, Part No. 3.
133. Same as Prob. 130, Part No. 4.
134. Same as Prob. 130, Part No. 5.
135. Same as Prob. 130, Part No. 7.

142b. In the following assembly problems, all necessary bolts, screws, nuts, lock nuts, gaskets, etc., necessary for the proper functioning of the parts are to be shown in the assembly whether included in the figures given or not. The figures give only the major parts which are to be shown.

Each assembly should have two views shown, both sectioned unless one will be sufficient. A sheet size of 12″ × 18″ will be satisfactory unless noted otherwise in the problem. A scale suitable to the circumstances should be selected and dimensions omitted.

Each part of an assembly should be marked in some way, and then a list of parts, giving the sheet number of the detail, should be included on the assembly sheet as shown in Fig. 141, changing, of course, the term "Fig. No." to Sheet No.

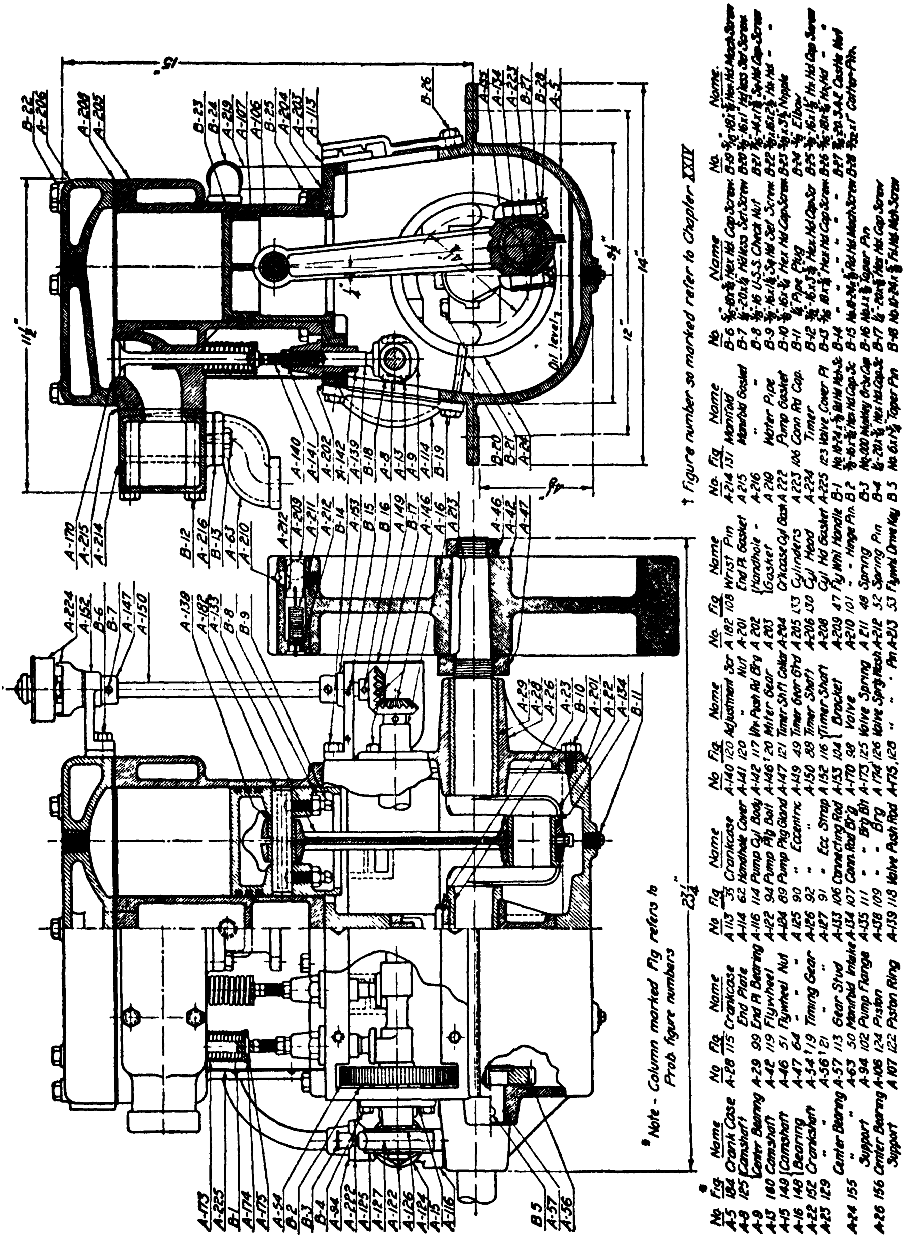


Fig. 141. Marine motor assembly.

136. Make a copy of the assembly shown in Fig. 141.

137. Make an assembly drawing of the water pump and its connecting rod shown in Figs. 89 to 94, 100, 102, and 114. Number parts as shown in the figures. Two $\frac{3}{4}$ inch steel balls are required to act as valves.

138. Make an assembly of the quick-opening valve shown in Figs. 38, 79, and 80. Design a handle to operate the valve and a packing gland and cover for the valve stem to make it water tight.

139. Make an assembly drawing of an oil burner nozzle from Figs. 69 and 70.

140. Design a bearing cap, and make an assembly of the end bearing shown in Fig. 61.

141. Make an assembly of the screw press shown in Fig. 6 of this chapter.

142. Make an assembly drawing of the eccentric shown in Figs. 23, 24, and 25 of Chapter VII. Parts having identical dimensions should be made to fit.

143. Make an assembly drawing of the swivel sheave shown in Figs. 67 and 68 of Chapter V. Two parts like Fig. 67 are required. Design the sheave and shaft. The sheave should hold a $\frac{3}{8}$ inch rope.

144. Make a sub-assembly of the gas engine connecting rod shown in Figs. 106, 107, 108, 109, 110, 111, 122, and 124. The number of parts as given in the figures is for a two-cylinder engine.

145. Make a sub-assembly of the cylinder block and connecting parts as shown in Figs. 98, 116, 123, 125, 126, 128, 130, and 133.

146. Make a sub-assembly of the flywheel and its parts as shown in Figs. 47, 48, 52, 53, 101, and 109.

147. Make a sub-assembly of the crankcase and adjacent parts as shown in Figs. 21, 35, 62, 113, 115, 117, 118, 120, and 132. Select your own scale. (Sheet size 18 × 24.) NOTE: Change design of Fig. 113 to have thread and nut on small end instead of taper pin.

CHAPTER IX

INTERSECTIONS AND DEVELOPMENTS

143. Intersections of Surfaces. — The draftsman is continually encountering the problem of how to represent the outlines of objects which include lines of intersections of geometrical surfaces such as the cylinder, sphere, cone, torus, and other common shapes. The general method for finding the intersection of any two surfaces requires the passing of a plane which will cut straight lines or closed curves from both surfaces that will show in projection as straight lines or circles. These lines, since they lie in the same cutting plane, will intersect in points which lie on the curve of

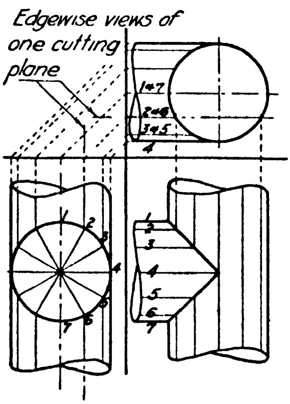


Fig. 1. Intersection of equal cylinders, axes at right angles.

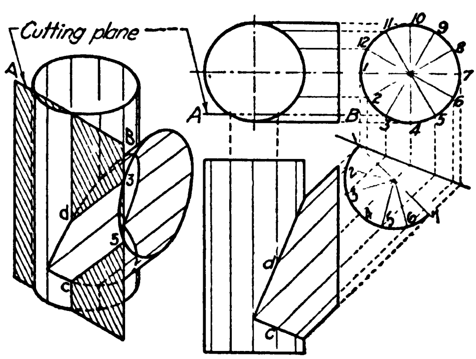


Fig. 2. Intersection of equal cylinders, axes inclined to each other.

intersection. This process of passing a cutting plane is repeated a sufficient number of times to locate accurately the curve of intersection. Figures 1, 2, and 3 illustrate the method both pictorially and orthographically for the case of two cylinders. Attention is called to the scheme of locating the elements of the horizontal and inclined cylinders in these illustrations. Figure 4 illustrates the general method applied to the case of a cone and cylinder. Figure 5 shows the scheme applied to a sphere and prism.

In the five cases mentioned in the preceding paragraph, the cutting planes are parallel and show edgewise in one or another of the views. The lines cut from each surface are easily projected, since they are either straight lines or circles. In Fig. 6, however, the cutting planes are not parallel

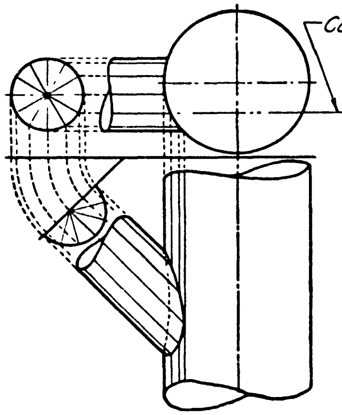


FIG. 3. Intersection of unequal cylinders, axes inclined to each other.

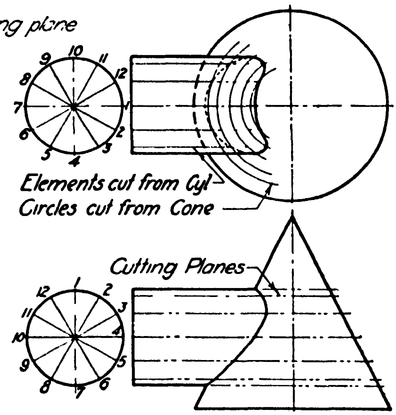


FIG. 4. Intersection of cylinder and cone, axes at right angles.

but all pass through the apex of the cone so that they may cut elements from it. They show edgewise only in an auxiliary view perpendicular to the axis of the cylinder. The projection of the curve of intersection in this view coincides with the projection of the cylinder. The " return " of the necessary points of intersection on the curve to the elevation and plan views, though not shown in the figure, is accomplished by means of the cone elements.

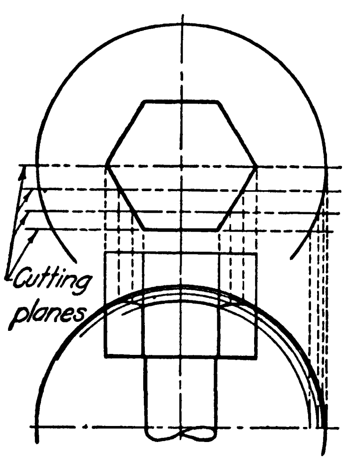


FIG. 5. Intersection of sphere and prism.

144. Prismatic and Pyramidal Surfaces. — With intersecting prisms and pyramids, the process of finding the lines of intersection, though based upon the principles stated above, may be shortened somewhat because the point in which a line pierces a plane surface may be obtained by inspection when an edgewise view of the plane is available. The method of solution is illustrated in Fig. 7, which shows the intersection of two prisms. The top view shows the four faces of the square prism edgewise; hence, the projections of the points in which the three edges of the triangular prism pierce these faces are shown directly in the top view at points *1* to *6*, inclusive, with the points *1′* to *6′* in the front view located on the corresponding projections of the same edge lines of the triangular prism. It remains

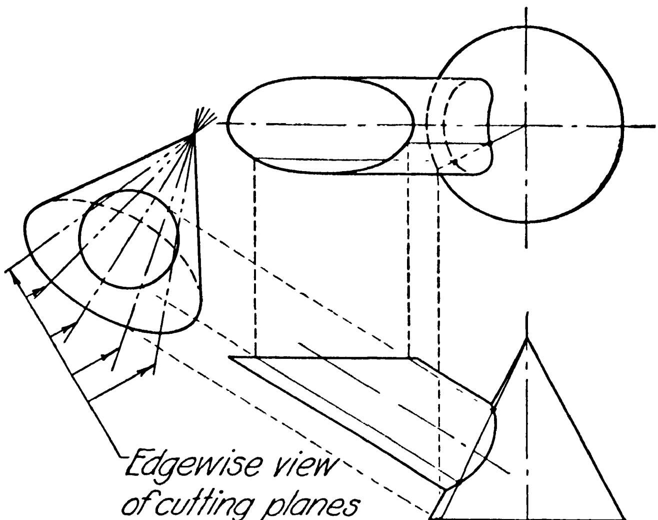


FIG. 6. Auxiliary view used to obtain edgewise view of cutting planes.

then to find where the two edges *AE* and *CG* of the square prism pierce the faces of the triangular prism. The construction is as follows:

1. Extend the plane of the face containing the elements *AE* and *DH*, and use it as a cutting plane.

2. Find, by inspection, the points *6* and *11* where *MN* and *MP* pierce this plane.

3. The line joining these two points is the line in which the cutting plane intersects the plane face *MNOP*. This line is shown as *6′–11′* in the front view. The intersection of *6′–11′* and *a′e′* locates *7′*, the vertical projection of the required piercing point. In the same way, *6′–12′* represents the front view of the intersection of the plane *MNSR* and the cutting plane containing the face *ADHE* of the square pyramid and locates *8′*, the last

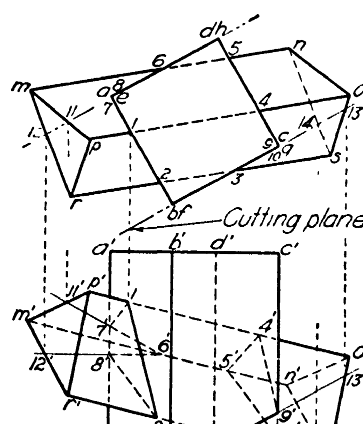


FIG. 7. Intersection of prisms.

point to be found on the projection of the left intersection of the two prisms. A careful study of the figure will show how the points *9* and *10* were found on the second intersection of the prisms by using the same method.

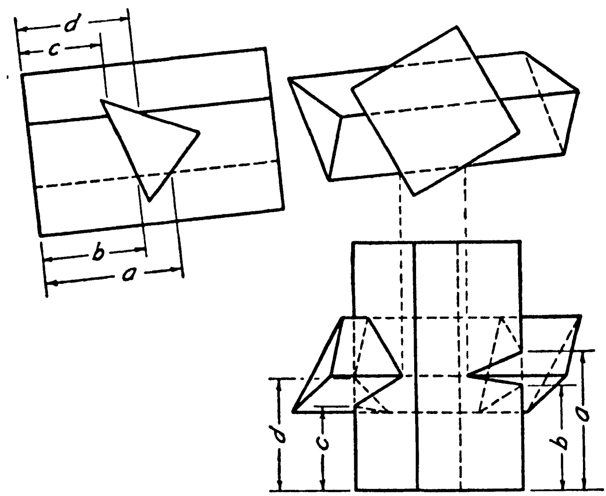


FIG. 8. Use of auxiliary view to obtain intersection.

If the triangular prism had been in a horizontal position, as shown in Fig. 8, it would have been simpler to get the edgewise view of the faces of the triangular prism by means of an auxiliary projection (see Chapter VI), thus providing a means of getting the piercing points of the edges of the square prism with the faces of the triangular prism. The construction is shown in the figure. The distances *a*, *b*, *c*, and *d*, which locate the heights of the piercing points above the lower base of the square pyramid, are obtained in the auxiliary view and transferred to the front view, thus establishing the points of the intersection which were not obtainable directly from the top view, as illustrated in Fig. 7.

145. Cylindrical Surfaces. — The intersection of two cylinders is of very common occurrence in practice. In this case it is usually best to pass the cutting planes in such a way that they will cut straight lines from both surfaces. This means that the cutting planes must be parallel to the elements of both cylinders. Such planes can always be found if an endwise view of one of the cylinders is available or can be obtained by auxiliary projection. A solution of this type is shown in Fig. 9. Only one of the cutting planes and the points obtained by it are shown in order not to make the drawing confusing.

When an endwise view of one cylinder is available, the draftsman can tell at a glance the form which the intersection will have. Only four forms are possible. They are shown in Fig. 10, with the cylinders placed in the most advantageous positions possible relative to the principal coördinate planes. With a complete penetration of one cylinder by the other, as in Fig. 10*a*, two loops are formed; with a partial penetration, as in 10*b*, one loop is formed; with a partial penetration in which one cutting plane is tangent to both cylinders, as in 10*c*, a crossed loop like a figure 8 is formed; and, finally, with a complete penetration of two cylinders of the same size with two cutting planes tangent to both cylinders, as in 10*d*, two ellipses are formed which cross each other at two points. The above statements concerning intersecting cylinders apply equally to two cones or to a cone and a cylinder, when under the same conditions as regards penetration and tangency of cutting planes. The

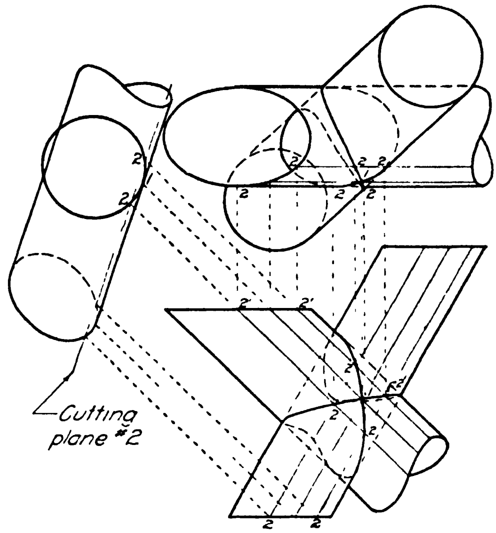


FIG. 9. Intersection of cylinders.

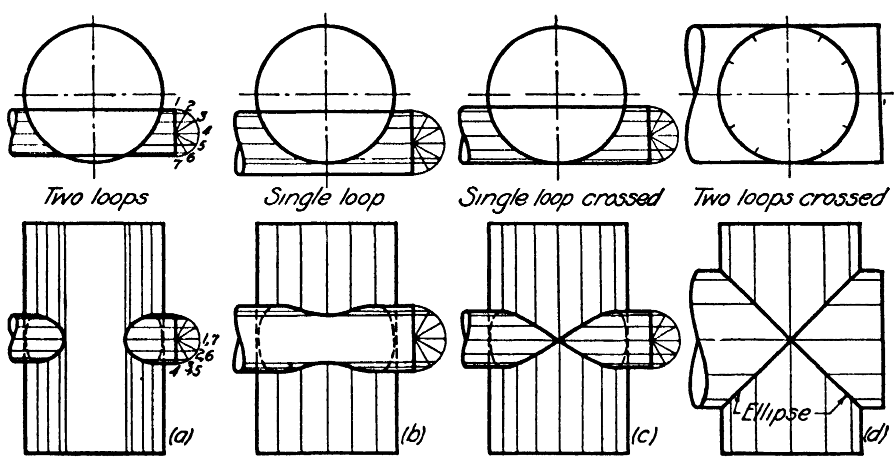


FIG. 10. Four possible types of intersections.

determination of the form of the intersection can be readily made from the auxiliary view in all cases, thus assisting the draftsman in interpreting his constructions in the other views.

146. Cylinders and Cones. — To cut straight lines from a cone, the cutting planes must pass through the vertex; and to cut straight lines from a cylinder, the planes must be parallel to the elements. Such cutting planes can always be found if an endwise view of the cylinder is obtained, as shown in Fig. 11. In certain cases, such as the one in Fig. 4, the cutting planes can be passed to cut straight lines from the cylinder and circles from the cone. This method can be employed only when the elements of the cylinder are parallel to the base of the cone and both are so arranged that the curve cut from the cone projects as a circle.

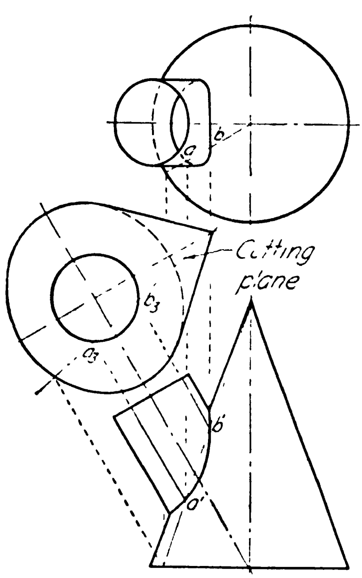


FIG. 11. Intersection of cone and cylinder.

147. Conical Surfaces. — The intersection of two cones is also a very common practical problem. In this case, if straight-line elements are to be cut from both surfaces, the cutting planes must pass through both vertices. Planes can be so passed if an endwise view of the line joining the two vertices is obtained, as illustrated in Fig. 12.

The problems which occur in engineering practice involve only frustums of cones, hence the vertex must usually be found by extending two or more elements. An illustration of this type of problem is shown in Fig. 13. Here the two cones have a common base which is, of course, one of the lines of intersection. When cones have a common base or common base plane, the solution is much simplified because the elements cut out by any cutting plane are very easily found. The procedure is as follows: Extend the line joining the two vertices until it pierces the plane of the bases. From this point draw a line across the bases. The intersections of this line with the curves of the bases locate the foot of all elements lying in the cutting plane determined by the two intersecting lines, i.e., the one through the vertices and the one drawn across the bases. The elements cut by one such plane intersect in points on the curve of intersection. The constructions for one cutting plane are shown in the figure. The line *XZ* pierces the plane of the bases at point *P*. *P3* is the line across the bases. The plane of *XZ* and *P3* is not shown. The elements *X3* and *Z3* are cut from the cones. They intersect at points *3* on the common bases and at point *3a* on the surfaces of the cones. Other points on the curve of intersection were obtained in a similar way.

If the line joining the vertices is parallel to the plane of the bases, the line across the bases is simply parallel to this line, since two parallel lines determine a plane as do two intersecting lines.

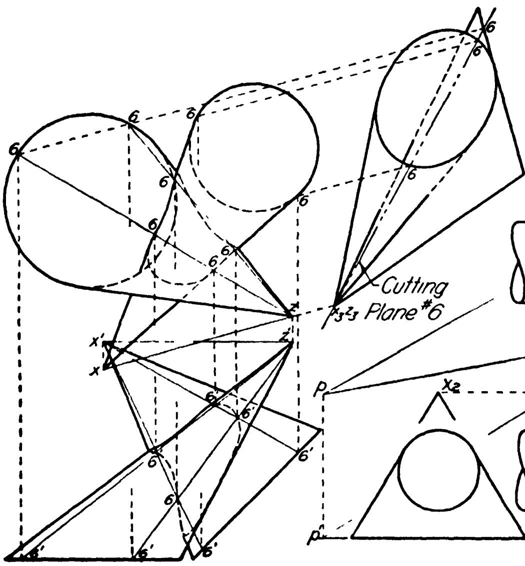


FIG. 12. Auxiliary projection used to obtain intersection of two cones.

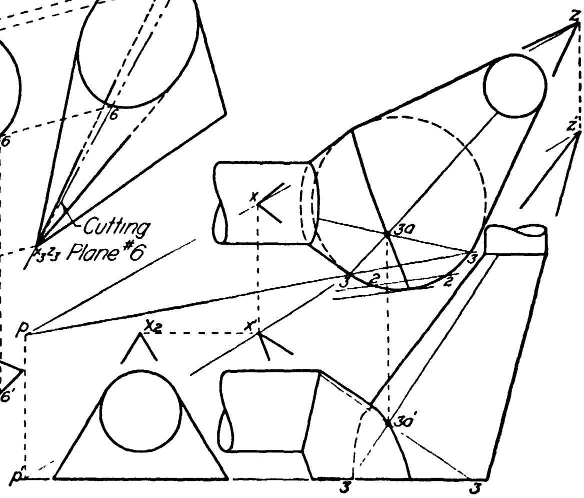


FIG. 13. Intersection of two cones.

For a complete discussion of intersections, the student is referred to texts on descriptive geometry.

148. DEVELOPMENT OF SURFACES. — Another practical problem which arises frequently in construction work and which is commonly associated with the work in intersections is that of the development of surfaces. The term development means the laying out of flat patterns from which curved surfaces can be formed without stretching the material.

149. Cylinders. — The cylinder is a very common surface encountered in design. If its bases are parallel and perpendicular to the axis, it is easily seen that when split along any element and rolled out flat, as in Fig. 14, a rectangle is formed. The width of this rectangle is equal to the length of the cylinder, and its length equal to the circumference of the cylinder. Both measurements are easily found from a working drawing.

When the bases are not parallel and neither is perpendicular to the axis, or when the cylinder is intersected by some other surface, such as a cone (see Fig. 6), the problem of layout or development is more involved. The length of the shape resulting from the development is found by taking the circumference of a right section of the cylinder and laying it out straight as a base line or stretch-out line from which to make other measurements. At suitable spaces along this base line corresponding to the true lengths of the arcs on the right section circle, distances to the left and right of it are

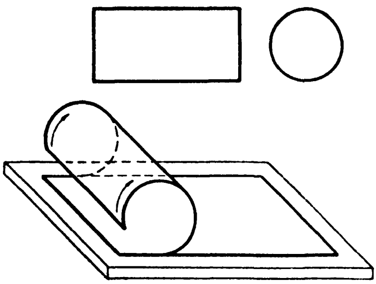


Fig. 14. Development of right cylinder.

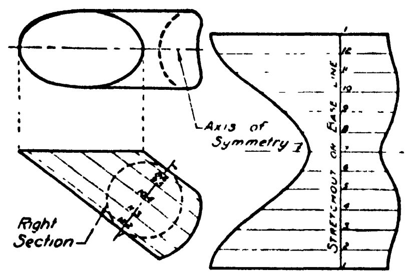


Fig. 15. Development of oblique cylinder.

laid off equal to the corresponding lengths of the elements to the left or right of the right section. A smooth curve joining the points thus located completes the development. Figure 15, which is a development of

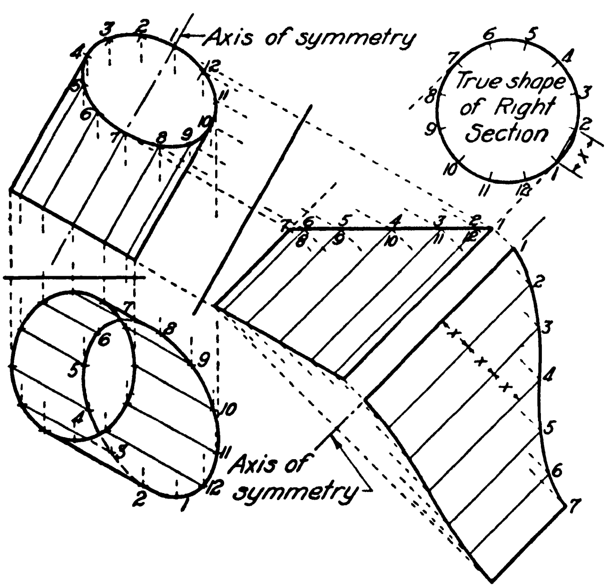


Fig. 16. Auxiliary projection used to obtain development.

the cylinder shown in Fig. 6, will make this procedure clear for simple cases.

Cylinders which are oblique to the principal planes must first have auxiliary views made which will show the true length of the elements. A second auxiliary showing an endwise view of the cylinder will then give the true length of the right section. With these two views obtained the construction may be continued in the usual manner as shown in Fig. 16.

Often, a plane of symmetry may be passed through the axis of the cylinder, and then the development is symmetrical about a line, provided, of course, that it is begun on one of the elements in which the plane intersects the surface of the cylinder. In such a case, only one half of the development need be shown. The cylinder in Fig. 16 has been handled this way.

150. Cones. — Cones, when rolled out flat, develop into shapes which actually are or closely resemble sectors of circles. Figure 17 shows a right

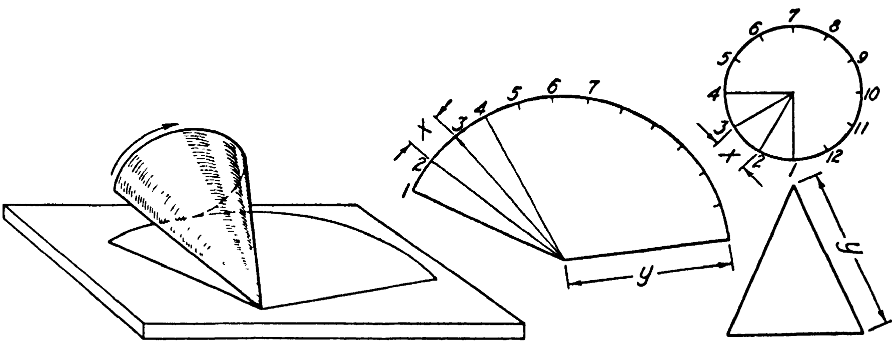


FIG. 17. Development of right cone.

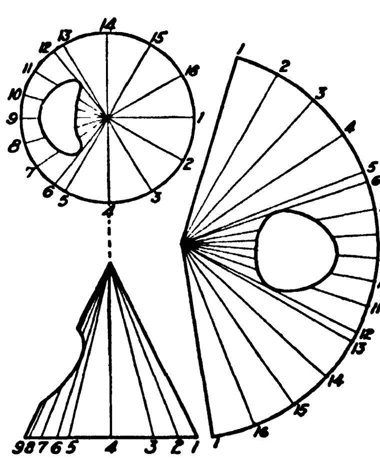


FIG. 18. Development of right circular cone.

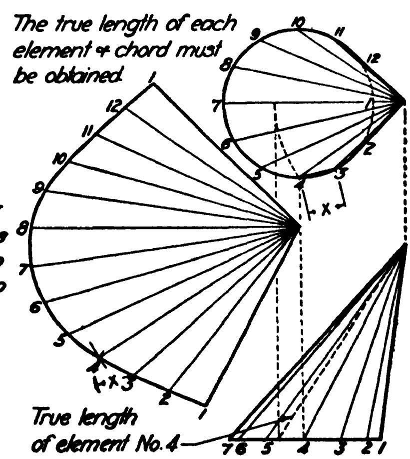


FIG. 19. Development of oblique cone.

circular cone rolled out flat. It will be observed that the apex, length of element, and successive chord distances on the base constitute the chief developing elements. If the cone is laid on a board along a split element, it will roll out flat with the apex remaining in one fixed position and the true length of the elements showing from this point to a circular curve. Successive elements will fall distances apart on the base curve approximately equal to the true chord distances on the base itself. We have, then, the joining together of several plane triangles, whose side lengths and bases are known (true lengths of the elements and successive chords) and whose vertices intersect at one fixed point, to form the cone development. A smooth curved line is drawn through the base vertices, instead of a series of straight lines.

Figure 18 illustrates the procedure when the cone is intersected by some other surface. Figure 19 shows the method for an oblique cone.

151. Plane Surfaces. — The surfaces of objects such as pyramids, prisms, and irregular-shaped plane-surface bodies can be divided into triangles if they are not already in that common shape. Any triangle can be laid out on the drawing paper by simply finding the true lengths of all its

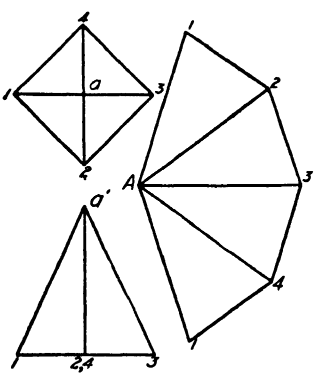


Fig. 20. Development of square pyramid.

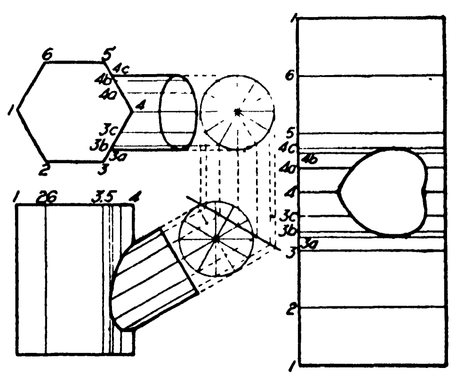


Fig. 21. Development of intersected prism.

sides by the method already explained, and connecting these true length sides in the usual way for constructing a triangle. Each triangle in any one surface can then be joined readily to its neighbors, and the whole development completed. Each surface is turned into the development plane on the edge common to it and the preceding surface. Figure 20 shows the procedure applied to the pyramid.

If the object to be developed is a prism, and the drawing shows a right section, as in the hexagonal prism of Fig. 21, it may be developed by the "rolling-out" method used with the cylinder, much more easily than by the triangulation method. The stretch-out line is the total length of the straight lines forming the periphery of the right section, and can be laid down as a straight line with the corner points determined. The location of the top corner points is readily determined by laying off the true length of the elements on the proper line perpendicular to the stretch-out line. It is a good practice to number these lines on both the drawing and development. Straight lines join the corner points, instead of curved ones.

152. Practical Suggestions. — Many times, to speed up development work, it will be found advantageous to make the development in such a position that the true length of elements can be projected directly from the orthographic views, as shown in Fig. 22, or rotated out to a convenient position with a compass, as in Fig. 23.

When one plane of symmetry exists, as in Figs. 15, 16, and 22, only one-half of the pattern need be laid out, provided the half chosen begins and

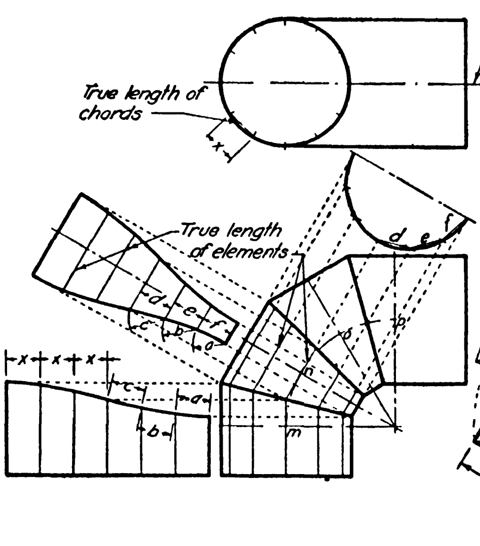


Fig. 22. Development of elbow.

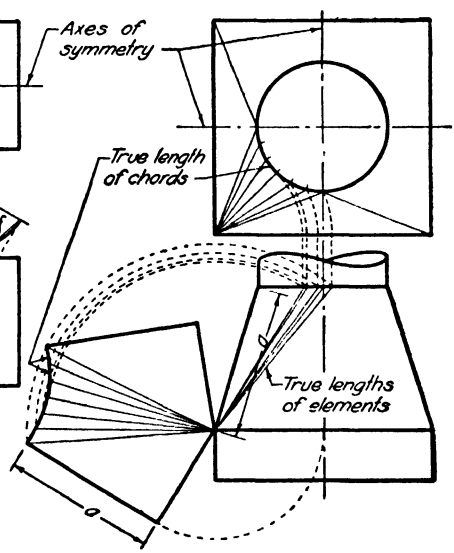


Fig. 23. Development of reducer.

ends on the plane of symmetry. If two planes of symmetry exist, only one-fourth of the total pattern need be drawn, again provided the pattern begins and ends on a plane of symmetry.

Unless other conditions prevent, it is customary to begin the pattern along the shortest element, since this will be most economical in riveting parts together. It is also necessary to consider economy of material in cutting out the pattern from large rectangular sheets. If material were more expensive than labor, this consideration might influence the way in which the pattern was begun. No definite rules can be given in these matters. Judgment in this respect must be attained largely through experience in the shop and drafting room.

PROBLEMS

153. In the first four groups of problems (1 to 32), disregard the directions on the drawings as to the location of views on the drawing sheet, as given in Figs. 24 to 31. Plan your own arrangement of views in all the problems below to make a well-balanced sheet. Use a full-size scale in each case, except in the last group where the scale is expressed on the drawings (see Art. 4, page 3).

1. Reproduce the views (undimensioned) of Fig. 24. Find the intersection of the object represented with a plane which is perpendicular to V and parallel to the line AB and ½ inch from it. Find the true shape of the face cut from the object by the plane.
2. Same as Prob. 1, Fig. 25.
3. Same as Prob. 1, Fig. 26.
4. Same as Prob. 1, Fig. 27.
5. Same as Prob. 1, Fig. 28.
6. Same as Prob. 1, Fig. 29.
7. Same as Prob. 1, Fig. 30.
8. Same as Prob. 1, Fig. 31.
9. Reproduce the views (undimensioned) of Fig. 24. Find the intersection of the object represented with a plane which is perpendicular to H and parallel to the line AB and ¼ inch from it toward the front. Find the true shape of the face cut from the object by the plane.
10. Same as Prob. 9, Fig. 25.
11. Same as Prob. 9, Fig. 26.
12. Same as Prob. 1, Fig. 27.
13. Same as Prob. 1, Fig. 28.
14. Same as Prob. 1, Fig. 29.
15. Same as Prob. 1, Fig. 30.
16. Same as Prob. 1, Fig. 31.

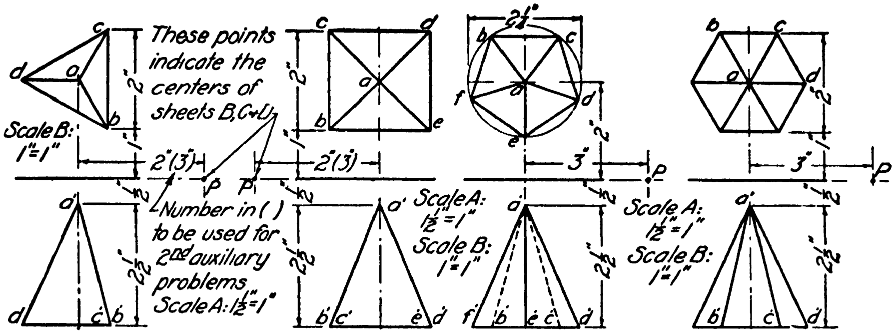


FIG. 24. Tetrahedron. FIG. 25. Pyramid. FIG. 26. Pyramid. FIG. 27. Pyramid.

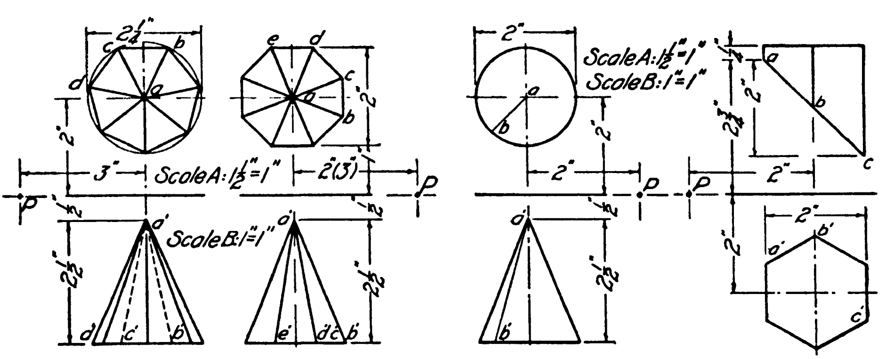


FIG. 28. Pyramid. FIG. 29. Pyramid. FIG. 30. Cone. FIG. 31. Prism.

17. Reproduce the views (undimensioned) of Fig. 24. Find the intersection of the object represented with a plane which is perpendicular to V and makes 30° with H, and which passes through the center of the axis of the object. Find the true shape of the face cut from the object by the plane. Develop the surface of the frustum.

18. Same as Prob. 17, Fig. 25.
19. Same as Prob. 17, Fig. 26.
20. Same as Prob. 1, Fig. 27.
21. Same as Prob. 1, Fig. 28.
22. Same as Prob. 1, Fig. 29.
23. Same as Prob. 1, Fig. 30.

24. Reproduce the views (undimensioned) of Fig. 24. Find the intersection of the object represented with a plane which is perpendicular to the profile plane and makes an angle of 45° with both the H and V planes, and which passes through the center of the axis of the object. Find the true shape of the face cut from the object by the plane. Develop the surface of the frustum.

25. Same as Prob. 24, Fig. 25.
26. Same as Prob. 24, Fig. 26.
27. Same as Prob. 1, Fig. 27.
28. Same as Prob. 1, Fig. 28.
29. Same as Prob. 1, Fig. 29.
30. Same as Prob. 1, Fig. 30.

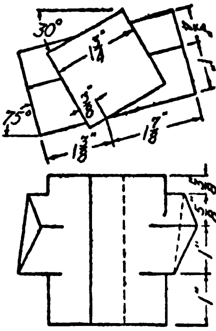


FIG. 32.

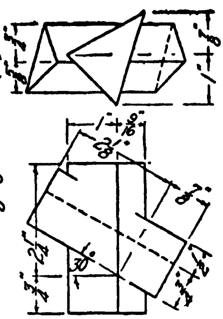


FIG. 33.

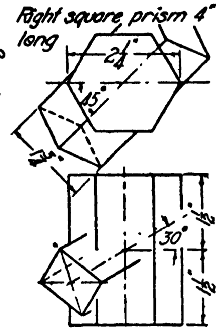


FIG. 34.

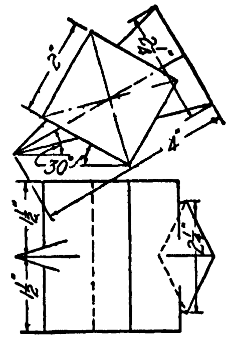


FIG. 35.

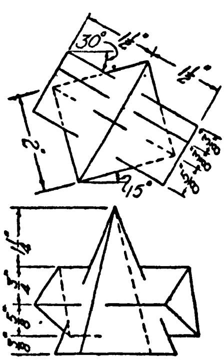


FIG. 36.

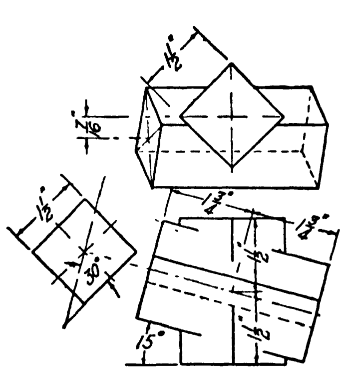


FIG. 37.

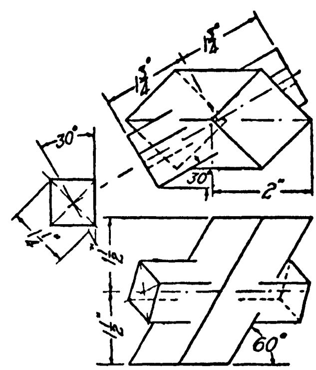


FIG. 38.

31. Reproduce the views (undimensioned) of the two solids of Fig. 32 and find the line of intersection of their surfaces. Show clearly the visibility of this line of intersection and make the proper connection with the outline of the solids. (NOTE: The termination of the interrupted outline, as shown, is not necessarily correct.)

32. Same as Prob. 31, Fig. 33.

33. Same as Prob. 31, Fig. 34.

34. Same as Prob. 31, Fig. 35.

35. Same as Prob. 31, Fig. 36.

36. Same as Prob. 31, Fig. 37.

37. Same as Prob. 31, Fig. 38.

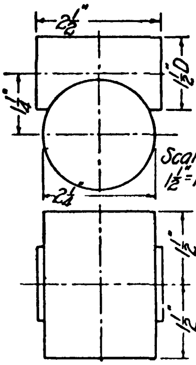


Fig. 39.

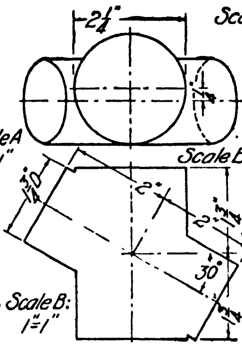


Fig. 40.

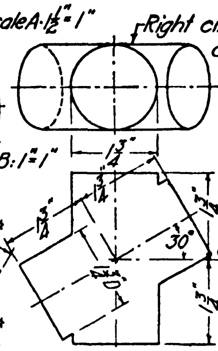


Fig. 41.

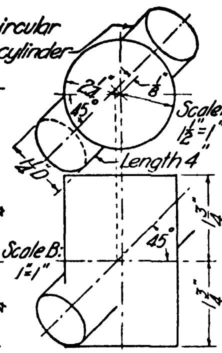


Fig. 42.

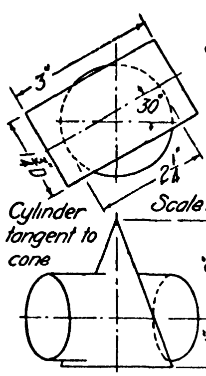


Fig. 43.

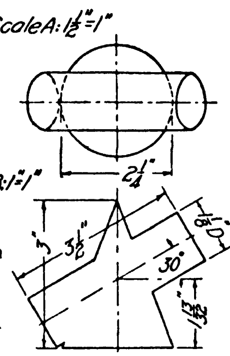


Fig. 44.

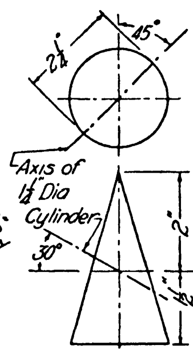


Fig. 45.

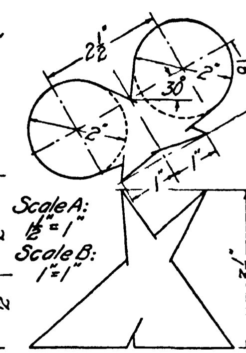


Fig. 46.

38. Reproduce the views (undimensioned) of the surfaces of Fig. 39 and find the line of intersection of the surfaces. Show clearly the visibility of the line of intersection and connect it properly with the outline of the objects. Outline elements, as shown in the figure, are not necessarily terminated at the intersection.

39. Same as Prob. 38, Fig. 40.
40. Same as Prob. 38, Fig. 41.
41. Same as Prob. 38, Fig. 42.
42. Same as Prob. 38, Fig. 43.
43. Same as Prob. 38, Fig. 44.
44. Same as Prob. 38, Fig. 45.
45. Same as Prob. 38, Fig. 46.
46. Same as Prob. 38, Fig. 47.

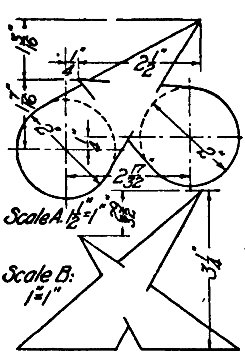


FIG. 47.

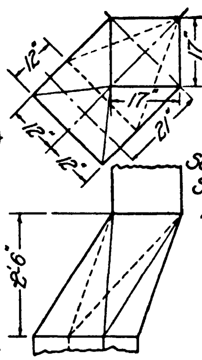


FIG. 48.

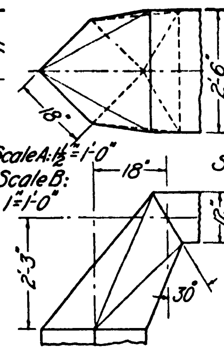


FIG. 49.

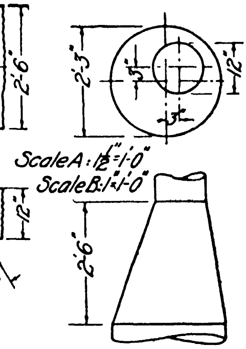


FIG. 50.

47. Reproduce the views (undimensioned) of the sheet-metal duct of Fig. 48 and make a development (pattern) of the transition piece. If the piece is symmetrical about one or more planes, make only the pattern for a symmetrical portion sufficient to construct the whole piece.

48. Same as Prob. 47, Fig. 49.

49. Same as Prob. 47, Fig. 50.

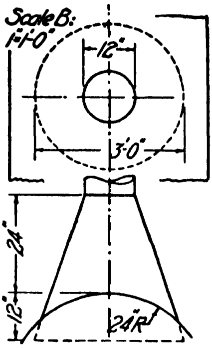


FIG. 51.

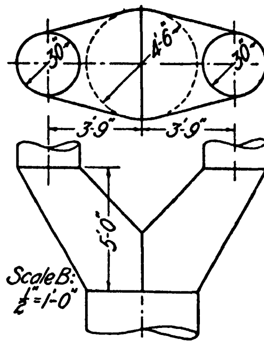


FIG. 52.

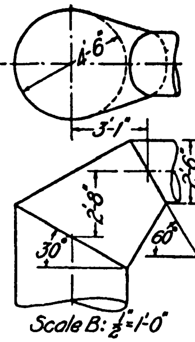


FIG. 53.

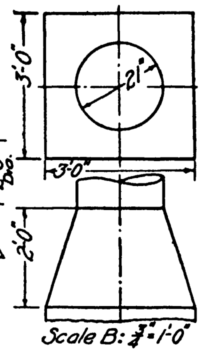


FIG. 54.

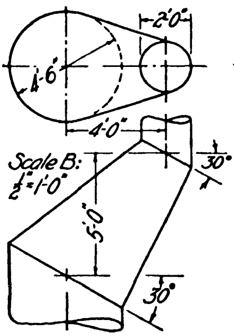


FIG. 55.

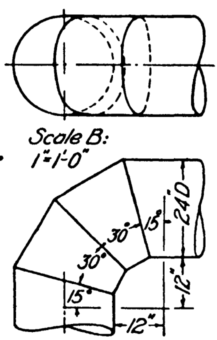


FIG. 56.

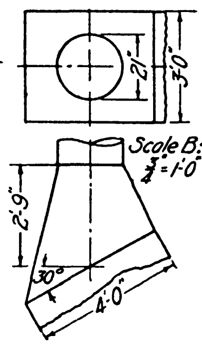


FIG. 57.

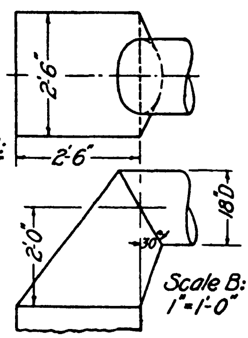


FIG. 58.

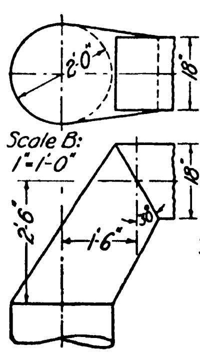


FIG. 59.

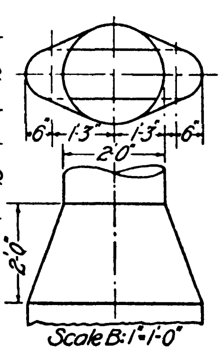


FIG. 60.

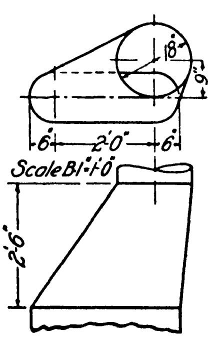


FIG. 61.

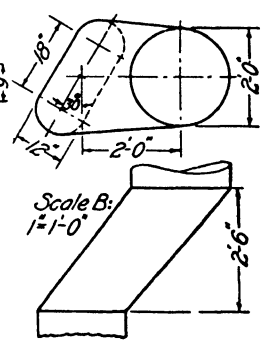


FIG. 62.

50. Reproduce the views (undimensioned) of the reducing section of Fig. 51 and make a development (pattern) of the transition piece. Develop a sufficient portion to construct the whole piece.

51. Same as Prob. 50, Fig. 52.
52. Same as Prob. 50, Fig. 53.
53. Same as Prob. 50, Fig. 54.
54. Same as Prob. 50, Fig. 55.
55. Same as Prob. 50, Fig. 56.
56. Same as Prob. 50, Fig. 57.
57. Same as Prob. 50, Fig. 58.
58. Same as Prob. 50, Fig. 59.
59. Same as Prob. 50, Fig. 60.
60. Same as Prob. 50, Fig. 61.
61. Same as Prob. 50, Fig. 62.

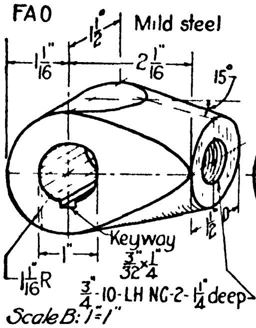


FIG. 63. Connecting rod end.

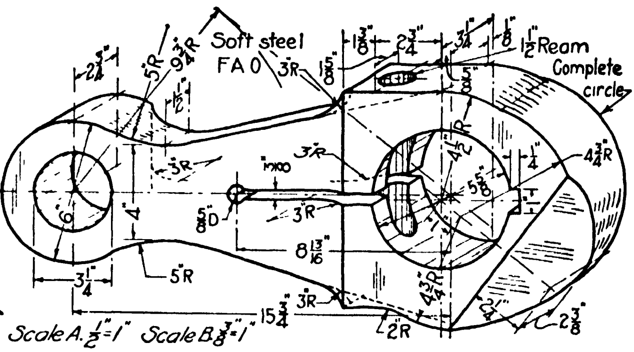


FIG. 64. Eccentric crank.

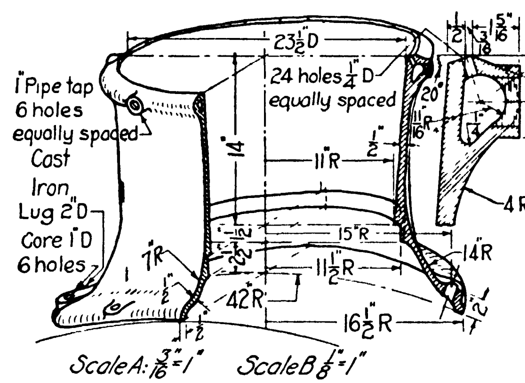


FIG. 65. Smoke stack.

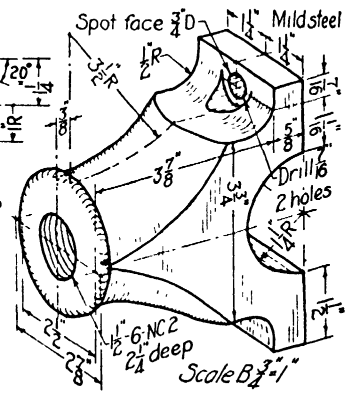


FIG. 66. Connecting rod end.

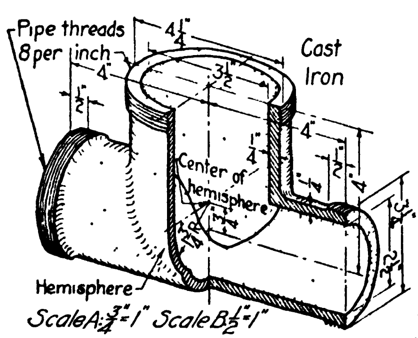


FIG. 67. Special Tee.

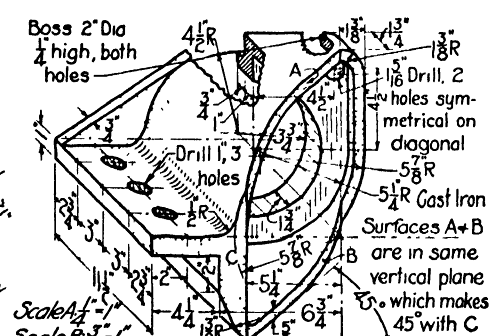


FIG. 68. Truck centering device.

62. Make a working drawing of the object represented in Fig. 63. In the pencil layout, show clearly how you obtained the lines of intersection.

63. Same as Prob. 62, Fig. 64.

64. Same as Prob. 62, Fig. 65.

65. Same as Prob. 62, Fig. 66.

66. Same as Prob. 62, Fig. 67.

67. Same as Prob. 62, Fig. 68.

CHAPTER X

FASTENERS

154. In all kinds of structures with which the engineer has to deal, the various parts are held together in one complete whole by devices known as fasteners. These fasteners vary in kind and use, from ordinary nails and glue for wood structures, to nicely made bolts and machine screws for either large or small machines, such as locomotives or watches.

On working drawings, the engineer may specify certain fastenings by means of notes, without actually showing the fasteners proper on his drawings, or he may show certain of them in actual projected outlines or in some customary conventionalized form. Included among the former class of fastenings are such common things as spikes, nails, brads, cotter-pins, dowelpins, and other simple devices. In the latter class are included such fasteners as bolts, rivets, keys, screws, pins of large size, clamp and lock devices, etc.

Little study of the fasteners listed in the first class is necessary from a purely drafting standpoint, and they are, therefore, omitted from further consideration in this text; but it must not be assumed from this omission that the engineer does not need to know when to use and how to specify them by proper notes and names on his drawings. Fasteners in the second class need careful study from the standpoint of the drafting-room methods and schemes of representing them, in addition to a knowledge of their use in field and shop.

155. BOLTS. — A bolt may be described simply as a rod of iron or other metal with a head on one end and threads on the other. The bolt acts as a fastener when it has been inserted through holes drilled in two or more parts and a nut has been turned on the threaded end, thus drawing tightly together any pieces or parts between the head and nut.

The heads on bolts are pressed into the desired shape by heading machines after the end of the rod from which the bolt is made has been heated, or they are formed by automatic machines turning down a square or hexagonal rod to the desired shank diameter and length, and then chamfering the head, threading the bolt, and cutting it from the rod.

156. Square- and Hexagonal-Head Bolts. — In Fig. 1 are shown the shapes and general proportions of several types of bolts. Of these the hexagonal- and square-head type are the most common. The hexagonal head and nut are preferred on high-grade machinery because of their better appearance. They are preferred in cramped places, particularly the nut, because they can be turned more readily with a wrench than the square shape which often requires a full quarter-turn before a new grip can be secured. Square-head bolts are used in general machine and structural work, particularly in heavy wood and machine construction, and often with the hexagonal nut. A washer is usually placed under the head and nut to protect the wood and give a greater bearing area.

The dimensions of the various parts of the heads of these two bolts are based upon the diameter of the shank, which is always a known starting point. These relationships have been standardized by the American

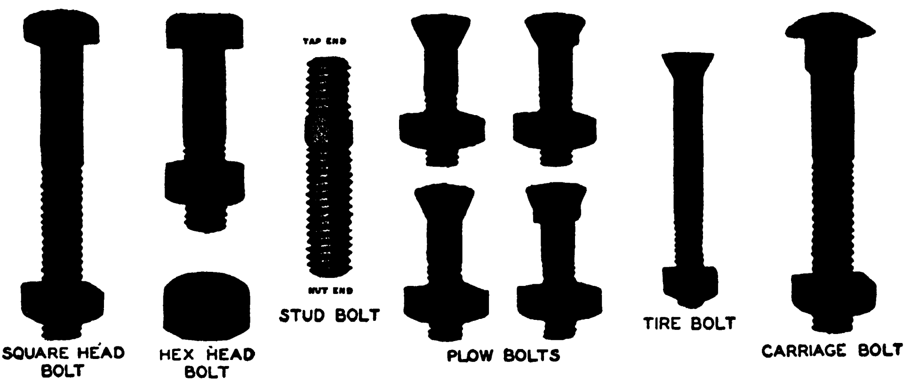


FIG. 1. Common types of bolts.

Standards Association and can be found in the bulletin of the Association, B 18.2–1933, which is entitled " Wrench-Head Bolts and Nuts and Wrench Openings."

Three kinds of square- and hexagonal-head bolts are made, namely, the *Unfinished*, *Semi-Finished*, and *Finished*. See Fig. 2. They differ chiefly in that the finished bolt head is machined on all surfaces and has a circular washer face on the under side of the head; the semi-finished bolt head does not have such a face and is machined on the under side of the head only; the unfinished bolt head is neither washer-faced nor machined on any surface. The nut is constructed similar to the head in each case.

On unfinished and semi-finished bolts, the distance across flats (F) is always one and one-half times the diameter, with adjustments to sixteenths to eliminate 32nd-inch size wrench openings. $F = 1\frac{1}{2}D$, in Fig. 2. On finished bolt heads, $\frac{1}{16}$ inch is added to F in sizes between $\frac{1}{4}$ inch and $\frac{5}{8}$ inch inclusive, with adjustments to eliminate 32nd-inch wrench sizes. Nuts also follow these rules for F, except that $\frac{1}{16}$ inch is added in sizes

$\frac{1}{4}$ to $\frac{5}{8}$ inch in all kinds of finish. The nominal height of the unfinished head is $\frac{2}{3}D$; the height of the semi-finished head is $\frac{2}{3}D$ minus $\frac{1}{64}$ inch to $\frac{1}{8}$ inch according to size. The nominal height of the finished bolt head is $\frac{3}{4}D$, which includes $\frac{1}{64}$ inch for the thickness of the washer face. The nominal thickness of the nuts in each case is $\frac{7}{8}D$ minus $\frac{1}{64}$ inch to $\frac{3}{32}$ inch in the semi-finished group, with the same provision for the washer face in the finished group as prevails on the head.

The heads of bolts and nuts are washer-crowned or flat on the top side, and are beveled or chamfered on that side to remove the sharp corners. This chamfer is conical in shape at an angle of 25 degrees and 30 degrees

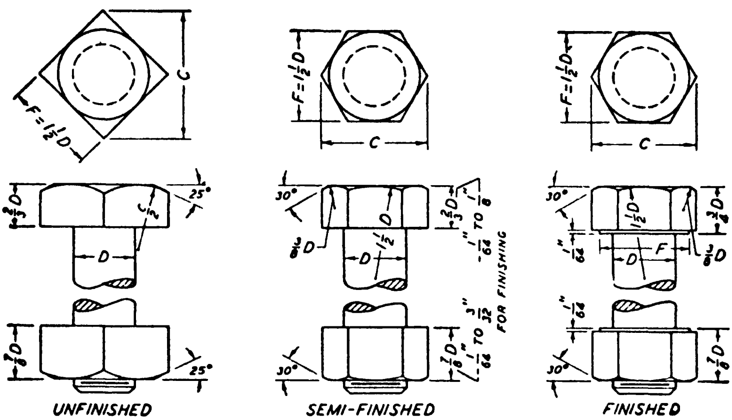


FIG. 2. Finish, semi-finished, and unfinished bolts.

with the top on square and hexagonal shapes, respectively. The diameter of the chamfer circle is equal to the distance across flats with a minus tolerance of 15 per cent. See Fig. 1. The important dimensions of bolt heads and nuts, up to 3 inches in diameter, are shown in Table I.

The threads on all bolts are the American (National) Coarse-Thread Series. See Art. 173. The threaded length varies according to the size and length of the bolt, three diameters being a common practice above the 1¼-inch size.

The length (L) of a bolt is the distance from the tip of the threaded end to the under side of the head. On stud bolts and flat-head bolts it is the overall length.

157. Carriage Bolt. — The oval head and square shank of the carriage bolt make it particularly useful for wood work where a high degree of finish is desired. Its head fits snugly down against the wood, and the piece of square shank prevents the bolt from turning when the nut is being tightened. See Fig. 1.

TABLE I

Square and Hexagonal Regular Bolt Heads and Nuts American (National) Standard

Diameter of Bolt (D)		Maximum Width (F) Across Flats			Minimum Width* (C) Across Corners			Nominal Height of Bolt Heads			Nominal Thickness of Nut	
		Bolt Heads		Nuts	Unfinished and Semi-finished		Finished	Unfinished	Semi-finished	Finished	Unfinished Sq. and Hex. Finished Hex	Semi-finished Sq. and Hex.
		Unfinished and Semi-finished	Finished		Sq.	Hex.	Hex.					
1/4	0.2500	3/8	7/16	Same as Finished Bolt Heads for All Three Finishes	0 498	0 414	0 488	11/64	5/32	3/16	7/32	13/64
5/16	0 3125	1/2	9/16		0 665	0 552	0 629	13/64	3/16	15/64	17/64	1/4
3/8	0 3750	9/16	5/8		0 747	0.620	0.699	1/4	15/64	9/32	21/64	5/16
7/16	0 4375	5/8	3/4		0 828	0 687	0 840	19/64	9/32	21/64	3/8	23/64
1/2	0 5000	3/4	13/16		0 995	0 827	0 911	21/64	19/64	3/8	7/16	27/64
9/16	0 5625	7/8	7/8		1.163	0 966	0 982	3/8	11/32	27/64	1/2	15/32
5/8	0 6250	15/16	15/16		1 244	1 033	1 051	27/64	25/64	15/32	35/64	17/32
3/4	0 7500	1 1/8	1 1/8		1 494	1 240	1 263	1/2	15/32	9/16	21/32	41/64
7/8	0 8750	1 5/16	1 5/16		1.742	1 447	1 474	19/32	9/16	21/32	49/64	3/4
1	1 0000	1 1/2	1 1/2		1 991	1.653	1.686	21/32	19/32	3/4	7/8	55/64
1 1/8	1 1250	1 11/16	1 11/16		2 239	1.859	1 896	3/4	11/16	27/32	1	31/32
1 1/4	1 2500	1 7/8	1 7/8		2 489	2.067	2.109	27/32	25/32	15/16	1 3/32	1 1/32
1 3/8	1 3750	2 1/16	2 1/16		2.738	2 273	2.321	29/32	27/32	1 1/32	1 13/64	1 9/64
1 1/2	1 5000	2 1/4	2 1/4		2 986	2 480	2 533	1	15/16	1 1/8	1 5/16	1 1/4
1 5/8	1 6250	2 7/16	2 7/16		3 235	2 686	2 744	1 3/32	1 1/32	1 7/32	1 27/64	1 23/64
1 3/4	1 7500	2 5/8	2 5/8		3 485	2 893	2 956	1 5/32	1 3/32	1 5/16	1 17/32	1 15/32
1 7/8	1 8750	2 13/16	2 13/16		3 733	3.100	3.168	1 1/4	1 3/16	1 13/32	1 41/64	1 37/64
2	2 0000	3	3		3 982	3 306	3.379	1 11/32	1 7/32	1 1/2	1 3/4	1 11/16
2 1/4	2 2500	3 3/8	3 3/8		4.480	3 720	3 802	1 1/2	1 3/8	1 11/16	1 31/32	1 29/32
2 1/2	2 5000	3 3/4	3 3/4		4.977	4.133	4 226	1 21/32	1 17/32	1 7/8	2 3/16	2 3/32
2 3/4	2 7500	4 1/8	4 1/8		5.476	4.546	4.649	1 53/64	1 11/16	2 1/16	2 13/32	2 5/16
3	3 0000	4 1/2	4 1/2		5.973	4.959	5.072	2	1 7/8	2 1/4	2 5/8	2 17/32

* Minimum widths across rounded corners of hexagon and square equal 1.14 and 1.373 times minimum widths across flats, respectively.

NOTE: Width across flats in the older U. S. Standard can be obtained by adding 1/8" to the American Standard; the height of head in the U. S. standard equaled one-half the width across flats; and the height of the nut equaled the diameter of the bolt.

158. Stud Bolt. — The stud bolt has no head and is turned into a threaded hole by means of a pipe wrench or special lock nut device. It is a very handy bolt because it can be used in places where it would be impossible to use a headed bolt, and it serves as an assembling guide for such parts as cylinder heads, manhole plates, and similar machine parts. See Fig. 1.

159. Stove Bolt. — The standard stove bolt is peculiar in that it has a round flat head which is beveled on the under side to fit a countersunk hole. It is provided with a screw-driver slot for turning the threaded end into the nut, rather than for holding the bolt so that the nut may be turned on to the threaded end. This bolt is used where it is desirable to have the

FIG. 3. Lag and stove bolts.

head of the bolt flush with the surface of the metal held in place. See Fig. 3, first type of stove bolt. The tire bolt is like this stove bolt with the exception that no screw-driver slot is provided. See Fig. 1. A second kind of stove bolt, shown in Fig. 3, is in common use; it differs from the other in that it has a button-shaped head and is not beveled on the under side

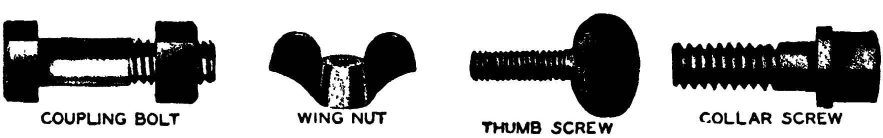


FIG. 4. Special bolts, screws, and nuts.

160. SCREWS. — The screw differs from the bolt in that it does not require a nut upon the threaded end. One of the parts to be held together by the screw is threaded and serves the same purpose as the nut on the bolt. Figures 5, 6, 7, and 8 show the shapes of a wide variety of screws.

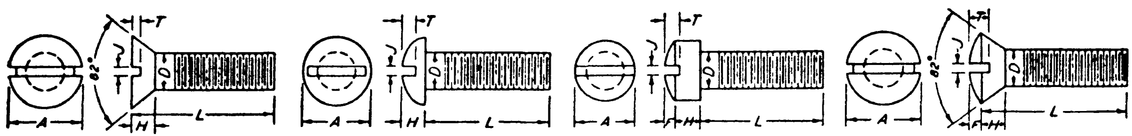
FIG. 5. Machine screws.

161. Machine Screws. — Machine screws have the four types of heads shown in Fig. 5 and also in the accompanying Table II of dimensions. The head sizes are not functions of the diameter of the shank.

Machine screws are specified by numbers from 2 to 12 below the $\frac{1}{4}$-inch sizes and then by diameter up to $\frac{3}{8}$ inch. The lengths of machine screws vary from $\frac{1}{8}$ inch to 3 inches, changing by $\frac{1}{16}$ inch up to $\frac{1}{2}$ inch, then by $\frac{1}{8}$

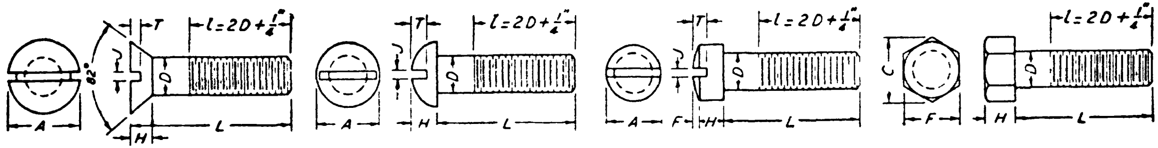
TABLE II
Slotted Head Machine Screws
(American Standard)

Flat Head — Round Head — Fillister Head — Oval Head



Nominal Size	Maximum Diameter	Threads per Inch (Coarse Series)	Maximum Diameter of Head			Maximum Height of Head			Maximum Width of Slot	Maximum Depth of Slot				Maximum Height of the Head Oval	
			Flat and Oval	Round	Fillister	Flat and Oval	Round	Fillister		Flat	Round	Fillister	Oval	Oval	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	0 099	48	0 199	0 187	0 161	0 059	0 078	0 063	0 038	0 027	0 053	0 043	0 052	0.038	0.032
4	0 112	40	0 225	0 211	0.183	0 067	0 086	0 072	0 040	0 030	0 058	0 048	0 059	0 040	0.035
5	0.125	40	0 252	0 236	0.205	0 075	0.095	0 081	0 043	0 034	0 062	0 054	0.067	0 043	0.039
6	0.138	32	0 279	0 260	0 226	0 083	0 103	0 089	0 045	0 038	0 067	0 060	0.074	0 045	0 043
8	0.164	32	0 352	0 309	0 270	0 100	0 119	0 106	0 050	0 045	0 076	0 071	0.088	0 050	0 050
10	0.190	24	0 385	0 359	0 313	0 116	0 136	0 123	0 055	0 053	0 086	0 083	0.103	0.055	0.057
12	0 216	24	0 438	0 408	0.357	0 132	0 152	0 141	0 059	0 060	0 095	0.094	0.117	0.059	0.064
$\frac{1}{4}$	0.250	20	0 507	0 472	0.414	0 153	0 174	0 163	0 066	0.070	0 108	0.109	0.136	0.066	0.074
$\frac{5}{16}$	0.3125	18	0 636	0 591	0 519	0 192	0 214	0 205	0 077	0.088	0 130	0.137	0 171	0 077	0.092
$\frac{3}{8}$	0 375	16	0.762	0 708	0.622	0.230	0 254	0 246	0 088	0 106	0 153	0 164	0 206	0 088	0.109

TABLE III SLOTTED AND HEXAGONAL-HEAD CAP SCREWS (AMERICAN STANDARD)



Nominal Size	Max. 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)
1/4	0 2500	20	1/2	7/16	3/8	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	5/8	9/16	7/16	0 183	0 246	13/64	0 079	0 091	0 151	0 115	0 050	0 5000	0 577	0 242
3/8	0 3750	16	3/4	5/8	9/16	0 220	0 273	1/4	0 088	0 110	0 167	0 142	0 064	0 5625	0 628	0 289
7/16	0 4375	14	13/16	3/4	5/8	0 220	0 328	19/64	0 098	0.110	0 202	0.168	0 071	0 6250	0.698	0 337
1/2	0 5000	13	7/8	13/16	3/4	0 220	0 355	21/64	0 110	0 110	0 219	0 188	0 084	0 7500	0 840	0 385
9/16	0 5625	12	1		13/16	0 256	0 410	3/8	0 123	0 128	0 253	0 214	0 091	0 8125	0 910	0 433
5/8	0 6250	11	1 1/8		7/8	0 293	0 438	27/64	0 138	0 146	0 270	0 240	0 099	0 8750	0 980	0 481
3/4	0 7500	10	1 3/8		1	0 366	0 547	1/2	0 154	0 183	0 337	0 283	0 112	1 0000	1 121	0 576
7/8	0 8750	9			1 1/8			19/32	0 173			0 334	0 126	1 1250	1 261	0 672
1	1 0000	8			1 5/16			21/32	0 194			0 372	0 146	1 3125	1 473	0 768
1 1/8	1 1250	7												1 5000	1 684	0 863
1 1/4	1 2500	7												1 6875	1 896	0 959

inch up to 1 inch, and by $\frac{1}{4}$ inch for lengths over 1 inch. These screws are threaded not less than $1\frac{1}{4}$ inches for all with shanks over that length, and as near to the head as possible for those shorter than $1\frac{1}{4}$ inches. Machine screws may be obtained with either coarse or fine threads. They are used for light machine work and, therefore, are made only in the smaller sizes and with slotted heads. Square and hexagonal nuts are made for all sizes of these screws.

162. Cap Screws. — Cap screws are larger than machine screws and are now manufactured with several styles of heads as shown in Fig. 6 and also in the accompanying Table III of dimensions. The head shapes are quite like those of the machine screws but differ from them in dimensions. There is an hexagonal head in this group not found among machine

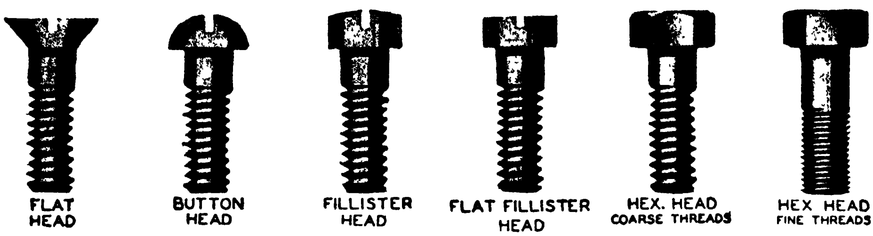


Fig. 6. Cap screws.

screws, but there is no oval-head cap screw. See accompanying Table. The size of the head is not a function of the diameter of the shank. The sizes of cap screws are specified by diameters as listed in the table. Cap screws may be obtained in lengths from $\frac{1}{4}$ inch to 6 inches, varying by $\frac{1}{8}$ inch up to 1 inch, then by $\frac{1}{4}$ inch up to 4 inches, and finally by $\frac{1}{2}$ inch up to 6 inches.

Slotted-head cap screws are regularly threaded with the American (National) coarse threads. The threaded length of these screws is two diameters plus $\frac{1}{4}$ inch. For screws too short to allow full formula thread length, the thread is carried as near to the head as practicable. The point of all cap screws is flat and chamfered 35 degrees to the flat surface and to a depth equal to the depth of the thread. Cap screws may also be obtained with American fine threads. On these, the S.A.E. Standard requires the threaded length to be one and one-half diameters plus $\frac{1}{4}$ inch.

163. Set Screws. — The standard square-head set screw and points are shown in Fig. 7. These screws are used primarily to prevent machine parts from rotating or sliding out of position on a shaft. The thickness of the head is $\frac{3}{4}D$; the radius of the crown is $2\frac{1}{2}D$. The American (National) coarse thread is used, and these screws are always threaded their full length. They are specified by giving the diameter, length, kind of point, and the head name. See Table IV.

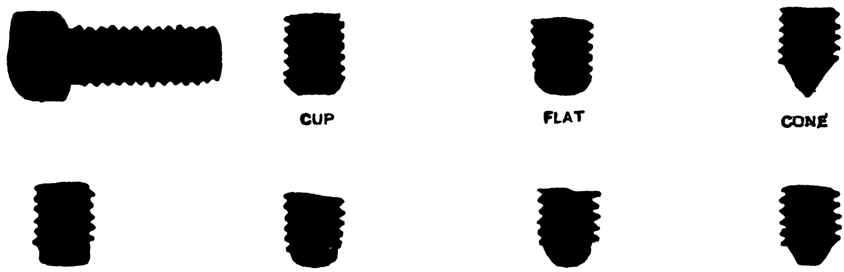
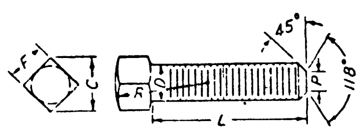


FIG. 7. Set screw points.

FIG. 8. Special screw heads.

TABLE IV
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*)
$\frac{1}{4}$	20	$\frac{1}{4}$	0.331	$\frac{3}{16}$	$\frac{5}{8}$	0.125
$\frac{5}{16}$	18	$\frac{5}{16}$	0.415	$\frac{15}{64}$	$\frac{25}{32}$	0.164
$\frac{3}{8}$	16	$\frac{3}{8}$	0.497	$\frac{9}{32}$	$\frac{15}{16}$	0.203
$\frac{7}{16}$	14	$\frac{7}{16}$	0.581	$\frac{21}{64}$	$1\frac{3}{32}$	0.242
$\frac{1}{2}$	13	$\frac{1}{2}$	0.665	$\frac{3}{8}$	$1\frac{1}{4}$	0.281
$\frac{9}{16}$	12	$\frac{9}{16}$	0.748	$\frac{27}{64}$	$1\frac{13}{32}$	0.321
$\frac{5}{8}$	11	$\frac{5}{8}$	0.833	$\frac{15}{32}$	$1\frac{9}{16}$	0.359
$\frac{3}{4}$	10	$\frac{3}{4}$	1.001	$\frac{9}{16}$	$1\frac{7}{8}$	0.438
$\frac{7}{8}$	9	$\frac{7}{8}$	1.170	$\frac{21}{32}$	$2\frac{3}{16}$	0.516
1	8	1	1.337	$\frac{3}{4}$	$2\frac{1}{2}$	0.594
$1\frac{1}{8}$	7	$1\frac{1}{8}$	1.506	$\frac{27}{32}$	$2\frac{13}{16}$	0.672
$1\frac{1}{4}$	7	$1\frac{1}{4}$	1.674	$\frac{15}{16}$	$3\frac{1}{8}$	0.750
$1\frac{3}{8}$	6	$1\frac{3}{8}$	1.843	$1\frac{1}{32}$	$3\frac{7}{16}$	0.828
$1\frac{1}{2}$	6	$1\frac{1}{2}$	2.010	$1\frac{1}{8}$	$3\frac{3}{4}$	0.906

Sizes larger than $\frac{5}{16}$ are necked to a width twice the pitch and to a diameter equal to the minor diameter of the threads.

164. Wood Screws and Hooks. — Figure 9 shows a group of screws and screw hooks commonly used in light wood construction and for general utility purposes.

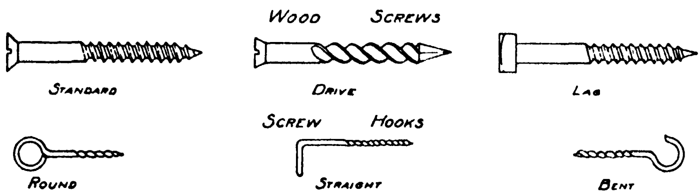


FIG. 9. Wood screws and hooks.

165. THREADS. — The important feature common to all bolts and screws is the thread. The basic curve for the thread is the helix.

166. The Helix. — This curve, often miscalled a spiral, is generated in its simplest form by moving a point on the surface of a cylinder in a circumferential direction, at a constant angular speed, with a simultaneous uniform rate of advance in an axial direction. Figure 10 shows such a curve and the method of obtaining its projections. The linear distance the moving point travels parallel to the axis of the cylinder in one revolution about the cylinder is called the pitch of the helix.

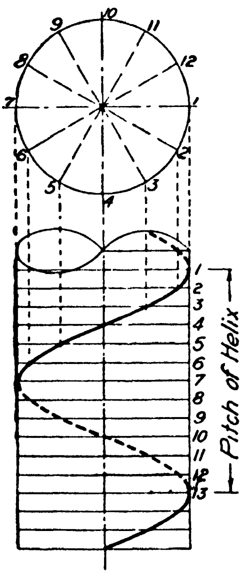


FIG. 10. The helix.

167. Thread Profiles. — The thread profile is the shape of a section of the thread cut by a plane passing through the axis of the thread. Figure 11, *A*, *B*, and *C*, shows the shape, dimensions, and names of common thread profiles. The American (National) standard form of thread, formerly known as the United States Standard (U.S.S.) or Sellers thread, is the one used exclusively on bolts and screws in this country. The Whitworth form is used in England. Other less common thread profiles are shown in Fig. 12. Each is designed to suit a special need, of which more may be learned by consulting any good mechanical engineers' handbook.

168. Square Threads. — When heavy loads are to be lifted or great pressures applied, as in jacks, presses, and the like, square threads are used, because they offer less frictional resistance to motion under load than the American standard thread. The profile, dimensions, and appearance of a square thread are shown in Fig. 13. The depth of the thread is equal to one-half the pitch as is also the width of the thread. There are, of course, small allowances for clearance, but these cannot be shown in a drawing.

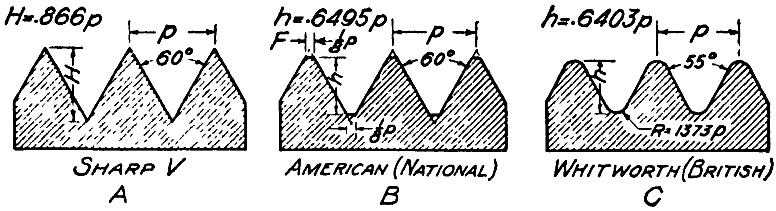


FIG. 11. Thread profiles.

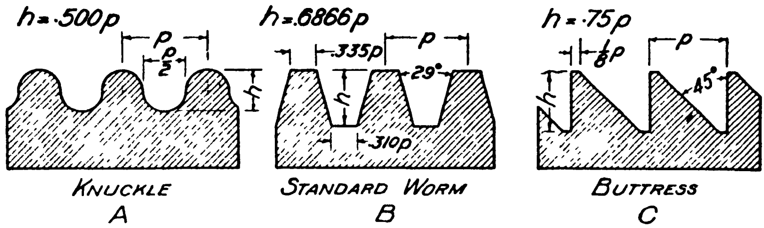


FIG. 12. Thread profiles.

169. Acme Threads. — The shape and dimensions of an Acme thread are also shown in Fig. 13. The Acme thread is used for the same general purpose as the square thread, but usually where the loads are comparatively light. It was devised because of the difficulty in cutting square threads.

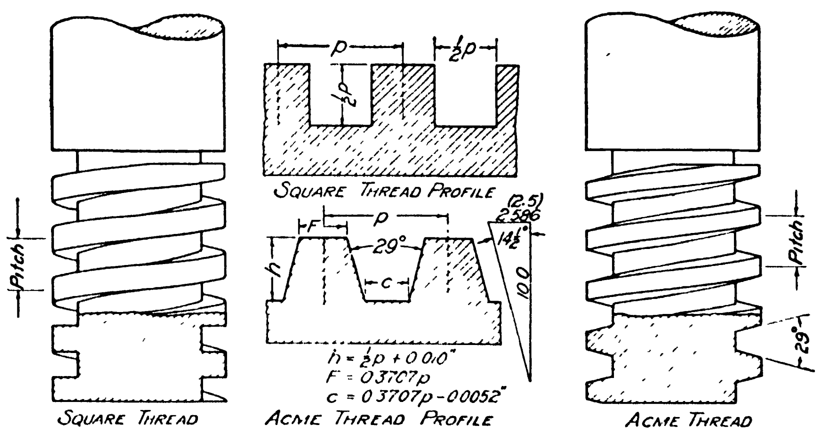


FIG. 13. Square and Acme threads.

The square and Acme threads are called the power threads because they transmit the forces involved almost parallel to the axis of the screw, thus avoiding the bursting thrust of the V-threads.

170. Right- and Left-Hand Threads. — Threads may be cut to slope in either of two directions just as a string may be wound around a rod in either of two directions. A thread is said to be right-handed when it will advance into a threaded hole if turned in a clockwise direction as one faces the hole; it is a left-hand thread if the reverse action occurs. Stated in another way, a right-hand thread, when viewed from directly in front with

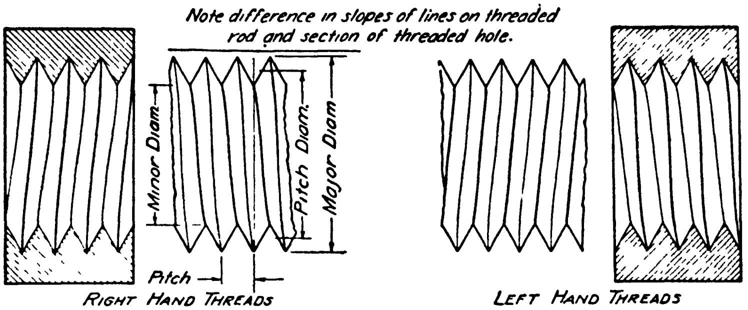


Fig. 14. Right- and left-hand threads.

the axis vertical, shows the crests of the threads, on the side nearest the observer, sloping up from left to right. Figure 14 shows the slope of right- and left-hand V-thread projections for threaded rods and threaded holes in section. Note that the slope in the holes is just the opposite from that on the corresponding rod, because the bottom of the hole must fit the back side of the rod where the slope is just the reverse of the front side.

171. Multiple Threads. — Sometimes it is desirable to have more than one thread upon a rod. Two, three, and four threads are not uncommon. If one imagines threads being formed by winding a triangular-shaped strip

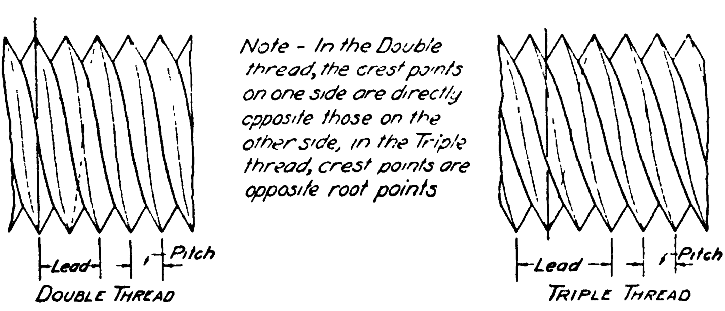


Fig. 15. Multiple threads.

of pliable material around a rod, then a double thread would be formed if two such strips were wound around side by side. Double and triple threads are shown in Fig. 15. It should be noted that, in the double threads, the crest points on one side are directly opposite those on the other side, while for triple threads, the crests are opposite root points. The purpose of cutting multiple threads is to secure faster action. Thus a double thread will travel just twice as far in one revolution as a single thread of the same pitch. See Art. 172. Common examples of the use of multiple threads are found on tightening screws on lathes and on valve stems.

172. Thread Terms and Abbreviations. — The American Standards Association has adopted a complete set of symbols and names by which the various dimensional elements of the American (National)

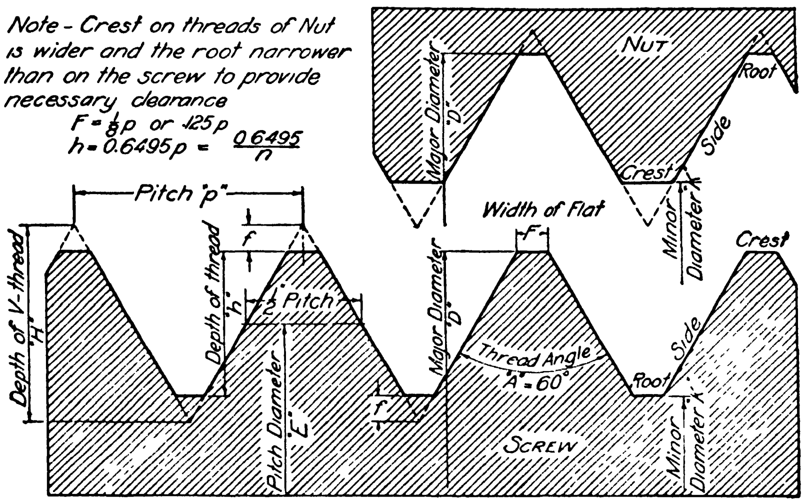


Fig. 16. American (National) thread profile.

threads are related in formulas and on drawings. These are illustrated in Fig. 16. The names of the symbols are given below the figure.

Dimensional Symbols for Use in Screw-Thread Formulas and on Drawings

Major diameter	D	Lead	$L = \frac{1}{N}$
Corresponding radius	d		
Minor diameter	K	Pitch or thread interval	$p = \frac{1}{n}$
Corresponding radius	k		
Pitch diameter	E	Angle of thread	A
Corresponding radius	e	One-half angle of thread	a
Width of basic flat, crest or root	F	Depth of sharp V-thread	H
Depth of basic truncation	f	Depth of American (National) form of thread	h
Number of turns per inch	N	Helix angle	s
Number of threads per inch	n	Tangent of helix angle $S = \frac{L}{3.14159 \times E}$	

Major diameter. — This is the diameter of the shaft on which the thread is cut. It is the diameter from crest to crest of the thread.

Minor diameter. — The diameter at the base or root of the thread is called the minor diameter.

Pitch diameter. — This is the mean of the major and minor diameter.

Pitch. — The pitch is the distance from crest to adjacent crest of a thread. This applies whether the thread is single or multiple.

Lead. — The lead is the distance from crest to crest of the same thread. On a single thread, therefore, the pitch and lead are the same. On a double thread, the lead is twice the pitch; and so on for any number of threads that may be specified.

Thread angle. — The thread angle is the angle included between the sides or faces on the thread profile.

Helix angle. — This is the angle which a tangent to the helix at the pitch diameter would make with a plane perpendicular to the axis of the thread. The tangent of this angle is the lead divided by the circumference of the pitch cylinder on which the helix lies.

173. Thread Series. — There are two series of threads in the American standard — coarse and fine. The Coarse-Thread Series consists of the older United States Standard Threads with additions below the $\frac{1}{4}$-inch sizes from the A.S.M.E. standards of 1907. The Coarse-Thread Series is used in general engineering work. The Fine-Thread Series, from $\frac{1}{4}$ inch up to $1\frac{1}{4}$ inches, inclusive, is made up from the S.A.E. standard threads with additions below the $\frac{1}{4}$-inch sizes from the A.S.M.E. 1907 Fine-Thread Series. These threads are used chiefly in automotive and airplane work. The basic dimensions are shown in Table V, entitled "The American (National) Standard Screw Threads."

174. Thread Fits. — There are four distinct classes of screw-thread fits in the American standard — loose, free, medium, and close. They are also called classes 1, 2, 3, and 4, respectively. Loose fit is recommended as a commercial standard for tapped holes in the numbered sizes (below $\frac{1}{4}$ inch) only; free fits for the great bulk of screw-thread work of ordinary quality; medium fit for the better grade of interchangeable screw-thread work; and the close fit for fine snug work. Sizes in both the coarse and fine series will be found in Table V.

175. Cutting Threads. — Standard threads are cut with special automatic machines when bolts, nuts, and screws are being made for the trade. In the ordinary shop they are cut on the lathe or by hand. In hand work, what are known as taps and dies are used — the tap for cutting threads in nuts and drilled holes, the die for cutting threads on bolts, screws, and rods. It should be noted that, in cutting threads with a tap, a hole must first be drilled with an ordinary twist drill, which when thus used is called a tap drill. For each size screw thread there is a corresponding tap drill as given in Table V, Standard Screw Threads. If fine sharp crested

TABLE V

American (National) Standard Screw Threads (Basic Elements)

	Coarse-Thread Series					Fine-Thread Series			
Sizes or Diameters (Nominal)	Basic Major Diameter	Threads per Inch	Basic Minor Diameter	Minimum Diameter of Nut*	Commercial Tap Drills† Number or Size	Threads per Inch	Basic Minor Diameter	Minimum Diameter of Nut*	Commercial Tap Drills† Number or Size
0	0 0600					80	0 0438	0 0465	$\frac{3}{64}$
1	0 0730	64	0 0527	0 0561	53	72	0 0550	0 0580	53
2	0 0860	56	0 0628	0 0667	50	64	0 0657	0 0691	50
3	0 0990	48	0 0719	0 0764	47	56	0 0758	0 0797	45
4	0 1120	40	0 0795	0 0849	43	48	0 0849	0 0894	42
5	0 1250	40	0 0925	0 0979	38	44	0 0955	0 1004	37
6	0 1380	32	0 0974	0 1042	36	40	0 1055	0 1109	33
8	0 1640	32	0 1234	0 1302	29	36	0 1279	0.1339	29
10	0 1900	24	0 1359	0 1449	26	32	0 1494	0 1562	22
12	0 2160	24	0 1619	0 1709	16	28	0 1696	0.1773	14
$\frac{1}{4}$	0 2500	20	0 1850	0 1959	7	28	0 2036	0 2113	3
$\frac{5}{16}$	0 3125	18	0 2403	0 2524	F	24	0 2584	0 2674	I
$\frac{3}{8}$	0 3750	16	0 2938	0 3073	$\frac{5}{16}$	24	0 3209	0 3299	Q
$\frac{7}{16}$	0 4375	14	0 3447	0 3602	U	20	0 3725	0 3834	$\frac{25}{64}$
$\frac{1}{2}$	0 5000	13	0 4001	0 4167	$\frac{27}{64}$	20	0 4350	0 4459	$\frac{29}{64}$
$\frac{9}{16}$	0 5625	12	0 4542	0 4723	$\frac{31}{64}$	18	0 4903	0 5024	$\frac{33}{64}$
$\frac{5}{8}$	0 6250	11	0 5069	0 5266	$\frac{17}{32}$	18	0 5528	0 5649	$\frac{37}{64}$
$\frac{3}{4}$	0 7500	10	0 6201	0 6417	$\frac{21}{32}$	16	0 6688	0 6823	$\frac{11}{16}$
$\frac{7}{8}$	0 8750	9	0 7307	0 7547	$\frac{49}{64}$	14	0 7822	0 7977	$\frac{13}{16}$
1	1 0000	8	0 8376	0 8647	$\frac{7}{8}$	14	0 9072	0 9227	$\frac{15}{16}$
$1\frac{1}{8}$	1 1250	7	0 9394	0 9704	$\frac{63}{64}$	12	1 0167	1 0348	$1\frac{3}{64}$
$1\frac{1}{4}$	1 2500	7	1 0644	1 0954	$1\frac{7}{64}$	12	1 1417	1 1598	$1\frac{11}{64}$
$1\frac{1}{2}$	1 5000	6	1 2835	1 3196	$1\frac{11}{32}$	12	1 3917	1 4098	$1\frac{27}{64}$
$1\frac{3}{4}$	1 7500	5	1 4902	1 5335	$1\frac{9}{16}$				
2	2 0000	$4\frac{1}{2}$	1 7113	1 7594	$1\frac{25}{32}$				
$2\frac{1}{4}$	2 2500	$4\frac{1}{2}$	1 9613	2 0094	$2\frac{1}{32}$				
$2\frac{1}{2}$	2 5000	4	2 1752	2 2294	$2\frac{1}{4}$				
$2\frac{3}{4}$	2 7500	4	2 4252	2 4794	$2\frac{1}{2}$				
3	3 0000	4	2 6752	2.7294	$2\frac{3}{4}$				

* Smallest Allowable Diameter of Tap Drill. Free and Medium (Class 2 and 3) Fits.

† Allows approximately 75 per cent of a full thread. Not an American Standard.

threads are desired, the drilled hole should be reamed before tapping. Some shops require that the note on the drawing include the size of the tap drill as well as specifying the size, number, and kind of threads.

176. Representation of V-Threads; American (National) Form. — Since the crest, or root, line of a thread is always a helix, it is very tedious to draw in true projection as shown in Figs. 14 and 15. An effect equally satisfactory can be obtained by using straight lines to represent the helix as shown at the left in Fig. 17. This is the first step in conventionalization used on thread drawings. The second step is to omit the V-shaped profiles altogether, leaving only the sloping straight

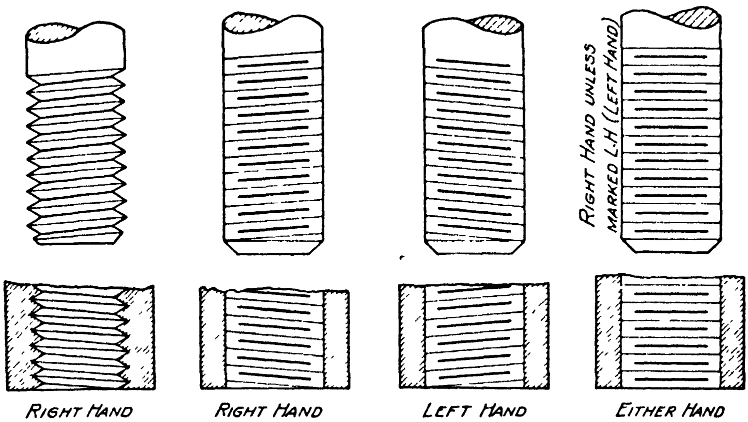


Fig. 17. Thread conventions or symbols.

lines to represent the crest and root lines, as shown in the two center drawings of Fig. 17. The third step, recently taken, is to turn the crest and root lines perpendicular to the axis of the thread, as shown in the last drawing of Fig. 17.

It is a good rule to follow that the conventionalization shown in the first drawing of Fig. 17 and at the top of Fig. 18 is to be used when the diameter of the threaded part projects $\frac{7}{8}$ inch or larger on the drawing, regardless of scale. The steps to be taken in laying out this thread symbol are shown in Fig. 19. When the threaded part projects less than $\frac{7}{8}$ inch on the drawing, the symbol in the last drawing of Fig. 17, or the adaptations of it in the center of Fig. 18, is to be used. The method of drawing such a symbol is also shown in Fig. 19. The representations of American standard screw threads upon drawings under various conditions will follow one or another of the forms shown in Fig. 18, which is a summary of the many different situations that may occur on drawings. These are the standards adopted by the American Standards Association in 1935.

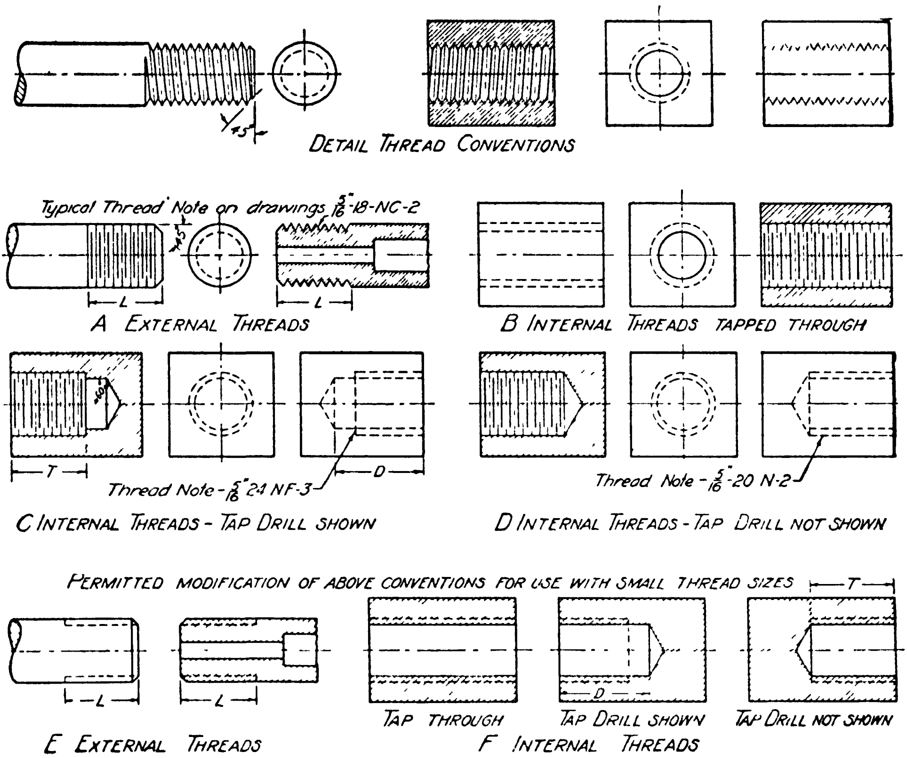


Fig. 18. Standard thread symbols.

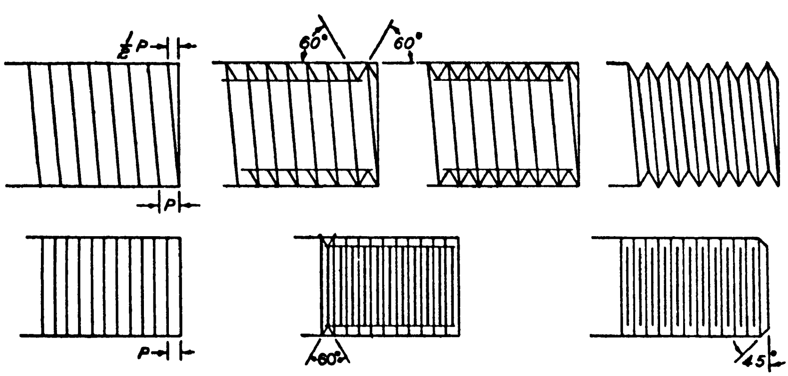


Fig. 19. Steps in drawing thread symbols.

177. Specifying V-Threads on Drawings. — Since the thread form is so highly conventionalized, the draftsman must indicate by a note just what kind of thread is desired. The form of this note has also been standardized as shown at three points in Fig. 18. The note takes the general form: $\frac{5}{16}''$-18-NC-2. The first figure gives the major diameter of the screw, the second specifies the number of threads per inch, the letters NC mean National Coarse threads, and the last number refers to the type or class of fit. When the letters NF are used instead of NC, the fine-thread series is referred to, and the letter N by itself means that a thread of the National form but of a special pitch is to be used.

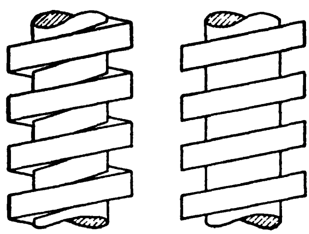


Fig. 20. Square thread symbols.

178. Representation of Square Threads. — The drawing of square threads has been conventionalized as shown in Fig. 20. When the diameter of the thread shows $\frac{7}{8}$ inch or more on the drawing, regardless of the scale, the thread convention at the left should be used. When the diameter projects less than $\frac{7}{8}$ inch, the convention at the right may be used. The method of laying out the square thread symbol is shown in Fig. 21. Square threads must always be fully dimensioned.

179. Representation of Acme Threads. — Acme threads may be conventionalized in the same manner as square threads. The dimen-

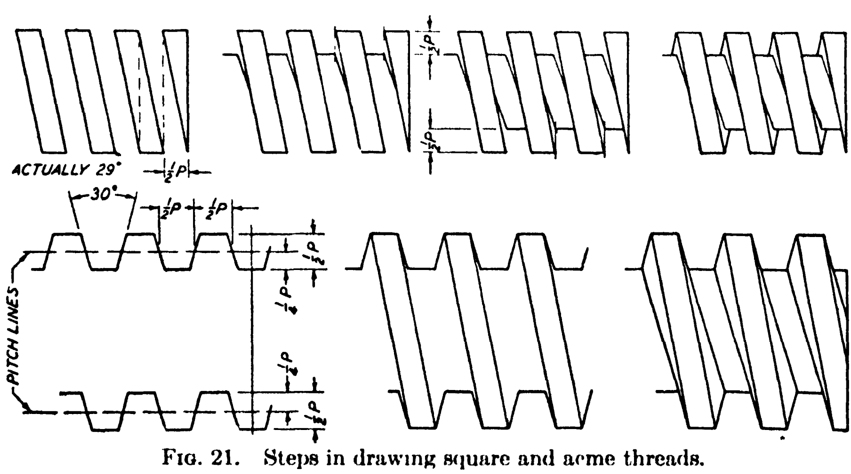


Fig. 21. Steps in drawing square and acme threads.

sions for standard Acme threads will be found in the Appendix and may be used in laying out such threads. The method of constructing the symbol is also shown in Fig. 21. The pitch of an Acme thread as well as its name must be specified on a drawing. All other dimensions are standardized and are derived from the diameter.

180. Representation of Multiple V-Threads. — Multiple threads may be laid out in the same manner as single threads, taking care to see that crest points on opposite sides of the thread are properly aligned as shown in Fig. 15. This applies also to multiple square and Acme threads.

181. Representation of Bolt and Screw Heads and Nuts. — It has been noted that the dimensions of the heads of square and hexagonal bolts, and of nuts, in all three classes of finish, were functions of the diameter of the shank. See Fig. 2. This fact is utilized in conventionalizing the drawing. The curves shown in the front views are formed by the intersection of the plane faces of the head and nut with the chamfer cone.

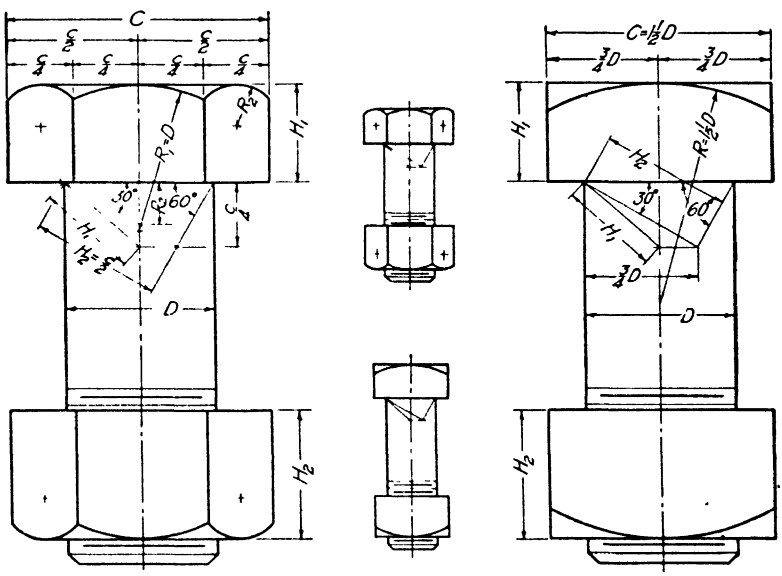


Fig. 22. Standard square and hexagonal bolts and nut symbols.

Since the planes are parallel to the axis of the cone these curves are hyperbolas. Such curves would be tedious to draw in true projection and would serve no useful purpose; hence they are conventionalized by circular arcs, as shown in the figure. To make the drawing of square- and hexagonal-head bolts and nuts as simple as possible, the further conventionalization shown in Fig. 22 has been recently adopted. This figure shows how to obtain all the construction dimensions of the heads and nuts and the radii of the arcs by graphical means. The method is known as the Jorgensen method. It gives sizes on the drawing almost identical with the actual sizes. It should be noted that the square-head bolt has been turned forty-five degrees from that represented in Fig. 2. This position of the head and nut, as well as the method of drawing the conventional parts, has been accepted as standard in this country.

When both a front and side view of the same hexagonal bolt head or nut occur, as in assembly drawings, with or without a corresponding top view (hexagonal), the head or nut is drawn as in Fig. 22 in both views, even though this is not according to the rules of projection. When a top view occurs, it is drawn as a true top view.

When cap screws and machine screws occur on drawings, they are made in orthographic projection to scale according to their dimensions as given in the tables on pages 196 and 197. Circular arcs are substituted for other more difficult curves when these occur, just as with square- and hexagonal-head bolts. The hexagonal-head cap screw should be treated as a bolt in representing its head.

182. Ordering Bolts. — When standard bolts and screws are used in the design of a machine or other structure, they are not shown upon the drawings but are listed in the bill of parts or materials. Such a list should give the diameter, length, type of head, and kind of bolt or screw desired, as, for example: 20 — $\frac{1}{2}''$ × 3″ Hex. Hd. Bolts, or 3 — $\frac{1}{4}''$ × $1\frac{1}{2}''$ Fillister Hd. Mach. Screws, or 6 — $\frac{1}{2}''$ × 2″ Rd. Hd. Cap Screws. All other dimensions are known when those above are specified. When placing orders with manufacturers, instructions for ordering given in their catalogues should be followed.

183. Special Bolts and Screws. — When special bolts or screws, not listed in the manufacturer's catalogues, are needed, exact working drawings that are complete in all respects must be furnished the manufacturer. Such drawings are not conventionalized and follow the usual rules for making working drawings.

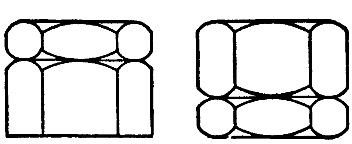


Fig. 23. Lock nuts.

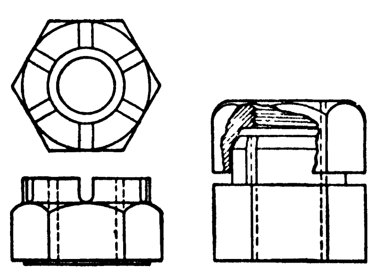


Fig. 24. Cottered and grip lock nut.

184. Lock Nuts. — A discussion of bolts and nuts cannot be considered complete without reference to an auxiliary fastener called a lock nut. Figure 23 shows the standard shape of such a nut. Its purpose is to keep the tightening nut from turning on the bolt after it has been set, a function which it performs admirably. In design, no allowance is made for the reduced stress in the tightening nut; hence it is kept at its usual thickness. The lock nut should be on top or underneath the tightening nut, depending upon the pressures developed between the nuts and between the lower nut and its bearing surface. Variations in lock-nut designs are also shown in Fig. 24. Their representation on a drawing is quite like that of the ordinary nut.

185. Pipe Threads. — The pipe thread used in this country is known as the American, formerly the Briggs, standard. It differs from the British pipe thread in that the sides of the thread form an angle of 60 degrees, whereas the British thread, which is built on the Whitworth system, shows an angle of 55 degrees. The top and bottom of the Standard American thread are slightly flattened and cut sharp. Figure 25 shows the form of this thread.

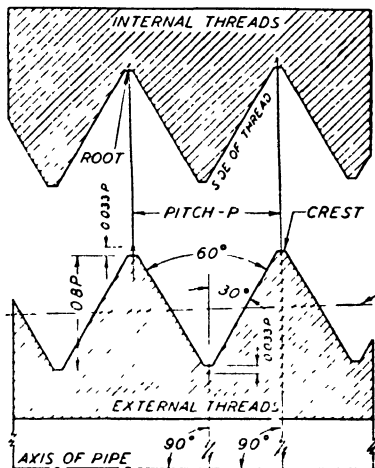


Fig. 25. Pipe thread profile.

Pipe threads are cut on a taper of 1 in 16, measured on the diameter. This causes a tight joint to be formed when pipe fittings are screwed on to the pipe, and it also allows the first few turns to be made by hand. A few of the threads of the pipe are, of course, slightly imperfect in form owing to the axial taper of thread, but they are counted as fully effective in holding the fitting to the pipe. See Fig. 26.

The pitch of the thread is measured axially and represents the distance a

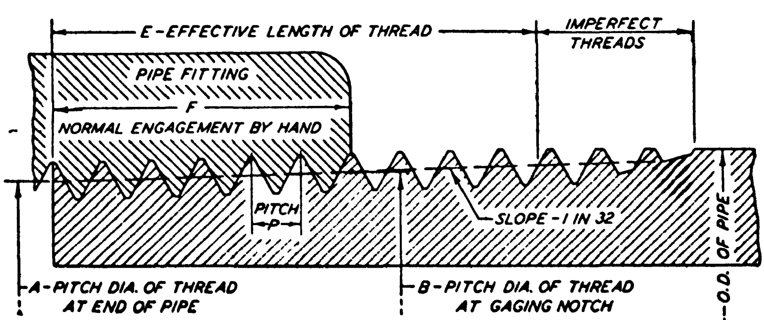


Fig. 26. Standard pipe thread.

fitting will advance on the pipe in one turn. The pitch of pipe threads has been standardized for various sizes of pipe as shown in Table III, Art. 377, Chapter XXII. Thus, when a given size of pipe is specified the pitch of the thread is determined. If a pipe must pass through the walls of a tank or reservoir, the taper thread cannot be used. Straight threads are cut on the pipe, and a lock nut with packing material is placed on each side of the wall, thus making a tight joint. The straight thread has the same form as the standard pipe thread, except that it is not tapered.

Pipe threads may be represented on a drawing by means of the same conventions used on regular threads. The taper may or may not be shown.

186. Rivets. — These fasteners are universally used and are too well known to require descriptions. They differ in form from one another in the shape of the head only. Figure 27 shows the common shapes of heads

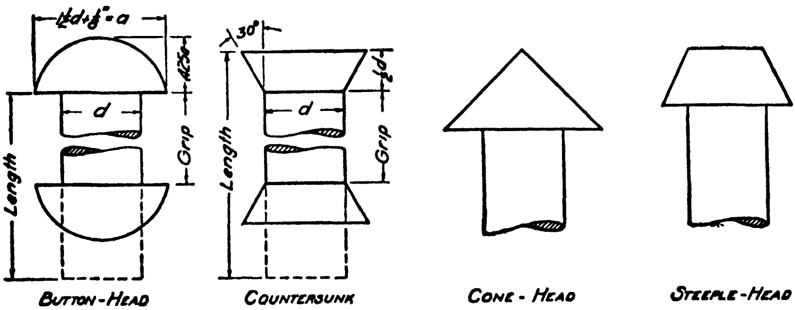


Fig. 27. Rivet head proportions.

and standard dimensions. The heads are simply pressed into any desired shape in proper machines, after the rod has been heated. The unheaded end of the rivet must be heated when the rivet is used, and headed by hand or by pneumatic hammers or riveters as they are called. This headed end is called the " point," to distinguish it from the pressed head.

On a structural drawing, the head of the rivet is shown in one view only as a circle, and in some cases it is not shown at all. Rivet heads are represented by symbols, there being one for each of the several kinds of heads. Since the pieces held together by rivets may be joined in the shop where they are fabricated or put together in the field, we have a further symbolism to indicate which way the riveting is to be done. Also, rivet heads may be countersunk or chipped to provide for clearances, and symbols have been devised to show these things. These various kinds of symbols have been deftly combined, and reference to the complete chart of rivet symbols should be made by turning to Chapter XXIII, on Structural Drafting.

In boiler and tank work more pains may be taken to show the actual shape of the rivet head and the kind of joint desired. Examples of this

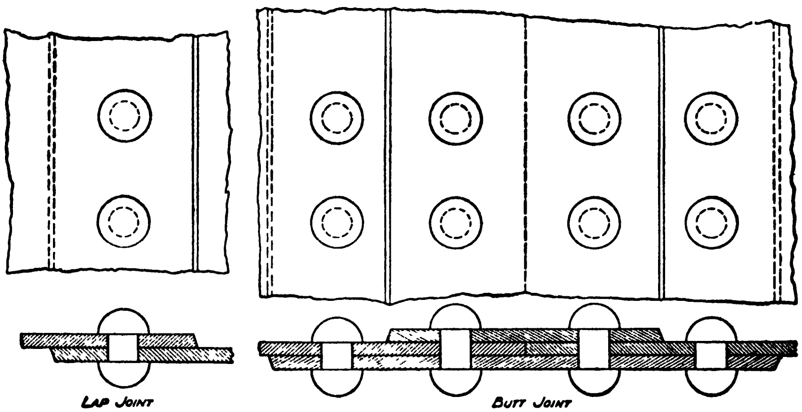


FIG. 28. Riveted lap and butt joints.

kind of riveting are given in Fig. 28, where the ordinary butt or lap joints are frequently met with.

Both the diameter and length of rivets vary in increments of one-eighth of an inch, the former running up to one inch, the latter reaching as high as six inches. The rivet hole is punched a little larger than the rivet diameter and filled by the expanding rivet when headed.

187. KEYS. — Those fasteners called keys are chiefly used to hold pulleys and rocker arms on rotating shafts. There are several standard types.

Figure 29 shows the four common types. On drawings, all keys and keyways should be shown. However, in the case of the Woodruff and the Pratt and Whitney keys, dimensions should be omitted, and these keys

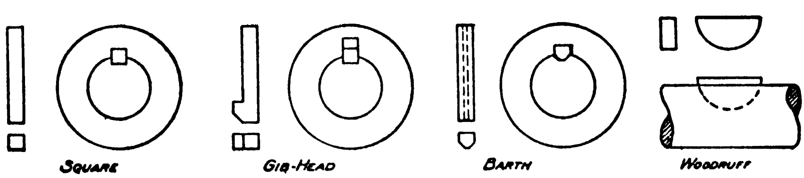


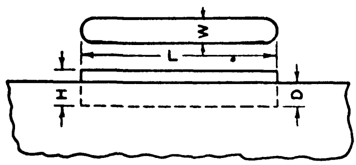
FIG. 29. Common keys.

should be specified by number and diameter of shaft only. Table VI shows the proportions of the Pratt and Whitney keys for each size or number. The key numbers correspond to those of the Woodruff system, and the dimensions of the keys are proportionately the same.

TABLE VI

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	$\frac{1}{2}$	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{16}$	22	$1\frac{3}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$
2	$\frac{1}{2}$	$\frac{3}{32}$	$\frac{9}{64}$	$\frac{3}{32}$	23	$1\frac{3}{8}$	$\frac{5}{16}$	$\frac{15}{32}$	$\frac{5}{16}$
3	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{8}$	F	$1\frac{3}{8}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{8}$
4	$\frac{5}{8}$	$\frac{3}{32}$	$\frac{9}{64}$	$\frac{3}{32}$	24	$1\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$
5	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{8}$	25	$1\frac{1}{2}$	$\frac{5}{16}$	$\frac{15}{32}$	$\frac{5}{16}$
6	$\frac{5}{8}$	$\frac{5}{32}$	$\frac{15}{64}$	$\frac{5}{32}$	G	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{8}$
7	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{8}$	51	$1\frac{3}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$
8	$\frac{3}{4}$	$\frac{5}{32}$	$\frac{15}{64}$	$\frac{5}{32}$	52	$1\frac{3}{4}$	$\frac{5}{16}$	$\frac{15}{32}$	$\frac{5}{16}$
9	$\frac{3}{4}$	$\frac{3}{16}$	$\frac{9}{32}$	$\frac{3}{16}$	53	$1\frac{3}{4}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{8}$
10	$\frac{7}{8}$	$\frac{5}{32}$	$\frac{15}{64}$	$\frac{5}{32}$	26	2	$\frac{3}{16}$	$\frac{9}{32}$	$\frac{3}{16}$
11	$\frac{7}{8}$	$\frac{3}{16}$	$\frac{9}{32}$	$\frac{3}{16}$	27	2	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$
12	$\frac{7}{8}$	$\frac{7}{32}$	$\frac{21}{64}$	$\frac{7}{32}$	28	2	$\frac{5}{16}$	$\frac{15}{32}$	$\frac{5}{16}$
A	$\frac{7}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$	29	2	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{8}$
13	1	$\frac{3}{16}$	$\frac{9}{32}$	$\frac{3}{16}$	54	$2\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$
14	1	$\frac{7}{32}$	$\frac{21}{64}$	$\frac{7}{32}$	55	$2\frac{1}{4}$	$\frac{5}{16}$	$\frac{15}{32}$	$\frac{5}{16}$
15	1	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$	56	$2\frac{1}{4}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{8}$
B	1	$\frac{5}{16}$	$\frac{15}{32}$	$\frac{5}{16}$	57	$2\frac{1}{4}$	$\frac{7}{16}$	$\frac{21}{32}$	$\frac{7}{16}$
16	$1\frac{1}{8}$	$\frac{3}{16}$	$\frac{9}{32}$	$\frac{3}{16}$	58	$2\frac{1}{2}$	$\frac{5}{16}$	$\frac{15}{32}$	$\frac{5}{16}$
17	$1\frac{1}{8}$	$\frac{7}{32}$	$\frac{21}{64}$	$\frac{7}{32}$	59	$2\frac{1}{2}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{8}$
18	$1\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$	60	$2\frac{1}{2}$	$\frac{7}{16}$	$\frac{21}{32}$	$\frac{7}{16}$
C	$1\frac{1}{8}$	$\frac{5}{16}$	$\frac{15}{32}$	$\frac{5}{16}$	61	$2\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{2}$
19	$1\frac{1}{4}$	$\frac{3}{16}$	$\frac{9}{32}$	$\frac{3}{16}$	30	3	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{8}$
20	$1\frac{1}{4}$	$\frac{7}{32}$	$\frac{21}{64}$	$\frac{7}{32}$	31	3	$\frac{7}{16}$	$\frac{21}{32}$	$\frac{7}{16}$
21	$1\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$	32	3	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{2}$
D	$1\frac{1}{4}$	$\frac{5}{16}$	$\frac{15}{32}$	$\frac{5}{16}$	33	3	$\frac{9}{16}$	$\frac{27}{32}$	$\frac{9}{16}$
E	$1\frac{1}{4}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{8}$	34	3	$\frac{5}{8}$	$\frac{15}{16}$	$\frac{5}{8}$

Any mechanical engineers' handbook furnishes data as to the sizes of the various types of keys and the diameter of shaft with which each should be used. When heavy loads are to be transmitted from the shaft to the

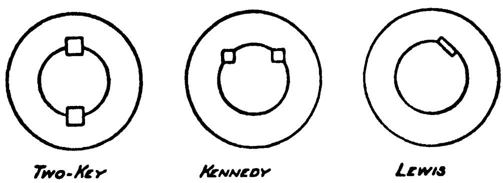


FIG. 30. Heavy duty keys.

pulley, or vice versa, two or more keys may be used, or the Kennedy and Lewis systems may be practicable. See Fig. 30.

188. Square Shaft and Splines. — Of late, and especially in automobile work, keys have to a large extent been eliminated or supplanted by the square shaft and multiple-spline shaft fittings. Figure 31 illustrates these fastening devices.

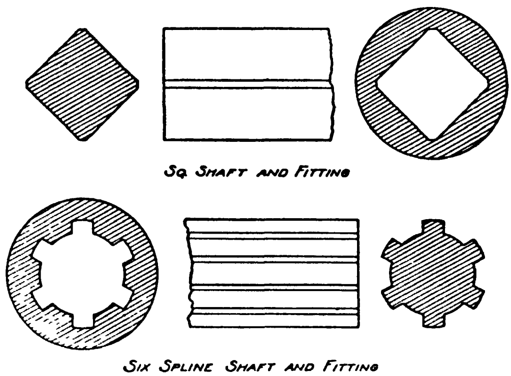
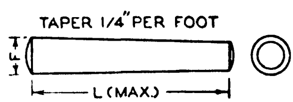


Fig. 31. Square shaft and multiple splines.

189. Taper Pins. — Taper pins are used as fasteners in place of keys and set screws, and as dowels. They taper one-fourth inch in diameter per foot of length. Table VII gives the diameter at the large end for each numbered size. The diameter of the small end can, of course, be computed for any specified length, or be obtained from a standard handbook. Lengths vary from three-fourths of an inch to thirteen inches.

TABLE VII

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	$\frac{3}{32}$	$\frac{3}{4}$	5	0 289	$\frac{19}{64}$	$2\frac{1}{4}$
0000	0 109	$\frac{7}{64}$	$\frac{7}{8}$	6	0 341	$\frac{11}{32}$	3
000	0 125	$\frac{1}{8}$	1	7	0 409	$\frac{13}{32}$	$3\frac{3}{4}$
00	0 141	$\frac{9}{64}$	$1\frac{1}{8}$	8	0 492	$\frac{1}{2}$	$4\frac{1}{2}$
				9	0 591	$\frac{19}{32}$	$5\frac{1}{4}$
0	0 156	$\frac{5}{32}$	$1\frac{1}{4}$				
1	0 172	$\frac{11}{64}$	$1\frac{1}{4}$	10	0 706	$\frac{23}{32}$	6
2	0 193	$\frac{3}{16}$	$1\frac{1}{2}$	11	0.860	$\frac{55}{64}$	$7\frac{1}{4}$
3	0 219	$\frac{7}{32}$	$1\frac{3}{4}$	12	1 032	$1\frac{1}{32}$	9
4	0 250	$\frac{1}{4}$	2	13	1 241	$1\frac{15}{64}$	11
				14	1 523	$1\frac{33}{64}$	13

PROBLEMS

190. Standard bolts and screws are not ordinarily shown upon working drawings, except in assemblies, but it is necessary to make drawings of all bolts and screws which depart from the standard forms. This is a common occurrence.

The problems below, however, have been confined to standard forms since they provide the necessary practice and are completely specified as to form and dimensions without the use of text figures. The student is referred to tables of standard dimensions, on pages 196 and 197.

The problems are to be made in ink or pencil as directed by the instructor. In either case show the necessary construction lines for bolt heads and nuts in light pencil lines. The scale will be full size unless otherwise specified. Specify the threads by means of a note of standard form, but in other respects leave the drawings undimensioned.

When the bolt or screw is under $\frac{7}{8}$ inch actual diameter on the paper, use the straight-line convention for threads; when $\frac{7}{8}$ inch or more in diameter, use the V-symbol for threads.

1. Make a two-view drawing of an American Standard bolt as described: Square head, unfinished bolt and nut, $2''$ in diameter and $4''$ long. Show the nut on the bolt.
2. Same as Prob. 1: Square-head finished bolt and nut, $1\frac{3}{4}'' \times 5''$.
3. Same as Prob. 1: Hex.-head unfinished bolt and nut, $2\frac{1}{4}'' \times 4\frac{1}{2}''$.
4. Same as Prob. 1: Hex.-head finished bolt and nut, $1\frac{1}{2}'' \times 5''$.
5. Make a two-view drawing of an American Standard machine, cap, or set, screw as described: Flat-head machine screw, $\frac{1}{4}'' \times 1\frac{1}{2}''$. Scale $2'' = 1''$. Use the straight-line symbol for threads.
6. Same as Prob. 5: Flat-head machine screw, $\frac{3}{16}'' \times 2''$.
7. Same as Prob. 5: Round-head machine screw, $\frac{5}{16}'' \times 1\frac{3}{4}''$.
8. Same as Prob. 5: Fillister-head machine screw, $\frac{5}{16}'' \times 1\frac{3}{4}''$.
9. Same as Prob. 5: Oval-head machine screw, $\frac{3}{8}'' \times 2\frac{1}{4}''$.
10. Same as Prob. 5: Flat-head cap screw, $\frac{5}{16}'' \times 2''$.
11. Same as Prob. 5: Button-head cap screw, $\frac{3}{8}'' \times 2\frac{1}{2}''$.
12. Same as Prob. 5: Fillister-head cap screw, $\frac{9}{16}'' \times 2\frac{1}{4}''$.
13. Same as Prob. 5: Hex.-head cap screw, $\frac{5}{8}'' \times 2\frac{1}{2}''$.
14. Same as Prob. 5: Square-head set screw, $\frac{3}{4}'' \times 2''$. Point as assigned—(*a*) Cup, (*b*) Flat, (*c*) Cone, (*d*) Dog, (*e*) Round.
15. Make a one-view drawing of the thread specified. Use straight lines to represent the helix curve. Show one turn of the invisible part of the thread. Make the thread $3''$ long and show $\frac{1}{2}''$ of shaft beyond the thread on each end, the minor diameter of the thread. Show the conventional cylindrical break on each end. The thread to be: single, right-hand, square thread, $2\frac{1}{2}''$ diameter, $\frac{1}{2}''$ pitch.
16. Same as Prob. 15: Double, left-hand, square thread, $3''$ in diameter and $\frac{3}{4}''$ pitch.
17. Same as Prob. 15: Double, right-hand, square thread, $2\frac{3}{4}''$ diameter, $\frac{5}{8}''$ pitch.
18. Same as Prob. 15: Triple, right-hand, square thread, $3''$ diameter, $\frac{3}{4}''$ pitch.
19. Same as Prob. 15: Single, right-hand, Acme thread, $2''$ diameter, $\frac{1}{2}''$ pitch.
20. Same as Prob. 15: Single, left-hand, Acme thread, $2\frac{1}{2}''$ diameter, $\frac{5}{8}''$ pitch.
21. Same as Prob. 15: Double, right-hand, Acme thread, $3''$ diameter, $\frac{3}{4}''$ pitch.
22. Same as Prob. 15: Double, left-hand, Acme thread, $3''$ diameter, $\frac{3}{4}''$ pitch.

CHAPTER XI

SHOP TERMS AND PROCESSES

191. The relation of the drafting room to the various shops is often underestimated in teaching the draftsman the techniques of his profession. No design has commercial value unless the thing designed can be made in the shops, and at a cost that will allow it to compete with similar products in the markets. Odd-size tools, impractical methods, and even impossible operations are often specified on drawings of the uninformed. The draftsman must know the capabilities and limitations of the shops. His drawings must " talk " in the shopman's language.

The best way for one to acquire intimate and accurate knowledge of the shops is through actual service in them. It is not possible nor desirable, perhaps, that everyone learning to do engineering work should serve apprenticeships in the shops. Everyone should, however, learn the fundamental shop processes, the names of machines and tools used, and the general advantages of one method over another. The four important shops are: pattern, foundry, forge, and machine shops. Those of a special character are omitted from consideration here, although most of them will be found to be equipped with standard machines used in the regular shops.

192. PATTERN SHOP. — The genesis of all cast metal work is found in the pattern shop. All drawings specifying castings must first go to the pattern-maker, who constructs a wood or plaster model of the thing to be cast. This model is called a pattern. Several important processes and shop terms used in the pattern shop will be briefly described.

193. Pattern-maker's Rule. — The draftsman gives dimensions on his drawing which are to be exactly those of the object after it is machined and polished. Since the casting shrinks as it cools, an allowance must be made for this in the pattern; hence, the pattern-maker's " shrink rule " is oversized an amount sufficient to take care of contraction. This oversizing is approximately equal to $\frac{1}{8}$ inch in every 12 inches. The allowance for machining is made dependent upon the size and shape of the casting and also upon the method of machining. About $\frac{1}{8}$ inch is allowed on small castings, and as much as $\frac{3}{4}$ inch on large castings. No reference to the shrinkage of the metal need be made on the drawing.

194. Draft and Parting Lines. — Casting molds are made up of sections which may be locked together in combinations of two or more for a single casting. Therefore, every pattern must be so constructed that at least one plane can be passed through it in such a way that, when this plane in the pattern is made to coincide with the plane between sections of the mold, the portions of the pattern on each side of this plane may be withdrawn from the sand in the respective sections without injury to the walls of the cavity left in each part. Sometimes the top surface of the pattern is put in the plane between sections, so that only one part of the mold will actually have an imprint of the pattern left in it when the pattern is withdrawn. In either case, a slight taper must be put on the pattern to allow it to be drawn out of the mold easily and without injury to the walls of the cavity. This taper is called the *draft*, or *draw*, of the pattern. Sometimes the pattern itself is made in halves.

From the above it is easily seen that any design of an object must be so made that at least one "parting" plane can be found on the object; or it must be such that the pattern of it can be placed in one section of a mold and drawn out as previously explained. The line on the drawing which indicates this dividing plane in the first case is called a *parting line.* In the second case, this line would be on an outside edge of one of the views. The draftsman does not put these lines on the drawing, but he must be sure his design is such that the pattern-maker may do so. Several parting lines may be used in making a single pattern.

195. Fillet. — Sharp angles on a casting are places of weakness. To strengthen these angles extra metal is provided; this process is called filleting the casting. On the pattern this takes the form of quarter-

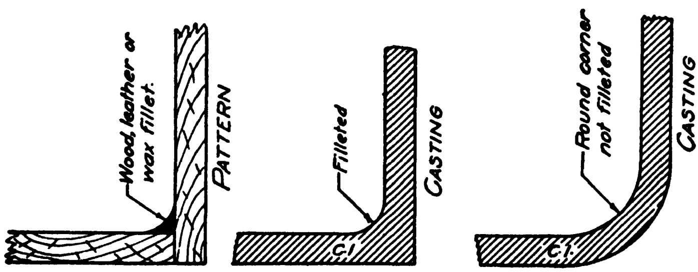


Fig. 1. Fillet on pattern and casting.

rounds of wood or leather nailed into these angles, as shown in Fig. 1. Wax is often used for this purpose. Simply rounding outside corners on a casting is not filleting.

196. Core. — In many castings, large holes are desired or interior passageways are needed. To avoid boring or machining operations, or where both of these are impossible, cores are inserted in the molds before the molten metal is poured into them. These cores occupy the places in the mold where openings are desired in the casting. They are made of a specially prepared mixture of sand and binding material and are then baked hard in a core oven. When the pattern is withdrawn from the mold, these cores are inserted and held in place by small extensions or arms, which fit into holes left in the walls of the sand by projections on the

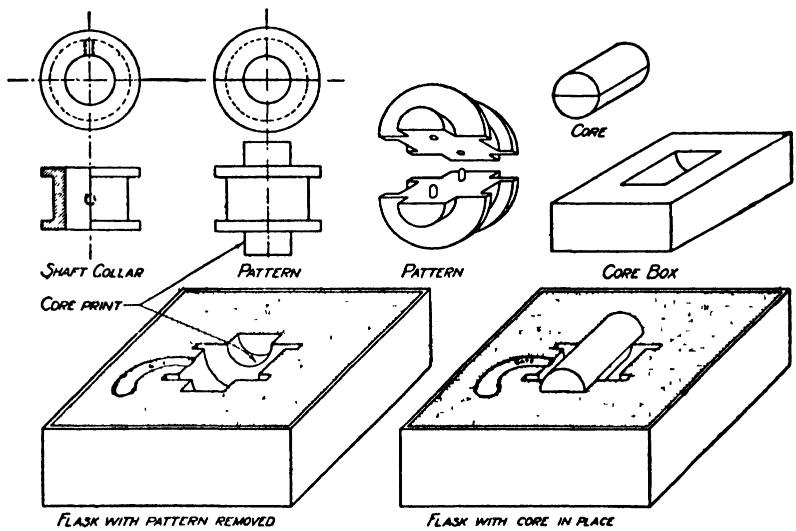


Fig. 2. Pattern, core, core box, and flask.

pattern provided for this very purpose. These projections are known as *core prints* and are simply dowels projecting from the proper places on the pattern. Figure 2 illustrates these several relations of pattern, core, and mold. When the metal has cooled, the cores are easily disintegrated and shaken out of the castings.

197. Core Box. — The wooden mold in which the core is made is called the core box. It is constructed by the pattern-maker; the core is made by the core-maker.

198. Foundry. — The draftsman has little immediate connection with the foundry, since the pattern-maker acts as an intermediary between him and the molder. He should, nevertheless, acquaint himself with the machines and materials with which the foundry is equipped, chief among which are the cupola, the molding sand, and the mold. The mold is generally made in two parts, although three and four parts are sometimes used. The bottom part is known as the drag, the top part as the cope, and the two together are called the flask.

Shop drawings do not, as a general rule, include any reference to foundry operations. However, there probably is no place where the item of cost is of more vital importance than in the foundry. Excessive metal and difficult shapes to cast are things which make the manufactured product costly, and the designer must always be on guard against these expensive items.

199. FORGE SHOP. — Many parts of a machine or structure cannot be cast, but have to be rolled, pressed, or forged into shape in the respective shops. Several forge-shop terms may occur on any drawing. Heat treatments of metals are included, because in many plants these treatments are considered a part of the forge-shop activity, as a matter of convenience and economy.

200. Drop Forging. — Instead of hammering the heated metal into the proper form by manipulation on the anvil, the forge man may use a die or mold of the desired shape, into which the heated metal is forced by means of drop hammers. The process may be considered a semi-casting scheme, in that the heated metal is made to conform to a desired shape in a mold. The character of the metal used, however, is entirely different from the casting metal used in the foundry.

201. Hardening and Tempering. — The properties of steel such as, tensile strength, ductility, hardness, etc., depend upon the chemical composition of the steel and the heat treatment to which it is subjected. If steel is heated between temperatures of 1550° and 1750° F. and then suddenly cooled, it will be hardened. Steel is hardened for the purpose of resisting wear and increasing the tensile strength and elastic limit. The process of hardening decreases the ductility and makes the steel more brittle. For cutting tools this is undesirable.

If hardened steel is reheated to temperatures between 400° and 1100° F. and then allowed to cool, the hardness and brittleness are reduced and the ductility is increased. This process is called tempering. The temperature required depends upon the composition of the steel and the purpose for which the steel is to be used. Heat treatments have been standardized and may be specified by number or letter on drawings.

202. Annealing. — As in tempering, one of the objects of annealing is to make a hardened steel softer and less brittle. In addition to accomplishing this end, the method of heating and cooling removes all temperature stresses that may have been set up in the metal upon its first treatment. This result is obtained by slow and even heating of the steel in specially prepared boxes or beds of sand, powdered charcoal, and the like, and then allowing it to cool slowly in similar beds of charcoal or other slow heat-conductors. Molten lead and heated oil baths are often used for heating the steel.

203. MACHINE SHOP. — It is with the machine-shop processes that the draftsman must be most familiar. Shop tools, machines in which they are used, and the modes of operation of the machines have their limitations and possibilities. Some of the more important machines are drill presses, lathes, grinders, shapers, planers, milling machines, etc. A brief explanation of the purpose of each machine and the method of indicating its use on a drawing are given hereafter. The tools to be used and the manner of indicating their sizes are also included.

204. The Drill Press. — A common type is the radial drill press, in which the drill proper is held in a chuck, which in turn is mounted on an arm that can be revolved around and moved up and down on a vertical central axis of the machine. The chuck is given a horizontal motion on its carrying arm by means of a screw and gear arrangement, so that it is possible to drill a hole in almost any part of a rather large piece without reclamping or moving the piece about on the bed of the machine. The cutting tools used in a drill press are called drills. The simple drill press without a swinging arm is a requisite to any shop and is familiar to all. These machines are used for reaming and counterboring, as well as for drilling.

205. Drills. — The ordinary twist drill, the outlines of which are shown in Fig. 3, is familiar to everyone. When used to precede a thread tap, it is

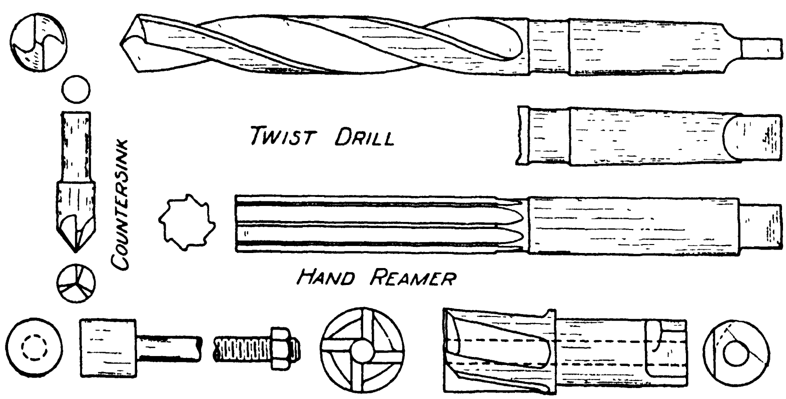


FIG. 3. Drill, reamer, counterbore, and countersink.

termed a tapping drill, or simply a tap drill. It is specified on a drawing by giving its diameter only. The noun or verb may be used to specify the size, thus, " Drill $\frac{3}{8}''$ or $\frac{3}{8}''$ drill." Drills from $\frac{1}{64}$ inch up to 3 inches in diameter and 14 inches in length are obtainable.

206. Reamers. — A hole that has been drilled is left with a rough and slightly scored surface. It is not suitable for close fits or for tapping if fine thread crests are desired. The reamer is used to finish and smooth this rough surface. There are several types of reamers, but most work is done with the fluted reamer shown in Fig. 3. The draftsman indicates both the drill and the ream to be used by giving the diameter of each, thus, "Drill $\frac{39}{64}$″, Ream $\frac{5}{8}$″." Reamers up to 3 inches in diameter and 17 inches in length can be secured.

207. Boring. — Closely associated with the process of drilling and reaming, in respect to the results achieved, is that of boring. The operation is done on a lathe or specially designed boring machine, and consists of making a round hole in a piece of considerable length or size, such as an engine cylinder or gun barrel. Very small holes can be bored, and all holes beyond the sizes and lengths of drills and reamers must be bored. The cutting tool is held on a boring bar which advances into the bored hole as the piece itself or as the boring tool is revolved. The note on the drawing to indicate the boring process simply gives the diameter of the finished hole and the name of the operation, thus "3″ bore."

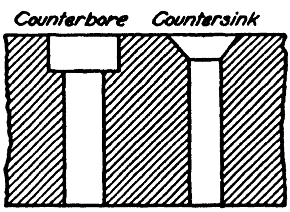


Fig. 4. Counterbore and countersunk holes.

In some instances a counterbore is indicated, in which case the depth must also be given, thus, "4″ counterbore, $3\frac{1}{2}$″ deep." Heads of bolts and screws are brought level with the surface of parts through which they pass by counterboring a hole larger than the drill or tapped hole a depth equal to the height of their heads. This is usually done on the drill press. Heads of screws with tapering sides are brought level with the surface through which they pass by countersinking instead of counterboring. Figure 4 shows the result of the two operations.

208. The Lathe. — The lathe is the most generally used machine in the shop. Practically all machining of cylindrical surfaces such as spindles, glands, etc., is done on the lathe. The piece to be machined is supported between two centers, one in the tailstock, the other in the headstock, and then revolved by power supplied through the headstock. A tool post, which may be moved longitudinally along the lathe, carries the cutting tool, which removes a thin layer of metal each time it traverses the length of the surface being machined. The operation is called turning.

Other things besides turning may be done on a lathe, such as boring, already alluded to, grinding, reaming, knurling, threading, and polishing.

209. Grinding. — Grinding machines may vary from the ordinary coarse and fine emery wheels to high-speed abrasive wheels like those made of silicon carbide (Carborundum). The purpose of grinding is to leave a finished surface on the metal, and at the same time to remove economically the small amount of stock left after the last rough cut in the lathe has brought the size to within $\frac{1}{32}$ or $\frac{1}{64}$ inch of the required size. In other words, the draftsman indicates the grinding operation on his drawings when he wants the outer surfaces left smooth and to an exact size, say within 0.001 inch. Both external and internal grinders are available, and although both the grinder and piece being ground are usually revolved against each other, stationary surfaces may also be ground.

210. Polishing. — Polishing must not be confused with grinding. Although a ground surface is very smooth, it is not said to be a polished surface until it has been gone over carefully with a fast-revolving disk of material like muslin or leather, containing a fine abrasive, which gives it a luster impossible to attain with the finest grinders. The draftsman indicates such an operation by the note, " grind and polish."

211. The Milling Machine. — The milling machine is like the ordinary rotary saw seen in lumber mills and wood shops, in its manner of operation. The cutters are circular disks, with teeth which cut away the metal from any piece as it is automatically fed along under the revolving cutter. Slots, keyways, gear teeth, and similar cuts are easily made with the milling machine. End mills, for such work as finishing ends of bosses and bearings, are available in the average shop. The draftsman specifies the size of the slot or other cut to be made and the shop man chooses the proper cutter with which to do the work.

212. The Planer. — When large, flat surfaces are to be finished, a machine called a planer is used. The piece to be planed is mounted on a long horizontal bed which moves the surface of the piece forward and backward under the cutting tool which in turn moves laterally a small amount each run of the bed. Numerous pieces of the same kind may be clamped to the bed and planed at once. The draftsman makes no reference to this machine on his drawing, but simply writes the word " finish," on the surface to be planed or uses the small letter *f* as previously explained.

213. The Shaper. — The shaper is particularly adapted to the cutting of slots and grooves and to general utility finishing work. It is so arranged that the piece being machined is held on a bed that may be moved by the operator in any desired direction while the cutting tool is operated with a reciprocating motion at comparatively high speeds.

214. Jigs and Fixtures. — In operating machines in the shop it is necessary to repeat the same operation scores of times in identically the same way and to exactly the same dimensions, on a part that is being turned out in quantities. No shop man could accomplish this task with rule and calipers only, and maintain standard conditions. Devices known as jigs and fixtures overcome the difficulties of inexact measurements and greatly shorten the time of operation.

In general, we may say that the *fixture* is fastened rigidly to the machine and serves to hold the work in place, while the tools are doing their work; hence the name fixture. A *jig*, on the other hand, may be held on the work, or it may hold the piece being machined and at the same time act as a guide for the tools.

Up-to-date shops have their own designer of jigs and fixtures, and the draftsman need not pay attention to these devices in turning out machine drawings.

215. Broaching. — In cutting internal slots, plane square and rectangular holes, holes for splines, etc., a tool called a broach is used. This tool is simply a stiff, hard-tempered shaft of steel, of a shape to cut the required hole, with cutting teeth along each side. The broach is either pushed or pulled through a round hole which has been previously drilled, and the interior of the hole is left smooth and of the desired shape. When a push broach is used, some type of press, either hydraulic or otherwise, is provided; for the pulling broaches a standard broaching machine has been devised in which the force is applied through a screw.

CHAPTER XII

PICTORIAL DRAWING

216. Two- or three-view orthographic projections of objects are unintelligible to many people who have had no training in the art of drawing, because the drawings bear so little resemblance to what the eye actually sees. Two- or three-view drawings show only one face, and give only two dimensions of an object at a time, with no idea or suggestion of depth, whereas the eye ordinarily sees three sides of an object at once. Hence, if a drawing is made that presents three sides of an object in one view, it becomes easily readable and conveys a definite meaning to the average person. Even by the man who is trained in reading drawings, the true relation of parts can be more readily and quickly grasped from a pictorial representation than from ordinary working drawings. In order to present three-dimensional objects in this way, different pictorial schemes are commonly employed, called isometric, oblique, and perspective drawing.

All these schemes possess the advantage of presenting three faces of an object in one view; but, combined with this advantage, are certain disadvantages which seriously limit the use of pictorial drawing for the engineer:

1. It is more difficult to dimension isometric and oblique drawings than the usual three-view drawings, and perspective does not lend itself to dimensioning at all.

2. Although isometric drawings can always be scaled, oblique drawings may be scaled only under certain conditions, and perspectives can never be scaled.

3. The time required for the execution of pictorial drawings is much longer than for two- or three-view drawings, except those of very simple objects.

4. Isometric and oblique views sometimes have a distorted appearance which is very disagreeable, because the receding lines on the drawing are parallel, whereas to the eye the receding parallel lines which they represent actually appear to converge.

In spite of these disadvantages, however, the fact that ideas may be presented in a form which all can understand makes a thorough knowledge of the fundamentals of pictorial drawing almost indispensable to the engineer.

217. Uses of Pictorial Drawings. — The architect and architectural engineer make very frequent use of perspectives, to study the form and proportions of a building, and also to give to their clients an idea of the appearance of the finished structure. Isometric drawings are often used in making piping and wiring diagrams. See page 425. Both isometric and oblique drawings are sometimes used for shop purposes, especially where there are workmen who are not skilled in reading working drawings. For patent-office drawings and for advertising and display purposes, any one of the three schemes may be used to advantage.

218. Classification of Types of Projection. — As has been stated, all pictorial drawings are one-plane drawings. For convenience, the vertical plane is chosen as this *picture plane*, although for purposes of explanation other planes are used. Three distinct methods are employed to obtain the three kinds of pictorial drawings named in the preceding paragraph:

1. The object may be turned in respect to the principal coördinate planes in such a way that, when projected orthographically upon any one of them (usually the vertical), three faces of the object will be shown in one projection. This method gives what is termed *axonometric projection*, which in turn is subdivided into isometric, dimetric, and trimetric projection, depending upon the position of the object relative to the plane of projection.

2. Instead of turning the object from its customary position relative to the principal coördinate planes, the parallel projecting lines are made to intersect the plane of projection obliquely, instead of at right angles as in orthographic projection. This, in effect, is changing the point of sight, and obviously accomplishes the purpose of showing three faces of the object at one time.

3. The third method consists of moving the point of sight a finite distance from the picture plane, the object remaining in its usual position relative to the plane, or being rotated on a vertical axis some predetermined angular amount. The projecting lines converge, of course, on this finite point of sight. In the first case the result is called *parallel* or *one-point perspective;* in the second, the result is called *angular* or *two-point perspective.*

The following table is a classification of the various kinds of projection used in mechanical drawing. It gives briefly the salient features of each of the types and shows their relation to each other.

A careful study of the chart will fix in the student's mind the whole fundamental theory of projection underlying the expression of ideas by means of the graphical language. As stated elsewhere in this text, the kind of drawing produced by the draftsman depends upon the simple relations existing between the object, the plane of projection, and the projecting lines, or lines of sight. These relations are epitomized in the table.

CLASSIFICATION OF PROJECTIONS USED IN MECHANICAL DRAWING

Mechanical drawing.	Orthographic projection. Point of sight at infinity. Projecting lines at right angles to the plane of projection.	Polyplane projection.	Two- and three-view drawings. Faces parallel to the planes of projection.
		One-plane projection. (Axonometric.)	Isometric. Faces equally inclined to the plane of projection. Dimetric. Two faces equally inclined to the plane of projection. Trimetric. All faces unequally inclined to the plane of projection.
	Oblique projection. Point of sight at infinity. Projecting lines oblique to the plane of projection but all making same angle with it.	One-plane projection.	Cavalier projection. Cabinet drawing. Pseudo-perspective.
	Scenographic projection. Point of sight at a finite distance. Projecting lines oblique to the plane of projection and making different angles with it.	One-plane projection.	Parallel or one-point perspective. Object has one face parallel to the plane of projection. Angular or two-point perspective. Object has two faces equally or unequally inclined to the plane of projection.

NOTE: This table does not include the various phases of map projection.

CHAPTER XIII

ISOMETRIC AND DIMETRIC PROJECTION

219. An axonometric projection of an object is an orthographic projection (projecting lines perpendicular to the plane) upon a single plane, showing three faces of the object in one view, with the principal coördinate axes foreshortened by varying amounts according to the different arrangements of the axes in respect to the plane. If the foreshortening is the same on all three axes, the projection is called *an isometric;* if two axes are foreshortened equally and the third by a different amount, the projection is called *a dimetric;* and finally, if the foreshortening on all three axes is different, it is called *a trimetric projection.*

Isometric projection, while properly classified under the heading of orthographic projection, differs from anything studied heretofore in that only one plane of projection, called the isometric plane, is used. This plane makes equal angles with the three principal planes of projection, as shown in Fig. 1. Assuming a cube in the first quadrant in the normal position for orthographic projection, i.e., with the faces parallel to the principal planes, it is evident that one body diagonal of the cube is perpendicular to the isometric plane. This body diagonal is called the *isometric axis.* The edges of the cube make equal angles with the isometric plane, and consequently, if projected upon it orthographically, will be equally foreshortened; hence, the projection is called an *isometric,* which means equal measurement. The point of sight is assumed to be on the isometric axis at an infinite distance from the plane. Therefore, *an isometric of an object is an orthographic projection of the object on the isometric plane.*

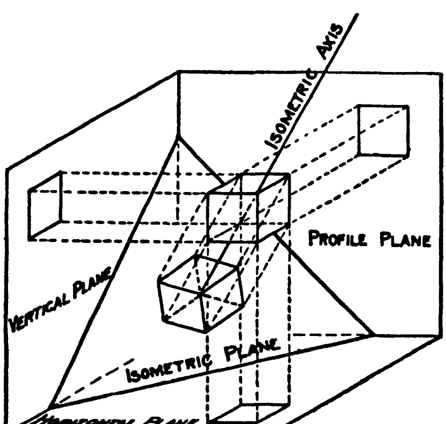


FIG. 1. The isometric plane.

If the cube of Fig. 1 is orthographically projected onto an auxiliary plane 4 (see Chapter VI) set up perpendicular to the isometric axis, or body diagonal, of the cube, the result will be, by the definition above, an isometric projection of the cube. Plane 4 becomes the isometric plane in this instance. In Fig. 2, the construction has been carried out in accordance with the principles developed in Arts. 90 and 92 of Chapter VI. An intermediate auxiliary plane 3 was first set up *parallel* to the diagonal of the cube, followed by plane 4 *perpendicular* to the diagonal.

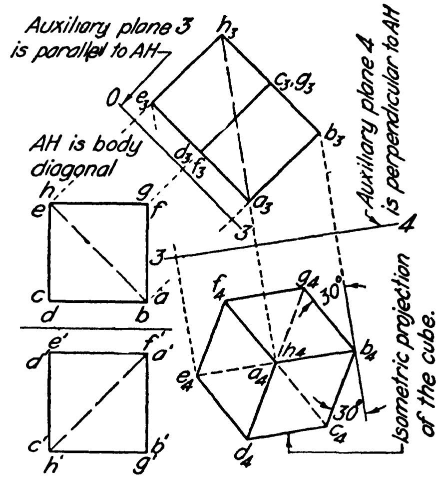


FIG. 2. Isometric obtained by means of auxiliary projection.

It will be noted that the projections of the edge lines of the cube in the isometric of Fig. 2 do not show perpendicular, parallel, or at the same angle to the horizontal, although the projection is a true isometric of the cube. A more natural view is obtained by rotating the drawing a quarter-turn to the left. Also, it is not easy to visualize the exact position of the auxiliary plane relative to the object in space, from the drawing.

However, it is not necessary for the student to visualize the isometric plane, since an object can be placed relative to any plane as the cube described above is placed relative to either isometric plane of Figs. 1 or 2. The vertical plane is perhaps the

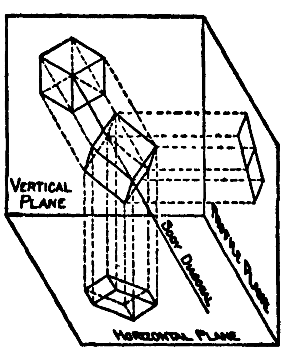


FIG. 3. Isometric projection on vertical plane.

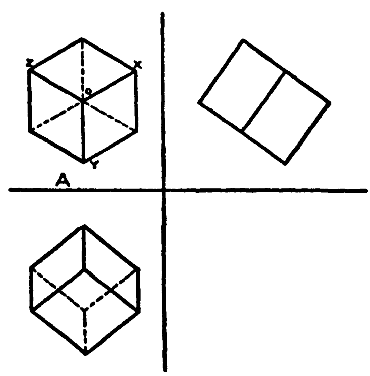


FIG. 4. Orthographic projections of cube shown in Fig. 3.

most convenient, and hence is used as the isometric plane. Figure 3 shows a cube in this position and Fig. 4 shows the three orthographic projections of the cube thus placed. The view marked A — the vertical projection — is also the isometric of the cube.

A clearer understanding of the details involved in obtaining the isometric A of Fig. 4 can be had by following the steps taken in turning the cube into

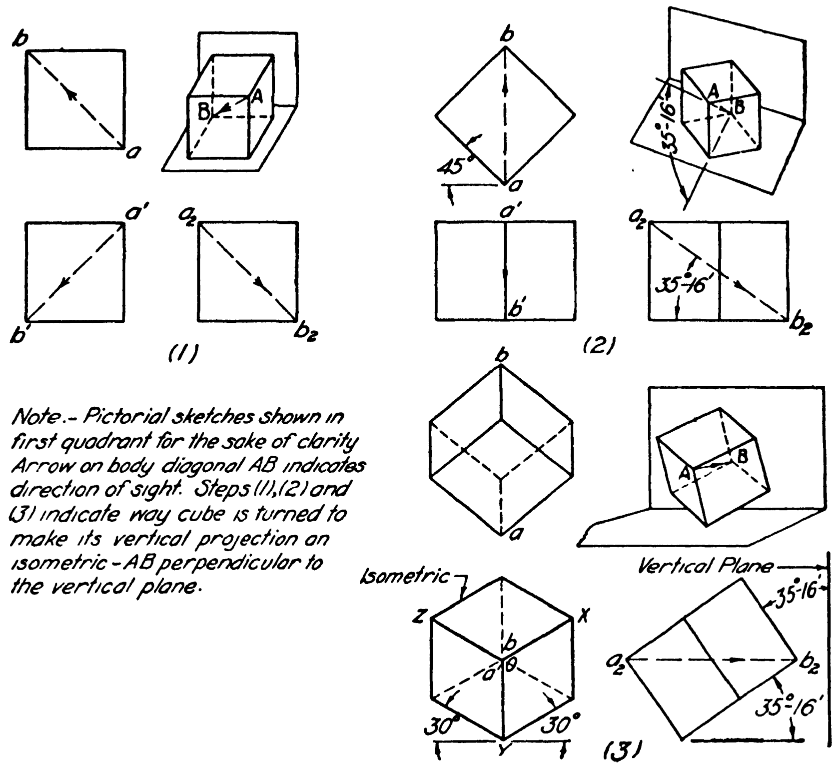


FIG. 5. Turning cube into position to obtain isometric projection on vertical plane.

the desired position, shown in Fig. 5. The constructions have been carried out as though the cube were in the third quadrant, but this has no effect on the final result, as the figure shows.

220. DEFINITION OF TERMS. — The projection of the front corner of the cube is called the *origin*, and is indicated by O in the isometric A of Fig. 4. The projections of the three front edges of the cube, OX, OY, and OZ are called the *isometric directrices*. All lines on the cube parallel to these three edges are called *isometric lines*. Since the edges of the cube make equal angles with each other and with the body diagonal of the cube, their projections on any plane make equal angles with each other when the body diagonal is perpendicular to the plane. Thus, angle ZOX = angle XOY = angle YOZ = 120°. The planes of the three faces of the cube are called *isometric planes.* Any planes parallel to these three are also called *isometric planes.*

221. ISOMETRIC SCALE. — From Fig. 5 and the discussion in the preceding paragraphs, it is clear that the lines of the isometric are all shorter than the actual lengths of the edges of the cube. The angle which the edges of the cube make with the plane of projection is 35° 16′, so that the projections are about eight-tenths of the true length of the lines. In order to make an isometric of an object which shall be mathematically correct, it is necessary to construct a special scale, called the isometric scale, on which all units of measurement have been foreshortened in the same ratio as were the edges of the cube when projected on the isometric

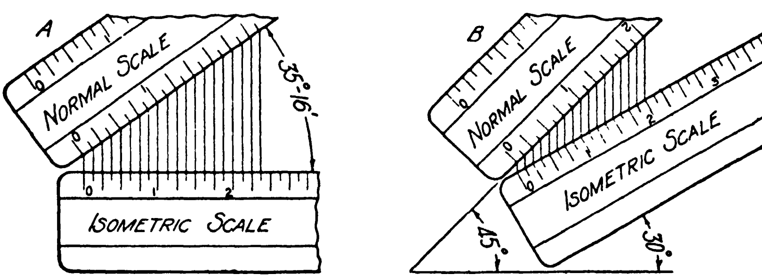


FIG. 6. Construction of isometric scale.

plane. Two methods for constructing such a scale are shown in Fig. 6, *A* and *B*.

To construct an accurate isometric, therefore, two scales must be used — the one a normal scale with which to measure the object, the other an isometric scale with which to make the drawing. This is very inconvenient, and such a drawing would be impractical since it could not be scaled in the shop or elsewhere without an isometric scale. For this reason, *isometric drawings* are seldom real projections of objects, but are about one and one-quarter times larger in linear dimensions than the true projections, because made with the normal scale. Thus, by disregarding all foreshortening of lines, yet retaining strict ratios of lengths and the same proportions, the draftsman is able to produce a useful and effective drawing for ordinary purposes with a minimum expenditure of his time. To avoid confusion and error, drawings made upon isometric principles, but without the use of an isometric scale, are termed *isometric drawings,* while real projections, or those on which an isometric scale is used, are termed *isometric projections.*

222. ISOMETRIC DRAWING OF A CUBE. — To make an isometric drawing of a cube, a convenient point on the paper may be selected as the origin, and from this, by means of a T-square and a 30°–60° triangle, the three axes or front edges may be drawn, one vertically, one up 30 degrees from the horizontal to the right, and one up 30 degrees from the horizontal to the left. Along these three lines the actual length of the edges of the cube may be measured to any convenient scale. From the three corners thus located, the remainder of the cube may be readily obtained with the 30°–60° triangle by paralleling the three lines already drawn. See *A*, Fig. 3.

223. Isometric Drawing of Plane Figures. — The isometric drawing of a solid object consists mainly in representing three more or less irregular plane faces, which are parallel to isometric planes and in which there may be several non-isometric lines. The outlines of the plane faces with the non-isometric lines in them constitute a series of plane geometrical figures which must be drawn in isometric. Hence, the drawing of plane figures will be considered first.

Let it be required to draw a triangle in an isometric plane. Lay out the triangle and enclose it in a square, as in *A*, Fig. 7. Then draw the square in isometric as if it were any one of the three faces of a cube, and locate the three corners of the triangle in this square by measurement. Thus, in *B*, Fig. 7, *a* and *c* are at opposite corners of the square, and *b* is

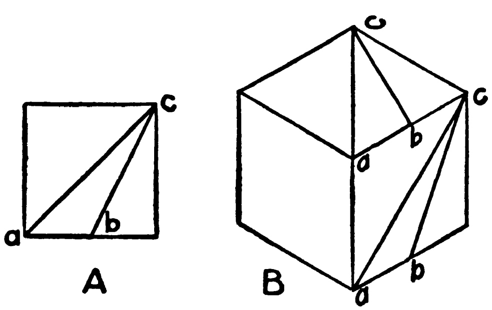


Fig. 7. Isometric of triangle.

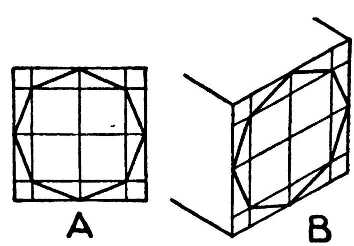


Fig. 8. Isometric of octagon.

located by measuring from *a* in the isometric square a distance equal to *ab* in the true square. If the triangle could not have been enclosed in a square, an enclosing rectangle could have been drawn and the procedure would then be the same as in the square.

To draw the isometric of an octagon, proceed in the same general manner as with the triangle above, first enclosing the octagon in a square, as in *A*, Fig. 8. Then draw coördinate lines through the points of the octagon which do not lie on the sides of the square. Draw the square in isometric and rule in the coördinate lines by means of measurements along the isometric axes, thus locating the corners of the octagon. See

B Fig. 8. By drawing lines from point to point, the octagon may be constructed.

A circle or any irregular plane figure may be drawn in isometric by the coördinate method described above. Figure 9 shows a circle and a smooth

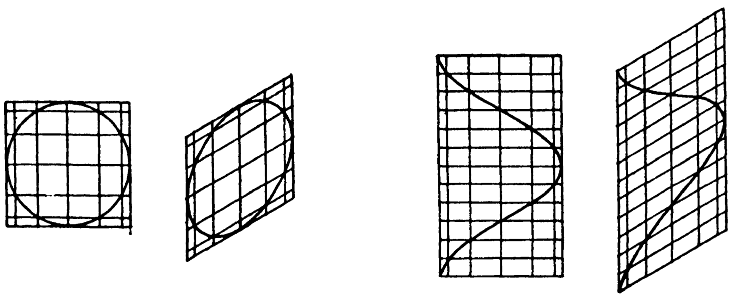


FIG. 9. Isometrics by the coördinate method.

curve from which the actual steps of construction are self-evident. The curves, of course, must be drawn through the plotted points with the aid of an "irregular" curve.

An approximate isometric of a circle may also be drawn by the method shown in Fig. 10. 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 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*, *fc*, and *mn*. The method involves less labor than the coördinate 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.

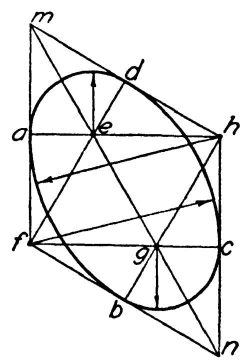


FIG. 10. Isometric of circle by the four center approximate method.

224. ISOMETRIC DRAWING OF SOLIDS. — 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 coördinate distance. First imagine the object enclosed in a rectangular box; then make a two- or three-view drawing of both the object and the enclosing box. Finally, draw the isometric of the enclosing box and fix the significant points on the object by coördinate measurements taken from the multi-view drawing. The construction of the isometric of a truncated hexagonal pyramid is illustrated in Fig. 11.

The hexagonal base of the truncated pyramid may be drawn in by the methods discussed under isometric drawing of plane figures. All lines in the base of this figure, with the exception of two, are non-isometric, and therefore no measurement can be made on these lines themselves. After

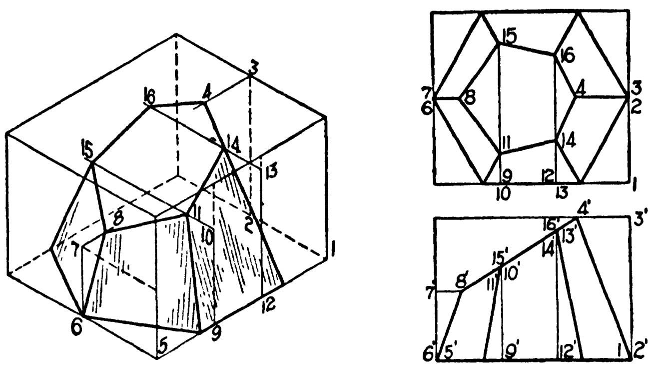


FIG. 11. A solid in isometric.

the base has been drawn, it is necessary only to locate the six points of the truncated face and then connect them with the proper points in the base and with each other, to complete the figure. Since the truncated face does not lie in an isometric plane, a third coördinate measurement is necessary for each point.

For example, to locate point *4*, it is necessary to measure off the three coördinates *1–2*, *2–3*, and *3–4*. The length of these coördinates is obtained from the two-view drawing, and the measurement made along isometric lines, beginning at the corner of the box marked *1* and laying off *1–2* along the lower rear edge, then *2–3* vertically, and finally *3–4* in the proper direction in the upper face of the enclosing parallelopiped.

Point *14* may be located in the same manner by laying off the coördinates *5–12*, *12–13*, and *13–14*, or the coördinates *1–12*, *12–13*, and *13–14*. The method of measurement is clearly indicated in the figure for all the points. For further illustrations of isometric constructions see Figs. 4, 5, and 6, Chapter V.

After the entire construction has been completed in light pencil lines, the visible lines of the figure may be made heavier or inked in, after which the construction lines should be erased. It is customary in isometric drawing to omit all hidden lines except where they may be necessary to make clear the construction of the object.

It will be observed in the above construction that all measurements are made along isometric lines only. This point should be carefully noted, because measurements made in any other way will be in error, for the isometric lines are the only lines of equal foreshortening or equal measurement. Any violation of this rule will lead to failure.

The simple bearing shown in Fig. 12 will serve further to illustrate isometric construction. Considerable time can be saved in drawing, if the draftsman recognizes that a great deal of the construction of an object

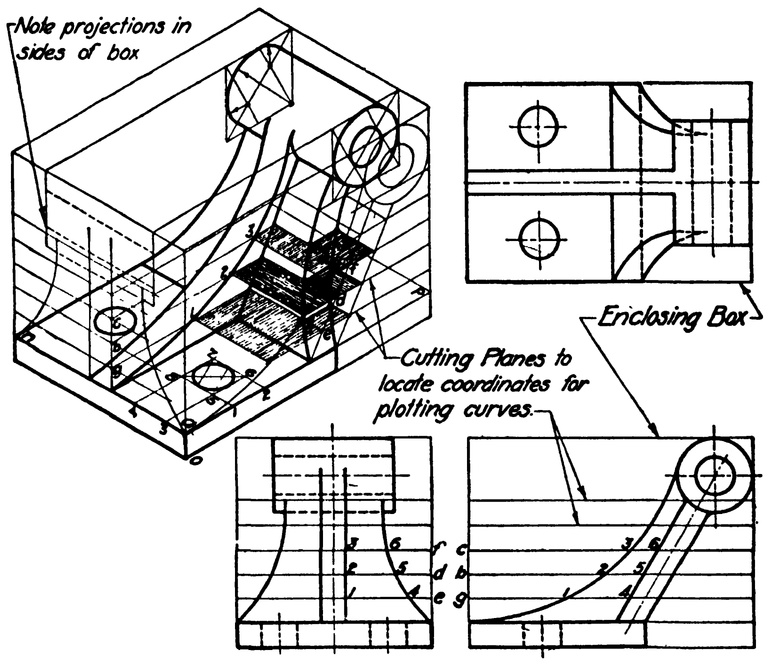


FIG. 12. Isometric planes of construction.

falls naturally into several isometric planes. For example, the holes in the base of the bracket bearing have the construction of the circles representing their upper edges entirely in the plane *n–a–p*. If the coördinate *oa*, representing the thickness of the base, is laid off, and the plane *n–a–p* drawn in lightly, the remainder of the construction can then be measured along isometric lines lying in this plane. Thus, the coördinates *a–1*, *a–2*, *a–3*, and *a–4* can be laid off, and the parallelogram *5–6–7–8* for one of the circles can be readily found.

A careful examination of this figure will show the various planes of construction used and the general method of procedure. Much of the work shown in the figure would be unnecessary to the skilled draftsman in making an isometric of such a simple object. Many short cuts will suggest themselves to the thoughtful draftsman who thoroughly understands the principles of isometric projection. To this end, the habit of visualizing and carrying on the construction in isometric planes, as indicated in the figure, will be found helpful.

To draw curved lines other than circles, or circles which do not lie in isometric planes, it is necessary to plot a number of points on the given lines and then draw a smooth curve through them.

225. DIMENSIONING. — For shop purposes, 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:

1. 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 in which dimensions should read, and it is the only safe one to follow at all times.

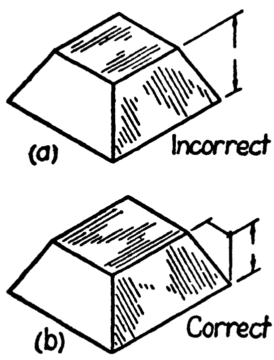


FIG. 13. Dimension and extension lines in same plane.

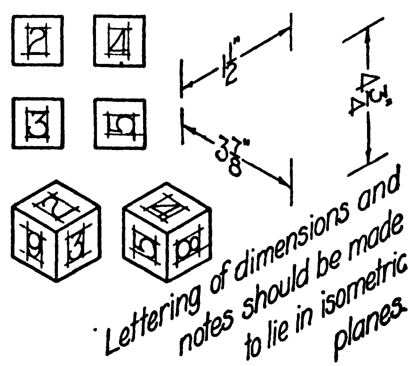


FIG. 14. Lettering in isometric.

2. All dimension lines must be isometric lines and lie in isometric planes. This point must be carefully observed. Difficulty usually occurs in objects having non-isometric lines. Figure 13*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 13*b* illustrates the correct method.

3. Figures and lettering of notes must be made to lie in isometric planes. Only vertical-style lettering should be used in isometric. Figure 14

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, while the two isometrics of the cubes show the six possible positions in which these parallelograms and figures may appear. Figure 15 illustrates the dimensioning of a rectangular object, placing the numerals in one or another of the positions shown in Fig. 14.

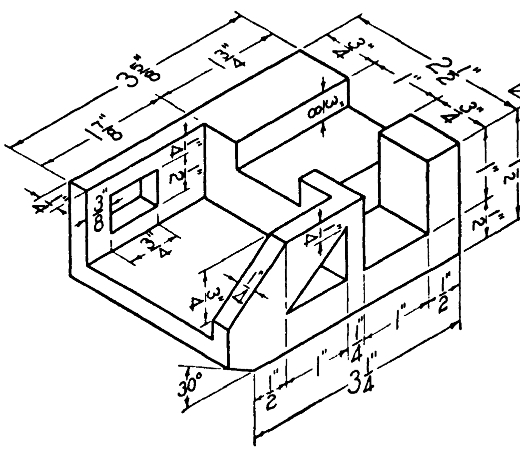


FIG. 15. Dimensioning in isometric.

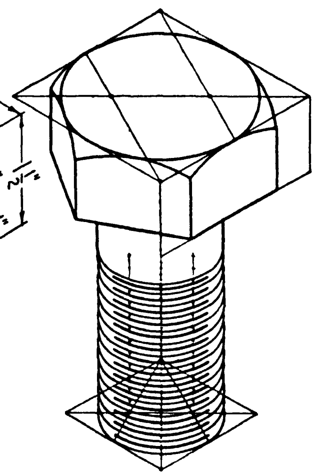


FIG. 16. Screw threads in isometric.

226. SCREW THREADS. — Screw threads can be drawn in isometric, but the process is so laborious that a conventional scheme has been adopted. Arcs of circles are used to represent the crest and root of the thread. These arcs may be drawn by the approximate method, and only three of the four centers need be found. See Fig. 16. The first arc is drawn, and then centers for the remaining arcs are laid off on the line of centers, according to the pitch of the thread. Figure 16 also illustrates the best way to construct the isometric of the hexagonal head on belts and screws. The isometric square for the chamfer circle is made equal to the distance across flats, and one face of the hexagon is turned into a second isometric square. Three points on each face curve can be readily determined by constructing these curves according to the dimensions given in Fig. 2, Chapter X, and then transferring the desired points to the proper isometric squares containing the corners of the hexagon in the manner shown for the base of the frustum in Fig. 11.

227. SECTIONS. — Sections are frequently necessary in isometric drawing, especially if the interior construction of some object is to be shown without using hidden lines. Half or full sections may be made, just as in a three-view drawing. The cutting planes are usually isometric planes. Figure 17 illustrates a section in isometric. Care should be exercised in cross-hatching to give the effect of superposition of lines, if the two surfaces on which the section lines fall should be revolved together. Figure 18

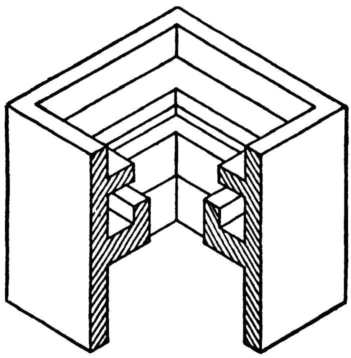


FIG. 17. Section in isometric — correct section lining.

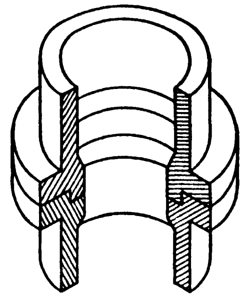


FIG. 18. Incorrect section lining in isometric.

illustrates the poor effect produced when attention is not given to this phase of isometric drawing.

228. POSITION OF DIRECTRICES. — Thus far we have considered isometric drawing with the object always in one particular position. The directrices, however, may be drawn in an infinite number of positions, but four are easily drawn and permit different sides of the object to be shown. The rectangular box shown in Fig. 19 illustrates the four customary posi-

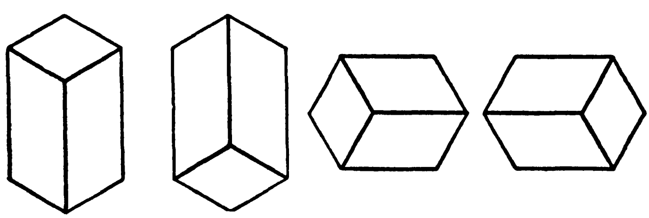


FIG. 19. Convenient positions of isometric axes.

tions of the directrices. In the first two, one directrix is kept vertical; in the last two illustrations, one directrix is placed horizontal. All other lines are 30 degrees or 60 degrees to the horizontal in each drawing.

229. FAULTS OF ISOMETRIC. — There are exactnesses of symmetry and an overlaying of lines in different planes, in an isometric, which are sometimes confusing and often make the drawing impossible of interpretation. These difficulties may be overcome by making a dimetric instead, thereby very frequently lessening the appearance of distortion. The dimetric scheme is very often employed in freehand sketching.

230. Dimetric Projection. — The underlying principles of dimetric projection may best be explained by means of a figure. If we assume a cube in the proper position for isometric projection — the position represented by the dotted lines in *A* of Fig. 19*a* (see also figure 5), and then imagine it to be rotated through any desired angle about a horizontal axis through the front corner and parallel to the V-plane, to the position represented by the solid lines, it is then in a suitable position for dimetric

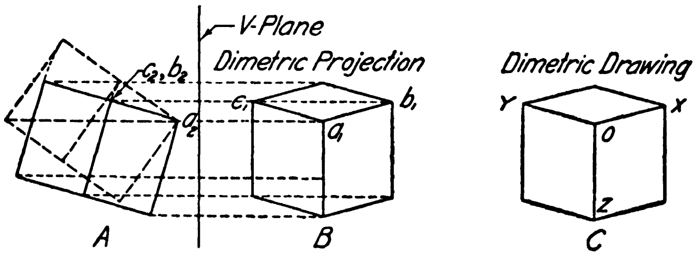


Fig. 19*a*. Cube rotated from isometric position for dimetric projection.

projection upon the plane, since the edges *AB* and *AC* make equal angles with the plane and are hence equally foreshortened. The view marked *B* in Fig. 1 is an exact dimetric projection; the one marked *C* is a dimetric drawing made by using the full-size scale of the object on the axis *OZ* and a shorter scale on the other two axes. The scales were selected to make the drawing *C* as nearly like the projection *B* as possible.

231. Dimetric Drawing. — The same distinction exists between dimetric *projection* and dimetric *drawing* as obtains between isometric projection and isometric drawing. Only dimetric drawings are of interest,

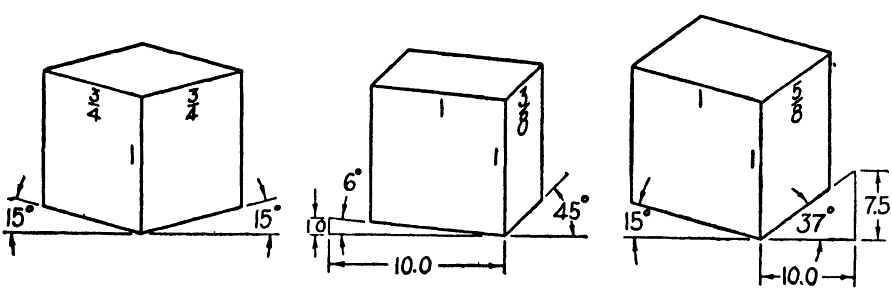


Fig. 19*b*. Convenient positions of axes for dimetric drawing.

and the method of drawing rather than the theory of projection will be discussed.

In Fig. 19*b* are illustrated three convenient positions for the dimetric axes with the proportion of scales for each one nearest the actual projected ratios. The construction in dimetric is carried on in the same manner as in isometric, except that on one axis the scale is changed. The simplest way to make a dimetric drawing is to proceed in the following manner:

1. 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.

2. 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. A method of obtaining this third scale is explained below.

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

A convenient method of changing scale for the odd axis is illustrated in Fig. 19*c*. The dimension for plotting the point is obtained from the ortho-

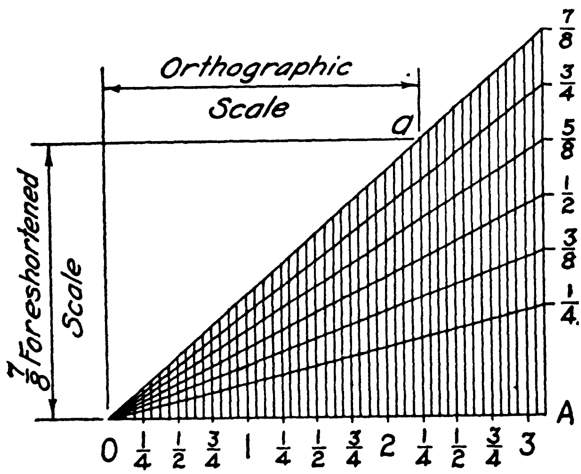


FIG. 19*c*. Diagram for changing scales.

graphic view with dividers which are then set on a chart like Fig. 19*c* from *O* toward *A*. By rotating the dividers 90 degrees about the point nearest *A* and closing the free leg until its point rests on the chosen diagonal scale, the proper setting for use in the dimetric on the odd axis may be obtained. Such a chart may be constructed for any desired ratio of scales.

The same general principles in regard to dimensioning, sectioning, etc., should be followed as in isometric.

PROBLEMS

232. In the following problems, care should be taken to lay out the isometric enclosing box as the first step in order that the isometric of the object when finished may occupy a well-balanced position on the drawing sheet. The isometric scale is not to be used. Except on straight-line drawings, two or more orthographic views of the object, drawn to the scale specified, should be included with the isometric. All pencil construction lines should be left on the drawing until it has been checked by the instructor. Dimension the isometric unless directed otherwise. For sheet sizes indicated on the drawings, see Art. 4, page 3.

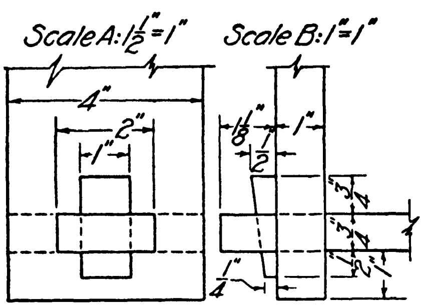


FIG. 20. Pinned mortise and tenon.

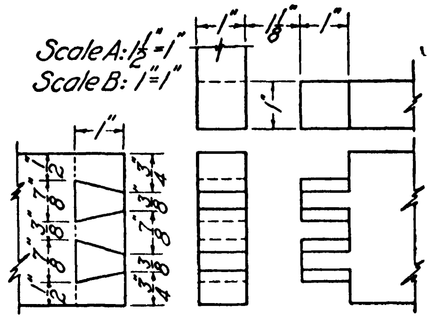


FIG. 21. Dovetail joint (parts separated).

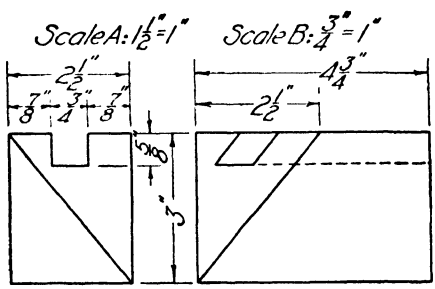


FIG. 22. Cut block.

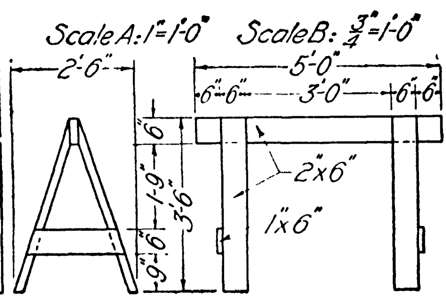


FIG. 23. Carpenter's horse.

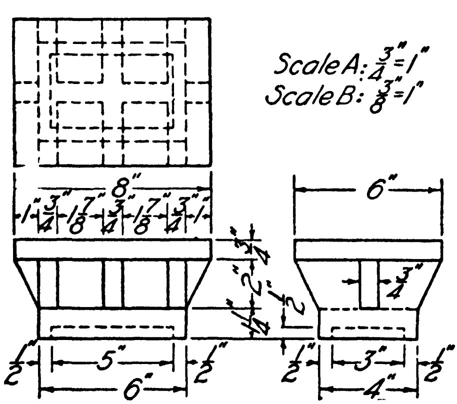


FIG. 24. Post cap.

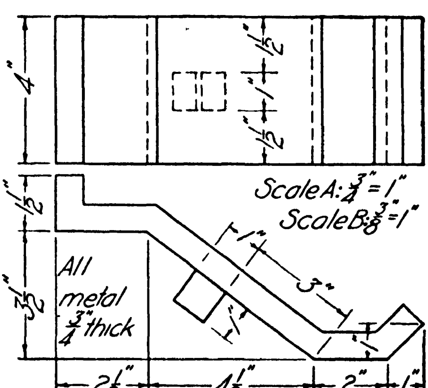


FIG. 25. Truss strap.

1. Make an isometric drawing of the object represented in Fig. 20.
2. Same as Prob. 1, Fig. 21.
3. Same as Prob. 1, Fig. 22.
4. Same as Prob. 1, Fig. 23.
5. Same as Prob. 1, Fig. 24.
6. Same as Prob. 1, Fig. 25.

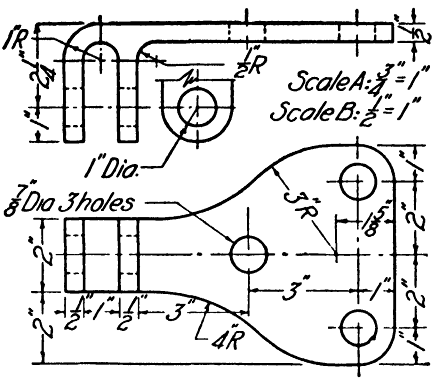


FIG. 26. Hinge strap.

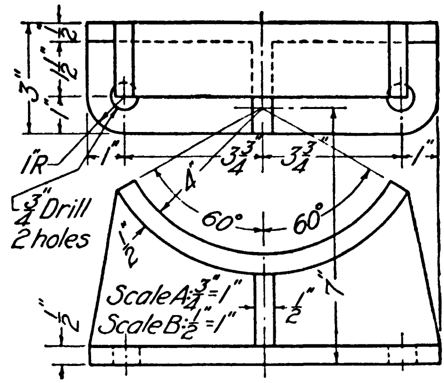


FIG. 27. Conveyor saddle.

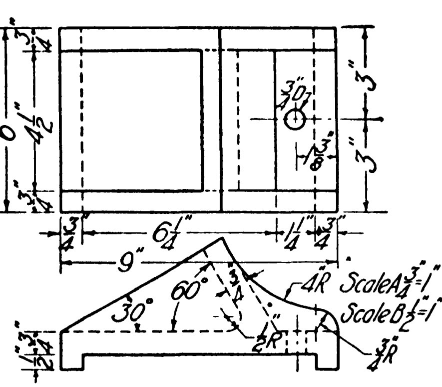


FIG. 28. Truss block.

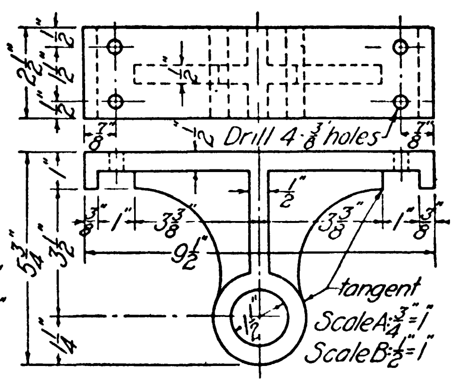


FIG. 29. Conveyor shaft support.

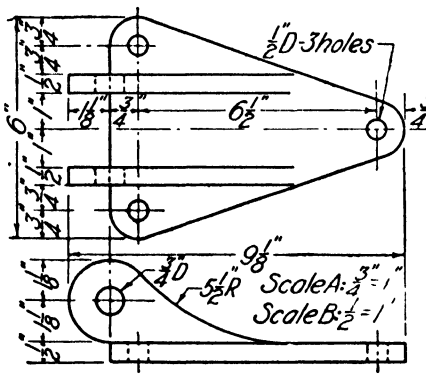


FIG. 30. Hinge.

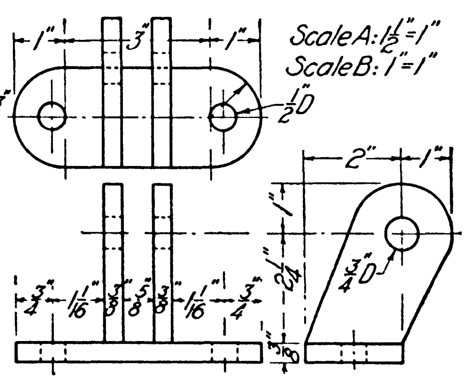


FIG. 31. Offset hinge.

7. Make an isometric drawing of the object represented in Fig. 26.
8. Same as Prob. 7, Fig. 27.
9. Same as Prob. 7, Fig. 28.
10. Same as Prob. 7, Fig. 29.
11. Same as Prob. 7, Fig. 30.
12. Same as Prob. 7, Fig. 31.

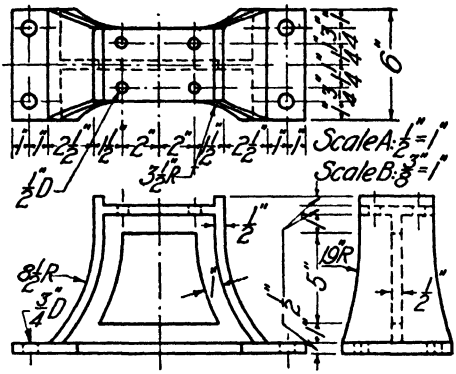


FIG. 32. Floor stand.

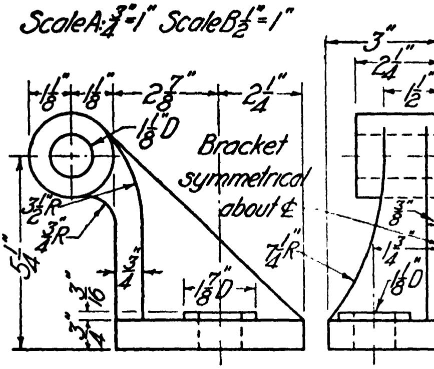


FIG. 33. Bearing bracket.

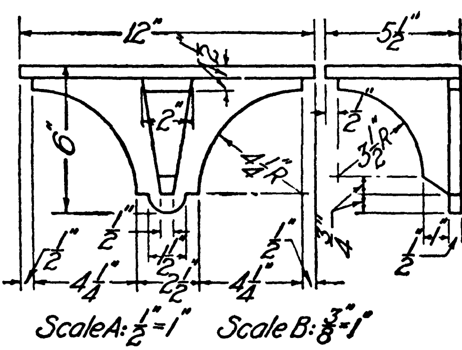


FIG. 34. Shelf.

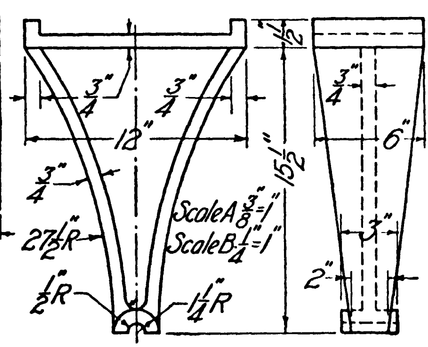


FIG. 35. Truss post.

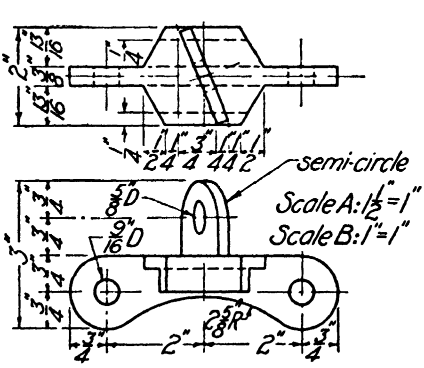


FIG. 36. Flight attachment.

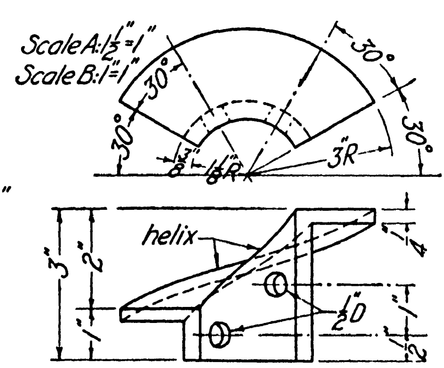


FIG. 37. Conveyor flight reinforcement.

13. Make an isometric drawing of the object represented in Fig. 32.
14. Same as Prob. 13, Fig. 33.
15. Same as Prob. 13, Fig. 34.
16. Same as Prob. 13, Fig. 35.
17. Same as Prob. 13, Fig. 36.
18. Same as Prob. 13, Fig. 37.

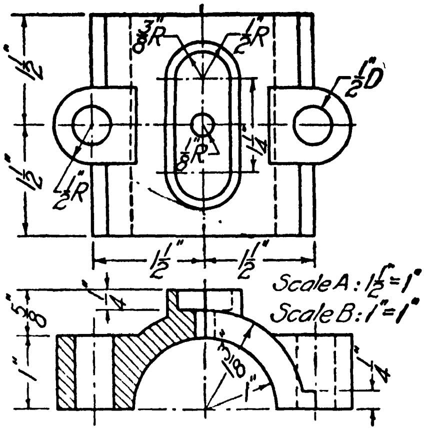


FIG. 38. Bearing cap.

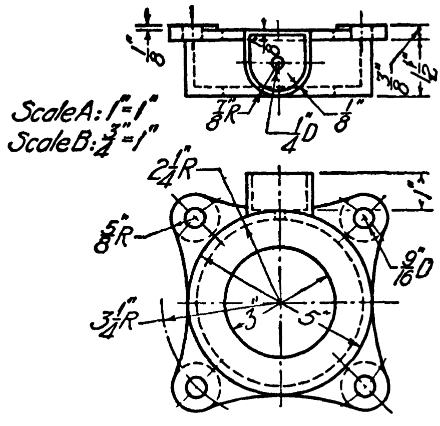


FIG. 39. Rod swab holder.

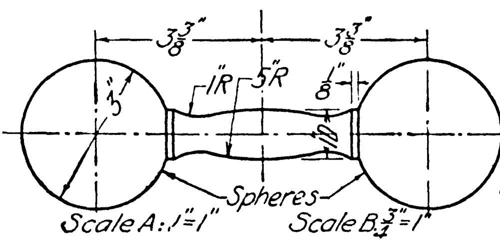


FIG. 40. Dumb-bell.

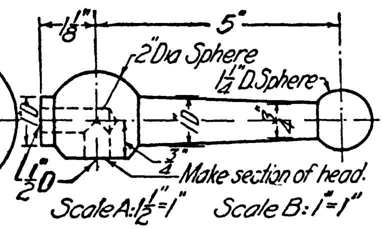


FIG. 41. Ball handle.

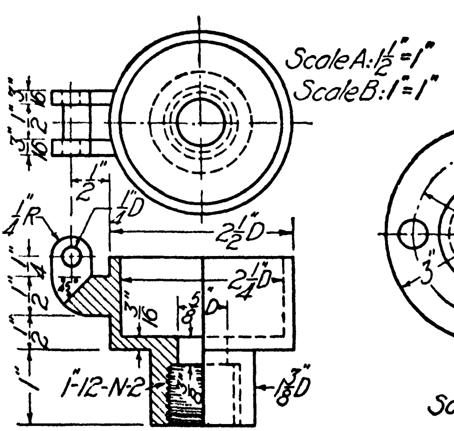


FIG. 42. Grease cup.

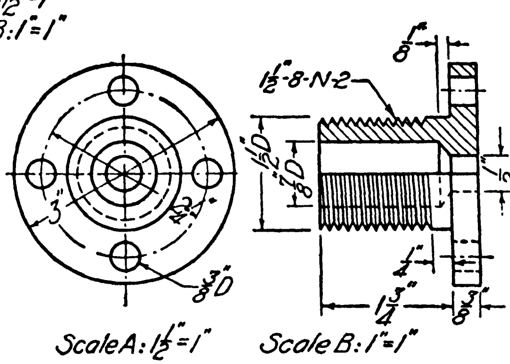


FIG. 43. Stuffing box body.

19. Make an isometric drawing of the object represented in Fig. 38.
20. Same as Prob. 19, Fig. 39.
21. Same as Prob. 19, Fig. 40.
22. Same as Prob. 19, Fig. 41.
23. Same as Prob. 19, Fig. 42.
24. Same as Prob. 19, Fig. 43.

CHAPTER XIV

OBLIQUE PROJECTION

SECTION 1

233. In both orthographic and isometric drawing, already discussed in this text, the projecting lines have been at right angles to the planes or plane of projection. We shall now consider a kind of drawing in which, as in isometric, 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 parallel to the vertical plane which is used as the plane of projection, as in isometric drawing. The angle which the projecting lines make with the plane may be of any desired value except 90 degrees. When, however, the angle is chosen as 45 degrees, the drawing is called a *cavalier* projection, which, by virtue of the 45-degree angle, has certain advantages not obtainable when other angles are used. We shall fully consider, therefore, only cavalier projection and its modifications.

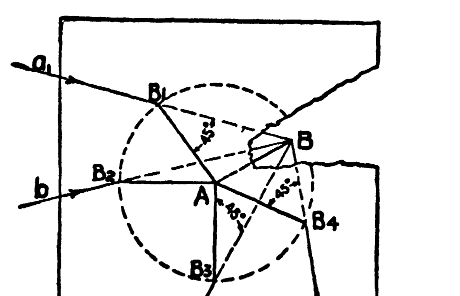


Fig. 1. Cavalier projection of line *AB*.

234. Cavalier Projection of Lines. — Assume a vertical plane V as the plane of projection and a line AB perpendicular to it, with the end A in the plane and the end B lying behind the plane, as in Fig. 1. If the line AB is viewed from infinity in the direction of the projecting line a_1, which makes an angle of 45 degrees with V, then A and its projection on V coincide, and B is projected to B_1. Obviously, the projection AB_1 is equal in length to the line AB. This relation holds true if the line AB is viewed from the direction of the lines b, c, and d, respectively, or from any other direction so long as the projecting lines, or lines of sight, as they are called, make an angle of 45 degrees with V. Hence, in cavalier projection, any line which is perpendicular to V will project in its true length upon V regardless of the direction of the projecting lines, provided they make 45 degrees with V. The direction of the *projection* of a line on the plane relative to a horizontal or vertical line must not be confused with the direction of the *projecting lines* relative to the plane itself. Clearly, from Fig. 1, the projection of AB on the V-plane may be in any position in the whole arc of 360 degrees around A, while the projecting lines will always make 45 degrees with the plane. The statements just made hold true for a line perpendicular to V when neither end is in the plane of projection; but, of course, the projecting lines must be kept parallel to each other.

From the above discussion it follows readily that a horizontal line in space parallel to the plane of projection will project as a horizontal line, and a vertical line will appear vertically on the plane of projection. Figure 2 assists in making these facts clear. The projection of the three coördi-

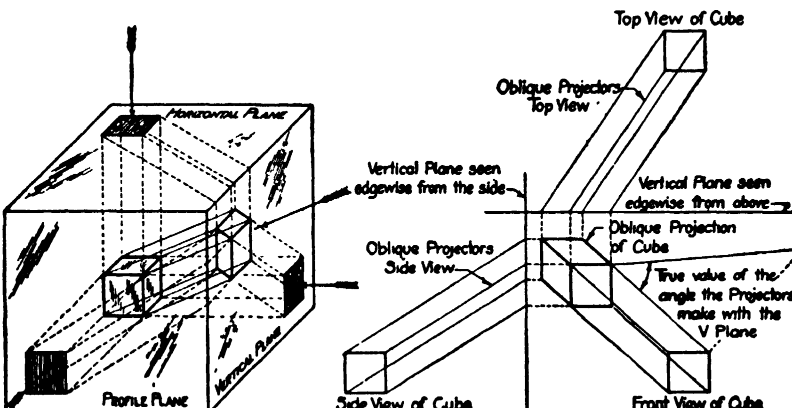


FIG. 2. Construction of an oblique projection.

nate axes OX, OY, and OZ, ordinarily used in solid geometry, are called the *directrices* or *oblique axes*. It should be observed in Fig. 3 that OX and OY are respectively horizontal and vertical and should always be assumed to be so, irrespective of the angle chosen for the receding directrix.

235. CAVALIER PROJECTION OF A SOLID. — Assume a rectangular box with one of its faces parallel to the plane of projection, as in Fig. 2. Obviously, the front face, since it is parallel to the V-plane, projects upon that plane in its true size and shape. Likewise, the edges which are perpendicular to the plane project in their true length, as do all other lines parallel to them, because the projecting lines make 45 degrees with the plane. Therefore, as in isometric drawing, true measurements can be made along the three directrices or parallel thereto. They can also be made in any direction in the front face or in any plane parallel to it, since lines in the front face, or in parallel faces, project in their true relation to each other, just as they do in orthographic projection.

To make a cavalier projection of a block, select any point O as an origin, and draw the two axes OY and OX at right angles to each other, the one vertically and the other horizontally as in Fig. 3. The remaining axis OZ may then be drawn at any convenient angle which will meet the space requirements of the drawing. If the two sides are of chief interest, the line OZ should be made to approach the horizontal, whereas, if the front and top are of chief importance, the axis OZ should approach the vertical. Since lines which are parallel have their projections parallel, the remainder of the block may be quickly drawn, using the same scale for measurements on all axes.

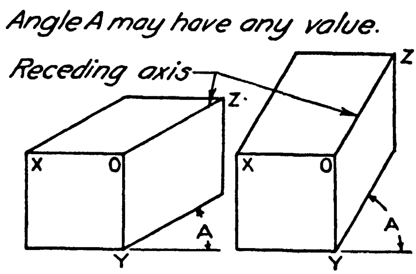


FIG. 3. Two positions of oblique axes.

236. Cavalier Projection of Plane Figures. — The drawing of plane figures in cavalier projection involves little difficulty, since the scheme of construction is identical with the coördinate method, described fully under Isometric Projection. Figure 4 shows clearly how such figures may be constructed by coördinates.

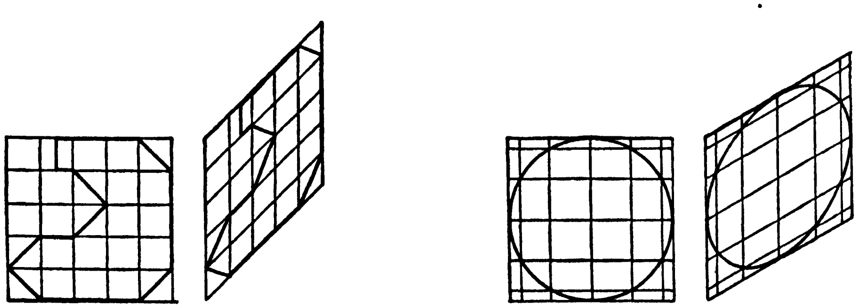


FIG. 4. Cavalier projection of plane figures — coördinate method.

One of the advantages of cavalier projection is in the fact that the front face of an object is shown without any distortion, as is the case in true orthographic projection. Good judgment, therefore, suggests that the face of an object having the greatest number of circles or other curved lines and irregularities in it should be made the front face, unless the object is shown to best advantage with other faces in the foreground. Figure 5 illustrates this point. It occasionally happens, however, that more than

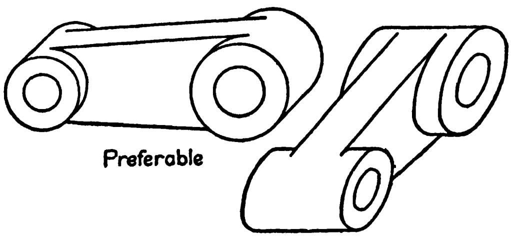


FIG. 5. Choice of positions of object.

one face contains circles and curved lines. If so, those in receding faces may be constructed by the coördinate method illustrated in Fig. 4.

Circles, however, may be represented by an approximate mechanical method in which arcs of circles are substituted for separate portions of the true ellipse, as illustrated in Fig. 6. A circle may always be inclosed in a

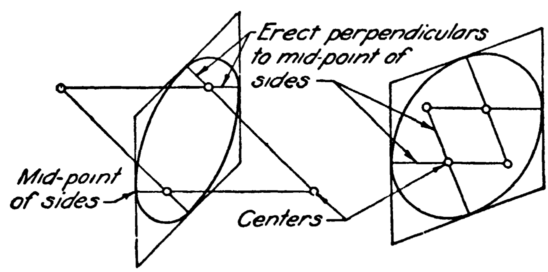


FIG. 6. Circles in cavalier by the four center approximate method.

square; and since it is tangent at the midpoint of the sides of the square, the cavalier projection must show an ellipse which is tangent to the midpoint of the sides of its inclosing parallelogram. Hence, to find the centers of the four arcs, erect perpendiculars to the midpoints of the four sides and find their intersections as shown in the figure. It should be noted that, as the ratio of the major to the minor axis of the ellipse increases, the approximation becomes less accurate.

A cavalier projection frequently has a very disagreeable appearance of distortion or spread in the receding parallel lines, especially if the object is longer than it is wide. This apparent lack of parallelism would be reduced if one always took care to adjust his point of view to a position more suited to the particular drawing he is observing than is usually convenient when reading from a textbook page. On objects which have one dimension decidedly shorter than the other two, the apparent distortion may be lessened slightly by making the shorter dimension on the receding directrix. This suggestion cannot be laid down as a fixed rule, however, for the advantage gained may be more than offset by other bad effects produced, chief among which is that of false expression of the proportionalities of the length, breadth, and thickness of the object.

The ideal in any pictorial drawing is to represent an object as it actually exists or as it appears to the eye. Figure 7 is drawn to scale in cavalier projection to represent a box, the lower part of which is 3′–0″ wide, 1′–6″ deep, and 5′–0″ long. The drawing at the left has the long dimension on the receding axis, whereas the view to the right is drawn with the short dimension on the receding axis. The distortion in the first case may be a trifle more noticeable than in the second; but the drawing appears considerably more like a box that is almost twice as long as it is wide than does the second, which seems to portray a box that is almost square in plan with a lid that will not reach all the way across.

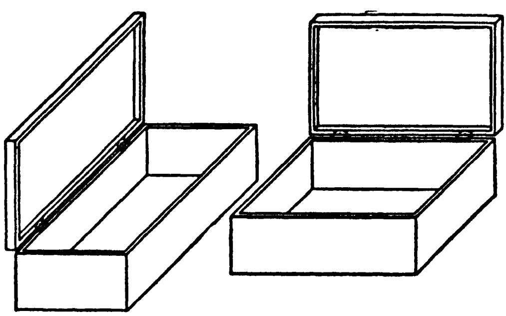


Fig. 7. Apparent distortion in cavalier projection.

Hence, although it is true that making the longer dimension parallel to the plane of projection may reduce the apparent distortion somewhat, it is quite clear that the draftsman must use his judgment in applying any " rule of thumb " in oblique projection.

The first suggestion, however, in regard to making the irregular face the front of the object, always holds, and should take precedence over the second suggestion in regard to distortion, because the elimination of difficulties of construction is usually more important than the elimination of unpleasing appearance.

237. General Oblique Drawing. — If the projecting lines make an angle other than 45 degrees with the plane of projection, the projection on the receding axis will no longer be equal to the true length of the line. Hence, in making a general oblique projection, as such drawings are called, a scale must be used on the receding axis which differs from that used on the other two axes. In practical drawing it is customary to select the two scales rather than the angle which the projecting lines make with the plane of projection since this is a matter of theory which does not enter into the rule of thumb construction. By a careful selection of scales much of the distortion common to cavalier projection may be eliminated. Scales varying from $\frac{3}{8}'' = 1''$ to $\frac{3}{4}'' = 1''$ will give good results. For example, the box shown in Fig. 7 has been redrawn in Fig. 8, showing it in both positions with the dimensions on the receding axis foreshortened by one-third. The appearance in either case is quite pleasing to the eye. In this example, both views can easily be imagined to represent the same box.

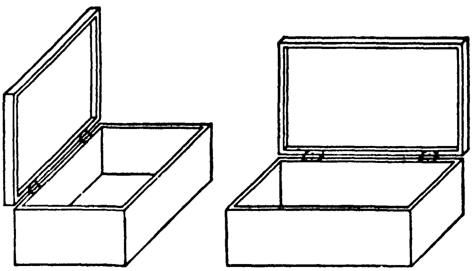


FIG. 8. General oblique drawing, reducing distortion.

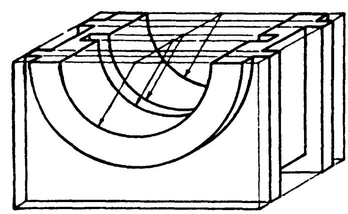


FIG. 9. Construction planes in oblique projection.

The receding axis may be drawn at any convenient angle with the horizontal. The four-center approximate method of drawing circles in receding planes, as explained in cavalier projection, cannot be used in general oblique projection.

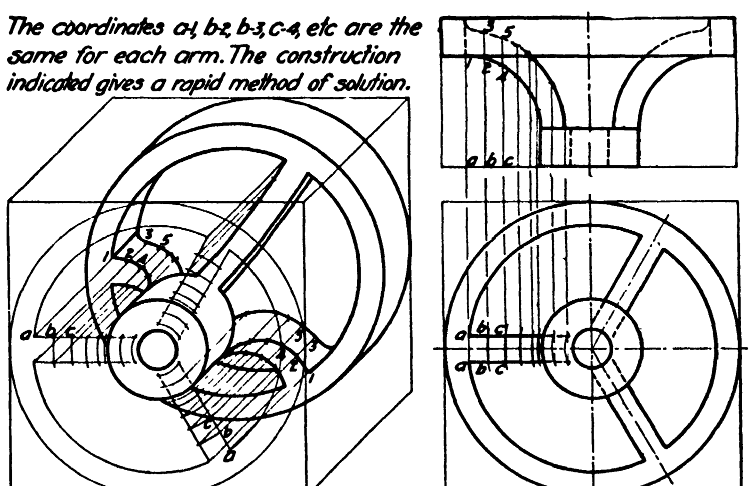


FIG. 10. Box construction in oblique projection.

As in isometric, the construction of objects naturally falls into a series of parallel oblique planes, and care should be exercised to make constructions in the proper plane. Figures 9 and 10 illustrate the general scheme or procedure.

Figure 10 shows how radial lines may be used in plotting points such as those on the curved arms of the bracket bearing. In the front face of the box a true orthographic view of the bearing is drawn lightly. Then, by drawing a series of arcs in this face, of the same radius as *aa*, *bb*, etc., in the view at the right, points corresponding to *a*, *b*, *c* can be located on each arm at one setting of the compass. The distances *a–1*, *b–2*, *c–4*, etc., can then each be set off parallel to the receding axis, thus speeding up the work of plotting the curved lines for the bracket arms.

When an object is composed of more or less cylindrical parts like the rocker arm in Fig. 11, the construction can be readily based upon a center

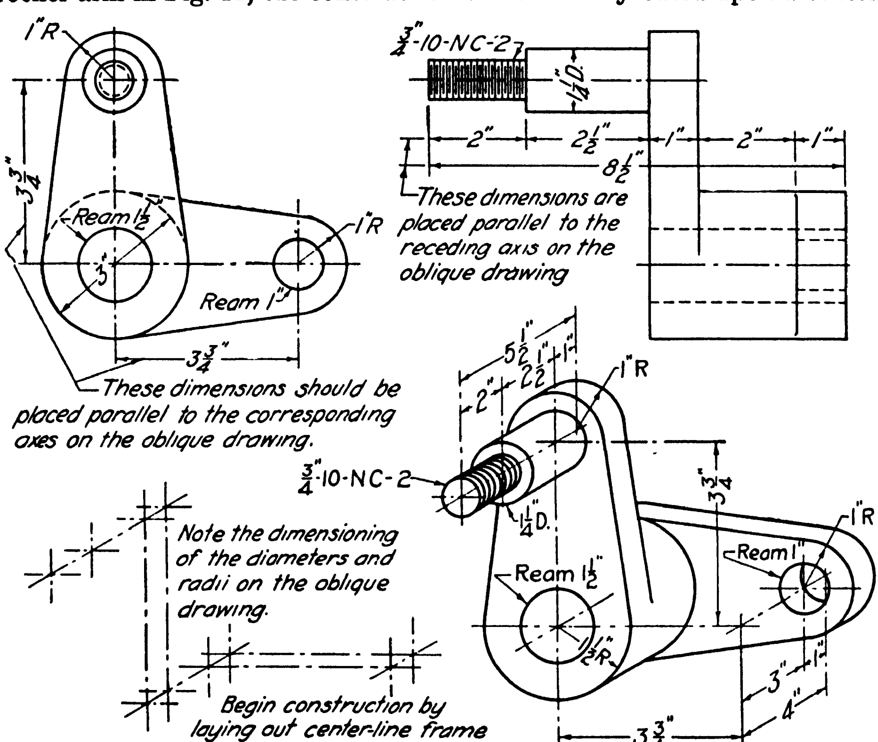


Fig. 11. Center line frame construction in oblique projection.

line framework, as shown at the left in this figure, instead of the box construction of Fig. 10. With the centers of all circles and arcs thus marked, the circles can be quickly drawn and then the straight lines put in tangent to them, thus giving the final result at the right in Fig. 11.

238. Cabinet Drawing. — When the scale used on the receding axis is one-half that used on the other two axes, the oblique projection is called a *cabinet drawing*. For example, if the scale used on the axes of the front face is $\frac{3}{4}'' = 1''$, then the scale on the receding axis should be $\frac{3}{8}'' = 1''$.

The projecting lines in this case make an angle of 63° 30′ with the plane of projection. Although the projecting lines do not enter into the actual construction of a cabinet drawing, they are referred to again, so that they will not be confused with the receding axis of the drawing which may make any convenient angle with the horizontal. Cabinet drawings are constructed, in all respects, in the same manner as general oblique drawings. The four-center approximate method for drawing circles cannot be used.

239. Dimensioning Oblique Drawings. — The principles of dimensioning studied in orthographic projection apply in general to oblique projection with the following additions:

1. Dimensions should be made to read from one point of view, in so far as possible. See Fig. 11.
2. Dimension lines and the witness lines must lie in the same oblique plane.
3. Dimensions must lie in the oblique plane determined by the dimension and witness lines.
4. As far as possible, dimensions should be made to lie in the front face or parallel thereto, since this makes the lettering the same as in orthographic. See Fig. 11.

Figures may be made to lie in oblique planes in the same manner as shown for isometric. See Fig. 15, Chapter XIII.

240. Sectioning Oblique Drawings. — Objects may be sectioned by using oblique cutting planes as shown in Fig. 12. Many of the prob-

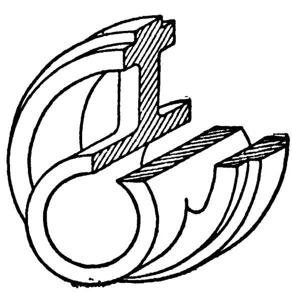


Fig. 12. Sectioning in oblique projection.

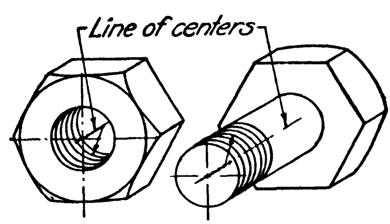


Fig. 13. Screw threads in conventional oblique projection.

lems in the chapters on orthographic projection and working drawings offer further illustration of various schemes of sectioning. The cross-hatching lines lying in two cutting planes should be sloped in such a way that they would seem to coincide if the planes were rotated together. If the lines were produced to the line of intersection of the cutting planes, they would meet in pairs.

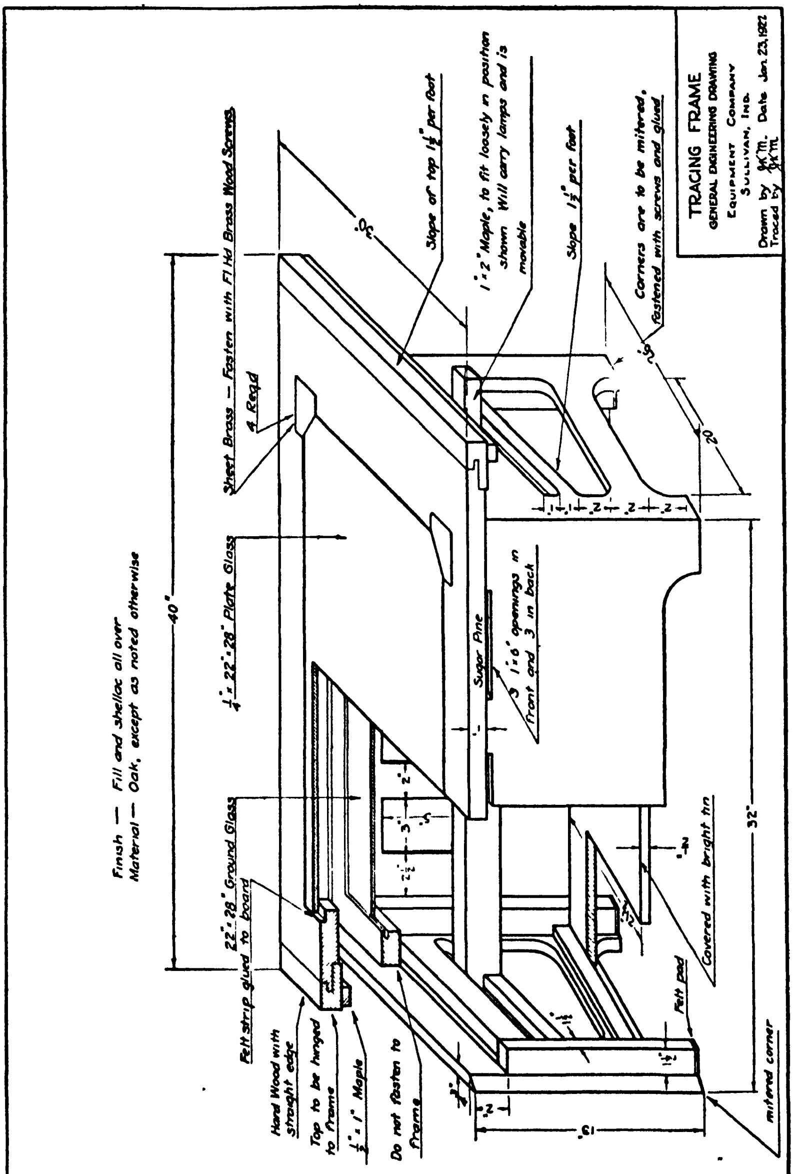


FIG. 14. Shop drawing in oblique projection.

241. 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. 13, 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 the same as the pitch of the thread.

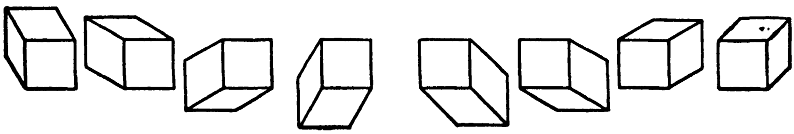


FIG. 15. Convenient positions of oblique axes.

242. ADVANTAGES OF OBLIQUE DRAWING. — From the foregoing paragraphs, it is quite clear that oblique drawing has several advantages over isometric drawing. These may be summarized as follows:

1. The front face of an object or any face parallel to it may be drawn like the true orthographic projection. Circles and other curves show in their true shape in these faces.

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

3. Dimensioning is simpler since only one set of dimensions need be made in an oblique plane. See Fig. 14.

4. There is a somewhat greater range of choice of position of the axes. A comparison of Fig. 15 above with Fig. 19 of the preceding chapter will make this point clear.

PROBLEMS

243. In making oblique drawings in the following problems, orthographic views should be included only when necessary to determine curves and dimensions not in oblique planes. The problems are designed mainly for general oblique drawings, as evidenced by the scales given. Some scales give cabinet drawings. Any problem may be done in cavalier projection, hence a selection must be made by the instructor in assigning the problem. The receding axis is always up to the right or left as indicated by the letters *R* or *L* on the drawing in parentheses. The drawings should be dimensioned unless otherwise directed. For sheet sizes indicated on the figures, see Art. 4, page 3.

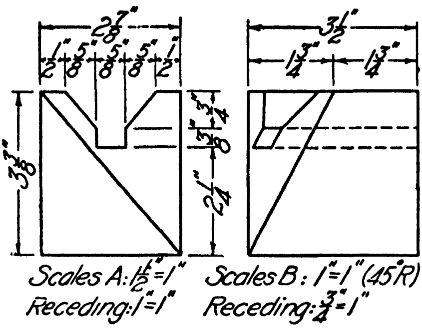


FIG. 16. Cut block.

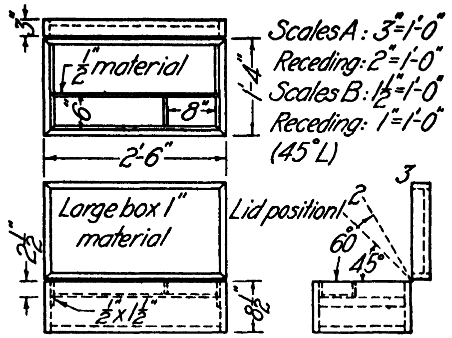


FIG. 17. Tool box.

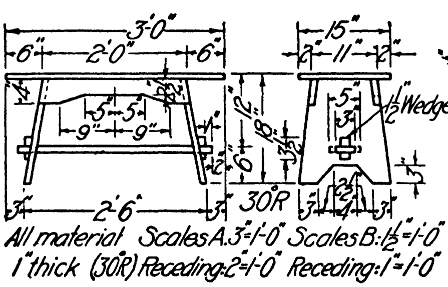


FIG. 18. Bench.

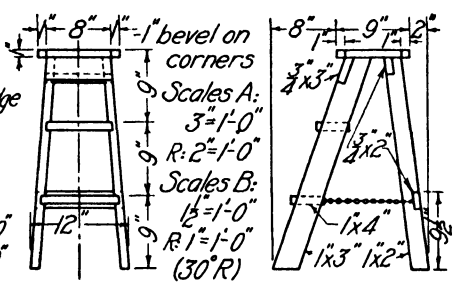


FIG. 19. Step ladder.

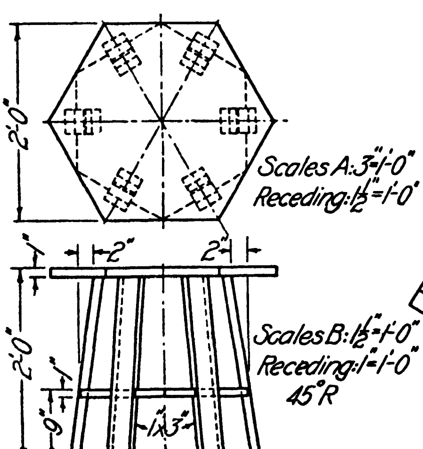


FIG. 20. Taboret.

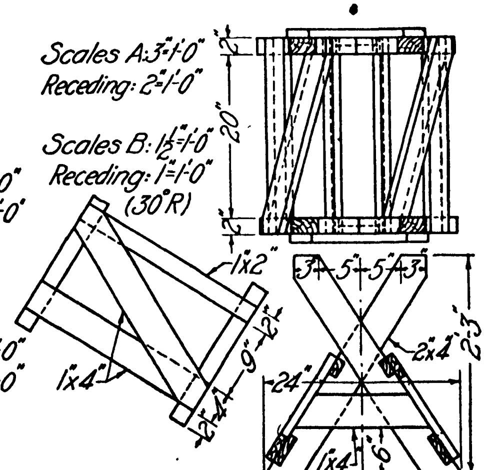


FIG. 21. Saw-buck.

1. Make an oblique or cavalier drawing, as assigned, of the object represented in Fig. 16.
2. Same as Prob. 1, Fig. 17.
3. Same as Prob. 1, Fig. 18.
4. Same as Prob. 1, Fig. 19.
5. Same as Prob. 1, Fig. 20.
6. Same as Prob. 1, Fig. 21.

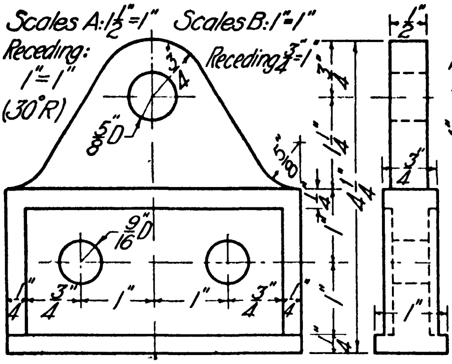


FIG. 22. Flight attachment.

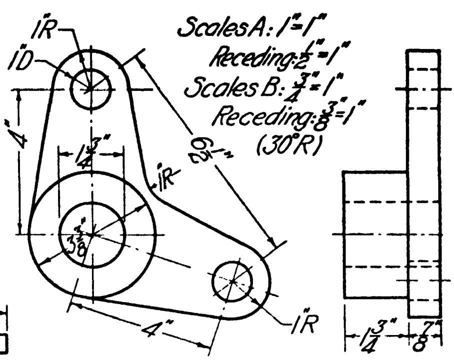


FIG. 23. Rocker arm.

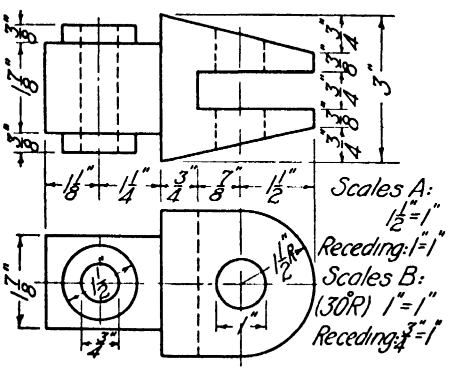


FIG. 24. Link.

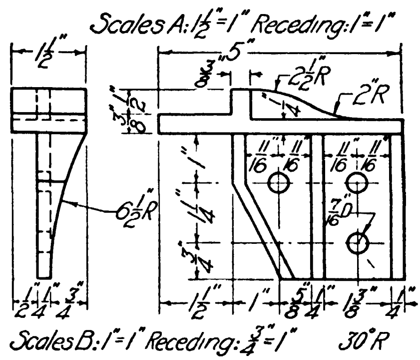


FIG. 25. Flight guide.

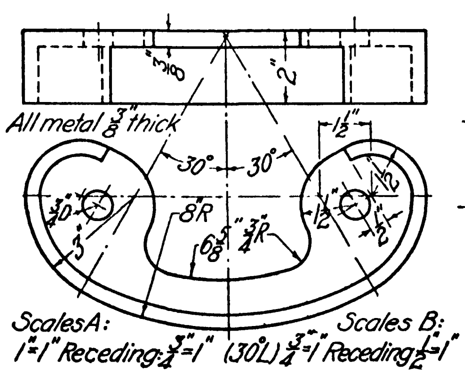


FIG. 26. Conveyor bucket rocker.

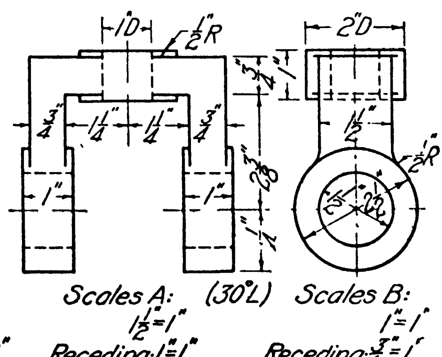


FIG. 27. Swivel link.

7. Make an oblique or cavalier drawing, as assigned, of the object represented in Fig. 22.

8. Same as Prob. 7, Fig. 23.

9. Same as Prob. 7, Fig. 24.

10. Same as Prob. 7, Fig. 25.

11. Same as Prob. 7, Fig. 26.

12. Same as Prob. 7, Fig. 27.

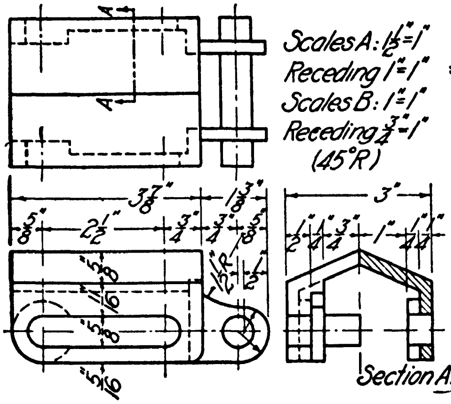


FIG. 28. Chain link.

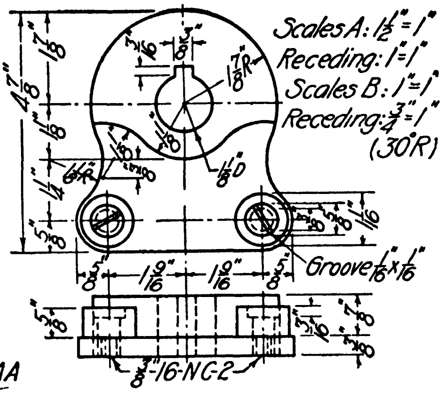


FIG. 29. Cam follower.

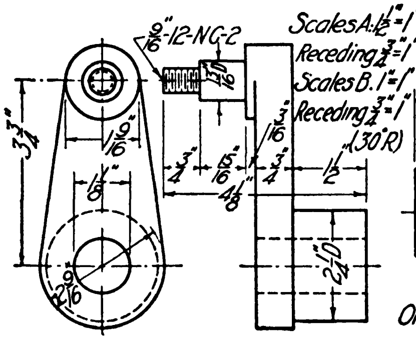


FIG. 30. Crank.

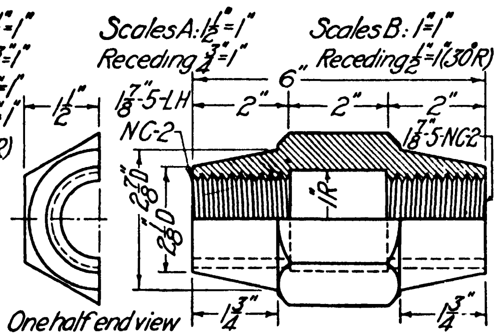


FIG. 31. Turnbuckle.

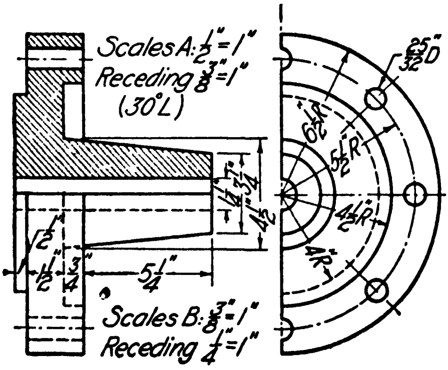


FIG. 32. Cylinder end.

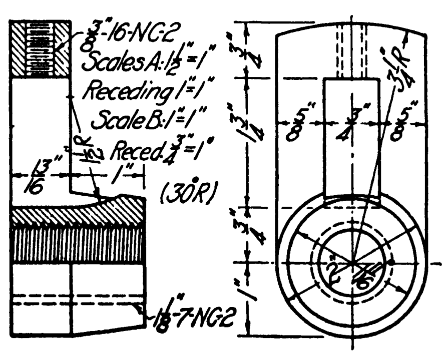


FIG. 33. Flue-hole cutter head.

13. Make an oblique or cavalier drawing, as assigned, of the object represented in Fig. 28.
14. Same as Prob. 13, Fig. 29.
15. Same as Prob. 13, Fig. 30.
16. Same as Prob. 13, Fig. 31.
17. Same as Prob. 13, Fig. 32.
18. Same as Prob. 13, Fig. 33.

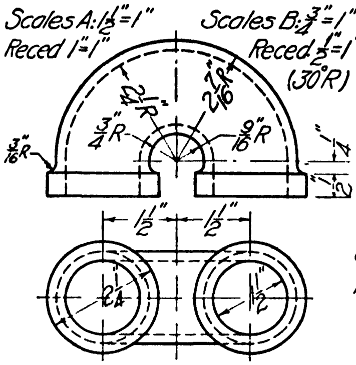


FIG. 34. Return bend.

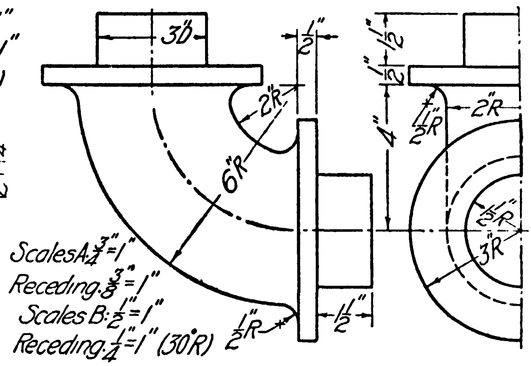


FIG. 35. Elbow pattern.

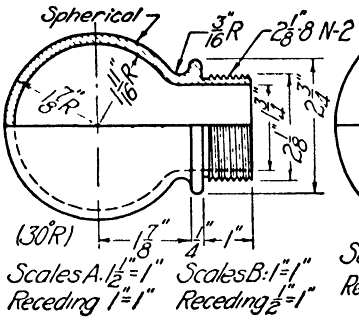


FIG. 36. Post cap for pipe rail.

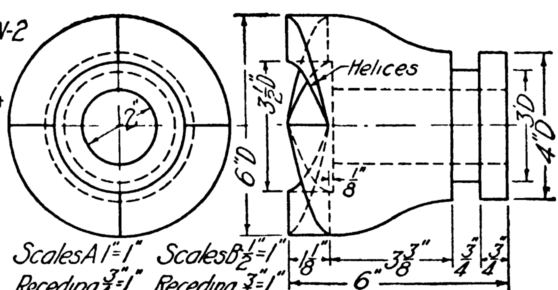


FIG. 37. Four jaw clutch.

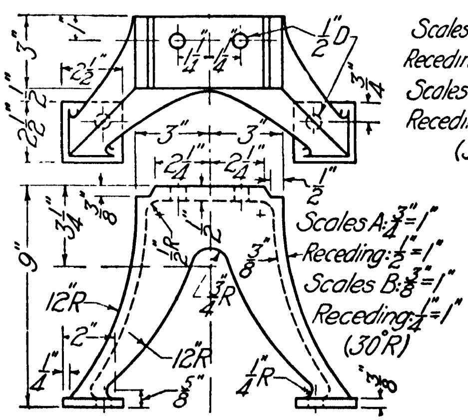


FIG. 38. Lathe bed support.

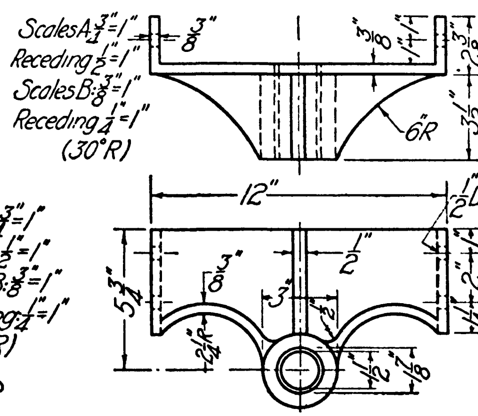


FIG. 39. Conveyor end bearing.

19. Make an oblique or cavalier drawing, as assigned, of the object represented in Fig. 34.

20. Same as Prob. 19, Fig. 35.

21. Same as Prob. 19, Fig. 36.

22. Same as Prob. 19, Fig. 37.

23. Same as Prob. 19, Fig. 38.

24. Same as Prob. 19, Fig. 39.

CHAPTER XIV

VARIATIONS OF OBLIQUE PROJECTION

SECTION 2

244. In the first section of this chapter, the object to be drawn was always placed with one face parallel to the plane of projection; this is an essential element in oblique projection, as there discussed. Although the advantages to be obtained by this means are of considerable practical importance in the way of convenience and speed, it must be borne in mind that oblique projections of an object can be made regardless of its position relative to the plane. The essential fundamental concept in oblique projection lies in the fact that the projecting lines are parallel to each other and oblique to the plane of projection. The position of the object relative to the plane may or may not facilitate the work of construction, but this does not change the method of projection.

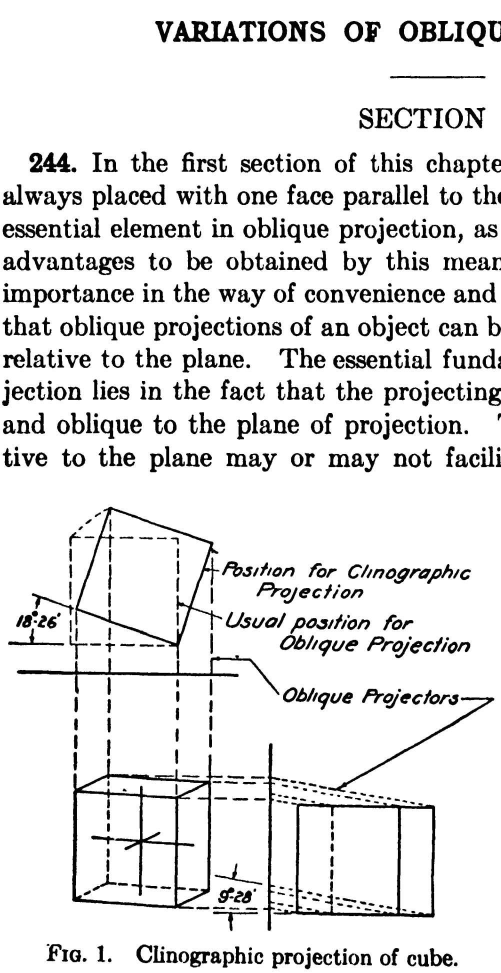


FIG. 1. Clinographic projection of cube.

For some purposes it may be desirable to turn the object at an angle to the plane of projection, particularly if there are no curved edges in its outlines. In fact, just such a system of oblique projection, called clinographic projection, has become firmly established in the field of mineralogy and crystallography, in representing the various mineral crystals.

In clinographic projection, the angles which the three principal axes of the crystal make with the plane of projection, and the angle which the projecting lines make with the plane, have become fixed by usage, although there is no inherent reason why other angles might not have been used just as effectively.

These angles are shown in Fig. 1, in the clinographic projection of a cube. For construction purposes, it is well to remember that the tangent of 18° 26′

is $\frac{1}{3}$, and the tangent of 9° 28′ is $\frac{1}{6}$. From an observation of the figure, it is clear that the vertical line projects in true length, while the others are foreshortened, each by a different amount. In clinographic projection these foreshortened scales are determined accurately; approximations of scales or arbitrary assumptions are not permitted. In practice, the three coördinate axes shown inside of the cube are used as the skeleton upon which the crystal is drawn, as illustrated in Fig. 2.

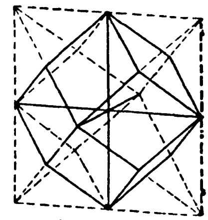


Fig. 2. Crystal in clinographic projection.

Three of the six principal systems of crystals have their three axes of varying lengths and at right angles to each other. The other three systems have axes which make angles with each other, differing from 90 degrees, as shown in Fig. 3. All six sets of axes are drawn upon the cubic axes as a basis.

Clinographic projection is strictly an oblique projection, and although three different scales are used upon the axes, it is not for this reason to be called a trimetric projection, any more than we should call a cavalier projection an isometric projection, for the same reason. So far as appearance and actual construction are concerned, however, oblique projections can be made to appear quite sim-

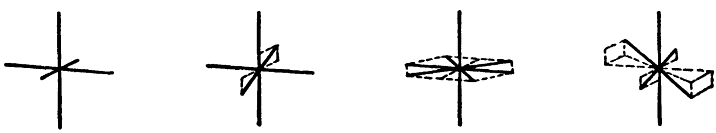


Fig. 3. Axes in six crystal systems.

ilar to dimetric projection, as is quite evident from a comparison of the clinographic projection of the cube in Fig. 1 and the dimetric of the cube in Fig. 19*b* of Chapter XIII.

Further information concerning clinographic projection may be found in the texts listed below.

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Crystallography and Practical Crystal Measurement. Chapter XXV. By A. E. H. Tutton. Macmillan and Co., New York, 1911.

CHAPTER XV

PERSPECTIVE

245. The following discussion of the principles of perspective projection and their application to simple problems should be considered by the student of this kind of projection as the mere foundation of a further study of the whole subject. Only fundamental conceptions are here set forth. Some authors have found it necessary to use two volumes of concisely written exposition in order to present properly the various phases of perspective drawing. Each object presents new problems peculiar to itself. Shading and rendering, multiple vanishing points, short cuts in construction, etc., are some of the points to be developed in more extended discussions than this chapter is planned to give. To those interested in perfecting themselves further in the techniques of this fascinating subject, the texts listed at the end of this chapter are recommended.

246. DEFINITION. — A perspective drawing of an object is a representation of that object upon a plane, as it (the object) would appear to the eye from some one definite point of view. Perspectives are sometimes called *scenographic projections.* These projections are very useful when accompanying working drawings for explanatory purposes, or when drawn by the architect or engineer to convey to others definite ideas of form as it is desired in the finished structure that has been conceived and designed. Figure 3, Chapter XXI, very well illustrates the appeal that a perspective may make to the observer — an appeal that is quite impossible with other forms of projection. A single drawing showing the combined plan and perspective gives information of a character hard to excel in any other way. On account of the very close resemblance of the drawing to the object itself as it exists in nature, we find perspective drawing much resorted to by those who wish to produce a pleasing and correct effect upon the observer.

While a perspective drawing, when viewed from any angle, gives a general idea of the object, there is only one point from which it can be viewed to obtain the true proportions of the object represented. This point must bear the same relation to the drawing, when the scale of the drawing is taken into account, as the real point of sight in space does to the picture plane.

247. Point of Sight. — In all the kinds of drawings studied heretofore, the point of sight has been at an infinite distance from the object, and, as a consequence, the lines of sight, or projecting lines as they are called, have always been parallel to each other. In perspective drawing, however, the point of sight is definitely located at a finite distance from the object. Hence, the lines of sight, or visual rays as they are often called in perspective drawing, will be divergent from the point of sight and will make different angles with the plane of projection.

In fixing upon the exact location of the point of sight in reference to the object, it is customary to keep within the limits ordinarily assumed by an observer in examining the object in its natural environment. Usually this will be a little above and to the right or left of the center of all small objects.

The limits within which the foregoing suggestion holds will depend largely upon the nature of the object and the purpose for which the perspective is to be used. If the top of the object contains features which must be shown, the point of sight must be above the top, regardless of whether this is the usual position or not. Whether the point of sight is in front of the center of the object or to the left or right will also depend upon what one wishes to show of the sides.

For large structures, like buildings and dams, the point of sight should be chosen to best depict the beauty or utility of the structure. A common rule, in the case of buildings of moderate size, is that the distance between the eye and the nearest line on the building should be twice the longest dimension. In the case of a dam, the point of view might be assumed to be as much as a mile away from the actual site.

The suggestions in the preceding paragraphs do not take into consideration the actual appearance of the finished drawing, for the location of the point of sight alone will not determine this. The position of the picture plane must also be considered.

In examining a drawing or photograph, it is customary, particularly if it be of a size to be held in the hand, to hold the picture directly in front of the observer, thus making the line from the eye to the center of the paper almost perpendicular to the paper. This being the case, the picture plane and point of sight should be so located that when the finished drawing is examined as described above the eye will bear the proper relation to the drawing, as discussed in the third paragraph of this chapter.

This requires that the picture plane shall be almost perpendicular to the line from the point of sight to the center of the perspective area under consideration.

248. Picture Plane. — The plane of projection — and there is only one in perspective drawing — is usually chosen as a vertical plane, the same as in isometric and oblique projection, because with this plane the drawing of the object appears in the most natural and usual manner. This plane, which is called the picture plane, is usually located between the object and the point of sight, so that the drawing may be smaller than the object itself. In Fig. 1, the object and point of sight have been drawn with the picture plane between them. If the eye is placed at S in Fig. 1, then the projection on the picture plane will present the same appearance as the object itself, because for every point on the object there is a corre-

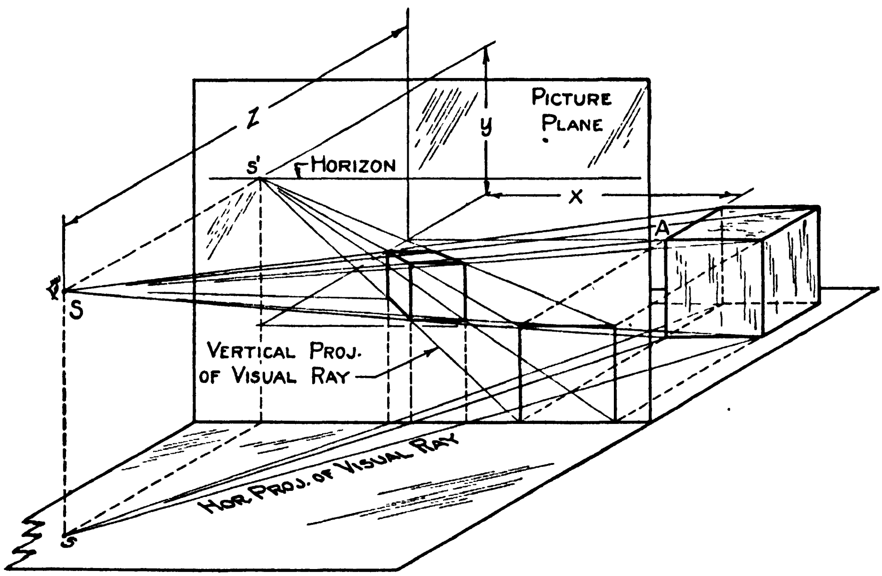

Fig. 1. Theory of perspective.

sponding point in the drawing obtained by intersecting the picture plane with a visual ray drawn from the point of sight to each point on the object.

A correct picture of the object would be obtained by setting up the picture plane behind the object; but, of course, the drawing would be larger than the object itself. Occasionally it is desired to show a group of buildings or some proposed development plan by making a so-called bird's-eye view. In this case the picture plane is chosen as a horizontal plane.

249. Perspective of a Point. — From Fig. 1 it is evident that to find the perspective of an object, it is only necessary to locate the piercing points of the visual rays, drawn from the eye to the various points on the object, with the picture plane. Figure 2 shows pictorially a point A in the second angle and a point of sight S in the first angle a distance x to the right of A, a distance y above A, and a distance z in front of A. It will be noted that this arrangement corresponds to that of Fig. 1 when the corner of the box at A is considered as the point A of Fig. 2. The method of laying out the distances x, y, and z are indicated in Fig. 1 but omitted in Fig. 2. The orthographic projections of S, A, and the line of sight are shown on the horizontal plane and on the picture plane. The line of sight from S to A pierces the picture plane at Ap; and Ap, therefore, is the perspective of A. That is, Ap is the representation of A in the picture plane just as it would appear to the eye from S.

It should be noted that Ap is on $s'a'$ which is the vertical projection or elevation of the line SA. It should be observed further that Ap is directly

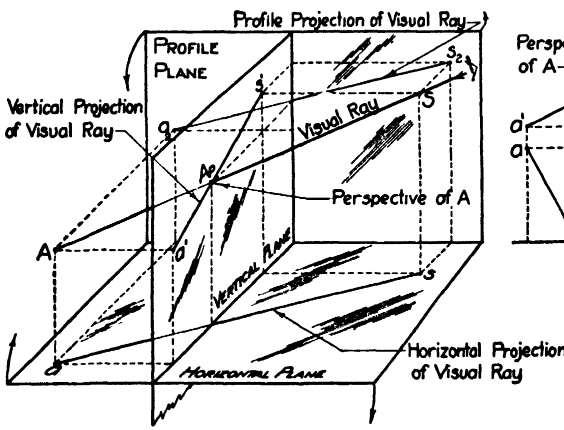

Fig. 2. Perspective of a point (pictorial).

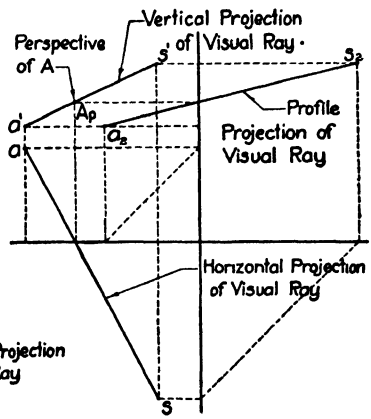

Fig. 3. Perspective of a point (orthographic).

above the point where sa, which is the horizontal projection or plan of the line SA, crosses the ground line. Figure 3 shows orthographically the projections which lie in the horizontal and vertical planes in Fig. 2, and also the projections on the end or profile plane.

Two projections of a point, line, or object are always necessary to determine completely its position in reference to the principal planes. Therefore, if we have given or can find any two views of a point taken at random in space or located on an object, such as might be shown in any shop drawing, a perspective of the point can be obtained by applying the simple rules given below:

(1) If a perpendicular is erected from the point at which the horizontal projection of a visual ray to the given point crosses the ground line, to the vertical projection of this same ray, the perspective (Ap) of the point is located; or (2) if a perpendicular to the profile ground line is drawn from the point where the profile projection of the visual ray crosses the profile

ground line, to the vertical projection of the ray, the same point Ap is located; or (3) if both perpendiculars are drawn, the vertical projection of the ray may be dispensed with altogether and the point Ap located just as well.

This last rule is true because the horizontal projection of the line of sight gives the location of Ap in a horizontal direction, and the profile projection gives the location in a vertical direction just as does the vertical projection.

250. Vanishing Points. — It is a matter of common observation that long, straight, horizontal, parallel, lines seem to converge as they recede, and finally appear to come together in the distance at a point in the horizon. If, therefore, a line is drawn through the point of sight parallel to any one of a group of parallel lines, let us say the horizontal ones on a building, it will seem to meet not only one but all of them at an infinite distance away and in the horizon. This fact is sometimes expressed in geometry by the statement that "parallel lines meet at infinity." Hence, the point where this parallel line through the point of sight pierces the picture plane is the perspective of the apparent meeting or vanishing point of all the parallel lines. The perspective of the apparent vanishing point is itself universally called the vanishing point of this particular group of lines. Since only one line can be drawn through the point of sight parallel to any group of parallel lines, such a group can have only one vanishing point. Each separate system of parallel lines, however, will have its own vanishing point. Figure 4 shows the method of finding vanishing points pictorially, and Fig. 5 shows the same thing orthographically. It is well to remember in this connection that *parallel lines in space have their projections parallel on the same coördinate plane.*

Two horizontal lines, AB and BC, are shown in the second quadrant with a point of sight, S, in the first quadrant. In Fig. 4, a line is drawn through S, parallel to AB. Where this line pierces the picture plane at v' is the vanishing point for AB and all lines parallel to it. In the same way, the vanishing point v_1' is found for BC and lines parallel thereto.

In Fig. 5 the same procedure is carried out after the horizontal plane has been revolved into the picture plane, as is shown pictorially in Fig. 4. Through s draw a line parallel to ab until it crosses the line representing the picture plane. Here erect a perpendicular and extend it until it intersects a line drawn through s' parallel to $a'b'$. This is the vanishing point for AB. The vanishing point for BC may be found in the same manner. It will be noted that both these vanishing points lie in the horizontal line passing through s'. This line is called the *horizon*, and it will contain the vanishing points of all sets of parallel horizontal lines. We may visualize this fact the better by recalling that lines on the earth's surface which are horizontal and parallel, such as the two rails of a track, seem to vanish in nature's horizon. The line of sight from the eye will also be parallel to thė tracks in the above case, and will also vanish with them in the same point in the horizon. On the drawing paper, the horizon is the intersection of the picture plane with a horizontal plane passed through the point of sight. If this horizontal plane is extended, it will seem to contain nature's

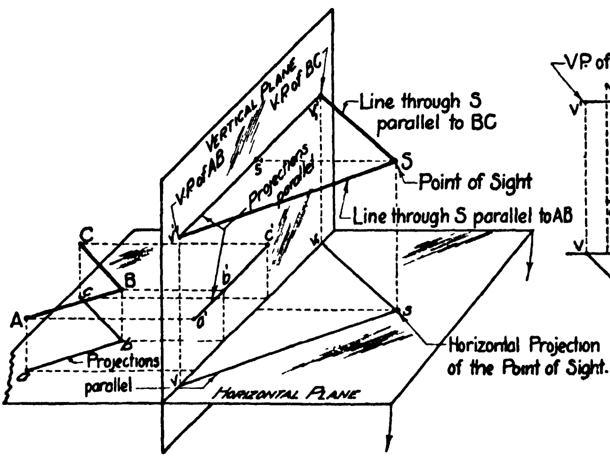

FIG. 4. Vanishing points of horizontal lines (pictorial).

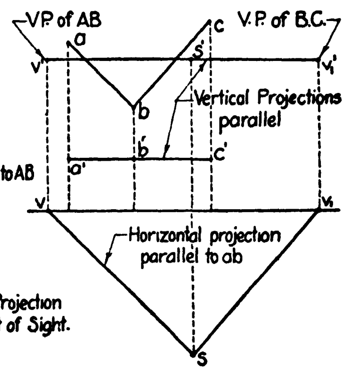

FIG. 5. Vanishing points of horizontal lines (orthographic).

horizon also; hence the real reason for the term horizon as used in perspective drawing.

251. VANISHING POINTS FOR OTHER THAN HORIZONTAL LINES. — The draftsman must not conclude that, since horizontal lines all have their vanishing points in the horizon, regardless of their direction, the same thing is true for lines not parallel to the horizontal plane. However, the principles for finding the vanishing points of horizontal lines, which were fully explained in the preceding paragraphs, still hold good for oblique lines. These principles may be briefly summarized in rule form as follows:

Through the point of sight, draw a line parallel to the lines whose vanishing point is desired, and find where this line pierces the picture plane. This piercing point is called the vanishing point of the group of parallel lines.

The rule as stated above applies to the conditions as they exist in space; hence, to apply the rule on paper it must be remembered that two projections of the point of sight and two projections of each line are absolutely necessary to fully represent them, and further that two projections of the line drawn through the point of sight must also be shown. Figure 6 illustrates the case pictorially, and Fig. 7 represents the same thing orthographically — as the draftsman would represent it. The horizon is not shown in either of these figures, but it would pass horizontally through s', if it were drawn.

The vanishing point of all lines perpendicular to the picture plane is the vertical projection of the point of sight.

Lines perpendicular to the horizontal plane or parallel to the picture plane have no vanishing point.

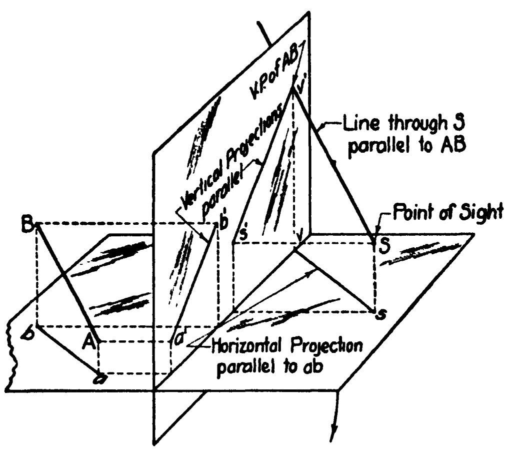

FIG. 6. Vanishing point of oblique lines (pictorial).

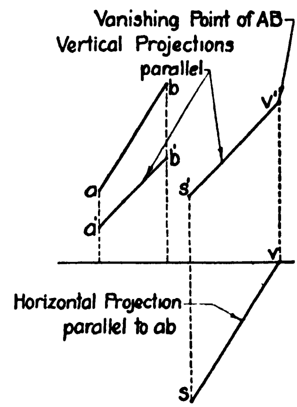

FIG. 7. Vanishing point of oblique lines (orthographic).

252. PERSPECTIVE OF A SOLID. — Since the perspective of a solid object consists simply of the perspective of its outlining or definitive points and edges, such a perspective may be constructed by simple repetition of the procedure described above, which is known as the *visual-ray method*, and which is further elaborated below under two main divisions. A problem may be stated as follows: Find the perspective of a cube in the third quadrant, 1 inch on the edge, having one face parallel to the picture plane and 1 inch behind it. The point of sight is to be 4 inches in front of the cube, 2 inches to the right of it, and 2 inches above it. The location of the point of sight might also be expressed in terms of the usual three coördinate distances, x, y, and z. Thus $+ x$ would indicate the distance to the right and $- x$ the distance to the left; $+ y$ would indicate the distance above and $- y$ the distance below; and z the distance in front of the point of reference on the object.

253. Parallel or One-Point Perspective. — It is first necessary to draw the horizontal and profile projections of the cube and point of sight, showing them in their true relation to each other and to the picture plane (vertical plane), as specified in the problem. These are shown in Fig. 8, in the customary third- and fourth-angle projection. The vertical projection is omitted, because it is not necessary to the construction, and it would quite seriously interfere with the finished perspective. The perspective of the eight corners of the cube may now be located in the same manner as the single point Ap in Fig. 2. If these points are then connected in the proper order, the perspective of the cube is complete. Evidently the edges of the cube which are perpendicular to the picture plane will vanish at s'. The other lines do not have vanishing points.

Since the object in Fig. 8 is placed with one of its principal faces parallel to the picture plane, thereby leaving only one set of parallel lines which

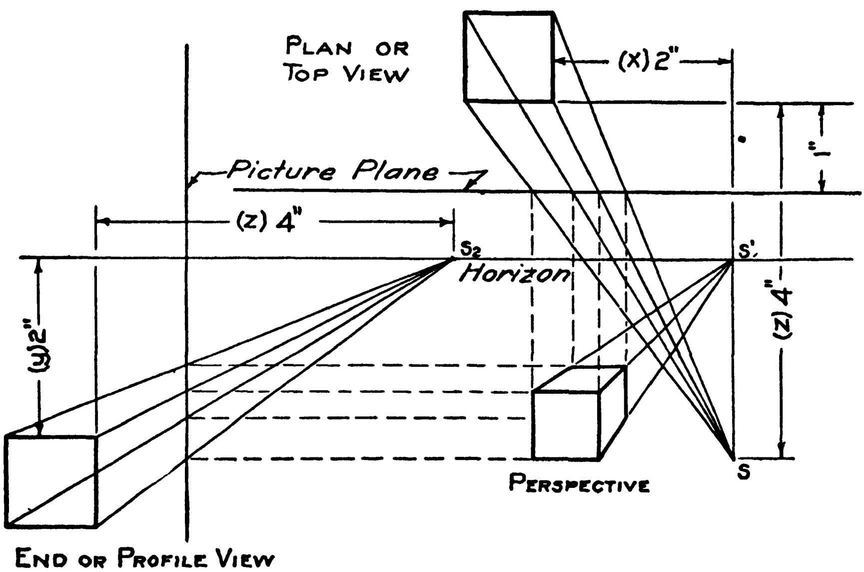

Fig. 8. Parallel perspective by the visual ray method.

can have a vanishing point, this type of perspective is called *parallel, or one-point, perspective.*

254. Angular or Two-Point Perspective. — Suppose the cube to be placed in the position shown in Fig. 9. The vertical faces make angles of 30 degrees and 60 degrees, respectively, with the picture plane, and the front edge is 1 inch behind it. The point of sight is 2 inches above the top face, 4 inches in front of, and 1 inch to the right of the front edge. The construction of the perspective may be completed as before, by finding the perspectives of the eight corners, using the visual-ray method exclusively with plan and profile views of the cube. It will be noted that the profile or end view has been turned in the opposite direction from that in Fig. 8.

The various steps in the construction of the perspective are shown in the figure.

After the perspective of Fig. 9 had been obtained as explained above, its right and left edge-lines were extended to meet on the horizon in right and left vanishing points, respectively, which were then checked by drawing visual rays through the point of sight parallel to the edge-lines of the cube and finding their piercing points in the picture plane as shown. This type of perspective is called *angular, or two-point, perspective.*

The perspective of so simple an object as a cube may be readily found by the *visual-ray method* described above and illustrated in Figs. 8 and 9; but for more complicated problems this method would be very cumbersome.

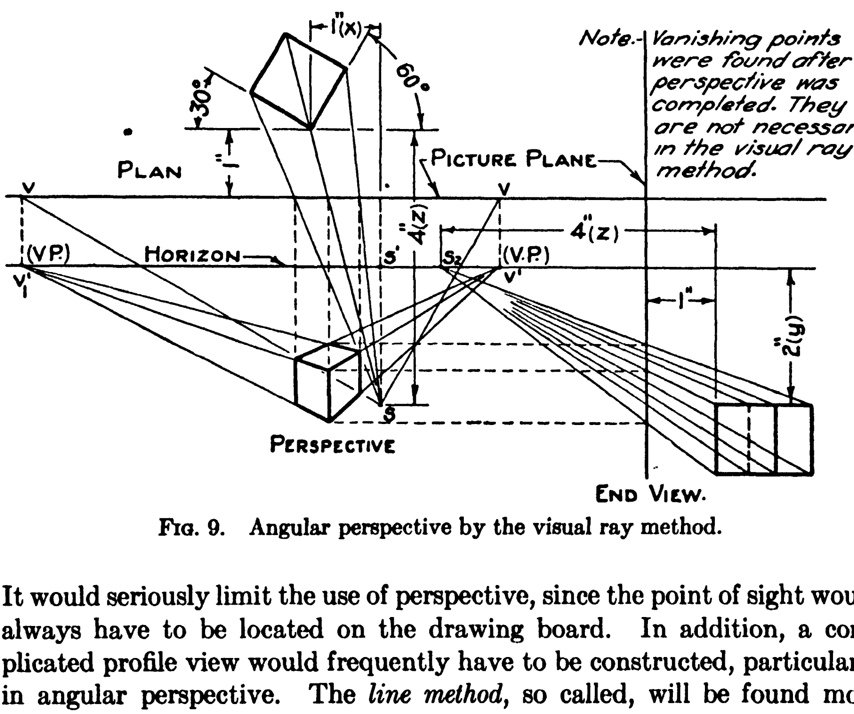

FIG. 9. Angular perspective by the visual ray method.

It would seriously limit the use of perspective, since the point of sight would always have to be located on the drawing board. In addition, a complicated profile view would frequently have to be constructed, particularly in angular perspective. The *line method,* so called, will be found more suitable in most instances.

255. Line Method. — In order to simplify the process of construction, the perspective of a line may be used as the foundation of the work, instead of the perspective of the point as in the above schemes. The perspective of a line may be found by finding the perspective of any two of its points. One of these points may be the vanishing point and the other the point where the line extended pierces the picture plane. The latter point is its own perspective. By drawing from this point to the vanishing point the perspective of the line is found.

In Fig. 10 for example, the perspective of one point of the line AB may be found by extending it until it pierces the picture plane at c'. The vanishing point for AB and all lines parallel to it may be found in the usual manner. Then by connecting c' with the vanishing point v', the perspective of the unlimited line, of which AB is a segment, is found. In Fig. 11, this procedure is carried out orthographically. The vanishing point is found by first drawing a line through s parallel to ab and through s' parallel to $a'b'$. Where the line through s crosses the ground line, which is the intersection of the picture plane with the horizontal plane, erect a perpendicular until it crosses the line through s'. This intersection is the

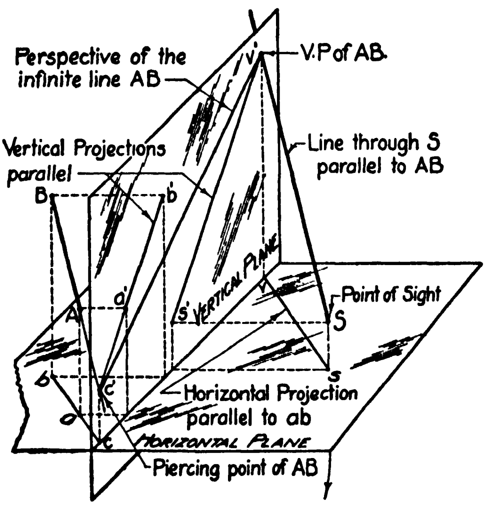

Fig. 10. Perspective of a line by means of two points in it (pictorial).

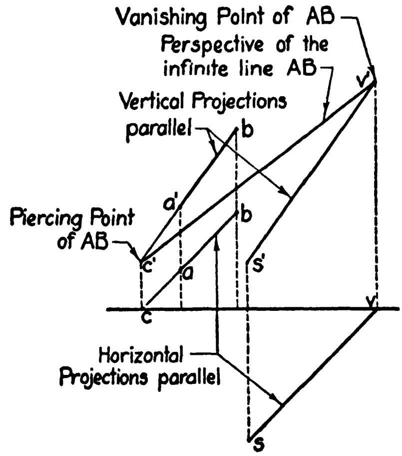

Fig. 11. Perspective of a line by means of two points in it (orthographic).

vanishing point v'. To find c' extend ab until it crosses the ground line, and there erect a perpendicular until it crosses $a'b'$ produced. Then $c'v'$ is the perspective of the unlimited line indicated by AB. How to find the perspective of the limited portion AB is clearly brought out in Fig. 12 and the following discussion pertaining thereto.

To find the perspective of an object by the method just described, it is first necessary to draw the plan of the object and point of sight in their proper relation to the picture plane. The plan of the object should be placed well toward the top of the sheet, or it may be made on a separate sheet and placed above the sheet on which the perspective is to be made. Next, the horizon is drawn in such a position that the finished perspective will have the desired location on the sheet. An elevation of the object may then be drawn at the left end of the sheet, in proper relation to the horizon, but without reference to the plan view, as it is used only to determine the vertical dimension of the perspective. This relation is easily established when we remember that the horizon is simply the intersection of a horizontal plane, through the point of sight, with the picture plane. Both the plan and elevation views of the point of sight should, of course, be shown in their proper relation to each other and to the views of the object.

As an example of this method, assume a cube as in Fig. 12, having the same dimensions and relations to the picture plane as in the problem in

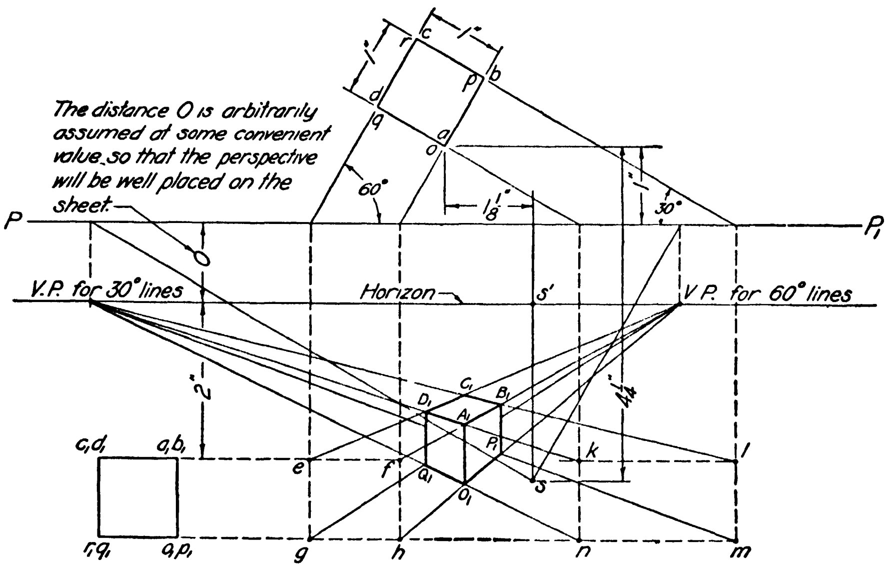

FIG. 12. Angular perspective by the line method.

Fig. 9. Locate the vanishing point for AB and lines parallel to it, by drawing through s a line parallel to ab until it crosses PP_1. Then drop a perpendicular from this point on PP_1 to the line through s' parallel to the vertical projection of AB, which line, of course, coincides with the horizon. The intersection is the vanishing point for the 60-degree lines. Likewise, find the vanishing point for AD and other 30-degree lines. In one or the other of these two vanishing points, we now have a point in the perspective of every line in the cube except the vertical lines. If the horizontal edges of the cube be extended to meet the picture plane, another point in each line may be found as in Fig. 11. Produce ab and ad until they intersect PP_1. Then drop perpendiculars from these intersections until they cross lines projected horizontally in from the elevation of the cube at the left. These projecting lines are, of course, the same distance below the horizon as the lines AB and AD are below the point of sight.

This locates the piercing points f and k. Connecting f and k with the proper vanishing point gives the perspectives of the lines AB and AD extended. The intersection of these two perspective lines at A_1 gives the perspective of the front corner of the cube. Other lines and corners may be determined in the same way, and the whole perspective of the cube completed.

A casual comparison of Figs. 9 and 12 is sufficient to show the advantages of the line method over the visual-ray method, on even as simple an object as a cube. On more complicated objects, still greater economies of time and space are effected.

256. Measurements in Perspective. — Since the cube in Fig. 12 is 1 inch on the edge, the distances eg, fh, kn, and lm will be 1 inch, but not a single line in the perspective of the cube itself will be 1 inch long. Measurements can be made to scale in perspective work in the location of the projections of the object and point of sight, in the coördinate planes, and in a vertical direction on the picture plane in constructing the perspective by the *line* method. No scale measurements may be made on the perspective itself, unless, perchance, one of the lines or faces of the object is placed in the picture plane, whereupon the elevation of all such lines becomes the perspective. Distances are obtained, in general, by intersecting lines, as in Fig. 12.

It will be observed that the only use made of the point of sight in the line method is to locate the vanishing points. See Fig. 12. The vanishing points are, of course, dependent upon the distance of the point of sight from the object, and are sometimes referred to as *distance points*. If it is not necessary to have the point of sight in some very definite position, the vanishing points may be assumed at will, and the location of the point of sight allowed to come as it may. An experienced draftsman, by locating his plan relative to the chosen vanishing points, can make the point of sight very close to any specified location.

257. Combined Methods. — The minimum construction, and hence the maximum speed, can be attained by combining the visual-ray and line methods as circumstances dictate in a particular case. Thus, in Fig. 13, points A_1 and C_1, and all points on the pyramid were obtained by use of the visual ray in combination with one or the other of the vanishing points. The point O_1 was obtained by means of a line through the apex of the pyramid parallel to a base line, and a visual ray to the same point. It should be noted that no loss in accuracy of construction need occur since either of the two schemes may be used at will, and also, that in the case of isolated or independent points like the apex of the pyramid, the combined methods are particularly effective. Here, as in all pictorial drawing, invisible lines are omitted.

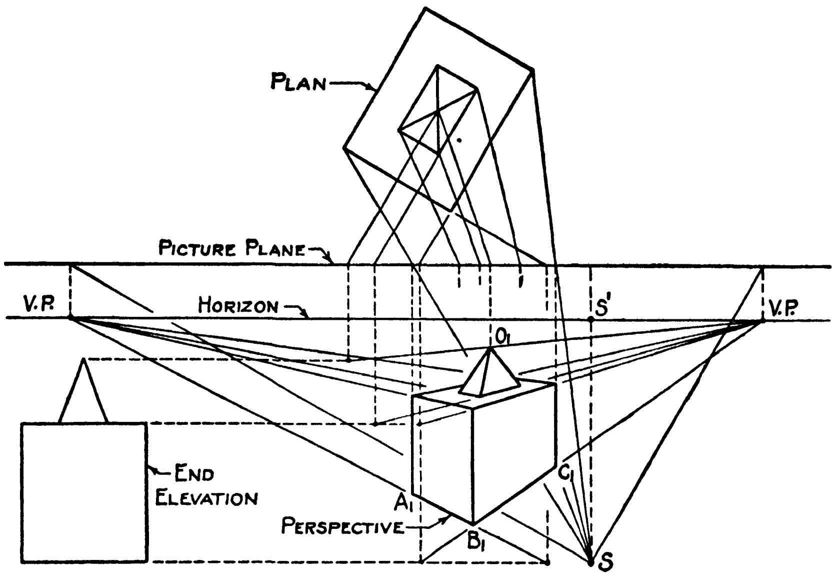

FIG. 13. Angular perspective by the combined, visual ray and line methods.

258. GENERAL METHODS. — In Fig. 14, the construction of geometric plane figures in perspective is shown. Briefly, the method consists of drawing two lines through the point whose perspective is desired, and then

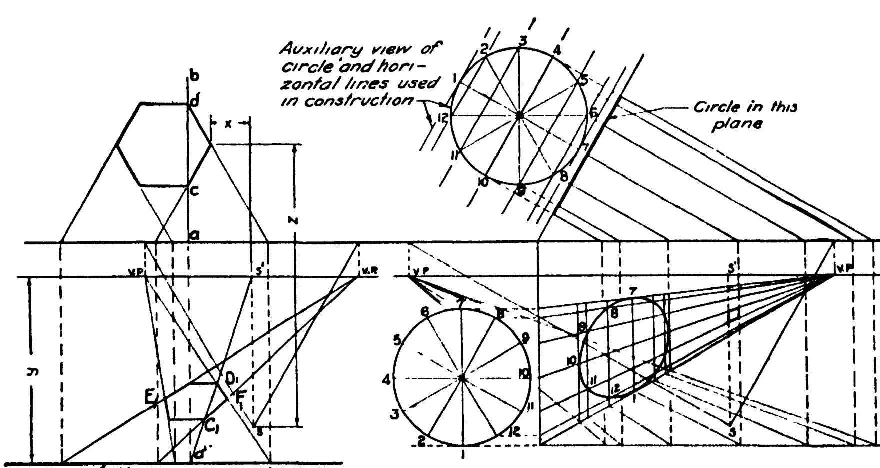

FIG. 14. Perspectives of plane figures.

finding the intersection of these two lines in perspective. Naturally, one would choose lines whose perspectives are easily found.

The hexagon is shown lying in a horizontal plane, a distance y below the point of sight. The vanishing and piercing points for both sets of 60-degree lines are found in the usual manner. Their perspectives are then drawn. Only the intersections E_1 and F_1 of these four lines locate corners on the hexagon. The remaining corners may be found by drawing a line, such as AB, through the corners C and D, and locating its perspective. The intersection of this perspective $s'a'$ with the perspectives of the 60-degree lines locates the corners C_1 and D_1.

The circle is shown in a vertical plane which is inclined to the picture plane. The perspective of the circle may be found by locating the perspectives of twelve or more points on it, and then drawing a smooth curve through the points thus found with an irregular curve. The perspectives of the twelve points may be found by drawing through them a series of coördinate lines, vertically and horizontally. The perspectives of these coördinate lines can be readily found in the usual manner. It will be noted that the circle just to the left of the perspective is used only for vertical dimensions, which are transferred to the right, to the line where the horizontal coördinate lines pierce the picture plane.

Familiarity with the theory of perspective, which comes from practice, will enable the draftsman to discover many short cuts for himself, which will save not only time but considerable labor as well.

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PROBLEMS

258a. In the following problems, the location of the point of sight is given on the figures by coördinates referring to a certain lettered point on the object as explained in the text proper. The picture plane always passes through this reference point. The object in some cases extends through the picture plane.

Some figures have two " set-ups " given on them, one for parallel perspective and the other for angular perspective. The method of solution is likewise specified on the figure. Thus the designation (P–1) means a parallel perspective solved by method 1 (visual-ray method) while (A–2) means an angular perspective made by method 2 (vanishing-point method combined with a judicious use of the visual ray). The instructor may change the method of solution by assignment.

The position of the object for angular perspective is specified on the figure by giving the angle which some lettered line on the object makes with the picture plane or by marking the angle on the drawing.

In all solutions, the plan and at least one elevation of the object should be shown on the finished drawing with sufficient pencil construction lines left in to clearly indicate the method used in obtaining the perspectives of the principal points on the object.

The location of the plan and elevation (two elevations in some cases) on the sheet must be determined by trial unless specified in the figure by the location of the reference point with regard to the border line of the sheet as in Fig. 17. When making a trial layout, draw only outline rectangles of the proper size to represent the plan and elevation and then determine the point of sight and vanishing points. If these do not fall within the border line, shift the plan until they do. The plan may actually extend beyond the upper border line, but a break should be made as indicated in Fig. 17. All points visible in the perspective should be within the border line. For angular perspectives, only one half of the elevations need be drawn.

As in other problems in the text, two scales are sometimes specified. Scale A is for the 12″ × 18″ sheets and scale B for the smaller sheets; see Art. 4, page 3.

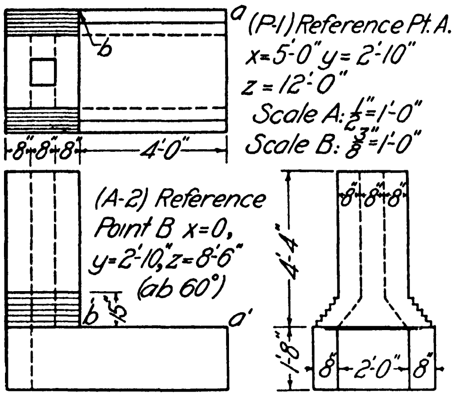


FIG. 15. Outdoor fireplace.

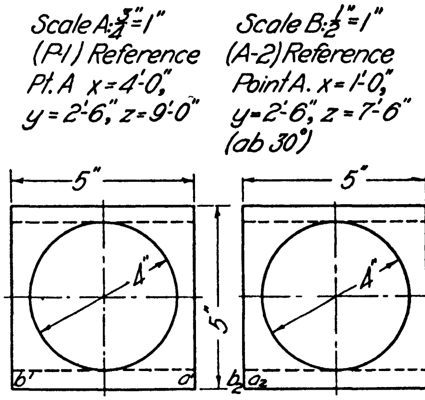


FIG. 16. Drilled cube.

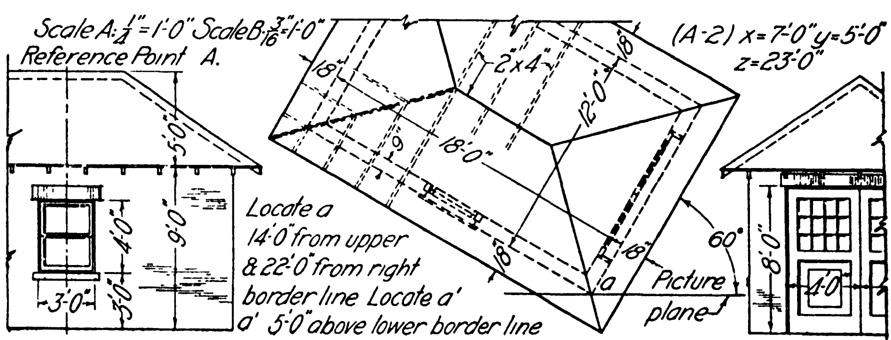


FIG. 17. Garage.

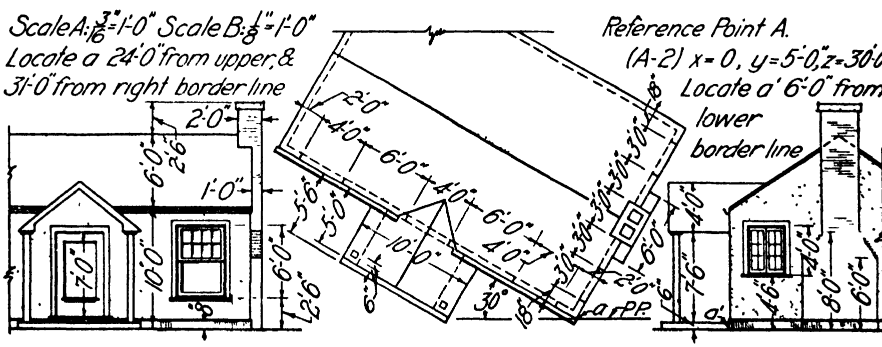


FIG. 18. Cottage.

1. Make a parallel perspective of the object shown in Fig. 15.
2. Make a parallel perspective of the object shown in Fig. 16.
3. Make an angular perspective of the object shown in Fig. 15.
4. Same as Prob. 3, Fig. 16.
5. Same as Prob. 3, Fig. 17.
6. Same as Prob. 3, Fig. 18.

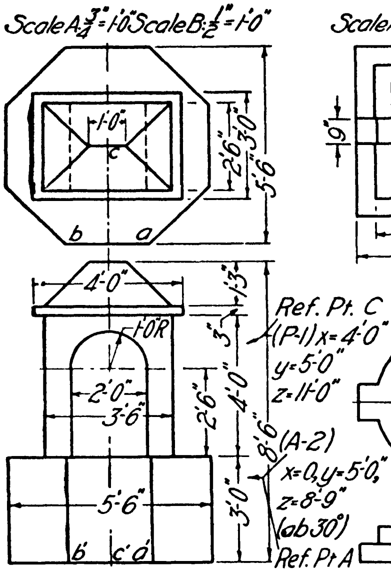


Fig. 19. Memorial Fountain.

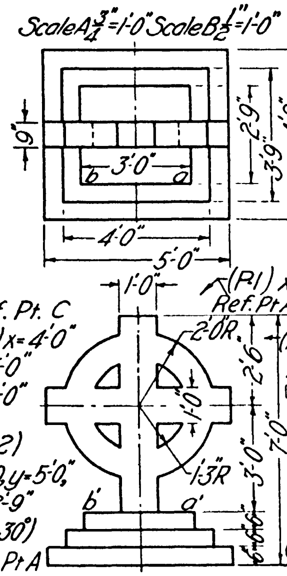


Fig. 20. Monument.

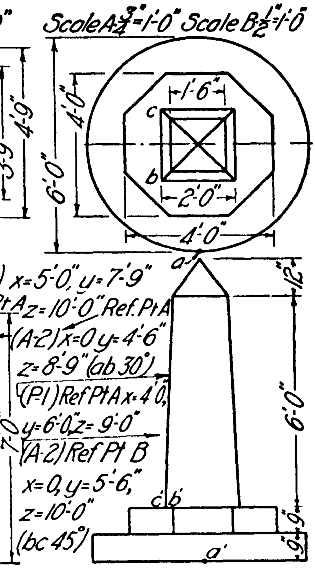


Fig. 21. Monument.

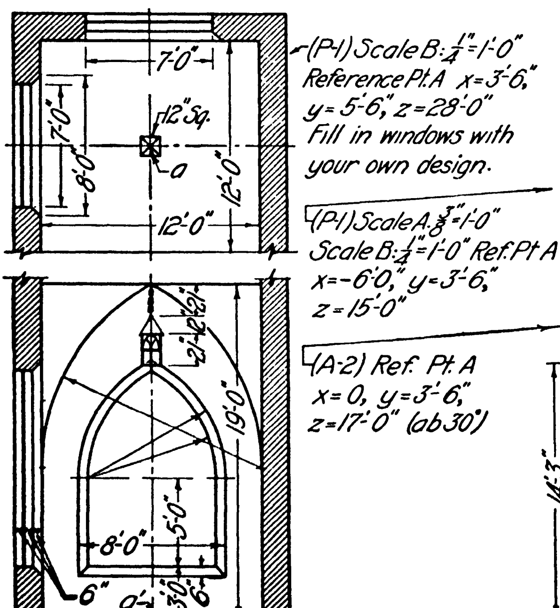


Fig. 22. Nave.

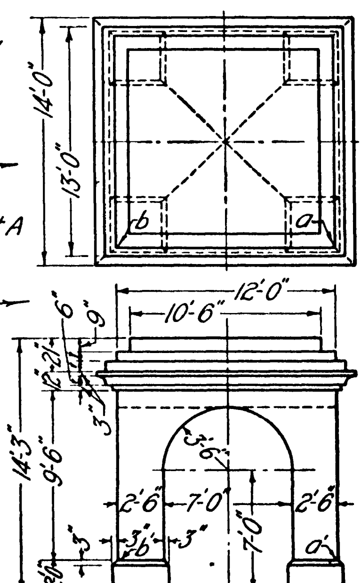


Fig. 23. Memorial Arch.

7. Make a parallel perspective of the object shown in Fig. 19.
8. Same as Prob. 7, Fig. 20.
9. Same as Prob. 7, Fig. 21.
10. Same as Prob. 7, Fig. 22.
11. Same as Prob. 7, Fig. 23.
12. Make an angular perspective of the object shown in Fig. 19.
13. Same as Prob. 12, Fig. 20.
14. Same as Prob. 12, Fig. 21.
15. Same as Prob. 12, Fig. 23.

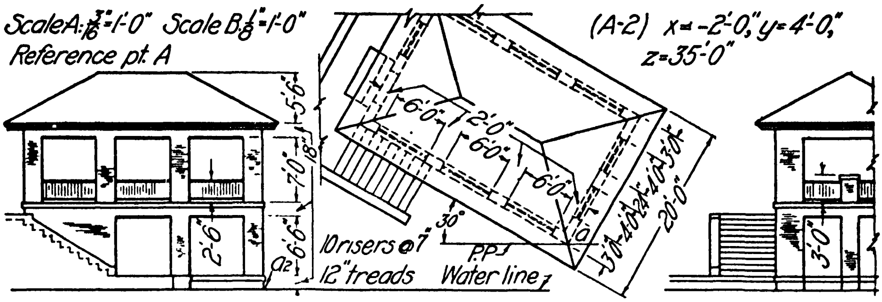


FIG. 24. Boat house.

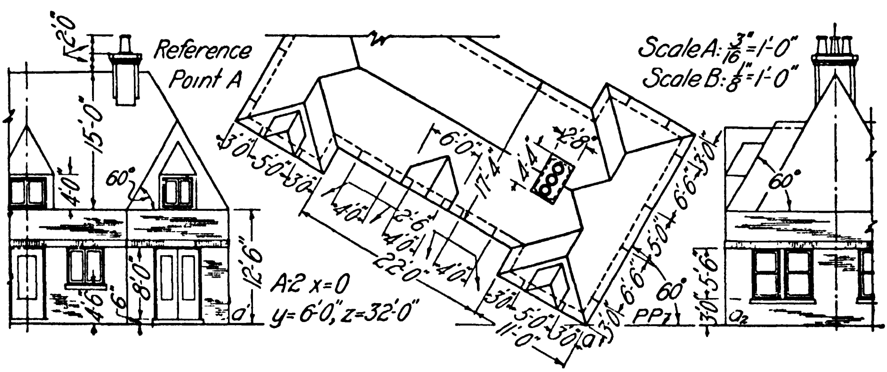


FIG. 25. Residence.

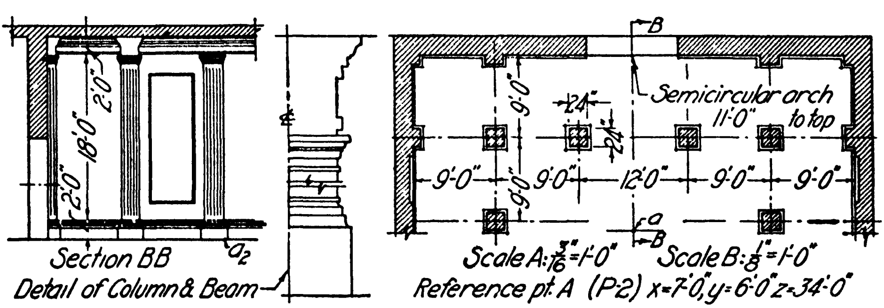


FIG. 26. Lobby.

16. Make an angular perspective of the object shown in Fig. 24.
17. Same as Prob. 16, Fig. 25.
18. Make a parallel perspective of the object shown in Fig. 26.

CHAPTER XVI

SKETCHING

259. However expert and proficient the engineer may have become in presenting his designs to others in the graphical language through the use of drawing instruments, he cannot hope to attain full success in the use of this language, and hence, in his profession, until he has mastered tolerably well the art of sketching, in the technical sense. By the term sketching, as here used, is meant the representation, by means of *freehand drawings*, of objects with which the engineer has to deal. Any one of the four major projections hitherto discussed in this text may be used. These freehand drawings, or sketches, are not to be thought of as the pen or pencil sketches of the artist or architect. They have nothing to do with the art of painting on canvas. They are simply freehand orthographic, isometric, oblique, or perspective drawings of machines or parts of machines, buildings, and other structures with which the engineer has to do. They may or may not be dimensioned, depending upon the use to be made of them. In every important way, they conform to the conventional standards of mechanically made drawings. For the sake of better explanation and distinction they are sometimes called technical sketches.

260. Purposes of Sketches. — The purposes of technical sketches are (1) to transmit information obtained in the field to the drafting office, (2) to form a medium through which one engineer or draftsman may transmit a true understanding of his designs and plans to another person, thus forming a basis for discussion, and (3) to serve as a means for working out preliminary designs incident to the actual preparation of working drawings. It is necessary, therefore, that most sketches be made in orthographic projection, with as many views and sections as are necessary for the correct and complete recording of all the information to be transmitted by the sketches.

It may be helpful to the student, in his attempt to grasp the full importance of sketch work, to call attention to the fact that the major portion of all the designs made by the designing engineer of any company are first prepared in the form of freehand or instrumental sketches, which are turned over to the detailer or draftsman, who then draws them to scale, thus making them ready for the shops. Such sketches are usually made on the sheets used in computing the sizes of the parts required to carry the loads specified, or on separate sheets which are bound with the computations. It is helpful to know, further, that sketches are indispensable when measurements are being taken on repair work, where it is not only necessary to secure dimensions of the broken part, but often information concerning surrounding parts needs to be obtained. Suggested improvements, extensions, and revisions of existing equipment and structures also require the engineer to exercise his ability at sketching.

Isometric and other pictorial sketches are useful for conveying ideas of form or shape, but can hardly serve for purposes of dimensioning when the object represented is more or less complicated. As auxiliary to orthographic sketches, although drawn to a much smaller scale, they serve a very useful purpose and should be freely used in this way.

By the beginner in technical sketching, two important elementary points must be mastered before the physical work involved can be done with ease and speed. The first element entering into successful sketching is the freehand stroke of the pencil. The second element is that of correct proportion and size. Each of these elementary factors in good sketching is discussed hereafter.

261. Sketch Stroke. — A freehand line should be made up of a series of short, sketchy strokes of the pencil, each succeeding stroke lapping

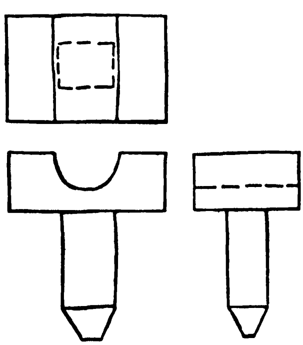


Fig. 1. Freehand sketch.

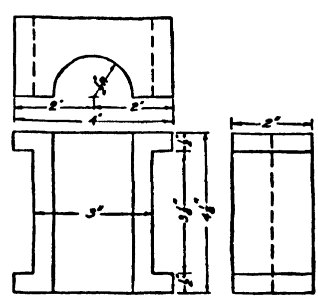


Fig. 2. Dimensioned sketch.

back a short distance over the preceding one. By means of this overlapping of strokes and short extension process, one may produce a line indefinitely, and at the same time keep it fairly straight, though somewhat rough. The element of roughness may be removed, if desirable, after the sketch is proportioned satisfactorily, by erasing and retracing the lines more carefully. The complexity of the sketch and one's judgment are the only guides in determining how roughly a sketch may be executed.

The direction of stroke should be from left to right for all lines of not more than 45-degree slope to the horizontal, in either direction. For other lines, the stroke may be either up or down the drawing sheet. Figure 1 shows the character of the sketch line accepted for purposes of indicating the shape of an object only, such as would be used if one engineer were explaining his designs to another. If dimensions are to be given, the sketch stroke should be as smooth as that shown in Fig. 2.

262. PROPORTIONING. — Since measurements are seldom taken on the object while the sketch proper is being made, it is important that a keen sense of relative proportions be developed by the draftsman or engineer. It is not so necessary in sketch work that one be able to estimate closely the *actual* dimensions of any object, but one must be able to judge the *relative* lengths of the various lines to be represented. That is, one must first estimate carefully the relation between the overall lengths, widths,

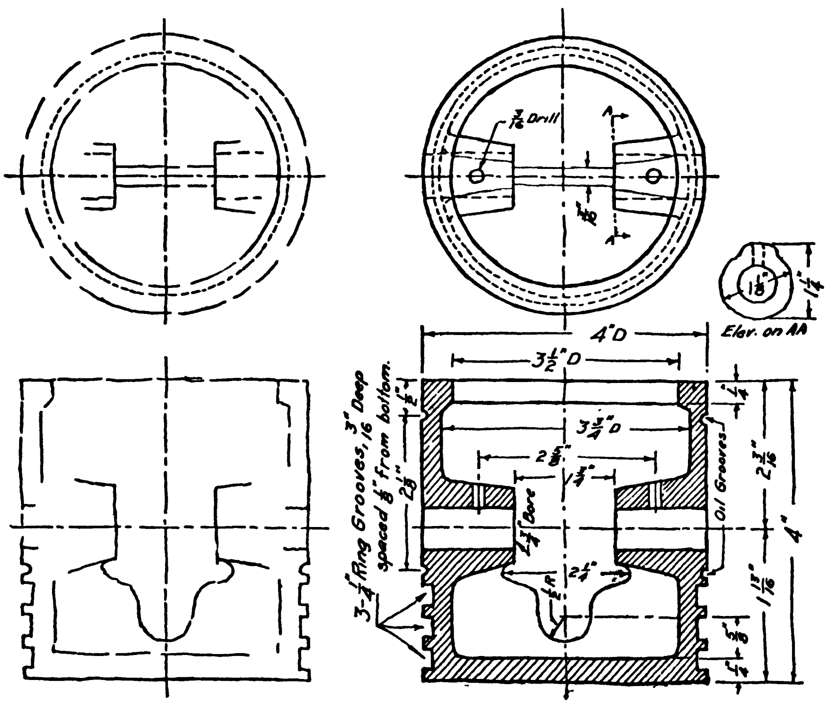


FIG. 3. Progressive steps in sketching.

and heights on the object, and block out spaces on the sketch sheet for each view, with close approximation to the relations existing among the corresponding sizes on the object. After the main outlines have been satisfactorily proportioned, some of the more important features should be located, such as the center lines of holes, bosses, shafts, pulleys, whereupon the lines representing these things should be sketched in. After this has been done, the small details may be put in and the dimensions added. Figure 3 shows these three stages in the execution of a sketch for a gas-engine piston. After the outlines have been gone over and smoothed out and poorly placed dimensions changed, general notes should be put in, including, of course, the name of the sketcher, the date, and the name of the object sketched. Contrast between lines should be kept as much as possible like that used on working drawings, and to this end one should go over the outlines a second time and bring them out clearly from the other lines.

263. Sketch Materials. — Most draftsmen find H, 2H, or 3H pencils best suited to sketch work, depending upon the surface of the sketch paper. It is well to have all three available. The 3H is soft enough to make erasing very easy; yet it is not so soft that frequent sharpening is necessary; neither does it give a very black, charcoal effect to the sketches. The H or 2H may be used for bringing out important outlines, and the 3H for putting on dimensions and notes when the space for them is limited, otherwise the 2H may be used.

The paper to be used will, of course, depend upon the circumstances under which the sketch is made. Generally speaking, drafting offices carry regular sketch pads or books in which the sheets are ruled with horizontal and vertical lines, and in some cases with isometric lines, to facilitate proportioning and to assist the sketcher in keeping his lines straight and parallel. Any paper may be used, however; but sketches done on anything at hand are often lost, and new ones have to be secured.

Other essential pieces of equipment are an eraser, steel scale, calipers, cloth or steel tape, and a small triangle. The last three are for the purpose of securing the dimensions of the object.

264. Dimensioning a Sketch. — After all the detail has been drawn in on the various views, the dimensions must be secured from the object and added to the sketches. Often a sketch is made in the field, where access to the measuring devices of the shop are not possible. Recourse to measuring schemes of all kinds must be had, in order that no important dimension is left off the sketch. The rule in sketching is to get all the dimensions, and get them right, while the sketcher is on the job the first time. Extra trips are costly in time and money.

After all the measurements thought necessary have been taken from the object, the dimensions on the sketch should be checked up by the processes of addition and subtraction, to see that no error has crept in through mismeasurement or otherwise. All additive overall dimensions should be rechecked against actual measurements, if this was not done in the first instance.

Again, the sketcher must exercise good judgment in choosing the dimensions that will be needed in the drafting room and in deciding upon the relative degrees of accuracy with which various measurements are to be taken. In places where every part of the machine or object being sketched is machined, care must be taken to secure dimensions accurate to within the customary allowances and limits used on such work. On rough and poorly designed castings, less accurate measuring is permissible. Cases will even arise in which the sketcher should change dimensions to correct obvious mistakes in fit or design. For instance, it is not unusual to find castings, supposedly symmetrical about a plane or axis, with the dimensions on one side of the axis seriously disagreeing with those on the other side. The sketcher should note this discrepancy and decide, in the field, which dimensions are right.

Too much emphasis cannot be put upon the necessity of discriminating between dimensions that are useful and required, and those that are of little value or wholly useless. It is very easy to cover a drawing completely with dimensions which no one will ever use and some of which cannot be used. Such, for instance, are radii of slightly rounded corners and intersection curves due to machining processes, curves caused by insertion of bosses, interior dimensions which cannot be connected with outside dimensions, and others of like character.

It will be found advisable to adhere closely to the regular rules of dimensioning prevailing in the drafting room, except where substitutes can be made with considerable saving in time. Frequent use of leaders is recommended. Sectional views for explanatory purposes are very desirable and should be dimensioned freely. Paper templates should be cut and fitted to curved portions, in order that more accurate dimensions may be taken. In this connection it may be well to point out that it is often better, instead of trying to determine the exact curvature of an outline in the field, simply to coördinate various points on the curves from base lines which may be set up easily in the field, and leave the form of the curve to be worked out in the drafting room when the working drawings are being made.

265. Possible Procedures. — Since all sketches are for temporary purposes and do not go to the shop man for his use in building the machine or structure, many short cuts and variations may be resorted to in securing the desired results. A few of these are listed below. Others will suggest themselves to the alert and skilful sketcher.

1. When objects are complicated by small detail at certain places, the sketches may be enlarged at these points in reference to the rest of the object, and the detail thus shown in its entirety.

2. When objects are symmetrical about one axis, only half of the object

need be shown; if symmetrical about two axes at right angles to each other, only a quarter need be shown.

3. Spokes of wheels and teeth on gears may be shown by simply drawing one of either and indicating the total number. Rims and bands of all kinds may be treated in a similar way by simply drawing an outside circle and a cross section of the solid portion.

4. Standard fillets, threads, and machine processes should be indicated by notes, and no attempt made to fix their size by actual dimensions on the sketch.

5. In many cases only one view is necessary, and no others should be drawn.

6. Different views of an object may be put on separate sheets, with clear notes explaining the direction from which each was taken.

7. Circles may best be drawn by first putting in a few dots on the circumference in each quadrant, and one on each center line. Errors in curvature will be discovered and corrected very easily by this method.

PROBLEMS

266. The problems in the following group have been selected from various chapters throughout the book. No specifications are given as to the number of views, sections, etc. The student should use his own judgment in these matters and not be governed entirely by the contents of the chapter in which the figure occurs.

The sketch should follow all the rules governing the kind of drawing called for in the sketch problem.

In each of the groups of problems below, no figure number has been given in the last problem in order that the instructor may make his own selection. The sketch paper is to be designated by the instructor.

1. Make the freehand orthographic views necessary to describe the shape of the object shown in Fig. 22, Chapter V.

(Note: Following figure numbers are from Chapter V.)

2. Same as Prob. 1, Fig. 24.
3. Same as Prob. 1, Fig. 25.
4. Same as Prob. 1, Fig. 28.
5. Same as Prob. 1, Fig. 30.
6. Same as Prob. 1, Fig. 35.
7. Same as Prob. 1, Fig. 38.
8. Same as Prob. 1, Fig. 39.
9. Same as Prob. 1, Fig. 40.
10. Same as Prob. 1, Fig. 42.
11. Same as Prob. 1, Fig. 43.
12. Same as Prob. 1, Fig. 44.
13. Same as Prob. 1, Fig. 45.
14. Same as Prob. 1, Fig. 66.
15. Same as Prob. 1, Fig. ( ).

(Note: Following figure numbers are from Chapter VI.)

16. Same as Prob. 1, Fig. 31.
17. Same as Prob. 1, Fig. 32.
18. Same as Prob. 1, Fig. 33.
19. Same as Prob. 1, Fig. 34.
20. Same as Prob. 1, Fig. 38.
21. Same as Prob. 1, Fig. ( ).

(Note: Following figure numbers are from Chapter VII.)

22. Same as Prob. 1, Fig. 18.
23. Same as Prob. 1, Fig. 19.
24. Same as Prob. 1, Fig. 20.
25. Same as Prob. 1, Fig. ( ).

26. Make a freehand working drawing of the object described in Fig. 29, Chapter VII.
27. Same as Prob. 26, Fig. 30.
28. Same as Prob. 26, Fig. 31.
29. Same as Prob. 26, Fig. 33.
30. Same as Prob. 26, Fig. ( )

(NOTE: Following figure numbers are from Chapter VIII.)

31. Same as Prob. 26, Fig. 37.
32. Same as Prob. 26, Fig. 38.
33. Same as Prob. 26, Fig. 40.
34. Same as Prob. 26, Fig. 42.
35. Same as Prob. 26, Fig. 43.
36. Same as Prob. 26, Fig. 46.
37. Same as Prob. 26, Fig. 55.
38. Same as Prob. 26, Fig. 56.
39. Same as Prob. 26, Fig. 61.
40. Same as Prob. 26, Fig. 65.
41. Same as Prob. 26, Fig. 66.
42. Same as Prob. 26, Fig. 69.
43. Same as Prob. 26, Fig. 70.
44. Same as Prob. 26, Fig. 79.
45. Same as Prob. 26, Fig. 80.
46. Same as Prob. 26, Fig. 82.
47. Same as Prob. 26, Fig. 83.
48. Same as Prob. 26, Fig. ( ).
49. Make a freehand, undimensioned, isometric sketch of the object described in Fig. 52, Chapter V.

(NOTE: Following figure numbers are from Chapter V.)

50. Same as Prob. 49, Fig. 53.
51. Same as Prob. 49, Fig. 56.
52. Same as Prob. 49, Fig. 57.
53. Same as Prob. 49, Fig. ( ).

(NOTE: Following figure numbers are from Chapter XIII.)

54. Same as Prob. 49, Fig. 20.
55. Same as Prob. 49, Fig. 23.
56. Same as Prob. 49, Fig. 25.
57. Same as Prob. 49, Fig. 26.
58. Same as Prob. 49, Fig. 28.
59. Same as Prob. 49, Fig. 38.
60. Same as Prob. 49, Fig. 42.
61. Same as Prob. 49, Fig. ( ).
62. Make a freehand, undimensioned, oblique sketch of the object described in Fig. 59, Chapter V.

(NOTE: Following figure numbers are from Chapter V.)

63. Same as Prob. 62, Fig. 61.
64. Same as Prob. 62, Fig. 62.

(NOTE: Following figure numbers are from Chapter XIV.)

65. Same as Prob. 62, Fig. 16.
66. Same as Prob. 62, Fig. 18.
67. Same as Prob. 62, Fig. 23.
68. Same as Prob. 62, Fig. 24.
69. Same as Prob. 62, Fig. 27.
70. Same as Prob. 62, Fig. ( ).
71. Make a dimensioned orthographic design sketch of a bench vise. Show enough views and dimensions so that a draftsman could make details from your sketch.
72. Same as Prob. 71, Small auto jack.
73. Same as Prob. 71, Screw clamp — 4″ span.
74. Same as Prob. 71, Small emery wheel — one gear step.
75. Same as Prob. 71, Monkey wrench.
76. Same as Prob. 71, Drinking fountain.
77. Make a freehand orthographic sketch of a model assigned by your instructor. Dimension if so directed.

CHAPTER XVII

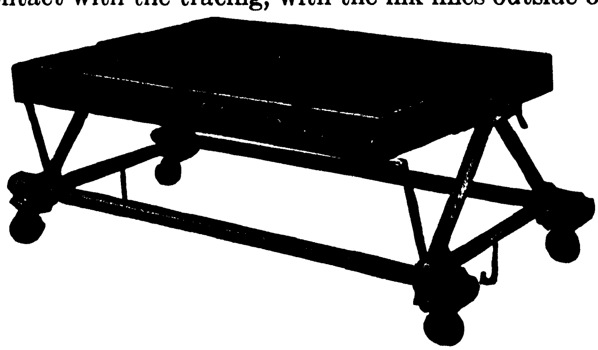
REPRODUCTION OF ENGINEERING DRAWINGS

267. The greater part of this text has been devoted to a study of the science and art of making engineering drawings. A single drawing of an object, however, would be of very limited service, since only a few men could have access to it at the same time, and then they would all have to be at the same place. The different parts of a machine or structure are often fabricated in cities miles apart; hence, copies of the original drawing are very necessary. Several very satisfactory methods of duplication are described below.

268. BLUEPRINT PROCESS. — One of the most common methods of duplication of engineering drawings is the blueprint process, of which there are several variations. Only the more important ones will be considered in this text.

The original blueprint process, which was first invented by Sir John Herschel in 1840, was introduced into the United States at the Centennial Exposition in 1876. Briefly, the process consists in exposing a sensitized paper to white light through a negative — usually a tracing of the drawing, and developing the exposed paper in water.

To make a blueprint from a tracing, the sensitized side of the paper is placed in contact with the tracing, with the ink lines outside or away from



Courtesy C. F. Pease Company.

FIG. 1. Sun printing frame.

the paper, and then both are placed in a printing frame which can be rotated on a central axis so that the glass top is underneath while loading and holds the tracing and paper in firm contact while exposure to the light is made. See Fig. 1.

269. Exposure. — The time of exposure depends both upon the intensity of the light and the speed quality of the paper. In strong sunlight, 20 or 30 seconds will give satisfactory results. One cannot set a definite time for sun exposures, however, because the light is so greatly affected by climatic conditions. With a single arc light, about 2 minutes will be required for ordinary rapid paper. Experience will enable one to determine the proper time of exposure, by observing the color of the paper projecting beyond the edges of the tracing. For uniformity in color, it is best to time prints with a watch, after the proper time has been determined experimentally by using small strips of blueprint paper.

270. Washing. — After exposure, the tracing is carefully laid aside and the print developed by washing in water. In running water the time of washing should be about 3 to 5 minutes. In a flat pan where the water is not constantly changing, the time should be about 10 to 15 minutes. When the print is thoroughly washed it is hung up to dry. The print should show clear white lines on a deep blue blackground.

271. Intensifying. — Occasionally, it will happen that a print has been over-exposed. Upon developing, the white lines appear with a blue tinge, or they may scarcely appear at all, and the blue field has a mottled gray appearance. Such a print may be restored by washing in any oxidizing solution, usually potassium or sodium bichromate. The lines will then become pure white and the remainder of the paper an intense blue. The print must be washed in water again before it is hung up to dry.

272. PAPER. — The paper to be sensitized should be pure white and free from traces of sulphur and wood pulp. It must be properly sized, tough, fairly hard, not too absorbent, and not too heavily grained.

273. SENSITIZER. — The sensitizing solution is composed of ammonia citrate of iron and potassium ferricyanide. The proportions of the two substances can be varied through a wide range and still produce satisfactory results. A combination frequently given is as follows:

Ammonia citrate of iron [$(NH_4)_2 H Fe (C_6H_5O_7)_2$], 1 oz.; water, 4 oz.
Potassium ferricyanide ($K_3 Fe C_6N_6$), 1 oz.; water, 4 oz.

If these two substances are placed in separate, dark-colored, well-stoppered bottles, they may be kept for a long time. To sensitize the paper, mix equal volumes of the two solutions and apply to the paper with a camel's-hair brush, stroking first in one direction, and then at right angles thereto. This must be done in a darkened room, and the paper allowed to dry in a cool, dark place. When dry, the paper presents a pale green color. The more rapid papers contain uranic salts in addition to the above.

274. CHEMISTRY OF THE PRINTING PROCESS. — The two soluble chemicals, ammonia citrate of iron and potassium ferricyanide, when in solution and away from the light, do not act upon each other. Therefore, if an unexposed piece of blueprint paper should be washed in water, the chemicals would simply be dissolved off, leaving the white paper. Under the action of light, the two compounds act upon each other, thereby reducing some of the ferric iron to an insoluble ferrous state and forming either Turnbull's blue or Prussian blue. These compounds adhere firmly to the paper. Hence, where the light shines through the tracing, this reducing action takes place, but under the opaque lines of the drawing there is no action. When the print is developed in water, the unchanged chemicals are washed away, leaving the white paper exposed, while on the remaining part the blue precipitate is deposited. It will be noted that the chief chemical action involved in this process is that of reduction.

The intensifying process, on the other hand, is an oxidizing action. It is used when the print has been " burned," that is, when it has been exposed too long and the reduction process has been carried too far. By washing the print in an oxidizing solution the over-reduced iron compound is restored to Turnbull's blue and a good print is obtained. Sodium bichromate is the oxidizing agent most frequently used.

If a print has been under-exposed, as evidenced by a pale blue color after washing, it should be discarded.

Blueprints are unsatisfactory to work upon with the ordinary inks and pencils since the markings are hardly distinguishable against the deep blue background. Red and white pencils and certain special inks may be used with success. A freshly made saturated solution of potassium or sodium hydroxide can be used on blueprints as though it were an ink, because it bleaches out the Prussian blue and leaves the white surface of the paper exposed. The effect is that of using a white ink.

275. Brownprint Process. — It is sometimes desirable to make prints on which the lines of the drawing appear blue and the background white. This may be accomplished by first making a negative from the tracing on sepia or Van Dyke paper, so called, and then using this negative, instead of the tracing, with the regular blueprint paper. In preparing sepia paper, a very thin, tough paper is coated with a solution of potassium sodium tartrate, citric acid, ferric oxalate, and silver nitrate. The composition of the sensitizer may be varied as to proportions and also as to contents. The action of the light is the same as with blueprint paper, the ferric salt being reduced as before. The precipitate formed in this case, however, is a deep brown.

To make a sepia negative, the tracing is placed in contact with the sensitized side of the paper, the ink lines being turned in next to the paper. After exposure, which must be somewhat longer than for blueprints, the sepia print is washed in water. The color of sepia paper before exposure is a light yellowish green, which upon proper exposure turns to a light bronze color.

In addition to being developed in water, which turns it a midnight brown, the print must be passed through a fixing bath of hyposulphite of sodium. This makes the print permanent and seems to make the color denser. If the " hypo " solution is too strong, it will have the effect of bleaching the print.

When the print has dried it must be " transparentized " by rubbing the back with an oil which is especially prepared for the purpose. A satisfactory " transparentizing " oil may be obtained by making a solution of white vaseline and banana oil or benzine. The oil makes the lines of the print translucent, while the remainder of the surface is left opaque. This print, which is now a negative in every sense of the word, may be used in place of the tracing. The oiled side must, of course, be placed away from the blueprint paper to prevent spotted prints and to give positive prints.

An excellent negative may be made by printing with the ink lines of the tracing away from the sepia paper, as is done when a tracing is used with blueprint paper. Such a negative has the additional advantage of being readable from the face side. It should be transparentized on the front side.

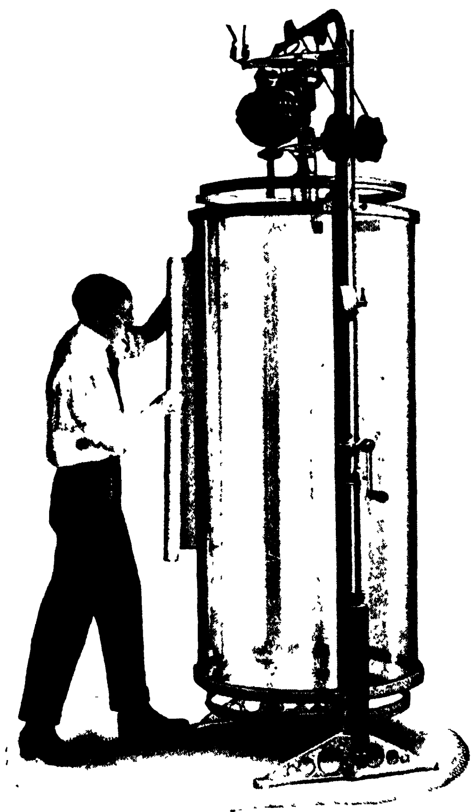
276. Blue-Line Process. — A blue-line print can be made directly from the tracing if the paper is coated with a solution of gum arabic, ammonia citrate of iron, and chloride of iron. The method of printing is the same as for blueprints. Instead of developing in water, however, the print is developed in a solution of potassium ferrocyanide. This developer acts upon the ammonia citrate of iron, which has been unaffected by the light under the black lines of the drawing, and produces a blue precipitate. After passing through the developer, the print is washed in water.

277. Ozalid Process. — A new process of reproducing drawings, called the ozalid process, was invented in Germany and introduced into the United States in 1923. This process gives a positive print directly from the tracing. The lines of the drawing come out a deep maroon color on a creamy white background. The ozalid print, therefore, possesses all the advantages of the blue-line print and has the additional advantage of being true to scale, since the process is entirely dry and does not involve the usual washing procedure with its consequent shrinking of the paper.

The ozalid process is based upon the fact that diazo-oxides are destroyed by the action of light; and on the further fact that if certain azo colors are added to the emulsion which are not subjected to the action of light, such azo colors may be permanently fixed upon the paper by subjecting them to the influence of alkalies.

The process of making an ozalid print consists of two steps, namely, exposure to light and development. The exposure is made in the same way and for a somewhat shorter time than for ordinary blueprint paper, but the development is made by exposing the print to the fumes of ammonium hydroxide (ammonia-water). Forty or fifty prints may be rolled together and developed at the same time. Five to ten minutes are required for development.

278. BW Direct Printing Process. — The black-and-white (BW) direct printing process has been developed in recent years by the Charles Bruning Company, Inc. As in the ozalid process, positive prints can be

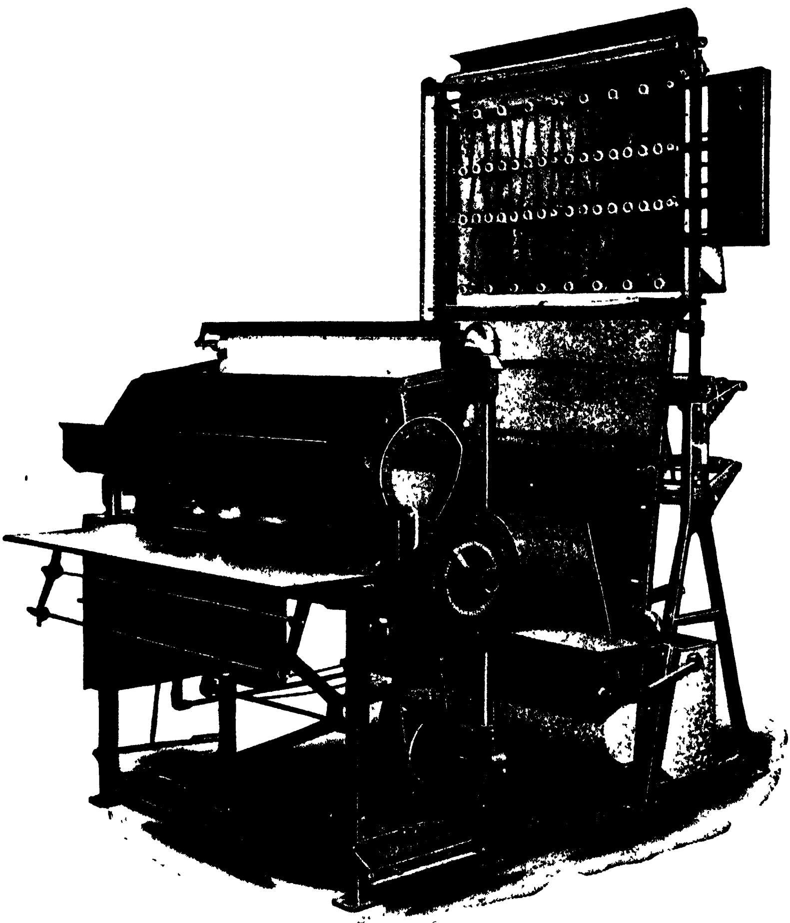


Courtesy C. F. Pease Company.

Fig. 2. Arc light blueprinting machine.

made directly from the tracing, with black, red, or brown lines on a white background depending upon which of three developing solutions is used. The method of printing from the tracing is the same as for blueprints. The chemical solution for sensitizing the paper is very complex, as is also the developing solution. Great care must be taken in applying the developer to see that exactly the right amount is used, hence it is advisable to employ the mechanical equipment perfected by the company in making prints by this process.

279. Reproducing Tracings. — It is also possible to make tracings from other tracings, by chemical means, which are identical with the original in all respects. This is accomplished by the use of a sepia negative



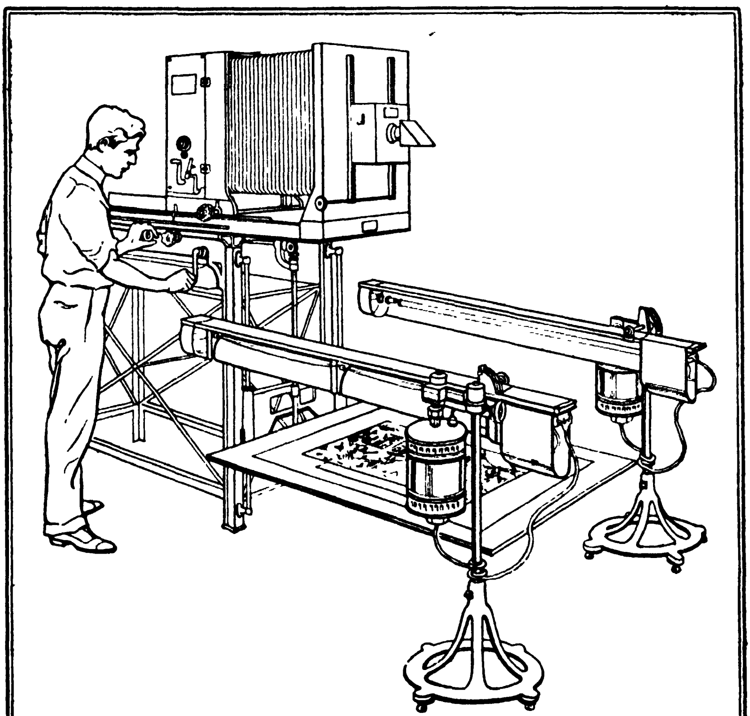
Courtesy C. F. Pease Company.

Fig. 3. Continuous blueprinting machine.

and "See Bee Cloth" sold by the American Blue Print Company of Chicago. No special apparatus is required to make these tracings, and full directions for development may be obtained from the company.

280. BLUEPRINTING MACHINES. — In every progressive office where much blueprinting is to be done, the old sun frame has been replaced by a blueprinting machine, either of the vertical cylindrical type shown in Fig. 2 or of the continuous type shown in Fig. 3. In the cylindrical type the light moves up and down through the cylinder past the print; in the continuous type the prints move past the light.

281. 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,



Courtesy Photostat Corporation.

FIG. 4. Photostat.

films, or dark rooms. 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. 4. The machines are made in several sizes, one of the larger making a print 11″ × 14″. Drawings may be enlarged or reduced within the limits of this print. This particular type of photographic reproduction is known as photostating, and the machine is called a photostat.

282. Hectograph. — Another method of reproducing small drawings, sketches, and notes is by means of the hectograph. Various adaptations of this old method, arranged in convenient forms, are now on the market under different trade names, and they are quite satisfactory where less than 150 copies are required. Such a copying pad may be made by preparing a gelatinous base, consisting of an intimate mixture of glue and glycerine in the ratio of one to four. For a 9 by 12 pad, 4 ounces of glue (flakes) and 1 pint of glycerine will be enough. Dissolve the glue in 1 pint of cold water, and when it is soft and has absorbed all of the water, add the glycerine and let the mixture come to a boil, stirring it the while to prevent burning. As soon as it comes to a boil, pour it out into a shallow pan and skim off all bubbles as it cools, so that it will harden with a smooth surface.

A special hectograph ink, carbon paper, or typewriter ribbon must be used, with a glazed paper, to make the original copy. The lines should be comparatively thin, but of uniform weight throughout, and must be allowed to dry thoroughly before using.

To make duplicates, lay the original face down upon the gelatin base, rub it firmly with the hand, to ensure a uniform contact, and allow it to remain from $\frac{1}{2}$ minute to 2 or 3 minutes, depending upon the number of copies desired. Remove the original and place upon the hectograph a sheet of unglazed paper. Rub it to ensure uniform contact and remove. As many copies may be made as desired, within a maximum limit of about 200 to 300. As soon as the copies have been made, the hectograph should be washed with a soft rag and water to remove the surplus ink. As soon as it is dry, it may be used again.

283. Line Etchings. — To reproduce line drawings in great numbers, e.g., illustrations in textbooks, the etching process is used. The drawing to be reproduced is photographed in the usual manner, the size of the negative usually being made from one-third to two-thirds the size of the original. A print from this negative is then made, by exposure to " white " light, upon a sheet of planished zinc or copper coated with a combination of shellac and bichromate of ammonium. This coating is soluble in water unless it has been exposed to the light. Hence, where the light has passed through the white lines on the negative, representing black lines on the drawing, hard metallic lines will remain on the zinc or copper plate when it is washed in water. After washing, the plate is dried and then sprayed with acid which eats away all parts of the plate except the portions protected by the hard lines. After the plate has been etched the required depth, it is scrubbed with lye to remove the hard coating from the lines which are then polished with charcoal or other similar substance to give a smooth, bright surface to receive the ink from the printing-press rolls. The plate is then mounted on a block of wood and is ready for printing.

284. Drawings for Etchings. — The drawing for an etching should be made upon a smooth-surfaced, white paper, or on tracing cloth which

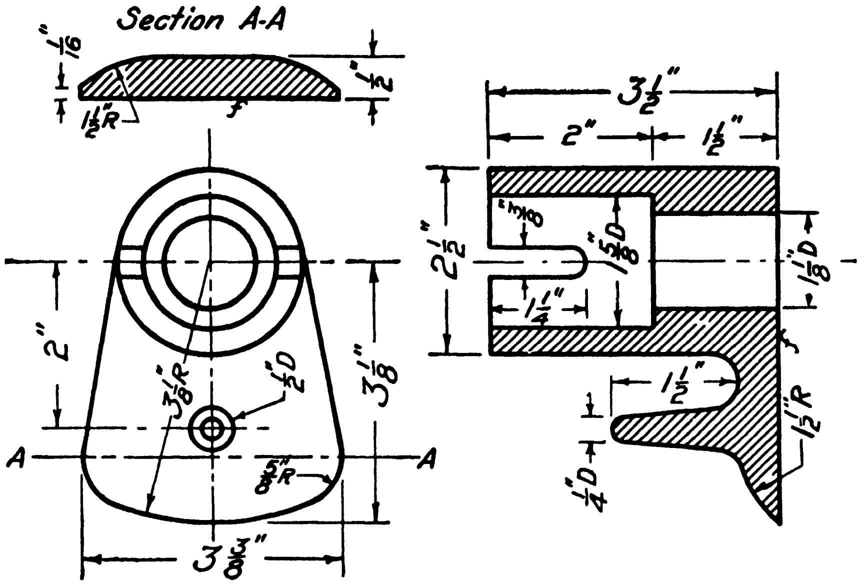


Fig. 5. Original drawing. No reduction.

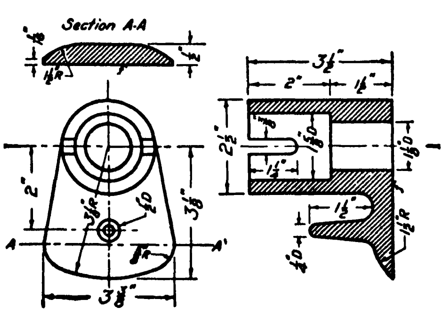


Fig. 6. Half reduction.

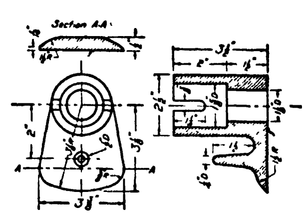


Fig. 7. Two-thirds reduction.

may be backed with white paper. The ink used should be a dead or glossy jet black. Almost any of the prepared drawing inks now on the market are satisfactory. As a rule, the drawings are made larger than the desired finished size of the etching and then reduced photographically. They may, however, be kept the same size or even enlarged. It should be borne in mind that reduction does not eliminate the faults or blemishes in the drawing. Nevertheless, in the case of one-half or greater reductions, the slight irregular waves in lettering will disappear almost entirely because of the failure of the eye to detect such small imperfections.

The weight and spacing of lines must be carefully considered. The lines themselves, except very thin ones, are reduced in width, hence the greater the reduction the heavier the lines should be made. In cross-hatching and shading, the lines should not be made too heavy or placed too close together, for if they are, a heavy black area will appear on the print. The spacing of lines should also be in proportion to the reduction. Figures 5, 6, and 7 show the effects of progressive reductions of a drawing.

285. Half-Tone Process. — The zinc or copper process, outlined in the preceding paragraphs, cannot be used to represent varying tones of black unless these are shown in pen lines on the original drawing. This can only be done by means of small dots or lines, which by their varying weight produce an imitation of tones, hence, the name *half-tone*. The half-tone process is quite similar to the etching process described heretofore, except that the original negative is made through a screen which is placed quite close to the negative. The screen is made by ruling lines on a waxed glass plate and then etching them in with acid. The plate is then cleaned and the etched lines filled with an opaque substance. Two plates are cemented together with Canada balsam, so that their lines are at right angles to each other, thus forming a screen where the light can penetrate only the little squares between the lines. The number of lines varies from 50 to 300 to the inch. The coarser rulings are used for newspaper work.

286. Wax Process. — Another method of reproducing line drawings is called typographic etching, or the *wax process*. A blackened, waxed copper plate has the drawing either photographed upon it or transferred to it by rubbing down from a tracing. The lines are then incised upon the wax, and later the space between the lines is built up with more wax. This forms a mold from which an electrotype may be made. The draftsman may also make the drawing directly upon the wax surface from a rough sketch or copy. This method, however, is not recommended, since the draftsman may not be familiar with the subject of the drawing and errors are likely to be made. Prints from electrotypes made in this way are always very uniform and neat in appearance, but they lack the life-like tone of line drawings and are more expensive. Figure 8 illustrates the character of cuts made by this method.

287. Lithographic Process. — The lithographic process is rarely employed in reproducing engineering drawings, except maps. The drawing is reproduced on a lithographic stone, either by photography or by transfer through the rubbing process, and then the prints are made from the stone or indirectly by an offset method. The stone used is a product of the Saar valley in Germany, almost the only part of the world in which it is found in suitable quantity.

Patent Office drawings are all reproduced by the photolithographic process and printed in the *Official Gazette.* This is one reason why the

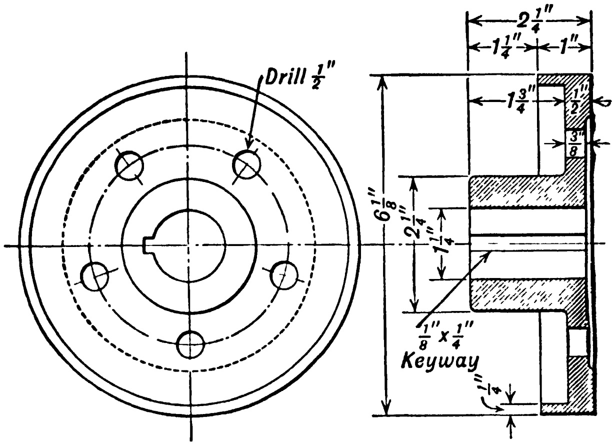


FIG. 8. Wax process reproduction.

details of such drawings are explicitly specified in the Rules of Practice of the Patent Office. The process is a very tedious and expensive one, if the drawings are not well standardized.

PART II

CHAPTER XVIII

DRAWING AND DESIGN

288. In the introductory chapter of this text, a careful attempt was made to point out the true relation of the draftsman and of fine draftsmanship to the engineer and engineering practice. It was stated that the one is simply a stage or step in progressing to the other; that drawing is a graphical medium through which the engineer expresses himself, in the same way as the written or verbal language is a medium through which he conveys his ideas to others.

Nevertheless, when the terms draftsman and engineer or drafting and engineering are synonymously used, as they often are, it must be thoroughly understood that it is the element of engineering design which differentiates the one from the other. This term, design, has been used frequently heretofore in this text, but it has been left undefined until now. Before elaborating this point, however, it should be stated that there may be, and truly is, a large group of men who practice only the art of drafting and are not, therefore, engineers, or architects in the sense that they create or design new things. This is simply because such individuals do not combine their skill and knowledge of drafting with a knowledge of the well-established principles of physics, mechanics, and other sciences; or, more precisely perhaps, they limit their field of activity to one phase of design, namely, empirical or conventional design.

289. DESIGN. — As stated in previous sentences, it is essential for the draftsman to combine his knowledge of the principles of projection and approved drafting standards with various elements of engineering design. These elements of design are commonly thought of as embodied in two main divisions, called theoretical or technical, and empirical design, respectively. Often the words "strict," "formal," or "exact" are used to convey the meanings implied in the term "theoretical," while the words "practical," "conventional," or "approximate" are used in place of "empirical."

290. Technical Design. — By technical engineering design we mean the application of known principles of mechanics, physics, chemistry, mathematics, and other sciences to given or assumed conditions of loading or applications of force, to the end that new structures and machines may be created, to meet new conditions which develop as man comes to understand the forces of nature and attempts to direct them to his comfort and use.

Such design presupposes a thorough knowledge of the fundamental sciences just enumerated. It also assumes that the direction and size of forces acting on or in the thing designed, and resulting from loads and pressures applied, are known. It further assumes that the distortion or displacement of the materials used in building up the actual machine or structure, due to applications of loads or forces, are known. In engineering language, these things are often indicated by the words " stresses and strains." Obviously, no textbook on engineering drawing should deal with any phase of technical or formal design, except in a most incidental way. This corollary, therefore, is strictly adhered to, both in the preceding chapters of Part I and in the chapters to follow in Part II.

291. Empirical Design. — In spite of what has just been said, there are certain considerations of form and convention, often inclusively expressed in the word " standards," which must be learned by the draftsman, quite apart from any formulas dealing with stresses and strains, and which are properly dealt with in books on drawing. Some of these factors are simply draftsman's rules to aid in unifying drawings turned out in different places; others result from codification of universal practices in technical design and are summed up in the term empirical design. So completely have these customary practices been standardized and thereupon conventionalized to a large extent in symbolic drafting, that it is imperative that both the engineer and the draftsman become fully acquainted with them. The use of the term " empirical design " in the restricted sense implied in the foregoing, does not, of course, exclude that type of design in which empirical formulas are used, although, for the purposes in mind in preparing this text, such design is more properly called " technical design."

To clarify these phases of empirical design to which we are to direct our attention, and to bring out the draftsman's relation to them, a few references will serve:

Clearances. — The assembly of the various members of a structure on a pin, the arrangement of moving parts on shafts, the free space for installations of electrical and mechanical equipment, have to a greater or lesser extent been reduced to a set of empirical rules, which, of course, represent the results of long experience with, and observation of, the practical workings of good technical design.

Rivet Spacing. — In spacing rivets in standard structural forms, gage lines have been established for each size of flange; and rules have been laid down as to the size of rivets and the minimum distance from the edges of any plate at which they may be placed. These empirical rules are published in the various standard engineer's handbooks, with which every draftsman and engineer should be familiar.

Shop Methods. — Economical methods of handling the shop work on any piece of design must be known and kept in mind by the draftsman and engineer when the drawings are being prepared, in order that expensive shop operations may be eliminated as much as possible. Of still more importance in many respects is the question of whether the job can be done at all, if certain shop standards are not complied with in the drawings. Too often, drawings have to be sent back from the pattern shop because provisions for parting lines have not been made, lugs and bosses are improperly placed, and other simple details have been overlooked, which make the mechanical operations in the shop impossible. These considerations apply, of course, to all design, but they are cited here to emphasize the fact that to the draftsman they should be more or less empirical rules.

Building Details. — Akin to standard shop methods are those practices which have become universal in structural work, such as kind and type of lintels for various sizes of windows, ratios of thickness to height of wall, thickness of mortar layers for various purposes, and similar details too numerous to mention.

292. Art in Engineering Design. — Another phase of design which the draftsman must be able to interpret and present in his drawings, when occasion demands, is the element of beauty, a quality which the designer should strive for constantly if his machines and structures are to compete on even terms with those of other designers. In other words, the drawings must sell the designs. This is a well-understood principle in the design of buildings and monumental structures, and the architect employs every skill and artifice at his command to make his drawings present a pleasing impression of the proposed structure. Obviously, perspective drawings lend themselves most readily to treatments that bring out the details of form, color, and proportion most desired. However, single orthographic elevations and plans may be so handled by the skilled draftsman or artist as to impress the observer both with a feeling of the beautiful in the design and an understanding of its details of proportion and form, at one and the same time. An example of the use of perspective drawings for the purpose indicated is to be found in Fig. 3, page 382. The use of an elevation for this same purpose is illustrated in Fig. 1 below, where the beauties of a simply constructed entrance are brought out effectively.

In preliminary studies of the possible design of any kind of engineering structure, however, and in the sales appeal that must be developed if the design is to be approved and the machine or structure built, the factors mentioned in the preceding paragraph must be used frequently. Modern advances in construction such as welding, pressing, and the large number of methods of finishing have made it possible for the engineer-designer to consider the artistic phases of his creations without the restraint that old methods imposed. Many companies now employ expert art advisers in

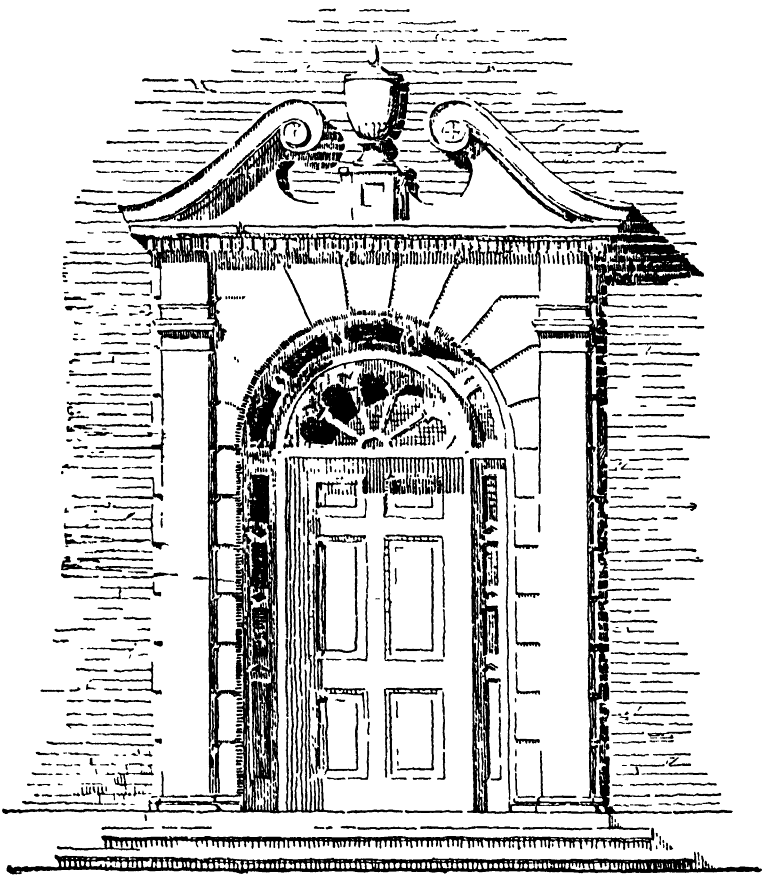


FIG. 1. Rendered elevation of an entrance.

their design offices to assist in the incorporation of every element of beauty that the limits of construction and economics will permit.

Drawings of engineering designs do not lend themselves so readily to drafting-board treatments as do architectural drawings, since probably 90 per cent of engineering designs are outright production drawings, where clearness, accuracy, and cheapness are the prime requisites. Even here it may be shown that something is gained in considering the good and bad effects produced by the drawing itself.

The scope of this text does not permit the inclusion of a discussion of the numerous artistic factors that enter into the actual design of an engineering structure. Only those elements that make the *drawings* of the structure artistic, and thereby convey the ideas of the designer more readily to the observer, are treated in the following paragraphs.

293. Art in Working Drawings. — Those elements of beauty described by the words uniformity, contrast, balance, and symmetry may be embodied in working drawings just as truly as in any work of art, and, in fact, such drawings may be considered good or bad, to a very considerable degree, in the measure they reveal these four qualities. They are discussed briefly in the following paragraphs.

Uniformity. — Line work of any one type, for example, the visible outline, should be uniform in weight and character throughout the drawing. The contrasts of Figs. 2 and 3 serve to emphasize this point. The pleasing

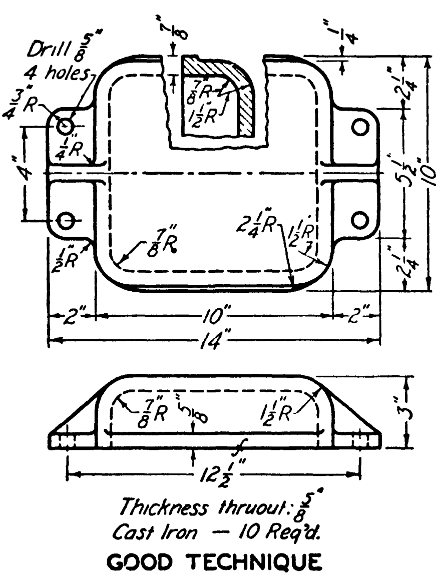


Fig. 2. Good effect secured by contrasting weight of lines.

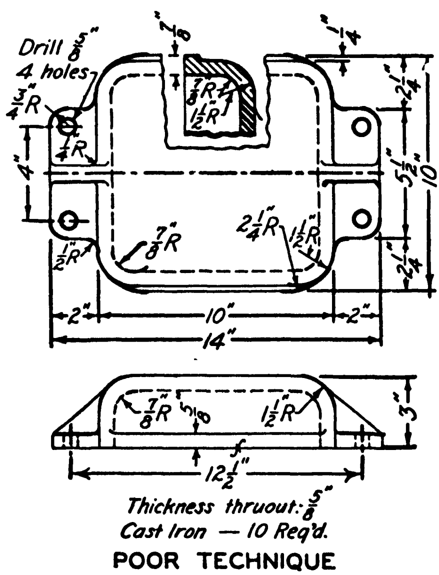


Fig. 3. Poor effect due to insufficient contrast in weight of lines.

effects and clear readability of the drawing of Fig. 2, attained almost wholly through uniformity in weights of lines used for the same purpose, are lost entirely in the second drawing, where little attention is given to this particular quality of beauty. It should be noted, however, that to give this appearance of uniformity, an actual difference in weight of lines must be made where the details are small as, for example, where screw threads, small pins and keys, and similar devices appear.

Contrast. — The artist's work is frequently discussed in terms of tones, meaning, in engineering terms, the varying degrees of density of lines made with the drawing instrument. For good work the tones should be distinct and few in number. Three tones are usually considered the optimum in art work. With more tones, greater and greater skill is required on the part of the artist to secure equally attractive work.

Likewise in engineering drawing three weights of lines are considered to give the most pleasing effects. These three weights should be quite distinct. Heavy outlines for visible parts of the object, medium weight for invisible outlines, and light lines for dimension lines, center lines, and cross-hatching give the most pleasing results. See again Fig. 2 above, and also Fig. 19, Art. 60, page 51.

Balance. — In art work a drawing may be balanced in various ways, but, in engineering drawing, balance is most usually attained around a center line. Simply expressed, the unused or white areas of the drawing sheet should be balanced, that is to say, there should be just as much unused area at the top as at the bottom of the sheet, and as much on the right side as on the left. Care in arranging dimensions, notes, and leaders around the several views will help to give balance and hence beauty to the drawing sheet.

Symmetry. — In engineering drawing, the element of symmetry finds expression chiefly in the location or balancing notes, titles, legends, etc., because the object itself cannot be varied to meet artistic requirements of the drawing sheet. Much, however, can be done by the judicious placing of notes and legends about the views, by sloping leaders in parallel or opposite directions, and in other ways suggesting the quality of symmetry, not only of the drawing sheet but also of the object itself. Carried to near perfection by a skilled draftsman, the quality of rhythm will seem to be imparted to the drawing as well as to the object itself.

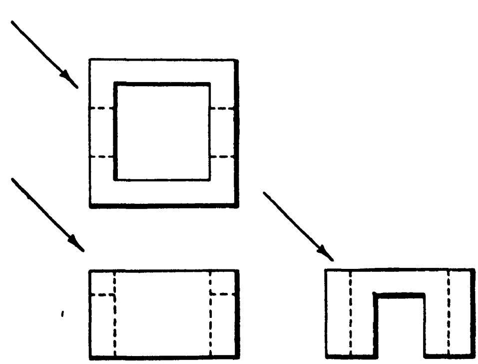


FIG. 4. Shade lining.

294. SHADE LINING. — To the unexperienced layman, engineering drawings frequently appear as flat geometric figures. Drawings which are intended for his use may be given the appearance of depth and three-dimensional solidity by *shade lining* the orthographic views, that is, by making heavier the lines which represent the edgewise views of surfaces that are in the shade. The light is arbitrarily assumed to come from the upper left-hand corner of the sheet at an angle of 45 degrees for each separate view. Figure 4 represents a simple object in which the shade lines have been properly accentuated. It will be noted that this has the general effect of making each view an oblique drawing, with the scale on the receding axis very small. The additional weight of line is usually put on the outside of the original line on solid bodies and on the inside of openings. Circular parts are given a varying weight by simply shifting the center of

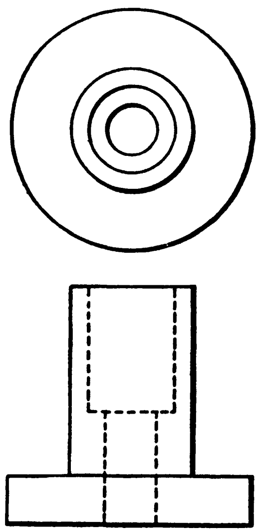


FIG. 5. Shade lining circular object.

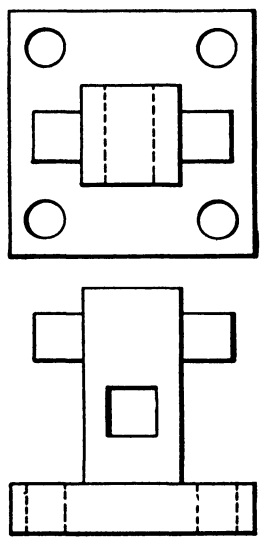


FIG. 6. Shade lining.

the circles along a 45 degree line as illustrated in Fig. 5. Figure 6 illustrates the effects in a drawing combining both circles and straight lines. Shade lining is adaptable only to orthographic views.

295. Ruled-Line Rendering. — Orthographic *views* may also be made to suggest the depth or solidity of the object by bringing out the varying degrees of light and shade which the object would possess if placed before the observer, and assuming the light rays to strike the object from over his left shoulder, by means of straight or curved ruled lines of varying weights and spacings. With orthographic views the treatment is, of course, purely artificial but, none the less, effective. See Fig. 7. By representing the rays of light projected in the usual way upon the drawing, the theory of line rendering may be worked out upon the principles of orthographic projection. The basic rules are briefly stated in the following paragraphs.

All objects are visible to us by the light which they reflect, and it may be stated as a general principle that the surfaces of an object are shaded in accordance with the amount of light which they reflect, the brightest area being made white and the darkest being represented by heavy rulings.

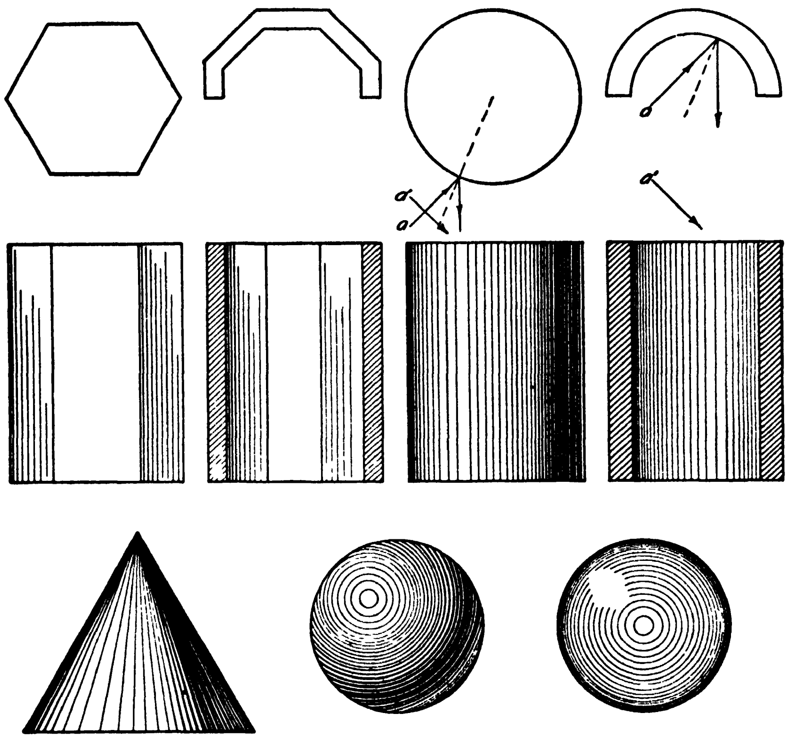


FIG. 7. Ruled-line rendering.

The varying degrees of shade may be obtained in two ways, i.e., by drawing lines of uniform weight and changing the spacing, or by changing both the spacing and the weight of lines. The latter method gives the most brilliant effects. The light is always assumed to come over the draftsman's left shoulder, as indicated by the arrows *a*′ and *a* in Fig. 7. Important exceptions to the general principle are stated in the next paragraph.

For illuminated, flat, inclined surfaces, which presumably reflect light uniformly, the general principle is modified and the portion of the surface nearest the observer is made light, with a gradual increase in the density of the shading as the surface recedes Likewise, for unilluminated, flat surfaces which would be uniformly dark, the rule is modified and the nearest portion is made dark with a very slight but gradual diminishing of the density of the shade as the surface recedes. Both these rules are exemplified in the hexagonal prism in Fig. 7.

For cylindrical, conical, or spherical surfaces, the brightest portion of the surface is on the line or point of direct reflection. The location of this line on the cylinder is shown in Fig. 7. The shading is increased in density in both directions from this line. The darkest part of a curved surface is placed along the line of tangency of the rays, although one would ordinarily suppose that the reflection from the parts beyond would be even less. Instead, however, the density of the shade is slightly reduced beyond the tangent line as shown in Fig. 7.

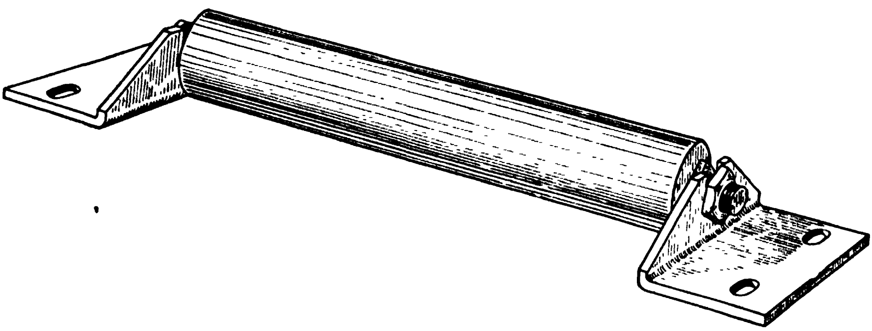


Fig. 8. Ruled-line rendering.

The same type of rendering may also be applied to pictorial drawings with even greater effectiveness. Here the shading is more naturalistic. It may be either ruled straight-line elements of the surface or curved elements, as conditions dictate. Figure 8 illustrates the practice. It is obvious that this type of rendering is best suited to surfaces that are finished or at least very smooth. If the object is drawn freehand, then the rendering should also be done freehand. The direction of light may be assumed at pleasure to produce the best results. Reference to the problem sections of previous chapters will illustrate the type of rendering appropriate for those kinds of drawings.

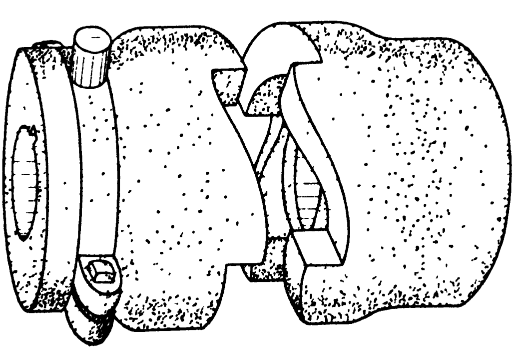


Fig. 9. Hand stippling.

296. Stippling. — Another method of rendering which may be applied to either orthographic or pictorial drawings is that of producing the effects of light and shade by means of varying densities of dots. These dots may be produced in a variety of ways. They may be put on the drawing freehand with pen as shown in Fig. 9, or they may be produced by the use of a screen and brush, with mats to protect the parts of the drawing which are not to be stippled.

The technique of stippling freehand with pen or pencil needs no particular discussion. Skill in the proper placing of high lights and the varying degrees of shade can be acquired by observation of good examples of drawing or, better still, by an observation of properly lighted objects themselves. The light should be controlled so that it comes from one source only in order to avoid confusing shades and shadows. This method of rendering is peculiarly well adapted to objects whose surface textures are rough or mottled, like cast iron, for instance.

296a. Combination of Line and Stipple Rendering. — The two methods of rendering described above are very effective in combination when used on drawings of objects like that represented in Fig. 10, where both rough and finished surfaces are involved. The contrasts between

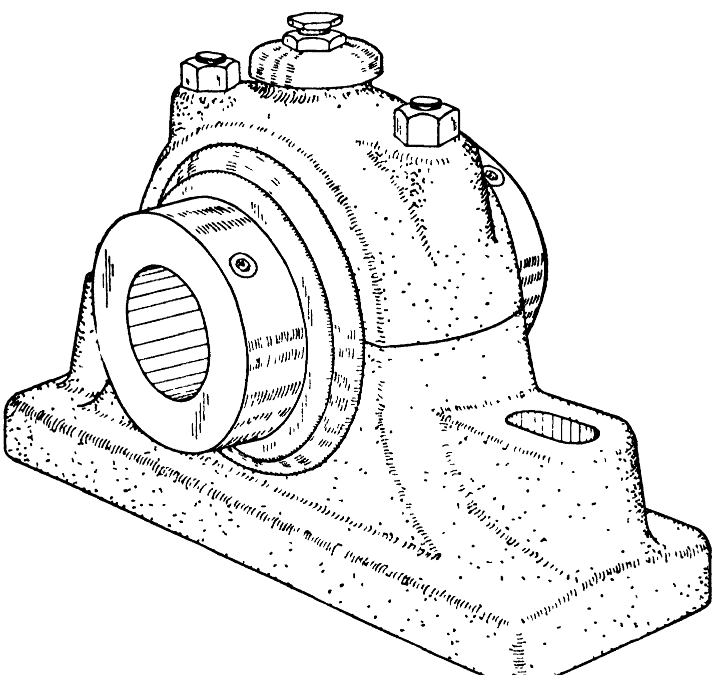


Fig 10 Combination of line rendering and stippling.

surfaces are emphasized, and the tonal effects from assumed lighting are satisfactorially maintained. It should be noted, however, that ruled-line rendering is less effective in showing lighting effects on rough surfaces than stippling, but it is very useful in bringing out highly polished surfaces that would otherwise remain indistinct.

296b. Pencil Rendering. — When an object has been sketched in some form of pictorial drawing with a pencil, the drawing may be rendered very acceptably and rapidly by use of pencils in the manner shown in Fig. 11. Here the gradations between the strongly lighted areas and those receiving small amounts of light are represented by the

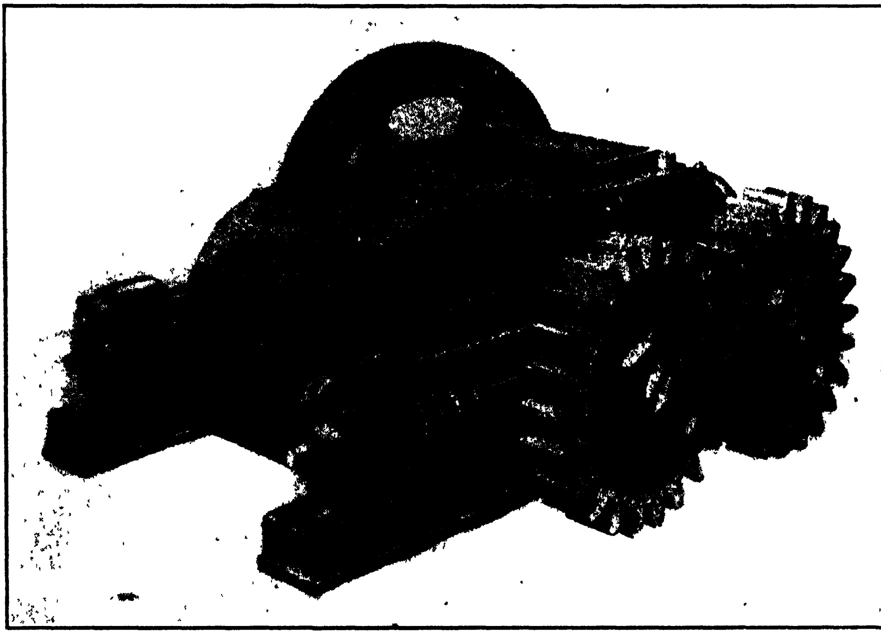


Fig. 11. Pencil rendering.

application of more or less lead from the pencil, either by a greater number of strokes on a given area or, better still, by the density of the lead applied with each stroke. This latter effect can be best obtained by using pencils of different hardness. A satisfactory set of pencils for rendering work consists of six in number, ranging in hardness from a 2H, medium hard, down to 4B, very soft and black.

The hardest pencil may be sharpened to a conical point and used for preliminary outline sketching. The soft pencils should be sharpened to a bevel point. The oval area on the point should be used for rendering broad areas, and the sharp edge at the point may be used for finer work. The selection of pencils to use on any particular piece of work depends upon the roughness and "tooth" of the paper.

In general, the smoother papers are used for small drawings because it is possible to show small details on such paper. Rough papers are used for larger drawings, especially where extreme detail in delineation is unnecessary. Many artists prefer white, smooth surface, bristol board to all other papers for general pencil drawing.

Best results are obtained in tonal gradations by stroking the pencil in one general direction only. Working the pencil back and forth in contact with the paper in both directions tends to make the drawing smeary and, therefore, is not recommended. The deliberate smudging of a drawing with an eraser or finger tends to impart a dirty appearance, and the practice should be avoided.

While working on the drawing, smudging can be prevented by keeping a sheet of paper under the hands and arms in contact with the paper. The drawing should be permanently protected, when finished, by spraying it with a thin clear shellac and alcohol preparation called *fixatif*.

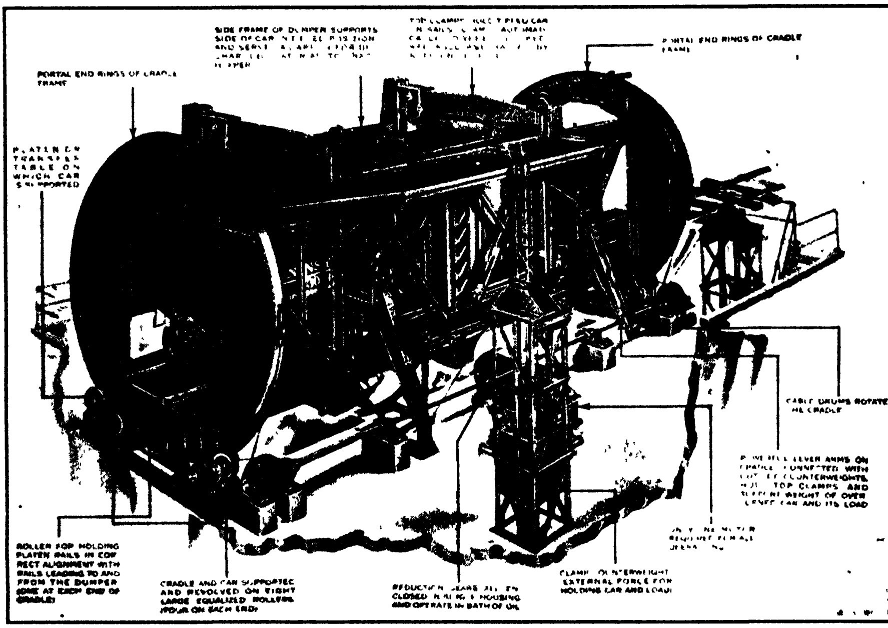
An error frequently made by beginners, is in representing edges of the object by distinct lines much darker than the surfaces which meet at the edges. The practice of outlining should be followed when it is the only means by which necessary detail can be shown. The outlines drawn preliminary to the rendering should be sketched lightly. A better means of showing edges is by abrupt changes in tone. In Fig. 11, it may be noted that high lights may be used effectively to represent the edges of the object.

Another common fault of the novice in pencil rendering is the tendency to draw everything in black, when a truer and more pleasing picture would be presented if the well lighted parts were shown by leaving them white or very light against a dark background, this background being a darker rendering of other details in the picture.

A pencil drawing can be given character by exaggerating the contrasts between the light and dark areas. This act of making the light areas lighter and the dark areas darker than they actually are, is termed " forcing the values " and is very effective in adding life, snap, and sparkle to a drawing.

Limitations of space make it impossible to treat the subject of pencil rendering thoroughly in this text. The technique of representing various shapes and textures is not an exact science. No two artists would treat the same subject in exactly the same way. Possible ways of representing various common things such as grass, trees, brick surfaces, clouds, etc., may be found in the excellent works on the subject listed in the bibliography of this chapter.

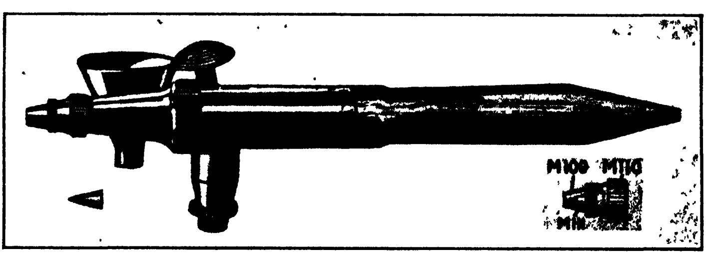
297. AIR-BRUSH RENDERING. — Drawings and photographs for reproduction can be given very pleasing effects by means of successive sprays of atomized ink applied with an air brush. The ink is drawn from an inkwell by means of the suction action of compressed air flowing through the nozzle of the brush under the control of the operator. As in the screen-brush method of stippling, mats must be provided to cover portions of the drawing while other parts are being sprayed. Figure 12 illustrates what



(*Courtesy of Link Belt Co.*)

FIG. 12. Air-brush rendering.

may be done with the air brush in bringing out various degrees of shade on a photograph used for advertising purposes. This figure also shows how ruling-pen work can be used to good advantage in designating certain



(*Courtesy PaascheAirbrush Co.*)

FIG. 13. Air brush.

details of the object. Reference should also be made to Fig. 3*a* of Art. 120, where photography, air-brush treatment, ruling-pen work, and the artist's pen have combined to make the so-called phantom drawing a real sales agent for the designer. Figure 13 shows one type of air brush which is very effective in general utility work.

298. Designer Versus Draftsman. — From what has been said in the foregoing paragraphs of this chapter, it is clear that before the would-be engineer can become a full-fledged designer, he must thoroughly acquaint himself with the scientific principles underlying technical design, so called. He must also have a good understanding of the principles which

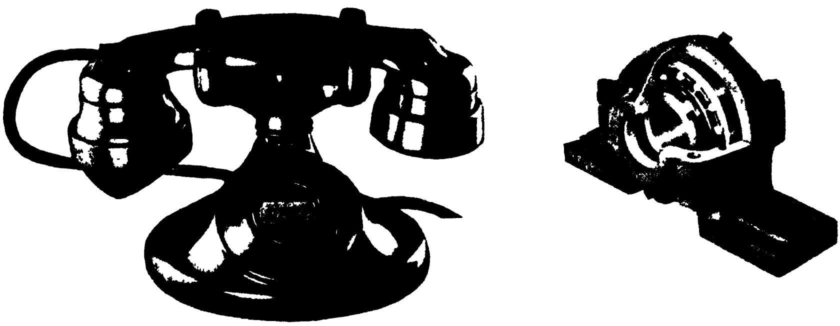


Fig. 14. Beauty embodied in technical design.

contribute to the quality of beauty in his designs. The two factors are by no means antagonistic in planning the general form and details of any machine or structure. Nevertheless the quality of beauty is too often neglected by the engineer-designer, so that in some large companies a specially trained person of artistic abilities is attached to the design office to assist the designers, draftsmen, and constructors in bringing out every possibility the product offers for pleasing the artistic sense of the public at large. Figure 14 illustrates the care exercised in this respect with everyday articles of use.

On the other hand, the draftsman need not understand the principles of technical design, but he must be quite familiar with the rules of empirical design, which, of course, fit harmoniously into the general design procedure. The draftsman must not only understand the principles upon which the artistic qualities of a design depend, but he must also know how to bring out these qualities on the drawings he makes by means of the devices presented in previous paragraphs of this chapter, and by other schemes of rendering which are used effectively by architects and artists.

The purpose of the following chapters is to present those phases of topographical, architectural, structural, machine, and other specialized drawing which are properly limited to the fields of drafting and empirical design, and which offer opportunity to develop the artistic attributes of drawings to a considerable degree. The correlated subjects of chart and diagram drawing and nomography are treated at some length. Questions of technical design are omitted almost exclusively, although definitions and glossaries of terms used are included.

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CHAPTER XIX

CHART AND DIAGRAM DRAWING

299. Broadly, all graphical representations may be divided into two primary groups: first, those showing the shape, size, and material of any tangible thing, such as a machine or geometric form; and second, those showing facts, statistics, and laws, where a line, area, or volumetric symbol drawing is used to present a visual tabulation of the related facts and data. The first group is called pictorial or projection drawing, and has been studied already in previous chapters, under the headings of Orthographic, Isometric, Oblique, and Perspective Projections. The second group is called chart or diagram drawing, and is a kind of drawing which is non-projective in character. Charts and diagrams represent facts and the relationship between facts, rather than the size and shape of objects. Such drawings are finding an ever-wider field of usefulness, not only in technical engineering and scientific work but also in industrial management and sales service.

Judgment, based upon a knowledge of the uses of charts, is required to select the proper kind of chart for any particular problem which may confront the engineer or business man. Skill in drawing is required to make a chart accurate and readily readable. It is our purpose here to classify the more common types of charts and diagrams, explain their uses, and discuss the drafting problems involved.

300. CHARTS AND DIAGRAMS. — Figure 1 represents several types of technical charts and diagrams. The name of the class of chart or diagram of which each cut is a typical example is given in the following table in the order of the cut numbers.

1. Plane Curves — drawn on coördinate papers.
2. Line, Area, and Volume Diagrams and Charts.
3. Map or Distribution Charts and Diagrams.
4. Graphic Statics and other Vector Diagrams.
5. Nomographs, or Alignment Diagrams.
6. Three-Dimensional Charts and Diagrams.

It should be emphasized that, although the illustrations used are taken from technical fields, it would have been as easy to find illustrations in social, religious, and other realms for the first three diagrams. The last three of the group apply almost exclusively to technical or scientific work. It should be pointed out further that, as far as everyday use is concerned, the words *charts* and *diagrams* are synonymous.

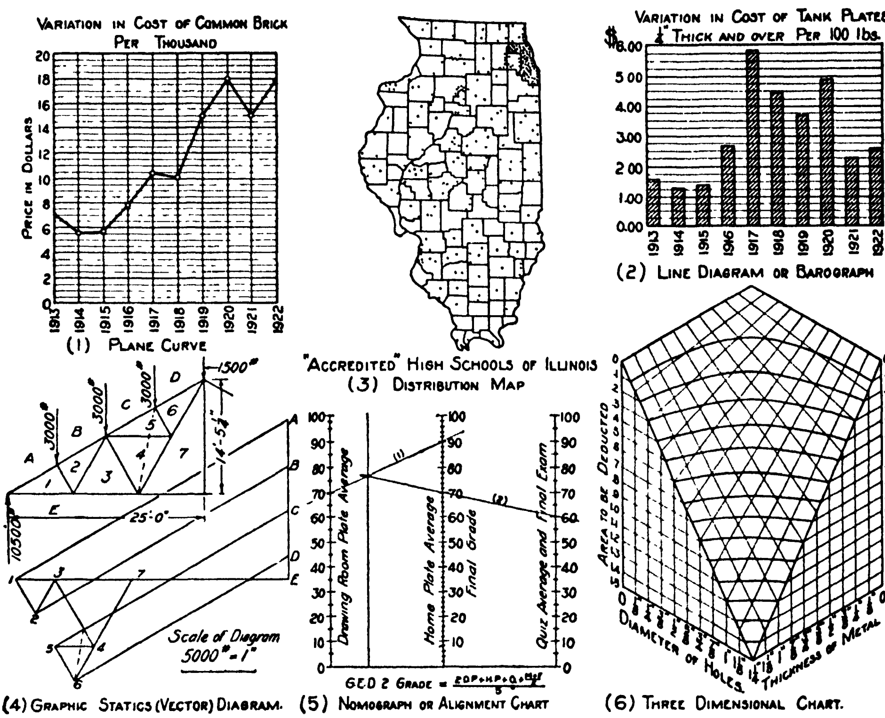

Fig. 1. Typical charts and diagrams.

The first named three diagrams of this table are of special interest to us in this text, since they deal with simple everyday laws and statistics. The last three require an intimate knowledge of mechanics and mathematics on the part of one who studies them understandingly, and, consequently, are here given space sufficient only for definition and illustration.

Two additional types of great importance are represented in Figs. 27 and 28, the first being known as an *Organization Chart* and the second as a *Flow Sheet.* They are quite alike in appearance and principle of construction.

Finally, a group of charts known as *Computation Charts* is illustrated in Fig. 9. These charts are usually composed of sets of plane curves or straight lines, but differ from the ordinary plane curve chart in the use made of them, as will be developed later.

301. Plane Curves. — The term plane curves includes those diagrams or charts which express graphically, by means of one or more continuous lines on coördinate paper, the known relations existing between two or more variables, such as time and distance, time and velocity, or pressure and volume. Because of this graphic quality of representation, they are often called graphs, especially by mathematicians. The graph proper may be a single straight line, a simple curve, a continuing series of straight lines or curves, or, in a few cases, a combination of both. See Fig. 2.

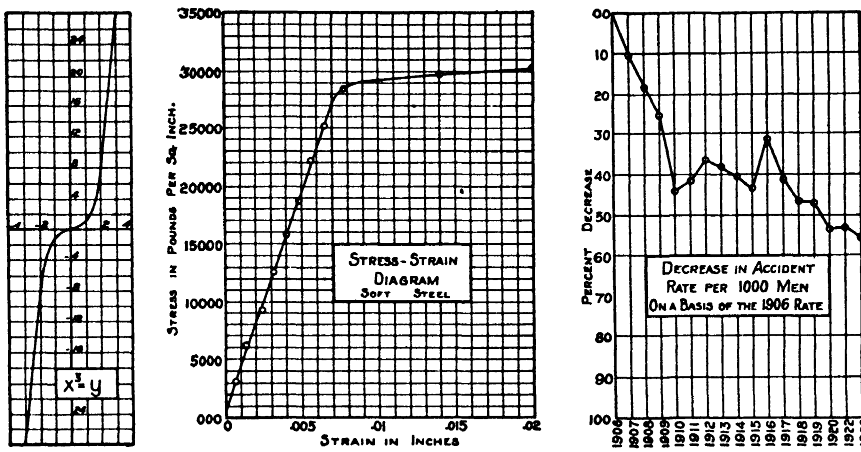

Fig. 2. Types of plane curves.

The usual graph is obtained by plotting or locating on coördinate paper a series of points which represent successive and simultaneous values of two variables. These simultaneous values of the variables are shown by the respective distances of the plotted points to two coördinate axes, often called the X- and Y-axes. The graph line is drawn through, or approximately through, the various plotted points. Just how the graph line shall be drawn must depend upon the uses to be made of it, which uses will be discussed later.

The simultaneous values spoken of in the preceding paragraph may be derived by successive solutions of an algebraic formula containing two mutually interdependent variables, where values of one variable are assumed and substituted in the formula, and the corresponding values of the other are computed; or they may be obtained by taking readings on tests conducted in the field or laboratory; or by observing natural phenomena. Figure 2 illustrates each of these types of curves.

302. Coördinate Papers. — To facilitate the numerous measurements which have to be made along and perpendicular to the axes, and to obviate the use of the measuring scale altogether in many instances, sheets of paper called coördinate (cross-section in the trade) paper can be purchased, already ruled or printed with horizontal and vertical lines which are some convenient unit of measure apart, such as one-tenth, one-hundredth, or multiples of one-sixteenth of an inch. Radial and circular rulings are also made. Figure 3 shows a few common types of coördinate papers. They

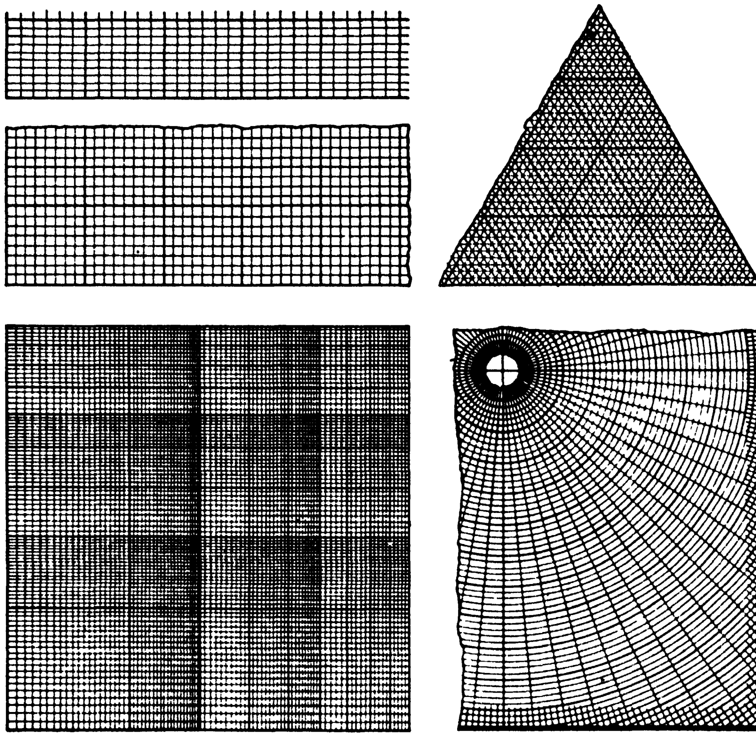

FIG. 3. Typical coördinate papers.

may be obtained in several colors of ink and in various weights and grade of paper.

The great majority of curves are drawn upon rectangular papers, although the other forms find wide usage for special purposes. Thus, for example, polar coördinate paper is used extensively in automatic recording devices, in illumination charts, and for equations written in polar coördinate form. Figure 4 shows a typical recording chart in which the lines radiating from the center are circular in order to prevent error in the " time of day " readings of the recording pen which is pivoted on a fixed center instead of sliding in a radial groove. It would be necessary for the pen to slide were straight radial lines ruled on the chart.

Logarithmic paper is very useful in plotting curves from experimental data since such curves will reduce to straight lines upon this paper, if the equation of the curves is of the exponential form $y = mx^a$, a fact of great assistance in determining the equation represented by the data. See Fig. 30. Semi-logarithmic paper is useful where the rate of change is of

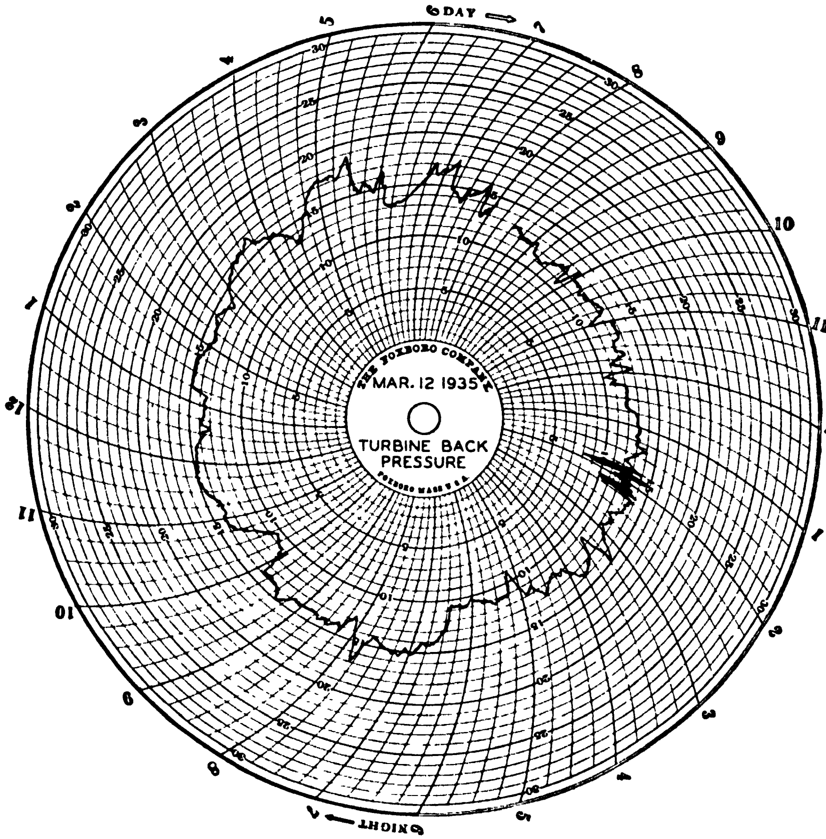

FIG. 4. Polar chart.

primary interest rather than the actual numerical change. See Fig. 29. This paper is also called " ratio " paper, and will be spoken of in detail later.

303. Locating and Marking of Coördinate Axes. — Referring again to Fig. 2, it should be pointed out that the intersection of the coördinate axes is called the origin, or point of zero coördinates. Usually the lower left-hand corner of the hand-ruled sheet is selected as the origin. The bottom line then becomes the X-axis and the left-hand line the Y-axis. All plus values of X are measured to the right of the Y-axis, and all plus values of Y are measured above the X-axis. See Figs. 2 and 11. If there should be negative values of either X or Y, then the axis affected should be moved up or to the right, as the case may be, to allow for the plotting of these negative quantities on the opposite side of the axis to the plus values. In such a case, the position of the axes should be indicated by heavy, black lines drawn over the regular coördinate lines. In fact, it may be of advantage in many instances to show the axes in heavy, black lines even though they coincide with the outside coördinate lines on the sheet.

Measurements along or parallel to the Y-axis are called ordinates; measurements along or parallel to the X-axis are called abscissas. Hence, the distance of a plotted point above or below the X-axis is called the ordinate of the point; the distance of a point to the right or left of the Y-axis is called the abscissa of the point. The ordinate and abscissa, when referred to together, are called the coördinates of the point.

It will be noted, in using the commercial coördinate papers, that heavier rulings occur at regular intervals, such as at every tenth line, for instance. See Fig. 3 or Fig. 6. These coördinate lines are usually the only ones that are marked with numbers to indicate their distances from the zero axis. These numbers are not usually in terms of inches or millimeters and the like, but are in the units which the particular axis has been assigned to represent. For the Y-axis, these numbers should be put at the left of the vertical line representing this axis, as a general rule; for the X-axis they should be put just below the horizontal line representing this axis. However, there may arise cases where the procedure of putting the markings inside the lines is convenient or necessary. This condition may occur when negative quantities are being plotted, or when the margins are small on the coördinate paper. If the curve passes over a large share of the paper and the paper itself is large, it is well to put the coördinate markings at both sides of the sheet and at the top and bottom.

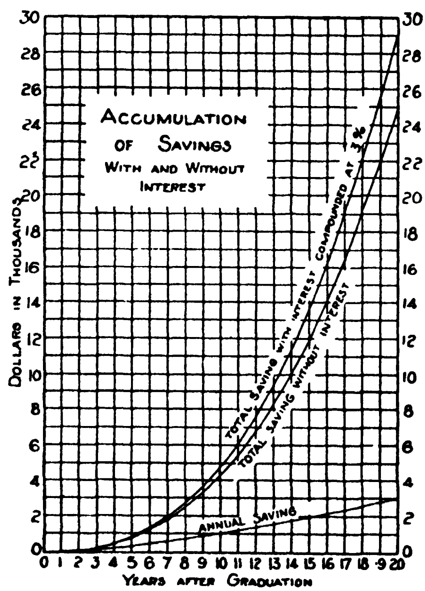

Fig. 5. Marking coördinates.

In addition to the numerical markings, there should be added, outside and parallel to them, a descriptive phrase telling what quantities the numbers represent, such as "Discharge in feet per second," "Time in minutes," etc. See Fig. 5. Where the paper has been cut from rolls, it may be well to add border lines to the sheet to give it a finished appearance. This is often done even on the standard-sized sheets of coördinate paper. See Fig. 6.

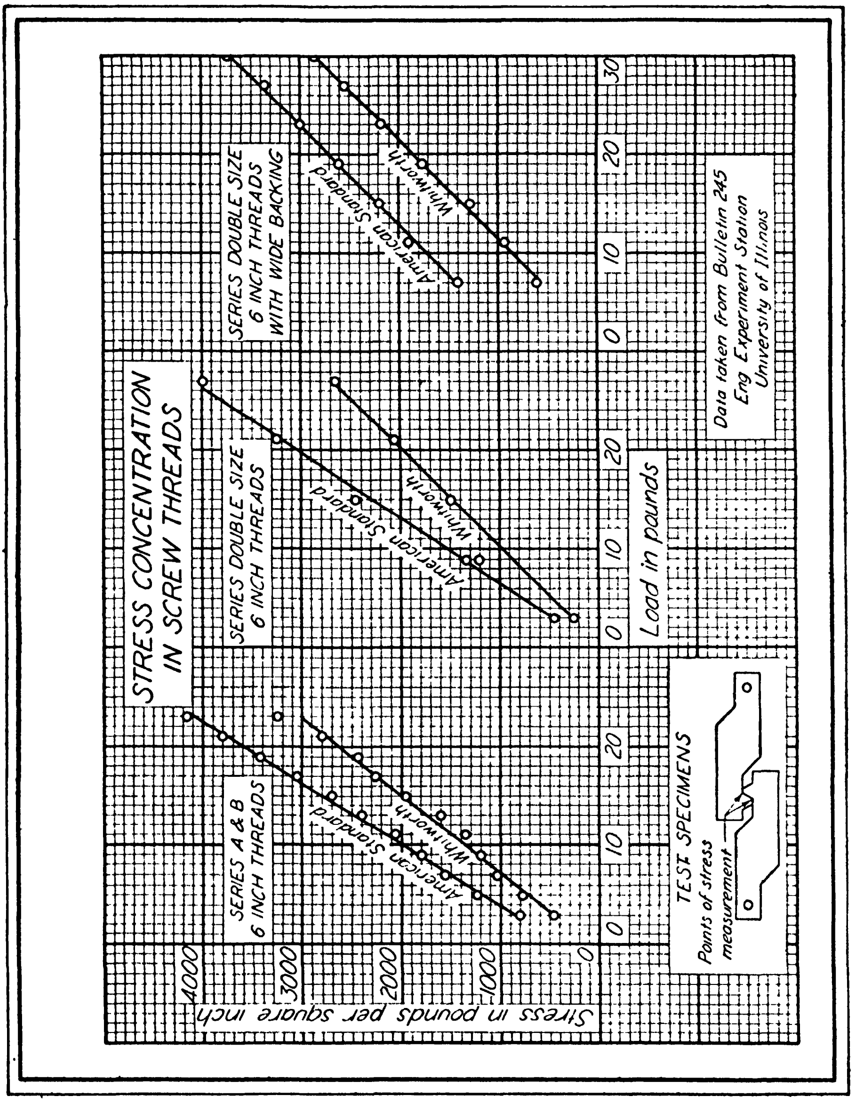

Fig. 6. Hand-ruled paper. All lettering should be within printed area on commercial papers.

When commercially prepared coördinate papers are used, it generally proves more satisfactory to select coördinate axes that are set in from the border lines even though negative values are not involved, because there is seldom room in the margins for the scale markings and the necessary descriptive phrases. Several sets of axes may even be drawn on a single sheet.

Open spaces for titles and legends cannot be made readily on these papers, but such spaces can be provided where the draftsman rules his own papers, or they can be made on commercial coördinate cloth by removing the ink lines with alcohol and a clean cloth. Figure 6 shows the technique employed in drawing on these papers in the way described, using in this instance a hand-ruled sheet.

If it is desirable to begin the lowest vertical coördinate, for instance, at a value considerably above zero, then the bottom line should be made

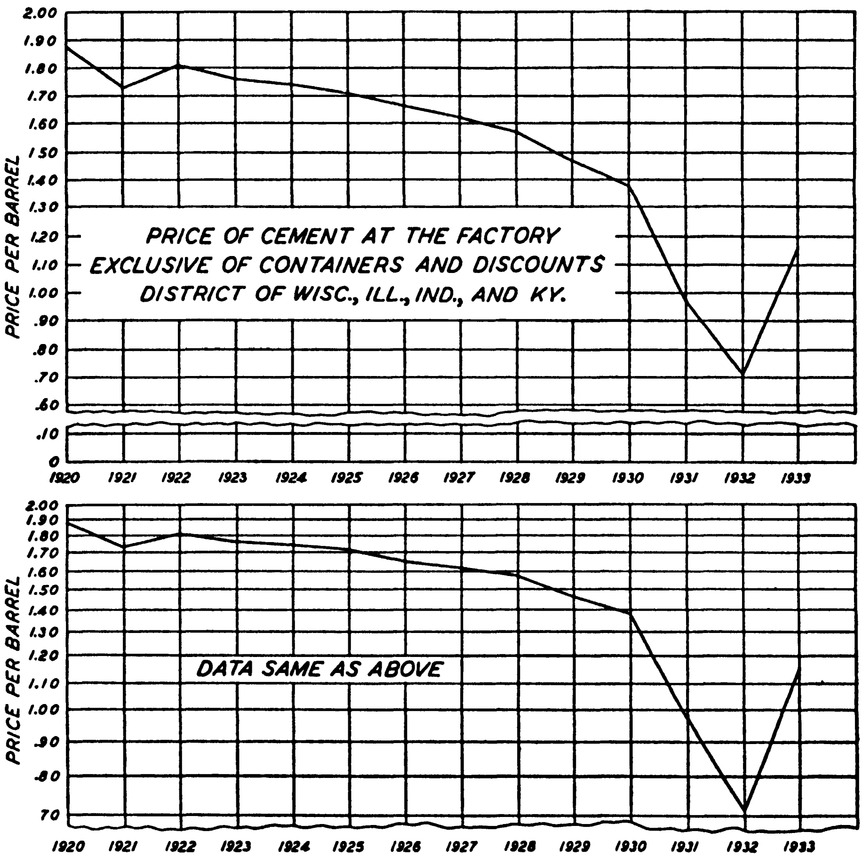

Fig. 7. Methods of indicating zero ordinate.

slightly wavy; or, better still, it should be left as the original zero ordinate, and two rough lines drawn horizontally across the paper just above the bottom line, to indicate the omission of intermediate coördinate lines. See Fig. 7.

304. Indicating Plotted Points. — The particular methods of representing the plotted positions of the numerous individual sets of values of the variables on the coördinate paper, is, of course, somewhat empirical, but long usage has given sanction to the simple dot or circle wherever plottings are for one set of data only, or where no confusion will arise even though several curves are drawn on a single sheet of paper. Squares, triangles, crosses, and other signs may be used to keep several sets of data apart. In special instances, different-colored inks may be used for the different sets of data, in which case the same colored ink should be used in drawing the curve as was used in plotting the corresponding points.

The plotted points used in drawing the curve should always show in the finished drawing if the data from which they are derived were obtained from tests or from observation of natural phenomena. Plotted points should not be shown when they are derived from a mathematical equation, since points on the curve can always be derived from the equation by computation. They are left on the curves of Fig. 11 simply for purposes of illustration. Plotted points may also be omitted when the graph is simply a series of straight lines intersecting at these points, as illustrated in Fig. 7.

305. Selecting Coördinates. — When the variables are expressed in terms of X and Y — the generally used letters for unknown or variable quantities in algebraic formulas — the X-axis is taken horizontally and the Y-axis vertically, as has been explained.

When the variables are not expressed in terms of X and Y but are given in such terms as velocity in miles per hour, cubic feet per second, and the like, the selection of coördinate axes should be based upon the following rule:

> Plot values of the *independent* variable along the horizontal axis in all cases, unless weighty reasons make the reverse procedure necessary or desirable. The *dependent* variable will, of course, be placed on the vertical axis.

The general principle of coördinate selection, just given, agrees exactly with that for choosing coördinates for variables in algebraic formulas, since X is considered the independent variable and its values are plotted along the the horizontal axis.

Figure 8 shows the same data used in Fig. 5, plotted with the time element on the vertical axis. The first part of the figure has the earliest time element, or zero ordinate, at the bottom, of the sheet. The second part of the figure shows the time element plotted in a reverse manner. Reference to Figs. 5 and 8, simultaneously, shows at once the misconceptions that are bound to arise if the time element is not put on the horizontal axis. Figure 5 gives the correct impression at the first glance. The left diagram in Fig. 8 gives a wrong first-glance impression, because the slowly increasing *rate* of annual or total accumulated savings is depicted on the

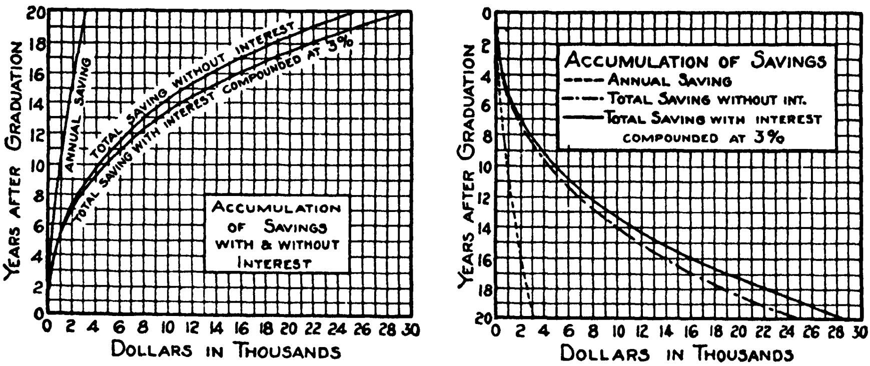

FIG. 8. Independent variable (time) on wrong axis.

chart by a rapid rise in the curve, thus causing a wrong interpretation. The diagram on the right is an improvement over the one on the left, but still gives a false impression at first sight. Although objectionable, the latter diagram can be made to function effectively if the reader will turn the page so that its left side comes at the bottom. The first diagram should never be used; the second is permissible but not advisable.

The placing of the values of the independent variable on the vertical axis in Fig. 9 is justified by the fact that these represent vertical distances on the chimney and, therefore, the diagram is "oriented" naturally, height on the diagram producing concepts of heights on the chimney.

Along with the proper choice of axis for each variable goes the problem of selecting the best distance on each axis to represent the unit in which the corresponding variable is measured. Upon the final decision in this respect rests the whole matter of the apparent slope of the curve on the paper.

306. Slope of Curve. — In general, it is easier to read values of each variable from curves that incline about 45 degrees to each axis than it is to take such readings from curves that are nearly horizontal or vertical. The accuracy attained in drawing a curve, or in reading values from it after it is drawn, varies directly with the angle of slope from a 45-degree line. If the curve is to be used as a computation curve only, then a judicious change in the scale of units on one axis, to make it more nearly approach the ideal, without, of course, making the unit of measurement too small for accurate use or too large to keep the curve on one sheet of coördinate paper, is often advisable. Figure 9 illustrates the effect of changing the scale of units on either or both axes.

If the curve is intended to convey impressions of tendencies only, through slope characteristics, then even more care must be exercised in

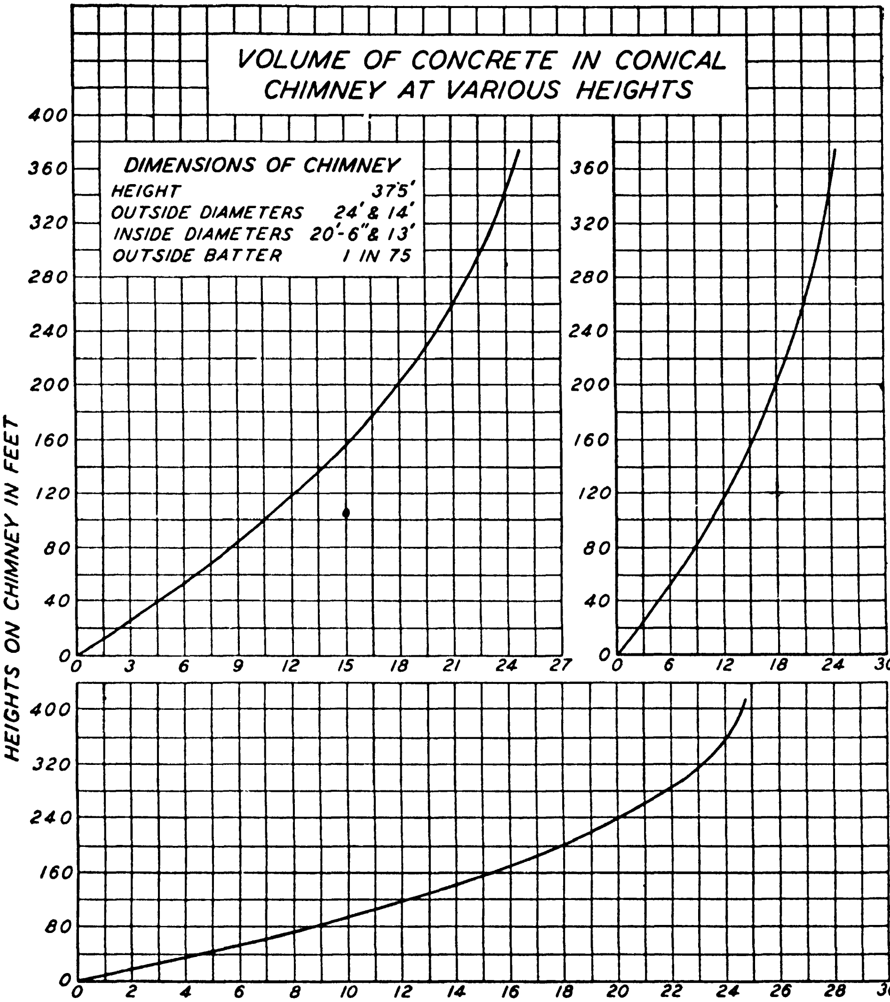

FIG. 9. Effect of scale upon apparent slope of curve.

the choice of axial units. It is clear that the impressions of the *rate* of increase in annual sales obtained from a casual study of the pair of graphs in Fig. 10 are very different in the two graphs; yet both curves are plotted from the same data. Much can be made of these apparent differences for either good or bad purposes.

When the chief concern with any set of data is the *rate of change* rather than the actual numerical change, this can be best shown on semi-logarithmic paper. Rectangular coördinate plotting will give an erroneous impression of the change in rate of increase or decrease, as may be seen by a comparison of the two parts of Figs. 7 and 29, particularly 29. This effect is produced entirely apart from the scale selected for the coördinates.

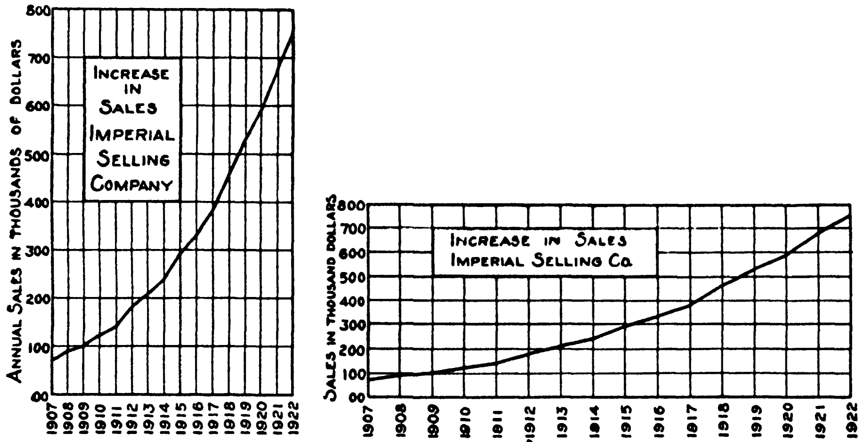

FIG. 10. Different impression produced by change of scale.

307. Drawing the Curve. — As already pointed out, the graph itself may be a straight line, in which case the draftsman lays a straight edge along the plotted points and draws in the required line. If the points do not fall on a straight line, the draftsman must decide whether to draw a series of straight lines from point to point, or to draw an average straight line through some median position which will balance the points on each side of it against each other, or to use a smooth curve through each point, or to balance the points on a smooth median curve. To answer this question intelligently, the draftsman must know the purpose for which the curve is being drawn. If the curve is to represent simple facts from which no generalization is to be made in the form of a mathematical law, it will be of one character; if a law is to be derived from the data, the curve will have quite a different character, as explained in the following examples:

1. **To draw a graph representing a law in mathematics which has been expressed by a formula.** — It will be found in such a case that all values plotted from numerous solutions of the equation will fall directly on a straight line or on a smooth curve. A series of discontinuous straight lines or short arcs of curves from point to point may not be used. The graph must pass through every point. See Fig. 11. In practice, the

plotted points are marked in pencil only and erased after the curve has been inked.

2. **To draw a graph representing data secured by tests or observations of any natural phenomena.** — If the data at hand have been taken very accurately and they represent some law of science or nature which can be reduced to mathematical language, then the conditions of (1) will obtain. This is unlikely to be the case. More often an average curve must be found which will pass close to each plotted point and balance those on the one side with contiguous ones on the other side of the curve. The simplest method of doing this is to make the shortest distances from the points to the curve the same on each side and as small as possible. This will mean, in some cases, that two and three points on one side of the curve will have to be balanced against only one point on the other side of the curve. Stated in another way, the sum of the distances from the plotted points to the curve must be the same on each side of the curve. Judgment must be exercised in applying this method, however, since some points have been located with greater accuracy than others, through more careful observation of the facts expressed by certain portions of the data, and hence should be given more weight in the balancing.

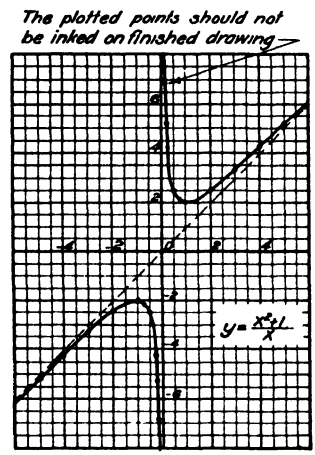

FIG. 11. Mathematical curve. (Curve through all points.)

Points on opposite ends of a curve cannot be used to balance each other, as they are too little related in the data. Obviously wrong points should be disregarded altogether, but mere doubt is not enough to reject a point. Groups of thickly plotted points on the paper may be given more weight than points scattered far apart, in determining the general characteristics of the graph. All these considerations are illustrated in the graphs of Fig. 6.

Sometimes it will be found that the observed data cannot be represented even approximately by a smooth curve, in which case the only thing to do is to connect the points by a series of straight lines. This condition occurs, of course, when there is little mutual relation between the variables being represented. A good example is shown in Fig. 12, where the amount of rainfall for each month at New Bedford, Mass., for the years 1880 to 1885, inclusive, has been plotted. Not even an approximate average curve is possible in this case, since very little relation exists between the successive months. Such graphs fall more logically into that group of diagrams classed as line diagrams, to be discussed fully in subsequent paragraphs.

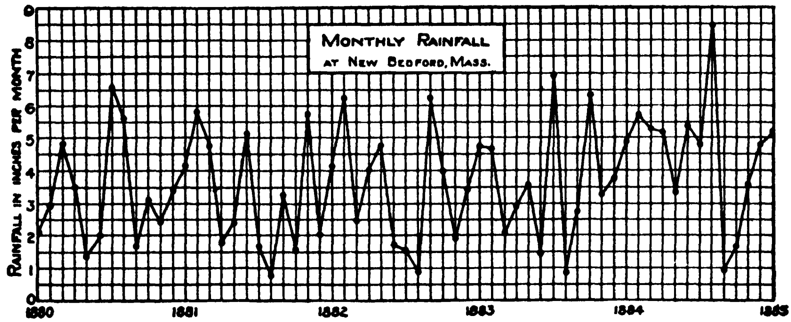

FIG. 12. Rainfall curve. (Curve through all points.)

3. **To draw a graph representing limiting conditions outside of which values of either variable will be found only very rarely or not at all.** — The second part of Fig. 13 so clearly typifies this kind of use of the plane curve that further comment is unnecessary. It is important to point out that

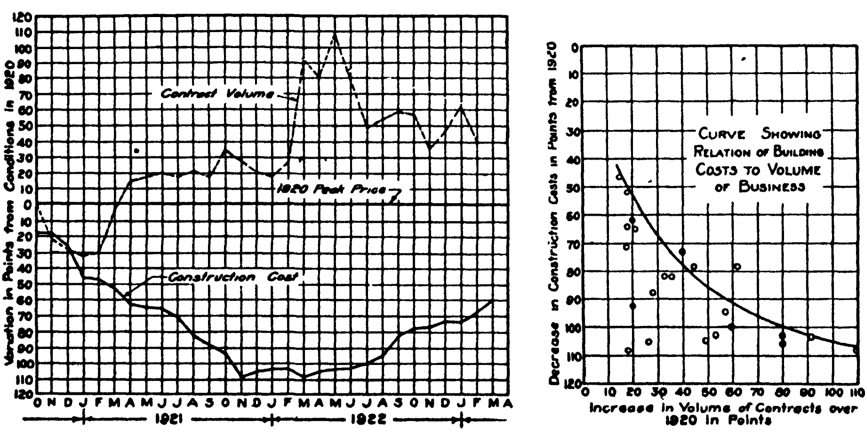

FIG. 13. Different methods of presenting data — comparison and maximum curves.

this curve is derived from the same data used in the first part of the figure and that two methods of representing data, as here employed, contribute much to a true understanding of the facts.

The following points, quoted from the preliminary report of the Joint Committee on Graphical Representation, are excellent guides to the general practice of curve drawing:

GENERALITIES

1. The general arrangement of a diagram should proceed from left to right.

2. Where possible represent quantities by linear magnitudes, as areas or volumes are more likely to be misinterpreted.

3. For a curve, the vertical scale, whenever practicable, should be so selected that the zero line will appear on the diagram.

4. If the zero line of the vertical will not normally appear on the curve diagram, the zero line should be shown by the use of a horizontal break in the diagram.

WHICH LINES TO EMPHASIZE

5. The zero lines of the scale for a curve should be sharply distinguished from the other coördinate lines.

6. For curves having a scale representing percentages, it is usually desirable to emphasize in some distinctive way the 100 per cent line or other line used as a basis of comparison.

7. When the scale of a diagram refers to dates, and the period represented is not a complete unit, it is better not to emphasize the first and last ordinates, since such a diagram does not represent the beginning or end of time.

8. When curves are drawn on logarithmic coördinates, the limiting lines of the diagram should each be at some power of ten on the logarithmic scales.

9. It is advisable not to show any more coordinate lines than necessary to guide the eye in reading the diagram.

10. The curve lines of a diagram should be sharply distinguished from the ruling.

AUXILIARY INFORMATION

11. In curves representing a series of observations, it is advisable, whenever possible to indicate clearly on the diagram all the points representing the separate observations

12. The horizontal scale for curves should usually read from left to right, and the vertical scale from bottom to top.

13. Figures for the scales of a diagram should be placed at the left and at the bottom or along the respective axes.

14. It is often desirable to include in the diagram the numerical data of formulas represented.

15. If numerical data are not included in the diagram, it is desirable to give the data in tabular form accompanying the diagram.

16. All lettering and all figures on a diagram should be placed so as to be easily read from the base as the bottom, or from the right-hand edge of the diagram as the bottom.

17. The title of a diagram should be made as clear and complete as possible. Subtitles or descriptions should be added if necessary to ensure clearness.

308. Technique of Curve Drawing. — In Figs. 2 and 6, it will be noticed that the curve or straight lines have been drawn up to each circle representing a plotted point, instead of being passed through the circle as one continuous line. The purpose of this is not only to present a neater appearance, but also to preserve the coördinate values of the point, so that they may be read accurately from the center of the circle. In graphs plotted from algebraic formulas, the points used in locating the curves are not inked in, and all trace of their pencil positions is removed. Such curves are generally used for computation purposes, and the entire line must be available for readings. See Fig. 9.

The curve itself should be a fairly heavy line, so that a good contrast is made with the coördinate lines. If, however, the curve is drawn definitely for the purpose of furnishing numerous and accurate readings, as a calibration curve, then a sharp, fine line is justifiable.

If several curves representing different sets of data are drawn on the same sheet, it is well to distinguish between them by the use of dot and dash, dash, or even dotted lines, in addition to the full line commonly used. A key to the meaning of each kind of line may be lettered on the sheet, or a descriptive word may be put on the curves themselves. Too many curves on a single sheet should be avoided.

When coördinate paper is being ruled in the drafting room on tracing cloth or drawing paper, care must be taken not to space the lines too close together. The eye is able to interpolate a space of one-fourth inch as accurately as is necessary for most curve plotting.

If the graph is to be used for reproduction purposes, it will be best to draw it on the opposite side of the paper from the printed coördinate lines. Erasures on the right side of printed commercial papers remove the printer's ink, and it is very difficult to repair such damage satisfactorily.

309. Titles and Legends. — Somewhere on the curve diagram, a neat title should be lettered, in much the same way as on working drawings, giving the name of the curve, the source of data from which it was plotted, date, and name of draftsman or investigator. For added effect, a rectangular area may be cleared of all coördinate lines by the use of alcohol, and the title may then be printed in this open space and the area enclosed with black borders. Legends are sometimes printed on the curve itself to explain it in greater detail than is done in the title. See Fig. 8. It will often be necessary also to add other informational legends about the sheet, in order to make unmistakably clear what the curve is and what information it may give the observer. Notes should be added to explain any great irregularity which appears in the plotted points, or which surrounds the taking of the curve data. A key to the various symbols used should also be included. Equations of curves and tabulated data are sometimes included.

310. LINE OR BAR DIAGRAMS AND CHARTS. — It is often necessary to present statistical data in some diagrammatic form which will be understood by everyone and which will give a simple and complete picture and summary of the facts to be presented. Single straight lines and curves, such as were discussed in preceding pages, will not be suited at all to the purpose mentioned, because not everyone has an understanding of curve characteristics, and the picture qualities of the curve itself are almost nil to the average person engaged in the non-technical pursuits.

If, however, the data at hand can be separated into well-defined divisions, such as periods of time — days, weeks, and months of the year — or units of size, like companies in a regiment, weight of persons at different ages, etc., then the quantitative aspects of each division of the data may be represented by a chart of consecutive heavy lines or bars, the lengths of which shall correspond to the respective quantities to be compared. Such a series of bars is called a *Line or Bar Diagram.* The width of the representing lines has nothing to do with the size of the quantities represented, and should not be so great that the observer secures an impression of comparative areas instead of comparative lengths. The width should be great enough, however, to make each line easily distinguishable at the

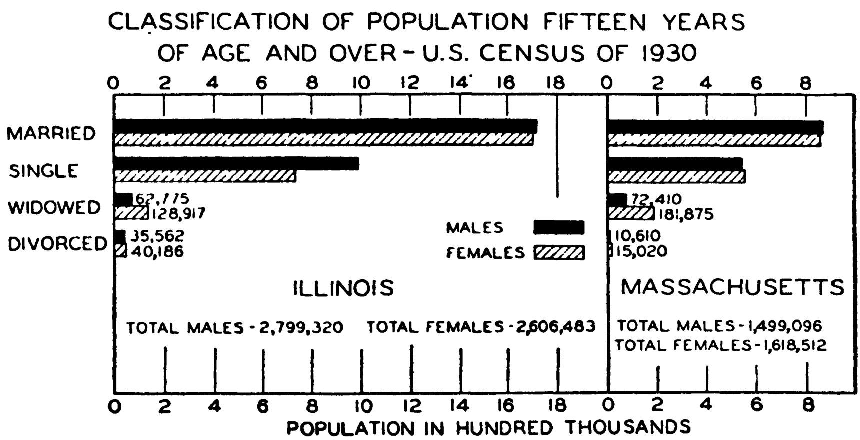

FIG. 14. Bar or line diagram.

distance from which the observer will view it. In any case, all the bars must be of the same width on a single diagram. Figures 14 and 15 illustrate the principle of arrangement of a line diagram. From these typical illustrations, several general deductions, applicable to all cases in which the line diagram is to be used, can be tabulated:

1. Commercial coördinate papers are of little use in line-diagram work, since the chief purpose of such a diagram is to leave a comparative picture in the mind of the observer, and numerous coördinate lines in the background of such a picture have no additive effect in the process of comprehending the diagram. The heavy bar-lines must be spaced equally along the base line, however, and coördinate lines are helpful for this purpose, as well as being an aid in fixing the length of the bars. Since the end coördinate of each bar is the only thing of importance in reading the dia-

gram quantitatively, it will be found advantageous simply to rule in lines at regular intervals perpendicular to the bars and extend them across the diagram to the coördinate line representing the scale of quantities. They may or may not be extended to the opposite side of the diagram. Note

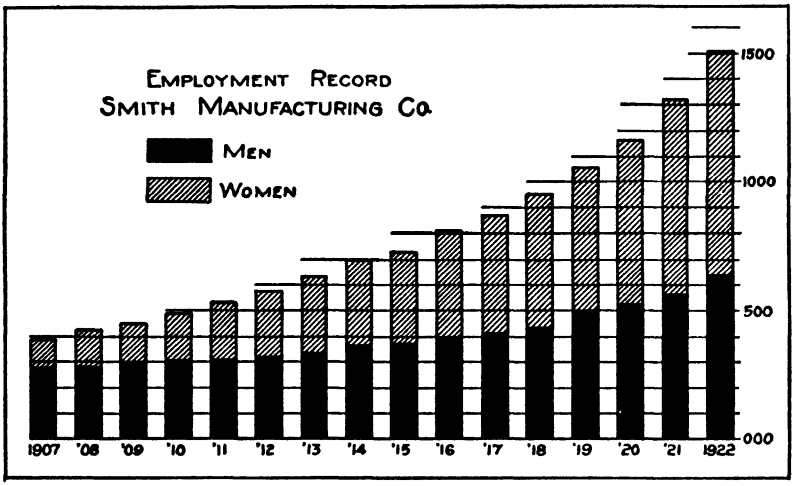

FIG. 15. Bar diagram, quantities additive.

Fig. 15. Lines parallel to the bars may be omitted altogether. See Fig. 14. When the unit and kind of quantities represented on either or both axes are readily understood, the descriptive phrase, telling what quantities the units represent, may be omitted. See Fig. 15. Otherwise, these descriptions should be included. See Fig. 14.

2. When the data to be represented are expressed in numerical quantities for certain definite periods of time, the heavy lines or bars should be drawn vertically, and the units of time should be marked off on the horizontal base line. See Fig. 15. The naturalness of this arrangement is apparent when one recalls that time, in everyday language, is spoken of as a sort of horizontal progress, while the functions depending upon time have their " ups and downs," as is clearly shown by the diagram. Since units of time should almost always be placed on the horizontal base line, horizontal bars are seldom seen when such quantities are involved. This type of diagram is particularly appropriate when definitive classifications are being represented, such as the names of states, types of industries, divisions of labor, population, costs, etc. The classification terms may be written vertically at the left side of the diagram in whatever order preferred and to any height necessary, and the horizontal bar opposite each will then give the quantity involved. Figure 14 illustrates these properties.

3. When an attempt is being made to fix exact numerical quantities in the mind of the observer, in addition to the comparative qualities expressed by a line diagram, the specific values should be written along or at the end of each bar. Even the practiced eye does not readily grasp and transfer specific values to the mind when they are taken from a single base scale on which they can be read only approximately, as shown in Fig. 14.

4. When each main unit of data is composed of several subclasses, such as the labor of adult men and women and children of adolescent age, these facts may be clearly expressed by subdividing each bar into the proper proportions to fit the conditions. This has been done in Fig. 15. Black and white lengths can be contrasted with variously cross-sectioned lengths. Colored inks may also be used. Another scheme often resorted to is that of dividing the width of the bars into equal parts according to the number

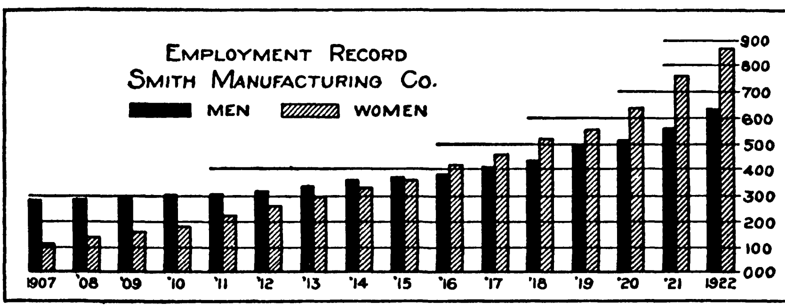

FIG. 16. Bar diagram, quantities compared.

of factors to be represented, and extending each part of the bar the proper length. See Fig. 16. The first scheme is additive rather than comparative in effect; the second is simply comparative in its results. Both make it unnecessary to construct separate diagrams for each factor involved.

311. AREA AND VOLUME DIAGRAMS. — Practically all data suitable for representation by any form of chart or diagram should be shown by a curve diagram, or they should be put into a bar diagram, as just explained. Occasionally, however, an area or volume diagram may be better suited to the purpose. This will occur when the differences between the quantities compared is very great, and where the purpose of the comparison is simply to impress the observer with the fact of large and small magnitudes. For example, the cross-section of an electron and an orange could be compared better by this method than by a

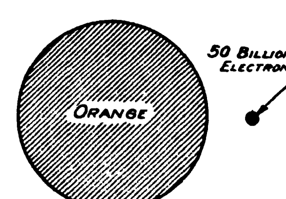

FIG. 17. Area diagram.

bar diagram. See Fig. 17. An area diagram may also be used profitably when the quantities to be compared are themselves areas and can be superimposed upon one another, to scale. The eye can easily compare sector areas of a circle. See Fig. 18.

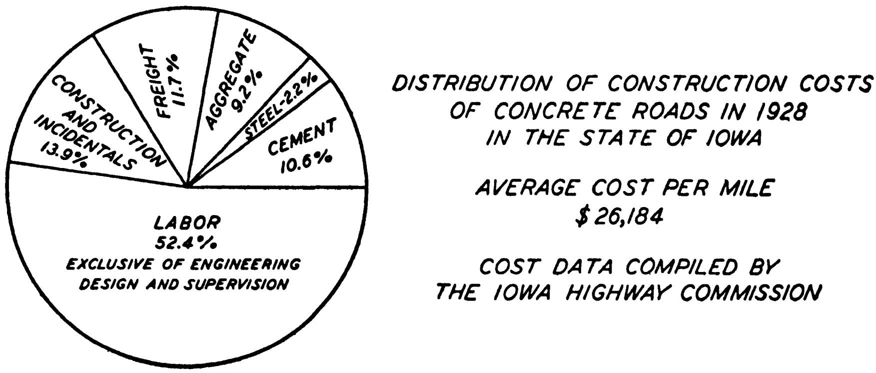

FIG. 18. Sector or pie diagram.

A very effective area diagram, shown in Fig. 19, has been made up from the report of tests conducted at Cornell University and published in the *Country Gentleman*, June 7, 1919. The effect of the several areas shown is to give total quantities, while the irregularity of the outlines serves to

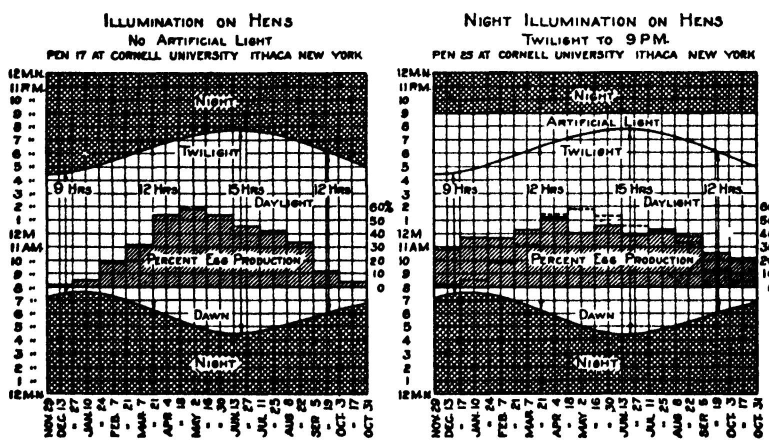

FIG. 19. An effective area diagram.

accentuate the periods and amounts of production at the different stages of the experiment. An added feature of helpfulness in this diagram is the superimposing of the outline of the production area of the first half of the diagram on the corresponding area of the second half.

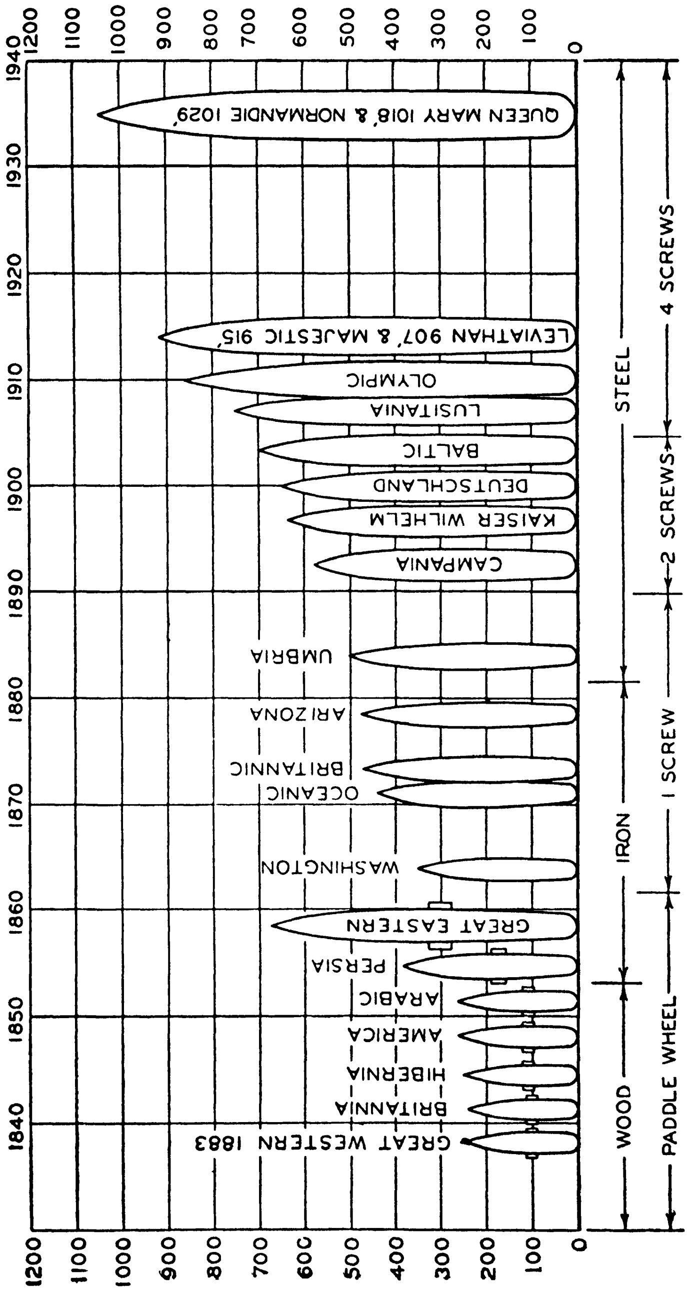

FIG. 20. Bar diagram. Symbol used for bars.

Still another form of area diagram which is worth mentioning is the miniature life diagram represented in Fig. 20,[1] in which certain facts concerning persons or things are set forth by various miniature drawings of the things themselves, and in which the sizes of the drawings depict the corresponding sizes of the things represented. The facts presented are thus vitalized and vivified and thereby become permanently fixed in the mind. The skill of the draftsman in pictorial drawing is brought into effective use in this kind of graphical representation.

Volume diagrams should seldom be used. If, however, the idea of bulk and mass is paramount in the comparison, a suitable volume diagram done in isometric or oblique projection is justified. The mass of an iceberg compared with that of a ship might very well be represented by two cubes.

The chief objection to area and volume diagrams lies in the fact that in the hands of most persons they are incorrectly used and constitute a source of misinformation. Such an instance occurs in the use of triangles to compare quantities, in which the effect of areas enters into the comparison, while in fact only the heights of the triangles represent the real state of things. Always the comparison of areas inadvertently takes place in the mind of the observer and, except in very limited cases previously mentioned, such comparisons are faulty. In the same way, improper use of volumes, such as cylinders, is made when only heights of the cylinders give the true conditions. If all dimensions except heights are kept constant, then such diagrams are no more than bar diagrams and should be replaced by them.

In line, area, and volume diagrams, as in plane curve diagrams, a sufficient amount of descriptive material to make the meaning of each part clear should be placed on the diagram proper in the form of base-line scales, notes, legends, and titles. A simple, clear style of lettering is imperative on all diagrams of this character, since they are intended for popular use and must be easy to read. The general laws of technique in drafting, hitherto explained, are applicable to these types of diagrams.

312. Map or Distribution Diagrams. — This type of graphical representation is very useful in presenting facts and statistics which have a geographical or place significance. Figure 21 represents this type of chart or diagram very well. The salient features are at once evident and need not be elaborated. It is important to point out, however, that in addition to the element of place, which is always present in map diagrams, the effect of quantity can also be readily added, as is done in the first part of the figure by means of a legend, or in the second part of the figure by means of numerals placed on the diagram to indicate quantities directly.

The draftsman is given opportunity to display his ingenuity and creative-

[1] Taken in part from "Graphic Methods for Presenting Facts," page 51, 1914 edition, by W. C. Brinton.

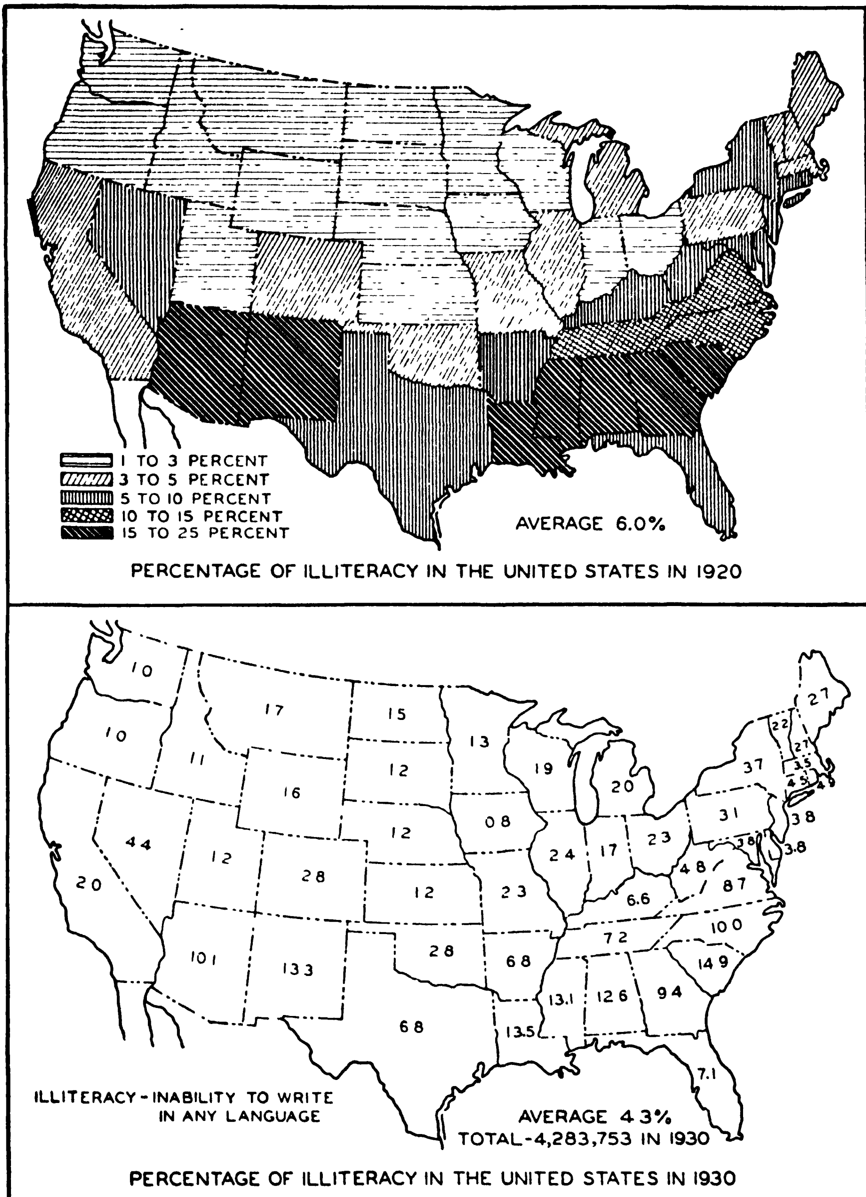

FIG. 21. Distribution map or diagram.

ness in this form of chart and diagram drawing quite as much as in any other. The numerous devices for indicating the quality, quantity, or shape of the things represented on such a distribution diagram are often very clever and instructive. The use of cross-hatching gives the very desirable effect of varying degrees of density of distribution, an attribute that can also be secured by the use of colors. Miniature drawings of soldiers, shocks of grain, cartons of goods, etc., can be used effectively to express three characteristics, namely, quantity, kind, and distribution.

313. Graphic Statics and Vector Diagrams. — Graphic statics diagrams are used to determine stresses directly, or to check the analytical computation of stresses in members of trusses or other structures under load. The construction of such diagrams presupposes a thorough knowledge of the representation of forces by vector quantities, that is, by the lengths and directions of straight lines. Further, the construction depends upon an understanding of stress analyses of structures, which is, in turn, dependent upon analytical mechanics. Figure 22 shows such a diagram. It need only be pointed out that the length of each line in the diagram and its direction corresponds respectively to the size and direction of the stress in the truss member which the line represents. Vector diagrams in any field are based upon similar considerations of direction and magnitude and need not be elaborated here.

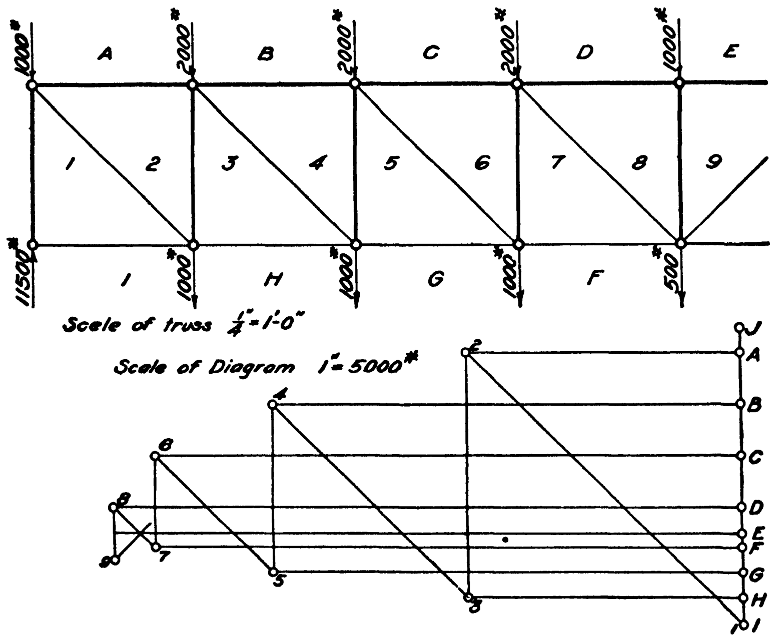

Fig. 22. Graphic statics diagram.

The drawing problems involved in the construction of such diagrams are few, and consist chiefly of accurate scaling and layout of parallel lines.

314. Nomographs. — The subject of nomography is of especial interest to engineers, scientists, and others who are constantly dealing with problems involving the repeated solution of algebraic equations. Because of the simplicity of manipulation of a nomograph, which, after its construction, eliminates the laborious process of repeated substitution in, and solution of, a complicated formula, it should continue to find wider and wider use among engineers.

Briefly, a nomograph is simply a set of vertical scales, or a set of inclined and vertical scales, straight or curved, which are so spaced and arranged on a chart that they represent the various elements of a formula (nomogram) in a graphical way. Any unknown value in the formula can be found by simply laying a straight edge across the scales, either once or several times, and reading the correct result from the proper scale. Known values in the formula are cut on the proper scales by the straight edge, while the unknown values can be read from other scales at points where the straight edge cuts them in the successive applications of it to the diagram. The straight edge when so used is called an *isopleth* which means "corresponding values of the variables of an equation."

Figure 23 shows a simple nomograph and the method of using it. It will be noted that each scale is marked, to correspond with the variables

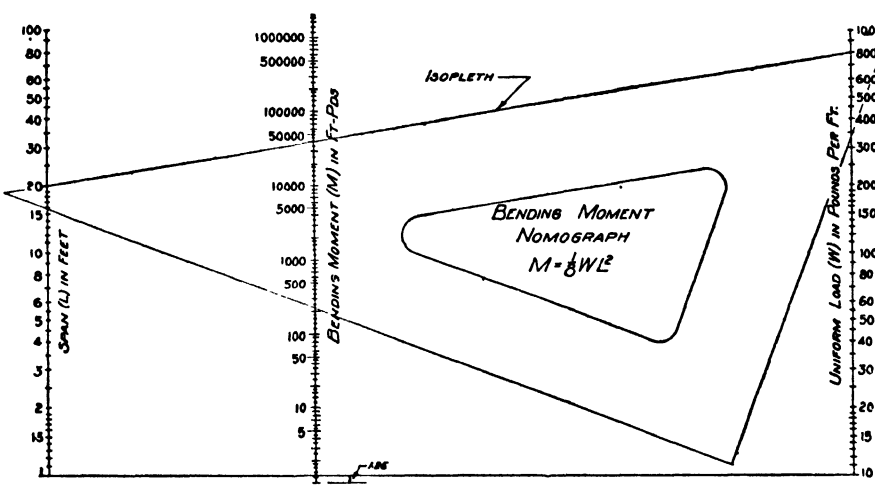

Fig. 23. Nomograph — computation chart.

in the nomogram, either with the symbol itself or the thing the symbol stands for. The scales are all vertical. Every variable in a formula must be represented by a scale in the nomograph, which may be in decimal or logarithmic units, depending upon the nature of the equation. Figure 24 shows the data used in Fig. 23 plotted on the ordinary coördinate paper.

A comparison of the two figures serves to show move vividly the advantages of the nomograph, which were mentioned above. Because of the almost exclusive use of straight lines in nomographs, they are often called "straight-line diagrams" or "alignment diagrams."

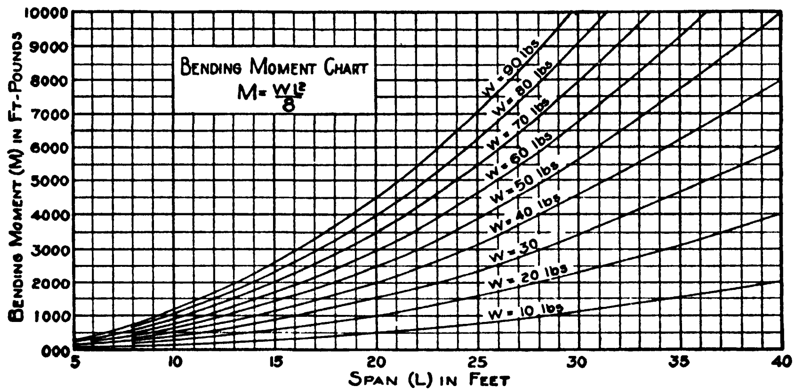

FIG. 24. Plane curves — computation chart.

The only drafting skill required in the preparation of a nomograph is that of careful measurement in the layout of the various scales and their subdivision into correct units of value. Heavy, non-expanding paper or board should be used for such diagrams.

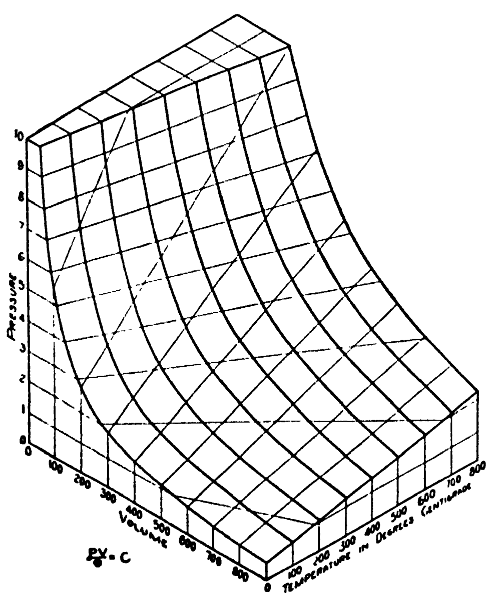

FIG. 25. Three-dimensional chart.

In a very real sense, we may say that the slide rule and many other sliding or rotating devices for computation work are based on the principles of the nomograph.

315. THREE-DIMENSIONAL CHARTS. — Figure 25 shows a typical three-dimensional chart and the mathematical formula used in deriving the values which are plotted on each coördinate axis. It will be noted that the drawing is simply an isometric in which the various points are determined by values derived from a formula of three variables.

The smooth surface formed by the points and interpolations between points is of very great value in demonstration work, especially in connection with the study of laws governing the expansion of gases. Such a diagram is a good substitute for the more expensive models sometimes

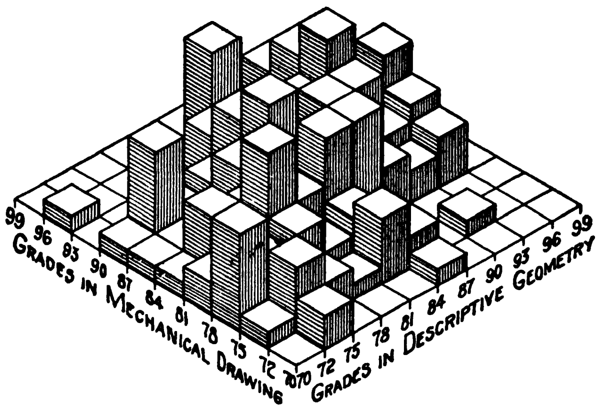

FIG. 26. Three-dimensional chart.

used. Figure 26 illustrates a variation of the three-dimensional chart which is often used in statistical work. The figures are self-explanatory as far as the drafting problems are concerned.

316. ORGANIZATION AND FLOW CHARTS. — These two kinds of charts are quite alike in general appearance and even in purpose. The organization chart shows the flow of authority from the executive source to the division and subdivision heads or departments of an organization, or, vice versa, it shows the exact officer to whom each person in the organization must report and be responsible. It shows permitted interlocking and interrelated activities within the organization. It is very useful in planning and defining the separate functions of the various units in large companies. Figure 27 illustrates the typical organization chart. The flow sheet, on the other hand, shows the flow or distribution of materials as they pass through a plant in the process of manufacturing a product, purifying and disposing of wastes, sorting and marketing a commodity, and the like. Figure 28 shows a typical flow sheet.

Intricate organizations or processes may be clarified by using colored inks wherever necessary in making either of the above charts. Otherwise, they present no involved problems of draftmanship.

317. RATIO OR PERCENTAGE CHARTS. — The first diagram of Fig. 29 represents the usual bar diagram type of chart showing the population of the Continental United States at successive census periods since 1790. A plane curve has been drawn through the tips of the several bars to show

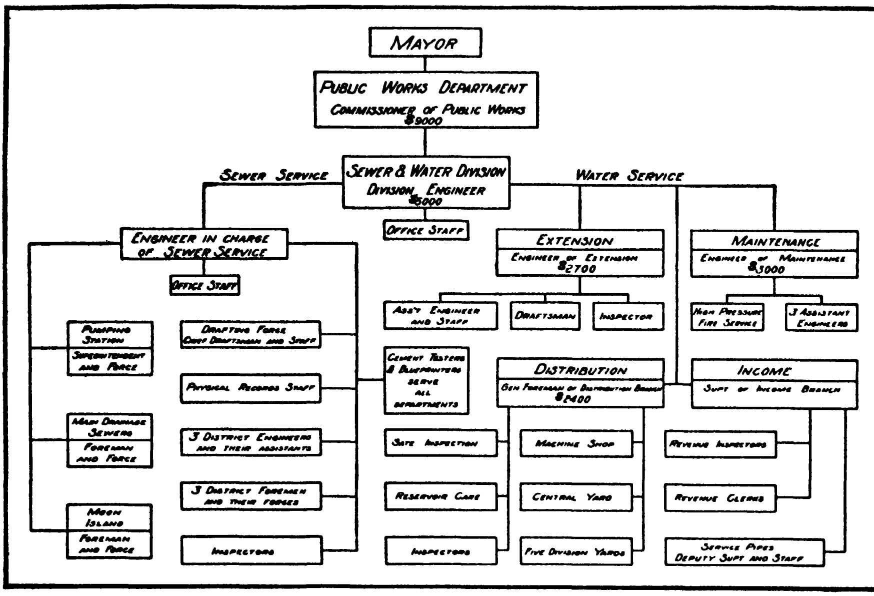

FIG. 27. Organization chart.

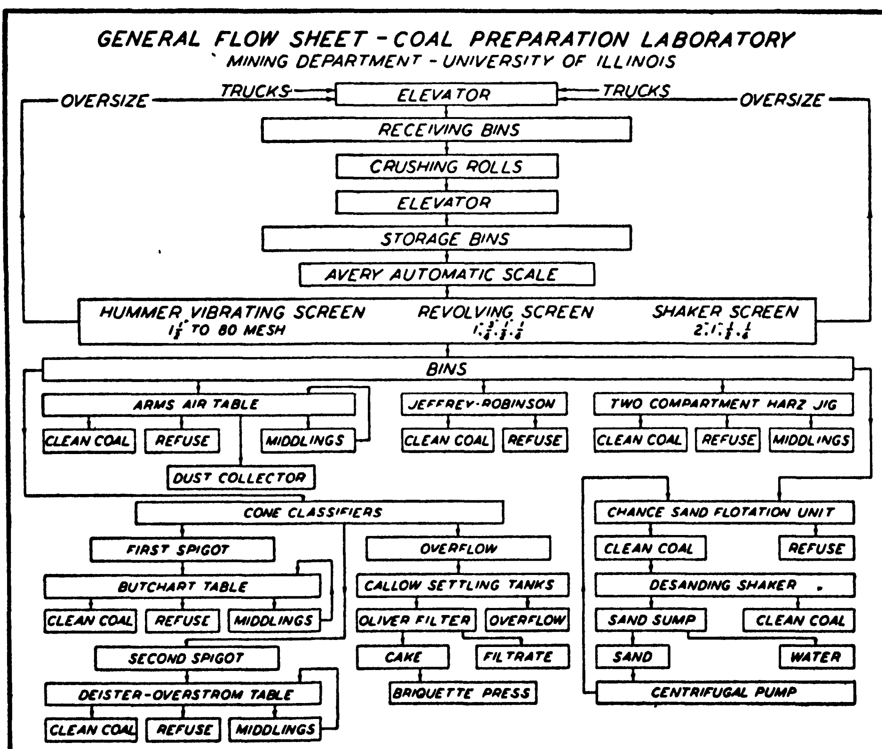

FIG. 28. Flow sheet.

the trend of the population growth more clearly and to indicate the form the algebraic equation must have to calculate correctly the population at any given time after 1790. The rapid rise of this curve after 1830 leads to the impression that the *rate* of increase has been constantly growing

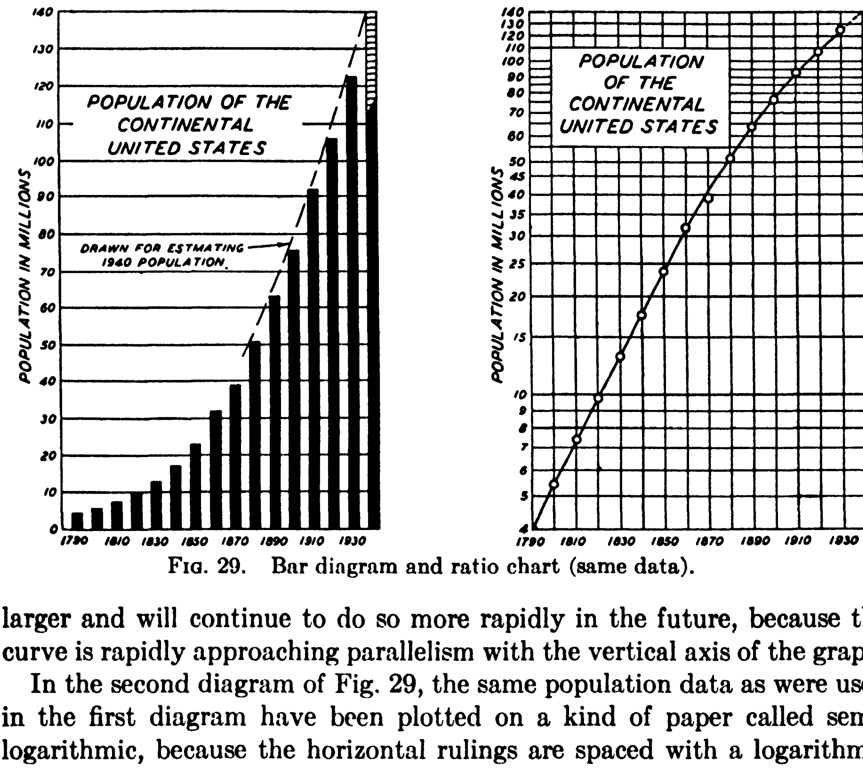

FIG. 29. Bar diagram and ratio chart (same data).

larger and will continue to do so more rapidly in the future, because the curve is rapidly approaching parallelism with the vertical axis of the graph.

In the second diagram of Fig. 29, the same population data as were used in the first diagram have been plotted on a kind of paper called semi-logarithmic, because the horizontal rulings are spaced with a logarithmic scale. Curves drawn on such papers express directly, by their slope with the horizontal axis, the change in rate of increase or decrease in any given set of data — an increase in angle of slope indicating an increase in rate, while a decrease in the angle indicates the opposite tendency. Thus it will be noted that the rate of increase in population remained constant between 1800 and 1860, since which time the rate has been constantly decreasing, a fact not discernible from the first diagram of the figure without calculation.

The first diagram of Fig. 29 is called an *arithmetic* chart; the second is called a *ratio* chart. The advantages of the latter over the former are obvious, particularly for business and industrial purposes where change in the rate of increase or decrease of a particular variable is important. It should be pointed out, perhaps, that the *actual* rate factor cannot be read directly from the chart, but, rather, the *change* of rate is what is indicated graphically. The actual rate of increase or decrease in any case must be calculated from two readings taken at the beginning and end of some unit of time on the diagram, if the graph is a straight line, or it must be calculated from the tangent to the curve at a point representing any particular instance of time.

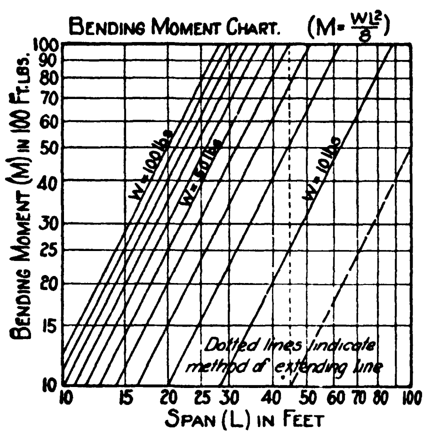

FIG. 30. Logarithmic chart.

318. LOGARITHMIC CHARTS. — Another very convenient method of presenting the graphs of equations to be used for computation purposes is shown in Fig. 30. The same data shown in Figs. 23 and 24 are here shown on full logarithmic paper. It will be noted that the graphs have become straight lines, as is always the case with any equation of the form $y = mx^a$.

319. CHARTS AND DIAGRAMS OF SCIENTIFIC DATA FOR LANTERN SLIDES. — Drawings from which lantern slides are to be made and which present scientific and engineering data in the form of curves and other graphical representations should follow a few clearly defined principles in their construction. So far as possible, the drawings should be made about three to four times the size of the standard lantern slide, which is $3\frac{1}{4}'' \times 4''$ overall, but only $2\frac{3}{4}'' \times 3\frac{1}{2}''$ inside the opaque tape edging. Since not all of the transparent area of the slide should be covered by the outlines of the photographically reduced drawing, it is a safe rule to follow that the margin lines of the slide shall be approximately $2\frac{1}{4}'' \times 3''$. This will make the dimensions of the margin lines of the drawing about $7'' \times 9''$. The American Standards Association recommends $6\frac{3}{8}'' \times 9''$. If a great deal of material must be represented on the chart, larger but proportionate size drawings must be used. Figure 31 shows the actual size of a standard lantern slide. The number in the lower left-hand corner shows the position of the slide in a series and also the way the slide should be inserted in the projection holder, the slide being turned till the number comes in the upper right corner under the thumb of the operator.

Since lantern slides are always accompanied by oral discourse, they are to be considered as aids to the speaker only, and therefore should not be cluttered up with a mass of detail. Legibility and strong contrasts are the cardinal points to be sought in their construction. As few grid rulings as possible should be shown on the drawing, and the graphs presenting the data should be strong firm lines.

The lettering should be Gothic capitals placed horizontally, and not crossed by grid rulings or other outlines on the drawing. The height of letters should, of course, vary with the size and complexity of the chart, but in no case should they be less than $\frac{1}{8}$ inch high for reductions as great

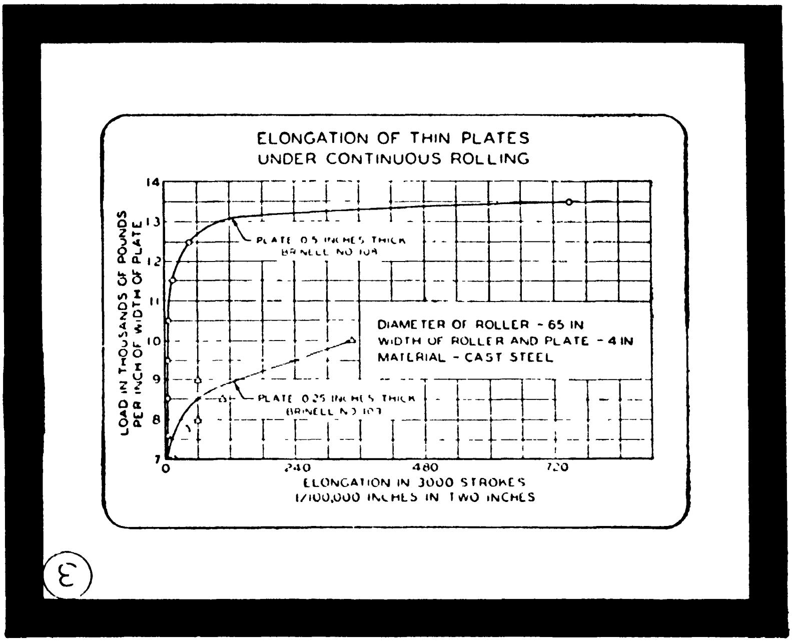

FIG. 31. Lantern slide.

as two-thirds the size of the original drawings. A better rule to follow is to have the height of letters on the screen show in proportion to the distance to the farthest spectator as 1 is to 300. That is, a 2-inch letter on the screen should be used in a 50-foot auditorium, a 4-inch letter in a 100-foot room, and so on. This means that the smallest letter on the slide should be 0.040 to 0.045 inch high and about 0.006 inch in line width. If the drawing is to be four times as large as the slide, the smallest lettering on the drawing would thus be 0.16 to 0.18 inch high. Letters in general titles should be correspondingly higher. Commerical lettering guides, such as the " Wrico " sets, should be used when available.

Color photography is very helpful in preparing slides of varicolored objects and even in showing scientific data, but if the drawings are also to be used for reproduction purposes in publications, they should be drawn in black and white only and the lantern slides colored by hand. Photographic negatives can be used as lantern slides, thus showing white lines on a black background on the screen, which is less fatiguing to the audience. The negatives cost less, but they cannot be used in a room that is not thoroughly darkened.

Reference to the American Standards Association's publication Z15.1 — 1932, entitled "Engineering and Scientific Charts for Lantern Slides," will bring many helpful suggestions to those engaged in preparing charts of this kind.

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PROBLEMS

320. In the following problems it is assumed that the student will use commercial coördinate papers.

For bar charts and plane curves, use 20 to the inch coördinate paper, $8\frac{1}{2}'' \times 11''$.

For sector diagrams, use circle chart divided into 100 parts.

For logarithmic charts, use a double deck logarithmic paper. Note that coördinate values cannot be plotted to zero on this paper.

Unless otherwise specified, plane curves, whose values are computed from formulas, should be carried from the origin to the limits of the coördinate area.

Proper titles, coördinate markings, etc., are, of course, to be included.

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

PLANE CURVES — RECTANGULAR COÖRDINATE 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, $V = 0.5236d^3$, 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. $V = \pi h\left(\frac{c^2}{8} + \frac{h^2}{6}\right)$, where h = depth of liquid and c = diameter of liquid surface. Show a sketch in your chart to explain terms in 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 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 data below. 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	A	B	A	B
121	0.78	38	1 82	32	2.70	45	1.30	60	1.20
122	1.18	34	2.80	26	2.92	24	1.61	56	2.20
25	1.21	4	5.92	180	0 90	8	1.46	22	3.93
56	1.26	10	5.10	82	0 70	63	2.06	12	4.88
103	2.10	10	4.15	70	1.10	15	3.10	7	5.92
63	1.32	27	3.52	72	1.77	15	3.62	11	2.30
32	2.11	18	4.31	70	1.90	15	4.51	16	3.87

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	Unit Stress	Unit Strain	Unit Stress	Unit Strain
0	0	23200	00075	32800	.0022	53400	.1250
4080	.00012	26700	.00087	33500	.0030	54100	.1500
7670	.00025	30100	.0010	34400	.0052	54800	.1875
11100	.00037	32800	.00113	37000	.0250	55100	2375
15400	.00050	33800	00119	47000	0625	54700	.2625
18700	.00063	32700	.0015	52000	.1000	47500	.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 coördinates so that the curve goes well across the sheet.

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

DURALUMIN

Unit Stress	Unit Strain	Unit Stress	Unit Strain	Unit Stress	Unit Strain	Unit Stress	Unit Strain
0	0	24900	.0023	35700	.0087	48000	.0625
4520	.0004	29400	.0030	36300	.0107	50100	.0750
9100	.0008	32000	.0044	37300	.0130	51500	.1000
15820	.00143	33500	.0057	41300	.0250	53300	.1250
20300	.00186	34500	.0069	46100	.0500	53500	.1600

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

FREE-CUTTING BRASS

Unit Stress	Unit Strain	Unit Stress	Unit Strain	Unit Stress	Unit Strain	Unit Stress	Unit Strain
0	0	26300	0023	34900	0083	40800	.0667
5750	00033	29200	0030	35200	.0100	44200	.1000
10600	00066	32200	0039	36600	0133	47500	.1500
16800	.00122	32200	0051	37500	0208	49400	2000
21600	.00166	34000	0059	39100	0333	50500	.2333

14. Draw three curves representing the effect of moisture on the stiffness of timber as given in the data below.

Deflection in Inches	Load in Pounds			Deflection in Inches	Load in Pounds		
	Per Cent of H_2O				Per Cent of H_2O		
	2 1	22 9	49 5		2 1	22 9	49 5
.05	351	320	259	.30	1924	1638	1289
.10	710	615	510	35	2140	1780	1390
.15	1065	912	771	.40	2279	1926	1445
.20	1395	1218	988	.45	2360	2000	1484
.25	1592	1434	1148				

Specimen: 1.5″ × 2.02″ × 26″. Maple.

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

SEMI-LOGARITHMIC CHART

20. Same as Prob. 8. Use semi-logarithmic paper.

BAR CHARTS

21. Make a bar chart showing the territorial expansion of the United States. Data: Page 536, *World Almanac,* 1934.

22. Same as Prob. 21. Show area of the 48 states in ascending order of size. Data from *World Almanac.*

23. Same as Prob. 21. Show population of the 48 states. Data from *World Almanac.*

24. Make a bar chart showing a comparison between the cargo traffic of the Panama, Suez, and Kiel Canals for the years 1915 to 1932, inclusive. Data: Page 772, *World Almanac,* 1934.

25. 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	Metal	$MgCl_2$	$CaCl_2$	NaCl
Zinc	0 57	0.21	0.06	Lead	0 33	0 24	0.01
Cast Iron	0 51	0 12	0.06	Copper	0 15	0 12	0 01
Wrought Iron	0 51	0 18	0.15	Tin	0 10	0 08	0.00
Aluminum	0.10	0 03	0.00	Nickel	0 03	0 05	0.00

Trilinear Chart

26. 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 Vol. Matter	Per Cent Fixed C	Type	Per Cent Moisture	Per Cent Vol. Matter	Per Cent Fixed C
Anthracite	4 1	4 8	91 1	Bituminous C	12 0	39 1	48 9
Semi-Anthracite	4 0	11 2	84 8	Bituminous D	19.8	35 7	44 5
Bituminous A	2 8	20 2	77 0	Lignite	37.6	29 6	32.8
Bituminous B	3 2	36 3	60.5	Peat	81.6	12 4	6.0

Sector Diagrams

27. 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	Items	Per Cent
General Government	14.4	Highways and Streets	13.7
Protection	9.6	Economic Development	5.8
Education	29.4	Public Utilities	10.2
Social Welfare	9.7	Debt Service	7.2

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

CHAPTER XX

MAP DRAWING

321. 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 text.

322. 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[1] 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.

323. 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, railroads, etc. 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, or it may not be shown at all.

324. Topographic Maps. — Much smaller areas are shown in maps of this class, and hence they may contain considerably more detail. Just how much detail may be shown on them will depend, of course, upon the scale. Topographic maps prepared by the United States Geological Survey, see Fig. 1, are made to a scale of approximately 1 inch to the mile in the thickly settled industrial districts, and to a scale of nearly 1 inch to 4 miles in the

[1] "Topographical Drawing," by Edwin R. Stuart, U. S. Military Academy.

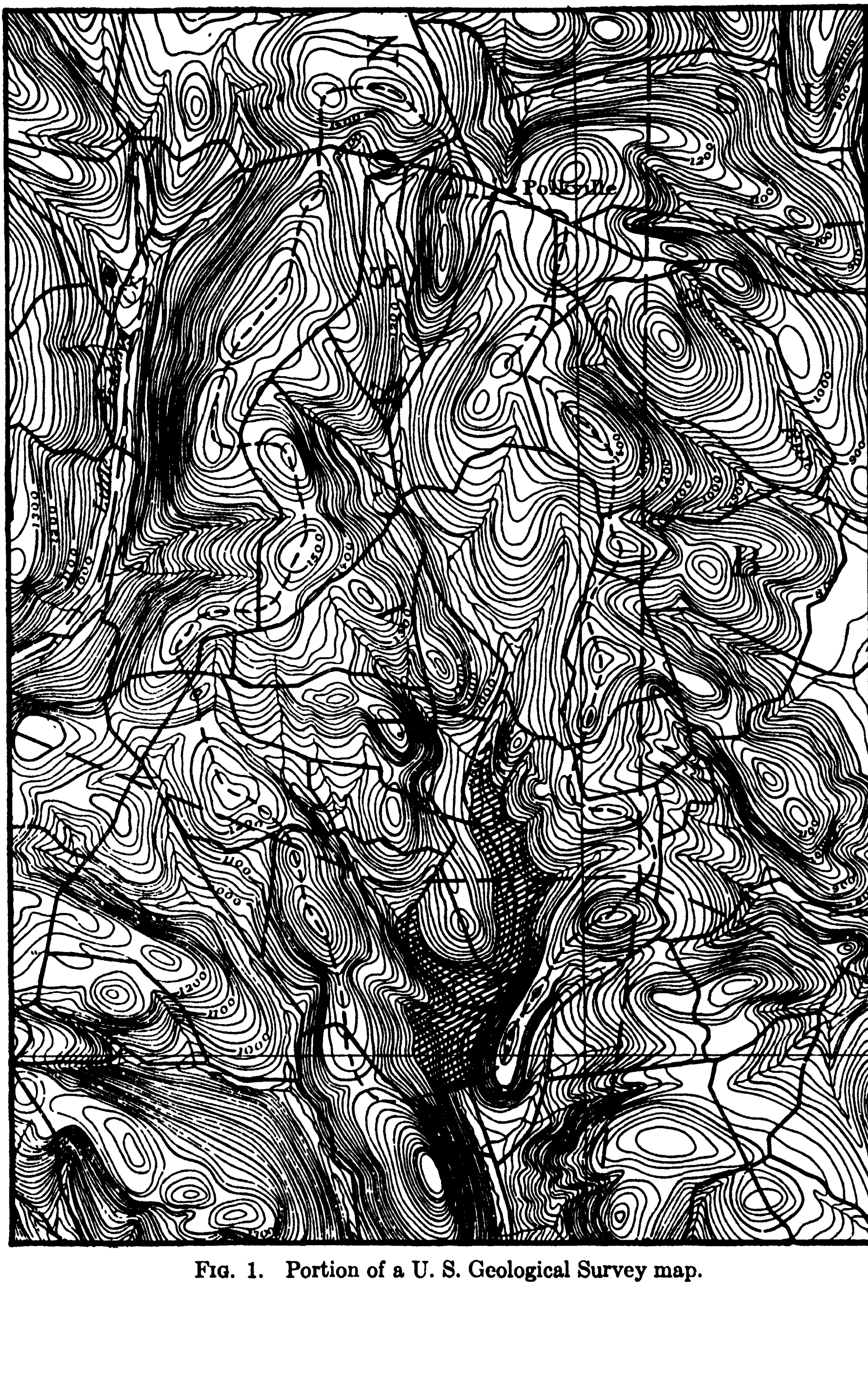

FIG. 1. Portion of a U. S. Geological Survey map.

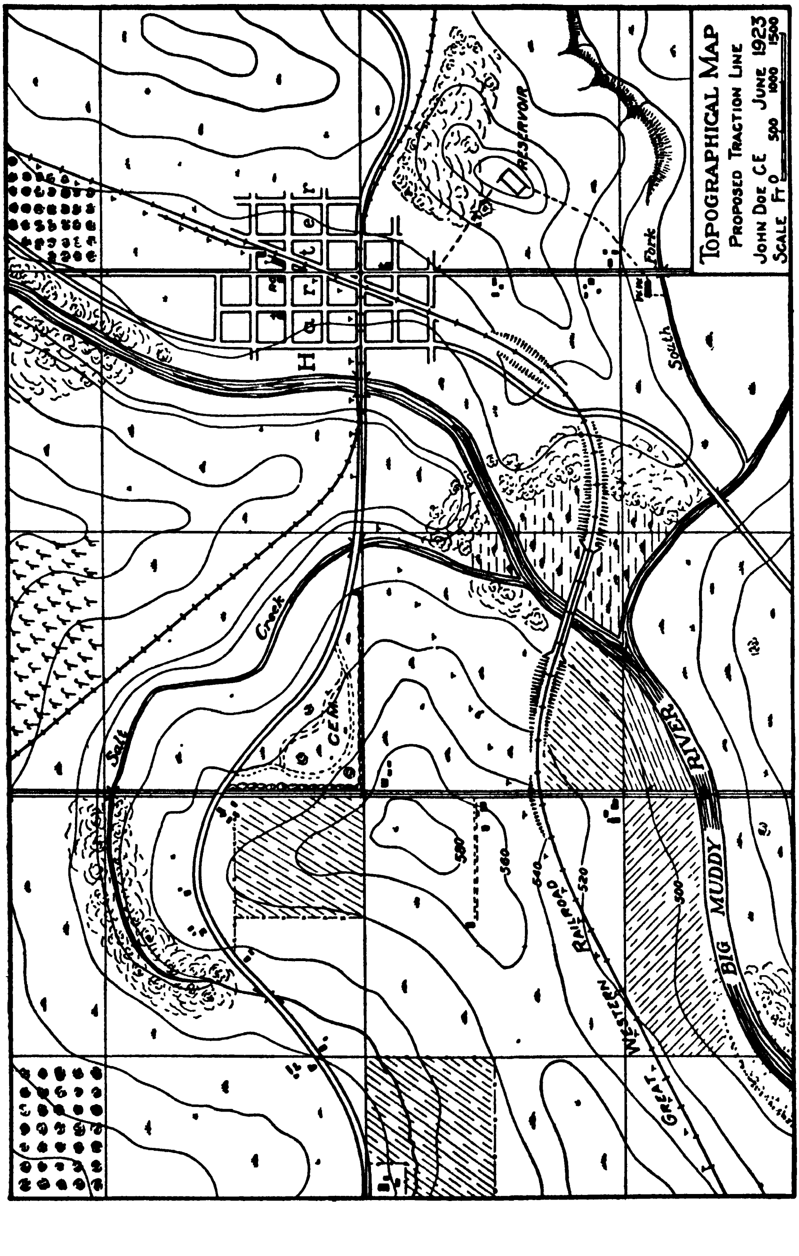

FIG. 2. Topographical map.

desert regions of the West. The large-scale maps show all natural features down to the little streams which run dry in the summer. Civil boundaries, city streets, country roads, tunnels, aqueducts, bridges, houses, and all the works of man of a permanent nature, are shown, together with permanent vegetation, such as forest areas. A portion of a topographic map is shown in Fig. 2. Elevations are shown in a definite manner by the use of contour lines. Topographic maps are frequently made to scales ranging up to 6 inches or more to the mile. The term "topographic" is sometimes applied to maps which include only a few of the features mentioned above.

325. Cadastral Maps. — Maps of this class are used primarily for showing political and civil boundaries, together with property lines, and are used for the purposes of taxation and the transfer of property. Hence,

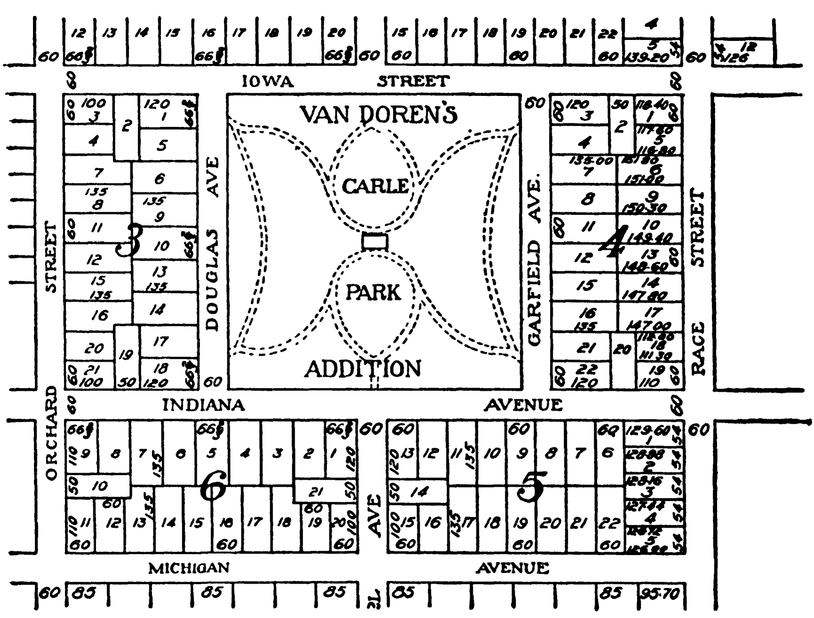

FIG. 3. City plat, cadastral map.

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. A small portion of a city plat is shown in Fig. 3. The scale for such maps is usually greater than 6 inches to 1 mile.

326. 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, $\frac{1}{8}$ inch equals 1 foot. Maps for railroad, highway, canal, or hydro-electric construction are excellent examples of this class of maps. Such maps frequently have the character of topographic maps in that they include practically all of the natural

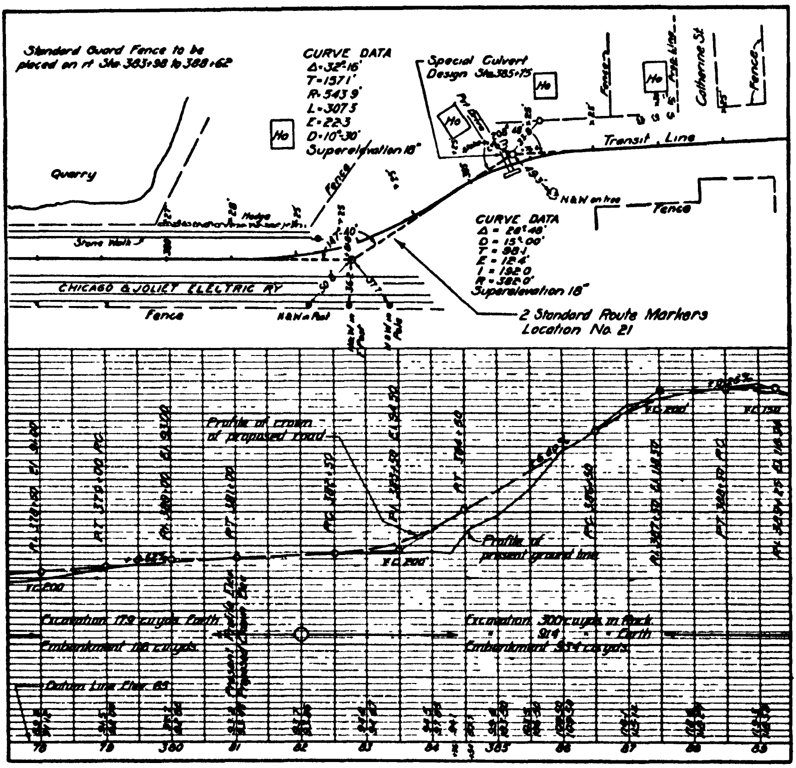

Fig. 4. Highway map.

features, vegetation, 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. 4, and a railroad station map in Fig. 5.

Still other classifications might be made; but usually further distinctions are in reality but subdivisions of one of the four classes given above. Thus, military maps are really general topographic maps with certain features emphasized, while hydrographic maps are engineering maps applied in particular to water-development purposes. Contour maps, showing only

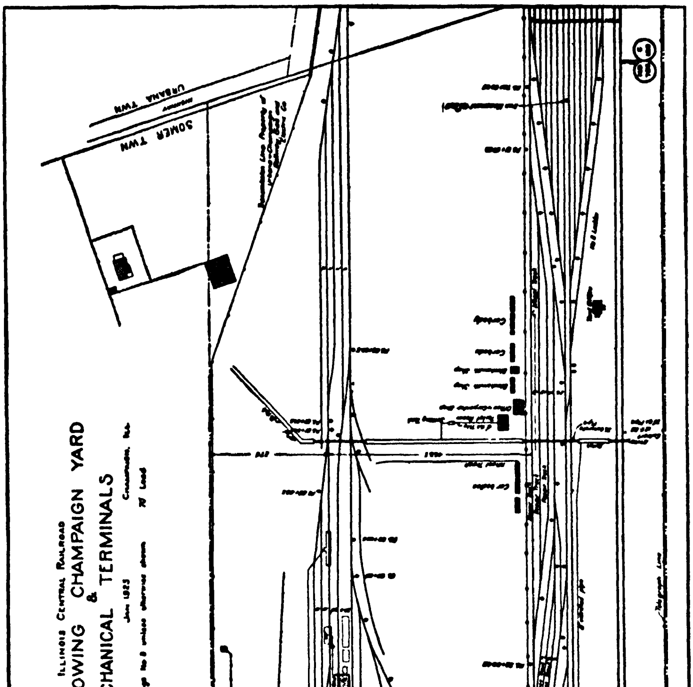

FIG. 5. Railway yard and terminal map.

elevations, are engineering maps and are usually employed for location purposes.

327. Map Scales. — From the foregoing classification of maps, it will be noted that scales are used ranging from 0.1 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. Sometimes the numerical scale is stated as a ratio which is always given in terms of inches. Thus, a scale of one inch to the mile is expressed as 1:63,360. United States Government maps are made on scales of 1:62,500, 1:125,000, or 1:250,000.

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 boxwood 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.

328. 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

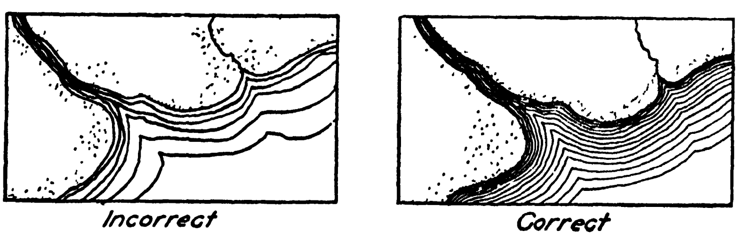

Fig. 6. Incorrect and correct water lining.

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 all map-making departments of the government, is published in a small booklet called "Conventional Signs," published by the War Department as Document

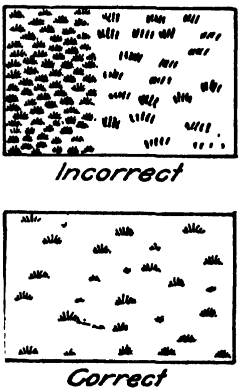

FIG. 7. Grass.

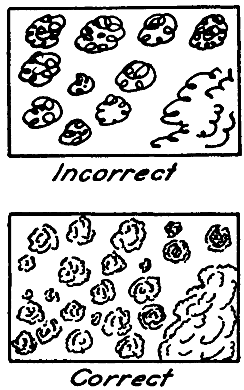

FIG. 8. Deciduous trees.

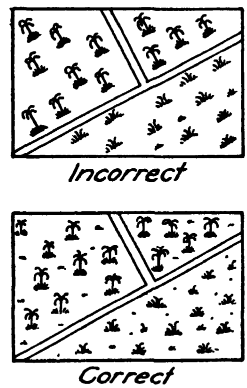

FIG. 9. Palm trees and tropical grass.

No. 418. The sizes of the symbols shown in this booklet are for maps made to a scale of 1 inch to the mile.

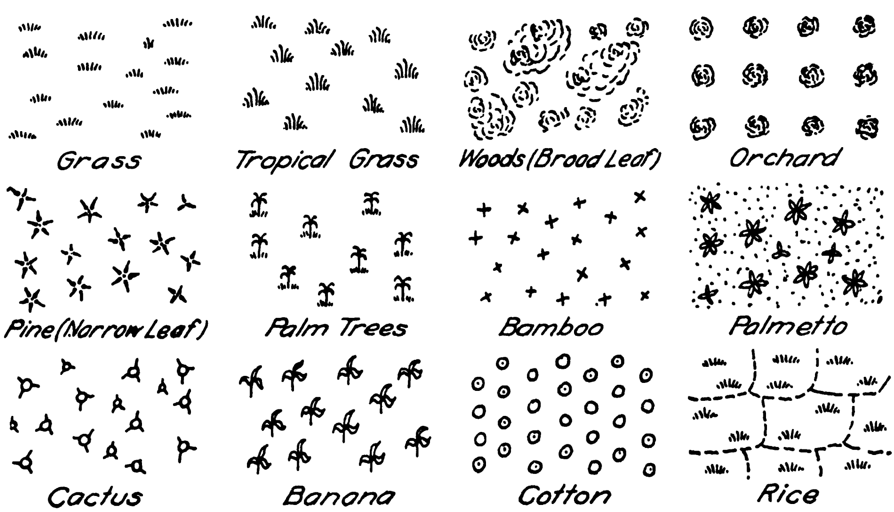

FIG. 10. Vegetation symbols (green).

329. 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. 10 to 16 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.

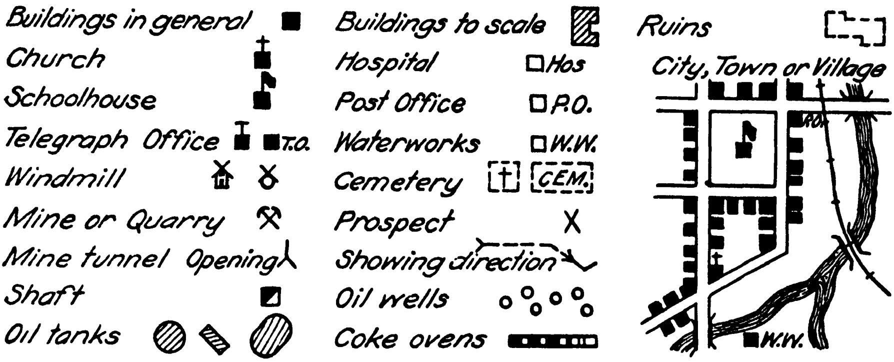

FIG. 11. Buildings (black).

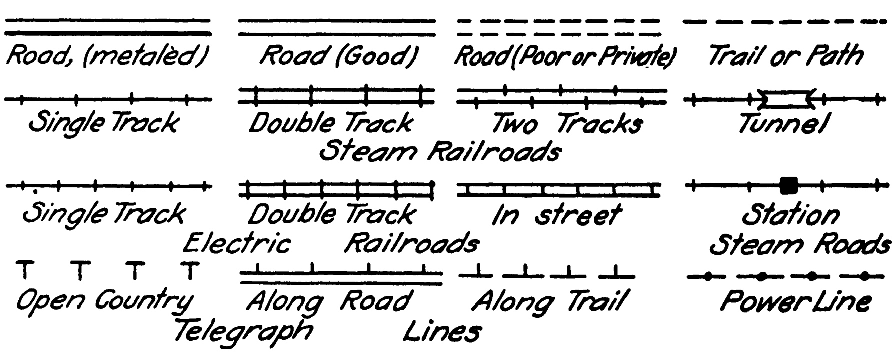

FIG. 12. Roads and communication lines (black).

330. 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 most 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. 6 will make clear that the first lines are drawn very near to the shoreline and follow it around very closely, while the lines become farther apart and less irregular as we approach the center

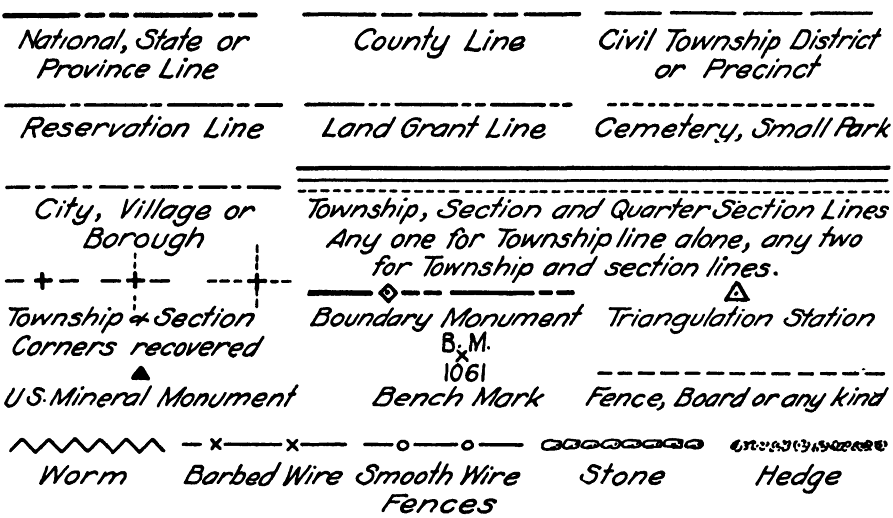

FIG. 13. Civil boundaries (black).

of the body of water. Examples of both correct and incorrect water lining are shown in Fig. 6.

Similarly, a careful examination of the symbol for grass in Fig. 7 will show that it consists of about seven short strokes, ranging in length from

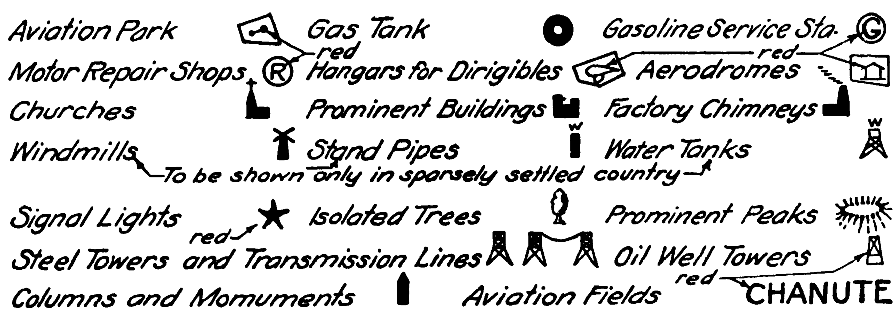

FIG. 14. Aviation symbols (black except where otherwise noted).

almost a dot at the ends to about $\frac{1}{32}$ 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. 7, in contrast with a correct execution. Likewise, the result of poor observation of the tree symbol is shown in Fig. 8.

331. Colors of Symbols. — On a finished map, the symbols should be shown in colors. The color for each symbol in Figs. 10 to 16 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 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

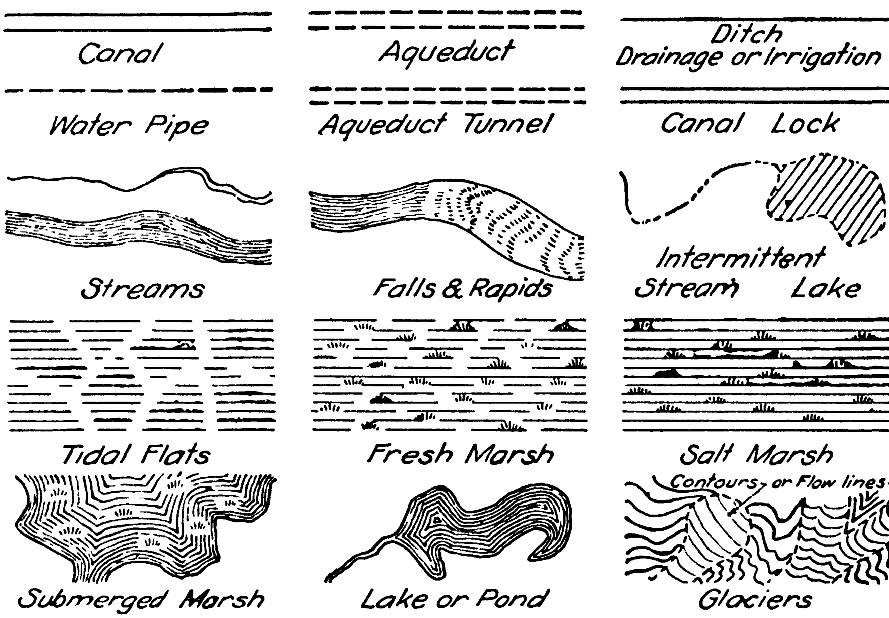

FIG. 15. Hydrographic symbols (blue).

the cost. Since vegetation, except very large forests, is not permanent, the green is usually omitted.

332. Spacing of Symbols. — One of the greatest difficulties in drawing symbols is to learn how to space them. 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.

333. Position of Symbols. — Another very important point is the position of the symbols on the sheet. All symbols which have a definite

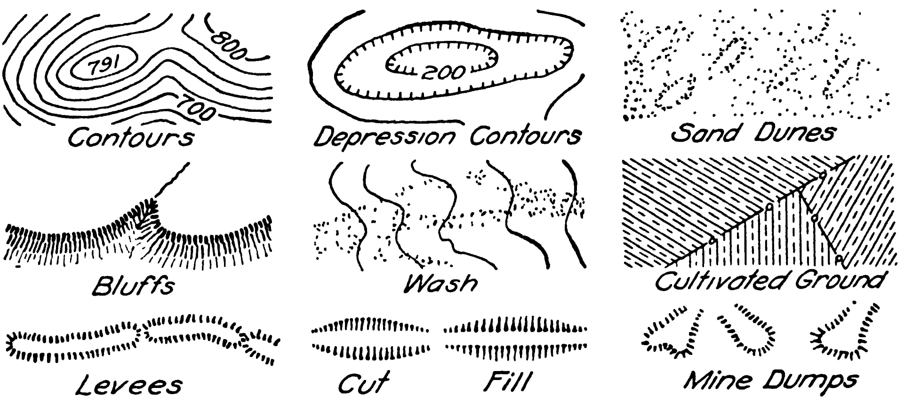

FIG. 16. Relief symbols (brown).

base, as for example, grass, marsh, palm trees, corn, etc., 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. 9. Symbols

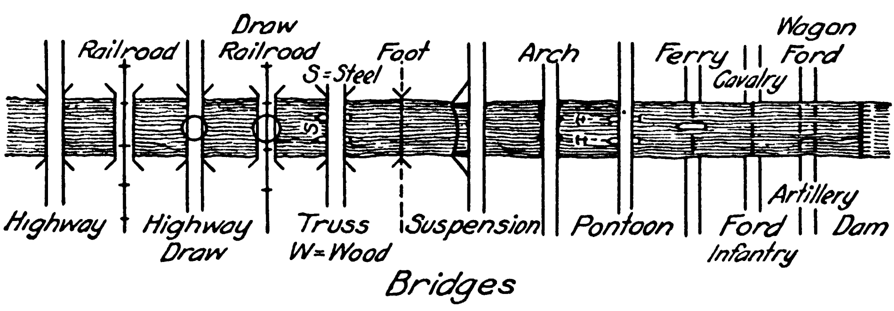

FIG. 17. Bridges and fords (black).

for vegetation which occurs in rows, however, may have the rows running in any direction.

334. SPECIAL SYMBOLS. — For some purposes, special symbols must be devised. Thus, for purposes of aerial navigation, a map must show clearly those objects which project up into the air and may be obstructions to flight. Some of these symbols is shown in Fig. 13. Such objects as roads, railroads, railway stations, rivers, lakes, woods, telegraph lines, and the like, 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.

335. 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 coördinate method.

336. 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.

℄ 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. 18. Typical survey notes.

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. 18. 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. 19 to be Sta. 2 and the line *BA* the "back-sight." 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

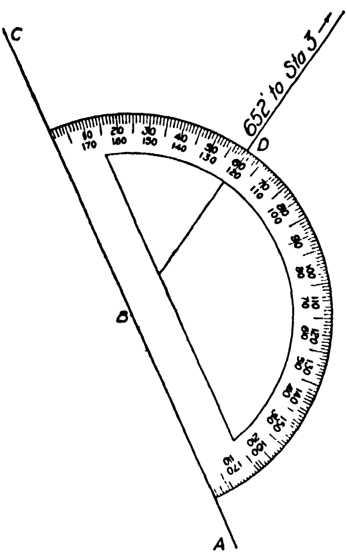

Fig. 19. Angles by the protractor method.

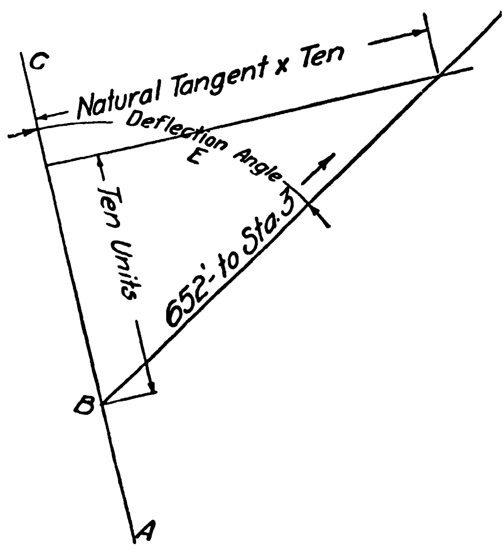

Fig. 20. Angles by the tangent method.

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.

337. Tangent Method. — This method is more accurate for the plotting of angles, but requires more time; hence, it is generally used for plotting traverses, while 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, 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 ten, which is 16.429. 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 degrees, 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 per-

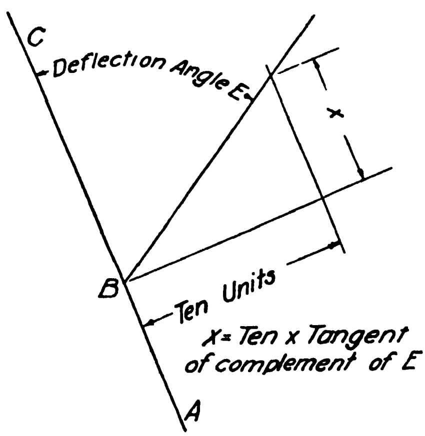

FIG. 21. Angles by the tangent method. Complement of angle used.

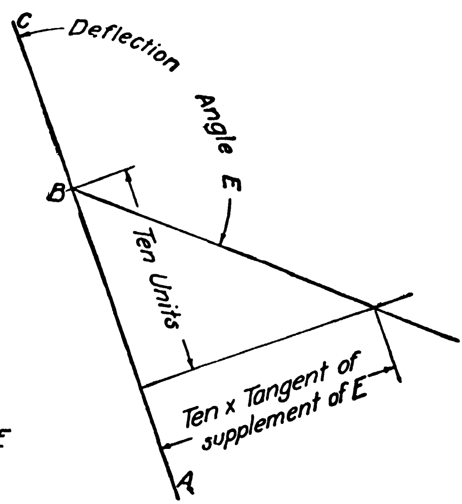

FIG. 22. Angles by the tangent method. Supplement of angle used.

pendicular on which may be laid off a distance equal to ten times the tangent of the complement of the angle as shown in Fig. 21.

If the deflection angle is greater than 90 degrees, the ten-unit line must be laid off between *B* and *A*, as shown in Fig. 22, and the tangent of the supplementary angle must be used.

338. Rectangular Coördinate 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 text. Complete information concerning this method may be found in surveying texts.

339. 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.

340. 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 of 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. 23, 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.

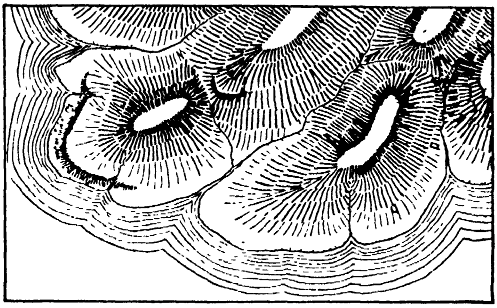

Fig. 23. Hachures.

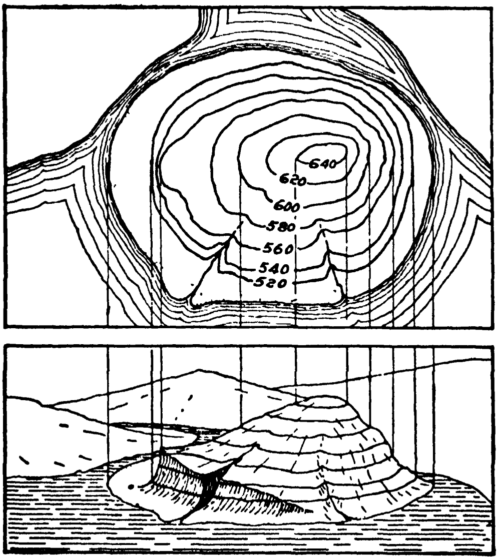

Fig. 24. Meaning of contour lines.

341. 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. 24, 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.

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.

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

2. 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. 16 and 25.

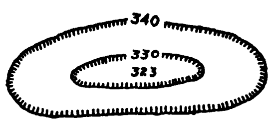

FIG. 25. Depression contours.

3. Contour lines never cross.

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

5. 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.

6. 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.

7. 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.

8. 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.

9. 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 the same color of ink 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. 24. 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. See Fig. 26. The point of this pen is on a swivel which allows it to turn freely in any direction.

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 Fig. 25.

342. 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 1 shows a portion of a topographic map taken from a United States Geological map of the Bloomsburg Quadrangle in Pennsylvania.

The dotted line delineates the watershed of the storage basin formed by the dam which is represented by the heavy black line in the figure. The cross-hatched portion indicates the area which will be inundated. The area of the watershed may be determined either with a planimeter or by ruling coördinates of a known size across the area and then counting the squares. The area of the fractional squares around the margin must be estimated. The size of the squares should be in some convenient unit such as 1 square mile, $\frac{1}{4}$ square mile, or 100 square feet, depending upon the size of the area.

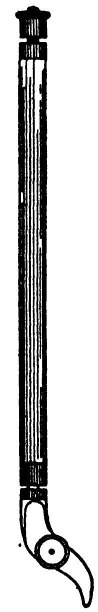

FIG. 26. Contour pen.

The volume of water stored behind the dam may be computed by obtaining the area enclosed by successive contour lines and the dam. The volume between any two contour lines is obtained by taking the average of the areas enclosed by two contour lines and multiplying it by the contour interval. The total is then the sum of these composite volumes. When greater accuracy is required the prismoidal formula should be used.

343. PROFILES. — A profile is a line, usually drawn on coördinate paper, 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 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.

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 coördinate paper called profile paper, in which the spacing of coördinates 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 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, while the difference of elevation varies only over a few hundred feet, it is quite evident, therefore, that a scale which would bring the horizontal length

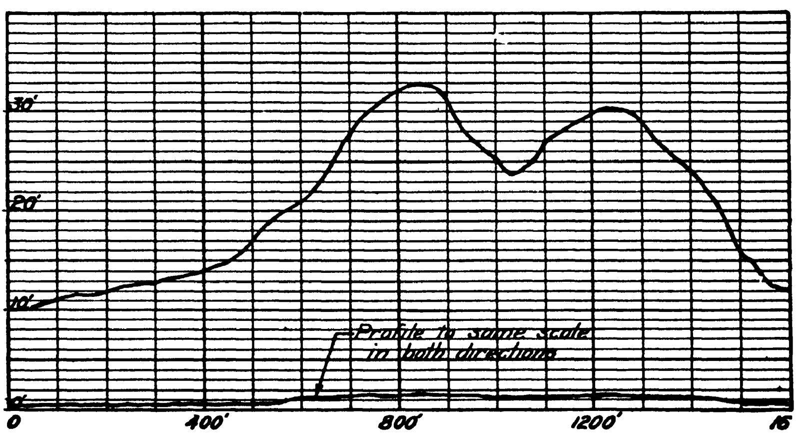

FIG. 27. Profile lines contrasted.

within workable limits, when applied to the vertical distances, would make them so small as to be insignificant. Figure 27 shows a profile plotted, first, to the same scale in both directions, and second, to two different scales. From an observation of these figures it is quite clear that the second scheme is the only one of practical value.

344. 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 of the curve are shown, and the degree of curvature is indicated, as in Fig. 28.

345. Profile Papers. — Profile paper is furnished to the trade in three standard rulings, 4 and 20, 4 and 30, and 5 and 25 lines to the inch. It is prepared in 220- and 50-yard rolls, 9, 10, and 20 inches wide, but it may also be obtained in sheets measuring 15 by 42 inches. The sheets are

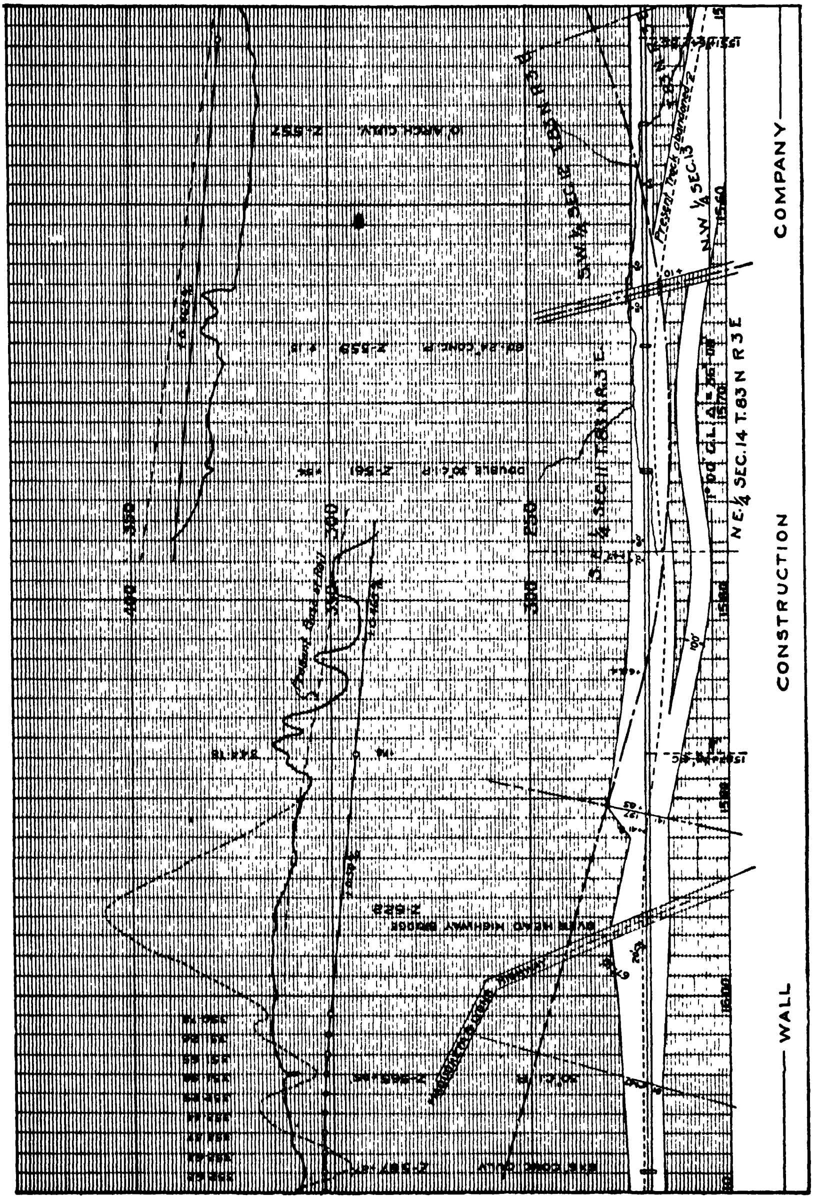

FIG. 28. Railway profile.

printed on drawing paper only, but the rolls may be had in drawing paper, tracing paper, tracing cloth, or paper mounted on muslin. There is also a paper called plan profile paper. It comes in 20-inch widths but only one-half the width is printed, the other half being left blank for plans and sketches. This kind of paper is used in highway work.

346. 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. Thus a 1 per cent grade is a line which rises at the rate of 1 foot in a horizontal distance of 100 feet. A 0.5 per cent grade indicates a rise of $\frac{1}{2}$ foot in 100 feet. 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.

347. VERTICAL CURVES. — In lines of any considerable length a uniform grade cannot be maintained from end to end. While two grade lines of different slope will intersect in a point, in actual construction they

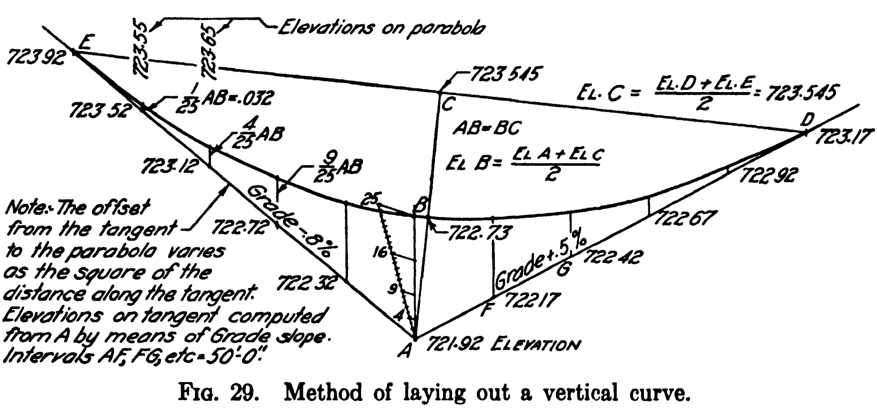

FIG. 29. Method of laying out a vertical curve.

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. 29. 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. 29) may be determined from the grade lines, and the elevation of the midpoint 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, the center of the curve, being known, offsets at the other points may be computed as shown in the figure.

348. Horizontal Curves. — When railroads and highways change direction, the change is accomplished by means of circular curves which 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 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.

349. Abbreviations and Common Map Terms. — The following terms and 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.

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.

Azimuth of a line. — The angle which the line makes with a north and south line measured clockwise from the south.

Station. — In railroad and highway work, stakes are driven along the center line every 100 feet for purposes of construction. These stakes are numbered and referred to as stations.

350. 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 at this style of lettering. The styles of lettering used by the map-making departments of the government for different features are shown in Figs. 30 to 34 inclusive.

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 so placed, as far as conditions will permit, that it may be readable from the bottom and right-hand side of a drawing.

ABCDEFGHIJK
LMNOPQRSTU
VWXYZ

States, Counties, Townships, Capitals and Principal Cities (all capital letters)

abcdefghijklmnopqrstuvwxyz

Towns and Villages (with capital initials)

FIG. 30. Map alphabets, civil divisions.

ABCDEFGHIJK
LMNOPQRSTU
VWXYZ

Lakes, Rivers and Bays (all capital letters)

abcdefghijklmnopqrstuvwxyz

Creeks, Brooks, Springs, Small Lakes, Ponds, Marshes and Glaciers (with capital initials)

FIG. 31. Map alphabets, hydrography.

351. 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 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.

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

ABCDEFGHIJKLMNO
PQRSTUVWXYZ

Mountains, Plateaus, Lines of Cliffs and Canyons (all capital letters)

abcdefghijklmnopqrstuvwxyz

Peaks, Small Valleys, Canyons, Islands and Points (with capital initials)

FIG. 32. Map alphabets, hypsography.

ABCDEFGHIJKLMNOPQRSTUVWXYZ

1234567890

Railroads, Tunnels, Bridges, Ferries, Wagon-roads, Trails, Fords and Dams (capitals only)

FIG. 33. Map alphabets, public works and contour numbers.

ABCDEFGHIJKLMNOPQRSTUV
WXYZ

abcdefghijklmnopqrstuvwxyz

(with capital initials)

FIG. 34. Map alphabets, marginal lettering.

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PROBLEMS

352. In the following problems, extreme care should be exercised in the layout of the traverses and in the plotting of the artificial features of the base maps, to ensure the necessary accuracy in closure and the proper position of profiles and grade lines. Error in the first problems will vitiate the results of later ones.

1. From the survey notes on Figs. 35, 36, 37, and 38 draw a topographic map. Use a scale of 1″ = 200′ and sheet size A: 12″ × 18″. First plot the traverse by the tangent method and have it checked. The traverse should close back on Sta. 0 within less than 20′ to scale. Then put in all topographic details, other than relief, by the protractor and scale method. When these details are completed, plot the contour points and draw the contour lines. Finally, put in the vegetation with the proper symbols in pencil and have all work checked. When the pencil work has been approved, ink in the map in proper colors. Reserve a space in the lower right-hand corner of the map for an unenclosed title. This is to be done in modern Roman letters of suitable size for the map. The contents of the title shall be selected by the student.

2. Same as Prob. 1, Figs. 39, 40, 41, and 42. Use a scale of 1″ = 400′.

3. Draw a horizontal and vertical center line very lightly on a small drawing sheet (8½ × 11 or 9 × 12), and then with these lines as coordinates plot the points shown in Fig. 43. The horizontal numbers are abscissas and the vertical numbers are ordinates. At each point, letter the elevation which is given by the inclined number. When all points have been plotted, draw in the contour lines at 10′ intervals, beginning at the lowest integral multiple of ten and ending on the highest. Assume that the slope of the terrain is uniform between plotted points. Show streams, buildings, streets, and railroad line in proper colors. Scale 1″ = 400′.

4. Same as Prob. 3, Fig. 44.

5. Secure a piece of standard profile paper and trim a sheet 5″ × 15″. Draw a border line 1″ from the left-hand short edge and ½″ from the other three edges. On this sheet, plot the profile along the railroad center line on the contour map made in Prob. 3, Fig. 43. Draw the profile line freehand through the plotted points. Estimate the elevation of points between contour lines upon the assumption that the ground slopes uniformly between lines. Vertical scale 1″ = 10′–0″; horizontal scale 1″ = 400′.

6. Same as Prob. 5, using the contour map made in Prob. 4, Fig. 44.

7. On the profile drawn in Prob. 5, lay out the grade lines as specified in Fig. 43. Draw the necessary vertical curves, each 400′ long. Compute the elevation at each station on the curve to the second decimal place, and letter it neatly on the corresponding station, as illustrated in Fig. 28.

8. Same as Prob. 7, using the profile of Prob. 6, Fig. 44.

9. Examine the contour map made in Prob. 3 and locate a new road center line which shall be more economical of construction or operation than the one shown. The new line must fulfill the following conditions:

a. It shall pass the building at the corner of Main and State Streets on either street. The elevation and grade of the street must not be changed within the city between present streets.

b. It shall connect again with the present line so that it will have the elevation, or grade and elevation, specified at the opposite end of the line from the city as given in the original map, Fig. 43.

c. Cut and fill shall be balanced as nearly as possible.

d. The maximum grade shall not exceed 1%, nor shall there be more than two changes of grade. Vertical curves shall not be less than 800′ long.

e. The maximum horizontal curve shall not exceed 6°.

10. Same as Prob. 9, using the contour map of Prob. 4, Fig. 44.

11. On a small drawing sheet (8½ × 11 or 9 × 12), make a study of twelve assigned symbols. Enclose them in small rectangles, and letter under each the name of the symbol.

Station	Defl. ∠s	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	149°30'L	1125'
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		

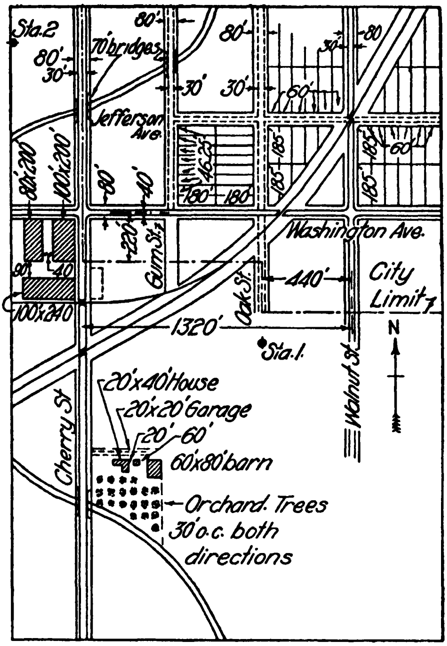


FIG. 35. Survey notes, map A.

Station	Defl. ∠s	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	10°00'R	755'
⊙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'

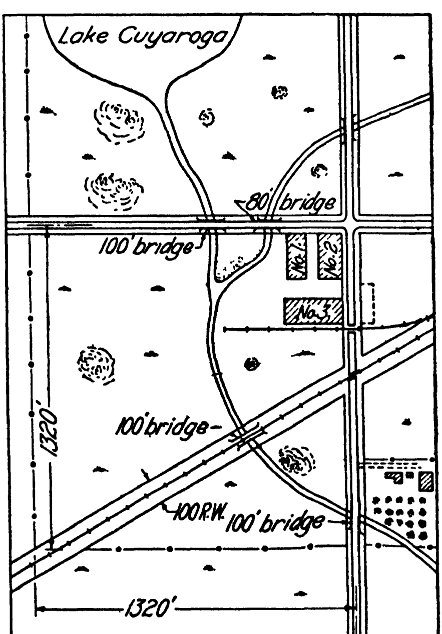


FIG. 36. Survey notes, map A.

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
Δ 2	135°55'	H.I. 4.7	1618			706.8

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.

These notes to be read down the page.

FIG. 37. 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
Δ 3	26°25'		1669'			697.2
Shot 1	2°45'		622'			699.2
2	66°50'		630'			706.2
3	" "		259'			701.4
4	137°45'		886'			700.6
5	154°32'		1410'			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'		1005'			696.1
13	305°55'		468'			694.0

Water level of lake 692.3

FIG. 38. Topography notes, map A.

Station	Defl. ∠s	Distance
West bank at 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	5°15'L	1285'
O2	48°45'R	2700'
PC on RR line	137°40'R	2420'
PC on ℄ of highway	118°15'R	1495'
PT on RR line	85°00'R	1535'
℄ of RR line	7°20'L	1915'
O1	50°30'R	3040'
Center of highway bridge	180°00'R	250'
PS on RR	159°30'R	490'
PT on RR 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.

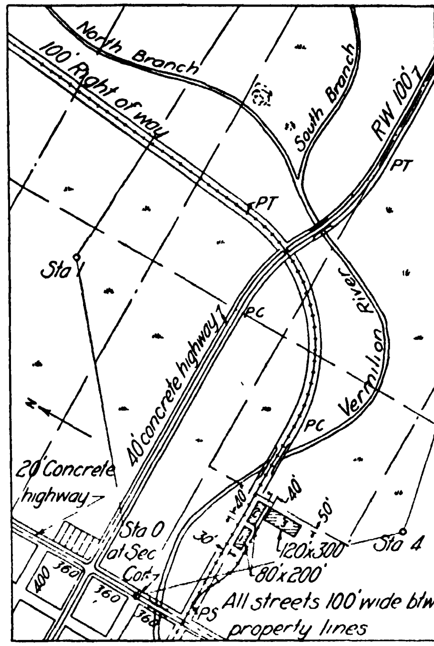


FIG. 39. Survey notes, map B.

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'

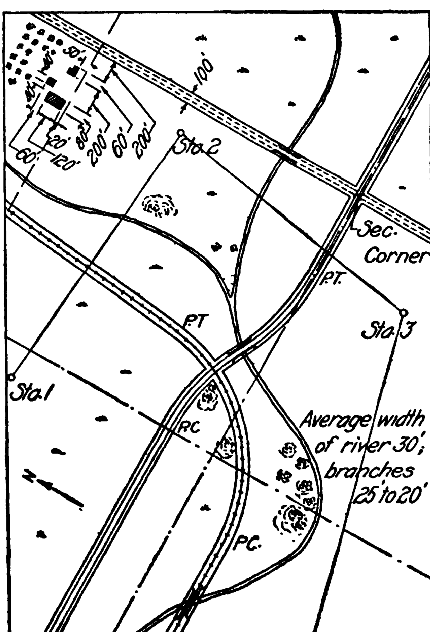


FIG. 40. Survey notes, map B.

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
Δ 1	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
Δ 2	279°15'	H.I. 4.6	2700			467.6

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

These notes read down the page.

FIG. 41. Topography 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	" "		1107			480.0
29	243°00'		910			473.8
30	264°45'		934			466.2
31	284°15'		1180			460.0
Δ 3	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
Δ 4	69°45'	H.I. 4.3	3040			462.1
37	16°30'		354			465.0
38	" "		775			468.9
39	" "		1180			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. 42. Topography notes, map B.

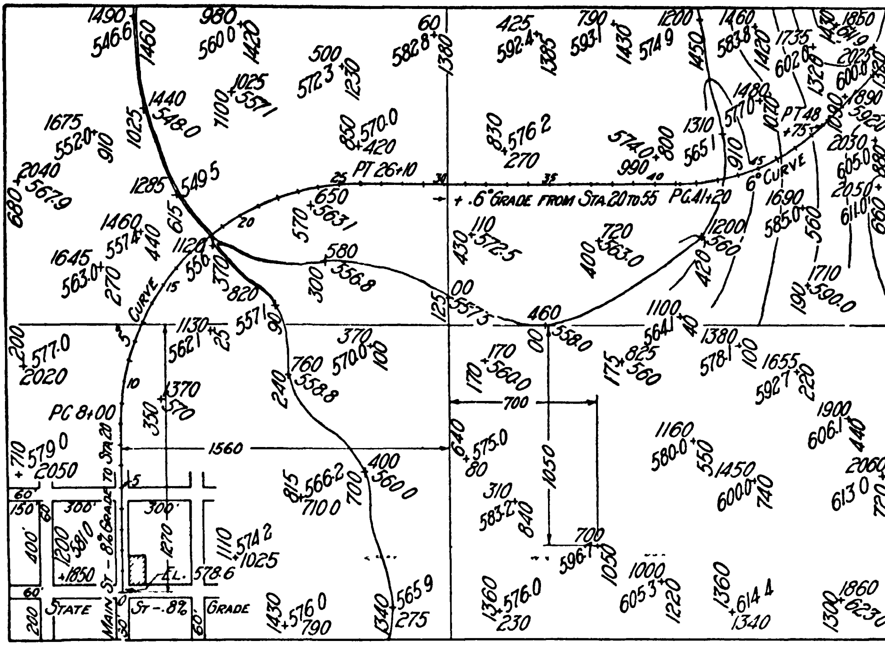


FIG. 43. Topography data, map C.

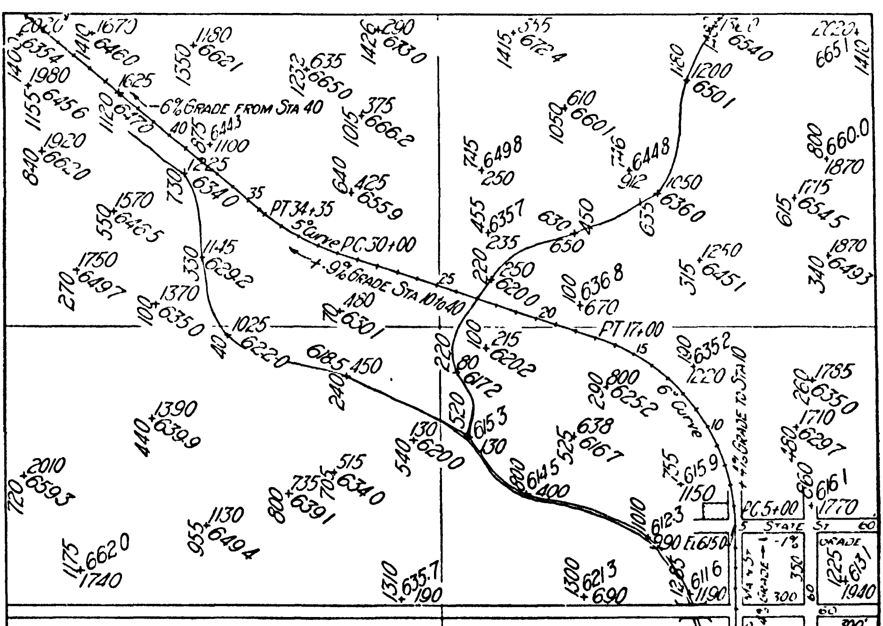


FIG. 44. Topography data, map D.

CHAPTER XXI

ARCHITECTURAL DRAWING

353. In the course of a few years' practice, every engineer, whether he be in civil, mechanical, electrical, or other special branches of engineering, will have occasion to use architectural working drawings; and it may happen that it will be necessary for him to make house or industrial building plans on his own responsibility. A general knowledge of architectural drawing will be valuable to any engineer, especially if he does contracting work.

Architectural drawing covers a wider field than that included in the term working drawings, but it is the purpose of this chapter to cover only that phase of it which interests the engineer from a practical standpoint. It is intended to leave to more extended treatises those questions which relate to art and design and to that phase of the architect's work having to do with the preparation of display drawings which depend for their effectiveness upon some method of rendering in shades of light and dark

As stated elsewhere in this text, the fundamental principles underlying all projection drawing are the same, but the peculiarities of expression may vary considerably. Although these variations in expression are not the main points to be emphasized, yet they should be understood in order to read an architectural drawing intelligently.

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 and to the fact that a plan must be made for each floor, the architect seldom thinks of his work in terms of 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. For example, in making the *four* elevations of a building, it is simpler to think of just one plane at a time placed parallel to the face of the building we wish to draw.

Usually, only one plan or elevation is drawn on a sheet; hence, instead of projecting from view to view as in machine drawing, the architect must resort to measurements which must be made according to the rules of projection.

A bottom view is used perhaps more frequently in architectural than in machine drawing. It is sometimes called a "reflected" view or a "plan looking up," and represents what would appear if one should look down in a mirror placed under the object or should look up at the under side. This is frequently done to show the detail of cornice or ceiling. See Fig. 1.

According to the purposes for which they are used, 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.

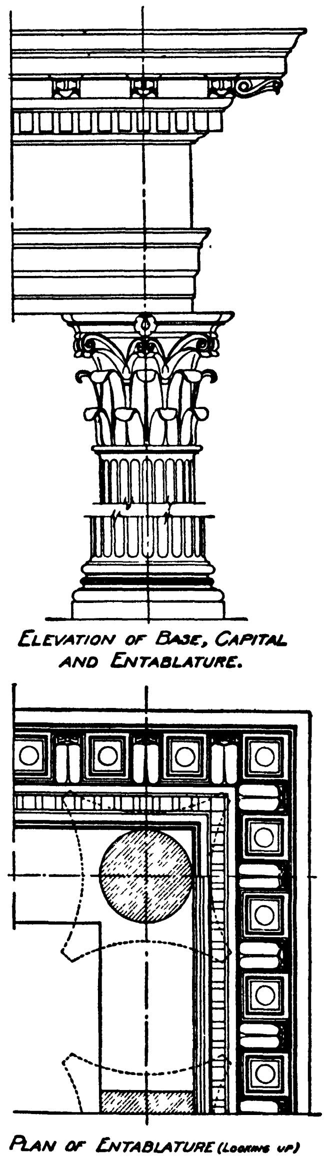


Fig. 1. Plan looking up.

354. 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 $\frac{1}{16}$ or $\frac{1}{8}$ 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 comparison of different floor plans can be readily made by placing one over the other.

355. 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, clouds, etc., the whole drawing being a problem in art, designed to secure the most pleasing effect and to show the building to the best advantage.

The floor plans are generally rendered in Poché and Mosaic. By Poché is meant the coloring of the walls black to make them stand out prominently; Mosaic refers to floor designs, furniture, gardens, walks and drives, which are rendered in lighter tints and tones, as in Fig. 2.

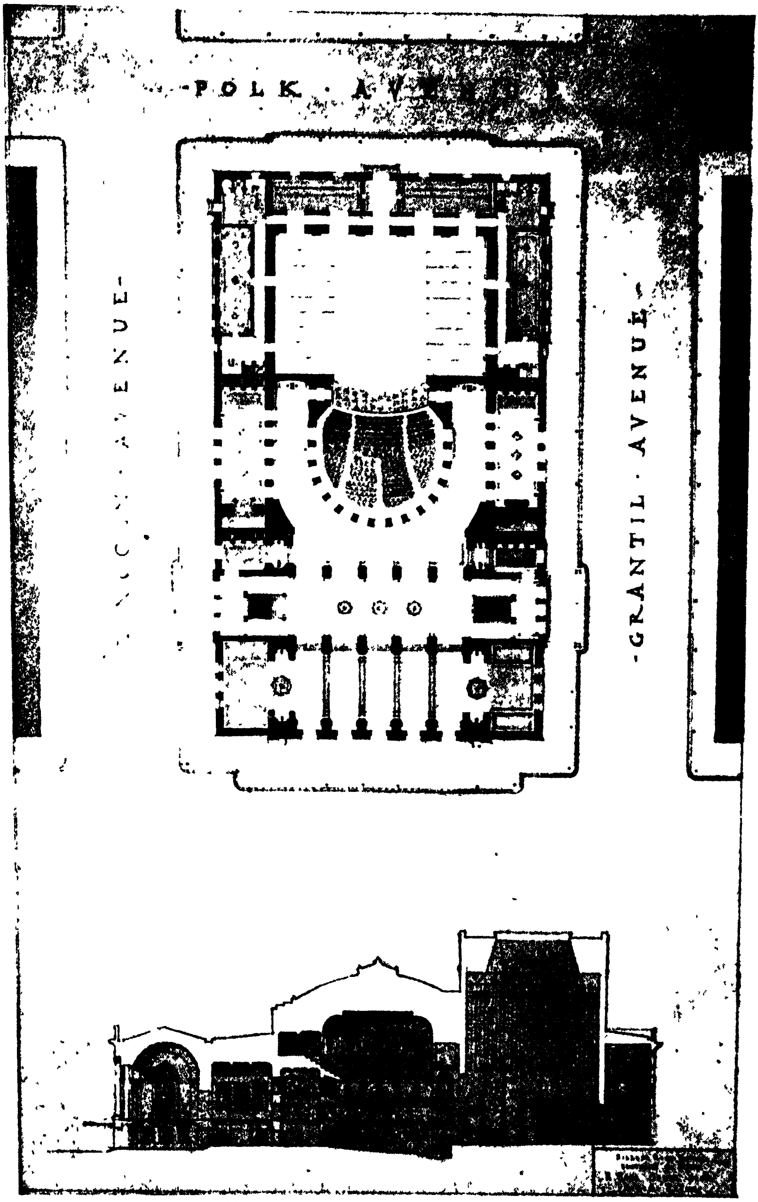
An ordinary front elevation may be made quite realistic by indicating the shades and shadows on the building and by putting in a foreground in parallel perspective.

Display drawings are not dimensioned, but the scale is represented graphically. They contain very little information that could be used by the builder. An example of a display drawing, submitted in a competition, is shown in Fig. 3.

356. 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 accurate estimates of cost can be made and from which the building can be constructed. They must, therefore, be accurately made to scale and include all necessary details and dimensions.

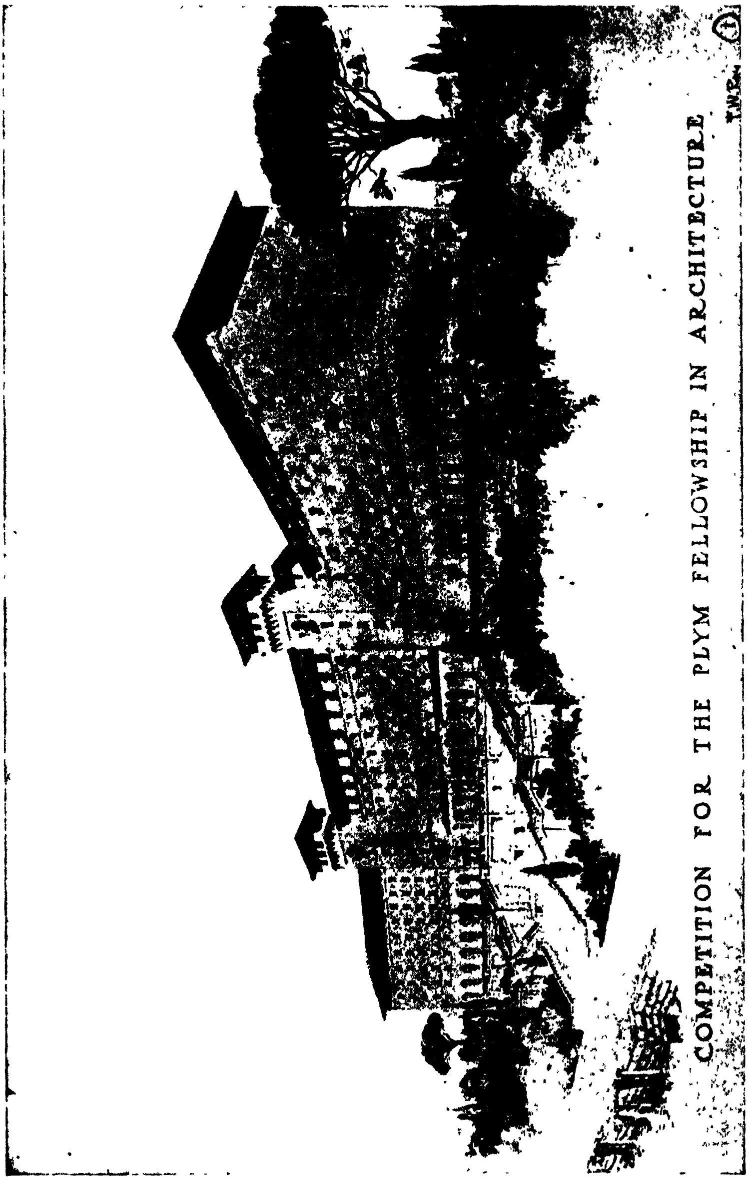
A complete set of working drawings, or set of plans, as they are sometimes called, will include the following six or more sheets: Plot Plan; Basement or Foundation Plan; Floor Plans in order — first, second, third, and so on, not duplicating, of course, where the floors are exactly alike; Four Elevations — 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 steel or of reinforced concrete, and separate plans for the plumbing and the heating and ventilating.

357. 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. The building is 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, walks and driveways, and any outbuildings to be constructed. If the building site is hilly, the elevations are shown by contour lines, and any



(Courtesy Department of Architecture, University of Illinois.)

FIG. 2. Display drawing, rendered in poché and mosaic.



(Courtesy Department of Architecture, University of Illinois.)

Fig. 3. Display drawing.

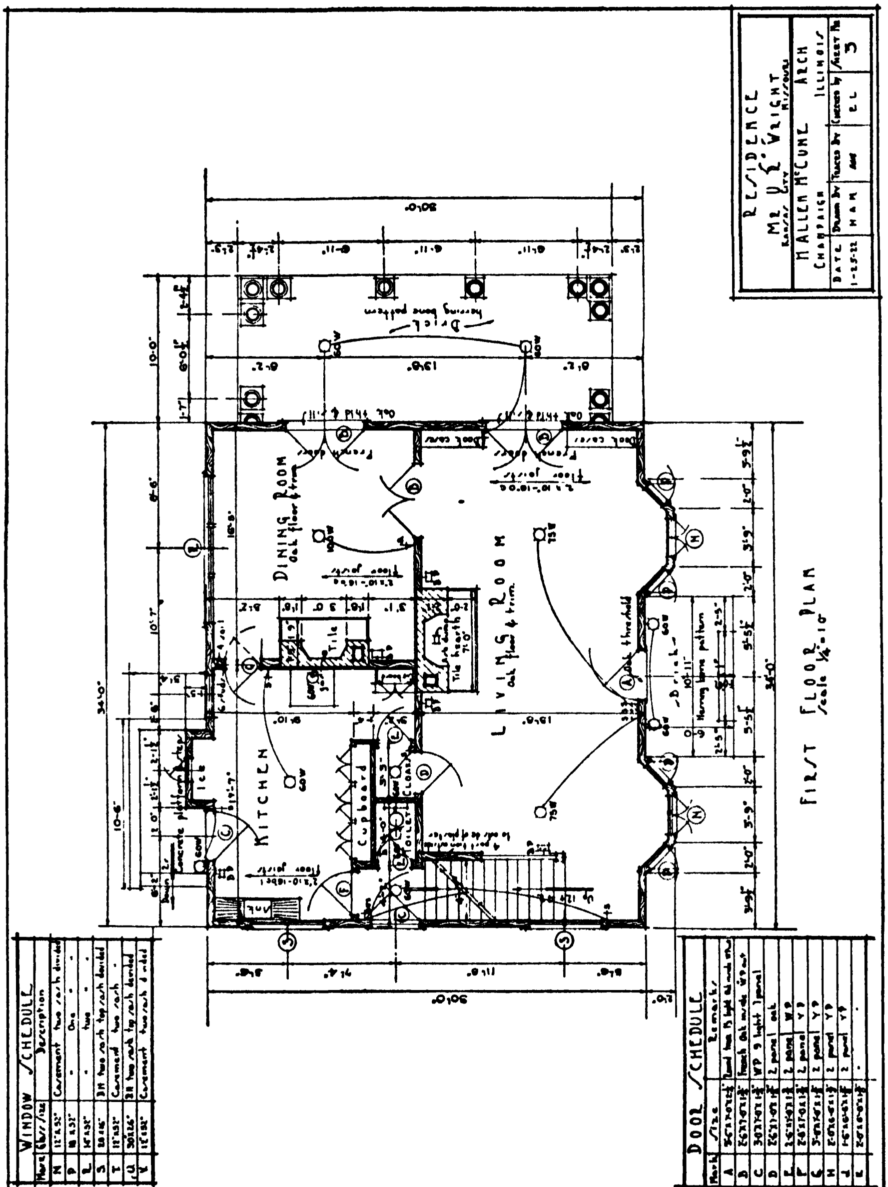
grading which may be necessary is indicated. This sheet, like the others, contains in the lower right-hand corner the architect's standard title, and at some convenient place on the sheet an arrow indicating the north point.

358. 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. It will show all the interior walls and the built-in features which are included in the building contract, such as the plumbing fixtures, special cases, cabinets, and the like. The location of heat outlets or ventilating ducts must 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 floor above and the floor below, either more or less as the conditions may require, and by marking upon the drawing the full number of risers. An illustration is shown in the floor plans in Figs. 4 and 5. Two consecutive floor plans must, therefore, show completely the stairway connecting them.

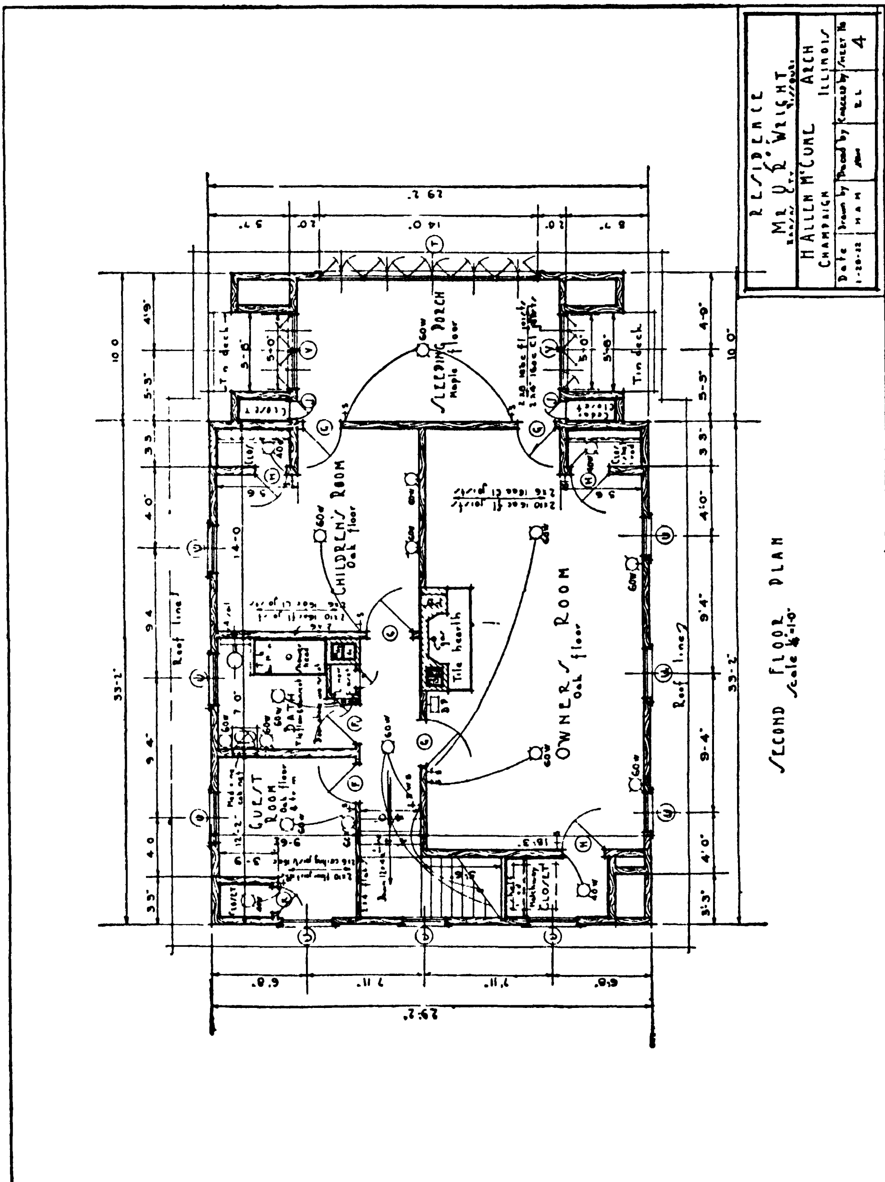
Stairways are frequently worked out to a large scale in order to make sure that they will properly fit in the space allowed. A common rule for proportioning the risers and treads is to make the sum of two risers and one tread equal 25 inches. Seven to eight inches is a maximum height for a comfortable 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 supporting the fourth floor would be indicated on the third floor plan. This, of course, does not apply where a special set of framing plans is prepared. Ceiling lights and outlets are indicated in the same way, by locating them on the plan of the floor below. The actual



(Courtesy Department of Architecture, University of Illinois.)

FIG. 4. First-floor plan.



(Courtesy Department of Architecture, University of Illinois.)

FIG. 5. Second-floor plan.

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, provision for conduits, piping, and ventilating ducts must be provided for in advance.

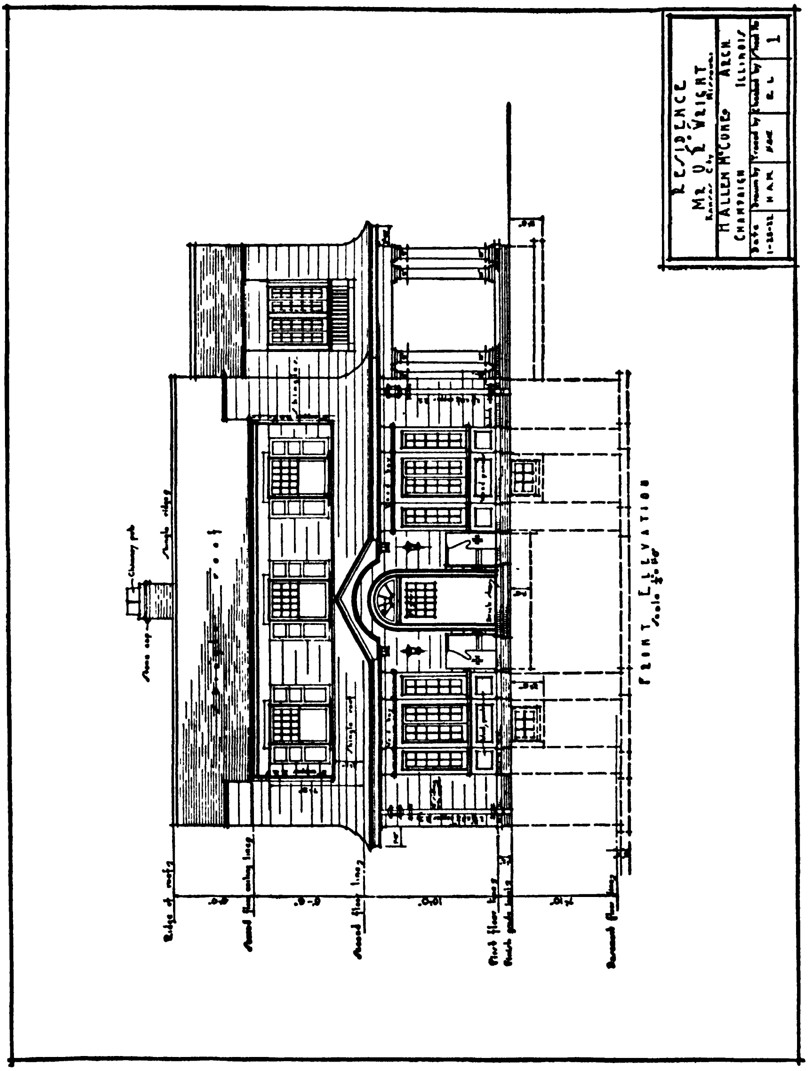
It has become an established practice to draw the floor plans so that the front of the building is toward the bottom or right edge of the sheet, depending upon the shape and size of the building. Elevations should read from the bottom of the sheet, or the right-hand edge in some instances.

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.

359. Elevations. — The elevation of a building is simply a projection of any side upon a vertical plane parallel to it, and shows the story heights, all openings in the outside walls, and the nature of the outside finish, such as stone, brick, ornamental iron, etc. Unless the sides of a building are identical, each elevation should be drawn. Where ornamental designs are worked out in brick, the general arrangement and location is shown on the elevation, and the exact construction is shown in a large-scale detail drawing. The portion of the building below the grade line is shown in dotted lines, as are also roof lines which may be concealed behind parapet walls. On elevations of small buildings, stairways are sometimes drawn in dotted 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 those in a vertical direction. 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. Figures 6 and 7 show the elevations of a frame building.

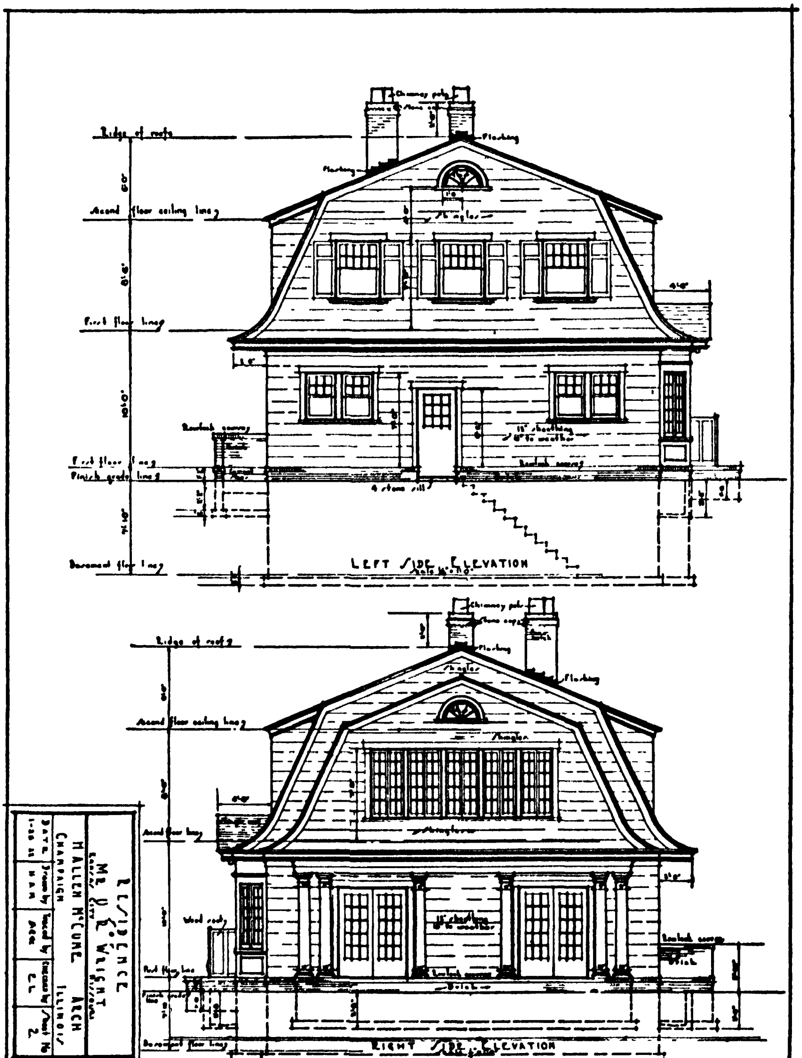
The elevations are given life and snap by shade lining and touches of ruled-line rendering to suggest the texture of the surface. This ruled-line rendering must be soft and subdued, and not an attempt at a rigid representation, as in machine drawing. By the term shade lining, used above, is meant making heavier and more prominent those lines and edges of the building which cast a shadow, or those lines which separate surfaces in shadow from those which are in direct light.

When the façade or front of a building is symmetrical about its center line, time and labor may be saved by making only one half of the front elevation and devoting the other half to a section.



(Courtesy Department of Architecture, University of Illinois.)

FIG. 6. Front elevation.



(*Courtesy Department of Architecture, University of Illinois.*)

FIG. 7. End elevations.

In making elevations, time can be saved by laying a narrow strip of tracing paper over the side of the floor plan and marking off the window and door openings and other features which must appear on the elevation. This strip can then be transferred to the elevation and the location and width of openings quickly marked off.

360. SECTIONS. — The floor plans and elevations are insufficient to show all the interior construction, and it is necessary, therefore, to show one or more sections taken at carefully selected places. A section cut across the narrow way of the building is called a transverse section; one lengthwise, is called a longitudinal section. In addition to the longitudinal and transverse sections, other sections may be taken of any part of a building, not necessarily clear across it but usually cutting entirely across some part that is a unit in itself. Cross-sections of the minor parts of a building, as, for example, a foundation or parapet wall, are called detail sections.

In drawing the cutting plane for a section, it need not be made as one continuous plane but may be offset one or more times to take in the im-

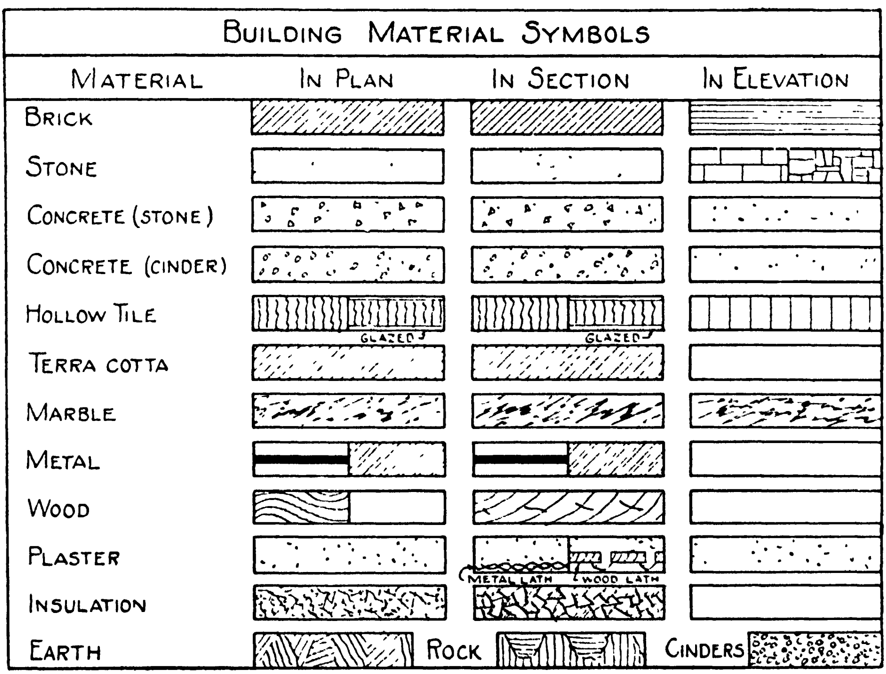
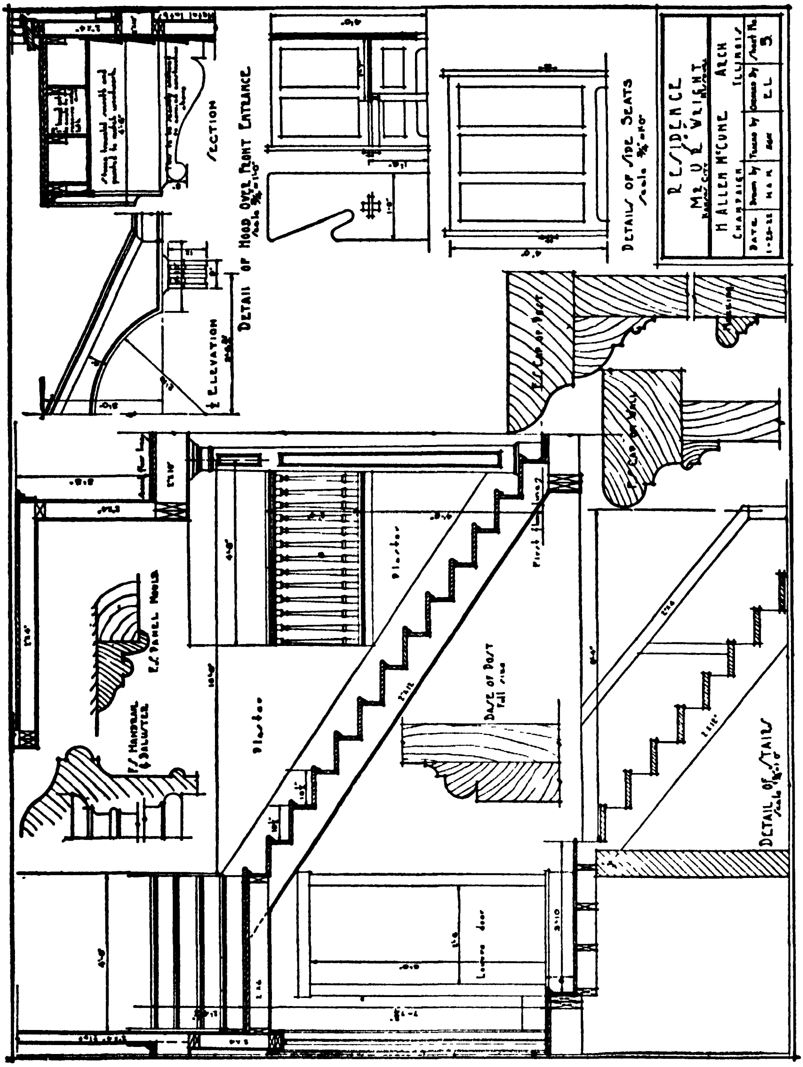


FIG. 8. Building material symbols.

portant features which it is desired to show. The cutting planes are always placed perpendicular to the principal axes of the building, and the offsets parallel thereto. The location of the cutting plane is shown on



(*Courtesy Department of Architecture, University of Illinois.*)

FIG. 9. Architectural details.

each floor plan by a heavy dash and dot line, with arrows at its ends outside the building line indicating the direction in which the view is taken. All parts which are cut by the plane are shown cross-hatched in some characteristic way, to represent the material, as shown in Fig. 8. All other parts lying behind the plane are shown in the usual way. Invisible lines are avoided.

361. 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. See Fig. 9. It is quite evident that an architect cannot in-

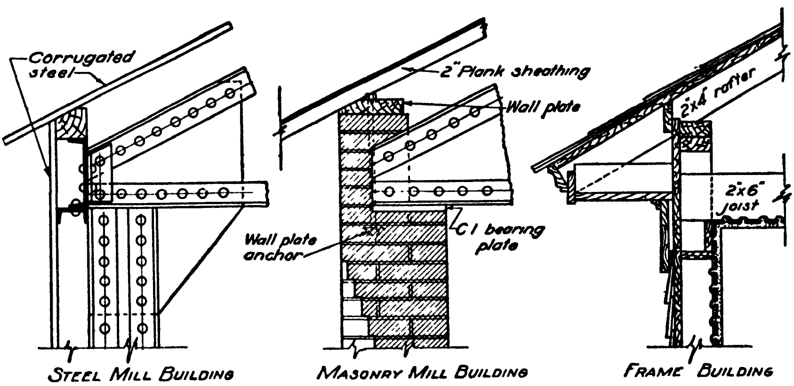


Fig. 10. Eave details.

clude everything that may need explanation, but his plans should embrace enough details to permit the making of an accurate estimate. It would be manifestly unfair for him to insist upon some type of construction not fully shown in the plans, when the contractor had perhaps figured on some

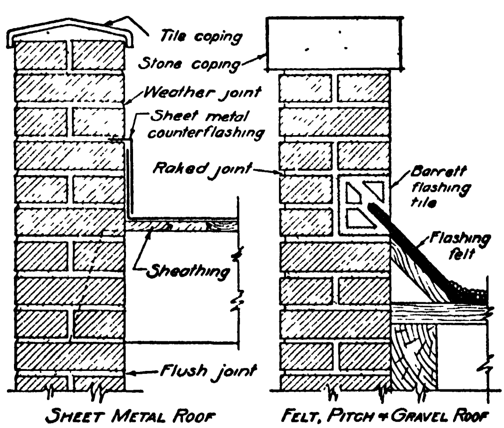
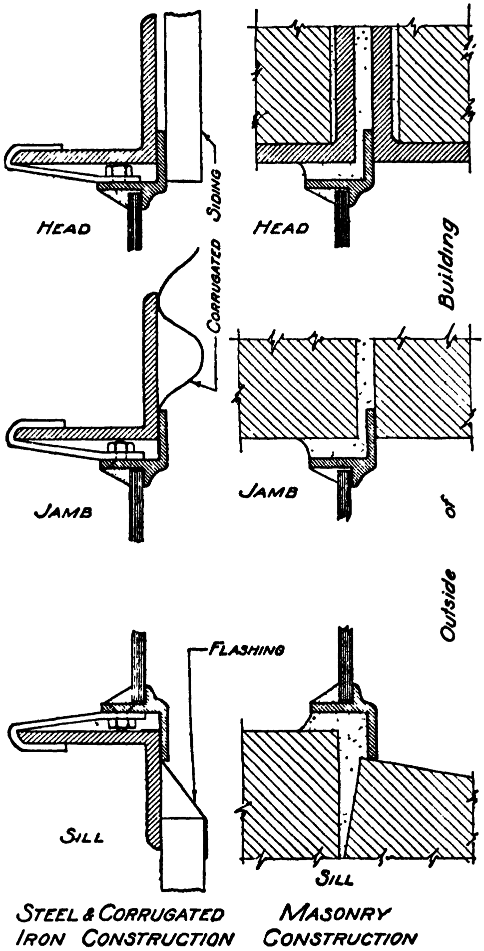
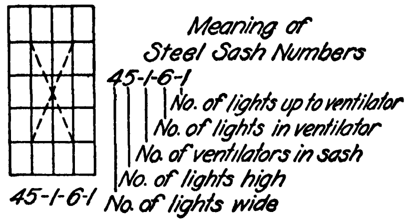


Fig. 11. Parapet wall details.

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. See Figs. 10, 11 and 12.

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 book, called "Sweet's





DIMENSIONS OF STANDARD STEEL SASH (PARTIAL LIST)

Sash type No.	Glass Size 12"x18"		Glass Size 14"x20"	
	Width	Height	Width	Height
33	3'-2"	4'-8"	3'-8"	5'-2"
43	4'-2 3/8"	"	4'-10 3/8"	"
53	5'-2 3/4"	"	6'-0 3/4"	"
63	6'-3 1/8"	"	7'-3 1/8"	"
34	3'-2"	6'-2 3/8"	3'-8"	6'-10 3/8"
44	4'-2 3/8"	"	4'-10 3/8"	"
54	5'-2 3/4"	"	6'-0 3/4"	"
64	6'-3 1/8"	"	7'-3 1/8"	"
35	3'-2"	7'-8 3/4"	3'-8"	8'-6 3/4"
45	4'-2 3/8"	"	4'-10 3/8"	"
55	5'-2 3/4"	"	6'-0 3/4"	"
65	6'-3 1/8"	"	7'-3 1/8"	"
36	3'-2"	9'-3 1/8"	3'-8"	10'-3 1/8"
46	4'-2 3/8"	"	4'-10 3/8"	"
56	5'-2 3/4"	"	6'-0 3/4"	"
66	6'-3 1/8"	"	7'-3 1/8"	"

FIG. 12. Steel sash details and dimensions.

Architectural Index." A similar index 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.

362. Standard Details. — Many of the details and materials used in building construction have been standardized. Such things as brick, tile, steel beams, steel sash, windows, doors, and the like are furnished to the trade in certain stock or standard sizes.

Brick. — Bricks made of burned clay may be obtained in several sizes, the more common of which are shown in Fig. 13. This figure also illustrates several common types of bond and the names applied to certain

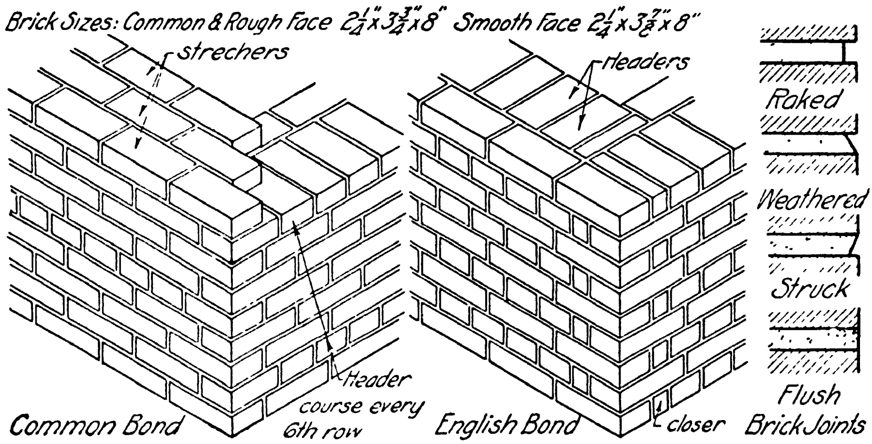


FIG. 13. Brick sizes and bonds.

bricks or courses of bricks. Brick joints are usually ¼, ⅜, or ½ inch thick. The names of several types of joints are shown in Fig. 13.

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

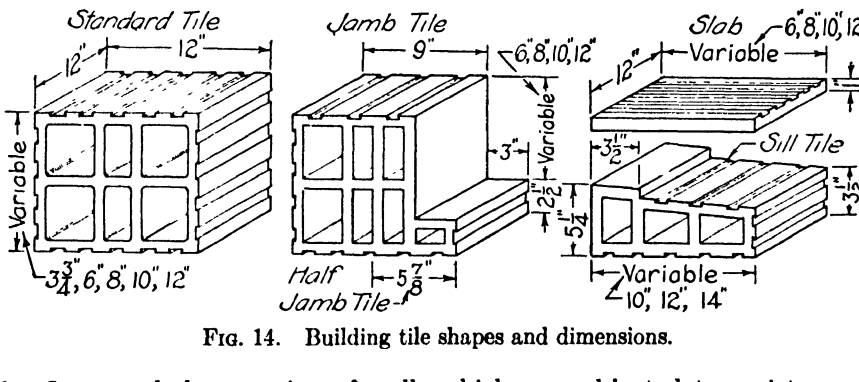


FIG. 14. Building tile shapes and dimensions.

for floors and the covering of walls which are subjected to moisture, as around kitchen sinks and in bathrooms. Both kinds may be obtained in standardized dimensions. Figure 14 illustrates common building tile sizes.

Structural Steel. — The common sizes and dimensions of standard steel beams, channels, and angles are given in tables on pages 437 and 438. For structural shapes and details, a structural-steel handbook should be consulted.

Steel Sash. — Steel windows are made in stock sizes and are specified by numbers which have the meanings indicated in Fig. 12. The detail construction of one type of sash is shown at the left in this figure.

Windows. — Figure 15 illustrates the common types of windows and the names and dimensions of their parts. The size of windows is usually indicated on the elevations of the building by lettering in the window

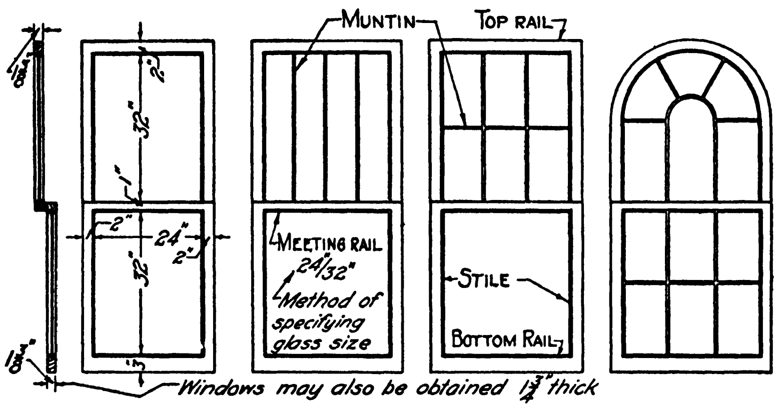


Fig. 15. Window sash, styles and dimensions.

space the size of the panes of glass, as shown in the second window from the left in Fig. 15. Glass sizes are always specified in even inches. The

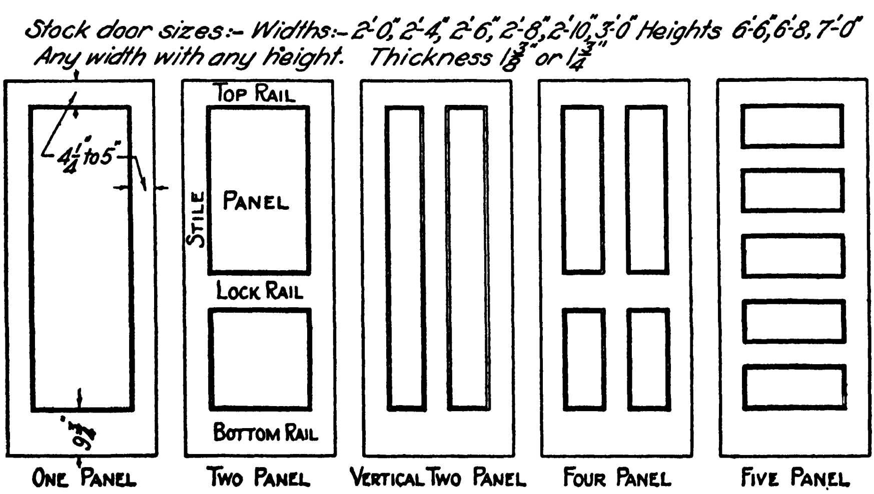


Fig. 16. Common types of doors with dimensions.

width is given as the numerator of the fraction and the height as the denominator. Two standard thicknesses of sash may be obtained, namely, 1⅜ and 1¾ inches.

Doors. — Several standard types of doors are shown in Fig. 16. The usual stock sizes are listed in the figure. Ornamental doors may be obtained in a great variety of styles. Fireproof metal doors having much the same appearance as wooden doors are also on the market. Manufacturer's catalogues should be consulted for details of any of these special types of doors.

Lumber. — Lumber used for ordinary building purposes (not including heavy timber for structural purposes or soft or hardwood factory timber) is called yard lumber. According to the American Lumber Standards it is divided into two main divisions called select and common. The select is subdivided into four grades called A, B, C, and D, and the common is divided into five grades specified by number, number 1 being the best of the series.

The finish desired on yard lumber is specified by letters as, for example, S1S, which means surfaced one side, or S1E, which means surfaced one edge. Lumber is specified by nominal dimensions, but the actual dimensions are smaller as shown in the table below.

SIZES OF YARD LUMBER
(Bureau of Standards)
The thicknesses apply to all widths and the widths to all thicknesses

	Nominal Size		Actual Dimensions	
	Thickness	Width	Thickness	Width
COMMON BOARDS	1	3	$\frac{25}{32}$	$2\frac{5}{8}$
	$1\frac{1}{4}$	4	$1\frac{1}{16}$	$3\frac{5}{8}$
	$1\frac{1}{2}$	5	$1\frac{5}{16}$	$4\frac{5}{8}$
		6		$5\frac{5}{8}$
		7		$6\frac{5}{8}$
		8		$7\frac{1}{2}$
		9		$8\frac{1}{2}$
		10		$9\frac{1}{2}$
		11		$10\frac{1}{2}$
		12		$11\frac{1}{2}$
DIMENSION LUMBER	2	2	$1\frac{5}{8}$	$1\frac{5}{8}$
	$2\frac{1}{2}$	4	$2\frac{1}{8}$	$3\frac{5}{8}$
	3	6	$2\frac{5}{8}$	$5\frac{5}{8}$
	4	8	$3\frac{5}{8}$	$7\frac{1}{2}$
	over 4	10	off $\frac{3}{8}$	$9\frac{1}{2}$
		12		$11\frac{1}{2}$

363. DIMENSIONING. — The common rules which apply to machine drawing hold in general for architectural drawing. However, it is a little 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. In other words, care must be exercised to see that the same thing is not represented as of one size on the plan and as of another size on the elevation. The inevitable variation in commercial sizes of material must be taken into consideration. This does not lessen the requirement 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:

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

2. 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 line. See Figs. 4, 5, and 7.

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

4. Dimension to the center line of openings in outside walls, unless the exact size of the opening is to have a specific value not affected by any variation in commercial sizes of materials.

364. 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.

365. SPECIFICATIONS. — Even with all the drawings and notes referred to heretofore in this chapter, it is impossible to give all the information necessary for the proper construction of a building. In order to make everything clear, the architect prepares what is termed a *set of specifications*, to accompany each set of plans. These specifications begin with the general terms of the contract, and then proceed in an orderly and logical manner to consider the work of the various trades that are involved in the construction of the building. The specifications cover those points of construction which cannot be shown in a drawing, namely, quality of materials, kind of finish, color of decorations, particular kinds of construction, such as thickness of mortar joints, kind of bond, etc., and in addition they reëmphasize such points as might be overlooked if the drawings alone were used. A valuable aid in the preparation of specifications is to be found in "Steven's Master Specifications."

366. Symbols. — Since working drawings are made to a scale of $\frac{1}{4}$ or $\frac{1}{8}$ inch to the foot, building plans must take on a rather conventional nature. It is not possible to show every edge and surface by a line, as in

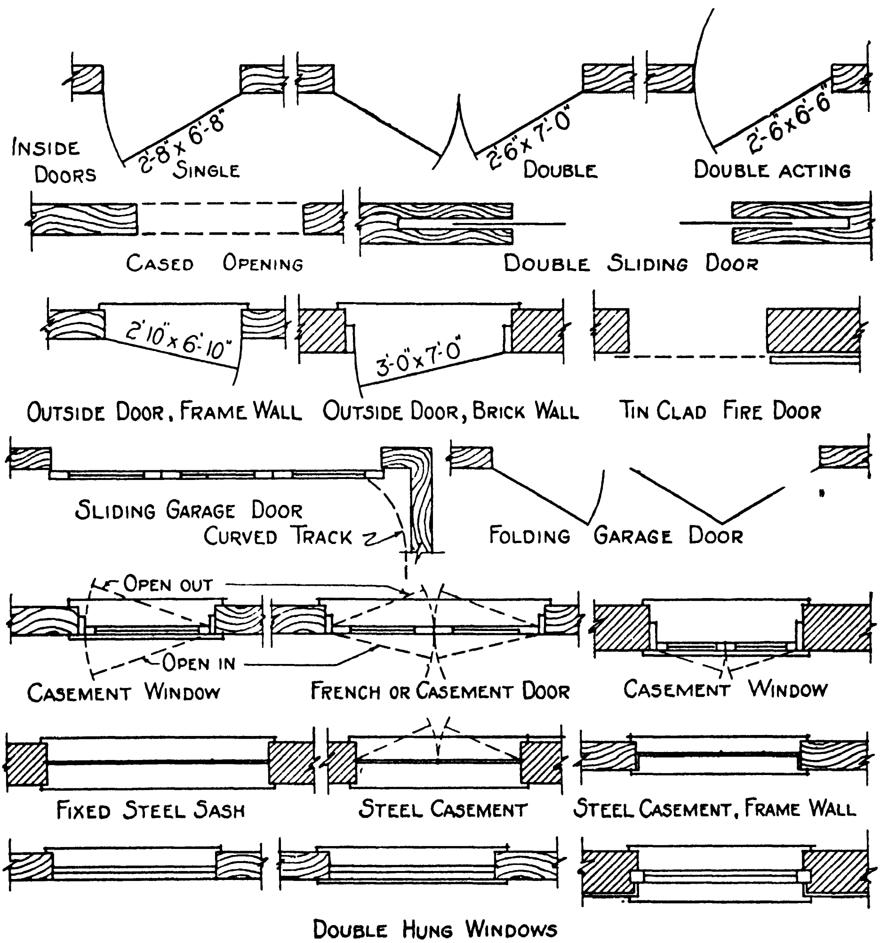


Fig. 17. Door and window symbols.

machine drawing; hence, most of the building parts must be represented by symbols which are made carefully to scale and show as nearly as possible the appearance or construction of the thing represented. For example, of the many lines which actually must be drawn in a large-scale detail of a window, only those few which most clearly show its nature and construction are possible in the small-scale symbol. This is made quite clear by a comparison of the window detail in Fig. 18 and the symbol for a double hung window in Fig. 17. A casual examination of these illustrations makes clear at once that more than ordinary skill and care must be exercised in making symbols even to a scale twice this size. It is clear also that the smaller the scale the simpler the symbol must become. A common fault of beginners is to make the symbols too large and bunglesome in proportion to the rest of the drawing.

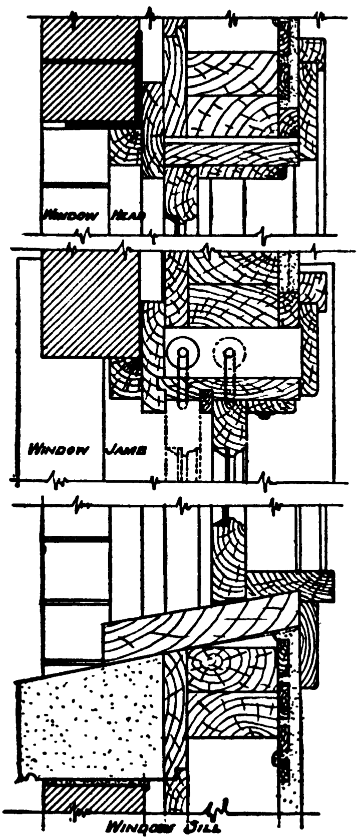


FIG. 18. Window detail.

The symbols shown in Fig. 17 are practically standard for the objects and scale shown, although some variations will be found. These variations, however, are very readily intelligible to anyone familiar with building construction, and offer no obstacle to the reading of the drawings.

Many features of a building are not standard at all; hence, the architect requires a knowledge of their construction in order to represent them by a small-scale symbol. To represent such parts, he has recourse to large-scale details and, from them or his own intimate knowledge, devises symbols to represent the parts.

Different materials are represented by various kinds of cross-hatching. Since such cross-hatching is not standardized, it is a common practice for architects to place on each set of drawings a key showing the particular cross-hatching they are using for each material. Such a key is shown in Fig. 8. To one familiar with building plans and operations, the cross-hatchings shown and commonly used in practice are readily understood without a key, except in the case of special materials not commonly used.

367. ELECTRIC WIRING LAYOUTS. — Three types of wiring diagrams are used by architects and engineers to show electrical circuits. The simplest of these represents merely the location of the electric outlet such as lamps, motors, etc., and the location of the switch which controls the outlet. Such a diagram is shown in Figs. 4 and 5. In small jobs of this kind the actual location of wiring and arrangement of circuits is left to the electrical contractor, who is governed by building-code restrictions. The symbols used in wiring diagrams of this kind are shown in Fig. 19.

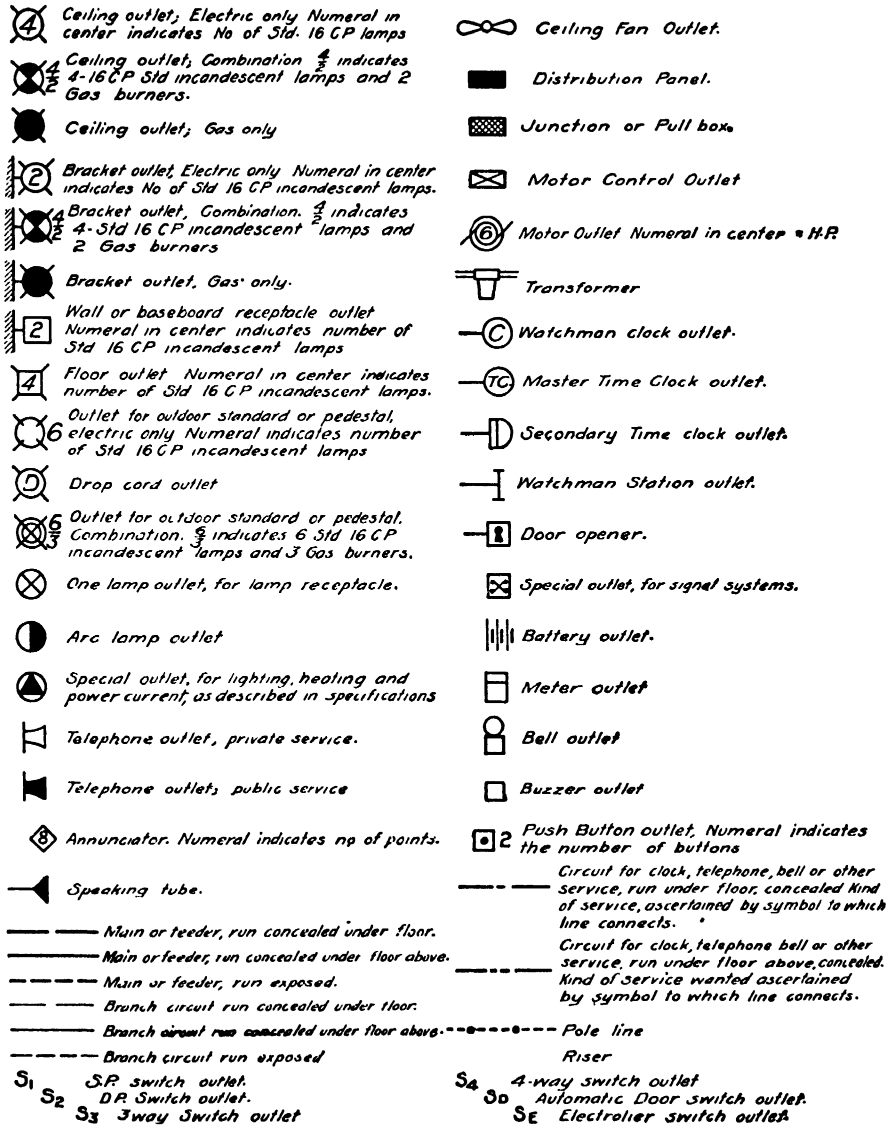


FIG. 19. Electric wiring symbols.

The power to be used at the outlet should always be indicated upon the drawing.

368. CIRCUIT DIAGRAMS. — On larger work the engineer must indicate not only the outlets and switches but also the circuits. In computing the load on the various circuits he is governed both by the requirements of good engineering practice and by city building codes. Circuits are indicated as shown in Fig. 20. The circuit diagram does not represent

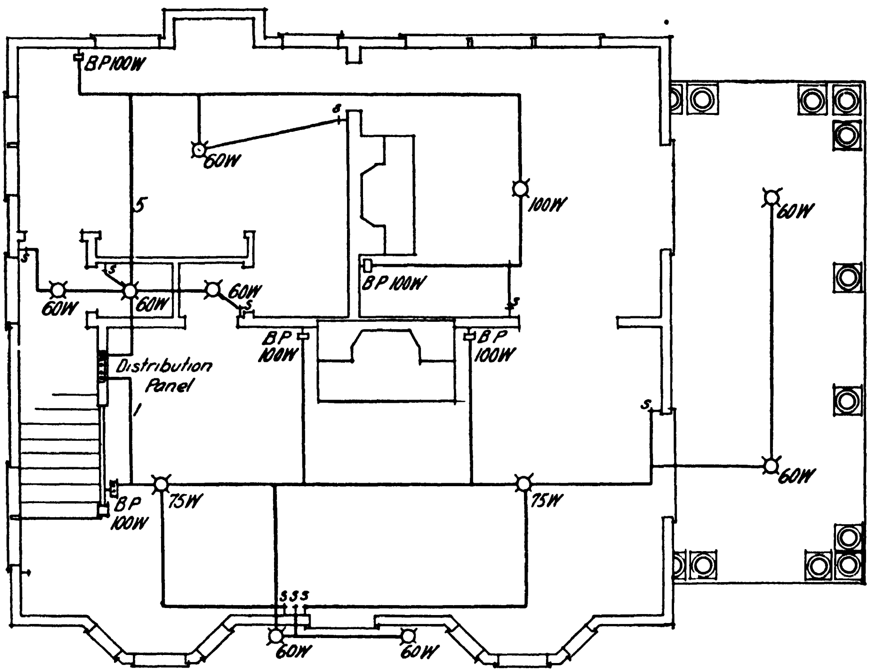


Fig. 20. Circuit diagram.

the actual wiring but merely indicates the outlets and switches which are on a single circuit. In Fig. 20 the circuit has been confined to one floor, but this need not be done.

369. Wiring Diagrams. — The final step in planning the wiring consists in representing the actual wiring in general arrangement, i.e., switch and outlet connections in detail, conduits and number of wires per conduit, and location of distribution panel. The exact location of conduits, however, is not attempted, in the sense of giving dimensions. The exact location will be made at the time of installation to give the shortest line within the physical limitation imposed by the building. An example of this type of wiring diagram is shown in Fig. 21. The symbols used in power plant and sub-station work are shown in Fig. 22.

The drawing technique involves no new principles. When separate wiring plans are made the outlines of the building are made very light, or in colored inks which will make light lines upon the blueprints, while the wiring layout is made in heavier lines. Such items as the size of wire, type of insulation, kind and make of switchboard, plug outlets, fixtures, and the like, are thoroughly covered in specifications and are not usually shown upon drawings.

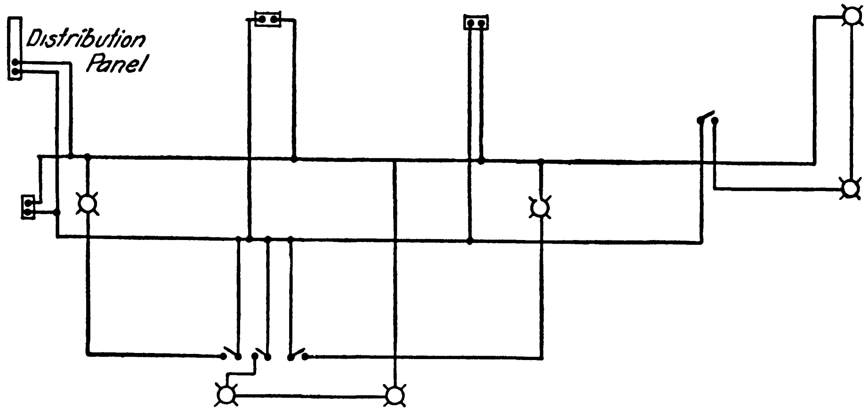


FIG. 21. Wiring diagram of circuit No. 1 in Fig. 20.

ELECTRIC APPARATUS	ONE LINE SYMBOL	COMPLETE SYMBOL[1]	ELECTRIC APPARATUS	ONE LINE SYMBOL	COMPLETE SYMBOL[1]	ELECTRIC APPARATUS	ONE LINE SYMBOL	COMPLETE SYMBOL[1]
A-C GENERATOR OR MOTOR BASIC SYMBOL[2]			D-C GENERATOR OR MOTOR BASIC SYMBOL			INDUCTION MOTOR		
SYNCHRONOUS CONVERTER[2]			DIRECT CONNECTED UNITS BASIC SYMBOL[2]			SINGLE-PHASE TWO-WINDING TRANSFORMER BASIC SYMBOL[2]		
DISCONNECTING SWITCH BASIC SYMBOL			KNIFE SWITCH SINGLE THROW			DOUBLE THROW SWITCH		
OIL CIRCUIT BREAKER SINGLE THROW			AIR CIRCUIT BREAKER			RHEOSTAT		
LIGHTNING ARRESTOR BASIC SYMBOL			INSTRUMENT SHUNT			CONDUCTORS CROSSING BUT NOT CONNECTED		
CONDUCTORS CROSSING & ELECTRICALLY CONNECTED			CONDUCTORS WITH BRANCHES			BUS WITH BRANCHES		
						CONDUCTORS		
FUSE			INDICATING INSTRUMENT BASIC SYMBOL[3]	(I)	(4)	AMPERE HOUR METER	(AH)	(4)
RESISTOR						AMMETER	(A)	(4)
REACTOR			GRAPHIC INSTRUMENT BASIC SYMBOL[2]	Graph	(4)	FREQUENCY METER	(F)	(4)
CAPACITOR						WATT-HOUR METER	(WH)	(4)
WATTMETER	(W)	(4)	VOLTMETER	(V)	(4)	GROUND CONNECTION		

FIG. 22. Standard wiring symbols.

1. The "complete" symbol is intended to illustrate the method of treatment for any desired polyphase combination rather than to show the exact symbol required.
2. Use symbol (\/\/\/\) for windings of apparatus as required, and connect to suit

particular case. It is recognized that no symbol list can show symbols for complete diagrams for all possible methods of connection.

3. Letter within circle indicates type of instrument if but one is used. If more than one instrument is used, " I " appears within the circle with abbreviation alongside. See Note 4.

4. For complete symbol show outline approximating that of rear view of actual device and indicate terminal in actual relative location, current terminals by open circles, and potential terminals by solid circles. Scale range and type number may be marked adjacent to symbol, if desired.

370. 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 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.

371. TECHNIQUE. — The technique of architectural drawing is similar in many respects to that of machine drawing. Visible outlines, such as walls, beams, columns, etc., 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 in these two groups, and perfect uniformity throughout the group itself, 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 over-running 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 over-run where confusion might result.

On elevations, shade lining 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.

372. 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 memorial tablets, which constitute a part of the ornamentation of a building. For inscriptions, the old Roman or modern Roman is most frequently used and the lettering is laid out with instruments. Examples of the Roman alphabet are shown in Chapter II. 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. The freak letters commonly seen in the work of some architectural draftsmen should never be used in notes on working drawings and are to be avoided even in legends and titles.

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Architectural Drawing, by Wooster Bond Field. McGraw-Hill Book Company, New York, 1922.

The Architects' and Builders' Handbook, Seventeenth Edition, by Frank E. Kidder and Harry Parker. John Wiley & Sons, Inc., New York, 1931.

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PROBLEMS

373. Upon being assigned a problem number, the student should turn to the Specifications and Description of the particular building referred to in his problem as given below. He should read these carefully before beginning any work on the problem. Scale A is to be used with a 12″ × 18″ sheet and scale B with a $8\frac{1}{2}$″ × 11″ sheet as noted in Art. 4. The instructor may add to the problems given below at many points, to the interest and benefit of the student.

Building A. — Figures 23 and 24. Specifications and Description

The building is to be an automobile sales and service station of fireproof construction throughout. The distance from first to second floor shall be 14′-0″, and the clear height in the second story shall be 9′-0″. The second floor shall be of reinforced concrete designed to support a load of 160 lb. per sq. ft. and shall be supported on steel beams and columns encased in concrete. The roof shall be a $2\frac{1}{2}$″ concrete slab reinforced with metal lath or mesh designed to carry a load of 50 lb. per sq. ft. in addition to its own weight. The roof shall be covered with tar and gravel and shall have a pitch of $\frac{1}{2}$″ per foot and shall be supported on roof trusses. See Fig. 32, page 463, for details.

The area of the first floor shall be divided as follows (areas to include walls and partitions): display space 1000 sq. ft., office 80 sq. ft., stock room 350 sq. ft., repair shop 760 sq. ft., elevator 200 sq. ft., two toilets 31 and 39 sq. ft. The remainder of the space shall be devoted to halls, stairways, doorway access, etc. There shall be a stairway 3′-0″ wide leading to the second floor.

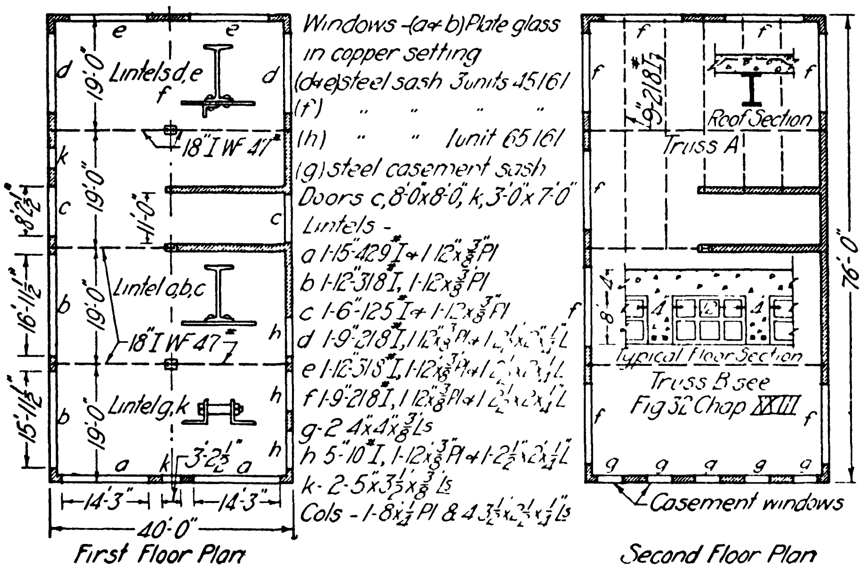


FIG. 23. Preliminary floor plans of garage.

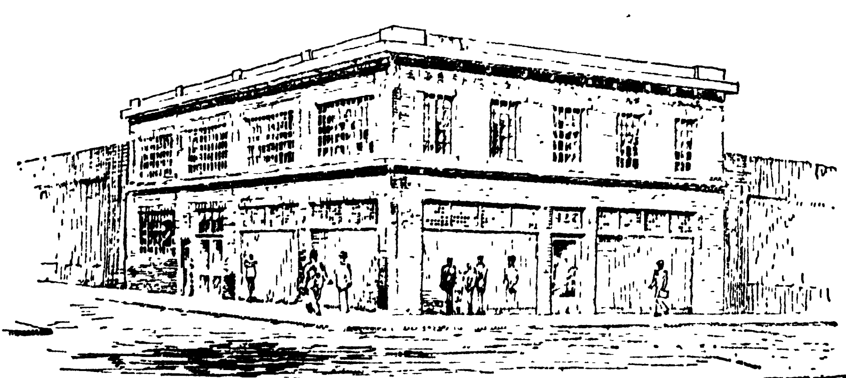


FIG. 24. Perspective of garage. Plans shown in Fig. 23.

The wall and column footings shall be 4′-0″ below the grade line. The ground floor shall be 4″ concrete resting on 12″ of tamped cinders. The outside walls shall be 13″ thick and shall have 17″ pilasters 2′-0″ wide under the beams and trusses. The maximum allowable soil pressure shall be 4000 lb. per sq. ft.

The repair shop shall be equipped with a traveling crane of about 17′-0″ span and 38′-0″ travel. All dimensions, except the outside dimensions and the story heights, may be altered slightly in either direction, as conditions may require. Assume building heated from outside source.

BUILDING B. — Figures 23 and 24. Specifications and Description

The building A described above is to be modified as follows: Basement under entire area with 4″ concrete floor resting upon 6″ of cinders. Wall and column footing to go 18″ below the floor level. Provide separate room for heating plant and coal storage (area approximately 19′ × 38′). Provide windows and area ways for light and ventilation. Area ways must be drained. Columns in basement to be of concrete 16″ × 18″. First floor to be of the same construction as the present second floor. Elevator and stairway to go to basement. Building to be unchanged in other respects.

BUILDING C. — Figures 25 and 26. Specifications and Description

The building is to be a manufacturing plant such as a small foundry or the like. The outside walls shall be tile, veneered with brick. Total thickness 13″. The foundations and footing shall be of concrete and shall extend 4′ below the grade line. The walls under the windows require no increase in width for footings. In the long sides of the building the walls between windows at *B*, *E*, *F*, and *G*, require 8 sq. ft. of footing in addition to the regular wall area. The walls *D* and *K* in the end of the building require 2 sq. ft. additional footing per linear foot of wall. The walls at *A*, *M*, *L*, and *H*, require 1 sq. ft. of additional footing per linear foot of wall. All symmetrical parts of the building will have the same footing as the parts specified. The 8 steel columns each require 9 sq. ft. of footing. The building will have a clay floor. For structural steel framing See Fig. 30, page 460. The size of all windows is given in Fig. 25. The size of brick opening may be determined from the table in Fig. 12. The size and type of lintels is also shown in Fig. 25. The building is to be heated from an outside source.

BUILDING D. — Figures 25 and 26. Specifications and Description

Modify building C above as follows: The building is to be of steel construction throughout with sheet-metal siding and roofing. Steel sash windows to be the same as in present building. Place concrete curtain walls 6″ wide by 21″ deep between outside column footings. Curtain wall shall extend 9″ out of the ground, and the siding shall lap over it by

3″. Large doors in ends of building and small door in the side to be of wood. See structural handbooks for details of construction.

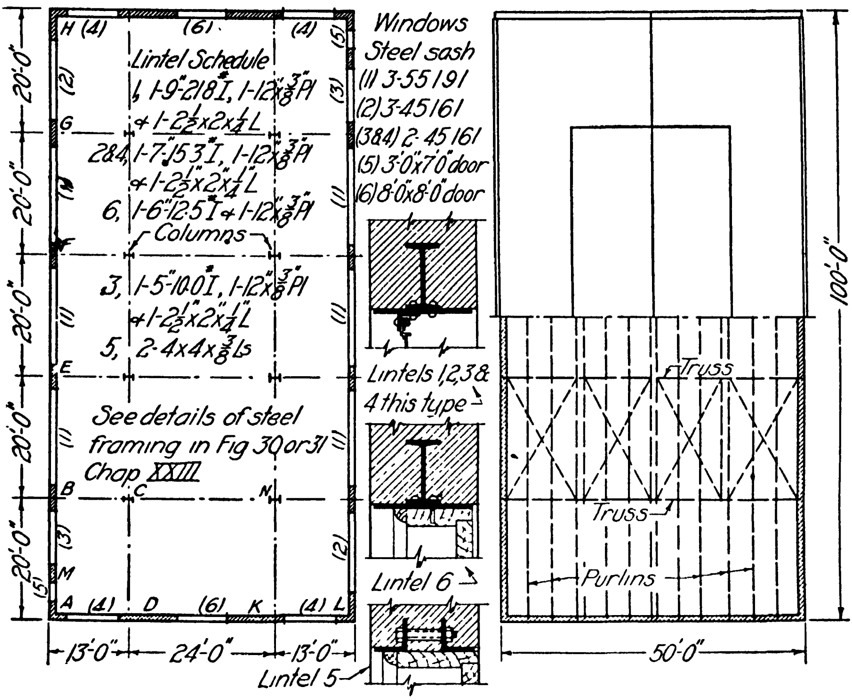


FIG. 25. Floor and roof framing plans of foundry.

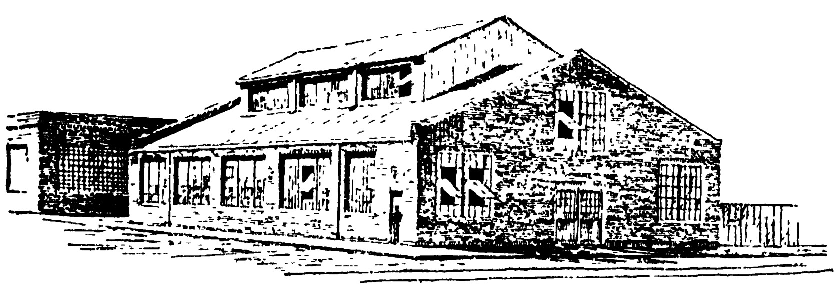


FIG. 26. Perspective of foundry. Floor plans showing in Fig. 25.

BUILDING E. — Figures 25 and 26. Specifications and Description

Modify building C as follows: In the corner of the building designated by *ABCD*, provide a wash and locker room with facilities for 20 men. The interior partitions to be of 6″ hollow tile plastered on the locker-room side. The walls shall line up with the column in both directions. There shall be a door leading into the shop. The room shall be equipped with lockers 12″ × 12″ in plan and 6′-0″ high, two separately enclosed toilets, 2 urinals, 2 shower baths, and 10 wash bowls. Beneath the locker room shall be a basement for the heating plant and coal storage. The locker-room floor shall be of 4″ concrete supported on steel or concrete beams. The stairway to the basement shall be in the shop portion of the building. In the portion of the building designated by the letters *CDKN* provide an office, the floor level of which shall be 13′-0″ above the ground floor. Extend the monitor to both ends of the building. The stairway to the office shall be along the line *CD* just outside the locker room so that entrance to the stairway may be had from the shop or the outside. Provide a ladies' rest room on the office-room floor level. Provide a glass partition in the office overlooking the shop. The office shall have a wood floor over concrete, all supported on steel. The partition walls shall be of hollow tile. In all other respects the building shall be like building C.

Building F. — Figure 19, Chapter XXII. Specifications and Description

This is to be a small industrial chemical plant with floor plan and section as shown. Bottom of concrete footings 5′-0″ below grade line. Brick and tile walls above grade line. Slate roof. Allowable soil pressure, 1000 lb. per sq. ft. Show position of tanks by dotted lines on floor plan.

PROBLEMS

Floor Plans

1. Make the first-floor and foundation plan of building A, Figs. 23 and 24. Scale A: ⅛″ = 1′-0″.
2. Same as Prob. 1, building C, Figs. 25 and 26. Scale A: ⅛″ = 1′-0″.
3. Make a basement and foundation plan of building B, Figs. 23 and 24. Scale A: ⅛″ = 1′-0″.
4. Make a basement and foundation plan of building E, Figs. 25 and 26. Scale A: ⅛″ = 1′-0″.
5. Make a first-floor and foundation plan of building F, Fig. 19, Chapter XXII. Scale A: ¼″ = 1′-0″.
6. Make the second-floor plan of building A, Figs. 23 and 24. Scale A: ⅛″ = 1′-0″.
7. Make a second-floor plan of building B, Figs. 23 and 24. Scale A: ⅛″ = 1′-0″.
8. Make a second-floor plan of building C, Figs. 25 and 26. Scale A: ⅛″ = 1′-0″.
9. Make a second-floor plan of building D, Figs. 25 and 26. Scale A: ⅛″ = 1′-0″.
10. Make a second-floor plan of building E, Figs. 25 and 26. Scale A: ⅛″ = 1′-0″.
11. Make the roof plan of building A, Figs. 23 and 24. Scale A: ⅛″ = 1′-0″.
12. Make a roof plan of building C, Figs. 25 and 26. Scale A: ⅛″ = 1′-0″.
13. Make a roof plan of building F, Fig. 19, Chapter XXII. Scale A: ¼″ = 1′-0″.

Elevation Problems

14. Make a side elevation of building A, Figs. 23 and 24. Scale A: ⅛″ = 1′-0″.
15. Make a side elevation of building C, Figs. 25 and 26. Scale A: ⅛″ = 1′-0″.
16. Make a side elevation of building D, Figs. 25 and 26. Scale A: ⅛″ = 1′-0″.
17. Make a side elevation of building F, Fig. 19, Chapter XXII. Scale A: ¼″ = 1′-0″.
18. Make an end elevation of building A, Figs. 23 and 24. Scale A: ⅛″ = 1′-0″. (Note: The scale specified will allow room for details on the sheet in addition to the end elevation.)

19. Same as Prob. 18, building C, Figs. 25 and 26.
20. Same as Prob. 18, building D, Figs. 25 and 26.
21. Same as Prob. 18, building F, Fig. 19, Chapter XXII. Scale A: $\frac{1}{4}''$ = 1′-0″.

Section Problems

22. Make a transverse section through building B, Figs. 23 and 24 at a point to be designated by the instructor. Use sheet A. Select your own scale.
23. Same as Prob. 22, building C, Figs. 25 and 26.
24. Same as Prob. 22, building D, Figs. 25 and 26.
25. Same as Prob. 22, building E, Figs. 25 and 26.
26. Make detail sections through portions of buildings A, B, C, D, E, and F at points assigned by the instructor. Use sheet B. Select your own scale.

Detail Problems

27. Make a large-scale detail of an assigned window or door lintel and head jamb from one of the buildings A, C, and F. Use scale B: 3″ = 1′-0″.
28. Make a large-scale detail of the stone cornice of building C, Figs. 25 and 26. Use sheet B. Select your own scale.
29. Make large-scale details of stairway from first to second floor for one of the buildings A, C, E, and F, as assigned by the instructor. Include small-scale layout or plan of entire stairway. Use one of the following types of construction: (*a*) wood construction, (*b*) concrete with pipe hand rail, (*c*) all steel with pipe hand rail.
30. Make any special or standard detail as assigned by the instructor, from the buildings A, B, C, D, E, and F.

Standard Details Problems

Material for Probs. 32 to 36 must be obtained from architectural textbooks, magazines, or trade catalogues.

31. Make isometric drawings of two portions of brick wall showing a corner. The wall should be 13″ thick and about 10 brick courses high. Each portion shall illustrate a different kind of bond. Use sheet size B. Select your own scale and the two types of bond you wish to illustrate. Indicate and letter upon the drawings the names of any bricks or courses which have special names.
32. Prepare a detail drawing of a double hung window frame. Show a section through the sill, side, and head jamb. Scale B: 3″ = 1′-0″. Use one of the wall types: (*a*) 13″ masonry wall, (*b*) 6″ frame wall, (*c*) 9″ tile and stucco wall.
33. Make a detail of an inside door frame in a wood partition wall. Scale B: 3″ = 1′-0″.
34. Construct a detail of a door frame in an outside wall. Scale B: 3″ = 1′-0″. Use: (*a*) a 9″ masonry wall, or (*b*) a frame wall.
35. Show by a large-scale detail two types of cornice for a frame building. Use sheet size B. Select your own scale.
36. Make a large-scale detail drawing of a cornice or parapet wall for a brick building. Use sheet size B. Select your own scale.

CHAPTER XXII

PIPE DRAWING

374. In structures with which the engineer has to deal, such as power plants, water works, chemical production plants, large hotels, and the like, the piping layout is of prime importance. Sometimes the piping-layout drawings must be finished before the structural details for shop fabrication can be completed. Even though the buildings are drawn to scale, all details of the piping cannot be shown to scale, hence it is essential to have a standard group of symbols to represent the pipe, pipe fittings, and fixtures.

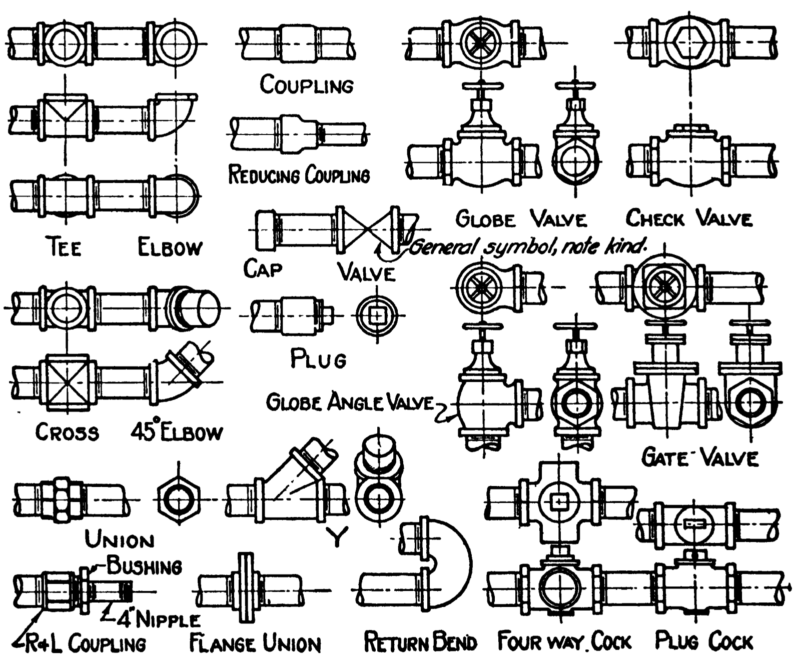


FIG. 1. Double line pipe and valve symbols for screw fittings.

The figures and tables of this chapter have been prepared to enable the student to make pipe drawings for any ordinary problem, and to compute cutting lengths, and to write the required bills of material.

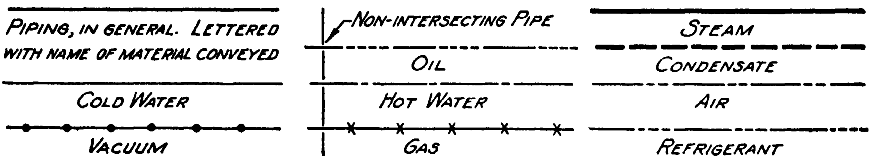


FIG. 2. Single line pipe symbols.

375. PIPE SYMBOLS. — In small-scale drawings, the piping, valves, and fittings are represented by single-line symbols as shown in Figs. 2 and 3. On large-scale drawings, or where the pipes themselves are large, they may be represented by double-line symbols as shown in Fig. 1. Heating and ventilating symbols are shown in Fig. 5.

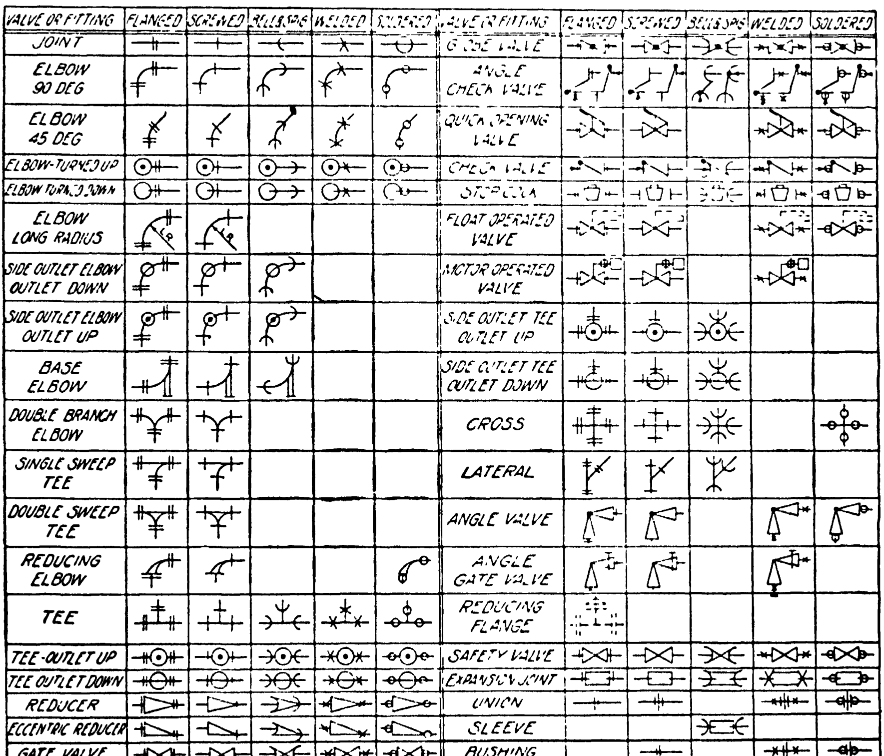


FIG. 3. Standard single line pipe and valve symbols.

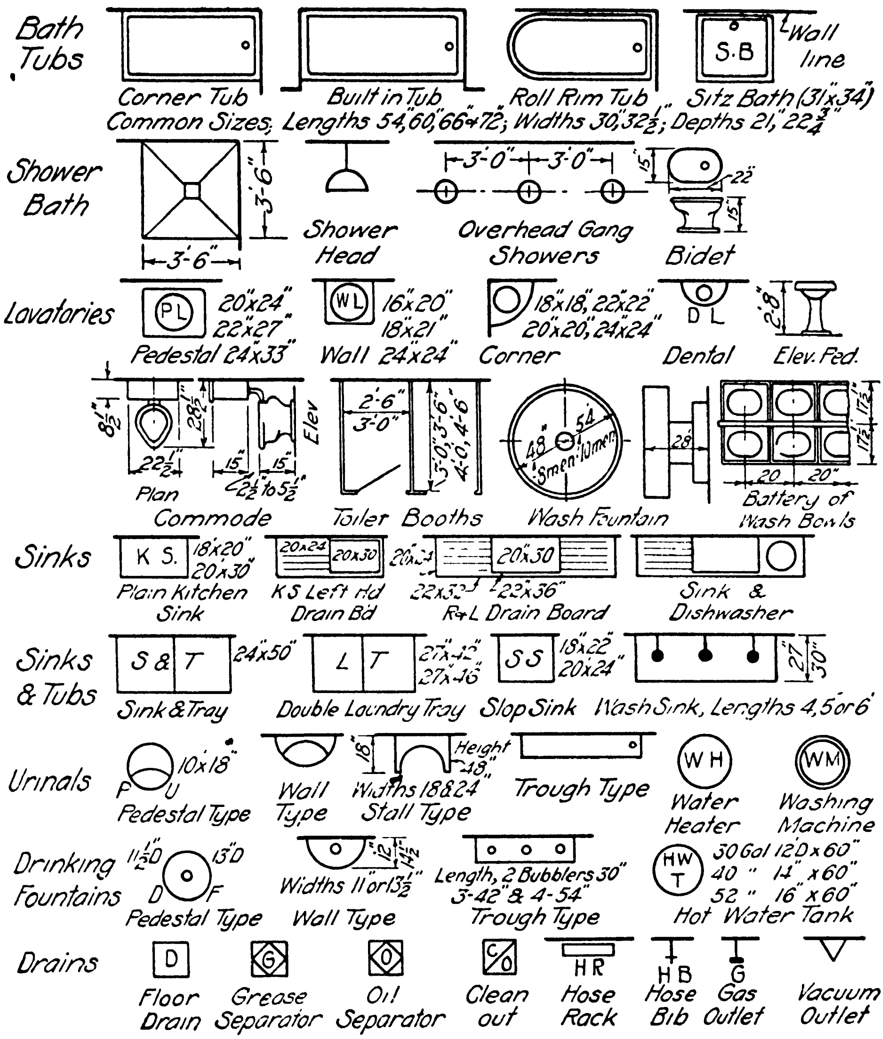


FIG. 4. Plumbing symbols.

376. PLUMBING SYMBOLS. — In homes, apartments, hotels, and other buildings, the plumbing fixtures must be shown upon the architect's plan. Standard symbols, together with dimensions for the common sizes, are shown in Fig. 4. These include the major symbols approved by the American Standards Association in 1935 and also some others in common use. On drawings, the outside dimensions of the symbols are made to scale.

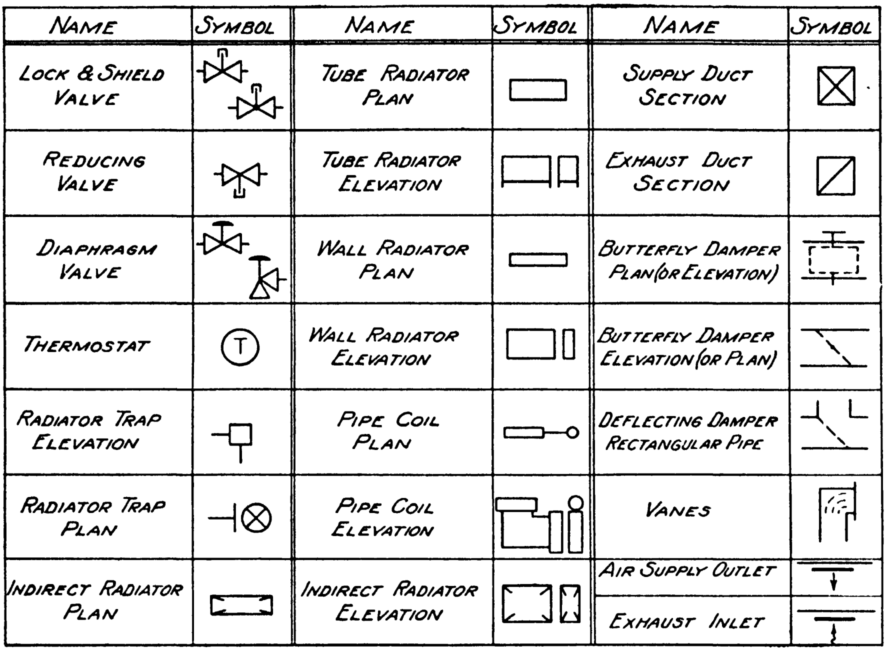


FIG. 5. Heating and ventilating symbols.

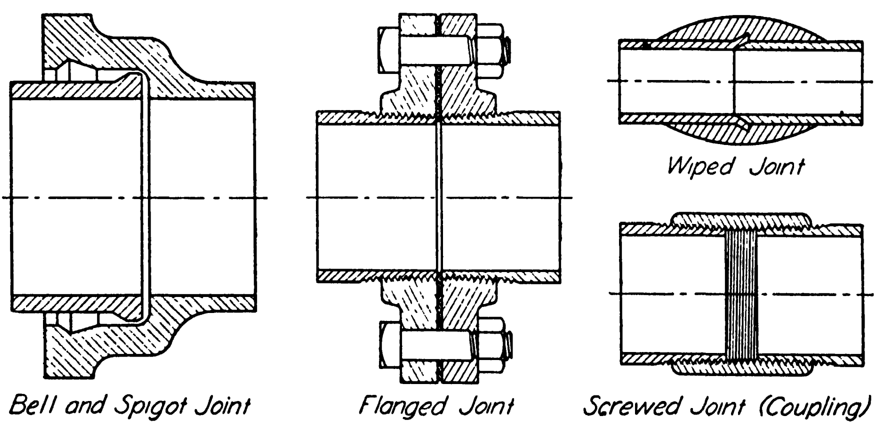
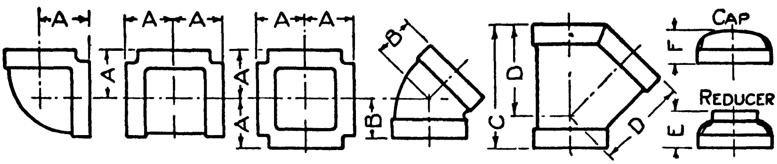


FIG. 6. Pipe joints.

377. PIPE JOINTS. — Pipes are connected to each other and to fittings by four general types of joints as shown and named in Fig. 6. The standard pipe thread for screw fittings is shown on page 211. Flanged joints are made in a wide variety of forms and may be found detailed in piping handbooks. The bell and spigot joint is used chiefly underground and for low-pressure work. Screw and flanged fittings are used for high-pressure work.

TABLE I
STANDARD CAST-IRON SCREW FITTINGS
(125 lb. per sq. in. pressure.)



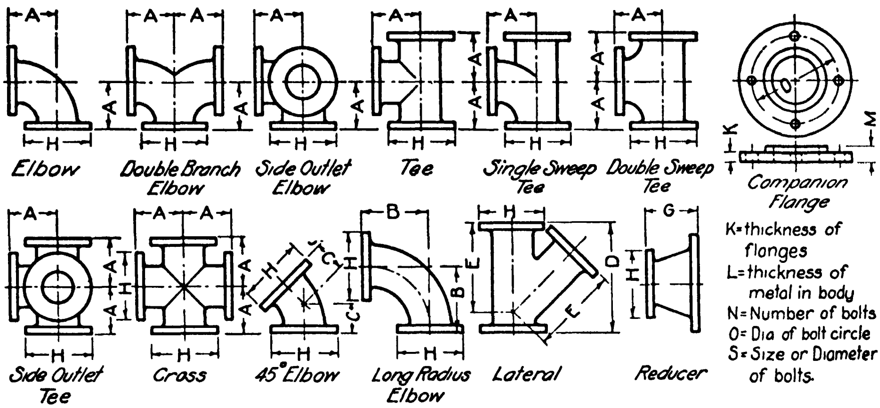
Size Inches	Dimensions in Inches					
	A	B	C	D	E	F
$\frac{1}{4}$	$\frac{13}{16}$	$\frac{3}{4}$	.....	....	....	....
$\frac{3}{8}$	$\frac{15}{16}$	$\frac{13}{16}$	....	...	......	....
$\frac{1}{2}$	$1\frac{1}{8}$	$\frac{7}{8}$	$2\frac{1}{2}$	$1\frac{7}{8}$	......	....
$\frac{3}{4}$	$1\frac{5}{16}$	1	3	$2\frac{1}{4}$	....	....
1	$1\frac{7}{16}$	$1\frac{1}{8}$	$3\frac{1}{2}$	$2\frac{3}{4}$	..	....
$1\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{5}{16}$	$4\frac{1}{4}$	$3\frac{1}{4}$	$2\frac{1}{8}$	......
$1\frac{1}{2}$	$1\frac{15}{16}$	$1\frac{7}{16}$	$4\frac{7}{8}$	$3\frac{13}{16}$	$2\frac{1}{4}$	....
2	$2\frac{1}{4}$	$1\frac{11}{16}$	$5\frac{3}{4}$	$4\frac{1}{2}$	$2\frac{7}{16}$	....
$2\frac{1}{2}$	$2\frac{11}{16}$	$1\frac{15}{16}$	$6\frac{3}{4}$	$5\frac{3}{16}$	$2\frac{11}{16}$	....
3	$3\frac{1}{8}$	$2\frac{3}{16}$	$7\frac{7}{8}$	$6\frac{1}{8}$	$2\frac{15}{16}$	....
$3\frac{1}{2}$	$3\frac{7}{16}$	$2\frac{3}{8}$	$8\frac{7}{8}$	$6\frac{7}{8}$	$3\frac{1}{8}$	...
4	$3\frac{3}{4}$	$2\frac{5}{8}$	$9\frac{3}{4}$	$7\frac{5}{8}$	$3\frac{3}{8}$	$2\frac{1}{16}$
5	$4\frac{7}{16}$	$3\frac{1}{16}$	$11\frac{5}{8}$	$9\frac{1}{4}$	$3\frac{7}{8}$	$2\frac{3}{8}$
6	$5\frac{1}{8}$	$3\frac{7}{16}$	$13\frac{7}{16}$	$10\frac{3}{4}$	$4\frac{3}{8}$	$2\frac{5}{8}$
8	$6\frac{1}{2}$	$4\frac{1}{4}$	$16\frac{15}{16}$	$13\frac{5}{8}$	$5\frac{1}{4}$	$3\frac{1}{8}$
10	$8\frac{1}{16}$	$5\frac{3}{16}$	$20\frac{11}{16}$	$16\frac{3}{4}$	$6\frac{3}{16}$	$3\frac{5}{8}$
12	$9\frac{1}{2}$	6	$24\frac{1}{8}$	$19\frac{5}{8}$	$7\frac{1}{8}$	$4\frac{1}{4}$

Fractional dimensions are nominal. See A.S.A. Bulletin for decimal dimensions.

378. PIPE FITTINGS. — Two general types of pipe fittings are in use, namely, screw fittings and flanged fittings. The shape and dimensions of standard cast-iron screw fittings are shown in Table I. The shape and dimensions of cast-iron flanged fittings are shown in Table II. The arrangement of bolt holes and the number and size of bolts to be used have been standardized as shown in the last three columns of Table II. Bolt holes are $\frac{1}{8}$ inch larger than bolts.

TABLE II

Standard Flanged Fittings, Straight Sizes — American Standard
(125 lb. per sq. in. pressure.)



Size	A	B	C	D	E	G	H	K	L	M	N	O	S
1	3 1/2	5	1 3/4	7 1/2	5 3/4		4	7/16	7/16	11/16	4	3 1/8	1/2
1 1/4	3 3/4	5 1/2	2	8	6 1/4	...	4 1/2	1/2	7/16	3/4	4	3 1/2	1/2
1 1/2	4	6	2 1/4	9	7	...	5	9/16	7/16	7/8	4	3 7/8	1/2
2	4 1/2	6 1/2	2 1/2	10 1/2	8	...	6	5/8	7/16	1	4	4 3/4	5/8
2 1/2	5	7	3	12	9 1/2	...	7	11/16	7/16	1 1/16	4	5 1/2	5/8
3	5 1/2	7 3/4	3	13	10	6	7 1/2	3/4	7/16	1 1/8	4	6	5/8
3 1/2	6	8 1/2	3 1/2	14 1/2	11 1/2	6 1/2	8 1/2	13/16	7/16	1 3/16	8	7	5/8
4	6 1/2	9	4	15	12	7	9	15/16	1/2	1 3/16	8	7 1/2	5/8
5	7 1/2	10 1/4	4 1/2	17	13 1/2	8	10	15/16	1/2	1 5/16	8	8 1/2	3/4
6	8	11 1/2	5	18	14 1/2	9	11	1	9/16	1 7/16	8	9 1/2	3/4
8	9	14	5 1/2	22	17 1/2	11	13 1/2	1 1/8	5/8	1 5/8	8	11 3/4	3/4
10	11	16 1/2	6 1/2	25 1/2	20 1/2	12	16	1 3/16	3/4	1 7/8	12	14 1/4	7/8
12	12	19	7 1/2	30	24 1/2	14	19	1 1/4	13/16	2 1/16	12	17	7/8
14O.D.	14	21 1/2	7 1/2	33	27	16	21	1 3/8	7/8	2 3/16	12	18 3/4	1
16O.D.	15	24	8	36 1/2	30	18	23 1/2	1 7/16	1	2 7/16	16	21 1/4	1
18O.D.	16 1/2	26 1/2	8 1/2	39	32	19	25	1 9/16	1 1/16	2 5/8	16	22 3/4	1 1/8
20O.D.	18	29	9 1/2	43	35	20	27 1/2	1 11/16	1 1/8	2 3/4	20	25	1 1/8
24O.D.	22	34	11	49 1/2	40 1/2	24	32	1 7/8	1 1/4	3	20	29 1/2	1 1/4

TABLE III

DIMENSIONS AND WEIGHT OF STANDARD WROUGHT IRON PIPE
(American Standard)

Nominal Size	Diameters		Thickness	Weight per Foot, Pounds		Threads per Inch	Length Pipe is Screwed into Fittings to Make a Tight Joint*
	External	Internal		Plain Ends	Threads and Couplings		
$\frac{1}{8}$	0.405	0.269	0.068	0.244	0.245	27	$\frac{5}{16}$
$\frac{1}{4}$	0.540	0.364	0.088	0.424	0.425	18	$\frac{7}{16}$
$\frac{3}{8}$	0.675	0.493	0.091	0.567	0.568	18	$\frac{7}{16}$
$\frac{1}{2}$	0.840	0.622	0.109	0.850	0.852	14	$\frac{9}{16}$
$\frac{3}{4}$	1.050	0.824	0.113	1.130	1.134	14	$\frac{9}{16}$
1	1.315	1.049	0.133	1.678	1.684	$11\frac{1}{2}$	$\frac{11}{16}$
$1\frac{1}{4}$	1.660	1.380	0.140	2.272	2.281	$11\frac{1}{2}$	$\frac{11}{16}$
$1\frac{1}{2}$	1.900	1.610	0.145	2.717	2.731	$11\frac{1}{2}$	$\frac{11}{16}$
2	2.375	2.067	0.154	3.652	3.678	$11\frac{1}{2}$	$\frac{3}{4}$
$2\frac{1}{2}$	2.875	2.469	0.203	5.793	5.819	8	$1\frac{1}{16}$
3	3.500	3.068	0.216	7.575	7.616	8	$1\frac{1}{8}$
$3\frac{1}{2}$	4.000	3.548	0.226	9.109	9.202	8	$1\frac{3}{16}$
4	4.500	4.026	0.237	10.790	10.889	8	$1\frac{3}{16}$
$4\frac{1}{2}$	5.000	4.506	0.247	12.538	12.642	8	$1\frac{1}{4}$
5	5.563	5.047	0.258	14.617	14.810	8	$1\frac{5}{16}$
6	6.625	6.065	0.280	18.974	19.185	8	$1\frac{3}{8}$
7	7.625	7.023	0.301	23.544	23.769	8	$1\frac{3}{8}$
8	8.625	8.071	0.277	24.696	25.000	8	$1\frac{7}{16}$
8	8.625	7.981	0.322	28.554	28.809	8	......
9	9.625	8.941	0.342	33.907	34.188	8	$1\frac{1}{2}$
10	10.750	10.192	0.279	31.201	32.000	8	$1\frac{5}{8}$
10	10.750	10.136	0.307	34.240	35.000	8	......
10	10.750	10.020	0.365	40.483	41.132	8	......
11	11.750	11.000	0.375	45.557	46.247	8	......
12	12.750	12.090	0.330	43.773	45.000	8	$1\frac{3}{4}$
12	12.750	12.000	0.375	49.562	50.706	8	......

* Crane Company standard.

379. Pipe Sizes and Dimensions. — Pipe sizes up to 12 inches are specified by *nominal* sizes, which are neither the true inside nor outside dimensions. In Table III, the actual dimensions and weights of pipe, number of threads, and length of thread which must be screwed into a fitting to make a tight joint are given for the nominal pipe sizes. Above 12 inches in diameter, pipe sizes are specified by giving the outside diameter and the thickness of metal. This is called *OD* pipe and can be secured in sizes up to 96 inches with thicknesses varying by $\frac{1}{16}$ inch from $\frac{1}{4}$ to $\frac{5}{8}$ inches. Wrought iron pipe can be threaded up to 24 inches inclusive, and couplings can be secured up to 20 inches inclusive. Three weights of wrought-iron pipe are available, called standard, extra strong, and double extra strong. All three weights have the same outside diameter as the standard or lightest weight. Unless specific lengths are ordered, pipe is shipped in random lengths varying from 12 to 22 feet. Cast-iron and brass piping differ in dimensions from wrought-iron pipe, and a handbook should be consulted for these dimensions when needed.

380. Valves. — On single-line or diagrammatic pipe drawings, valves are indicated by the symbols shown in Fig. 3. On double-line pipe drawings, the valves are indicated by the symbols of Fig. 1, which are made to look somewhat like the orthographic projection and should be drawn to scale in their principal dimensions. Figures 7, 8, and 9 show the general shape and interior construction of different kinds of valves. The principal dimensions necessary to draw them and to compute pipe lengths and clearances for the installation and operations are given in the Tables IV, V, and VI, respectively. The letters used in the tables refer to corresponding letters on the figures. The thickness and diameter of valve flanges are the same as the corresponding size flange fittings. See Table II.

Gate Valves. — Gate valves are used where free flow with little pressure drop through the valve is desired. They are commonly used on water lines and in boiler installations.

Globe Valves. — Globe valves are commonly used in steam and air lines where a close regulation of flow is desired.

Check Valves. — These valves are used where a return flow of fluid is to be avoided. Such valves usually do not close tight enough to prevent leakage, and hence, where contamination is possible by return flow, other valves should be installed.

Relief Valves. — Where pressure conditions may exceed safe values, relief valves are used to safeguard the system. These valves may be set to act at any desired pressure.

TABLE IV

DIMENSIONS OF STANDARD GLOBE, ANGLE AND CROSS VALVES
(All Dimensions in Inches)

Size	2	2½	3	3½	4	4½	5	6	7	8	10	12
A	6½	7	8	9	10	10½	11¼	13	14½	18½		
B	8	8½	9½	10½	11½	12	13	14	16	19½	24½	27½
T	11⅛	11¾	13⅛	13⅞	15⅜	15½	17¼	19	21¼	24¾	29	34
R	6½	6½	7½	7½	9	9	10	12	14	16	18	20

Substitute *A* for *B* with screw fittings

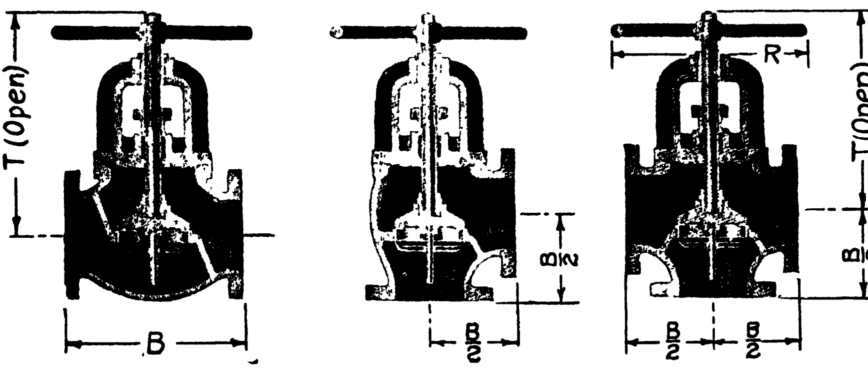


FIG. 7. Standard globe, angle and cross valves.

TABLE V

DIMENSIONS OF STANDARD LIFT AND SWING CHECK VALVES
(All Dimensions in Inches)

Size	2	2½	3	3½	4	4½	5	6	7	8	10	12
A	6½	7	8	9	10	10½	11¼	12½	14	18½		
B	8	8½	9½	10½	11½	12	13	14	16	19½	24½	27½

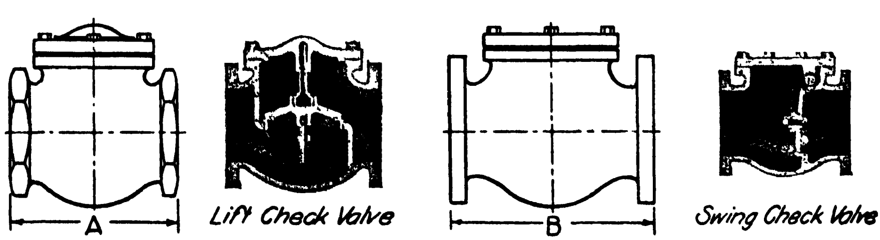


FIG. 8. Standard lift and swing check valves.

TABLE VI

DIMENSIONS OF STANDARD GATE VALVES
(All Dimensions in Inches)

Size	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	6	7	8	10	12
A	$5\frac{7}{16}$	$5\frac{7}{8}$	$6\frac{1}{8}$	$6\frac{1}{2}$	$6\frac{7}{8}$	$7\frac{1}{8}$	$7\frac{3}{8}$	$7\frac{3}{4}$	$8\frac{1}{4}$	$8\frac{3}{4}$	$9\frac{7}{8}$	$11\frac{5}{8}$
B	7	$7\frac{1}{2}$	8	$8\frac{1}{2}$	9	$9\frac{1}{2}$	10	$10\frac{1}{2}$	11	$11\frac{1}{2}$	13	14
O	$14\frac{1}{2}$	16	$18\frac{1}{2}$	$20\frac{3}{4}$	$23\frac{1}{2}$	$24\frac{3}{4}$	28	$31\frac{3}{4}$	$37\frac{1}{4}$	41	$49\frac{1}{2}$	$57\frac{1}{2}$
P	$12\frac{1}{4}$	$12\frac{3}{4}$	$14\frac{3}{4}$	$15\frac{1}{4}$	$16\frac{1}{4}$	$17\frac{5}{8}$	19	$21\frac{1}{4}$	$23\frac{1}{2}$	26	31	36
R	$6\frac{1}{2}$	$6\frac{1}{2}$	$7\frac{1}{2}$	$7\frac{1}{2}$	9	9	10	12	12	14	16	18

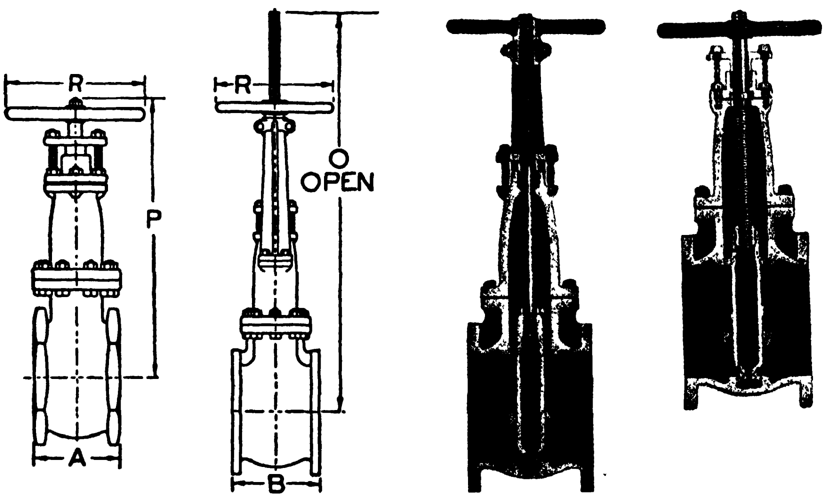


FIG. 9. Standard gate valves.

381. PIPE BENDS. — When the fluids in a pipe line are to have high velocities, pipe bends are used in place of standard fittings. If the pressures are under 150 pounds, cast-iron long-sweep fittings may be used. Long-sweep fittings have longer radii than the standard fittings. Dimensions of long-sweep fittings may be obtained from manufacturers' catalogues. Pipe bends are also used to provide for expansion in pipe lines. The radius of a bend must not be less than four diameters for 7 inch pipe and under, and not less than five diameters for pipe above that size. In low-pressure lines, expansion may be provided for by expansion joints of special design. Pipe bends are usually fitted with flanges.

382. PIPE SUPPORTS AND DRAINAGE. — Pipe lines must be supported at frequent intervals in order to avoid high stresses in the pipe, fittings, and valves. Several types of supports are shown in Fig. 10. The supports are designed to allow for the movement of the pipe due to expansion and contraction. Steam lines require drainage to take care of condensation in the pipe. Drip pockets and steam traps are used for this purpose. Pipe should be pitched in the direction of steam flow. A pitch of 1 inch in 20

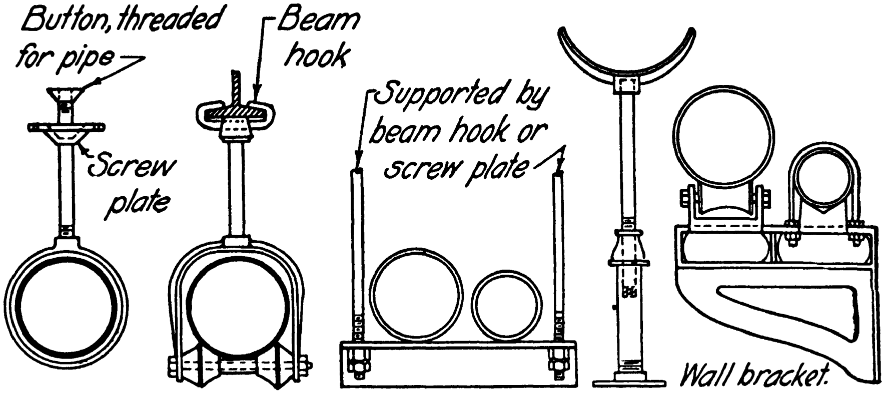


FIG. 10. Pipe supports.

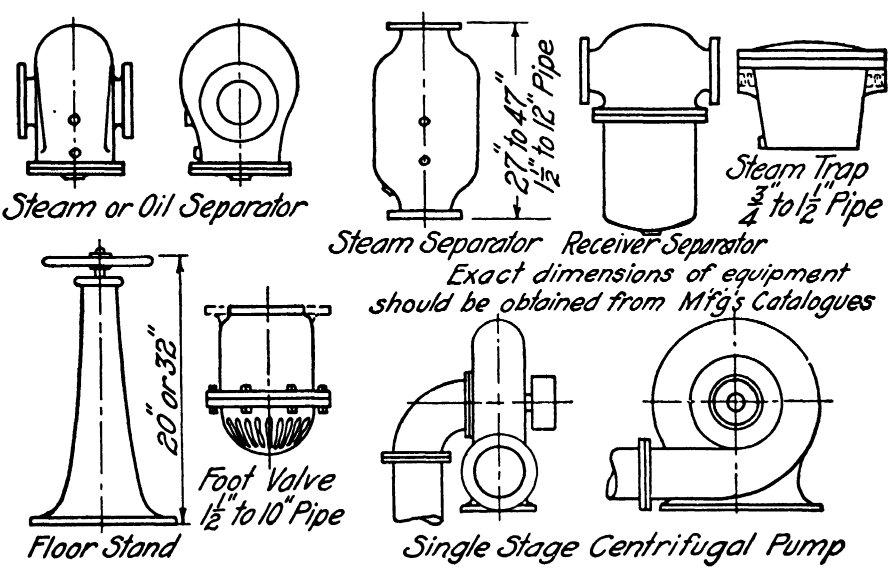
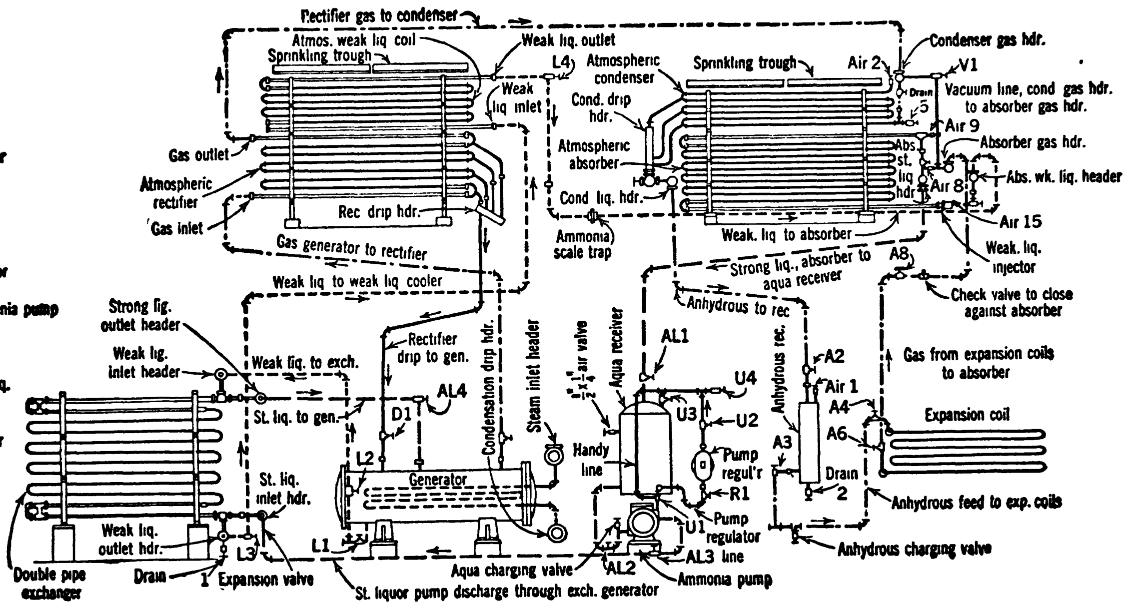


FIG. 11. Devices used in pipe lines.

feet is adequate in horizontal lines. Other types of pipe lines should also be pitched and provided with valves so that they may be cleaned and emptied. Symbols for a few common devices necessary in the operation of pipe lines are shown in Fig. 11.

Valves

A1 - Gas valve Gen to rec.
A2 - Anhydrous-condenser to rec.
A3 - Anhydrous feed from rec.
A4 - Expansion valves at coils
A6 - Gas valves, coil outlets
A8 - Gas expansion coils to absorber
L1 and L2 - Wk liq valves at generator
L3 - Exp. V. exchanger to wk. liq coil
L4 - Wk. liq from W.L. coil to abs.
AL1 - St liq. absorber to aqua rec.
AL2 - Pump suction valve
AL3 - Pump discharge valve
AL4 - Pump discharge valve at generator
D1 - Rectifier drip valve to generator
U1 - Valve on discharge chamber ammonia pump
U2 - Valve above pump regulator
U3 - Valve above aqua receiver
U4 - Valve to air from handy line
R1 - Valve on pump req line bottom req.
Drain 1 - Valve at bottom of exch.
Drain 2 - Valve at bottom anhyd. rec.
Drain 5 - Valve at bottom of condenser
V1 - Valve on vacuum line, between cond. and abs. gas hdrs.
Air 1 - Valve at top anhyd. rec.
Air 2 - Valve at top of cond.
Air 8 - At bottom of vacuum line
Air 9 - At top of absorber coils
Air 15 - At bottom of abs. coils



(*Courtesy of A. J. McIntire.*)

Fig. 12. The absorption machine complete. A diagrammatic pipe layout.

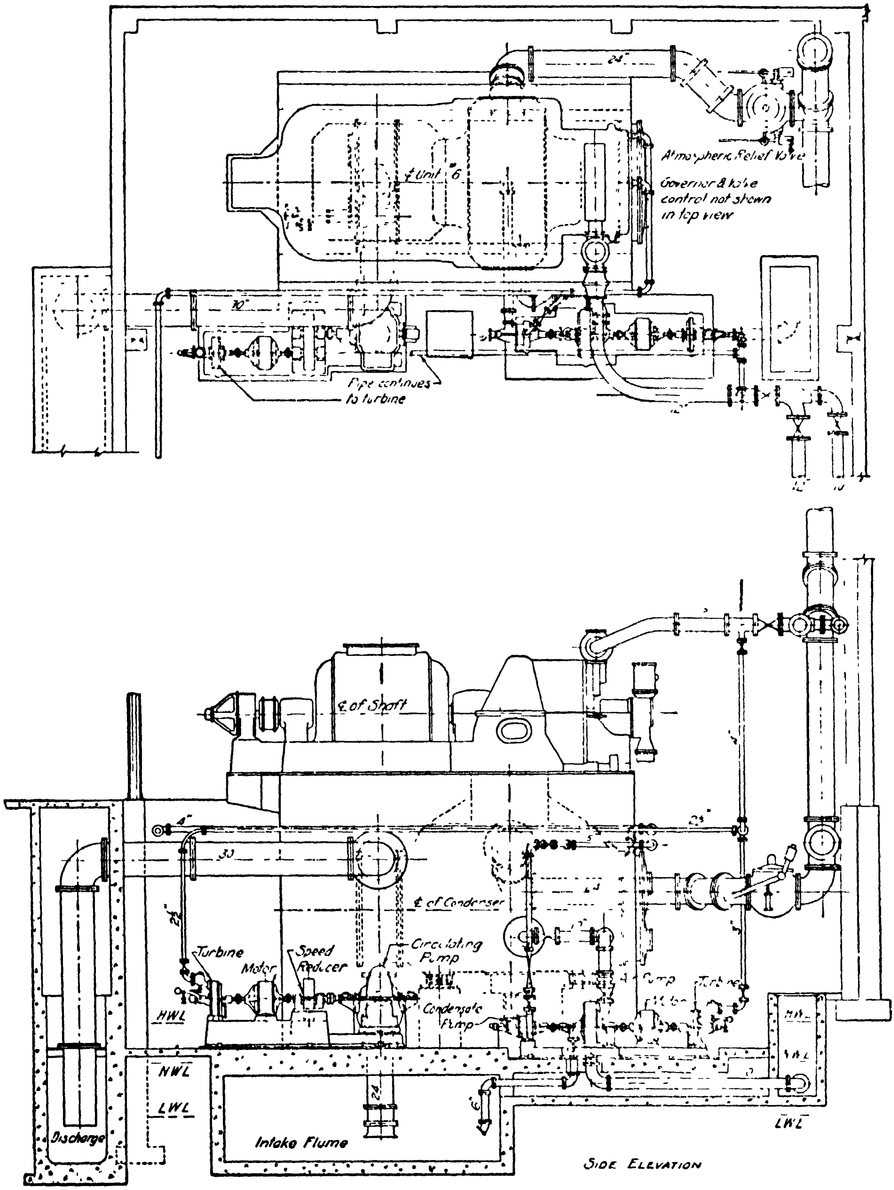


FIG. 13. Orthographic layout of power plant unit.

383. Pipe Drawings and Diagrams. — In large piping systems, the design usually begins with a diagrammatic layout which indicates merely the line of flow or transfer from one unit to another, in much the same fashion as a wiring diagram shows electrical circuits and connections. Figure 12 shows such a diagram. Double-line pipe symbols may be used, but single-line symbols are more common and require less time to draw.

384. Orthographic Drawings. — Pipe layouts for power plants and the like are drawn in the usual two- and three-view orthographic projections for construction drawings, as shown in Fig. 13. The equipment which the piping serves is shown by symbols drawn by the engineer to resemble the orthographic projections. Since the piping is large, double-line symbols are used and the pipe and fittings shown to scale. For single-line drawings the symbols shown in Fig. 14 are used. Where many different pipe lines are involved in the same general plant layout, it is

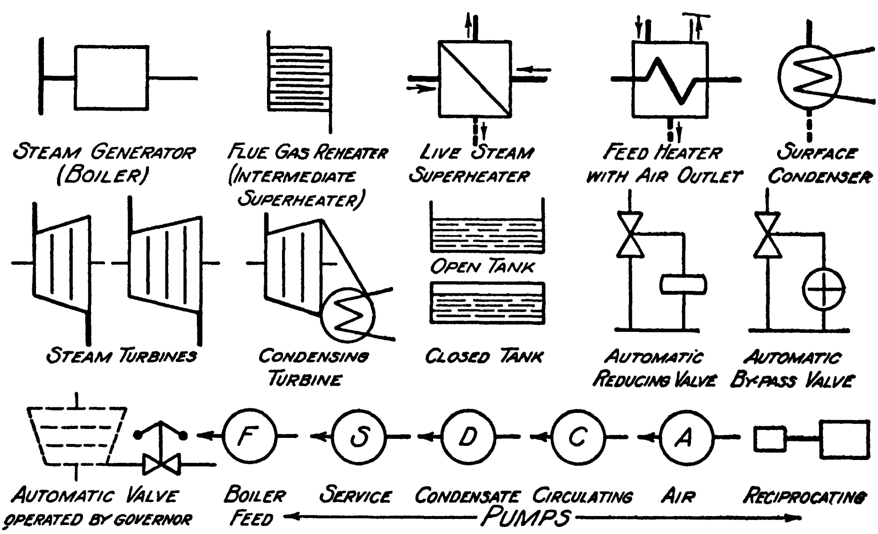
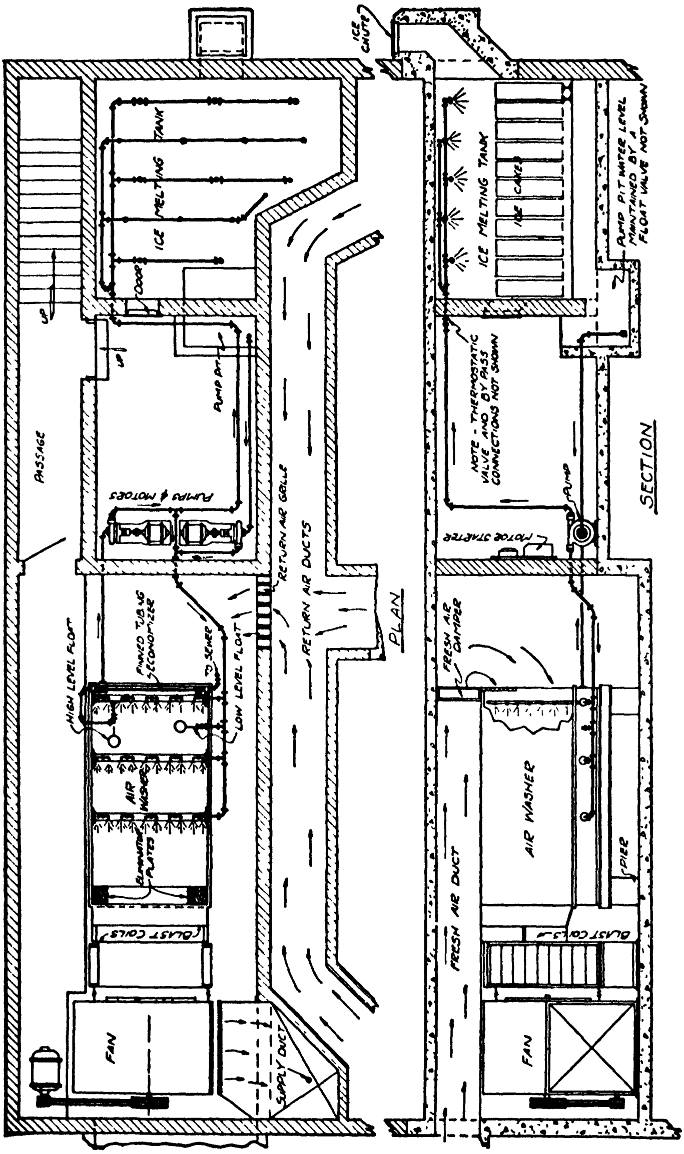


Fig. 14. Standard symbols for power plant layouts.

customary to make separate drawings for each piping system in order to avoid confusion. Thus, in a power plant, there would be one or more sheets for the main steam lines, another for the exhaust lines, another for boiler feed-lines, and so on. These sheets must be carefully checked against each other to see that there is no conflict in the pipe systems. Figure 15 illustrates a single-line orthographic layout of an air-conditioning plant.

385. Oblique Pipe Layout Drawings. — For such work as the distribution system of a heating plant where single-line symbols are to be



(Courtesy of Nickerson and Collins Co.)

FIG. 15. Single line orthographic layout of air conditioning plant.

used, the oblique projection scheme shown in Fig. 16 may be used. This is not an exact oblique projection since different oblique axes are used on the various sides of the layout. A true projection would cause the piping on the lower and right-hand sides to overlap the rest, hence the method

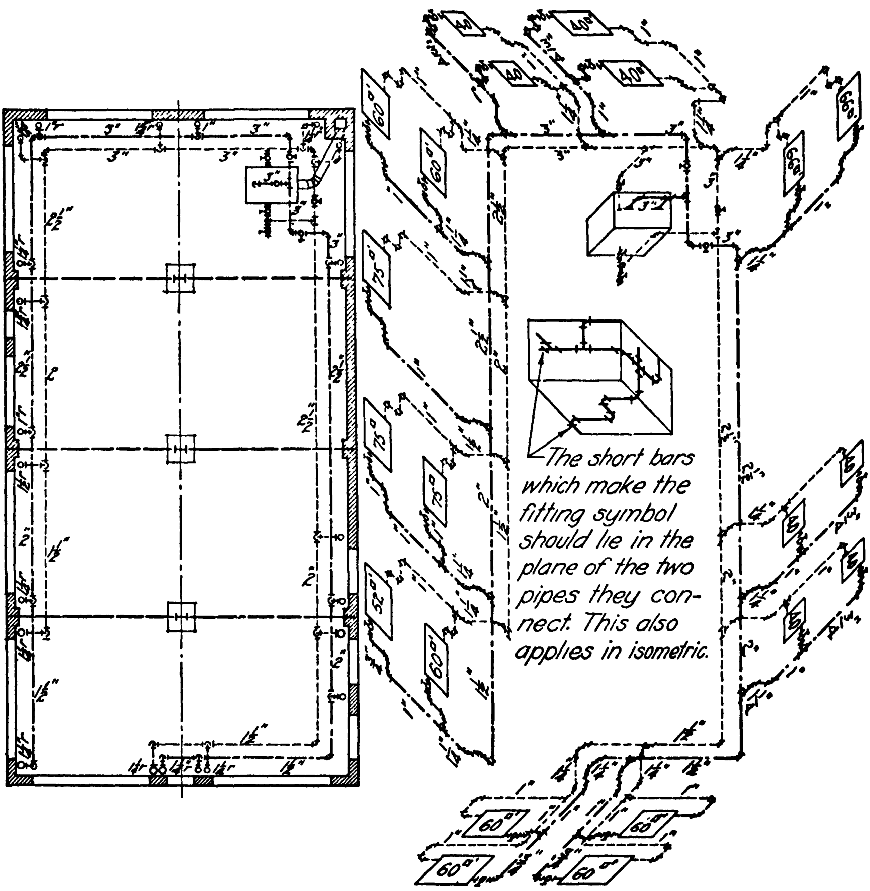


FIG. 16. Oblique pipe layout of heating plant.

adopted is much clearer. True oblique projections drawn to scale are frequently used for explanatory purposes. See Chapter XIV, "Oblique Projection."

386. ISOMETRIC PIPE LAYOUT DRAWINGS. — Isometric drawings are also used for the same purposes as the oblique layouts, but the axes in the isometric scheme are not so easily modified as in the oblique system. See Fig. 17. For explanatory purposes where there is no overlapping of the pipe lines the isometric scheme is very convenient and very clear. Isometric drawing is discussed in Chapter XIII.

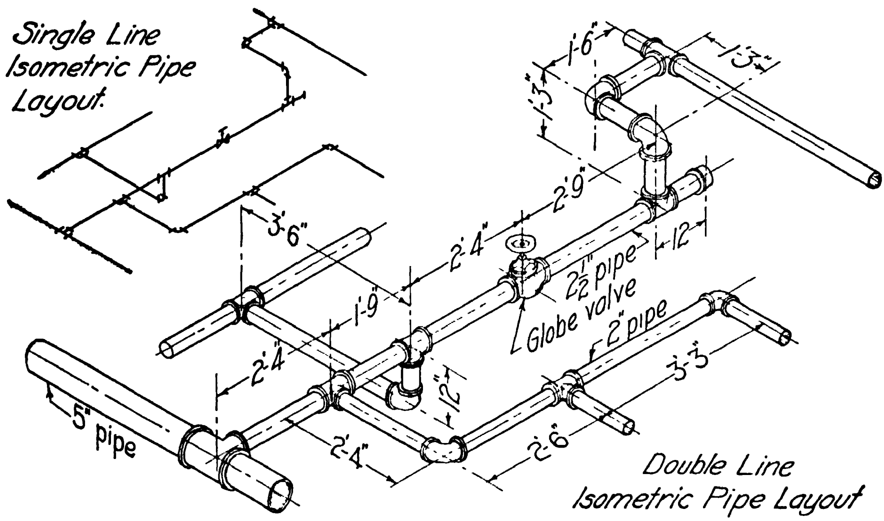


FIG. 17. Isometric pipe layouts.

387. DIMENSIONING PIPE DRAWINGS. — The rules for dimensioning isometric, oblique, or orthographic drawings apply to pipe drawings made by any one of these methods. Dimensions are always given to the center line of pipes, valves, and fittings. This can be done where double-line symbols are used, and it must be clearly understood that such is the case when single-line layouts are dimensioned.

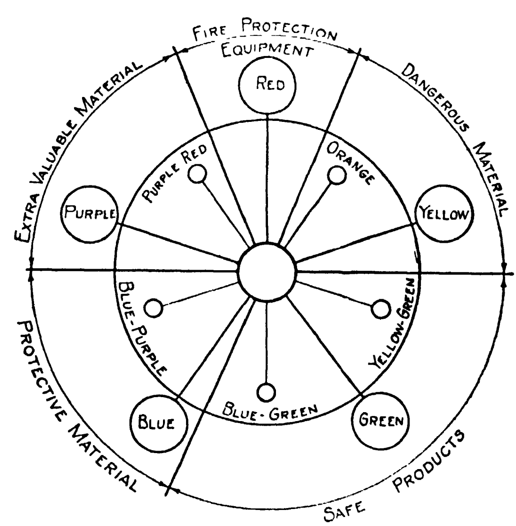


FIG. 18. Identification of pipe lines.

388. INDUSTRIAL-PLANT PIPING. — In many plants, fluids of a corrosive character such as acids must be handled in pipe lines. The pipe must, therefore, be of a metal which will resist attack by the substance handled, or it must be coated with a protective material such as lead, rubber, or other substance which will resist corrosion.

389. Identifying Piping Systems. — It is highly desirable, for reasons of safety, to identify pipe lines according to their contents. The American Standards Association, in their Bulletin A-13-1928, entitled "Scheme for the Identification of Piping Systems," has adopted five classifications of materials which may be identified by a color scheme as shown in Fig. 18. The piping is to be painted the color indicated or is to have bands of the proper color painted near all valves and outlets. The names of the material may be painted as a legend on the colored band. The bulletin divides a long list of materials commonly handled in industrial plants into these five classes. It also indicates the pigments best suited to obtain the proper color.

PROBLEMS

390. The following problems are typical of many that can be prepared from actual plans of buildings available to most instructional drawing rooms. Original designs should be used when available. For meaning of sheet sizes and scale specifications, see Art. 4, page 3.

1. On the plan and transverse section of the building shown in Fig. 19, draw the piping layout for emptying the six tanks, also outlets to sewer for cleaning tanks. The outlet of each tank is at the center of its bottom. Pipes to the pumps must run in trenches. Pipes from the pumps to outside discharge must have 10′ of clearance from the floor. Valves and piping must be so arranged that either pump can empty any tank. Arrange check valves so that one pump will not cause a backflow into the other. Either one may be idle. Use 3″ pipe with screw fittings. Give a list of all pipe and fittings. Each pump is fitted with an intake and exhaust nipple. Draw the building and tanks in light lines and the piping system in heavy lines. Scale A: $\frac{1}{4}$″ = 1′-0″. Scale B: $\frac{1}{8}$″ = 1′-0″.

2. On the plan and transverse section of the building shown in Fig. 19, draw the pipe layout for filling the two large horizontal tanks and for emptying them into the six smaller tanks, also for providing small tanks with water from an outside source. Provide piping and valves to empty either large tank into any one of the small tanks. Use 3″ pipe with flanged fittings for filling the large tanks and 2″ pipe with screw fittings to empty them. Use 2″ pipe for water supply. Piping must clear the floor by 10′. Draw the building and tanks in light lines and the piping in heavy lines. Scale A: $\frac{1}{4}$″ = 1′-0″. Scale B: $\frac{1}{8}$″ = 1′-0″.

3. Upon the plan and longitudinal section of the building shown in Fig. 19, draw the steam-pipe layout for heating the six small tanks. Both direct and return pipes must run in the pipe trench. Provide also a blowoff and drain line with steam trap connecting to the sewer. The steam supply line shall be 2″ pipe with screw fittings for 125-lb. pressure, and the return line to the condenser shall be 1$\frac{1}{2}$″ pipe. The blowoff line shall be 1$\frac{1}{2}$″ pipe. Provide valves so that any tank may be heated without disturbing the others. Make a list of pipe and fittings. Scale A: $\frac{1}{4}$″ = 1′-0″. Scale B: $\frac{3}{16}$″ = 1′-0″.

4. Make an oblique single-line layout of the piping for the heating system for building B, Figs. 23 and 24, Art. 373. Place a radiator under each window on both first and second floors. Smallest pipe will be $\frac{3}{4}$″ diameter at the radiator. Basements will require no radiators. Use sheet size B.

5. Same as Prob. 4, Figs. 25 and 26, Art. 373.

6. Make the first-floor plan of building B, Figs. 23 and 24, Art. 373, and then show upon it by single-line symbols the heating layout. The plan shall be in outline, showing door and window openings and sufficient other detail to locate radiators and risers to the second floor, if any.

7. Same as Prob. 6, building E, Figs. 25 and 26, Art. 373.

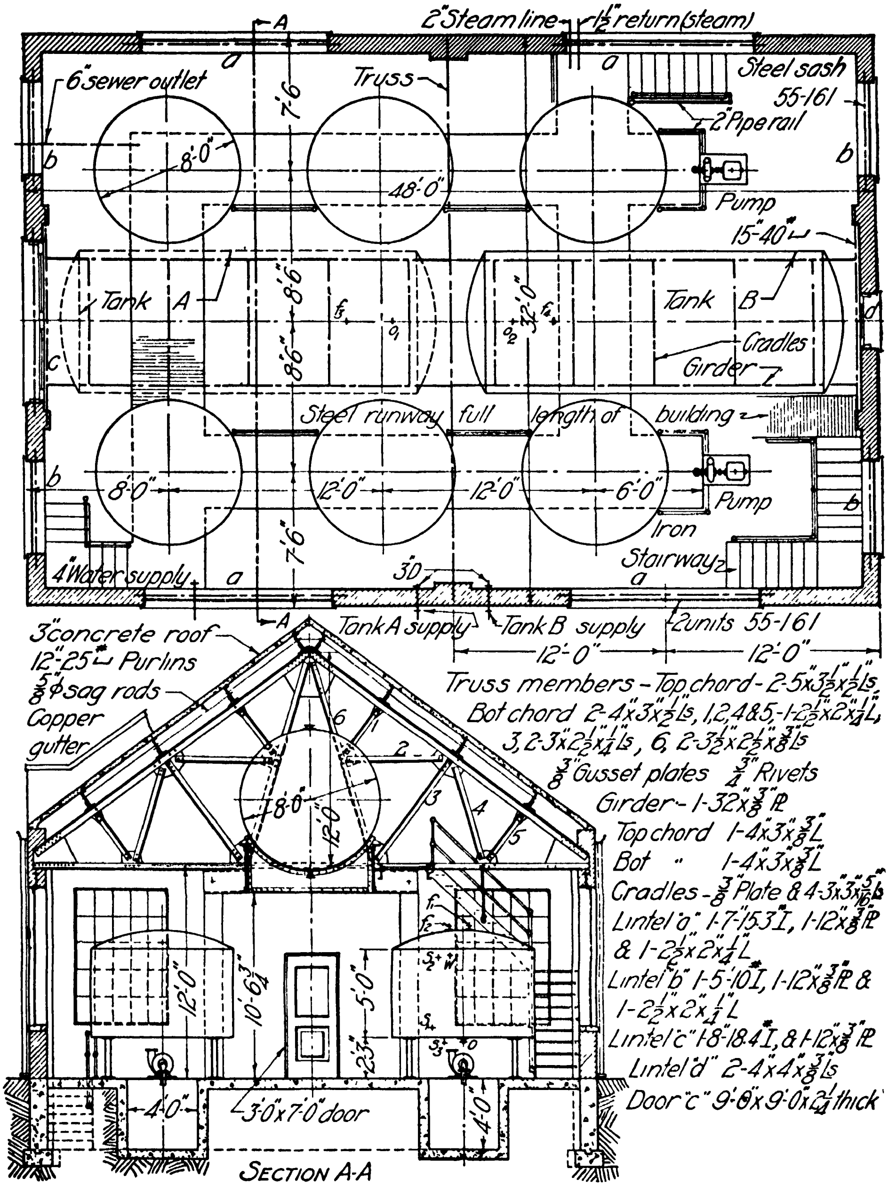


Fig. 19. Plan and section of small chemical treating plant.

CHAPTER XXIII

STRUCTURAL DRAWING

391. Structural drawing includes all layout problems 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 only are dealt with here, since timber structures offer no special drawing problem. No attempt is made to deal with engineering design of any structure.

In order that in later portions of this chapter the meaning of certain expressions, already quite familiar to the structural engineer, 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.

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. 1.

Bay. The space between two consecutive sets or tiers of columns and beams, or columns and trusses. See Fig. 2.

Bent. A vertical framework, usually columns and beams supporting other members. In Fig. 2 the truss and two columns supporting it constitute a bent. Figure 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.

Chord. The top or bottom members of a truss. See Fig. 2.

Clearance. The space left between members to allow for the slight inaccuracies of cutting, and also to facilitate erection. See Figs. 4 and 15.

Clip Angle. A small angle used to fasten light connections. See Fig. 15.

Column. A vertical compression member, usually supporting beams and girders. See Fig. 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. 4.

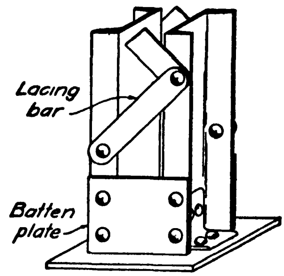


FIG. 1. Column base.

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. 6.

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. 6.

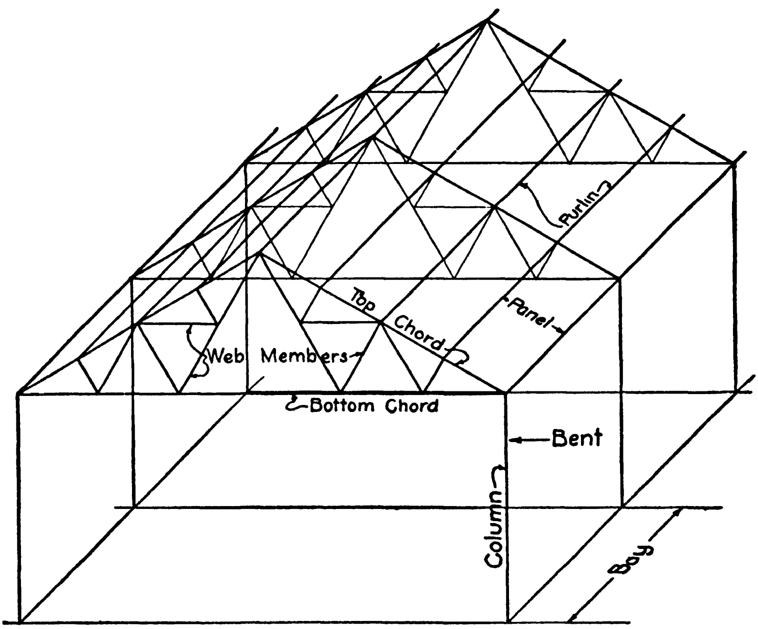


FIG. 2. Line diagram, mill building.

Flange. The top and bottom projection or outstanding parts of a beam, channel or girder. See Figs. 4 and 6.

Gage Line. The line along which rivet holes are punched in structural members. See Figs. 5, 6, and 14.

Girder. A member designed to carry bending stress, usually supporting other members. Figure 6 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 Figs. 5 and 14.

Lattice Bar or Lacing Bar. One of a series of short diagonal bars used to connect the several parts of a member. See Fig. 1.

Lintel. A structural member designed to carry the wall over a window, door, or other opening. See Fig. 7.

Panel. The space between two purlins in a roof or between two vertical members in a bridge truss. See Fig. 2.

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

Purlin. The horizontal members spanning from truss to truss, upon which the roof is carried. See Fig. 2.

Stiffener. An angle riveted to a plate to prevent it from buckling. See Fig. 6.

Truss. A steel framework whose members take only tension or compression stresses. See Figs. 2, 5, and 14.

Web. The portion of an I-beam, channel, or girder, between the upper and lower flanges. See Figs. 4 and 6.

Web Member. The members of a truss between the top and bottom chords. See Fig. 2.

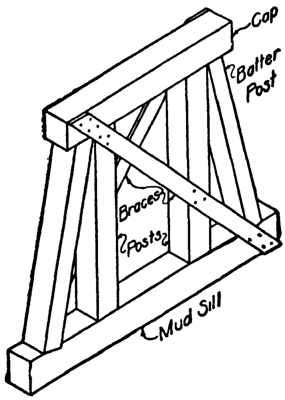


FIG. 3. Railroad trestle bent.

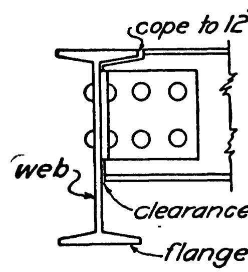


FIG. 4. I-Beam connection.

392. SCOPE OF STRUCTURAL DRAWING. — Professor Ketchum, in his "Handbook for Structural Engineers,"[1] says:

The plans (drawings) for a structure must contain all the information necessary for the design of the structure, for ordering of the material, for fabricating the structure in the shops, for erecting the structure, and for making a complete estimate of the material used in the structure. Every complete set of plans for a structure must contain the following information insofar as the different items apply to the particular structure.

General Plan. — This will include a profile of the ground; location of the structure; elevations of the ruling points in the structure; clearances; grades (for a bridge); direction of flow, high water, and low water; and all other data necessary for designing the substructure and the superstructure.

Stress Diagram. — This will give the main dimensions of the structure, the loading, stresses in all members for the dead loads, live loads, wind loads, etc., itemized sepa-

[1] "Handbook for Structural Engineers," by M. S. Ketchum, published by McGraw-Hill Book Co.

rately; the total maximum and minimum stresses; size of members; typical sections of all built members showing arrangement of material; and all information necessary for the detailing of the various parts of the structure.

Shop Drawing. — Shop detail drawings should be made for all structural steel and iron work and detail drawings of all timber, masonry and concrete work.

Foundation or Masonry Plan. — The foundation or masonry plan should contain detail drawings of all foundations, walls, piers, etc., that support the structure. The plans should show the load on the foundation; the depth of the footings; the spacing of piles where used; the proportions for the concrete; the quality of masonry and mortar; the allowable bearing on the soil; and all data necessary for accurately locating and constructing the foundations.

Erection Diagram. — The erection diagram should show the relative location of every part of the structure; shipping marks for the various members; all main dimensions; number of pieces in a member; packing of pins; size and grip of pins; and any special feature or information that may assist the erector in the field. The approximate weight of heavy pieces will materially assist the erector in designing his falsework and derricks.

Falsework Plans. — For ordinary structures it is not common to prepare falsework plans in the office, this important detail being left to the erector in the field. For difficult or important work, erection plans should be worked out in the office and should show in detail all members and connections of the falsework, and also give instructions for the successive steps in carrying out the work. Falsework plans are especially important for concrete and masonry arches and other concrete structures and for forms for all walls, piers, etc. Detail plans of travelers, derricks, etc., should also be furnished the erector.

Bills of Material. — Complete bills of material, showing the different parts of the structure with their marks, and the shipping weight, should be prepared. This is necessary in checking up the material to see that it has all been shipped or received, and to check the shipping weight.

Rivet List. — The rivet list should show the dimensions and number of all field rivets, field bolts, spikes, etc., used in the erection of the structure.

List of Drawings. — A list should be made showing the contents of all drawings belonging to the structure.

Of this list of drawings which are necessary for the building of a structure, this chapter concerns itself only with shop drawings.

393. Shop Drawings — Complete and Sketch Details. — Two general schemes of making shop drawings are in common use. In the first and most common method, all the work is completely detailed, down to the location of every hole and the determination of the size of every rivet, so that the template-maker and the man in the shop can proceed directly to lay out, cut, punch, and assemble the material without calculation or further drawing on their part. The advantages of this method lie in the fact that an exact estimate can be made from such a drawing and that, in the event of changes or additions at a later date, complete and accurate records are available. A roof truss detailed in this manner is shown in Fig. 14.

In the second method, much of the detail is left to the template-maker. The working lines of the pieces are given, together with the dimensions between working points or intersections of the gage lines of the various members, the number of rivets in each member, the maximum amd minimum rivet spacing allowed, the clearances required, and the thickness of plates and size of other structural parts. The actual layout of the rivets, the shape and size of the plates, etc., are left for the template-maker to work out full size, in the shop. Figure 5 shows a detail made in this manner.

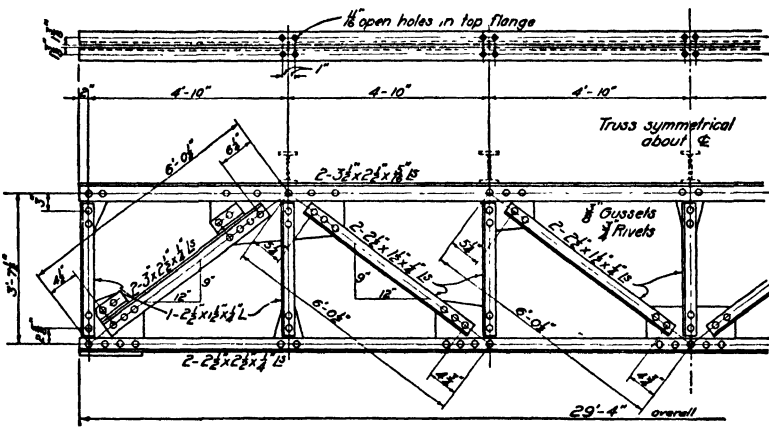


FIG. 5. Sketch detail of truss.

394. 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. 14. Frequently, 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.

395. 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. 6 and 14. 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.

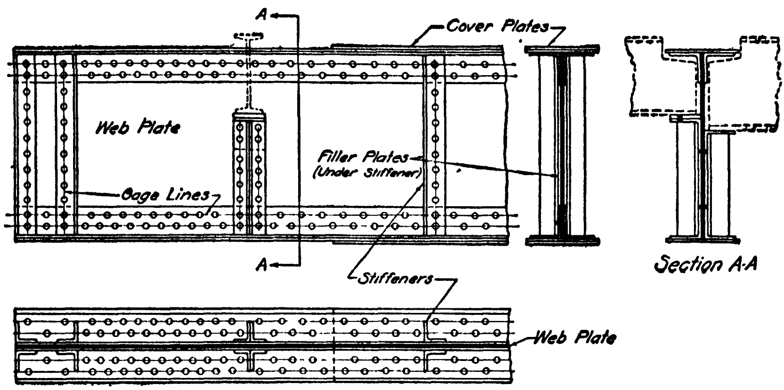


FIG. 6. Plate girder.

396. 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. 8. When they cannot be conveniently detailed in this manner, they are placed horizontally in the position in which they would fall.

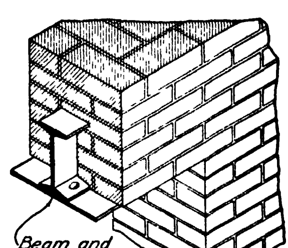


FIG. 7. Steel lintel.

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. 8. This holds true for all except plain building work. Where connections occur in building work upon the detailing of which other framing depends, the member connecting with the one detailed

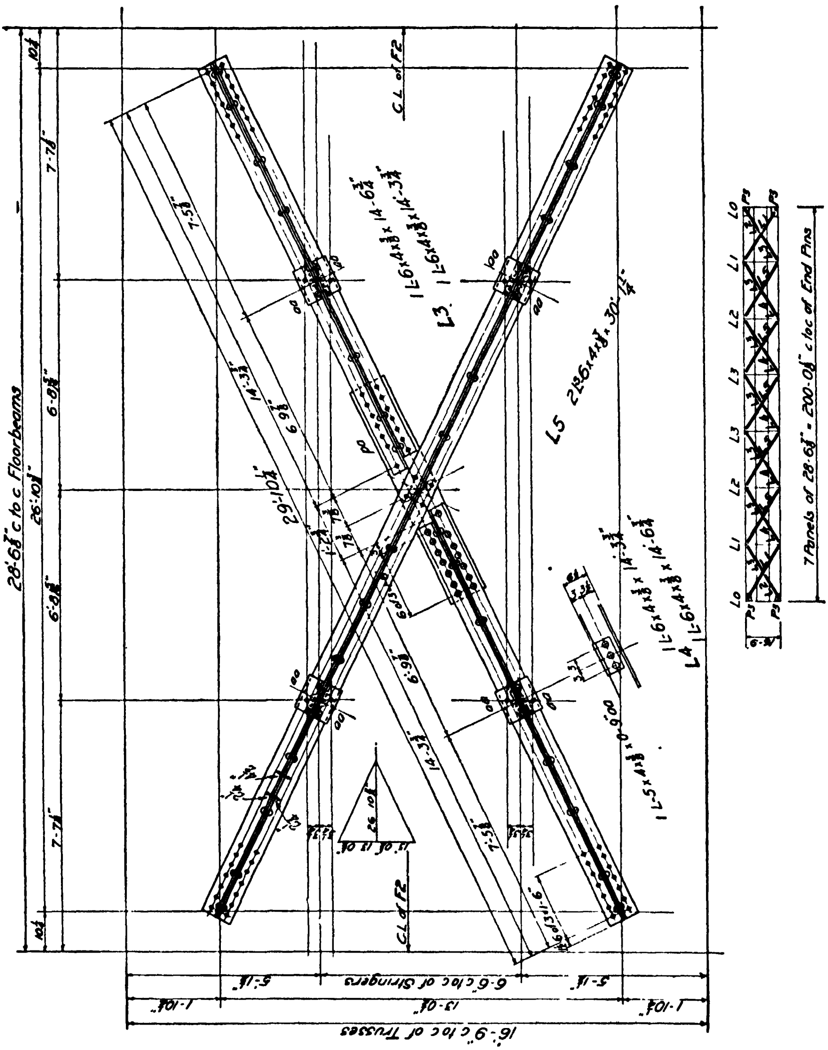


FIG. 8. Detail of wind bracing.

is shown in red ink or light, dotted, black lines, for the benefit of other draftsmen or the erector, who may wish information concerning the connecting piece. Figure 9 shows such a connection, the connecting member being shown in dotted lines.

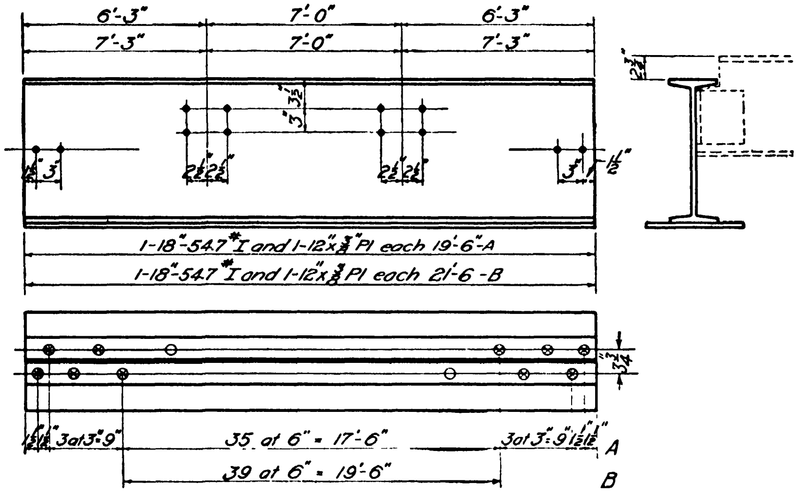


FIG. 9. Detail of steel lintel.

397. Symmetrical Members. — If large members 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 14 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.

398. 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. 6. Standard practice as regards cross-hatching is also shown in Fig. 6. 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.

399. 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.

400. 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 10 shows cross-sections of the more common

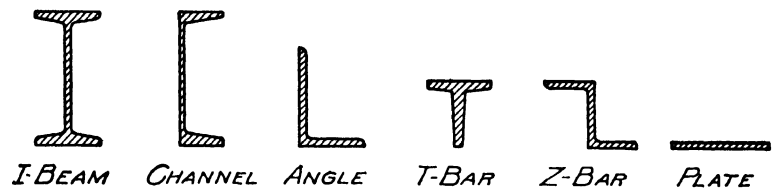


FIG. 10. Cross-section of structural shapes.

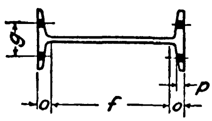
shapes, the sizes of which vary through a wide range although the general proportions remain about the same. Thus, I-beams may be obtained in sizes from 3 to 36 inches in height, and for each height there are a number of standard weights. The structural steel handbooks list all these completely, and the student is referred to them for further information. A list of the standard light sections is given in Tables I and II.

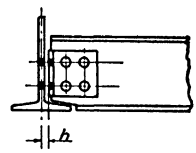
401. Gage Lines. — The lines along which rivets should be placed in the flanges of I-beams, channels, angles and other structural shapes, have become standardized through long usage. These lines are called gage lines. In angles, the gage line is measured from the back of the angle. The gage line in the 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 I, II, and III.

TABLE I

STANDARD GAGES AND DIMENSIONS FOR BEAMS

("Carnegie Pocket Companion")

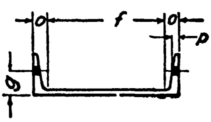


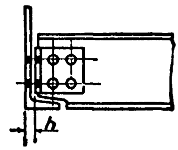


Depth of Beam	Weight per Foot	Flange Width	Web Thickness	½ Web Thickness	Gage g	Grip p	Distance f	Distance o	Distance h	Max. Rivet in Flange
In.	Lb.	In.	In.	In.	In.	In.	In.	In.	In.	In.
27	90 0	9	$\frac{1}{2}$	$\frac{1}{4}$	5	$\frac{3}{4}$	$22\frac{1}{2}$	$2\frac{1}{4}$	$\frac{5}{16}$	$\frac{7}{8}$
24	79 9	7	$\frac{1}{2}$	$\frac{1}{4}$	4	$\frac{7}{8}$	$20\frac{1}{4}$	$1\frac{5}{8}$	$\frac{5}{16}$	$\frac{7}{8}$
21	60 4	$8\frac{1}{4}$	$\frac{7}{16}$	$\frac{3}{16}$	4	$\frac{9}{16}$	$17\frac{1}{2}$	$1\frac{3}{4}$	$\frac{1}{4}$	$\frac{7}{8}$
20	65 4	$6\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	4	$\frac{3}{4}$	17	$1\frac{1}{2}$	$\frac{5}{16}$	$\frac{7}{8}$
18	54 7	6	$\frac{7}{16}$	$\frac{1}{4}$	$3\frac{3}{4}$	$\frac{3}{4}$	$15\frac{1}{4}$	$1\frac{3}{8}$	$\frac{5}{16}$	$\frac{7}{8}$
15	42 9	$5\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{16}$	$3\frac{1}{2}$	$\frac{5}{8}$	$12\frac{1}{2}$	$1\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{4}$
12	31 8	5	$\frac{3}{8}$	$\frac{3}{16}$	3	$\frac{9}{16}$	$9\frac{3}{4}$	$1\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{4}$
10	25 4	$4\frac{5}{8}$	$\frac{5}{16}$	$\frac{1}{8}$	$2\frac{3}{4}$	$\frac{1}{2}$	8	1	$\frac{1}{4}$	$\frac{3}{4}$
9	21 8	$4\frac{3}{8}$	$\frac{5}{16}$	$\frac{1}{8}$	$2\frac{1}{2}$	$\frac{1}{2}$	7	1	$\frac{3}{16}$	$\frac{3}{4}$
8	18 4	4	$\frac{1}{4}$	$\frac{1}{8}$	$2\frac{1}{4}$	$\frac{7}{16}$	$6\frac{1}{4}$	$\frac{7}{8}$	$\frac{3}{16}$	$\frac{3}{4}$
7	15 3	$3\frac{5}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	$2\frac{1}{4}$	$\frac{3}{8}$	$5\frac{1}{4}$	$\frac{7}{8}$	$\frac{3}{16}$	$\frac{5}{8}$
6	12 5	$3\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	2	$\frac{3}{8}$	$4\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{16}$	$\frac{5}{8}$
5	10 0	3	$\frac{3}{16}$	$\frac{1}{8}$	$1\frac{3}{4}$	$\frac{3}{8}$	$3\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{16}$	$\frac{1}{2}$
4	7 7	$2\frac{5}{8}$	$\frac{3}{16}$	$\frac{1}{8}$	$1\frac{1}{2}$	$\frac{5}{16}$	$2\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{16}$	$\frac{1}{2}$
3	5 7	$2\frac{3}{8}$	$\frac{3}{16}$	$\frac{1}{16}$	$1\frac{1}{2}$	$\frac{5}{16}$	$1\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{3}{8}$

TABLE II

Standard Gages and Dimension for Channels
("Carnegie Pocket Companion")

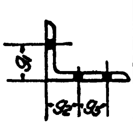




Depth of Channel	Weight per Foot	Flange Width	Web Thickness	½ Web Thickness	Gage g	Grip p	Distance f	Distance o	Distance h	Max. Rivet in Flange
In.	Lb.	In.	In.	In.	In.	In.	In.	In.	In.	In.
15	33 9	3⅜	⅜	3/16	2	⅝	12¼	1⅜	½	⅞
13	31 8	4	⅜	3/16	2½	9/16	10½	1¼	7/16	⅞
12	20 7	3	¼	⅛	1¾	½	10	1	⅜	⅞
10	15.3	2⅝	¼	⅛	1½	7/16	8¼	⅞	5/16	¾
9	13.4	2⅜	¼	⅛	1⅜	7/16	7¼	⅞	5/16	¾
8	11.5	2¼	¼	⅛	1⅜	⅜	6¼	⅞	5/16	¾
7	9.8	2⅛	3/16	⅛	1¼	⅜	5½	¾	5/16	⅝
6	8.2	1⅞	3/16	⅛	1⅛	5/16	4½	¾	¼	⅝
5	6.7	1¾	3/16	⅛	1⅛	5/16	3¾	⅝	¼	½
4	5.4	1⅝	3/16	1/16	1	5/16	2¾	⅝	¼	½
3	4.1	1⅜	3/16	1/16	⅞	¼	1¾	⅝	¼	½

TABLE III

Standard Gages for Angles, Inches



Leg	8	7	6	5	4	3½	3	2½	2	1¾	1½	1⅜	1¼	1	¾
g_1	4½	4	3½	3	2½	2	1¾	1⅜	1⅛	1	⅞	⅞	¾	⅝	½
g_2	3	2½	2¼	2											
g_3	3	3	2½	1¾											
Max. Rivet	1⅛	1	⅞	⅞	⅞	⅞	⅞	¾	⅝	½	⅜	⅜	⅜	¼	¼

402. 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 Tables IV and V.

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. Maximum sizes for I-beams, channels, and angles are given in Tables I, II, and III. Figure 11 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.

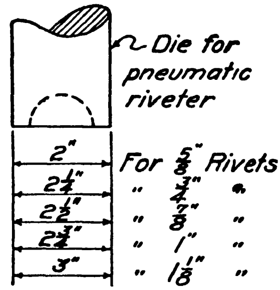


FIG. 11. Size of dies for rivet heads.

TABLE IV

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	....	....	....

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 IV.

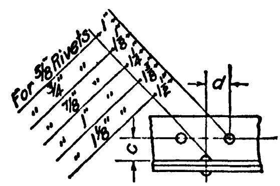
Besides these fundamental standards, others have become well established as, for example, the connection for beams and channels framing into columns or other beams as shown in Fig. 12. Built-up columns are also standardized. These standards and all others may be found in the handbooks of the various steel companies.

TABLE V

RIVET SPACING

(American Bridge Co. Standard)

Minimum Stagger for Rivets



Diameter of Rivets Inches	Minimum Stagger, d, Inches																
	c, Inches																
	$1\frac{1}{8}$	$1\frac{3}{16}$	$1\frac{1}{4}$	$1\frac{5}{16}$	$1\frac{3}{8}$	$1\frac{7}{16}$	$1\frac{1}{2}$	$1\frac{9}{16}$	$1\frac{5}{8}$	$1\frac{11}{16}$	$1\frac{3}{4}$	$1\frac{13}{16}$	$1\frac{7}{8}$	$1\frac{15}{16}$	$2\frac{1}{16}$	$2\frac{3}{16}$	$2\frac{5}{16}$
$\frac{5}{8}$	$\frac{15}{16}$	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{1}{2}$	$\frac{5}{16}$	0										
$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{3}{16}$	$1\frac{1}{8}$	$1\frac{1}{16}$	$\frac{15}{16}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{9}{16}$	$\frac{3}{8}$	0							
$\frac{7}{8}$	$1\frac{1}{2}$	$1\frac{7}{16}$	$1\frac{3}{8}$	$1\frac{5}{16}$	$1\frac{1}{4}$	$1\frac{3}{16}$	$1\frac{1}{8}$	1	$\frac{15}{16}$	$\frac{13}{16}$	$\frac{5}{8}$	$\frac{7}{16}$	0				
1	$1\frac{13}{16}$	$1\frac{3}{4}$	$1\frac{11}{16}$	$1\frac{5}{8}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{7}{16}$	$1\frac{3}{8}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{1}{8}$	1	$\frac{7}{8}$	$\frac{3}{4}$	0		
$1\frac{1}{8}$	$2\frac{1}{16}$	2	$1\frac{15}{16}$	$1\frac{15}{16}$	$1\frac{7}{8}$	$1\frac{13}{16}$	$1\frac{3}{4}$	$1\frac{11}{16}$	$1\frac{5}{8}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{5}{16}$	$1\frac{1}{4}$	1	$\frac{11}{16}$	0

Every engineer should have a copy of one of these standard handbooks, which may be purchased direct from the steel companies. Another book which is indispensable to the structural engineer is a Smoley's or Inskip's "Tables of Squares."

403. DETAILING A TRUSS. — To illustrate the procedure in structural drafting, and to explain the previous paragraphs more fully, we shall consider the various steps required in making a detail of a simple roof truss.

Assume that complete information is given the draftsman in a design sketch, as shown in Fig. 13. Since the truss is symmetrical, it will be necessary only to show 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. 14, which form a group of triangular figures. It will be noted that they intersect in points which are dimensioned and which are sometimes referred to as working points. After this has been done, the members of the truss may

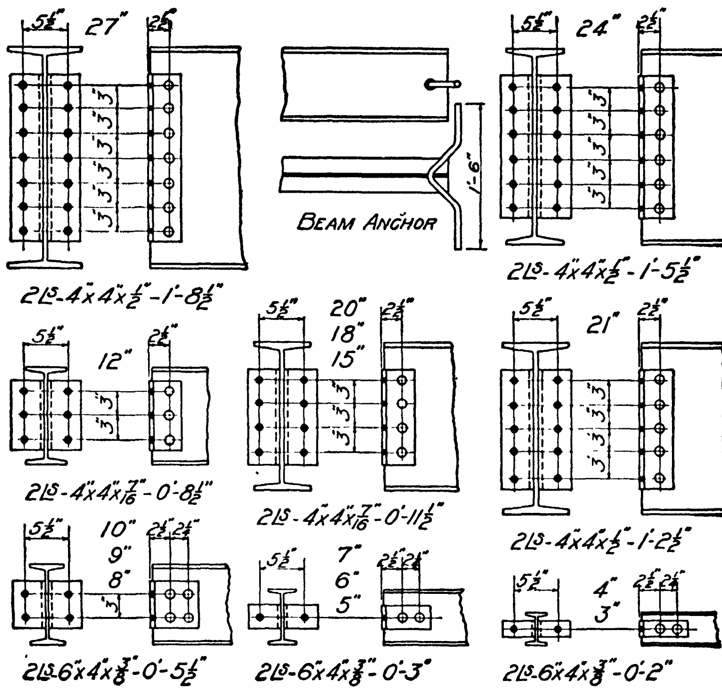


FIG. 12. Standard beam connections.

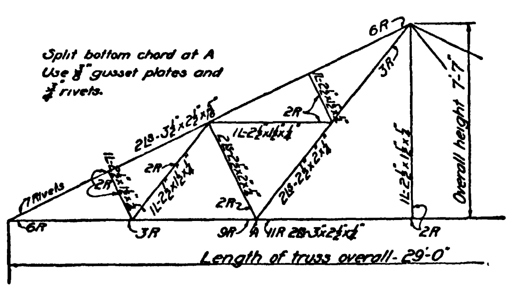


FIG. 13. Design diagram of steel truss.

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 $3'' \times 2\frac{1}{2}'' \times \frac{1}{4}''$ angles placed back to back with the long legs vertical. The standard gage for a 3″ angle, as obtained from the tables, is $1\frac{3}{4}''$. Hence, we scale down from the working line for the bottom chord a distance of

$1\frac{3}{4}''$ 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

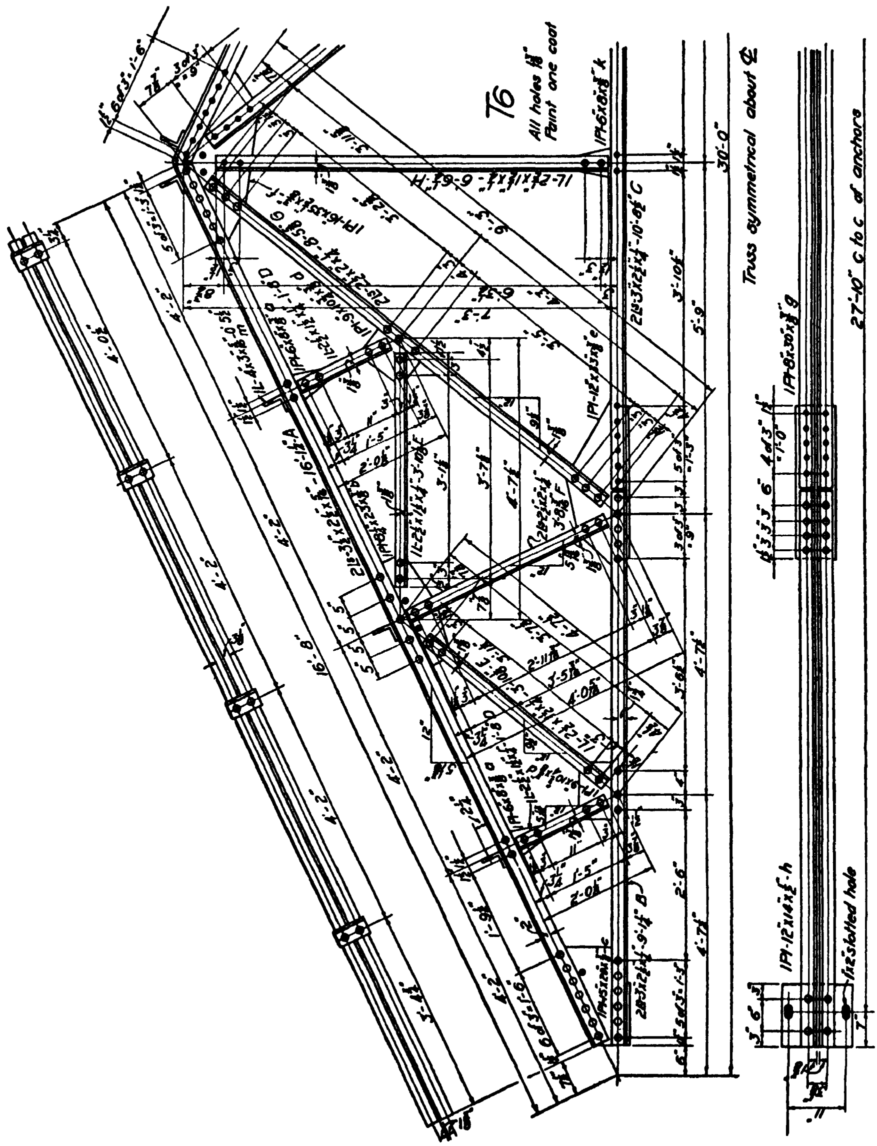


FIG. 14. Complete detail of truss.

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 represent 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. When the gusset plates have been drawn, the truss is ready for dimensioning. The rules for dimensioning are given in a later paragraph.

404. Layout of a Joint. — Where structural members meet at an angle other than 90 degrees, the distance from the working point to the

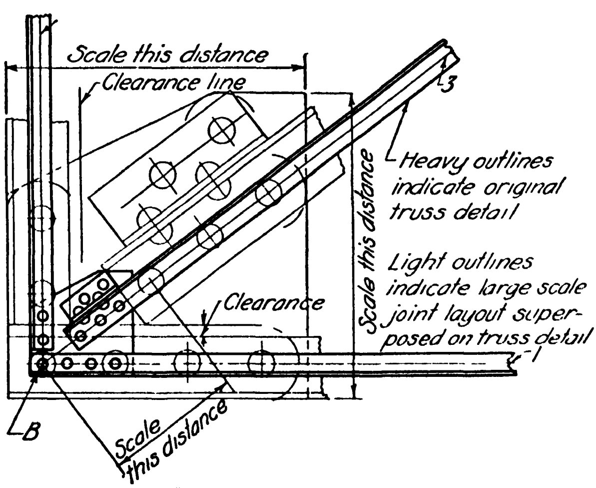


Fig. 15. Layout of joint.

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. 15 which represents joint *A* on Fig. 5. 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. 15, 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 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. 15. 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, one half 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 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 $1\frac{3}{4}''$ 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.

405. Scales. — Structural drawing differs from machine drawing again, in that on simple pieces the drawing is not scaled in one direction. Thus in Figs. 9 and 16 the end view is made to scale in both directions and the other two views are 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 also Fig. 16.

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 Figs. 9 and 16. 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 $\frac{1}{4}'' = 1'\text{-}0''$ for framing plans to $3'' = 1'\text{-}0''$ for the layout

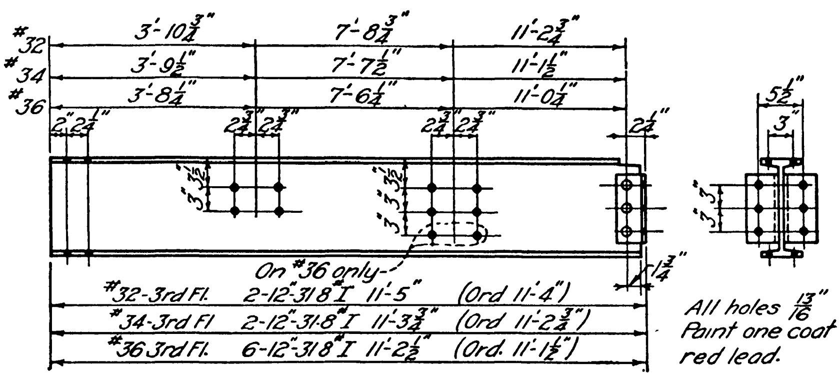


FIG. 16. Floor beam detail.

of joints. Almost any combination between these limits may be used. The more common ones, however, are $\frac{3}{4}'' = 1'\text{-}0''$ and $1'' = 1'\text{-}0''$.

406. 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.

407. Techniques. — 1. Dimension lines should be light, solid, black lines terminating in arrows.

2. 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.

3. Dimensions should be given as shown in *A*, Fig. 17.

4. 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. 17. Avoid this situation whenever possible.

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

6. When the space between the arrow heads is very limited, the dimension may be put in as shown in C, Fig. 17

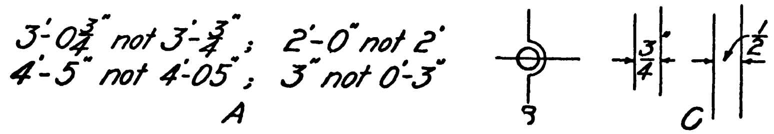


FIG. 17. Methods of dimensioning.

408. Placing Dimensions. — 1. On truss members, detail dimensions should be placed in a continuous row from end to end of the member, no dimension being omitted.

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

3. Where two or more lines of dimensions are given for the same piece, they should not be placed closer together than $\frac{5}{16}$ 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.

4. 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.

409. Fabricating Dimensions. — 1. 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.

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

3. 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.

4. 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. 5 and 14.

5. 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 up.

6. 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. 16 and 18. When the detail is continuous, as in Fig. 9, the dimensioning, likewise, is continuous from end to end.

7. End distances are given, but edge distances are omitted. Gage lines should be dimensioned even though they are standard.

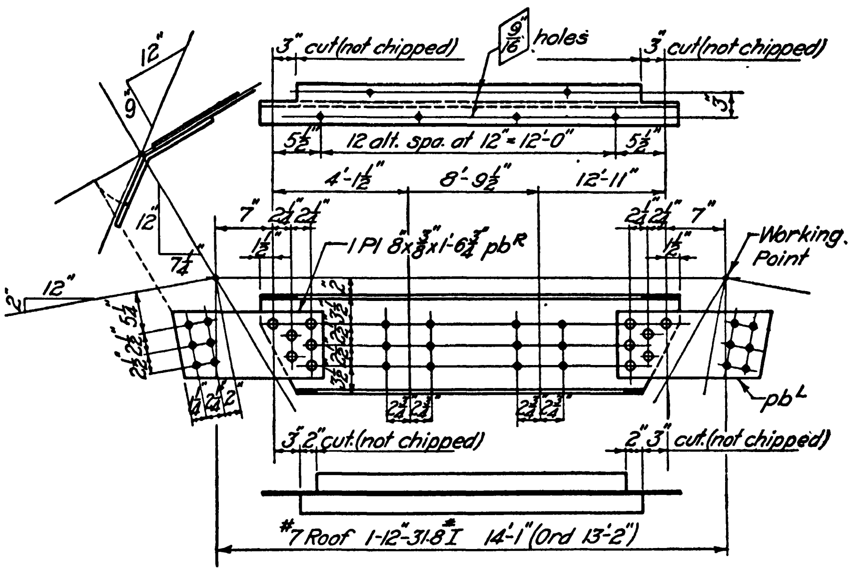


Fig. 18. Roof purlin detail.

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

9. 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 the various shops.

410. Marking. — Owing to the difficulty of recognizing structural pieces in the shop, it is necessary to give all pieces some distinguishing mark by means of which they may be labeled at the time of cutting or laying out and identified for assembling after they have been properly fabricated. In addition to the assembly marks given each individual piece, an assembled part which is to be shipped and erected as a unit must also have a distinguishing mark by means of which it can be identified in the process of erection.

It is customary in many shops to use small letters and numerals for the assembly marks and reserve large capital letters for the erection marks. The assembly marks originate with the structural draftsman, whereas the erection marks are usually shown on the general plan prepared by the architect or engineer. The draftsman places the marks on each piece on his drawing, and then the template-maker marks his templates to correspond; finally, the layout man marks the piece of steel in the same manner. Hence the assembling crew with the drawing at hand can readily assemble the steel. Various systems of marking have been worked out in different shops, but since each shop has its own system, only general instructions can be given. The following rules should be observed.

1. Each separate piece should be given some mark.

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

3. 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*.

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

5. For erection marks it is customary to use the initial letter of the name of the piece. Thus *B*2 will designate a beam, *G*3 will indicate a girder, and *C*2*a* may designate a column.

6. Rules 1 to 4 inclusive apply to both assembling marks and also to erection marks.

411. Notes. — As in any other kind of drawing, notes are to be used sparingly, although nothing which will make for clearness should be omitted. The purpose of notes is twofold: first, to make clear and definite certain information which cannot be shown by a drawing; and second, to save the draftsman's time, as, for example, where a single well-expressed note may save making another drawing quite similar to the one on which the note is made. Two kinds of notes appear on structural drawings: first, those of a general nature, as, for example, where only half of a structural member is shown, a statement to the effect that the other half is similar, or again a note specifying the size of holes to be punched, or the kind and number of coats of paint to be used; and second, those notes referring to some specific detail, as, for example, a note stating that certain holes occur in a certain specified member only, or that certain holes are to be of a size different from those indicated by the general note.

The general notes are usually placed somewhere near the bottom of the sheet, under all the views of the members to which they refer, or near the title space where they will come to the notice of the shop man at his first glance. Special notes are usually placed near the parts to which they relate, and are tied up with them in some definite way. If the note is long and the drawing is of such a complicated nature that the note cannot be placed near the part affected, it may be placed in some clear portion of the sheet and numbered or lettered. Then, at the point to which note " A " refers, the words " See Note A " may be lettered in.

Notes may be made referring to other sheets for details, but they should not refer the workman to a sheet which will in turn refer him to another sheet, to find the information he is seeking. The lettering for notes should be in the Reinhardt slant style about $\frac{5}{32}$ inch high.

412. 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. 19. It will be noted that

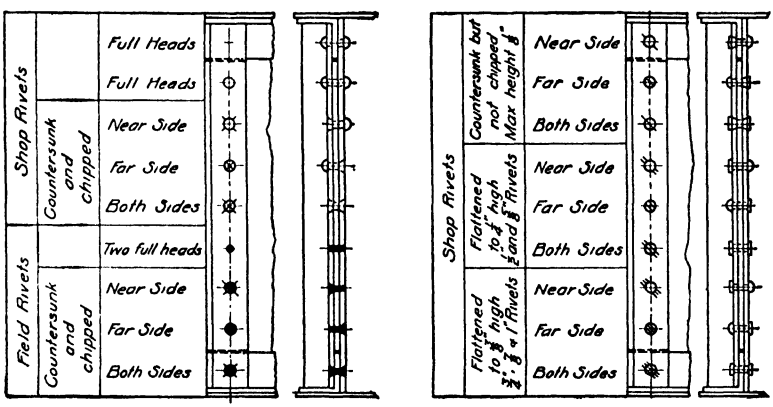


FIG. 19. Conventional rivet symbols.

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.

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.

413. Billing Materials. — In making a bill of material or in notes, the following symbols are used as abbreviations: The 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 the 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 above. The weight per foot, or thickness, in the case of the angle, must always be given, as all

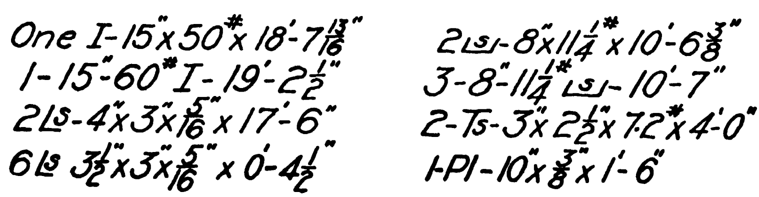


FIG. 20. Methods of billing materials.

the structural shapes are made in several weights for the same general dimensions. See Fig. 20.

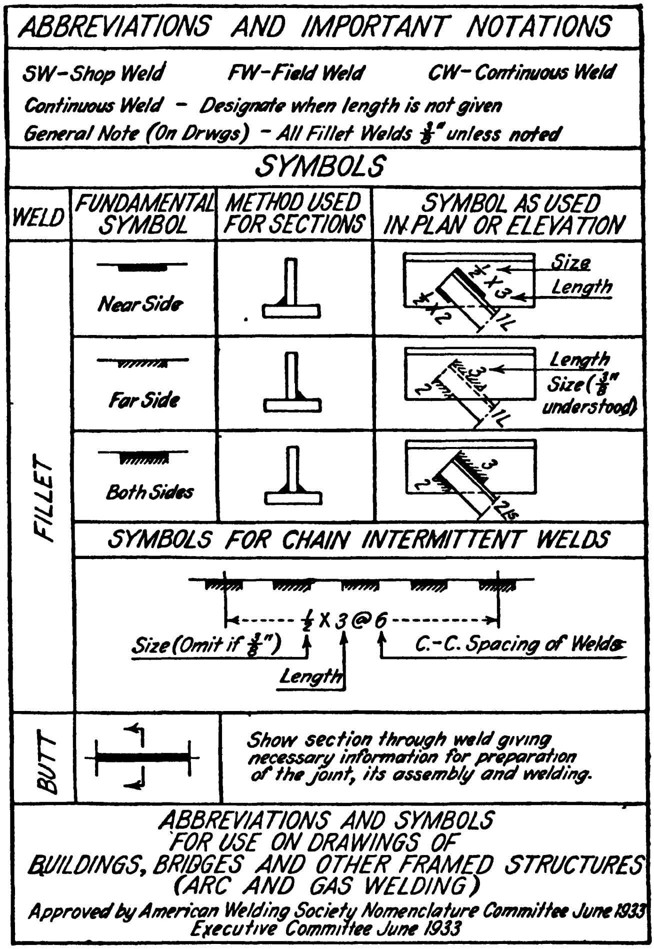
414. WELDING. — Welding by an electric arc or gas is being used in many instances as a substitute for rivets. Figure 21 shows the standard symbols and dimensions used to represent welds upon drawings. Methods of making welded beam connections are illustrated in Figs. 22 and 23. Typical column connections are illustrated in Fig. 24.

While the symbols for representing welds have become fairly well standardized, as represented in the figures referred to above, the general practice of making drawings for the field and shop has not as yet reached the same stage of standardization as has drawing for riveted structures. In general two different types of structures occur, namely, those of the tier type, like tall buildings, in which all the connections or joints of the steel framing are quite similar in character, and those in which the joints vary quite widely in detail, such as bridges, mill buildings, and the like.

In tier buildings, one method of detailing consists in working out joint details. Joints which are alike except for the load carried can be detailed on one sketch by indicating on it the different sizes of connections and welds. Joint types may be designated by number and the size by a letter.

Shop drawings in this system have the shop welds indicated in the usual manner, but the field welds are referred to by number and letter. The field welds are also indicated by number and letter on the assembly or erection drawings, so that the field welder may note the type and size of joint, refer to his joint sketch, mark the welds, and proceed with the work.

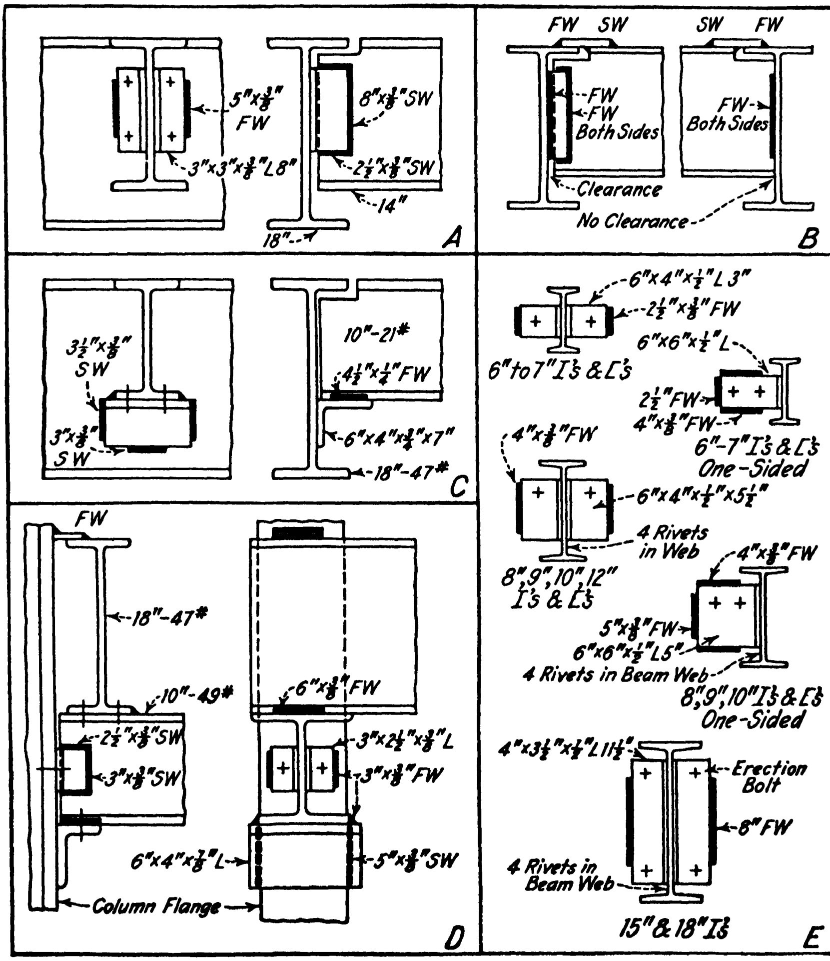
Since beams and girders in the welded system have few holes by which their position may be identified, it is easy to get them turned end for end or upside down. When either of these things makes a difference, the beam should be marked " this side up," or " this end north," or by other legends to indicate its proper position. Column faces are usually marked *A*, *B*, *C*, and *D* to coördinate with some conventional direction system.



(Courtesy of T. C. Shedd.)

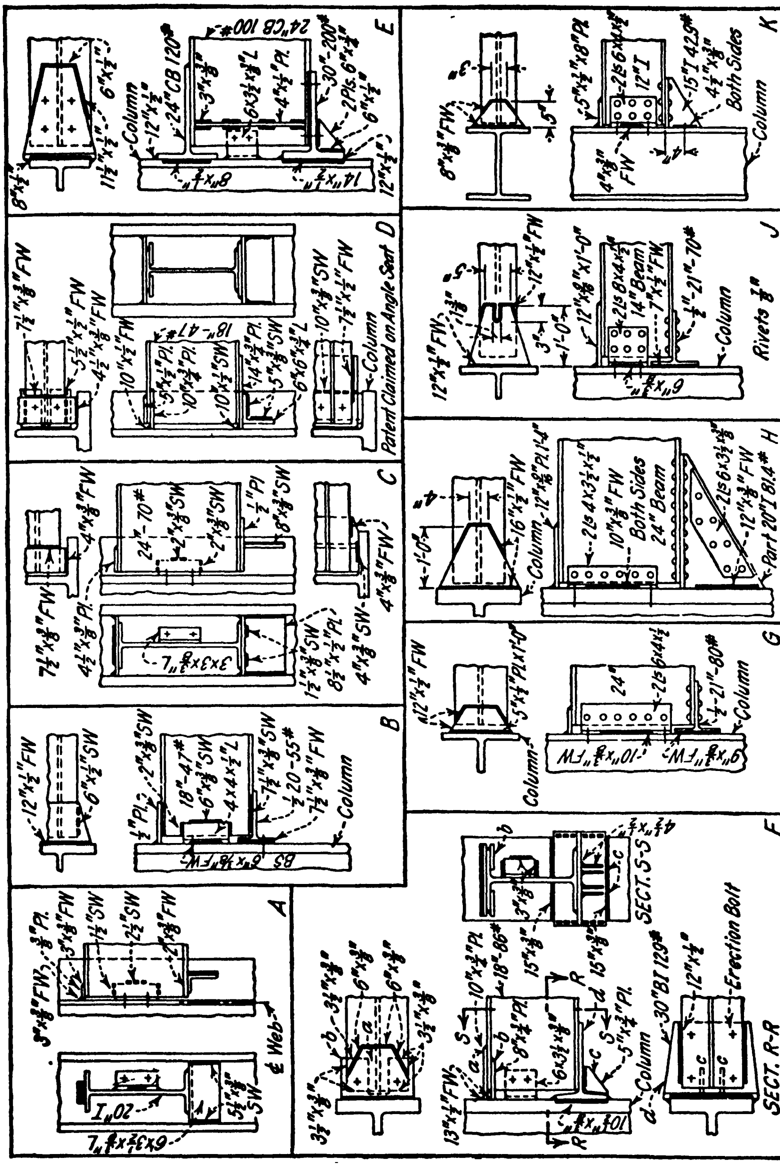
Fig. 21. Welding symbols and abbreviations.

In the case of trusses, plate girders, and other built up members, it is the common practice to detail them assembled, in the same manner as for riveted structures. In this type of work, since little confusion is likely to arise, the field welds are indicated on the shop drawing. Field welds must, of course, be carefully distinguished from shop welds by the symbols and conventions of Fig. 21. Welded truss drawings appear much simpler than riveted truss drawings, since fewer dimensions are required. The triangle system of layout, however, is adhered to since it forms the basis of both design and detail computation.



(*Courtesy of T. C. Shedd.*)

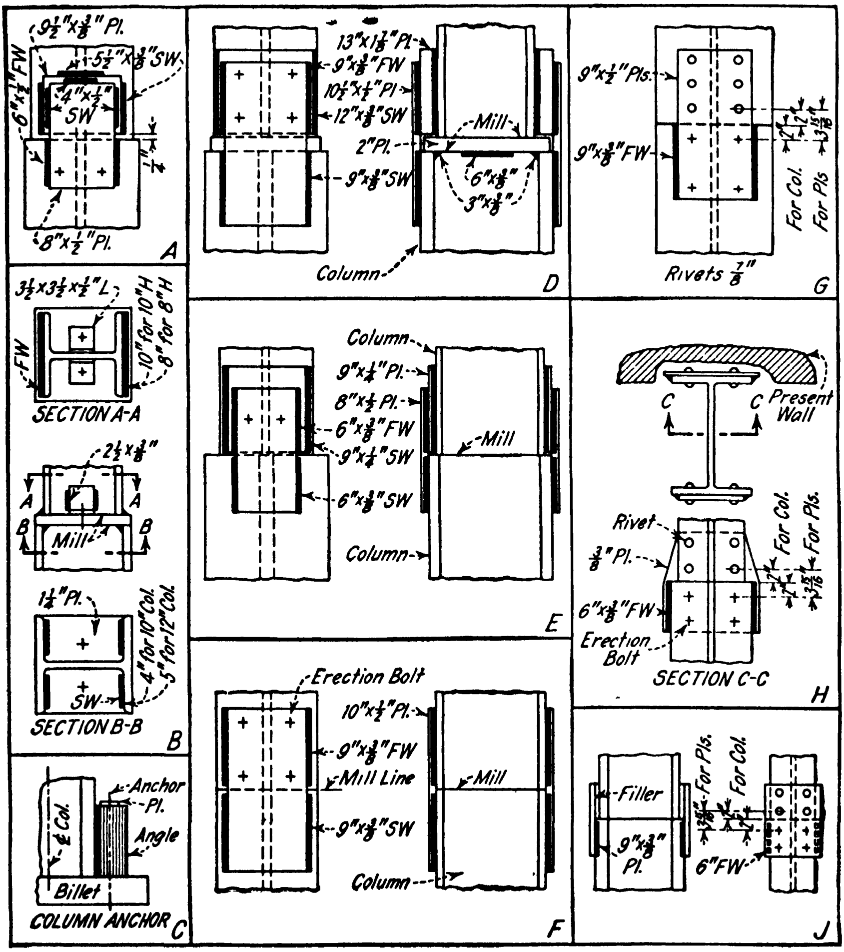
FIG. 22. Structural details. Sketches of connections of beams to beams in all-welded and in shop-riveted, field-welded, buildings.



(*Courtesy of T. C. Shedd.*)

Fig. 23. Structural details. Sketches of connections to columns in all-welded and in shop-riveted, field-welded, buildings.

415. Reinforced Concrete. — In making working drawings of reinforced-concrete structures, the draftsman must show two things: namely, the outlines of the concrete itself; and the shape, size, and location of the reinforcing steel. Outlines of the structure are shown by the usual



(*Courtesy of T. C. Shedd.*)

Fig. 24. Structural details. Sketches of column splices in all-welded and in shop-riveted, field-welded, buildings.

rules of orthographic working drawings. Where the outline is complicated, as, for example, in ornamental exteriors, it is represented in one drawing, and the reinforcing steel is indicated in another.

416. Plans. — Separate framing plans for the concrete structure are made in addition to the usual architect's drawings. Such framing plans are made in accordance with the usual rules of drawing, as shown in Figs. 25 and 26. The scales used are usually $\frac{1}{8}'' = 1'\text{-}0''$ and $\frac{1}{4}'' = 1'\text{-}0''$, which makes it practically impossible to show the reinforcing on the plan. For this reason diagrammatic details and schedules have been adopted to give this information.

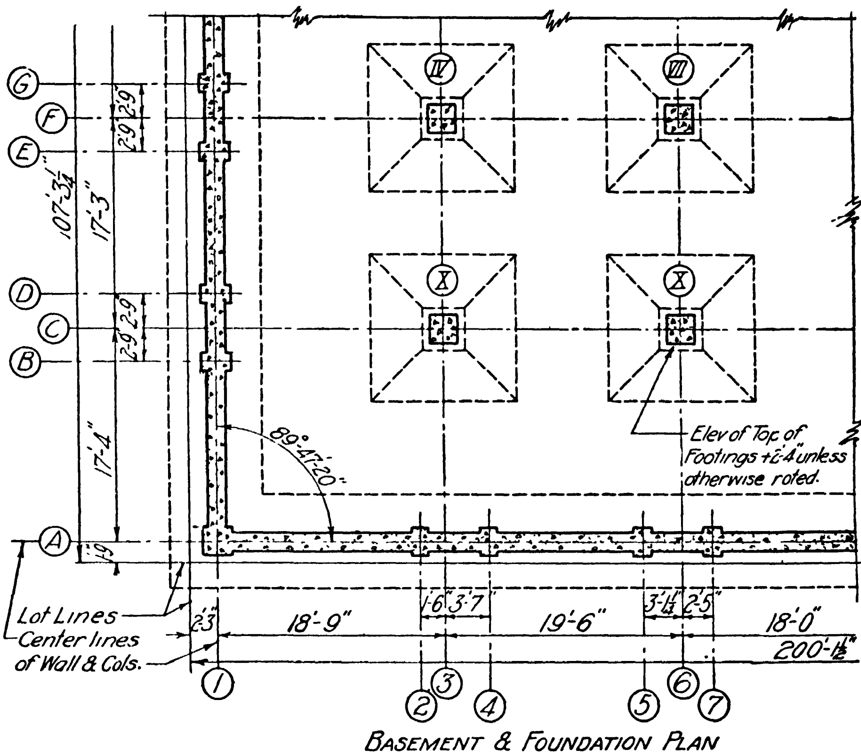


FIG. 25. Reinforced concrete footing or foundation plan.

The framing plans show only the concrete structure and such structural steel as must be placed or its anchorage provided for before the concrete is poured. Floor plans show sections of the columns in the story, while beams and girders supporting the floor are shown by dotted lines. Openings in the floor are represented, of course, by solid lines. Column rows are marked in one direction by letters and in the other direction by numbers. Any column can then be designated by the letter and number of the rows whose intersection it represents, as shown in Figs. 25 and 26. Beams and girders are given identifying marks, the same mark being used on all beams or girders that are identical. See Fig. 26.

417. Details. — Details of beams, joists, slabs, and columns are made to indicate the typical arrangement of steel as shown in Figs. 27 and 28.

These are diagrammatic in form and indicate merely the location and arrangement of the steel. These details are then accompanied by schedules which give the variation in size and number of bars, size of beams or columns, etc. Clearance between steel and the sides, top, and bottom of beams is usually indicated by dimensions in the diagram, and applies in all cases.

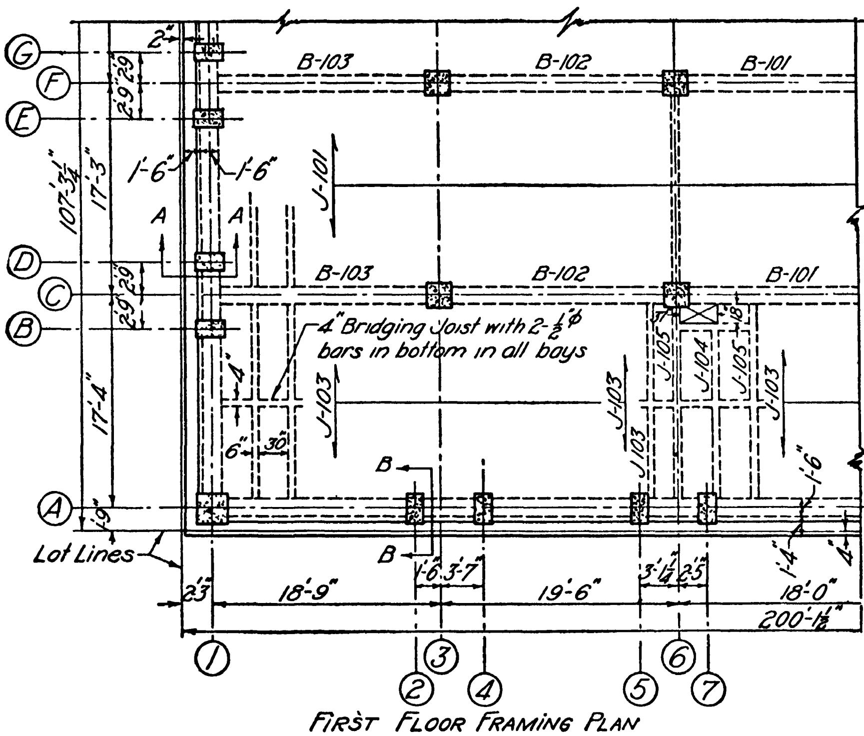


FIG. 26. Reinforced concrete framing plan.

Details are sometimes shown as in Fig. 29, with all dimensions for the size and locations of the steel given on the drawing. This is done as a rule only in simpler buildings. Regardless of the method used, tke details must give the following information:

1. Size and location of all main reinforcing steel, including length.
2. Shape and location of all bends.
3. Size, shape, and location of all stirrups, hoops, ties, and spacers.
4. Size and location of all bolts or other anchorages that must be cast in place.
5. Shape and dimensions of the concrete outline itself.

418. Footing Schedules. — The column footings shown in Fig. 25 are detailed in diagrammatic form at the right in Fig. 27. The drawing shows the shape of the footing and the arrangement and shape of the steel bars and the clearances required; the footing schedule below it gives the dimensions of the footings which are listed by mark and the number and

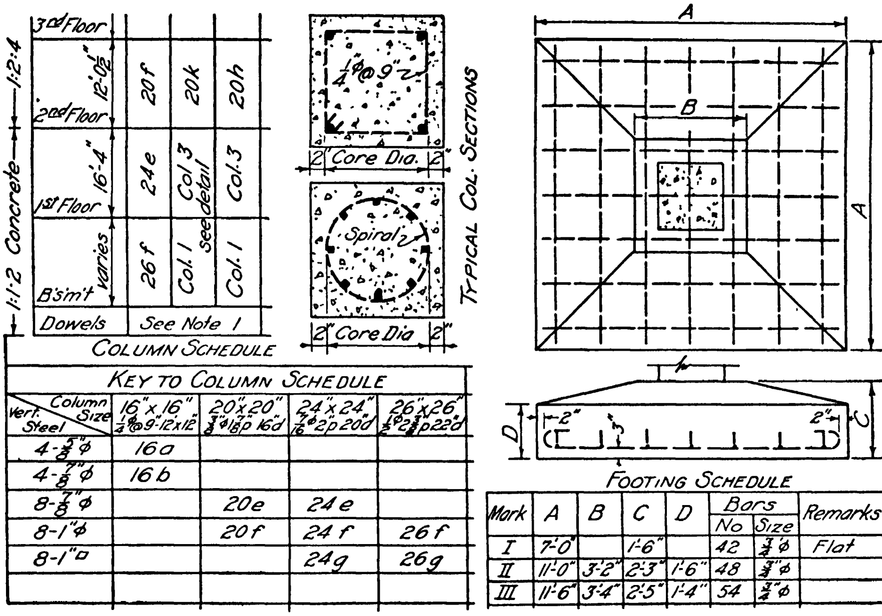


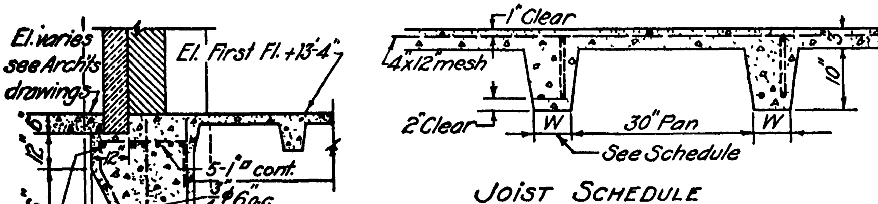
FIG. 27. Column and footing schedules.

size of bars to be used in each one, thus giving complete information for each footing. The bar spacing is determined by the number of bars.

419. Column Schedules. — In the same manner, the shape of columns and the diagrammatic arrangement of steel are shown at the left of Fig. 27; the column schedule and the key to it give the actual column dimensions on any floor and the size and number of bars and ties or spirals. Splicing of columns is provided for either by note or in the specifications.

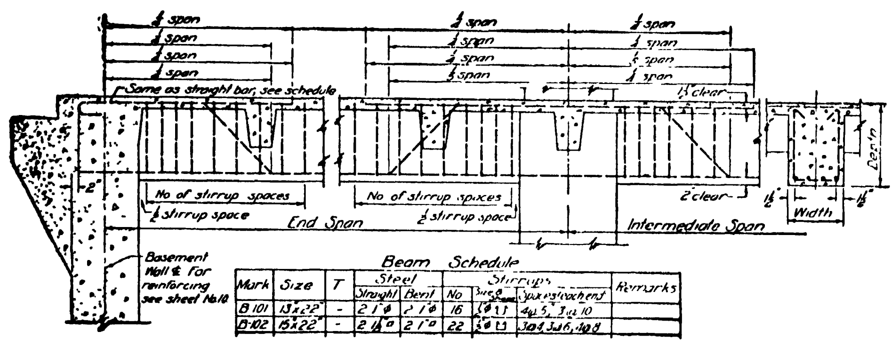
420. Beams and Joist Schedules. — Typical beams and joist schedules are shown in Figs. 28 and 29. Bars are shown by heavy dash lines to distinguish them from beam outlines and hidden lines. The location of bends is given in terms of the span. Some engineers use the double dash line to represent bars, but the better practice is to use the single dash line unless the scale of the detail is so large as to make the double line imperative. Notes should always be added if the detail diagram and schedule together do not suffice to make the construction clear.

Before steel can be cut and placed in the forms, bar lists and dimensioned bending diagrams must be made for the use of the workman. Straight bars can be listed by size and length, but bent bars must be carefully dimensioned so that necessary clearances can be maintained.



Mark	Size		Steel		Stirrups			Remarks
	Width	Depth	Straight	Bent	No.	Size & Shape	Spacing	
J-101	6"	10"+3"	1-7/8"φ	1-3/4"φ	20	1/4"φ U	3@3", 6@6"	
J-102	6"	10"+3"	1-1"φ	1-7/8"φ	18	1/4"φ U	3@3, 5@6"	
J-103	6"	10"+3"	1-7/8"φ	1-7/8"φ	18	1/4"φ U	3@3, 5@6"	
J-109	5"	10"+3	1-5/8"φ	1-1/2"φ	4	1/4"φ U	3@5"	
All straight bars to extend 1'-0" past ℄ of support								
Bent bars shall extend to the 1/4" point of the next span.								

FIG. 28. Joist detail and schedule.



Mark	Size	T	Steel		Stirrups			Remarks
			Straight	Bent	No	Size & Shape	Spaces to each end	
B 101	13"x22"	-	2 1"φ	2 1"φ	16	[illegible]	4@5, 3@10	
B-102	15"x22"	-	2 1 1/8"□	2 1"□	22	[illegible]	3@4, 3@6, 4@8	

FIG. 29. Beam detail and schedule.

421. TITLES. — The title should be placed in the lower right-hand corner and is preferably made in the vertical Gothic style. It should contain the name of the fabricating company, its location, the name of the company for whom the material shown is being made, together with the name of the place to which it is going. It should include the names of the pieces shown on the sheet and their location in the building if this is essential as, for example, Girder G-3, Fourth Floor. Also the usual items, such as sheet number, contract numbers, scale, date, drawn by, checked by, etc., should be included.

BIBLIOGRAPHY

STRUCTURAL ENGINEERS' HANDBOOK, by Milo S. Ketchum. McGraw-Hill Book Company, New York, 1918.

STRUCTURAL DRAFTING, by Carlton Thomas Bishop. John Wiley & Sons, Inc., New York, 1922.

STRUCTURAL STEEL DRAFTING AND ELEMENTARY DESIGN, by Charles Denton Conklin. John Wiley & Sons, Inc., New York, 1915.

STRUCTURAL DESIGN IN STEEL, by Thomas Clark Shedd. John Wiley & Sons, Inc., New York, 1934.

PROBLEMS

422. The structural details in Figs. 30 to 32, inclusive, are for the buildings shown in Chapter XXI, Figs. 23, 24, 25 and 26. The exact cross-reference is shown in the figure titles. In the problems below, reference is made only to the figure numbers in this chapter, but those in the preceding chapters should be consulted wherever necessary, to obtain a complete understanding of the framing. See Art. 4, page 3, for meaning of sheet sizes and corresponding scales.

1. Make a detail of the center truss, Fig. 30. Scale A: 1″ = 1′-0″.
2. Make a detail of the side truss, Fig. 30. Scale A: 1″ = 1′-0″.
3. Make a detail of the truss with monitor, Fig. 31. Scale ¼″ = 1′-0″ (Sheet 18″ × 24″).
4. Make a detail of the truss with monitor, Fig. 31. Scale ¾″ = 1′-0″ (Sheet 18″ × 24″).
5. Make a detail of the upper truss, Fig. 32. Scale A: ¾″ = 1′-0″.
6. Make a detail of the lower truss, Fig. 32. Scale A: ¾″ = 1′-0″.
7. Make a detail of the truss, Fig. 19, Chapter XXII. Scale 1″ = 1′-0″ (Sheet 18″ × 24″).
8. Detail the purlins of the end bay (2 kinds), Fig. 30. Scale B: 1″ = 1′-0″.
9. Detail the purlins of the end bay on monitor, Fig. 30. Scale B: 1″ = 1′-0″.
10. Detail the purlins of the center bays on side truss and monitor, Fig. 30. Scale B: 1″ = 1′-0″.
11. Detail all purlins (2 kinds), Fig. 31. Choose a suitable scale.
12. Make a detail of the wind bracing between columns, Fig. 29. Scale A: ¾″ = 1′-0″.
13. Make a detail of the wind bracing between the top chords of the trusses, Fig. 30. Scale A: ¾″ = 1′-0″.
14. Draw the details of the columns in Fig. 30. Scale A: ¾″ = 1′-0″. Note that end columns differ slightly from interior columns.
15. Make a detail of the girders supporting the tanks in Fig. 19, Chapter XXII. Scale A: ¾″ = 1′-0″.
16. Detail the cradles supporting the tanks in Fig. 19, Chapter XXII. Scale B: 1″ = 1′-0″.
17. Prepare the detail drawings for lintel (*a*), Fig. 23. Select sheet size and scale. (The figure references in this and the succeeding five problems are to those in Chapter XXI.)
18. Same as Prob. 17, lintel (*b*), Fig. 23.
19. Same as Prob. 17, lintel (*c*), Fig. 23.
20. Same as Prob. 17, lintel (*d*), Fig. 23.
21. Same as Prob. 17, lintel (*e*), Fig. 23.
22. Same as Prob. 17, lintel (*f*), Fig. 23.
23. Same as Prob. 17, lintel (1), Fig. 25.
24. Same as Prob. 17, lintel (2), Fig. 25.
25. Same as Prob. 17, lintel (5), Fig. 25.
26. Same as Prob. 17, lintel (6), Fig. 25.
27. Make a detail of the sloping channel supporting the purlins in the end bay. Fig. 30. Scale B: 1″ = 1′-0″.

28. Make details of the steel framing around windows and between the columns in Fig. 30. Scale A: select.

29. Make detail working drawings of any structural member assigned by the instructor.

a. Stairway — Fig. 19, Chapter XXII. Scale A: select.
b. Cat-walk — Fig. 19, Chapter XXII. Scale A: select.

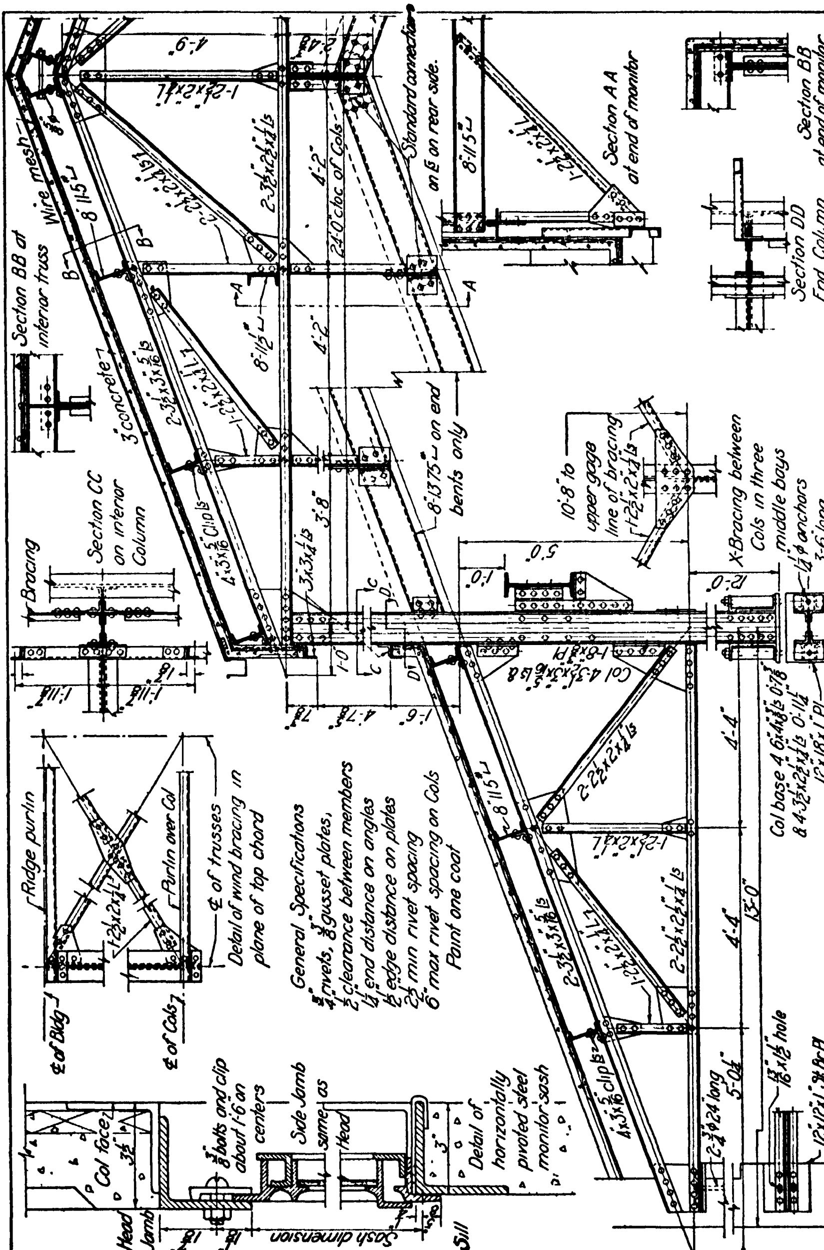


FIG. 30. Truss details for building shown in Figs. 25 and 26 Chap. XXI.

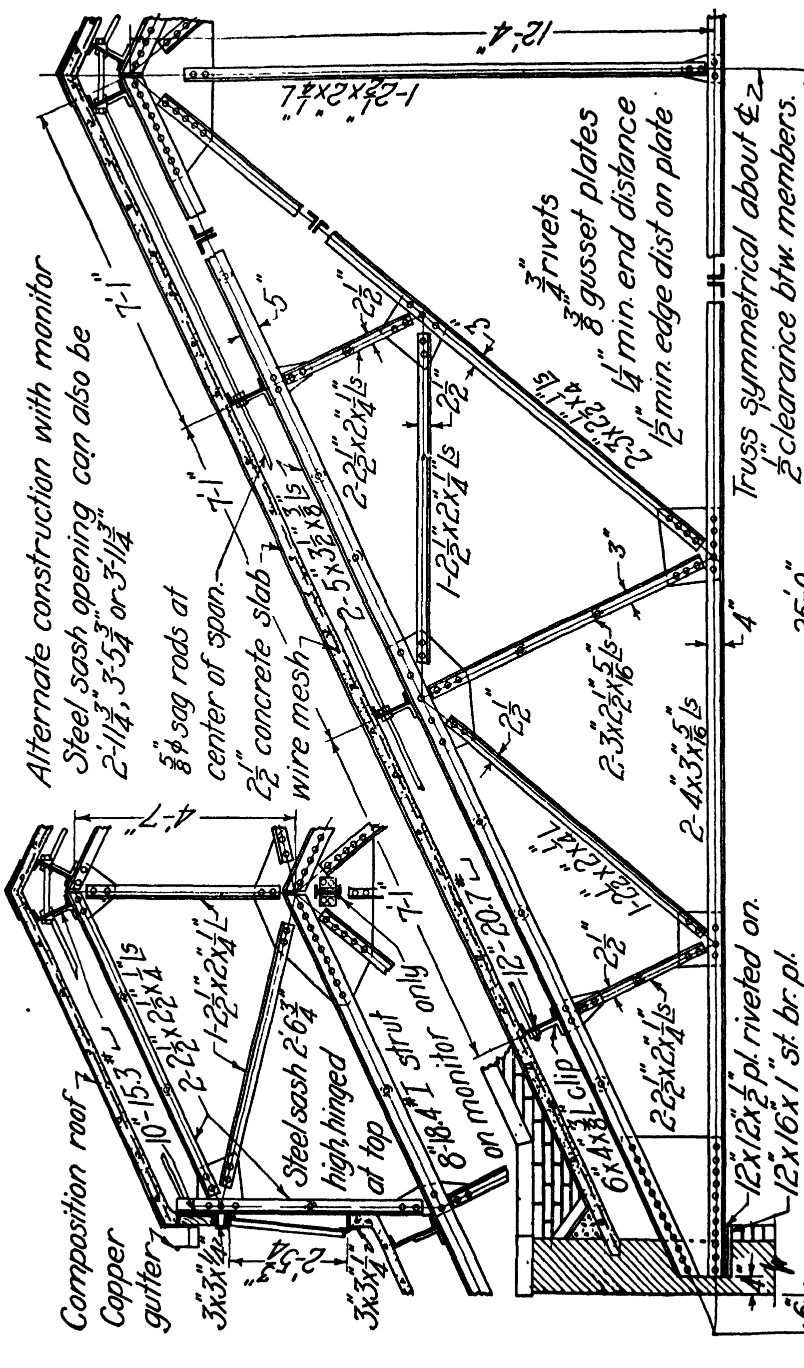


Fig. 31. Alternate truss detail for building shown in Figs. 25 and 26 Chap. XXI.

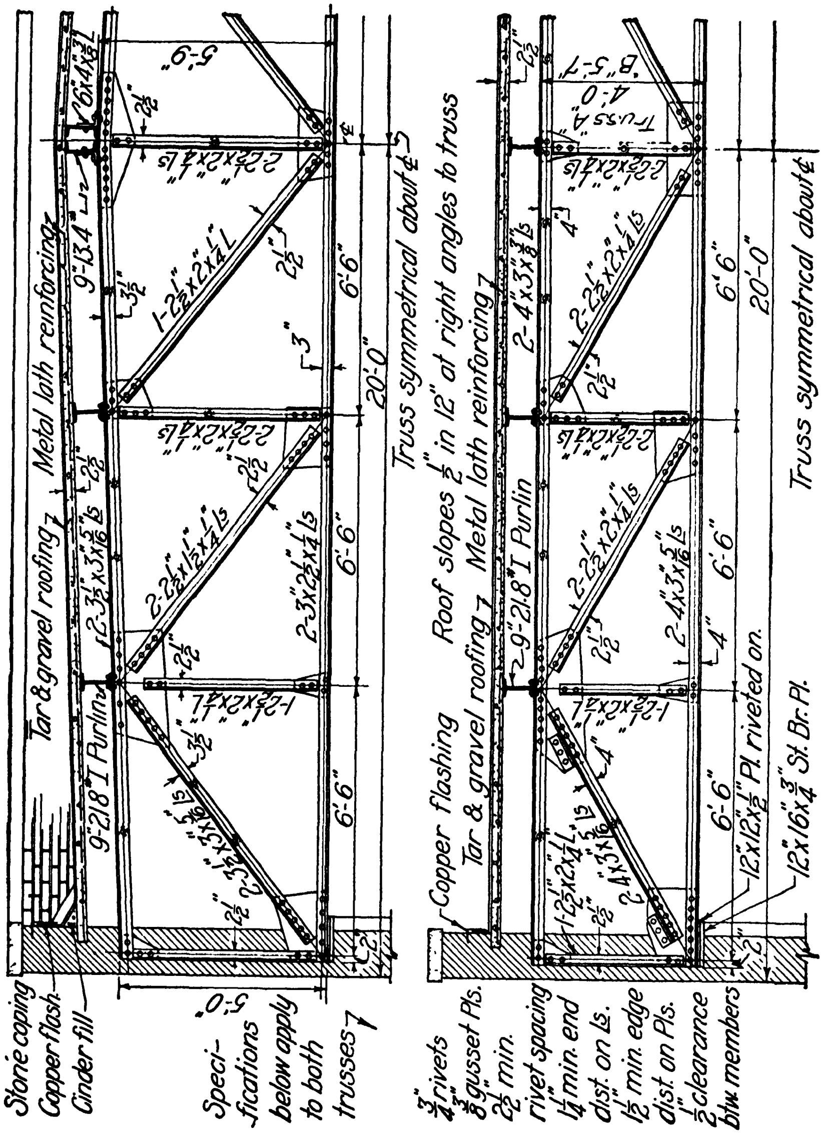


FIG. 32. Truss details for building shown in Figs. 23 and 24 Chap. XXI.

CHAPTER XXIV

GEARS AND CAMS

423. 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.

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

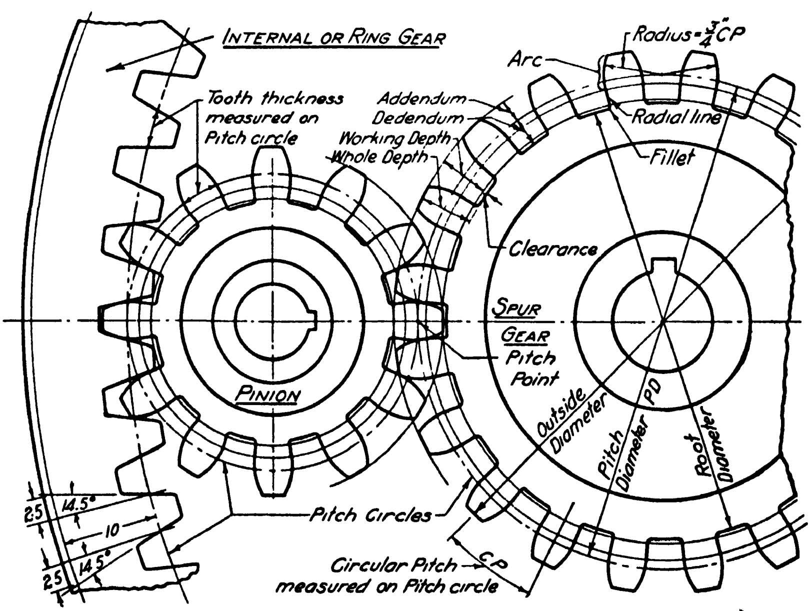


FIG. 1. Spur, pinion and ring gear.

to the axis of the cylinder. See Fig. 1. 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. 5 and 6. 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. 8. The teeth on the wheel resemble those of the spur gear, but each is turned 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. 1. The minimum number of teeth on a pinion is limited by common practice to twelve. When gear teeth are formed on a straight thick bar or plate, the product is called a *rack.* See Fig. 3. 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 several treatises in itself. Limits of space in this text 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.

424. 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 Fig. 1. 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. $CP = \frac{PD \times 3.1416}{N}$ 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. $C = 0.157/DP$.

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. — $(N + 2)/DP$.
To find the pitch diameters of two meshing gears when the distance between centers is known and the number of teeth is known:

$$(PD)_1 = [(2CD)/(N_1 + N_2)]N_1; \quad (PD)_2 = [(2CD)/(N_1 + N_2)]N_2$$

425. 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. 2. The profiles shown are theoretically those obtained

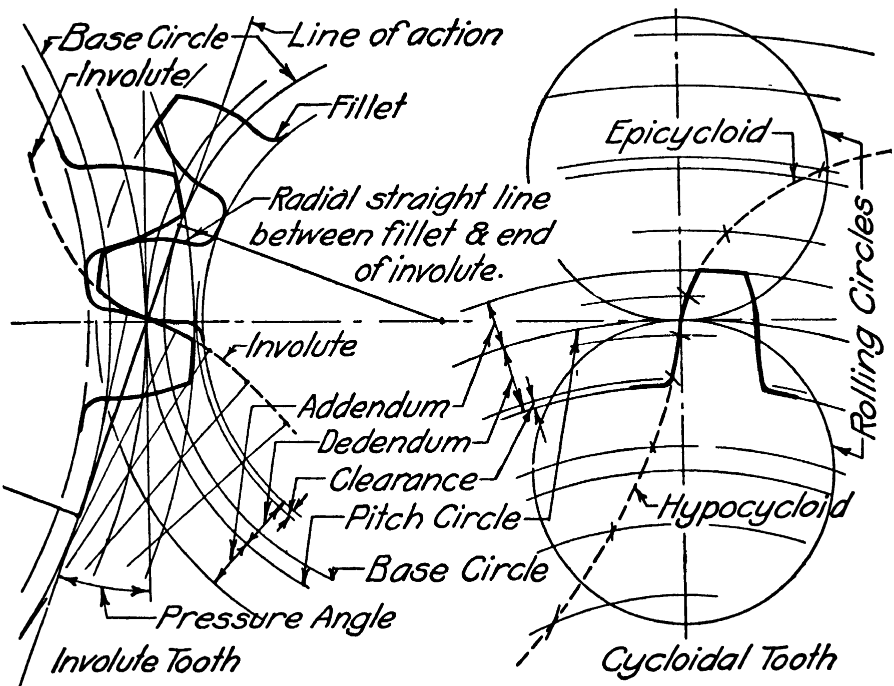


Fig. 2. Gear tooth curves or profiles.

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 considerations of strength. Circles are used on the drawings in place of the curves.

Figure 3 illustrates two important departures from the older tooth forms in the $14\frac{1}{2}$-degree Composite and 20-degree Stub tooth systems which have become Tentative American Standards, approved in 1927. Gears made with either one of these standards and having the same diametral pitch are interchangeable with each other but not as 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, as can readily be seen from the drawings.

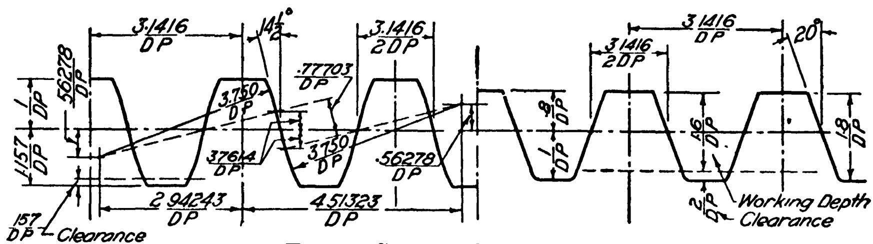


FIG. 3. Standard basic racks.

Close approximation to the actual tooth shape in the first case is obtained by using circles for the cycloids as shown in Fig. 3. When composite or stub teeth are cut on spur gears, the following tooth proportions are used.

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 Dedendum	$\frac{1.157}{DP}$	$0.3683 \times CP$	$\frac{1}{DP}$	$0.3183 \times CP$
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	$\frac{N-2}{DP}$	$0.3183 \times (N-2) \times CP$	$\frac{N-1.6}{DP}$	$PD - (2\text{ Addendum})$
7. Basic Tooth Thickness on Pitch Line	$\frac{1.5708}{DP}$	$0.5 \times CP$		
8. Minimum Clearance	$\frac{0.157}{DP}$	$0.5 \times CP$		

426. SPUR-GEAR CUTTERS. — Gear teeth are made in many different ways. One of the standard methods employs cutters. A set of eight cutters is necessary for each diametral pitch in the involute tooth system.

For more accurate work, however, a set of fifteen cutters is now commonly employed. In the cycloidal system of gear teeth, twenty-four cutters are necessary for each pitch. The "hobbing" process of cutting gear teeth is very widely used. A table of cutters for involute teeth is given below.

GEAR CUTTERS FOR INVOLUTE TEETH

Cutter Number	Number of Teeth in Gear	Cutter Number	Number of Teeth in Gear
1	135 to a rack	5	21–22
1½	80–134	5½	19–20
2	55–79	6	17–18
2½	42–54	6½	15–16
3	35–41	7	14
3½	30–34	7½	13
4	26–29	8	12
4½	23–25		

The equations given hitherto and the dimensional relationships shown in Fig. 3 are used for computation purposes in spur-gear drawing and design.

427. WORKING DRAWINGS OF SPUR GEARS. — The working drawing 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

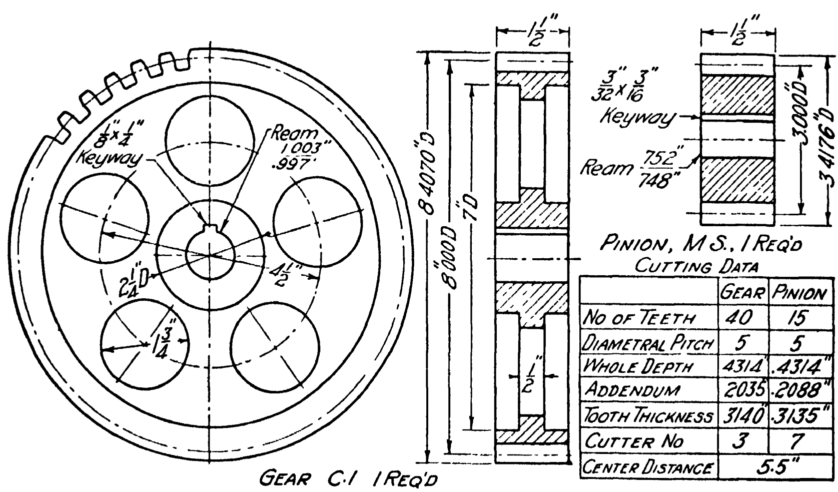


FIG. 4. Working drawing of spur gear.

blank. Information concerning the teeth is usually given in the form of notes as illustrated in Fig. 4. 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. 4.

428. 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. 1. First draw the addendum, pitch, clearance, and dedendum circles. 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. With a very slight adjustment of radii this method can be made to give proper contact between teeth on a one diametral pitch twelve tooth pinion. 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.

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. 3.

The $14\frac{1}{2}$- and 20-degree 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. 1. One type of internal gear tooth is actually made in this form.

429. Bevel Gears. — Bevel gears require the definition of a few new terms, the meanings of which are illustrated on the three common types of gears shown in Fig. 5. 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 (γ_r) $= \gamma - \delta$.
Face angle (γ_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 $\frac{1}{3}$ 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.

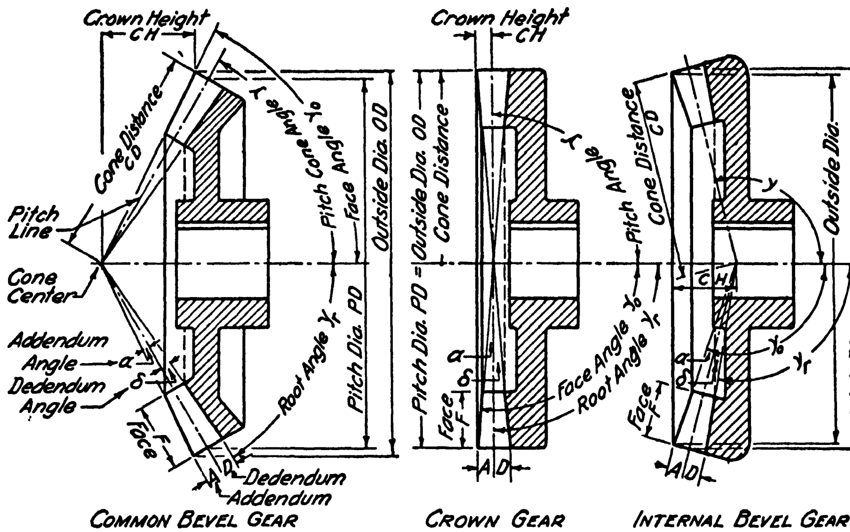


FIG. 5. Bevel gear types and terms.

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)	$\tan \gamma_g = \dfrac{\sin \alpha}{\dfrac{N_p}{N_g} + \cos \alpha}$	$\tan \gamma_g = \dfrac{N_g}{N_p}$	$\gamma_g = 90°$	$\tan \gamma_g = \dfrac{\sin (180° - \Sigma)}{\dfrac{N_p}{N_g} - \cos (180° - \Sigma)}$

430. WORKING DRAWINGS OF BEVEL GEARS. — Working drawing 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. 6. 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 draftsman works. Either front or rear face is used as the base for setting the gear blanks in the cutting machine, 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.

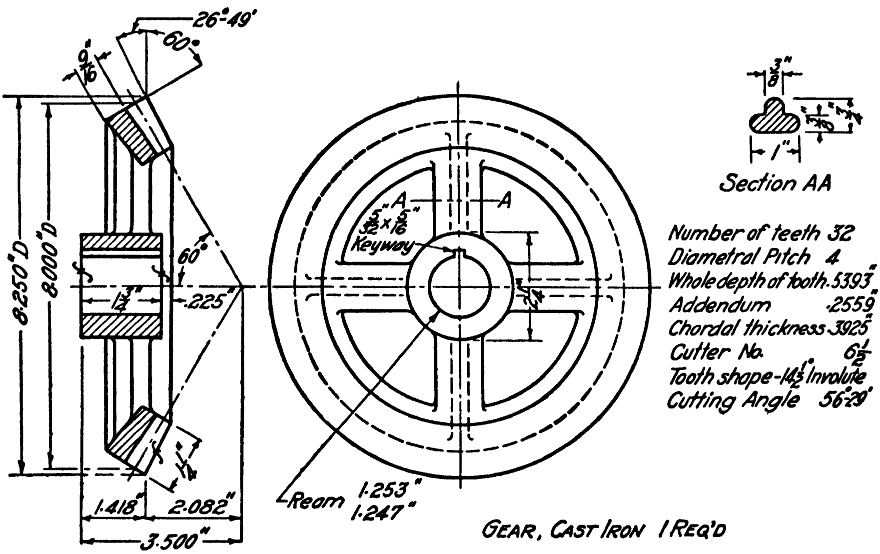


FIG. 6. Working drawing of bevel gear.

431. 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. 7.

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 small end of the tooth. On the large end lay out the dimensions of the tooth x, y, and z as indicated in Fig. 7. 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 than 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

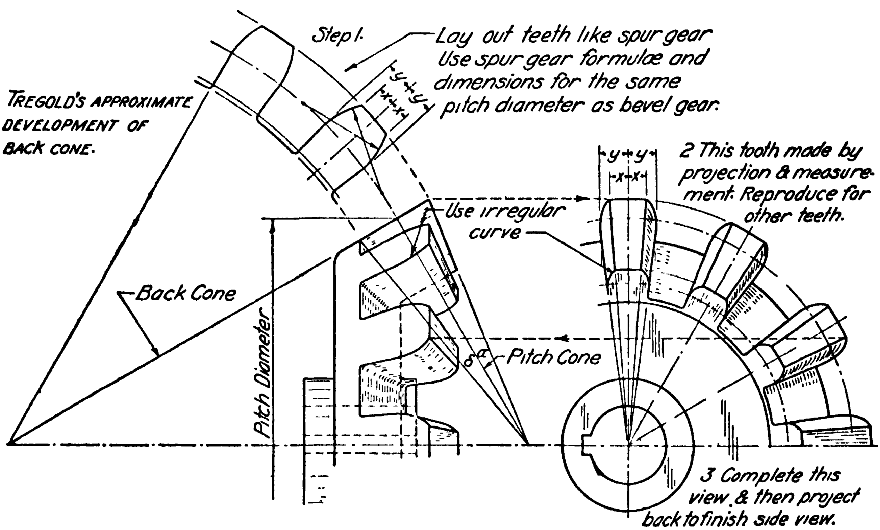


FIG. 7. Representing bevel gears in assembly drawings.

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.

432. 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 $14\frac{1}{2}$-degree slope. The meanings of new terms applying to these gears are illustrated in Figs. 8 and 9, and the equations for computation are also shown in these figures. Others may be determined from the figures 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 degrees. For thread or helix angles greater than about 15 degrees, 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.

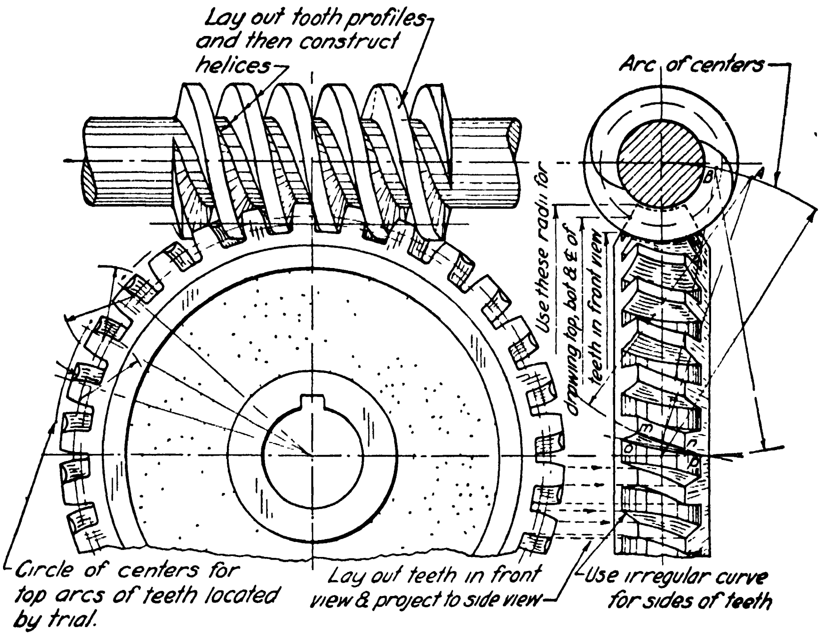


FIG. 8. Worm gear and wheel.

433. 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. 9.

434. Assembly Drawings of Worm Gears and Wheels. — As in all other gears, the teeth are represented in an approximate conventional manner as shown in Fig. 8. The worm is best represented by drawing the actual helix, especially for the larger thread angles. This is done as in drawing an Acme thread and needs no further explanation.

The front view of the wheel which shows a profile of the tooth may be made as indicated in Fig. 8, which is an approximation of the actual projection. In making such a drawing, first step off on the pitch circle the centers of the teeth, using a distance equal to the pitch of the worm. Draw radial lines through these points as indicated at the left. Then draw the three circles representing the top, bottom, and center of the tooth face. If the face angle is 60 degrees, the difference in position between the front and rear tooth faces will be one-sixth the pitch. This approximation will be satisfactory for the usual range of face angles. The arcs representing the flanks of the teeth may then be drawn as indicated.

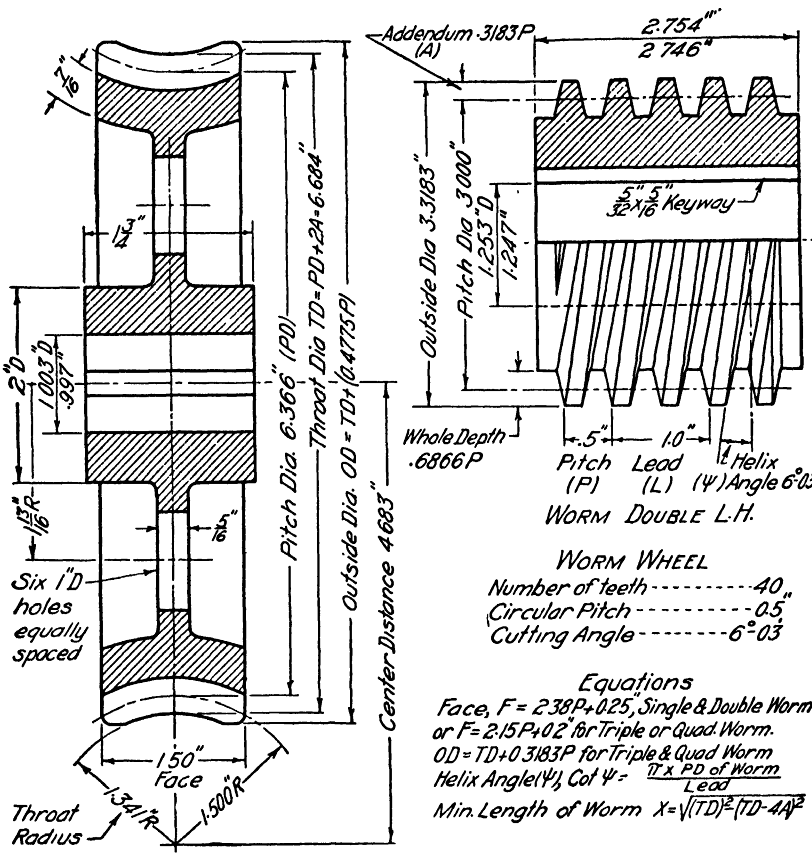


FIG. 9. Working drawing of worm gear and wheel.

The four corners at the top and bottom of each tooth in the side view are located by projection. The arc of centers is then drawn and the centers of the arcs representing the top of the teeth located by erecting perpendiculars at the midpoint of the lines through the corners of the teeth as, for example, *mn* for the top and *op* for the bottom. Where these perpendiculars cross the arc of centers, locate the centers *A* and *B* for the crest and root curves of the tooth. For teeth below the center line, the arc of centers is below in a symmetrical position with the one at the top.

435. 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. 10, 12, and 13. Some cams have an oscillating motion, as shown in Fig. 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

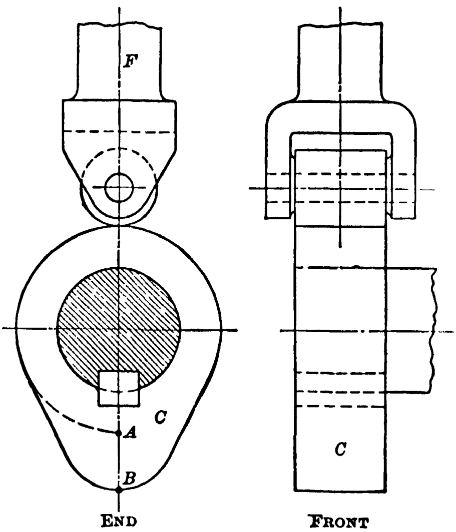


FIG. 10. Radial, single acting, cam.

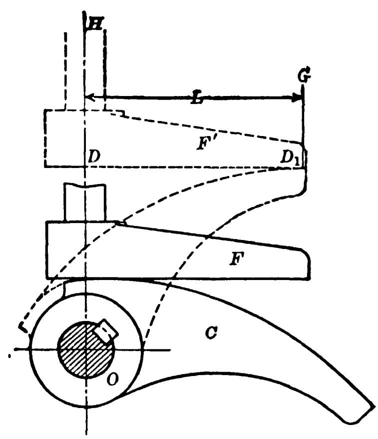


FIG. 11. Single acting cam ("Flat footed follower").

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. 10 to 13, inclusive.

The cam of Fig. 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. 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. 12 with the follower groove or track cut in the flat surface of the cam

Figs. 10 to 13 and Fig. 17 furnished by courtesy of F. D. Furman.

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.*

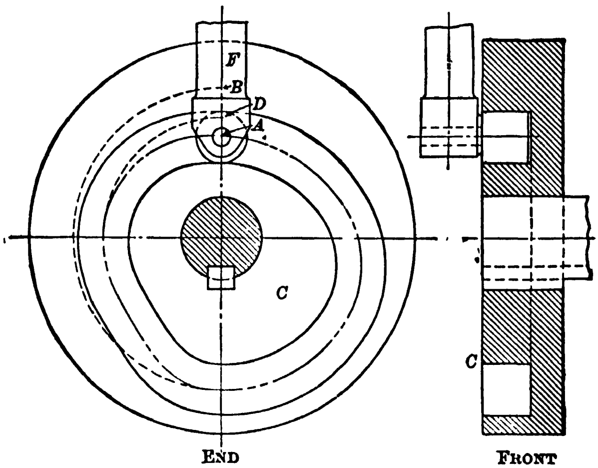


FIG. 12. Radial, double acting, face or plate groove, cam.

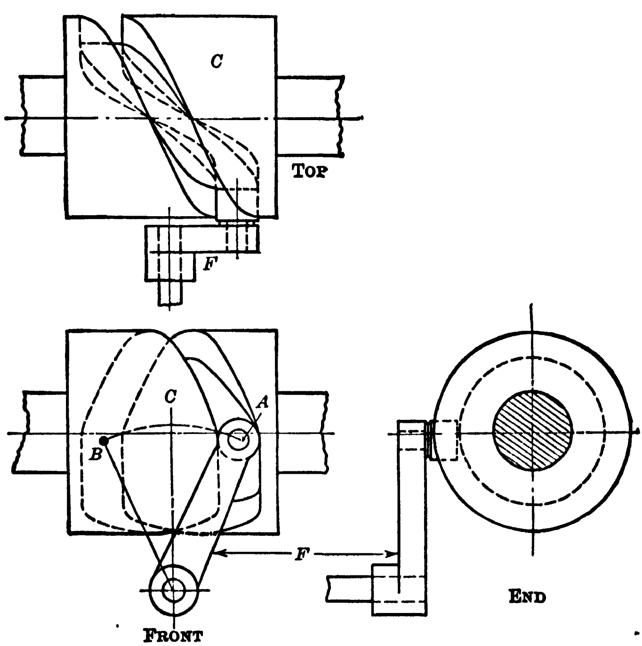


FIG. 13. Side or cylindrical, double acting, cam.

The positive control of the movement of the follower by the cams of Figs. 10 and 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. 12 and 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*.

436. Empirical Cam Design. — The technical design of cams not only involves the total range of motion imparted to the follower by the cam and the pressure developed against the sides of the follower guide as measured by the so-called pressure angle, but, also, it involves 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 test. 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.

437. 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

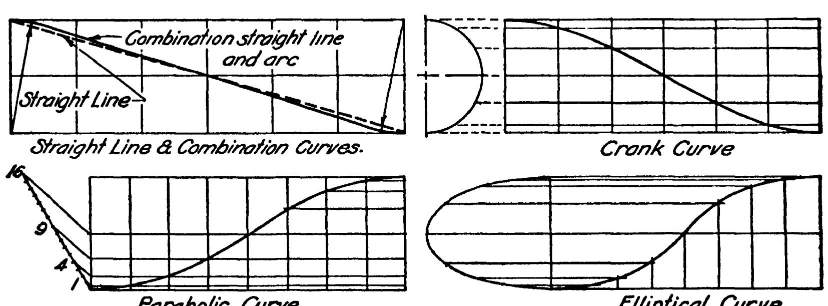


Fig. 14. Basic cam curves.

developed in the next article. Five common base curves used in cam design are shown in Fig. 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 degrees. If the rise occupies less distance, the radius is shortened proportionally. See Fig. 15.

The crank curve gives simple harmonic motion with a uniformity 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 accelerations but it is slower in the starting and stopping portions and faster in the central portion than some of the other curves.

438. 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. 15. Draw first the cam chart, as in Fig. 15, using the different types of curves as specified in the problem

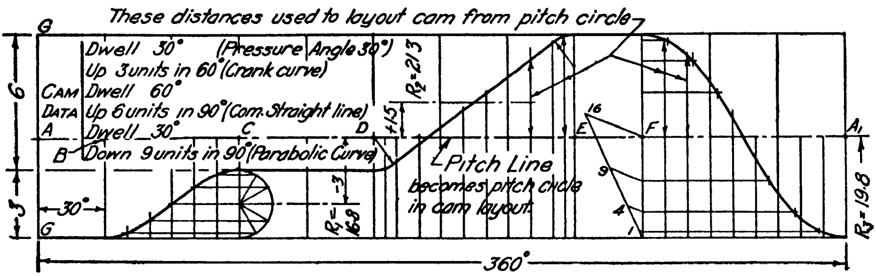


Fig. 15. Layout of a two-one step cam chart.

for the rise and fall of the follower. The chart should be to scale vertically, but it may have any convenient length to represent 360 degrees. 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. 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. 16. If the pitch circle is made to the same scale as the rise, AG, of the cam chart in Fig. 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. 15. 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

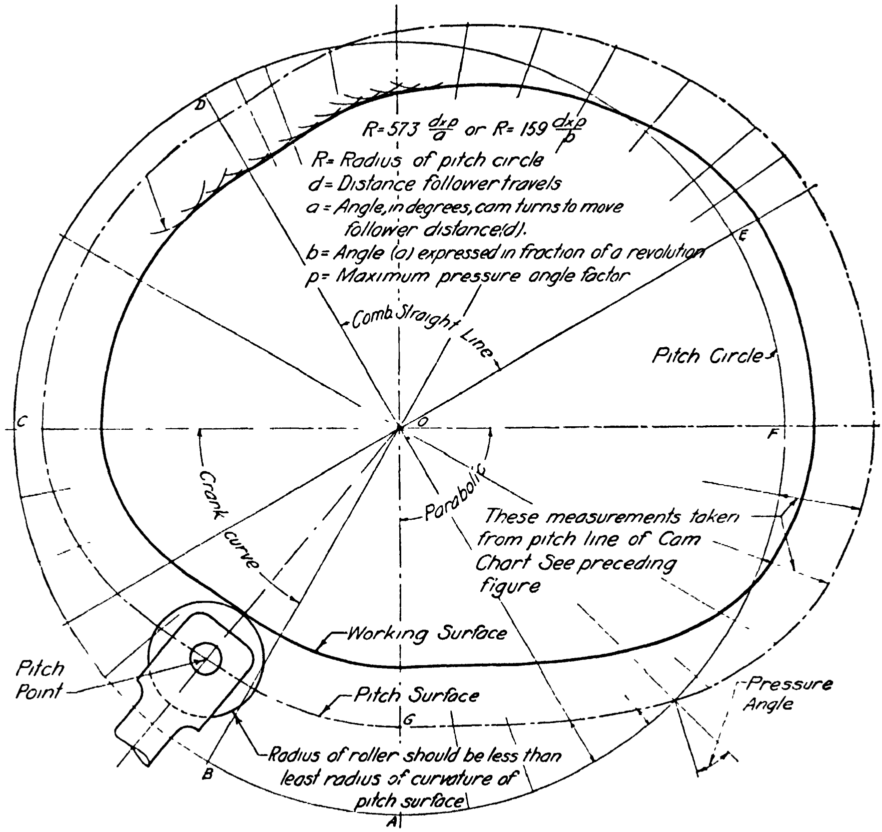


FIG. 16. Cam layout for base curve shown in Fig. 15.

the top of Fig. 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. 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, obviously 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. 15 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. $R_3 = \frac{57.3 \times 9 \times 3.46}{90} = 19.8$

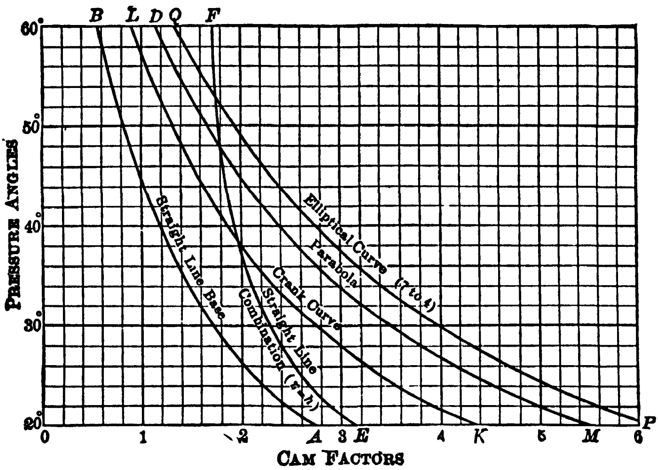


FIG. 17. Cam factors.

If the largest radius for the parabola is used as a trial pitch circle, then it can be observed by addition and subtraction that the pitch circles for the other two are larger than the computations require, and hence within the pressure angle limits specified. The large pitch radius is, therefore, used and the construction carried out as described before.

PROBLEMS

439. 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 Prob. 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 Prob. 3. Use a 2 *DP* tooth.

Spur Gears

5. Make a working drawing of the gear shown in Fig. 18.
6. Same as Prob. 1, Fig. 19.
7. Same as Prob. 1, Fig. 20. (Note this is a special type of bevel gear.)
8. Same as Prob. 1, Fig. 21.
9. Make a working drawing of a gear assigned from Fig. 22. 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*, and 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 of the speed-changing device shown in Fig. 22.
11. Make a copy of the assembly drawing shown in Fig. 22.
12. Make a working drawing of the gear and pinion shown in Fig. 23 *A*.
13. Same as Prob. 12, Fig. 23 *B*.
14. Same as Prob. 12, Fig. 23 *C*.
15. Same as Prob. 12, Fig. 23 *D*.
16. Design the conveyor end bearing shown in Fig. 23 *A* and make an assembly drawing of the bearing, gears, and pulley. Estimate the size and proportions of the pulley from the figure.

Bevel Gears

17. Make a working drawing of the large bevel gear assigned from Fig. 24. 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.
18. Same as Prob. 17. Pinion Fig. 24.
19. Same as Prob. 17. Largest gear Fig. 25. Gears *A* and *B*, with their respective clutch jaws, are free to turn upon the drive shaft. Clutch jaw *C* is keyed to the drive shaft and may engage either gear *A* or *B*, thus making it possible to change the direction of rotation and the speed of the driven shaft *F*.
20. Same as Prob. 17. Intermediate gear Fig. 25.
21. Same as Prob. 17. Small gear Fig. 25.
22. Make a complete set of details of the reversing mechanism shown in Fig. 24.
23. Same as Prob. 22, Fig. 25.
24. Make a copy of the assembly drawing shown in Fig. 24.
25. Same as Prob. 24, Fig. 25.
26. Make a working drawing of the bevel gear and pinion shown in Fig. 26 *A*.
27. Same as Prob. 26, Fig. 26 *B*.
28. Same as Prob. 26, Fig. 26 *C*.
29. Same as Prob. 26, Fig. 26 *D*.
30. Same as Prob. 26, Fig. 26 *E*.
31. Design the conveyor end bearing shown in Fig. 26 *B* and make an assembly drawing of the bearing and gears. Estimate the size of the conveyor from the size of the large gear.

Worm Gear and Wheel

32. Make a working drawing of the worm gear and wheel shown in Fig. 27.
33. Same as Prob. 32, Fig. 27. Change to double worm.
34. Same as Prob. 32, Fig. 28.
35. Same as Prob. 32, Fig. 28. Change to double worm.
36. Make a complete set of details of the object shown in Fig. 27.
37. Same as Prob. 36, Fig. 28.
38. Make a working drawing of the worm and wheel shown in Fig. 29 *A*.

39. Same as Prob. 38, Fig. 29 *B*.
40. Same as Prob. 38, Fig. 29 *C*.
41. Same as Prob. 38, Fig. 29 *D*.
42. Same as Prob. 38, Fig. 29 *E*.
43. Make a design of the housing, bearings, and gears shown in the speed reducer of Fig. 29 *A*. Show complete set of working drawings.

Cams

44. Draw the cam chart and layout 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 follower.
45. Same as Prob. 44. Use a combination straight line base curve.
46. Same as Prob. 44. Use a parabolic base curve.
47. Same as Prob. 44. Compute pitch circle radius for a 30° maximum pressure angle.
48. Draw the cam chart and layout 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.
49. Same as Prob. 48. Use combination straight line curve throughout.
50. Same as Prob. 48. Compute pitch circle radius for 45° maximum pressure angle.
51. Draw a cam chart and layout the cam curve for a roller follower which moves up 1″ in 60° — Dwell 30° — Up 1¼″ in 75° — Dwell 15° — Down 2½″ in 120° — Dwell 60°. Pitch radius 4″ for last step. Select size of roller.
52. Same as Prob. 51. Compute the pitch circle radius for a maximum pressure angle of 30°.
53. Same as Prob. 52. Maximum pressure angle 45°.

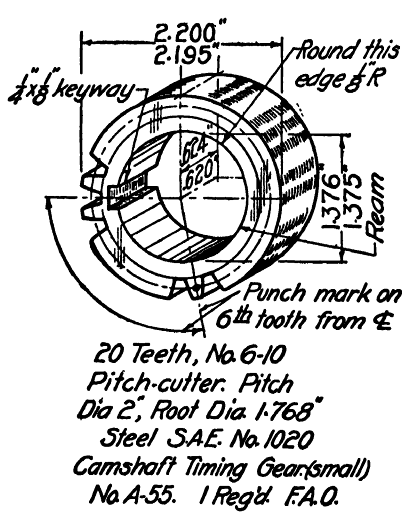


Fig. 18.

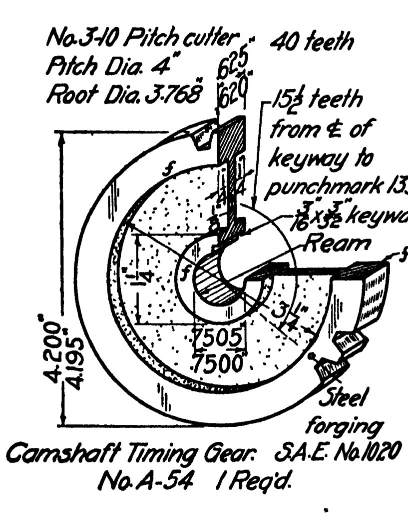


Fig. 19.

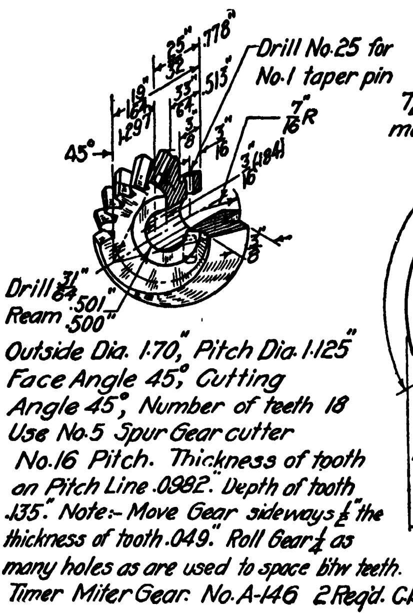


FIG. 20.

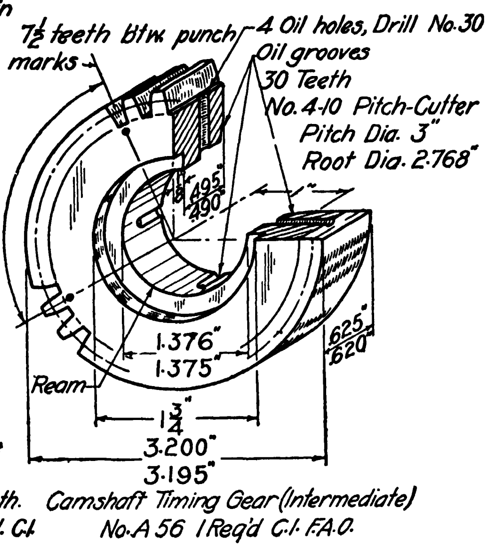


FIG. 21.

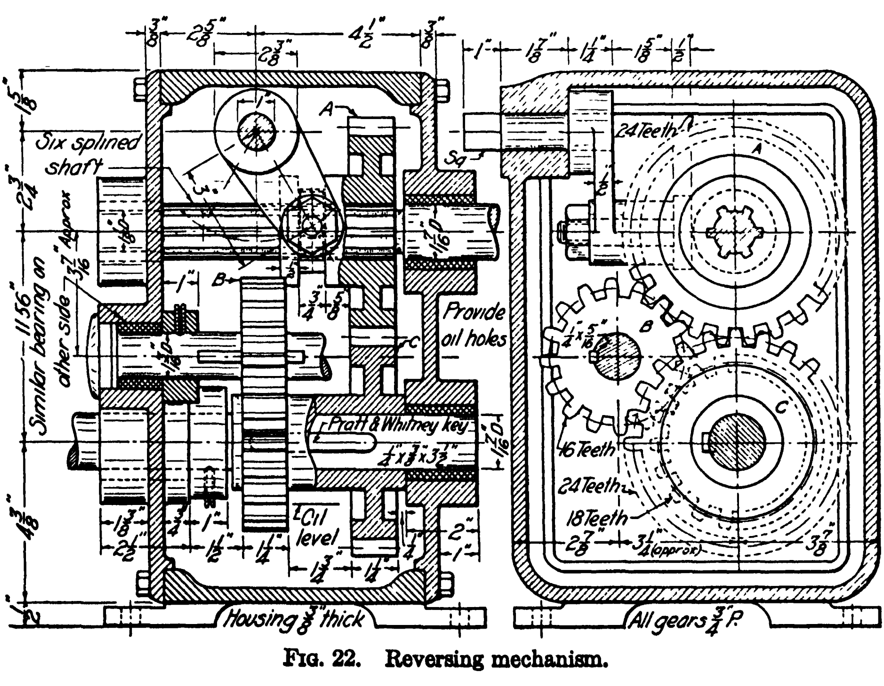
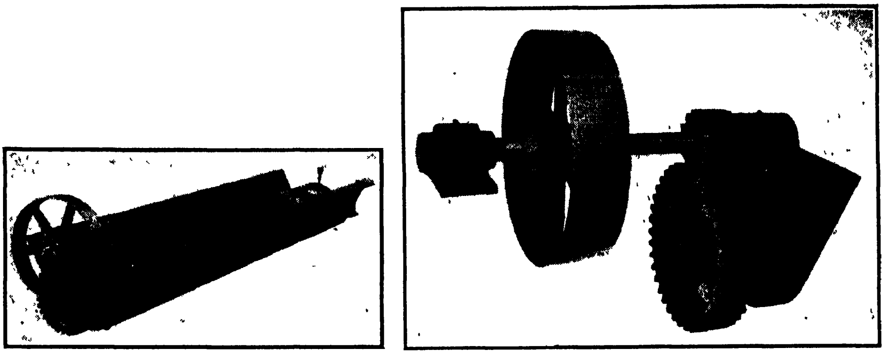


FIG. 22. Reversing mechanism.



Dimensions of Spur Gears and Bearing Frame

Dia. of Conveyor	Pinion P Dia	Gear P Dia	C to C. of shafts	Pitch	Pinion Bore	Gear Bore	Gear Face	Length of Bearing	Width at top of Bearing frame	Face of Bearing frame
A. 8	2.99	4.48	3.73	$\frac{5}{8}$	$\frac{15}{16}$	$1\frac{3}{16}$	$1\frac{1}{2}$	3	16	2
B. 9	5.73	11.48	8.60	$\frac{3}{4}$	$1\frac{7}{16}$	$1\frac{15}{16}$	$1\frac{3}{4}$	$3\frac{1}{2}$	18	$2\frac{1}{2}$
C. 12	6.37	15.92	11.12	1	$1\frac{11}{16}$	$2\frac{7}{16}$	$2\frac{1}{2}$	$4\frac{1}{2}$	24	$2\frac{3}{4}$
D. 20	7.96	23.87	15.92	$1\frac{1}{4}$	$2\frac{3}{16}$	$3\frac{7}{16}$	$3\frac{1}{4}$	6	34	3

FIG. 23. Spur gear data.

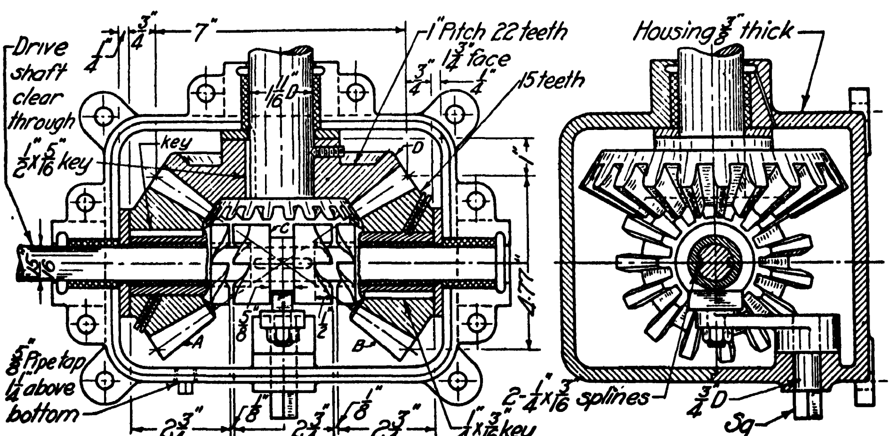


FIG. 24. Bevel gear reversing mechanism.

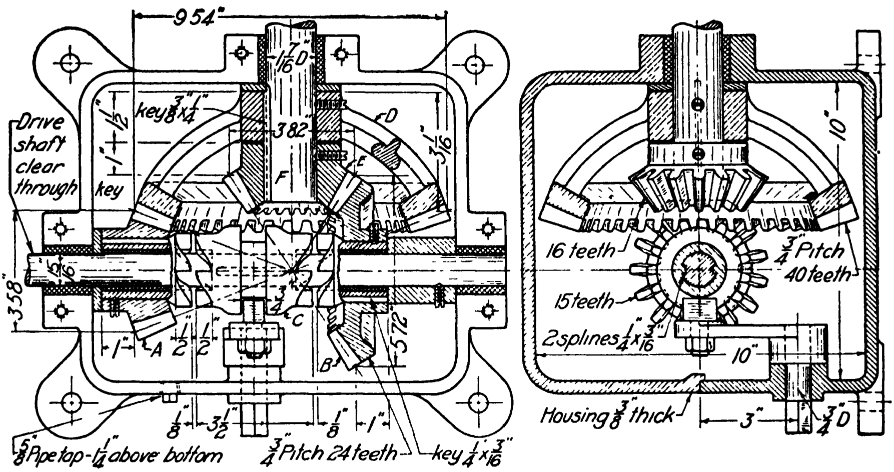
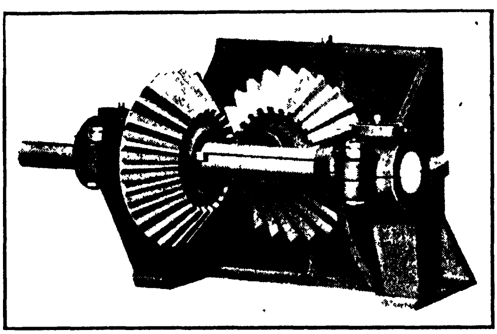
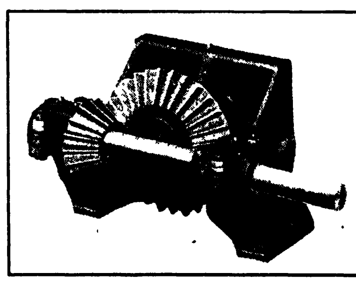


FIG. 25. Quick return mechanism.





Bevel Gear Dimensions

Speed Ratio	Pitch	Face	Gear				Pinion			
			No of teeth	Bore	Pitch Dia.	Backing	No of teeth	Bore	Pitch Dia.	Backing
A. 2	$\frac{1}{2}$	$\frac{7}{8}$	32	$1\frac{3}{16}$	5.10	$1\frac{3}{8}$	16	$\frac{15}{16}$	2.56	1
B. 3	$\frac{3}{4}$	$2\frac{1}{4}$	51	$1\frac{15}{16}$	12.18	3	17	$1\frac{3}{16}$	4.08	$1\frac{1}{4}$
C. 3	1	$2\frac{1}{2}$	48	$2\frac{3}{16}$	15.28	$3\frac{1}{4}$	16	$1\frac{7}{16}$	5.09	$1\frac{7}{8}$
D. 4	$\frac{3}{4}$	2	56	$1\frac{11}{16}$	13.37	$2\frac{3}{8}$	14	$\frac{15}{16}$	3.34	$1\frac{1}{4}$
E. 4	$1\frac{1}{4}$	3	60	$2\frac{15}{16}$	23.87	4	15	$1\frac{11}{16}$	5.97	$1\frac{7}{8}$

FIG. 26. Bevel gear data.

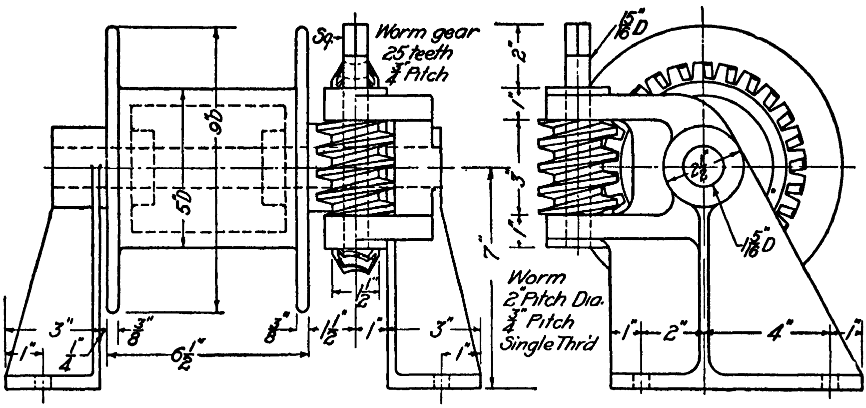


FIG. 27. Hand winch.

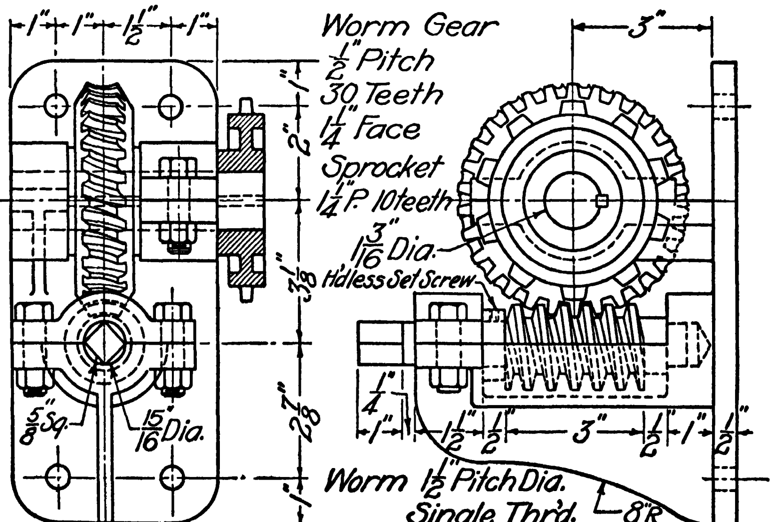
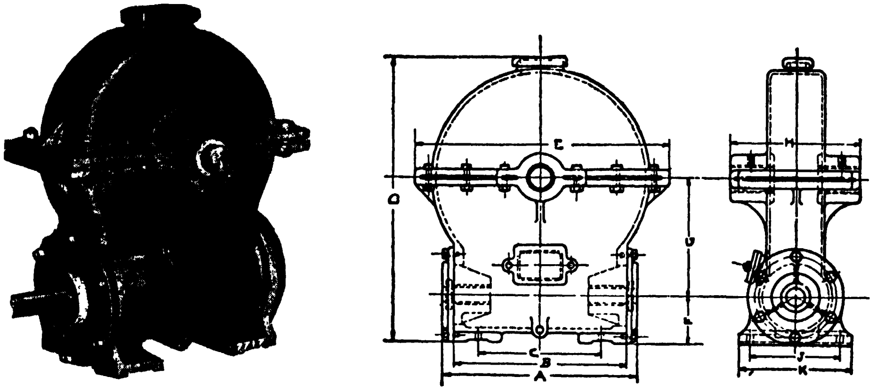


FIG. 28. Window sash operating device.



Dimensions of Worm Gear Speed Reducer and Housing

Gear					Worm				Housing										
No. of teeth	P.D.	Width	Pitch	Bore	P.D.	Length	Bore	Thr'd	A	B	C	D	E	F	G	H	J	K
A 20	9.60	2 1/2	1 1/2	2 15/16	4.5	6 3/4	1 11/16	Single	14 1/2	12 5/8	9 1/4	19 1/2	15 7/8	4 5/8	7 1/16	10 3/8	6 1/4	8 1/2
B 36	10.03	1 3/8	7/8	2 7/16	3.0	6 1/4	1 3/16	Single	13	10 3/4	7	17 1/4	15	3 1/4	6 9/16	9	5 1/2	7
C. 30	14.35	3 1/4	1/2	3 7/16	6.0	8 1/4	1 15/16	Double	16 3/4	14 1/4	10	25 1/8	21	5	10 1/4	12 3/8	7 1/2	9 1/2
D 48	19.11	2 1/2	1 1/4	2 15/16	4.39	8 1/4	1 11/16	Single	20 3/4	18 1/4	13 1/4	29 3/4	26 1/4	5 3/8	11 3/4	13 1/2	9 1/2	11 3/4
E. 50	27.87	4	1 3/4	5 7/16	7.5	10 7/8	2 7/16	Double	28	25 1/2	20 1/2	42 7/8	37 1/4	6 3/4	17 11/16	15	11 3/4	14

Fig. 29. Worm gear and wheel data.

CHAPTER XXV

PATENT OFFICE DRAWINGS

440. The drawings required by the Patent Office stand in a class by themselves when compared with other engineering drawings. The reason for this lies in the fact that they are drawn on one size sheet only, are reproduced by one process, have symbols quite peculiar to themselves, and in many other ways are standardized explicitly and to minute detail. Before going into these strictly drafting features of Patent Office Drawings, it may be well to point out their connection with other items entering into the successful obtaining of letters patent.

441. APPLICATION FOR PATENTS.[1] — Any person who has invented any new and useful thing or who has invented improvements on existing machines or structures may have such invention patented in the United States Patent Office within certain restrictions and in accordance with certain rules laid down by that Office. The first thing the inventor must do himself, or have an attorney do, is to file a formal application with the Commissioner of Patents. A complete application will consist of a petition, specification, oath, and initial fee of $15, and, when required, drawings of the thing to be patented.

442. Specifications. — The specification, besides setting forth the claim or claims of the inventor to the discovery of some new thing, must contain a complete description of the thing invented, first in a general way, then in a more detailed fashion; and, if there are drawings, the description must refer to the various views by letters or numerals. No drawing should be sent to the Patent Office unless proper reference to it and description of it are made in the specification.

443. Drawings. — It is thus seen that the drawings are bound up with other necessary parts of an application for patents. The first difference between a Patent Office drawing and any other drawing is already evident, in the fact that each view is numbered instead of all the views of an object being grouped over one figure number. This means that the various orthographic views are not generally arranged in relation to one another in the strict formal way employed in shop drawings. The top and

[1] See "Rules of Practice in the U. S. Patent Office" for complete descriptions. These "Rules of Practice" may be secured from the Patent Office without cost, and should be obtained by anyone who is planning to secure a patent.

front views of a device might be placed on separate sheets or in any unconnected positions on the same sheet. Pictorial drawings done in ink may be submitted with an application. Figure 1 suggests the general characteristics of a Patent Office drawing. Complete information regarding the details of making such a drawing is best obtained from the specifications for drawings, contained in sections 49 to 55, inclusive, of the " Rules of Practice," which are quoted verbatim in the following paragraphs.

" 49. The applicant for a patent is required by law to furnish a drawing of his invention whenever the nature of the case admits of it.

" 50. The drawing may be signed by the inventor or one of the persons indicated in Rule 25, or the name of the applicant may be signed on the drawing by his attorney in fact. The drawing must show every feature of the invention covered by the claims, and the figures should be consecutively numbered, if possible. When the invention consists of an improvement on an old machine the drawing must exhibit, in one or more views, the invention 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.

" 51. Two editions of patent drawings are printed and published — one for office use, certified copies, etc., of the size and character of those attached to patents, the work being about 6 by 9½ inches; and one reduction of a selected portion of each drawing for the Official Gazette.

" 52. This work is done by the photolithographic process, and therefore the character of each original drawing must be brought as nearly as possible to a uniform standard of excellence, suited to the requirements of the process, to give the best results, in the interests of inventors, of the office, and of the public. The following rules will therefore be rigidly enforced, and any departure from them will be certain to cause delay in the examination of an application for letters patent:

" (*a*) Drawings must be made upon pure white paper of a thickness corresponding to two-sheet or three-sheet Bristol board. The surface of the paper must be calendered and smooth. India ink alone must be used, to secure perfectly black and solid lines.

" (*b*) 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 downwardly 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.

" (*c*) All drawings must be made with the pen only. Every line and letter (signatures included) must be absolutely black. This direction

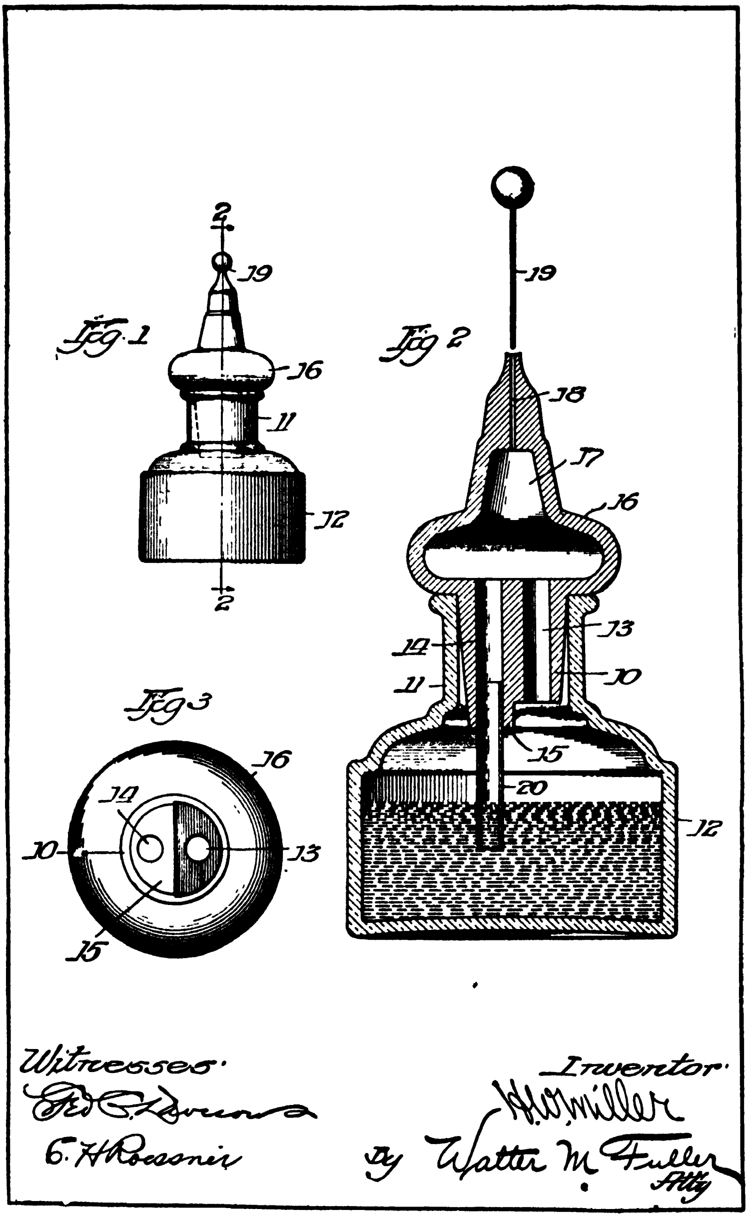


FIG. 1. Patent office drawing.

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 they must not be too fine or crowded. Surface shading, when used, should be open. Sectional shading should be made by oblique parallel lines, which may be about one-twentieth of an inch apart. 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*) Drawings should be made with the fewest lines possible consistent with clearness. By the observance of this rule the effectiveness of the work after reduction will be much increased. Shading (except on sectional views) should be used only on convex and concave surfaces, where it should be used sparingly, and may even there be dispensed with if the drawing be otherwise well executed. The plane upon which a sectional view is taken should be indicated on the general view by a broken or dotted line, which should be designated by numerals corresponding to the number of the sectional view. Heavy lines on the shade sides of objects should be used, except where they tend to thicken the work and obscure letters of reference. The light is always supposed to come from the upper left-hand corner at an angle of 45°.

" (*e*) The scale to which a drawing is made ought to be large enough to show the mechanism without crowding, and two or more sheets should be used if one does not give sufficient room to accomplish this end; but the number of sheets must never be more than is absolutely necessary.

" (*f*) The different views should be consecutively numbered. Letters and figures of reference must be carefully formed. 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 much larger when there is sufficient room. They must be so placed in the close and complex parts of drawings as not 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 should be placed at a little distance, where there is available space, and connected by lines with the parts to which they refer. They should not be placed upon shaded surfaces, but when it is difficult to avoid this, a blank space must be left in the shading where the letter occurs, so that it shall appear perfectly distinct and separate from the work. If the same part of an invention appear in more than one view of the drawing it must always be represented by the same character, and the same character must never be used to designate different parts.

" (*g*) The signature of the applicant should be placed at the lower right-hand corner of each sheet, and the signatures of the witnesses, if any, at the lower left-hand corner, all within the marginal line, but in no instance should they trespass upon the drawings. (See specimen drawing, Appendix.) The title should be written with pencil on the back of the sheet. The permanent names and title constituting the heading will be applied subsequently by the office in uniform style.

" (*h*) All views on the same sheet must stand in the same direction and must 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 proper illustration of the invention the sheet may be turned on its side. The space for heading must then be reserved at the right and the signatures placed at the left, occupying the same space and position 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.

" (*i*) As a rule, one view only of each invention can be shown in the Gazette illustrations. The selection of that portion of a drawing best calculated to explain the nature of the specific improvement would be facilitated and the final result improved by the judicious execution of a figure with express reference to the Gazette, but which must at the same time serve as one of the figures referred to in the specification. For this purpose, the figure may be a plan, elevation, section, or perspective view, according to the judgment of the draftsman. All its parts should be especially open and distinct, with very little or no shading, and it must illustrate the invention claimed only, to the exclusion of all other details. (See specimen drawing.) When well executed, it will be used without curtailment or change, but any excessive fineness, or crowding, or unnecessary elaborateness of detail will necessitate its exclusion from the Gazette.

" (*j*) Drawings transmitted to the office should be sent flat, protected by a sheet of heavy binder's board; or should be rolled for transmission in a suitable mailing tube, but should never be folded.

" (*k*) An agent's or attorney's stamp, or advertisement or written address will not be permitted upon the face of a drawing, within or without the marginal line.

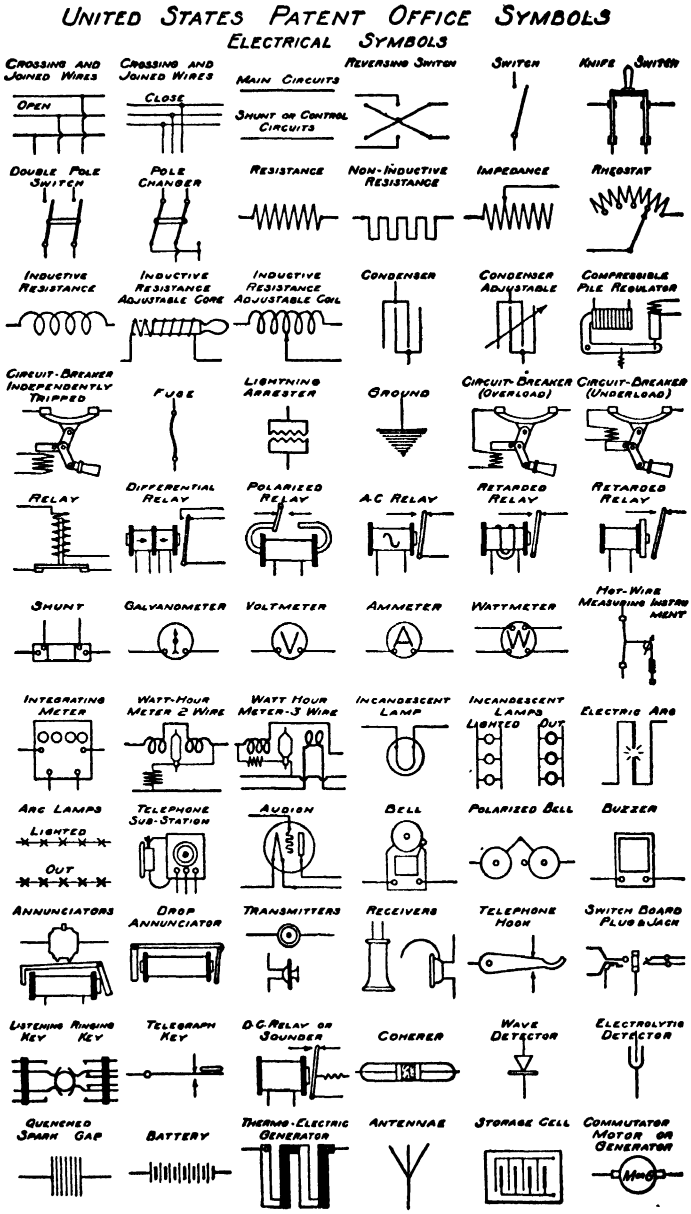
" 53. All reissue applications must be accompanied by new drawings, of the character required in original applications, and the inventor's name must appear upon the same in all cases; and such drawings shall be made upon the same scale as the original drawing, or upon a larger scale, unless a reduction of scale shall be authorized by the Commissioner.

" 54. The foregoing rules relating to drawings will be rigidly enforced. A drawing not executed in conformity thereto may be admitted for purposes of examination if it sufficiently illustrates the invention, but in such case the drawing must be corrected or a new one furnished before the application will be allowed. The necessary corrections will be made by the office, upon applicant's request and at his expense. (See Rule 72.)

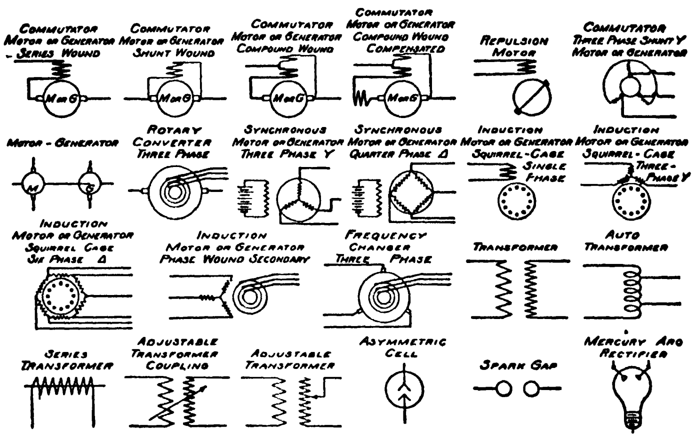
"55. Applicants are advised to employ competent draftsmen to make their drawings.

"The office will furnish the drawings at cost, as promptly as its draftsmen can make them, for the applicants who cannot otherwise conveniently procure them."

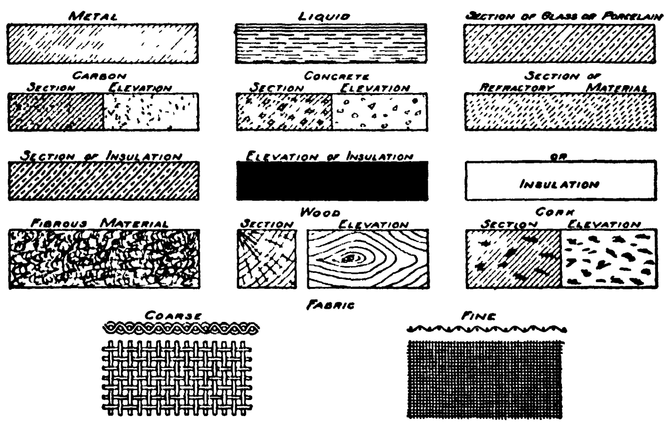
444. Symbols. — The following charts show the conventional signs and symbols adopted by the Patent Office for the guidance of draftsmen. It will be noted that many agree with those used in commercial practice, and others are distinctly different.


UNITED STATES PATENT OFFICE SYMBOLS
ELECTRICAL SYMBOLS
CROSSING AND JOINED WIRES
OPEN
CROSSING AND JOINED WIRES
CLOSE
MAIN CIRCUITS
SHUNT OR CONTROL CIRCUITS
REVERSING SWITCH
SWITCH
KNIFE SWITCH
DOUBLE POLE SWITCH
POLE CHANGER
RESISTANCE
NON-INDUCTIVE RESISTANCE
IMPEDANCE
RHEOSTAT
INDUCTIVE RESISTANCE
INDUCTIVE RESISTANCE ADJUSTABLE CORE
INDUCTIVE RESISTANCE ADJUSTABLE COIL
CONDENSER
CONDENSER ADJUSTABLE
COMPRESSIBLE PILE REGULATOR
CIRCUIT-BREAKER INDEPENDENTLY TRIPPED
FUSE
LIGHTNING ARRESTER
GROUND
CIRCUIT-BREAKER (OVERLOAD)
CIRCUIT-BREAKER (UNDERLOAD)
RELAY
DIFFERENTIAL RELAY
POLARIZED RELAY
A-C RELAY
RETARDED RELAY
RETARDED RELAY
SHUNT
GALVANOMETER
VOLTMETER
AMMETER
WATTMETER
HOT-WIRE MEASURING INSTRUMENT
INTEGRATING METER
WATT-HOUR METER 2 WIRE
WATT HOUR METER-3 WIRE
INCANDESCENT LAMP
INCANDESCENT LAMPS
LIGHTED
OUT
ELECTRIC ARC
ARC LAMPS
LIGHTED
OUT
TELEPHONE SUB-STATION
AUDION
BELL
POLARIZED BELL
BUZZER
ANNUNCIATORS
DROP ANNUNCIATOR
TRANSMITTERS
RECEIVERS
TELEPHONE HOOK
SWITCH BOARD PLUG & JACK
LISTENING KEY
RINGING KEY
TELEGRAPH KEY
D-C RELAY OR SOUNDER
COHERER
WAVE DETECTOR
ELECTROLYTIC DETECTOR
QUENCHED SPARK GAP
BATTERY
THERMO-ELECTRIC GENERATOR
ANTENNAE
STORAGE CELL
COMMUTATOR MOTOR OR GENERATOR

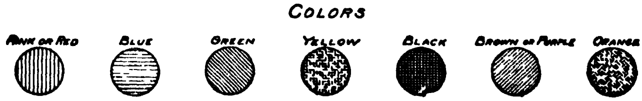
ELECTRICAL SYMBOLS CONTINUED



COMMERCIAL MATERIALS



COLORS



CONTENTS OF APPENDIX

APPENDIX

GEOMETRICAL CONSTRUCTIONS

The geometrical constructions given in the following pages are for the convenience of the draftsman. It is assumed that he may use all the instruments at his disposal and that they are sufficiently accurate for all practical purposes. Thus, when he finds it necessary to erect a line perpendicular to another, he may do it with his triangles, rather than with a compass and straight edge. It is further assumed that the draftsman is familiar with the principles of plane geometry. The methods here suggested are primarily for the drafting table and therefore may not always be applicable to the laying-out floor.

I. — CIRCLES OF FIXED RADIUS TANGENT TO RIGHT LINES AND CIRCLES

The solution of tangency problems involving the circle depends directly upon the following definition: *the circle is the plane locus of all points a given distance from a given fixed point.* Hence, if a circle of radius r is to be tangent to a straight line, the center must be on the plane locus of all points a distance r from the line. If in addition, it is to be tangent to a circle of radius b, the center must also be on the plane locus of all points a distance r from this circle. The intersection of these two loci gives a point which satisfies both conditions

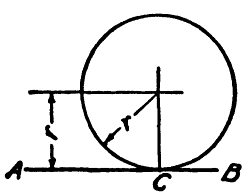


FIG. 1.

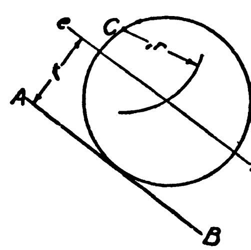


FIG. 2.

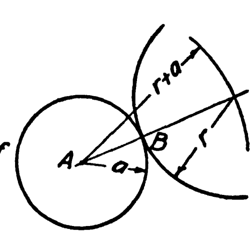


FIG. 3.

and locates the center of the required circle. By thinking along these lines, the reason for each step in the following constructions can be readily discovered.

Problem 1. — To find the center of a circle of fixed radius r tangent to a right line AB at a given point C upon it. See Fig. 1.

Construction. — At C erect a perpendicular to the line AB and on this perpendicular measure off the distance r, which locates the required center.

Problem 2. — To find the center of a circle of fixed radius r tangent to a given right line AB and passing through a point C not on the line. See Fig. 2.

Construction. — At a distance r from the line AB draw a line parallel to it. With C as a center and radius r draw an arc intersecting the line just drawn. The intersection is the required center.

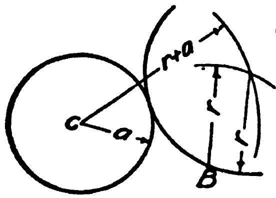


Fig. 4.

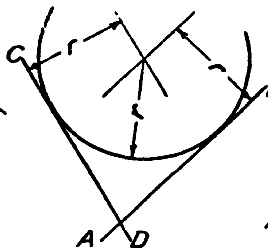


Fig. 5.

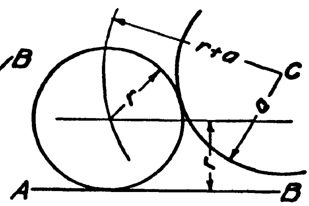
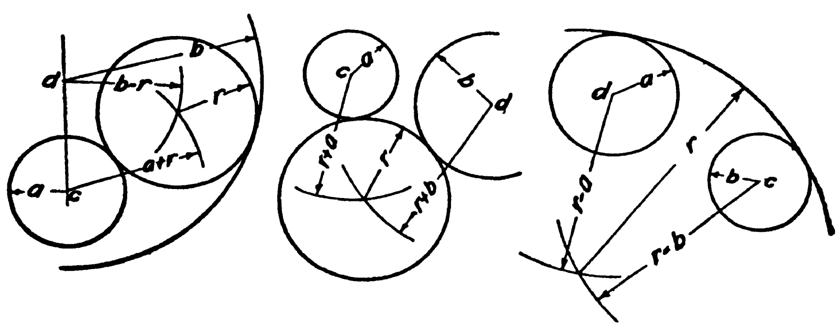


Fig. 6.

Problem 3. — To find the center of a circle of fixed radius r tangent to another circle of radius a at a point B upon it. See Fig. 3.

Construction. — Draw a line from the center through the point B, and then with A as a center and radius $r + a$ describe an arc intersecting the line. The intersection is the required center.

Problem 4. — To find the center of a circle of fixed radius r tangent to another circle of radius a and passing through a point B outside the circle. See Fig. 4.



A B C

Fig. 7.

Construction. — With center c and radius $r + a$ describe an arc, and then with B as a center and r as a radius describe another arc intersecting the first. This intersection is the required center.

Problem 5. — To find the center of a circle of fixed radius r tangent to two intersecting right lines AB and CD. See Fig. 5.

Construction. — Draw lines parallel to AB and CD at a distance r from each. The intersection of these lines is the required center.

Problem 6. — To find the center of a circle of fixed radius r tangent to a right line AB and to another circle of radius a. See Fig. 6.

Construction. — Draw a line parallel to AB a distance r from it. With c as a center and $r + a$ as a radius describe an arc. The intersection of the arc and straight line locates the required center.

Problem 7. — To find the center of a circle of fixed radius r tangent to two other circles of radius a and b respectively. See Fig. 7, *A*, *B* and *C*. Several cases arise in this problem, three of which have been shown in the Figure 7.

Construction A. — With d as a center and $b - r$ as a radius describe an arc, and then with c as a center and $a + r$ as a radius describe an arc. The intersection of the two arcs locates the required center.

Construction B. — With c as a center and $r + a$ as a radius describe an arc, and then with d as a center and $r + b$ as a radius describe another arc which will intersect the first, thus giving the required center.

Construction C. — With c as a center and $r - b$ as a radius describe an arc, and then with d as a center and $r - a$ as a radius describe another arc intersecting the first. The intersection is the required center.

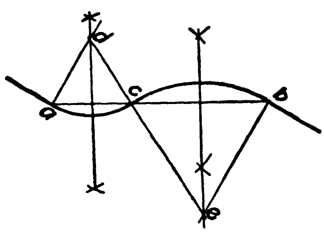


FIG. 8.

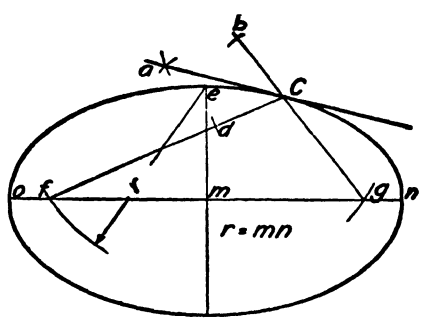


FIG. 9.

Problem 8. — To find the centers of two circles which will connect two parallel right lines by a reverse curve. See Fig. 8.

Construction. — Select the points a and b at which the curve is to join the parallel lines, and connect them by a straight line. Choose the point c at which it is desired the curve shall cross the line ab. At a and b erect perpendiculars to the two parallel lines. Erect perpendicular bisectors of the lines ac and bc. The intersection of the bisectors and the perpendiculars from a and b locates the centers d and e.

II. — LINES TANGENT TO CURVES OTHER THAN THE CIRCLE

Problem 9. — To draw a tangent to an ellipse at a given point C upon it. See Fig. 9.

Construction. — With either end of the minor axis as a center and a radius r equal to one half the major axis, draw arcs intersecting the major axis. The points of intersection locate the foci f and g of the ellipse. From the foci draw lines fC and gC. Bisect the angle fCb. The bisector aC is the required tangent.

Problem 10. — To draw a tangent to a parabola at any given point C upon it. See Fig. 10.

Construction. — From the given point C draw a line perpendicular to the directrix, and a second line to the focus. The bisector of the angle between these lines is the required tangent.

Problem 11. — To draw a line tangent to an hyperbola at a given point C upon it. See Fig. 11.

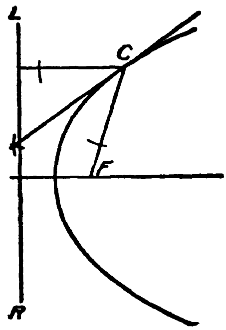


Fig. 10.

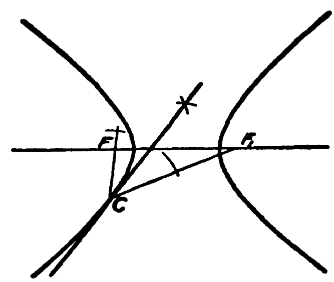


Fig. 11.

Construction. — Draw a line from the point C to each of the foci F and F_1. The bisector of this angle is the required tangent.

Problem 12. — To draw a line tangent to any given curve at any given point O upon it. See Fig. 12.

Construction. — Assume any curve AOC, to which a line is to be drawn tangent at the point O. With O as a center draw an arc hx of any convenient radius. Draw a number of secants from the point O to each side of the curve as shown. From the point h on the secant Oa extended, lay off the distance hk equal to Oa. Proceed in like manner with each secant, laying off those distances on the one side of O on the corresponding side of the arc as is hk, and those on the other side of O on the opposite side of the arc. Through the points thus obtained draw a smooth curve. The intersection of this curve with the arc locates a second point on the tangent. Proof of this method depends upon the proposition that the tangent is the limiting position of the secant.

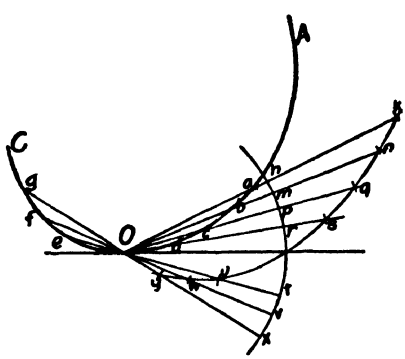


Fig. 12.

III. — THE CONIC SECTIONS

The term conic section is applied to a group of curves which are formed by the intersection of a plane and the surface of a cone. If we assume a right circular cone, we may pass a plane through it in five distinctive postions, four of which give the curves referred to as conic sections, as shown in the small drawings of Fig. 13.

1. If a plane is passed through the vertex of the cone so that it cuts the cone, it will cut right lines from the surface.

2. If a plane is passed through the cone at right angles to the axis at any point other than the vertex, it will cut circles from the surface.

3. If a plane is passed through the cone at an angle with the axis and not parallel to an element, it will cut an ellipse from the surface.

4. If a plane is passed through the cone parallel to an element and perpendicular to the plane of the axis and the element, it will cut a parabola from the surface.

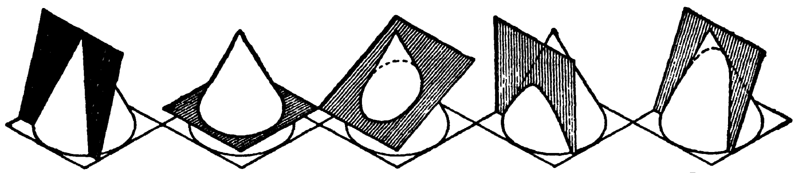


FIG. 13.

5. If a plane is passed through the cone parallel to the axis, it will cut an hyperbola from the surface.

Problem 13. — To construct any conic section. See Fig. 13.

Construction. — Any of these curves might be constructed by assuming a right circular cone and finding the intersection of a properly placed plane with its surface, as pictured in isometric in the figure, and explained in Section 2 of Chapter VII. Such constructions are laborious and properly belong in the realm of Descriptive Geometry. Several shorter and more practical methods for constructing the curves are given below.

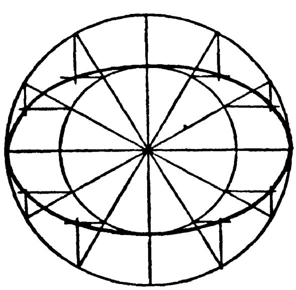


FIG. 14.

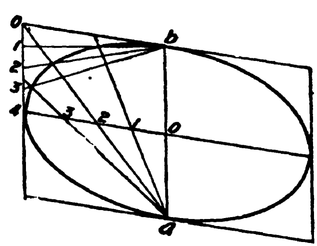


FIG. 15.

ELLIPSE. — An ellipse is the plane locus of all points the sum of whose distances from two fixed points, called the foci, is a constant.

Problem 14. — Given the major and minor axes of an ellipse, to construct the ellipse. See Fig. 14.

Construction. — Draw two concentric circles with diameters corresponding to the major and minor axes. Draw a line from the center crossing both circles. At the intersection of this line with the small circle draw a line parallel to the major axis, and from the intersection with the large circle draw a line parallel to the minor axis. The intersection of these two lines locates a point on the ellipse. Twelve or more points, equally spaced around the circles, should be found in the same way to make an accurate ellipse. The ellipse must, of course, be drawn with an irregular curve in the usual way.

Problem 15. — Given the conjugate axes of an ellipse, to construct the ellipse. See Fig. 15.

Construction. — Upon the given conjugate axes construct a rhomboid which will enclose the ellipse. Divide the major conjugate axis into any number of equal parts and make a similar division in the short side of the rhomboid. The intersection of corresponding lines, *a* — *1* and *b* — *1*, for example, locate points on the ellipse.

Problem 16. — (Approximate Method). Given the major and minor axes, to construct the ellipse. See Fig. 16.

Construction. — Four center method. Draw the rectangle *mnop* which will enclose the ellipse. Draw the line *dg*. Lay off on it the distance *df* equal to *cb*, equal to half the difference between the major and minor axes. Erect a per-

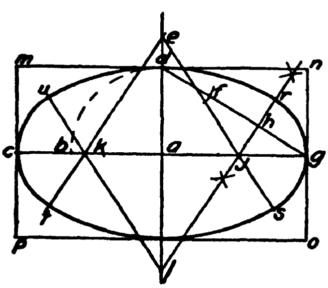


FIG. 16.

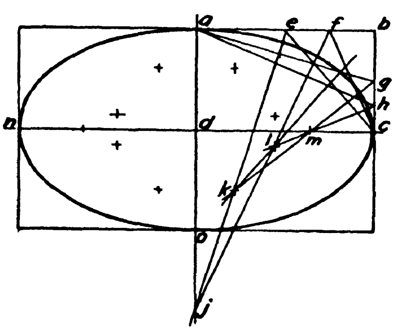


FIG. 17.

pendicular bisector of the remaining portion *fg*. The intersection of this bisector with the major and minor axes locates the centers *l* and *j*. The intersection of the perpendicular bisector from the opposite side locates the centers *k* and *e*.

Problem 17. — (Approximate method.) Given the major and minor axes, to construct the ellipse. See Fig. 17.

Construction. — Twelve center method. Draw the rectangle *abcd*. Divide *ab*, *eb*, *bc*, and *gc* in halves. Draw line *ag* and from *e* draw a perpendicular to it. Locate the intersection of this line with the minor axis produced. Draw line *ec* and from *g* draw a perpendicular to it till it intersects *ej* at *k*. Draw line *ah* and from *f* erect a perpendicular to it. Draw the line *fc* and from *h* erect a perpendicular to it until it intersects *fj* at *l*. Draw *kl* of sufficient length to cross the ellipse when drawn. The points *j*, *k*, *l*, and *m* are the centers for one-fourth of the ellipse. Locate the remaining centers in symmetrical positions around the axes by any convenient method. The centers thus found, if carefully worked out, will approximate very closely an ellipse of any size and ratio of axes. When the major and minor axes approach each other in length, the centers *k* and *l* may be omitted.

Parabola. — The parabola is the plane locus of all points which are equidistant from a given fixed point, called the focus, and a given fixed line, called the directrix.

Problem 18. — Given the width *AB* and the depth *BC*, of a parabola, to draw the parabola. See Fig. 18.

Construction. — Draw the rectangle *ABCD* which will enclose the part of the curve desired. Divide the short side of the rectangle into any number of parts and the long side into twice that number, as shown in the figure. Through

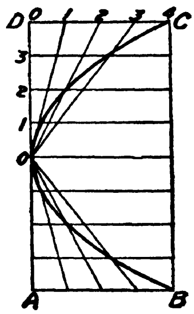


Fig. 18.

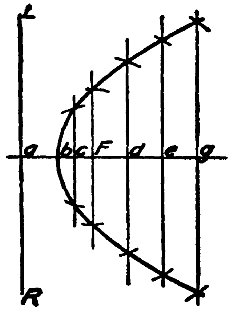


Fig. 19

the divisions on the long side, draw lines parallel to the short side, and from the center of the long side draw lines to the consecutive divisions of the short side. The intersections of the lines *0–1* and *1*, *0–2* and *2* locate points on the curve.

Problem 19. — Given the directrix and the focus, to draw the parabola. See Fig. 19.

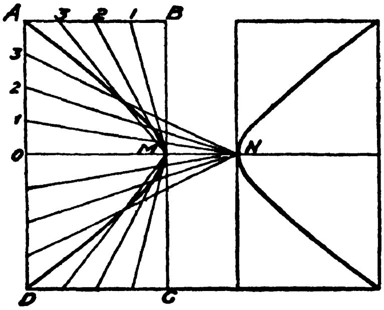


Fig 20.

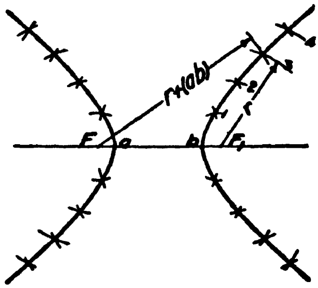


Fig. 21.

Construction. — This construction follows directly from the definition of the parabola. Draw the axis through *F* perpendicular to *LR*. Bisect the line *aF*. Through any convenient points *c*, *d*, *e*, and *g* draw lines parallel to *LR*. With *F* as a center and radii successively equal to *ac*, *ad*, *ae*, and *ag* strike arcs intersecting the corresponding parallel lines through *c*, *d*, *e*, and *g*. These points determine the parabola.

Hyperbola. — The hyperbola is the plane locus of all points the difference of whose distances from two fixed points, called the foci, is a constant.

Problem 20. — Given the width and depth of a portion of the hyperbola, to draw the hyperbola. See Fig. 20.

Construction. — Draw the rectangle $ABCD$ to enclose the portion of the curve desired. Another rectangle which will enclose the other limb should also be drawn. Divide the short side of the rectangle into any number of equal parts and the long side into double that number of equal parts. From the point M draw lines to the divisions on the short side and from the point N on the other rectangle draw lines to the divisions on the long side. The intersection of the corresponding lines M-*1* and N-*1*, *etc.*, locate points on the curve.

Problem 21. — Given the two foci, to draw the hyperbola. See Fig. 21.

Construction. — With F_1 as a center draw the arcs *1*, *2*, *3*, *etc.*, at any convenient distance. Then, with F as a center draw arcs intersecting the arcs *1*, *2*, *3*, *etc.* The radii of the arcs last drawn shall be equal to the former plus the distance ab, in each case. The points of intersection determine the curve.

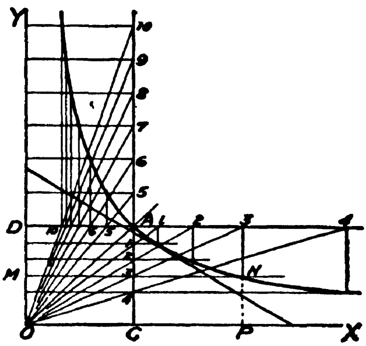


Fig. 22.

Rectangular Hyperbola. — This curve has far greater practical application than the other forms of the hyperbola, in that it always occurs in the study of laws governing the expansion of any gas.

Problem 22. — Given the location of one point A on the curve in rectangular coördinates, to draw the hyperbola. See Fig. 22.

Construction. — Draw the ordinate and abscissa through the point. Divide the ordinate into any number of parts and draw diagonals from the origin O through these points until they cross the abscissa through the point A. Draw horizontal lines through the intersections of the diagonals with the ordinate through A and vertical lines through the intersections of the diagonals with the abscissa through A. The intersections of these horizontal and vertical lines give points on the curve.

IV. — COMMON CURVES IN PRACTICAL WORK

Cycloids. — The cycloids form a group of curves generated by the path of a fixed point on the circumference of a rolling circle. When the circle rolls on a straight line, the path of the point is called simply a cycloid. If the circle rolls on the outside of another circle the path of the point is called an epicycloid, whereas if the circle rolls on the inside of another circle the path of the point is called an hypocycloid. These curves have a practical application in the design of gear teeth.

Problem 23. — To draw the cycloid. See Fig. 23.

Construction. — Divide the rolling circle into twelve or more equal parts and lay out on the straight line twelve divisions equal to the arcs of the circle. As the circle rolls along, the center will occupy successively the positions *1*, *2*, *3*, *etc.*, while the point on the circumference will rise to the elevation on the horizontal lines *a, b, c, d, etc.* The intersections of the circle in its successive positions with the horizontal lines will give the required points.

Problem 24. — To draw the epicycloid and the hypocycloid. See Fig. 24.

Construction. — The construction of the epicycloid and hypocycloid are quite similar to each other and can be readily grasped from the figure. Note that in both cases there is a separate line of centers for the rolling circles and in place of the horizontal lines *a, b, c, etc.*, we have the arcs *a, b, c,* and so on.

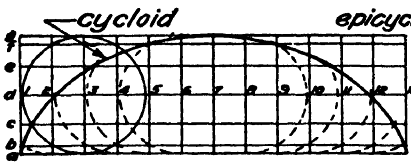


FIG. 23.

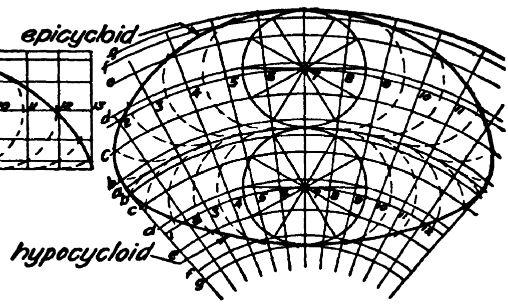


FIG. 24.

INVOLUTE. — The involute is another curve which also has a practical application in the design of gear teeth. It may, perhaps, be most clearly defined as the path described by the end of a string as it is unwound from a cylinder. It may be constructed on this principle.

Problem 25. — To draw the involute. See Fig. 25.

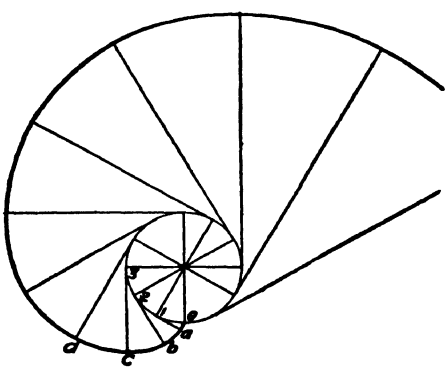


FIG. 25.

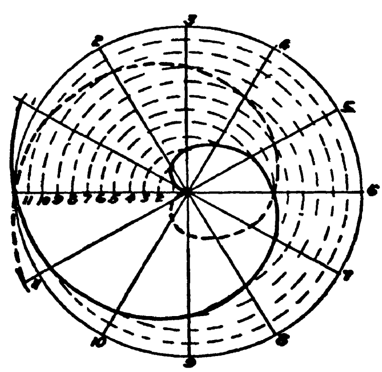


FIG. 26.

Construction. — Divide the circle which is tne intersection of a cylinder with the plane of the curve, into twelve or more equal parts. Then, beginning at any convenient point, draw tangents to the circle at the points of division and on each of these tangents lay off a length equal to the length of the arc from the point of beginning to the tangent point. Thus the line $3c$ is equal in length to the arc $o3$. The points thus obtained locate the curve.

SPIRAL OF ARCHIMEDES. — In the spiral of Archimedes, the radius of curvature increases directly as the angle through which it rotates. We may assume an arbitrary amount by which the radius shall increase in passing through a certain angle.

Problem 26. —To draw the spiral of Archimedes. See Fig. 26.

Construction. — With any convenient point as a center, draw a circle and divide into twelve equal parts. Divide the radius into the same number of equal parts. One of the divisions of the radius is then the increment by which the radius of curvature increases in passing through an angle of 30 degrees. Then beginning at the center and intersecting radius *1* by arc *1*, and radius *2* by arc *2*, and so on, twelve points on the curve can be found. The curve thus generated is commonly used in cam design.

ABBREVIATIONS

Metals

Aluminum	Almn.	Lead	Lead
Babbitt	Bb.	Malleable iron	M. I.
Brass	B.	Open hearth steel	O. H. S.
Bronze	Bz.	Phosphor bronze	Ph. Bz.
Carbon	Cbn.	Steel	Steel
Cast brass	C. B.	Steel casting	S. C.
Cast copper	C. Cop.	Wrought iron	W. I.
Cast iron	C. I.	Zinc	Zn.
Cast steel	C. S.	Tool steel	T. S.
Cold rolled steel	C. R. S.	Forged tool steel	F. T. S.
Copper	Cop.	High speed steel	H. S. S.

Mechanical & Electrical

Horsepower	H. P.	Kilowatt	K. W.
Brake horsepower	B. H. P.	Kilowatt hour	K. W. H.
British thermal unit	B. T. U.	Kilo-volt ampere	K. V. A.
Indicated horsepower	I. H. P.	Ampere	Amp.
Mean effective pressure	M. E. P.	Transformer	Trans.
Revolutions per minute	R. P. M.	Generator	Gen.

Gages

Brown & Sharpe, or American Standard Wire Gage	B. & S.
Birmingham, or Stubs Iron Wire Gage	B. W. G.
National, or Roebling's, or Washburn & Moen's	N. W. G.
Music Wire Gage	M. W. G.
United States Gage	U. S. G.
Twist Drill & Steel Wire Gage	T. D. G.
Stubs' Steel Wire Gage	S. W. G.

General

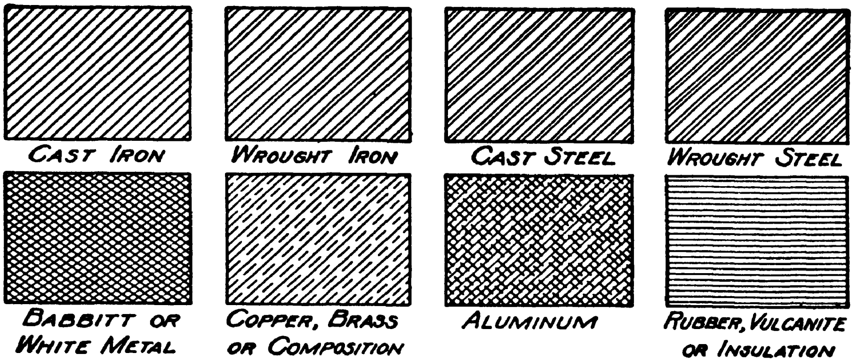
Building	Bldg.	General	Gnl.
Case harden	C. H.	Inch, inches	In. or "
Center	Cr.	Machine	Mach.
Center line	C. L.	Manufacturing	Mfg.
Circumference	Circum.	Maximum	Max.
Company	Co.	Minimum	Min.
Counterbore	Cbr.	Specification	Spec.
Countersink	Csk.	Square	Sq.
Cylinder	Cyl.	Standard	Std.
Diameter	dia. or D.	Threads	Thds.
Drawing	Dwg.	Weight	Wgt.
Foot, feet	ft. or '	Finish	f.

Symbols and Conventions

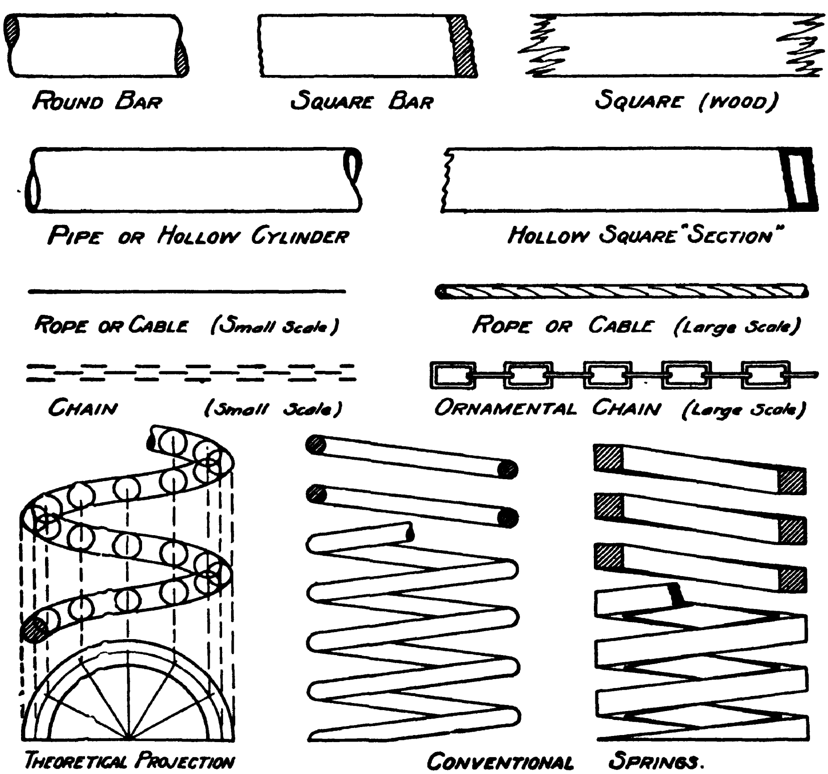
As civilization progresses and science and industry combine to produce new devices and appliances — some simple and easy to represent in both the spoken and graphical language, others intricate and well-nigh impossible of description or graphical representation — it becomes necessary to adopt symbols or conventional representations, so-called, to allow of quick and easy drawing of these generally used agencies in industry. Qualities of color, kind and texture of materials, as well as the shape of many things, are easily symbolized. Symbols and conventions are to drawing what idioms are to written composition. They are signs that are full of meaning because of what they connote and suggest, rather than because of any direct likeness to the thing they represent.

The use of the terms "conventional drawing," and "conventions" has been general throughout this text. Many symbols and conventions have been included with the text material of a number of chapters. Such for instance are the chapters on Working Drawings, Structural, Architectural, Map, and Patent Office Drawing. The wide scope of the draftsman's domain prevents any text of this kind from fully treating of the various fields in which he may need to work. Even the mention of some specialized topics has been impossible. The following pages, therefore, have been set aside for the presentation of the more important symbols used in different fields of engineering drawing not treated of elsewhere. They should be studied with the idea of fixing in the mind the fact that there are well-standardized symbols in this or that field of drafting, rather than of attempting to memorize any individual symbol which one may observe.

STANDARD CROSS-HATCHING



MISCELLANEOUS SYMBOLS



Wire Gages

There has come about, through lack of standardization, a great deal of confusion concerning wire gages to be specified on the engineer's drawings. Until wire manufacturers have agreed to some national standard it would be well to specify on the drawing the exact diameter of the wire wanted. In the case of steel wires, the Bureau of Standards at Washington has recommended that the American Steel and Wire Co.'s gage be adopted as the Steel Wire Gage. This gage is given in the table below in decimals of an inch, and is the same as the Washburn & Moen gage. When there is danger of confusion with the British gage, it should be called the United States Steel Wire Gage.

In the case of copper wire, the American Wire Gage is standard throughout the United States and is the same as the Brown & Sharpe gage. It is also given in the table below in decimals of an inch.

Sheet and Plate Metal Gage

Congress legalized the United States Standard Gage for sheet and plate iron and steel, March 3, 1893. The various gage sizes are given in decimals of an inch in the table below.

WIRE AND SHEET METAL GAGES

No. of gage	Steel wire gage	American copper or B & S. wire gage	British imperial wire gage	U. S. St'd. gage for plate	No. of gage	Steel wire gage	American wire gage	British imperial wire gage	U. S. St'd. gage for plate
0000000	0.4900	.....	0.5000	0.5000	23	0.0258	0.0226	0.0240	0.0281
000000	0.4615	0.5800	0.4640	0.4688	24	0.0230	0.0201	0.0220	0 0250
00000	0.4305	0.5165	0.4320	0.4375	25	0.0204	0.0179	0.0200	0 0219
0000	0.3938	0.4600	0.4000	0.4063	26	0.0181	0.0159	0.0180	0.0188
000	0.3625	0.4096	0.3720	0.3750	27	0.0173	0.0142	0.0164	0.0172
00	0.3310	0.3648	0.3480	0.3438	28	0.0162	0.0126	0.0148	0.0156
0	0.3065	0.3249	0.3240	0.3125	29	0.0150	0.0113	0.0136	0.0141
1	0.2830	0.2893	0.3000	0.2813	30	0.0140	0.0100	0.0124	0.0125
2	0.2625	0.2576	0.2760	0.2656	31	0.0132	0.0089	0.0116	0.0109
3	0.2437	0.2294	0.2520	0.2500	32	0.0128	0.0080	0.0108	0.0102
4	0 2253	0.2043	0.2320	0.2344	33	0.0118	0.0071	0.0100	0.0094
5	0.2070	0.1819	0.2120	0.2188	34	0.0104	0.0063	0.0092	0.0086
6	0.1920	0.1620	0.1920	0.2031	35	0.0095	0.0056	0.0084	0.0078
7	0.1770	0.1443	0.1760	0.1875	36	0.0090	0.0050	0.0076	0.0070
8	0.1620	0.1285	0.1600	0.1719	37	0.0085	0.0045	0.0068	0.0066
9	0.1483	0.1144	0.1440	0.1563	38	0.0080	0.0040	0.0060	0.0063
10	0.1350	0.1019	0.1280	0.1406	39	0.0075	0.0035	0.0052	. .
11	0.1205	0.0907	0.1160	0.1250	40	0.0070	0.0031	0.0048	.....
12	0.1055	0.0808	0.1040	0.1094	41	0.0066	0.0028	0.0044	.....
13	0.0915	0.0720	0.0920	0.0938	42	0.0062	0.0025	0.0040	.....
14	0.0800	0.0641	0.0800	0.0781	43	0.0060	0.0022	0.0036	.....
15	0.0720	0.0571	0.0720	0.0703	44	0.0058	0.0020	0.0032	.....
16	0.0625	0.0508	0.0640	0.0625	45	0.0055	0.00176	0.0028	.....
17	0.0540	0.0453	0.0560	0.0563	46	0.0052	0.00157	0.0024	.....
18	0.0475	0.0403	0.0480	0.0500	47	0.0050	0.00140	0.0020	.....
19	0.0410	0.0359	0.0400	0.0438	48	0.0048	0.00124	0.0016	.....
20	0.0348	0.0320	0.0360	0.0375	49	0.0046	0.00099	0.0012	.....
21	0.0317	0.0285	0.0320	0.0344	50	0.0044	0.00088	0.0010	.....
22	0.0286	0.0253	0.0280	0.0313					

METRIC EQUIVALENTS

Mm. to inches				Inches to mm.			
Mm.	In.	Mm.	In.	In.	Mm.	In.	Mm.
1 =	.0394	17 =	.6693	$\frac{1}{32}$ =	.79	$\frac{17}{32}$ =	13.49
2 =	.0787	18 =	.7087	$\frac{1}{16}$ =	1.58	$\frac{9}{16}$ =	14.28
3 =	.1181	19 =	.7480	$\frac{3}{32}$ =	2.38	$\frac{19}{32}$ =	15.08
4 =	.1575	20 =	.7874	$\frac{1}{8}$ =	3.17	$\frac{5}{8}$ =	15.87
5 =	.1968	21 =	.8268	$\frac{5}{32}$ =	3.96	$\frac{21}{32}$ =	16.66
6 =	.2362	22 =	.8661	$\frac{3}{16}$ =	4.76	$\frac{11}{16}$ =	17.46
7 =	.2756	23 =	.9055	$\frac{7}{32}$ =	5.55	$\frac{23}{32}$ =	18.25
8 =	.3150	24 =	.9449	$\frac{1}{4}$ =	6.34	$\frac{3}{4}$ =	19.04
9 =	.3543	25 =	.9843	$\frac{9}{32}$ =	7.14	$\frac{25}{32}$ =	19.84
10 =	.3937	26 =	1.0236	$\frac{5}{16}$ =	7.93	$\frac{13}{16}$ =	20.63
11 =	.4331	27 =	1.0630	$\frac{11}{32}$ =	8.73	$\frac{27}{32}$ =	21.43
12 =	.4724	28 =	1.1024	$\frac{3}{8}$ =	9.52	$\frac{7}{8}$ =	22.22
13 =	.5118	29 =	1.1417	$\frac{13}{32}$ =	10.31	$\frac{29}{32}$ =	23.01
14 =	.5512	30 =	1.1811	$\frac{7}{16}$ =	11.11	$\frac{15}{16}$ =	23.81
15 =	.5906	31 =	1.2205	$\frac{15}{32}$ =	11.90	$\frac{31}{32}$ =	24.60
16 =	.6299	32 =	1.2598	$\frac{1}{2}$ =	12.69	1 =	25.39

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 0671	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

Decimal Equivalents of Fractions of an Inch

1-32	1-64	Decimal	Fraction	1-32	1-64	Decimal	Fraction
	1	.015625			33	.515625	
1	2	.03125		17	34	.53125	
	3	.046875			35	.546875	
2	4	.0625	1-16	18	36	.5625	9-16
	5	.078125			37	.578125	
3	6	.09375		19	38	.59375	
	7	.109375			39	.609375	
4	8	.125	1-8	20	40	.625	5-8
	9	.140625			41	.640625	
5	10	.15625		21	42	.65625	
	11	.171875			43	.671875	
6	12	.1875	3-16	22	44	.6875	11-16
	13	.203125			45	.703125	
7	14	.21875		23	46	.71875	
	15	.234375			47	.734375	
8	16	.25	1-4	24	48	.75	3-4
	17	.265625			49	.765625	
9	18	.28125		25	50	.78125	
	19	.296875			51	.796875	
10	20	.3125	5-16	26	52	.8125	13-16
	21	.328125			53	.828125	
11	22	.34375		27	54	.84375	
	23	.359375			55	.859375	
12	24	.375	3-8	28	56	.875	7-8
	25	.390625			57	.890625	
13	26	.40625		29	58	.90625	
	27	.421875			59	.921875	
14	28	.4375	7-16	30	60	.9375	15-16
	29	.453125			61	.953125	
15	30	.46875		31	62	.96875	
	31	.48375			63	.984375	
16	32	.5	1-2	32	64	1	1

Natural Trigonometric Functions

Degrees	SINES 0′	10′	20′	30′	40′	50′	60′	Cosines
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01454	0.01745	89
1	0.01745	0.02036	0.02327	0.02618	0.02908	0.03199	0.03490	88
2	0.03490	0.03781	0.04071	0.04362	0.04653	0.04943	0.05234	87
3	0.05234	0.05524	0.05814	0.06105	0.06395	0.06685	0.06976	86
4	0.06976	0.07266	0.07556	0.07846	0.08136	0.08426	0.08716	85
5	0.08716	0.09005	0.09295	0.09585	0.09874	0.10164	0.10453	84
6	0.10453	0.10742	0.11031	0.11320	0.11609	0.11898	0.12187	83
7	0.12187	0.12476	0.12764	0.13053	0.13341	0.13629	0.13917	82
8	0.13917	0.14205	0.14493	0.14781	0.15069	0.15356	0.15643	81
9	0.15643	0.15931	0.16218	0.16505	0.16792	0.17078	0.17365	80
10	0.17365	0.17651	0.17937	0.18224	0.18509	0.18795	0.19081	79
11	0.19081	0.19366	0.19652	0.19937	0.20222	0.20507	0 20791	78
12	0.20791	0.21076	0.21360	0.21644	0.21928	0.22212	0 22495	77
13	0.22495	0.22778	0.23062	0.23345	0.23627	0.23910	0.24192	76
14	0.24192	0.24474	0.24756	0.25038	0.25320	0.25601	0.25882	75
15	0.25882	0.26163	0.26443	0.26724	0.27004	0.27284	0.27564	74
16	0.27564	0.27843	0 28123	0.28402	0.28680	0.28959	0 29237	73
17	0.29237	0.29515	0.29793	0.30071	0.30348	0.30625	0 30902	72
18	0.30902	0.31178	0.31454	0.31730	0.32006	0.32282	0 32557	71
19	0.32557	0.32832	0.33106	0.33381	0.33655	0.33929	0.34202	70
20	0.34202	0.34475	0.34748	0.35021	0.35293	0.35565	0.35837	69
21	0.35837	0.36108	0.36379	0.36650	0.36921	0.37191	0.37461	68
22	0.37461	0.37730	0.37999	0 38268	0.38537	0.38805	0 39073	67
23	0.39073	0.39341	0.39608	0 39875	0.40142	0 40408	0 40674	66
24	0.40674	0.40939	0.41204	0.41469	0.41734	0.41998	0.42262	65
25	0.42262	0.42525	0.42788	0.43051	0.43313	0.43575	0 43837	64
26	0.43837	0.44098	0.44359	0.44620	0.44880	0.45140	0.45399	63
27	0.45399	0.45658	0.45917	0.46175	0.46433	0.46690	0.46947	62
28	0.46947	0.47204	0.47460	0.47716	0.47971	0.48226	0.48481	61
29	0.48481	0.48735	0.48989	0.49242	0.49495	0.49748	0.50000	60
30	0.50000	0.50252	0.50503	0.50754	0.51004	0.51254	0.51504	59
31	0.51504	0.51753	0.52002	0.52250	0.52498	0.52745	0.52992	58
32	0.52292	0.53238	0.53484	0.53730	0.53975	0.54220	0.54464	57
33	0.54464	0.54708	0.54951	0.55194	0.55436	0.55678	0.55919	56
34	0.55919	0.56160	0.56401	0.56641	0.56880	0.57119	0.57358	55
35	0.57358	0.57596	0.57833	0.58070	0.58307	0.58543	0.58779	54
36	0.58779	0.59014	0.59248	0.59482	0.59716	0.59949	0.60182	53
37	0.60183	0.60414	0.60645	0.60876	0.61107	0.61337	0.61566	52
38	0.61566	0.61795	0.62024	0.62251	0.62479	0.62706	0.62932	51
39	0.62932	0.63158	0.63383	0.63608	0.63832	0.64056	0.64279	50
40	0.64279	0.64501	0.64723	0.64945	0.65166	0.65386	0.65606	49
41	0.65606	0.65825	0.66044	0.66262	0.66480	0.66697	0.66913	48
42	0.66913	0.67129	0.67344	0.67559	0.67773	0.67987	0.68200	47
43	0.68200	0.68412	0.68624	0.68835	0.69046	0.69256	0.69466	46
44	0.69466	0.69675	0.69883	0.70091	0.70298	0.70505	0.70711	45
Sines	60′	50′	40′	30′	20′	10′	0′	Degrees
	COSINES							

Natural Trigonometric Functions

Degrees	COSINES							Sines
	0′	10′	20′	30′	40′	50′	60′	
0	1.00000	1.00000	0.99998	0.99996	0.99993	0.99989	0.99985	89
1	0.99985	0.99979	0.99973	0.99966	0.99958	0.99949	0.99939	88
2	0 99939	0 99929	0 99917	0.99905	0.99892	0.99878	0.99863	87
3	0.99863	0.99847	0.99831	0.99813	0.99795	0.99776	0.99756	86
4	0.99756	0.99736	0.99714	0.99692	0.99668	0 99644	0.99619	85
5	0.99619	0.99594	0.99567	0.99540	0.99511	0.99482	0.99452	84
6	0.99452	0.99421	0 99390	0.99357	0.99324	0.99290	0.99255	83
7	0.99255	0.99219	0.99182	0.99144	0.99106	0.99067	0.99027	82
8	0.99027	0.98986	0.98944	0.98902	0.98858	0.98814	0.98769	81
9	0.98769	0.98723	0.98676	0.98629	0.98580	0.98531	0.98481	80
10	0.98481	0.98430	0.98378	0.98325	0.98272	0 98218	0.98163	79
11	0.98163	0.98107	0.98050	0.97992	0.97934	0.97875	0.97815	78
12	0.97815	0.97754	0 97692	0.97630	0.97566	0.97502	0.97437	77
13	0.97437	0.97371	0.97304	0.97237	0.97169	0.97100	0.97030	76
14	0.97030	0.96959	0.96887	0.96815	0.96742	0.96667	0.96593	75
15	0.96593	0.96517	0.96440	0.96363	0.96285	0.96206	0.96126	74
16	0.96126	0.96046	0 95964	0.95882	0.95799	0.95715	0 95630	73
17	0.95630	0.95545	0 95459	0 95372	0.95284	0.95195	0 95106	72
18	0.95106	0.95015	0 94924	0.94832	0.94740	0.94646	0.94552	71
19	0.94552	0.94457	0.94361	0.94264	0.94167	0.94068	0.93969	70
20	0 93969	0.93869	0.93769	0.93667	0.93565	0.93462	0.93358	69
21	0.93358	0.93253	0 93148	0.93042	0.92935	0.92827	0.92718	68
22	0.92718	0.92609	0.92499	0 92388	0 92276	0.92164	0.92050	67
23	0.92050	0.91936	0 91822	0 91706	0.91590	0.91472	0.91355	66
24	0.91355	0.91236	0.91116	0.90996	0.90875	0.90753	0 90631	65
25	0.90631	0.90507	0.90383	0.90259	0 90133	0.90007	0.89879	64
26	0.89879	0 89752	0.89623	0.89493	0.89363	0.89232	0.89101	63
27	0.89101	0.88968	0.88835	0.88701	0.88566	0.88431	0.88295	62
28	0.88295	0.88158	0.88020	0.87882	0.87743	0.87603	0.87462	61
29	0.87462	0.87321	0.87178	0.87036	0.86892	0.86748	0.86603	60
30	0.86603	0 86457	0.86310	0.86163	0.86015	0.85866	0.85717	59
31	0.85717	0 85567	0.85416	0 85264	0.85112	0.84959	0.84805	58
32	0.84805	0.84650	0.84495	0.84439	0.84182	0.84025	0.83867	57
33	0.83867	0.83708	0.83549	0.83389	0.83228	0.83066	0.82904	56
34	0.82904	0.82741	0.82577	0.82413	0.82248	0.82082	0.81915	55
35	0.81915	0.81748	0.81580	0.81412	0.81242	0.81072	0.80902	54
36	0.80902	0.80730	0.80558	0.80386	0.80212	0.80038	0.79864	53
37	0.79864	0.79688	0.79512	0.79335	0.79158	0.78980	0.78801	52
38	0.78801	0.78622	0.78442	0.78261	0.78079	0.77897	0.77715	51
39	0.77715	0.77531	0.77347	0.77162	0.76977	0.76791	0.76604	50
40	0.76604	0.76417	0.76229	0.76041	0.75851	0.75661	0.75471	49
41	0.75471	0.75280	0.75088	0.74896	0.74703	0.74509	0.74314	48
42	0.74314	0.74120	0.73924	0.73728	0.73531	0.73333	0.73135	47
43	0.73135	0.72937	0.72737	0.72537	0.72337	0.72136	0.71934	46
44	0 71934	0.71732	0.71529	0.71325	0.71121	0.70916	0.70711	45
	60′	50′	40′	30′	20′	10′	0′	
Cosines	SINES							Degrees

Natural Trigonometric Functions

Degrees	TANGENTS 0′	10′	20′	30′	40′	50′	60′	Cotangent
0	0 00000	0.00291	0 00582	0.00873	0.01164	0 01455	0.01746	89
1	0.01746	0 02036	0 02328	0 02619	0.02910	0 03201	0.03492	88
2	0.03492	0.03783	0 04075	0.04366	0 04658	0 04949	0.05241	87
3	0.05241	0.05533	0 05824	0 06116	0 06408	0 06700	0 06993	86
4	0 06993	0.07285	0.07578	0 07870	0 08163	0.08456	0 08749	85
5	0 08749	0.09042	0.09335	0.09629	0 09923	0.10216	0.10510	84
6	0.10510	0.10805	0.11099	0.11394	0.11688	0 11983	0.12278	83
7	0.12278	0.12574	0.12869	0 13165	0.13461	0.13758	0.14054	82
8	0.14054	0.14351	0.14648	0 14945	0.15243	0 15540	0 15838	81
9	0.15838	0.16137	0.16435	0.16731	0.17033	0.17333	0.17633	80
10	0.17633	0.17933	0.18233	0.18534	0.18835	0.19136	0.19438	79
11	0.19438	0.19740	0 20042	0 20345	0.20648	0 20952	0 21256	78
12	0.21256	0 21560	0 21864	0.22169	0 22475	0 22781	0 23087	77
13	0 23087	0 23393	0 23700	0 24008	0 24316	0 24624	0 24933	76
14	0.24933	0.25242	0.25552	0 25862	0 26172	0.26483	0.26795	75
15	0 26795	0.27107	0.27419	0 27732	0 28046	0 28360	0.28675	74
16	0 28675	0 28990	0 29305	0 29621	0.29938	0 30255	0 30573	73
17	0 30573	0 30891	0.31210	0 31530	0 31850	0 32171	0 32492	72
18	0 32492	0.32814	0.33136	0 33460	0.33783	0 34108	0 34433	71
19	0.34433	0.34758	0.35085	0.35412	0.35740	0.36068	0 36397	70
20	0 36397	0 36727	0 37057	0 37388	0 37720	0 38053	0.38386	69
21	0 38386	0.38721	0 39055	0 39391	0 39727	0 40065	0.40403	68
22	0 40403	0 40741	0.41081	0 41421	0 41763	0 42105	0 42447	67
23	0 42447	0.42791	0.43136	0.43481	0.43828	0 44175	0.44523	66
24	0.44523	0.44872	0.45222	0.45573	0.45924	0.46277	0.46631	65
25	0 46631	0 46985	0 47341	0.47698	0 48055	0.48414	0.48773	64
26	0.48773	0.49134	0.49495	0 49858	0 50222	0 50587	0 50953	63
27	0 50953	0.51320	0 51688	0 52057	0 52427	0 52798	0 53171	62
28	0 53171	0.53545	0 53920	0.54296	0.54674	0.55051	0 55431	61
29	0 55431	0 55812	0.56194	0 56577	0.56962	0.57348	0 57735	60
30	0.57735	0 58124	0.58513	0.58905	0.59297	0 59691	0 60086	59
31	0.60086	0.60483	0 60881	0.61280	0.61681	0 62083	0 62487	58
32	0 62487	0.62892	0 63299	0 63707	0.64117	0 64528	0 64941	57
33	0.64941	0.65355	0.65771	0.66189	0.66608	0 67028	0 67451	56
34	0.67451	0.67875	0.68301	0.68728	0 69157	0.69588	0.70021	55
35	0 70021	0.70455	0.70891	0.71329	0 71769	0 72211	0.72654	54
36	0.72654	0.73100	0.73547	0.73996	0.74447	0.74900	0 75355	53
37	0.75355	0.75812	0.76272	0.76733	0 77196	0.77661	0.78129	52
38	0.78129	0.78598	0.79070	0 79544	0.80020	0 80498	0.80978	51
39	0.80978	0.81461	0.81946	0.82434	0.82923	0.83415	0.83910	50
40	0.83910	0.84407	0.84906	0 85408	0 85912	0.86419	0.86929	49
41	0.86929	0.87441	0.87955	0.88473	0.88992	0.89515	0.90040	48
42	0.90040	0.90569	0.91099	0.91633	0.92170	0.92709	0.93252	47
43	0.93252	0.93797	0.94345	0.94896	0 95451	0.96008	0 96569	46
44	0.96569	0.97133	0.97700	0.98270	0.98843	0.99420	1.00000	45
Tangents	60′	50′	40′	30′	20′	10′	0′ COTANGENTS	Degrees

Natural Trigonometric Functions

Degree	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							

Elements of the Acme Standard Thread

Threads per Inch	Depth of Thread	Width of Flat at Top of Thread	Width of Flat at Root of Thread
1	0 5100	0 3707	0.3655
1½	0 3433	0 2471	0 2419
2	0 2600	0.1853	0 1801
2½	0 2100	0.1483	0 1431
3	0 1767	0 1236	0 1184
3½	0.1529	0 1059	0 1007
4	0 1350	0 0927	0 0875
4½	0 1211	0 0824	0 0772
5	0 1100	0 0741	0 0689
5½	0 1009	0 0674	0 0622
6	0.0933	0 0618	0 0566
7	0 0814	0 0530	0 0478
8	0 0725	0 0463	0 0411
9	0 0656	0 0412	0 0360
10	0 0600	0 0371	0 0319
12	0 0517	0 0309	0 0257

Formulas for Recommended Allowances and Tolerances

Class of Fit	Method of Assembly	Allowance	Selected Average Interference of Metal	Hole Tolerance	Shaft Tolerance
(1) Loose	Strictly interchangeable	$0.0025\sqrt[3]{d^2}$*		$0.0025\sqrt[3]{d}$	$0.0025\sqrt[3]{d}$
(2) Free	Strictly interchangeable	$0.0014\sqrt[3]{d^2}$		$0.0013\sqrt[3]{d}$	$0.0013\sqrt[3]{d}$
(3) Medium	Strictly interchangeable	$0.0009\sqrt[3]{d^2}$		$0.0008\sqrt[3]{d}$	$0.0008\sqrt[3]{d}$
(4) Snug	Strictly interchangeable	0.0000		$0.0006\sqrt[3]{d}$	$0.0004\sqrt[3]{d}$
(5) Wringing	Selective assembly		0.0000	$0.0006\sqrt[3]{d}$	$0.0004\sqrt[3]{d}$
(6) Tight	Selective assembly		0.00025 d	$0.0006\sqrt[3]{d}$	$0.0006\sqrt[3]{d}$
(7) Medium force	Selective assembly		0.0005 d	$0.0006\sqrt[3]{d}$	$0.0006\sqrt[3]{d}$
(8) Heavy force or shrink	Selective assembly		0.001 d	$0.0006\sqrt[3]{d}$	$0.0006\sqrt[3]{d}$

* d = diameter of fit in inches.

The formulas for allowance values give the ideal condition of fit for Classes 1 to 4.

The formulas for selected average interference of metal give the ideal condition of fit for Classes 5 to 8.

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